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Faculty of Engineering
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Numerical Modeling of Brine Disposal for Gaza Central Seawater Desalination Plant

نمذجة التخلص من المحلول الملحي الناتج من محطة غزة المركزية لتحلية مياه البحر

Prepared By:

Hassan S. Al-Najjar

Supervised By:

Dr. Mazen Abualtayef

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إقـــــرار

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Numerical Modeling of Brine Disposal for Gaza Central Seawater Desalination Plant

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Signature:			التوقيع:
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Numerical Modeling of Brine Disposal for Gaza Central Seawater Desalination Plant

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أ.د. عبدالرؤوف علي المناعمة

ص.ب. 108 الرمال، غزة، فلسطين هاتف Tel: +970 (8) 286 0700 فاكس fax: +970 (8) 286 0800 P.O. Box 108, Rimal, Gaza, Palestine

public@iugaza.edu.ps www.iugaza.edu.ps

بسم الله الرحمن الرحيم

" وَهُوَ الَّذِي مَرَجَ الْبَحْرَيْنِ هَذَا عَذْبٌ فُرَاتٌ وَهَذَا مِلْحٌ أُجَاجٌ
وَجَعَلَ بَيْنَهُمَا بَرْزَخًا وَحِجْرًا مَحْجُورًا "

(الفرقان:53)

In the name of Allah, Most Gracious, Most Merciful

"It is He (Allah) who has let free the two bodies of flowing water: one palatable and sweet, and the other salt and bitter; yet has He made a barrier between them, a partition that is forbidden to be passed."

(Quran 25:53)

Abstract

In Gaza, it is planned to construct one of the most important seawater desalination plant in the region of Levantine basin, the plant is named Gaza Central Seawater Desalination Plant (GCDP). In the short term, Phase (I), the plant will desalinate seawater for potable uses with a capacity of 55Mm^3 per year, while in the long term another phase, Phase (II), will be operated to double the plant`s desalination capacity to 110Mm$^3$ per year. As a product from the reverse osmosis process, a huge amount of brine with a salinity reaches 61ppt will be produced from GCDP, nearly 12,200m$^3$/h of brine will be rejected from Phase (I) while in the long term brine`s flow rate of 24,400m^3/h will be disposed from Phase (II).

In this study numerical simulations beside sensitivity analysis were carried out to optimize a configuration design for the disposal system of GCDP. Three disposal scenarios have been modelled in this study, the first scenario simulates the rejected brine via surface channel at sea face, the second scenario concerns in the brine behavior disposed via submerged single port diffuser, while the third scenario interests in the brine disposal through offshore multiport diffuser.

The results of the surface discharge show that no design meets the disposal regulations at the regulatory mixing zone (RMZ) for Phase (I) and Phase (II) simultaneously, but the channel's width of 4m at a slope of 3% in winter and summer where the brine`s concentrations above ambient at RMZ in winter were 1105ppm and 1904ppm, whilst the results in summer were 1057ppm and 1782ppm for Phase (I) and Phase (II), respectively. For offshore submerged single port scenario, the results show that the disposal regulations at RMZ were met at all port dimeters in all seasons at offshore disposal distances of 1450m or more for Phase (I) and Phase (II), simultaneously, the brine`s concentrations above ambient at RMZ at a port diameter of 1m at 2050m offshore distance were 676 and 1071ppm in winter, 654 and 1028ppm in spring, 705 and 1122ppm in summer, and 646 and 1014ppm in autumn for Phase (I) and Phase (II), respectively. In the third scenario, this study provides an environmental and feasible design for the disposal system of GCDP, the configuration design of the disposal system can be characterized as 36 risers (144 ports), 20.5m spacing (717.5m+2.4m diffuser`s length), 573m outfall`s length, and outfall`s inclination angle (ø) 74^o to coastline.

Finally, in this study and according to the modelling results it is recommended to dispose the produced brine from GCDP through offshore multiport diffuser system extended far into the sea at a disposal depth equal to 9.5m. Multiport diffuser system is the optimal device which can minimize the negative effects of the brine on the marine ecosystem as well as it can dilute the brine in manner that can guarantee the quality of the feed seawater.

Abstract in Arabic

الملخص

زيادة الحاجة للمياه في المناطق الحضرية والزراعية دفع المخططين والمنظمين للبحث عن مصادر بديلة ومتجددة للمياه. نتيجةً للتطور الحاصل في تقنيات تحلية المياه بالإضافة إلى الحاجة الملحة لسد العجز في إحتياجات المياه دفع الدول لإنشاء محطات لتحلية مياه البحر قائمة على تقنية التناضخ العكسي. في مقابل ذلك فإن مثل هذه المحطات ينتج عنها مخلفات ذات ملوحة عالية جداً أعلى من ملوحة مياه البحر بضعفين. في الآونة الأخيرة أصبح معظم إهتمام الباحثين، والمخططين، ووكالات حماية البيئة قائم على الآلية المثلى للتخلص من المحلول الملحي الناتج من محطات التحلية بطريقة لا تسبب أضرار بيئية كبيرة. لذلك عكف الباحثون على استخدام النمذجة العددية كأداة يمكن بها توقع تأثير الطرق المختلفة للتخلص من الملحول الملحي الناتج من محطات التحلية.

في غزة، يعكف المصممون حالياً على إنشاء محطة مركزية لتحلية مياه البحر تحت مسمى محطة غزة المركزية لتحلية مياه البحر، في المدى القصير المرحلة الأولى من المحطة ستكون قادرة على إنتاج 55 مليون متر مكعب سنوياً من المياه العذبة، مستقبلاً سوف يتم توسيع المحطة بإضافة مرحلة ثانية وذلك لمضاعفة سعة الإنتاج إلى 110 مليون متر مكعب سنوياً. محطة غزة المركزية لتحلية مياه البحر ستقوم بالأساس على تقنية التناضح العكسي، ونتيجة لذلك فإن المحطة في المرحلة الاولى سوف تنتج ما يقارب من 12,200 متر معكب لكل ساعة من المحلول الملحي، في المقابل فإن المحطة بقدرتها القصوى سوف تنتج ما يقارب من 24,400 متر مكعب كل ساعة من المحلول الملحي.

في هذه الدراسة تم إجراء نمذجة عددية لثلاثة سناريوهات للتخلص من المحلول الملحي الناتج من المحطة في البحر. السيناريو الأول يهتم بالتخلص السطحي للمحلول الملحي على الشاطئ، حيث أظهرت النتائج فشل هذا السيناريو لأنه لايحقق الشروط التنظيمية للتخلص عند حدود منطقة الخلط.

أما السيناريو الثاني فيأخذ بعين الإعتبار التخلص من المحلول المحلي في عمق البحر عن طريق أنبوب بعين واحدة، نتائج النمذجة العددية لهذا السيناريو أظهرت أنه يحقق متطلبات التخلص عند حدود منطقة الخلط لكنه لا يحقق معايرة كافية تضمن جودة مياه البحر المستخدمة في التحلية.

أخيراً، أظهرت النمذجة العددية للسيناريو الثالث للتخلص من المحلول الملحي في عمق البحر عبر أنبوب متعدد الأعين أنه الأفضل من حيث أنه يحقق شروط التخلص على حدود منطقة الخلط وكذلك لا يؤثر على جودة مياه البحر الداخلة إلى المحطة لتحليتها.

بناءً على نتائج النمذجة العددية وتحليل الحساسية فإن هذه الدراسة خلصت إلى أن أفضل طريقة للتخلص من المحلول الملحي الناتج من محطة غزة المركزية لتحلية مياه البحر هي بإستخدام أنبوب ذو أعين متعددة يمتد عميقاً في البحر لمسافة تبعد عن الشاطئ 550 متراً على عمق حوالي 6 متر، أما مركز نقطة التخلص من المحلول الملحي فيبعد عن الشاطئ ما مقداره 905 متر على عمق 9.5 متر.

Dedication

To my parents. Without their patience, understanding, support, and most of all love, the completion of this work would not have been possible.

Yours Sincerely
Hassan

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Finally, the study presented in this dissertation was carried out in the framework of a master studies at the department of Civil Engineering at Islamic University, Palestine, Gaza.

Hassan Al-Najjar
Gaza, December 2015

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List of Abbreviations

AS	Ambient Standard
CCC	Criterion Continuous Concentration
CFU	Colony Forming Unit
CMC	Criterion Maximum Concentration
CORMIX	Cornell Mixing Zone Expert System
CSO-G	Comparative Study of Water Supply Options for Gaza Strip
CWQG	Canadian Water Quality Guidelines
DO	Dissolved Oxygen
DoE	Department of the Environment
ED	Electro-dialysis
EPA	Environmental Protection Agency
ES	Effluent Standard
GCDP	Gaza Central Seawater Desalination Plant
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
GPS	Global Positioning System
KSA	Kingdom of Saudi Arabia
LC_{50}	Lethal Concentration for 50% of fish
MCM	Million Cubic Meter
MCWU	Municipal Coastal Water Utility
MED	Multiple Effect Distillation
MEDAR	Mediterranean Data Archeology and Rescue
MEnA	Ministry of Environmental Affairs
MSF	Multistage Flash
PCBS	Palestinian Central Bureau of Statistics
PEL	Palestinian Environmental Law
PWA	Palestinian Water Authority
PWL	Palestinian Water Law
RMZ	Regulatory Mixing Zone
RO	Reverse Osmosis
ROI	Region of Interest
SWRO	Seawater Reverse Osmosis
TDS	Total Dissolved Solids
UAE	United Arab Emirates
USAID	United State Agency for International Development
UF	Ultrafiltration
WHO	World Health Organization
WQS	Water Quality Standard

List of Notations

H_{avg}	Average water depth
D	Depth index
B	Sediment index
V	Vulnerability index
I_s	Susceptibility
I_{bps}	Biotope protection status
I_{bcs}	Biotope conservation
I_{bs}	Biotope sensitivity
γ	Alignment angle between diffuser line and current direction
ø	Inclination angle of outfall pipe to coastline

List of Units

Mm^3	million cubic meter
MCM	million cubic meter
m^3	cubic meter
m^3/h	cubic meter per hour
%	percentage
m^3/s	cubic meter per second
m	meter length
mm	millimeter
m/s	meter per second
ml	milliliter
MW	megawatt
ppm	part per million
ppt	part per thousand
mg/l	milligram per liter
^oC	Celsius degree
km	kilometer
km^2	squared kilometer
mS/cm	millisiemens per centimeter

Exclusive Summary

This study provides an investigation on the feasibility of disposing the brine produced from GCDP in its short term, Phase (I), and long term, Phase (II) into marine environments. Three disposal scenarios cover the adopted disposal methods in the field of brine disposal in the coastal areas have been checked in this study. Approaches of numerical modelling and sensitivity analysis have been exploited to detect the applicability of the three disposal scenarios in terms of serving GCDP in discharging the rejected brine from its Phase (I) and Phase (II), as well as their suitability in terms of achieving the environmental regulations of brine discharge into marine environment. The advantage of this study is its covenant in providing a design for the disposal system which can serve the plant in the worst ambient conditions, so the study provides modelling for the different designs over the annual seasons (winter, spring, summer and autumn). Moreover the study offers the most feasible design from the view of cost.

A summery on the modelling and sensitivity analysis findings of three disposal scenarios cover the onshore and offshore disposal methods can be outlined in the following points.

- The first scenario simulates the discharging of brine through onshore open surface channel, in this scenario, simulation modelling and sensitivity analysis for channel's designs have widths ranges from 0.5 to 6.5m with slopes ranges between 0.3 and 3% at disposal's depths between 1.5 and 5.5m have been executed for Phase (I) and Phase (II) over the four seasons. The results show that disposing brine from GCDP via open channel is not environmentally feasible where the dilution of brine doesn't meet the disposal regulations adopted by Sultanate of Oman, 2005 at RMZ.
- The second scenario presents the method of rejecting brine via offshore submerged single port diffuser, the results illustrate that this method can meet the discharging regulations at RMZ for Phase (I) and Phase (II). But this study is failed this scenario, because the aim beside meeting the regulations at RMZ is to guarantee the quality of seawater at the intake point in a manner to maintain the salinity of feed seawater to ensure that the quality of produced potable water will meet the WHO guidelines for drinking water.
- The third scenario concerns in disposing brine through offshore submerged multiport diffuser. This study provides its configuration that achieves the regulations at RMZ and guarantees the quality of feed seawater at intake point to ensure that the quality of permeate is in the range of WHO guidelines. In this scenario, after investigating the disposal of brine at different disposal depths, inclination angles, alignment angles, ports diameters and diffuser lengths over the four seasons for the two phases, the results show that it is urgent to use a multiport diffuser to dispose GCDP`s brine. Moreover the study provides (illustrated in Figure 6.22) a practical and optimum configuration design for the disposal system of GCDP.

CHAPTER 1: INTRODUCTION

1.1 Background

Water is a vital resource to human beings, as the world's population has drastically grown throughout the 20th century and into the current decades, existing renewable water resources, especially in regions whose climates are characterized as arid and semi-arid, are jeopardized by the rising demand for potable water (Maalouf et al., 2014).

Decreasing freshwater supplies and increasing pollution have become crucial problems that seriously affect a large population of people and our environment (Jacobson, 2010). To alleviate this problems, wastewater must be effectively treated before being discharged, and new freshwater sources must be identified, for instance, through desalinating seawater or brackish water, especially for some areas where seawater is readily available but freshwater sources are limited (Zhang and He, 2013).

Due to the abundance of saline water where over 97% of the earth's water is contained in oceans and other saline bodies (Peavy et al., 1985), desalination, which is a method that separates saline water into a stream of pure water with low concentration of salts and another stream of concentrated salt solution, has gained importance as an alternative water source in coastal countries where conventional water sources are insufficient or overexploited (Shatat and Riffat, 2012).

A number of seawater desalination technologies have been developed over the years to supplement the global supply of water. In general, desalination processes can be characterized into two major types: phase change or thermal processes, and membrane processes (Qasim, 2013).

The reverse osmosis (RO) desalination method is a membrane based process, under the applied of external pressure on the high-concentration side of the membrane, the reverse process occurs and water diffuses from the high-concentration solution into the low-concentration solution (Cath et al., 2006).

Seawater Reverse Osmosis (SWRO) is expected to be the most important desalination technology in the future, but one of the main challenges that face the seawater reverse osmosis technology is compromised by brine disposal challenges, while these methods reduce total dissolved solids (TDS) levels to produce potable water (permeate), large volumes of brine are redirected to the coastal waters (Palomar et al., 2012a).

Brine is a sub product of desalination and is usually discharged into seawaters, and can have negative effects on marine ecosystems especially on benthic and stenohaline species (Ahmad and Baddour, 2014).

Brine`s TDS concentration levels approximately double of that of ambient seawater and with an associate brine density higher than ambient water density, the effluent rapidly sinks and spreads over the sea bed. Subsequently, this may also lead to increased stratification effects that may in turn reduce vertical mixing. These effects may harm the benthic community adversely due to reductions in dissolved oxygen (DO) levels. Therefore brine must be discharged properly so that the ambient coastal water`s TDS concentration levels are maintained unaltered (Maalouf et al., 2014).

Modeling is an essential prediction tool for designing brine discharges, optimizing the dilution, and minimizing the environmental impact. Taking into account the brine effluent properties and the discharge configuration, the models predict brine behavior when discharged in seawater under different ambient conditions (Palomar et al., 2012b).

This study employs the tools of numerical modeling alongside sensitivity analysis for the brine discharged from the planned Gaza Central Seawater Desalination Plant (GCDP) in order to optimize designing brine discharges, optimizing the dilution and finding the best location of brine outfall so as to alleviate the negatively impacts of the brine on the marine environment over different ambient conditions.

1.2 Statement of Problem

The impact of brine disposal operations on coastal and marine environment is still largely unknown; however, it is commonly thought that the discharged brines must ultimately be diluted and transported before disposed to the sea (Purnama et al., 2003).

In Gaza, the proposed GCDP will produce a huge amount of brine approximately 12,200m^3/h from Phase (I) and 24,400m^3/h from Phase (II). If this effluent discharged arbitrary into the sea, it will cause negatively environmental impact on the marine ecosystem. Dense brine`s waste may concentrate along the shore or sink to the seabed and threaten the benthic environment, and thus in the end affect the productivity of fisheries resources. Coastal areas and beaches are important to the Palestinians for fishing, and local recreation. Therefore, it is important to understand how brine is dispersed into the sea, so that we can minimize its potential environmental impact.

1.3 Objectives of the Study

The main goal of this research is to numerically modeling the impact of the rejected brine from GCDP on the marine ecosystem. Moreover, this research is supposed to achieve the following objectives:

- To study the diffusion behavior of the disposed brine into receiving water bodies.
- To simulate the disposal behavior of brine through many brine disposal systems.
- To analysis the sensitivity of design configurations and ambient conditions on optimizing the brine dilution.
- To achieve the optimal disposal system that can minimize the negative environmental impacts on the marine ecosystem as well as that can optimize the costs of installation, operation and maintenance.

1.4 Research Significance

The study puts in our hands a numerical model about the behavior of brine disposal into seawater. The results of this study are valuable for the designers of GCDP, environmental protection agencies, engineers, scientific researchers, and other interested bodies.

1.5 Research Methodology

The methodology followed in this study is mainly based on conducting a numerical study for the disposed brine. Beside that and due to inherent uncertainty in the input data, sensitivity analysis was also carried out using iterative simulations by varying the ambient conditions and the design configurations. The research mainly covers the following topics:

- **Desk study for similar research about modeling of brine disposal**

The research has been enriched by studies and researches that have interested in the brine disposal modelling in order to put the readers and researchers in the view of the recent updating about progress in the modelling of discharges.

- **Data collection, and field survey**

Data about the characteristics of brine, discharge configurations, and diffuser scheme were gathered and created. Data about the ambient parameters, and bathymetric characteristics of disposal area were surveyed from the marine field in order to run the model.

- **Numerically modelling of brine disposal pattern**

Numerical iterative were implemented over many ambient conditions and design configurations scenarios in order to simulate the dilution and diffusion behaviors of the brine plume into the coastal environments. The model of CORMIX which is an EPA software was employed to model the brine behavior.

- **Results and Discussion**

In the results and discussion chapter, the numerical model results were presented and discussed, moreover the compatibility between the model results and disposal regulation in the regulatory mixing zone (RMZ) were checked.

- **The study ended with some conclusion and recommendations**

Based on the results of the modelling recommendations the design configuration that provides the least negative impact on the environment at the worst ambient condition was recommended as the optimal scenario for GCDP`s brine disposal system.

1.6 Thesis Structure

The basic structure of the thesis is organized in seven chapters, as follows:

Chapter One: Introduction: introduces a background on water crisis, desalination as prospective solution, description for the area of study, summary on the problem statement, research objectives, research methodology and structure of the research.

Chapter Two: Literature Review: summarizes the literature reviews along with background information related to environmental controls and modelling, water scarcity crisis, desalination as a promising technology, the environmental impact of brine, environmental standards and regulatory aspects, brine disposal methods, and modelling of brine disposal into marine environment.

Chapter Three: General Characteristics of Gaza Coastal Area: describes the geographically with briefing about its water resources and crisis, population growth, historical metrological data analysis, coastal morphology, marine ecosystem, and environmental legislative of study area.

Chapter Four: Description of Gaza Central Seawater Desalination Plant: demonstrates an overview for GCDP, characteristics of the produced brine, and the configuration for the brine disposal system.

Chapter Five: Model Setup of GCDP: describes in detailed the methodology followed in preparing this thesis, contains a real field collection of data about regional bathymetric of GCDP`s coastline, summary for the used data about currents and winds, a description for the outfall geometries and the selected RMZ.

Chapter Six: Results Analysis and Discussion: explains the findings, results and discussion of the discharging modelling via surface open channel, single port, and multiport disposal systems. All of these findings were discussed and compared with the environmental regulations of waste disposal into waterbodies.

Chapter Seven: Conclusion and Recommendations: provides a brief summary of the research findings as a conclusion followed by recommendations for optimizing the brine disposal systems in convenient with an optimal dilution ratio.

Bibliography: contains the basic references, which have been cited in the body of the research text.

Appendices: contain a detailed description for some of worldwide desalination plants, detailed design for several brine disposal systems and tables of the collected data and the simulations and sensitivity analysis` results.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

As environmental controls become more costly to implement and the penalties of judgement errors become more severs, environmental quality management requires more efficient management tools based on grater knowledge of the environmental phenomena to be managed. For water quality evaluation and management, predictive mathematical models are used to establish the initial dilution of a given discharge and the characteristics of its mixing zone (Akar and Jirka, 1991).

In order to predict the behavior of brine in seawater, modeling can be applied as an essential prediction tool for the environmental assessment of desalination projects. Taking into account effluent brine properties and the particular discharge configuration, the models predict brine behavior under different ambient conditions (Palomar et al., 2012a).

This chapter illustrates some literature reviews along with background information related to water scarcity crisis, desalination as a promising technology and its challenges, the environmental impact of brine, environmental standards and regulatory aspects, the brine disposal methods, and modelling of brine disposal into marine environment.

2.2 Water Scarcity Crisis

Water is one of the vital commodities that sustains and nurtures our life on earth and can be easily obtained from our surrounding (Ang et al., 2014). Its availability enhances the quality of life and the economy of a community (El-Sadek, 2010). However water is an abundant natural resource that covers three quarters of the earth’s surface. Only about 3% of all water sources is potable (Karagiannis and Soldatos, 2008).

Due to several factors such as overuse/misuse of water, pollution of water resources, improper management of water, climate change and population growth have led to a water scarcity crisis (Ang et al., 2014). In the 21st century water scarcity crisis has emerged as one of the most pressing problems (Mehta, 2006).

For the first time in human history, human use and pollution of freshwater have reached a level where water scarcity will potentially limit food production, ecosystem function, and urban supply in the decades to come. The primary reason for this shortage is population growth, which has increased at a faster rate than food production for some years and will add up to 3 billion more people by the middle of the twenty-first century, mostly in poor and water short countries. Water quality degradation has also contributed significantly to a number of problems of global concern, including human drinking water supply and species survival. As of today, some 1.1 billion planetary inhabitants do not have access to clean drinking water, and 2.6 billion do not have sanitation services (Jury and Vaux Jr., 2007).

Water stress in some form threats nearly 80% of the human population, and about 65% of continental discharge feeds habitats that face moderate to high biodiversity threats (Vörösmarty et al., 2010). Recently more than 18 countries around the world classified as water scarce (their per capita yearly freshwater resources are below 1000m^3/capita/year). The majority of these countries are in the Middle East and North Africa (Bremere et al., 2001). Where the Middle East and North Africa is home to 6.3 percent of the world's population, it holds only 1.4 percent of the world's renewable freshwater (Roudi-Fahimi et al., 2002).

In order to recovery the negative consequences of water scarcity, solutions such as water recycling, water reuse, desalination and improvement of currently available water treatment plants have been suggested (Ang et al., 2014).

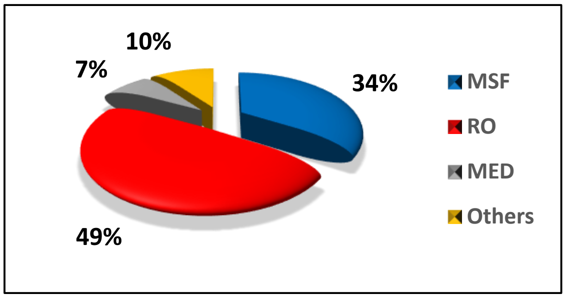
2.3 Water Desalination Technologies, Sustainability, and Challenges

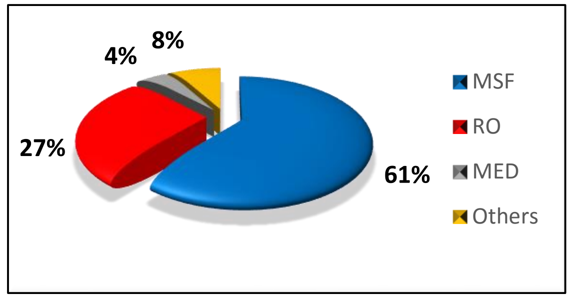
The trend is clear for the 21st century worldwide water consumption is growing, driven by an increasing population combined with increasing industrial and agricultural production. In arid zones and other water-scarce areas, this consumptive demand must largely be met through desalination plants using a variety of technological processes, e.g. thermal processes such as multistage flash (MSF) plants, or membrane processes such as reverse osmosis (RO) plants (Bleninger and Jirka, 2010).

Desalination of seawater has been considered as one of the most promising techniques for supplying freshwater in the regions suffering water scarcity (Oh et al., 2009). It has been gaining popularity as a feasible option for potable water production, as available water sources are gradually depleting due to water scarcity as well as quality deterioration (Wilf and Bartels, 2005).

A seawater desalination process separates saline seawater into two streams: a freshwater stream containing a low concentration of dissolved salts and a concentrated brine stream. The process requires some form of energy to desalinate. A number of seawater desalination technologies such as reverse osmosis (RO), multistage flash distillation (MSF), multiple effect distillation (MED) and electrodialysis (ED) have been developed during the last several decades to augment the supply of water in arid regions of the world. (Khawaji et al., 2008).

Almost half of the global desalination capacity which includes all source waters like, seawater, brackish water or river water is covered by reverse osmosis plants. Considering only seawater desalination capacities, MSF plants account for the highest share of the production (Münk, 2008). Figure (2.1) describes the global distribution of installed desalination capacity by technology and the global distribution of installed seawater desalination capacity by technology.





(a) **(b)**

Figure (2.1): (a) Global desalination capacity by technology and (b) Global installed seawater desalination capacity by technology (Münk, 2008).

Some states depend on desalinated water for more than 50% of their domestic use, where other drinking water sources are close to depletion. To avert the real threat to resource sustainability and to satisfy the immediate need to increase the production and supply of potable water, desalination is a key focus for governments around the word, generating massive investment and creating demand for global expertise plus the latest advanced systems and technologies (Bleninger and Jirka, 2010). As of June 2011, 15,988 desalination plants have been installed and operated in 150 countries producing a combined 66.5 million m^3 of freshwater per day (Xevgenos et al., 2014).

In Middle East, especially in the Gulf countries, where rainfall is scanty and evaporation rates are high. Surface water is limited and there are no perennial streams. The increase in population and socio-economic development has led to an imbalance between supply and demand. These countries depend mainly on desalination to meet the growing water needs (Nair and Kumar, 2013).

Kingdom of Saudi Arabia (KSA) is the largest desalinated water producer in the world, and it currently produces about one-fifth of the world productions (Ouda, 2014). KSA desalinates daily 9.9 million m^3 of water, about 7.4 million m^3 is produced from seawater desalination plants, this make it the highest country employing desalination around the world. United Arab Emirates (UAE) follows KSA as the second highest country employing desalination around the world with a desalination employing capacity of 8.4Mm^3/d, 7.3Mm^3/d is desalinated by seawater desalination plant (Nair and Kumar, 2013).

In (Israel), desalinated seawater contributed a growing share in covering annual water consumption. At the end of 2011, desalinated seawater was supplied continuously and reliably into the regional and national water grids from three large plants, Ashkelon, Palmachim, and Hadera, at the rate of about 300 million m^3/year. This quantity represented about 42% of all the potable water inputs into these grids (other inputs were groundwater and Sea of Galilee water). In (Israel) nowadays two additional large plants, at Soreq A and Ashdod, and an expanded Palmachim plant are producing an additional 300 million m^3/year, this rise the grid supplied water from seawater desalination to nearly 80% (Tenne et al., 2013).

As it is gaining increasing importance for addressing water needs, desalination technology has its disadvantages of costly and energy intensive and further strains the environment with brine disposal and greenhouse gas (GHG) emissions. In order to desalt seawater, either through membrane or thermal processes, a large amount of energy is required. Desalination has negative impacts in the form of depletion of fossil fuels and GHG emissions from the power production process to deliver this energy. What is more, the brine produced during the desalination process causes damages to the local sea environment where the brine is discharged (Xevgenos et al., 2014).

2.4 Brine of Desalination Process

The World Health Organization, for example, states that TDS levels between 300 and 600mg/L are considered good for potable uses. In addition, the US Environmental Protection Agency (USEPA) states that a TDS of 500mg/L is a recommended safe level for potable drinking water. Desalination of seawater with TDS of 35,000ppm to meet the safe levels of drinking water produces large volumes of brine with a TDS about twice the TDS of feed water (Maalouf et al., 2014).

The brine is the waste stream produced by desalination plants and is usually discharged into the sea. The brine flow rates are large, generally up to 40% (RO) and up to 90% (MSF, including cooling water) of the intake flow rate, thus either almost as large or even considerably larger than the required drinking water flow rate (Bleninger and Jirka, 2010).

2.4.1 Characteristics of Brine Effluent

Brine is generated as a by-product of the separation of the minerals from the source water used for desalination. This liquid stream contains most of the minerals and contaminants of the source water and pretreatment additives in concentrated form. The characteristics of reject brine are directly related to the quality of the feed water, the desalination technology used, the percent recovery, and the chemical additives used (Voutchkov, 2011).

Beside the high salinity of brine, several types of chemicals are used in the desalination process for pre- and post-treatment operations. Due to the presence of these different chemicals at variable concentrations, reject brine discharged to the sea has the ability to change the salinity, alkalinity and the temperature averages of the seawater and can cause change to marine environment (El-Naas, 2011). Table (2.1) presents the typical analyses of physical and chemical parameters of the rejected brine for the reverse osmosis (RO), and multi-stage flash (MSF) desalination techniques.

Table (2.1): Typical effluent properties of RO and thermal MSF seawater desalination plants (Dawoud and Al Mulla, 2012)

	RO Plants	MSF Plants
Physical Properties		
Salinity	up to 65,000–85,000 mg/L	about 50,000 mg/L
Temperature	ambient temperature	+5 to 15°C above ambient
Plume Density	negatively buoyant	positively, neutrally or negatively buoyant
PH	PH about 6–7	PH about 6–7
Biofouling control additives		
Chlorine	To control biofouling.	10–25% of source water feed dosage.
Halogenated organics	Typically low content below harmful levels.	Varying composition and concentrations, trihalomethanes
Removal of suspended solids		
Coagulants (e.g. iron-III-chloride)	May be present if source water is conditioned and the filter backwash water is not treated.	Not present (treatment not required)
Coagulant aids (e.g. polyacrylamide)	May be present if source water is conditioned and the filter backwash water is not treated.	Not present (treatment not required)
Scale control additives		
Anti-scalants Acid (H_2SO_4)	Not present (reacts with seawater to cause harmless compounds, i.e. water and sulfates; the acidity is	Typically low content below toxic levels. Not present (reacts with seawater to cause harmless compounds, i.e. water and sulfates; the acidity is consumed by the

	consumed by the naturally alkaline seawater, so that the discharge pH is typically similar or slightly lower than that of ambient seawater).	naturally alkaline seawater, so that the discharge pH is typically similar or slightly lower than that of ambient seawater).
Foam control additives Antifoaming agents (e.g. polyglycol)	Not present (treatment not required)	Typically low content below harmful levels
Contaminants due to corrosion Heavy metals Cleaning chemicals	May contain elevated levels of iron, chromium, nickel, molybdenum if low-quality stainless steel is used.	May contain elevated copper and nickel concentrations if inappropriate materials are used for the heat exchangers
Cleaning chemicals Cleaning chemicals	Alkaline (pH 11–12) or acidic (pH 2–3) solutions with additives such as: detergents (e.g. dodecylsulfate), complexing agents (e.g. EDTA), oxidants (e.g. sodium perborate), biocides (e.g. formaldehyde)	Acidic (pH 2) solution containing corrosion inhibitors such as benzotriazole derivates

2.4.2 Brine Disposal Methods

In desalination, high-salinity brine is produced that needs to be disposed with a minimum of environmental impact. Nowadays, brine discharge from desalination plants is the concern of all countries producing freshwater from desalination with different technologies (Bashitialshaaer et al., 2012).

The most important environmental issues for a desalination plant are the location of the plant, brine disposal and energy considerations (Barron et al., 2015).

The mitigation of environmental implications of brine disposal is most closely related to the means through which it is managed. The selection of disposal method depends on eight factors, which are: volume of brine, quality of brine constituents, geographical location of discharge point of brine, availability of receiving site, permissibility of the option, public acceptance, capital and operating costs, and ability of facility to be expanded (Sommariva et al., 2004).

Brine disposal from desalination plants is recognized as an environmental hazard. Each stage of the desalination either adds or concentrates chemicals, most of which are discharged along with the brine at the end of the process. Another potential environmental impact of brine disposal is eutrophication, due to the high levels of phosphates in the brine effluent (Hopner and Windelberg, 1996). All desalination methods have always been limited by the disposal costs of the concentrated waste brines produced and the adverse impact of brine compositions on the environment, particularly in large-scale plants. In coastal regions, disposal of brine water can be accomplished by discharging into the neighboring body of seawater (Mohamed et al., 2005). More sensitive to effluent discharges are enclosed seas, such as Red Sea and Arabian Gulf, which have limited water exchange capacities and are generally shallow and less energetic. The Mediterranean Sea is effectively a closed basin connected to the Atlantic Ocean via the Strait of Gibraltar. In contrast to the Gulf and the Red Sea, the brine residues from desalination are expected to have only a modest impact on it (The World Bank, 2012).

For brine disposal, the methods used are vital. There are two completely different scenarios regarding brine disposal, shown in Table (2.2), which is determined by the location of the plant. They are brine disposal in inland areas and in coastal areas with the main difference being possibility for discharge to a large saltwater body, i.e. the sea. Ocean disposal is recognized as the most simple and least costly method and is therefore almost exclusively used wherever it is possible. However, in inland locations too far from the sea, alternative methods have to be used increasing both the economic and environmental impacts of brine disposal (Svensson, 2005).

Table (2.2): Brine disposal methods (Svensson, 2005)

	Disposal Method	**Description**
Disposal in Inland Areas	Deep Aquifer Injection	This involves injecting the reject water through drilled wells to deep, consolidated aquifers containing non-drinkable water
	Aquifer Reinjection	This involves injection of brine into the same aquifer used as feed. This will gradually increase the salt concentration in the feed water
	Discharge to Wastewater Treatment Plant	This can be a viable option if the desalination plant is located near a wastewater treatment plant that has capacity to accommodate the brine`s volume.
	Discharge to Sewage System	Many desalination plants discharge the brine to a sewage system. This may affect the capacity of the sewage system and wastewater treatment efficiency.
	Discharge to Open Land	The reject water is simply discharged to a “natural pond”. This method will cause salinization of groundwater.
	Reuse for Agriculture or Landscaping	Water reuse for landscape, ornamental and agricultural applications such as very salt-tolerant turf grass is an alternative.

	Discharge to Inland Surface Water	Discharge to any surrounding inland surface water (lake, river) is not an environmentally viable option as these are not saltwater bodies.
	Evaporation Ponds	Evaporation ponds have been used for centuries to generate salt. Evaporation ponds are used to concentrate the brine into precipitation of salt crystals.
	Zero Liquid Discharge (ZLD)	Zero liquid discharge means that a dry end product is reached and no reject water is discharged into the environment. This introduces the possibility for resource recovery
Disposal in Coastal Areas	Discharge by Pipe Far into the Sea	The disposal of brine by pipe should therefore be sufficiently far out into the sea. The limitations is the cost, environmental impacts and the distance from the intake point.
	Direct Discharge at Coastline	This is normally not a viable option. However, due to economics, it can be considered for smaller plants at insensitive shores.
	Discharge at a Power Station Outlet	This is used extensively for thermal desalination plants where hybrid installations of water and energy production is combined. A less density brine is produced.
	Discharge to a Plant for Salt Production	This presents an environmental and economical option. The main limitations for this method is the presence of salt production plants close to the desalination plant.

2.5 Marine Brine Disposal Systems

Brine disposal into the sea is certainly the preferred method of managing waste brine when industry is close to the sea. Current brine disposal systems have various layouts and dimensions depending on different constraints, regulations, and design parameters. A review of typical existing marine disposal systems provides some guidelines to design new disposal systems (Ahmed and Baddour, 2014). In order to meet the regulations, it is urgent to optimizing the mixing efficiency of brine effluent discharges. Discharge strategies for negatively buoyant effluents into marine environment can be classified into (Bleninger and Jirka, 2008):

A. **Surface Discharge:** shoreline discharge via channel or weir. Figure (2.2).

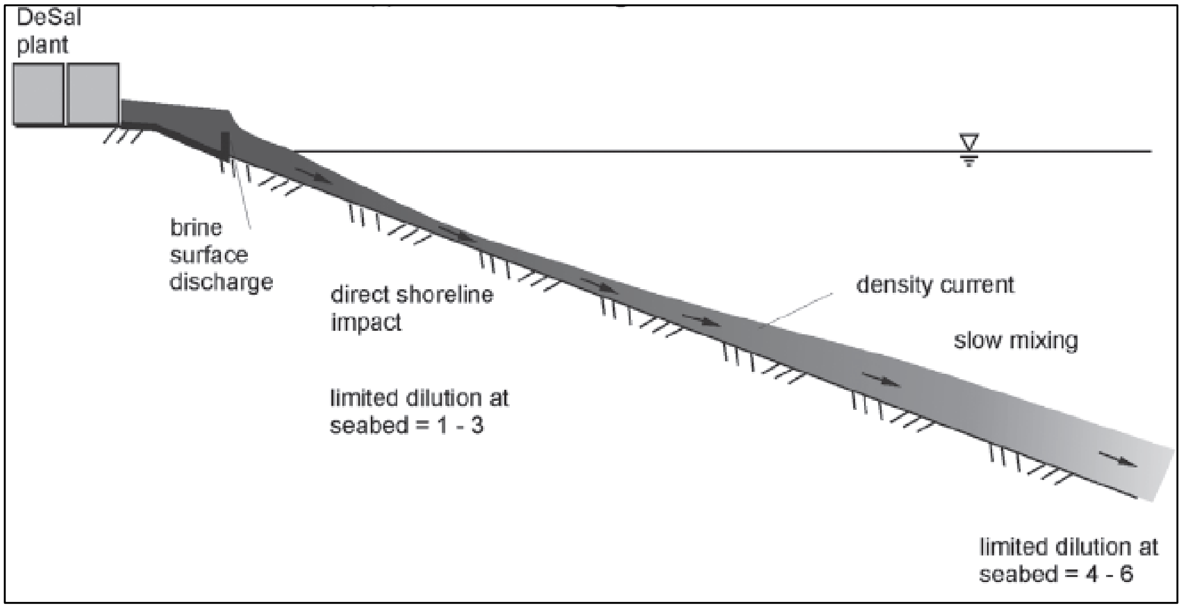


Figure (2.2): Surface discharge via channel or weir (Bleninger and Jirka, 2008)

B. **Submerged Discharge:** submerged discharge via pipeline and nozzle or diffuser. Figure (2.3)

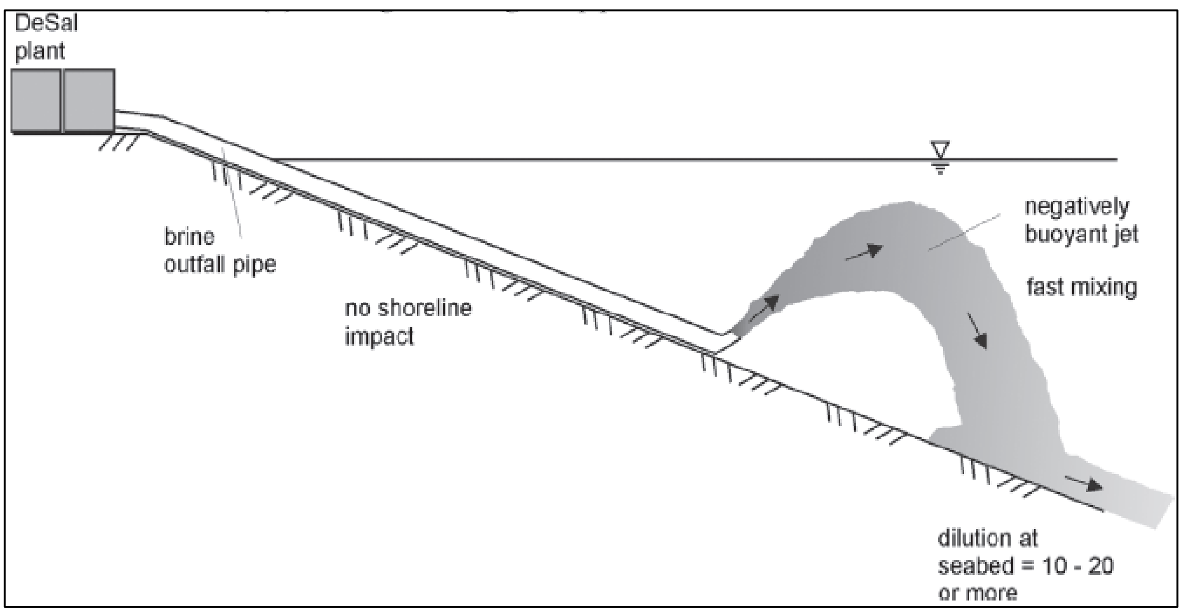


Figure (2.3): Submerged discharge via pipe and nozzle or diffuser (Bleninger and Jirka, 2008)

The brine discharge configuration should consider the particular characteristics of the discharge area and the degree of dilution necessary to guarantee compliance with environmental quality standards and the protection of marine ecosystems located in the area affected by the discharge. If there are any protected ecosystems along the seabed in the area surrounding the discharge zone, it is recommended to avoid direct surface brine discharge systems because the degree of dilution and mixing is very weak (Palomar and Losada, 2011).

The adoption of surface channels for brine discharge in shallow areas with limited circulation is not adequate to achieve acceptable mixing and dilution rates. Mitigation of adverse impacts of the direct surface discharge of brine on the local marine environment can be achieved either by the construction of several long single port outfalls or a multi-port diffuser (Alameddine and El-Fadel, 2007).

Nowadays, modern large capacity seawater desalination plants discharge a concentrated brine effluent into coastal waters by means of submerged marine outfalls equipped with a single port or a multiport diffuser system, as shown in Figure (2.4), in the form of a negatively buoyant jet, that ensure a high dilution in order to minimize harmful impacts on the marine environment (Jirka 2008).

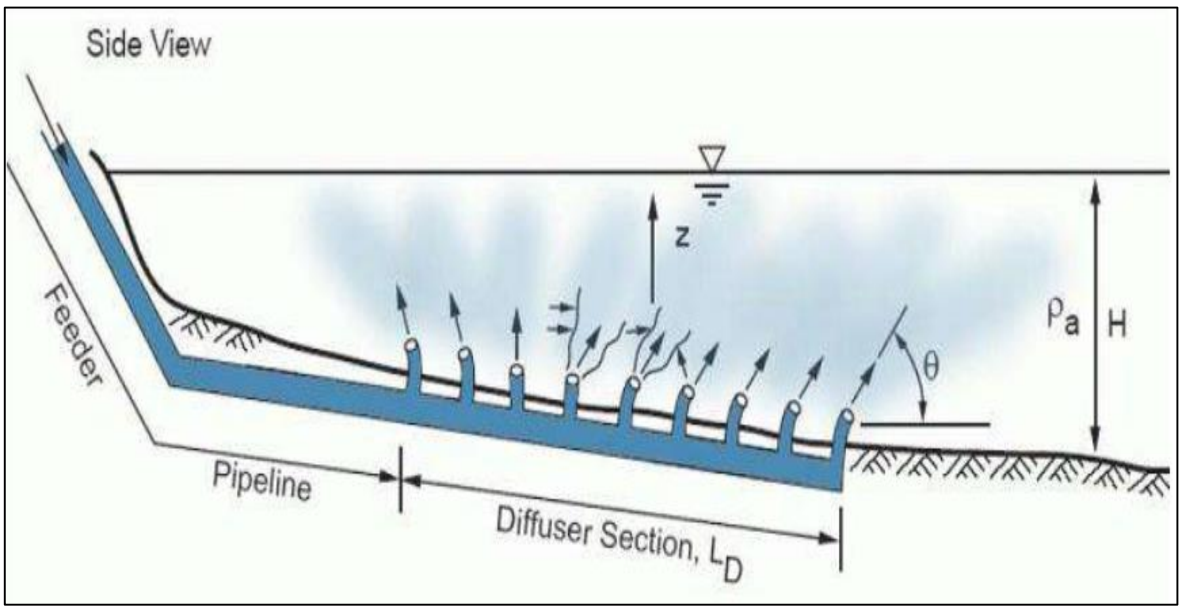


Figure (2.4): Layout of an outfall pipeline with multiport diffuser (Bleninger and Jirk, 2010)

Multiport diffusers are the effective engineering devices installed at the modern marine outfalls for the steady discharge of effluent streams from the coastal seawater desalination plants seawater desalination. The diffuser section is equipped with a number of ports that disperse brine discharge into coastal waters within the mixing zone. These ports are arranged either in a unidirectional, staged or alternating manner. Overall, marine outfalls vary considerably in terms of their construction material, installation techniques, pipeline and port diameters, as well as other design and construction related functions (Purnama, 2011; Maalouf and et al., 2014).

2.6 Environmental Impacts of Brine Disposal into Sea

Brine from desalination processes is normally discharged directly into the sea, forming a very dense plume of water that spreads out over the sea floor following the steepest gradients and affecting the benthic communities encountered along the way. The impact of brine discharges on the marine ecosystem increasingly needs further attention and study, particularly in relation to seagrass meadows (Portillo et al., 2013).

The impacts of a desalination plant discharge on the marine environment depend on the physical and chemical properties of the desalination plant reject streams, and the susceptibility of coastal ecosystems to these discharges depending on their hydrographical and biological features (Bleninger and Jirka, 2010).

The potential harmful of brine on the environment yield from either it's higher than normal salinity, or due to pollutants that otherwise would not be present in the receiving body of water. These include chlorine and other biocides, heavy metals, antiscalants, coagulants and cleaning chemicals (Ladewing and Asquith, 2012).

2.6.1 Salinity and Temperature

Salinity and temperature are controlling factors for the distribution of marine species, which normally dwell in those areas that provide favorable environmental conditions for the species. Most organisms can adapt to minor deviations from optimal salinity and temperature conditions, extreme situations may be tolerated temporarily, but not a continuous exposure to unfavorable conditions. The constant discharge of reject streams with high salinity and temperature levels can thus be fatal for marine life, and can cause a lasting change in species composition and abundance in the discharge site (Ciocanea et al., 2013).

The salinity of most oceans lies at about 35-40g/l. The salinity of desalination effluents depends on the recovery rate and can highly exceed the natural ocean levels as Table (2.1) shows. Several studies indicate that constant salinity levels above 45g/l alter the benthic community and reduce the diversity of organisms (Münk, 2008).

Moreover, increased temperatures reduce the oxygen solubility in water and significant decreases in oxygen levels can be toxic for species, also it increases the toxicity of the poison present in water where a 10^{o}C rise in temperature doubles the toxic effect of potassium cyanide while a 80^{o}C rise in temperature triples the toxic of oxylene, also the raised temperature disturbs spawning in water and interface the biological and reproduction activities (Meenakshi, 2012).

2.6.2 Pretreatment Chemicals

A lot of chemicals from pretreatment process for the feed water are found into the produced brine, these chemicals can have severe impacts on marine life (Lattemann and Höpner, 2008).

To prevent fouling in the membranes, among the broad-effect antifouling agents, the most commonly used antifouling additive is chlorine because it is cheap and much experience exists, where a typical dosage of 2mg/l is added for shock chlorination. Chlorine has a potential dangerous to marine life, where it has been proven to be toxic at concentrations of a few micrograms only (Hoepner, 1999). Figure (2.5) depicts the toxic concentrations (LC_{50}) of chlorine for a range of species.

Antiscalants are found in small concentrations in desalination discharge. Today the most commonly used antiscaling agents are polymeric antiscalants. Polymer antiscalants are of low toxicity, and have little environmental impacts. Studies about polymer antiscalnt has been carried out reporting that no accumulation in algae and fish was detected and that the agent is ecologically safe. (Hopner, 1999; Lattemann and Höpner, 2008).

Coagulants, which are present in filter backwash, are of low toxicity and are not considered a major environmental concern. One of the greatest effects of coagulants comes through the use of ferric salts, which are likely to cause coloration and increase turbidity of the backwash (Lattemann and Höpner, 2008).

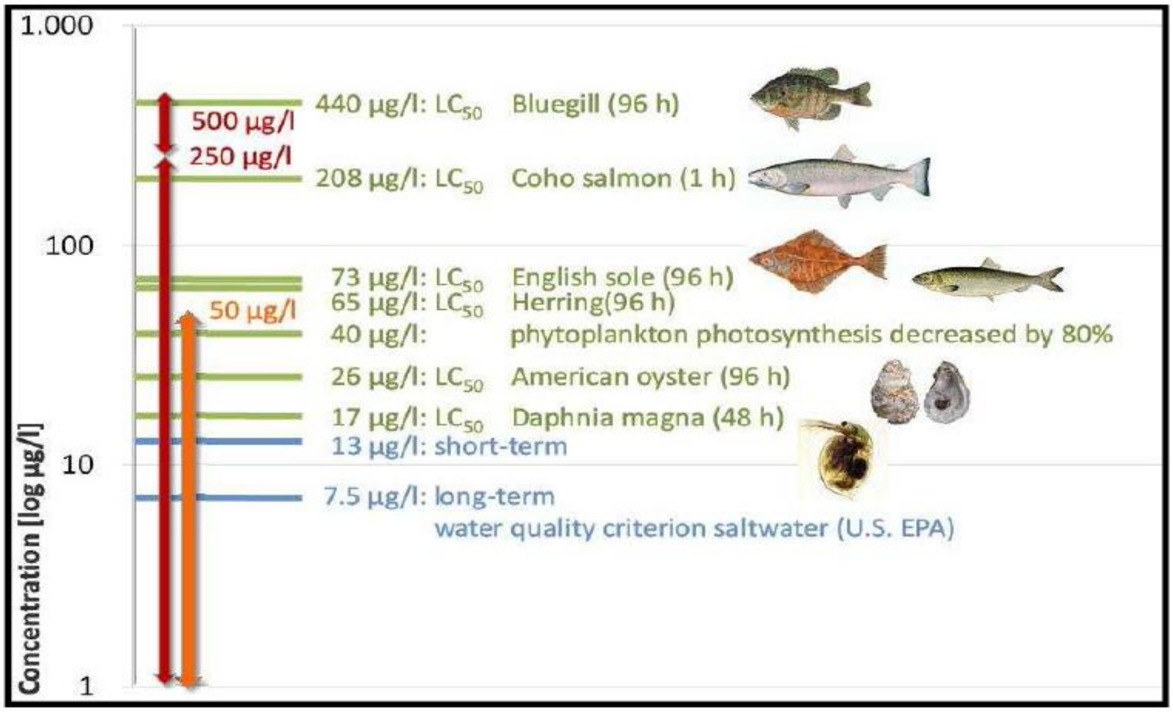


Figure (2.5): Chlorine toxicity levels for a range of marine species (Höpner et al., 2008)

2.6.3 Cleaning Chemicals

Most cleaning chemicals used for membrane desalination plants are harmful to the environment. Discharge of these solutions which are wither basic or acid are dangerous to marine life, and should be neutralized prior to discharge (Ladewing and Asquith, 2012).

2.6.4 Heavy Metals

Metal in the discharge can come from the source water, or a product of corrosion. Depending on the materials used for the heat exchanger tubes and vessels, copper, nickel, iron, zinc and other heavy metals are corroded and discharged (Hopner, 1999).

Copper as example of heavy metal has an average concentration in the oceans at a minimum of 0.1µg/l. Copper concentrations in MSF effluents were reported in the range of 15-100µg/l. the tolerance towards copper pollution is not yet entirely known for all species. Copper can be toxic at higher concentrations, causing enzyme inhibition in organisms and reducing growth and reproduction (Miri et al., 2005). Figure (2.6) illustrates the toxicity levels for a range of marine organisms.

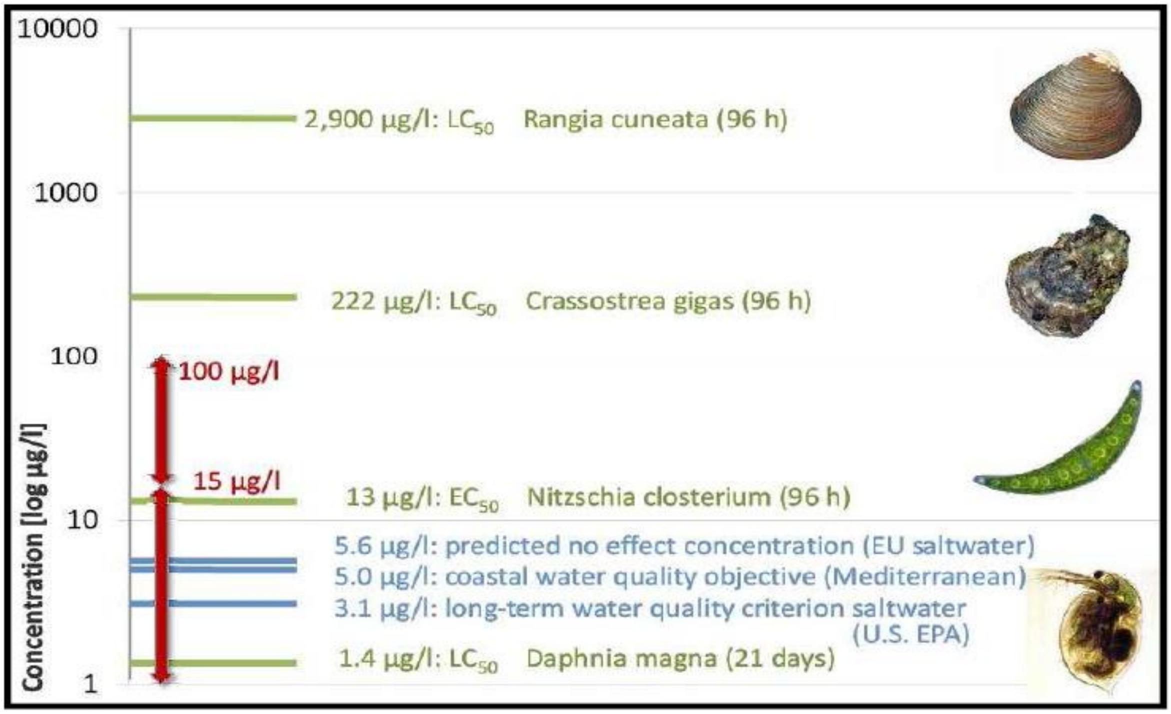


Figure (2.6): Copper toxicity levels for a range of marine species (Höpner, et al., 2008)

In particular, increased plant capacities increase impact concentrations of effluent constituents to levels that can become harmful to the marine environment. Moreover beside the environmental impacts of desalination plants, potential impacts on local fisheries or tourism resources with considerable economic consequences are some of the conflict points that arise when planning desalination plants (Münk, 2008).

2.7 Environmental Standards and Regulatory Aspects

Brine is produced in various quantities by many industrial processes. Understanding the impact of brine on the environment is important to develop and implement appropriate environmental policies by environmental protection agencies (Ahmad and Baddour, 2014).

One of the major environmental problems is the concern for an adequate water quality in all bodies of water, from streams, rivers and lakes to estuaries and coastal waters. In order to complete this goal, all wastewater discharges should subject to environmental regulations (Akar and Jirka, 1991).

An important way to control and restrict adverse environmental impacts of seawater desalination plants is to put up appropriate national laws or transnational agreements. These may regulate the brine discharge management, set up discharge limits or impose environmental standards and conditions mandatory for receiving operating permits. With respect to the worldwide desalination activities, the regulatory situation is very diverse and unclear. No common standards exist as each country has own water regulations which are more or less publicly accessible. Most regulations are abstract and do not apply specifically to desalination plants, but to industrial effluents in general (Bleninger and Jirka, 2010).

A key aspect of these regulations is the concept of a mixing zone. The mixing zone is a legally defined spatial quantity that allows for the initial mixing and dilution of a discharge. Local criteria specify the mixing zone shape and effluent concentrations which must be maintained outside and at the edge of the mixing zone (Akar and Jirka, 1991).

USEPA (1984) defined the mixing zone as an “allocated impact zone” where numeric water quality criteria can be exceeded as long as acutely toxic conditions are prevented. A mixing zone can be thought of as a limited area or volume where the initial dilution of a discharge occurs. Water quality standards apply at the boundary of the mixing zone, but not within the mixing zone itself.

A conceptual diagram for regulatory mixing zones appears in Figure (2.7). The figure shows the boundaries at which the acute criteria and chronic criteria must be met. The acute criteria or a criterion of maximum concentration to protect against acute or lethal effects; and the chronic criteria or a criterion continuous concentration to protect against chronic effects.

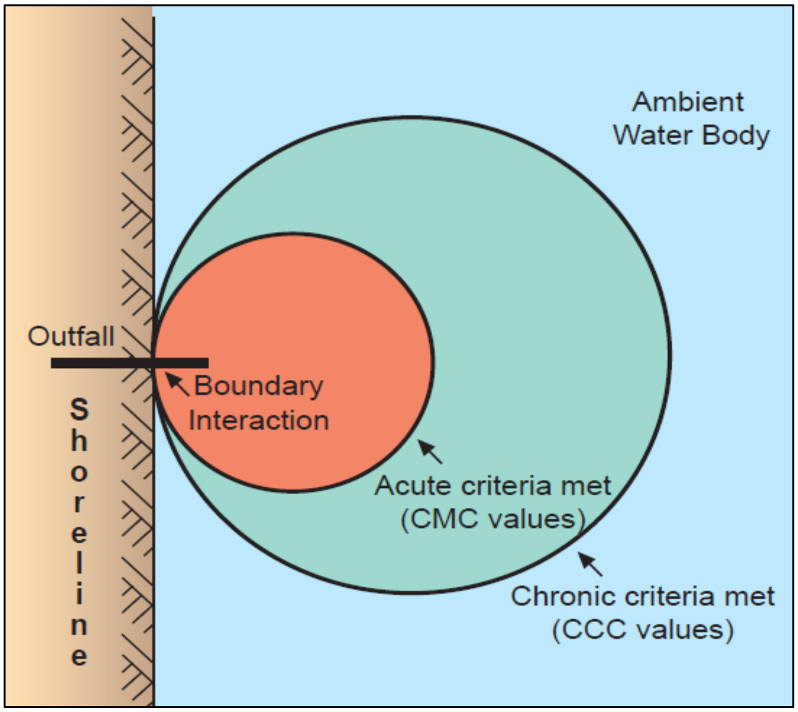


Figure (2.7): Conceptual diagram for a regulatory mixing zone (Doneker and Jirka, 2007).

When dealing with toxic discharges, USEPA maintains two water quality criteria for the allowable concentration of toxic substances: a criterion maximum concentration (CMC) to protect against acute or lethal effects; and a criterion continuous concentration (CCC) to protect against chronic effects. The CMC value is greater than or equal to the CCC value and is generally more restrictive. The CCC must be met at the edge of the same regulatory mixing zone specified for conventional and nonconventional discharges (Akar and Jirka, 1991).

Point-source discharges are usually controlled by setting environmental standards. Most common standards are effluent standards (ES) and ambient standards (AS). There are existing different philosophies in applying either just one of these standards or combinations of them for pollution management. ES encourage source control principles, such as effluent treatment and recycling technologies. AS require the consideration of the ambient response often associated with the concept of the "mixing zone". Concentration or load limits for ES and AS can be found in state, national, and international legislations for different substances, effluents, and receiving water characteristics. The most relevant parameters for seawater desalination plant effluents are salinity, temperature, pH, dissolved oxygen, turbidity, dissolved organic matter and residual chemical pollutants such as copper, nickel, residual free chlorine and chlorinated by products (Bleninger and Jirka, 2010).

Many national and international environmental regulations and guidelines are stipulating discharge limits for temperature and salinity to be compiled with by the projected desalination plant in order to obtain the environmental approval for operation (Schafer, 2010).

2.7.1 Temperature Regulations

The World Bank recommends that the discharge water temperature should not result in an increase greater than 3°C of ambient temperature at the edge of a scientifically established mixing zone, which takes into account ambient water quality, receiving water use, potential receptors and assimilative capacity among other considerations (World Bank Group, 2007).

The Omani Ministerial Decision No: 159/2005 for the discharge of liquid waste into the marine environment, states that the temperature of liquid waste at the discharge point should not exceed 10°C above the temperature of the water surrounding the seawater intake. The discharge should not result in a temperature increase in seawater of more than 1°C (weekly average) in a circular area of 300m diameter around the point of discharge (Sultanate of Oman, 2005).

US EPA (1986) limits the maximum acceptable increase in the weekly average temperature resulting from artificial sources to 1°C during all seasons of the year. Canadian Water Quality Guidelines (CWQG) for protection of marine life limits maximum temperature variation to 1% of ambient water temperature for any human activity (CCME, 2008).

In Australia, the Department of the Environment (DoE) requires the increase of temperature at the edge of the mixing zone (area of $0.01km^2$) is to be less than 0.1°C (Bath et al., 2004). While in (Israel), the thermal brine regulations limit the temperature rise to 4°C above ambient at the discharge point (Safrai and Zask, 2004).

2.7.2 Salinity Regulations

The Western Australian guidelines for fresh and marine waters specify that the median salinity increase is to be less than 5% from background. In the case of the Seawater Reverse Osmosis plant at Perth metropolitan, Australian EPA requires that salinity be within 1.2 units of ambient levels within 50m of the discharge point and within 0.8 units of background levels within 1,000m of the discharge point (WEC, 2002).

The US EPA recommendations state that salinity variations from natural levels should not exceed 4 units from natural variation in areas permanently occupied by food and habitat forming plants when natural salinity is between 13.5 and 35 (US EPA, 1986).

According to Omani regulations on the discharge of liquid waste into the marine environment, the salinity should not deviate from the surrounding average for more than 2 units on a daily basis in a circular area of 300m diameter around the point of discharge (Sultanate of Oman, 2005).

Ambient salinities in the Mediterranean range between 37 and 38ppt. For Mediterranean seagrass Posidonia oceanica meadows, salinity thresholds have been recommended based on field and laboratory experiments. Salinity should not exceed a value of 38.5ppt in any point of a seagrass meadow for more than 25% of the observations (on an annual basis) and should not exceed a value of 40ppt in any point of the meadow for more than 5% of those observations (Sánchez-Lizaso et al., 2008).

2.7.3 Regulatory Mixing Zone Regulations

It is necessary that national water authorities provide clear guidance for the actual specification of mixing zone dimensions. However, there are several authorities in different countries with such modern regulations, which are reluctant to undertake the additional work to implement the mixing zone concept. Their arguments are often related to the difficulty in defining mixing zones on one hand, and on the application of it on the other hand (Czernuszenko and Rowinski, 2005).

Geometrically, the mixing zone is a volume with vertical boundaries in the coastal water body that is limited in its horizontal extent to a distance DMZ equal to N multiples of the average water depth (H_{avg}) at the outfall location and measured in any direction from the outfall structure. This specification results in a cylindrical volume with the port in its center (Figure 2.8a) for a single port outfall. For a multiport diffuser outfall with many ports arranged along a straight diffuser line it would be a rectangular prismatic volume with attached semicircular cylinders at the diffuser ends located along the diffuser line (Figure 2.8b). The multiplier N accounts for physical, chemical, and biological characteristics of the receiving waters, and/or effluent characteristics. The value N would typically be in the range of at least 1 to about 10 and set by the regulatory authority. For highly sensitive waters the minimum of 1 should be set. Common values for most coastal waters might be N = 2 to 3 (Bleninger and Jirka, 2010).

N can be specified regarding effluent types and characteristics, as well as receiving water characteristics. Former can be done defining a value N for every discharged substance, based on factors like biodegradability, half-time decay coefficients, or the ES/AS ratio (Bleninger and Jirka, 2010).

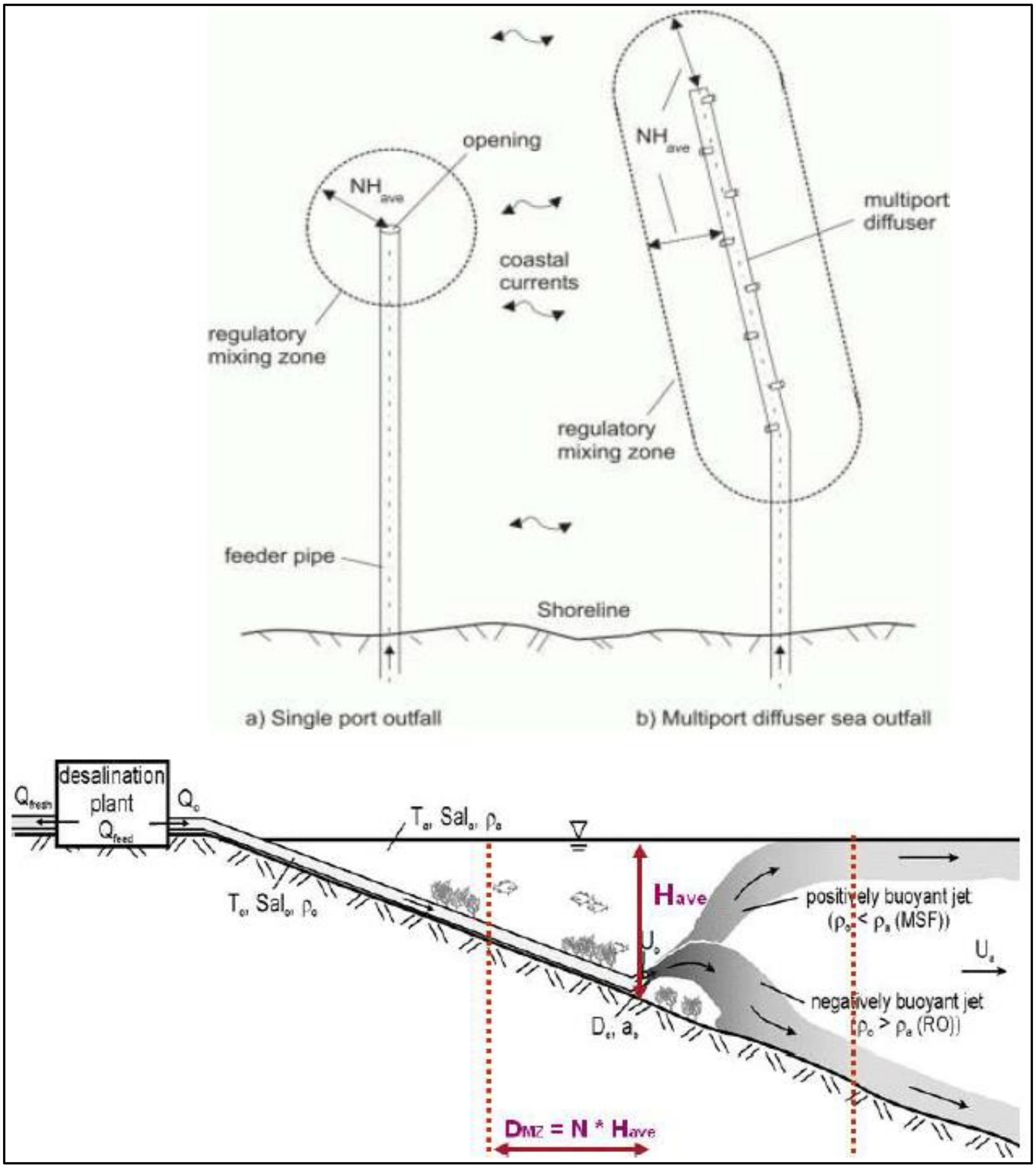


Figure (2.8): Example of regulatory mixing zone specification for offshore submerged coastal discharges: The horizontal extent of the mixing zone is defined by some multiple N of the average water depth H_{ave} at the sea outfall (Bleninger and Jirka, 2010).

Further approaches have been proposed in Spain (Freire, 2008 cited in Bleninger and Jirka, 2010) to compute the values for N = (D + B + V) / 3, with D = Depth Index, B = sediment index, V = Vulnerability index based on the sediment characteristics (hard substrates, mixed substrates and soft substrates) and ecological parameters (susceptibility, biotope protection status, biotope conservation status, and biotope sensitivity) combined to $V = (Is + I_{bps} + I_{bcs} + I_{bs}) / 4$ as shown in Table (2.3).

Table (2.3): Proposed indexes for defining N (Freire, 2008 cited in Bleninger and Jirka, 2010)

Index		Categories	Index Value
Water Depth (D)		0-30m	1
		30-60m	2
		> 60m	3
Bottom Substrate (B)		Hard Substrates (rocky)	1
		Mixed Substrates	2
		Soft Substrates (sandy or muddy)	3
Vulnerability of Coastal Waters to Outfalls Discharges	Susceptibility (I_s)	High	1
		Intermediate	2
		Low	3
	Biotope protection status (I_{bps})	High	1
		Intermediate	2
		Low	3
	Biotope conservation status (I_{bcs})	Extirpated	1
		Severely declined	1
		Significantly declined	2
		Probability of significant decline	3
	Biotope sensitivity (I_{bs})	High	1
		Intermediate	2
		Low	3
		Not sensitive	3
		Not relevant	3

2.8 Modeling of Brine Discharged to Water Bodies

Water quality modelling can simulate the behavior of brine discharges, thus it is an essential prediction tool in the environmental assessment of desalination projects. Simulation leads to prediction of the performance of quality standards in the receiving waters and to guarantee that critical salinity limits will not be exceeded. There are two types of modelling techniques (Palomar and Losada, 2011):

- Experimental modelling.
- Numerical modelling.

Experimental physical modelling consists in performing laboratory experiments using scale physical models, which are a copy of the real case being tested, i.e. the prototype, but normally at a smaller scale. Experimental tests can be carried out on any effluent, discharge configuration and ambient conditions (Palomar and Losada, 2011).

With the rapid increase in computer power in recent years, it seems that the physical models are getting too expensive. It is not surprising to note the shifting of numerical simulation from academic to practical applications. (Abualtayef, 2008).

Water quality modelling is a mathematical representation of the physical and chemical mechanisms determining the development of pollutant concentrations discharged into the seawater receiving body. It involves the prediction of water pollution using mathematical simulation techniques and determines the position and momentum of pollutants in a water body taking into account ambient conditions. Water quality modelling applied to brine discharges solves the hydrodynamics and transport equations adapted to a negatively buoyant effluent (Palomar and Losada, 2011).

Numerical modelling is a good prediction tool in the predesign and design stages due to the low cost of the experiments, and the ability to characterize brine behavior into the sea and predict its impact on water quality standards, considering effluent properties, discharge system features and ambient conditions (Palomar et al., 2012a, b).

The numerical modelling of brine discharge depends on several physical phenomena occurring during brine discharge into water bodies, e.g. the sea. Dispersion, diffusion, convection, and buoyancy are the main ones. The discharge process can be divided into two different regions as shown in Figure (2.9), the near field and the far field depending on the relative magnitude of the physical phenomena involved (Al-Sanea et al., 2014).

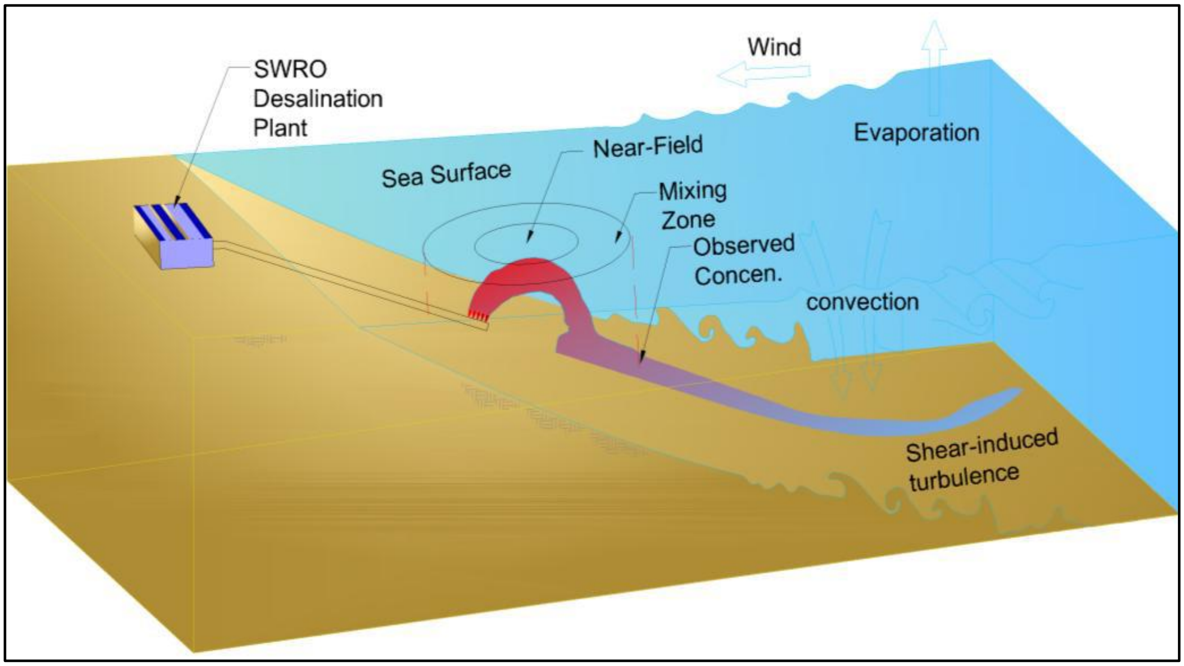


Figure (2.9): Brine discharge process (Maalouf et al., 2014)

It is more accurate to deal with a numerical simulations concern in brine disposal to consider two regions of interest: the nearfield region and the far field region. The near-field region is located in the vicinity of the discharge point and it is affected by turbulent jet mixing, which depends critically on discharge parameters, brine physical properties and environmental physical properties. This mixing area extends from the effluent's point of release to its interaction with a physical boundary (e.g the seafloor, or sea surface). Flow and mixing characteristics of the near field region are dominated by small scales (meters and minutes) (Portillo et al., 2013).

The end of the near-field is considered to be the point at which the turbulence collapses. At this point, the far-field region begins and the brine jet is now named brine plume. The far-field plume forms a gravity driven current moving along the seafloor and mixing is only affected by the physical processes of advection and diffusion. Flow and mixing characteristics are dominated by large scales (kilometers and hours). The brine dilution ratio is very small and depends on ambient conditions and density differences (Portillo et al., 2013; Palomar et al., 2012a).

Figure (2.10) demonstrates the behavior of a negatively buoyant effluent (Brine) discharged through a single port jet in the jetting turbulent region of near field and in the plume region of far field where the plume forms a gravity driven current moving under the effects of the physical process of advection and diffusion.

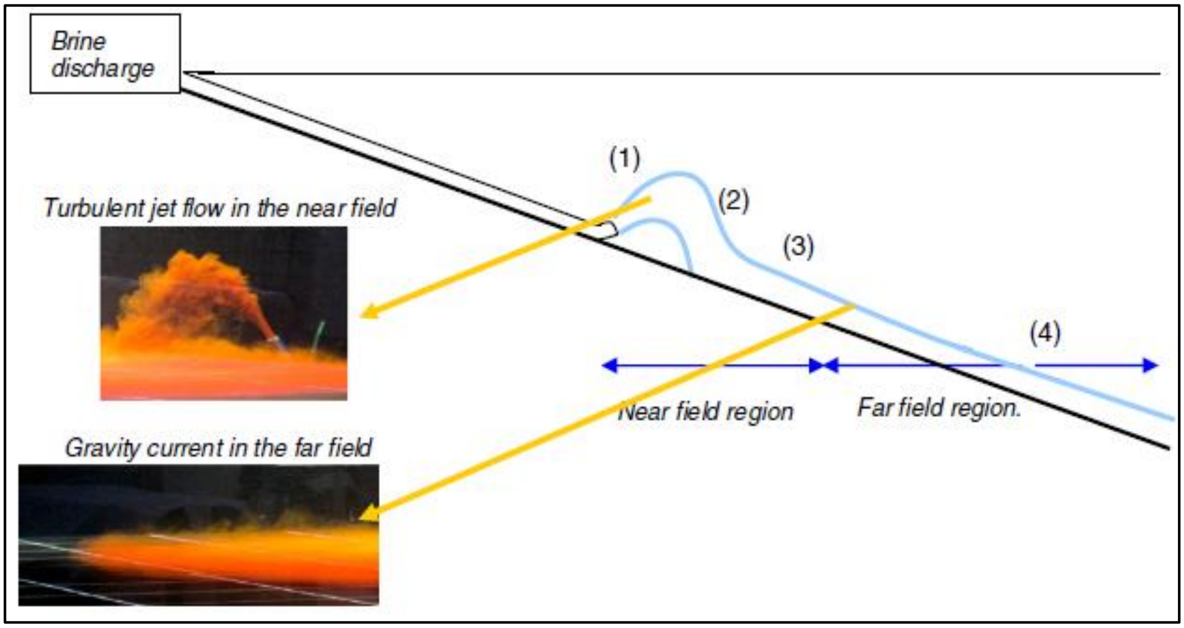


Figure (2.10): Jet discharge in near and far fields (Palomar et al., 2012a)

Form Figure (2.10) the following points can be notified about brine discharge by jetting process (Palomar et al., 2012a):

1. Dense brine discharged upwards creates a rising negatively buoyant jet, with an ascending trajectory in which buoyancy opposes the vertical component of momentum (due to discharge velocity). At some distance from the discharge point, the vertical component of the initial momentum reduces to zero (due to the continuous action of the negative buoyancy force), the buoyant force equals the momentum and the jet reaches its maximum height. From this point buoyancy is the dominant force and the jet descends.
2. The brine jet impacts the bottom, with an additional dilution due to turbulence phenomena and flow expansion. The region between the bottom impact zone and the far field region.
3. A transition zone, where flow behaves as a "spreading layer".
4. In the far field region, brine turns into a gravity current.

The mixing processes of brine discharges have widely varying length and time scales. Since it is not possible to simulate them with one overall model, separate models are used in the near-field and far-field (Niepelt, 2007)

To be able to model the entire trajectory of the plume from the initial meters to its effects several kilometers away, separate near and far field models must be used in combination.

The most common engineering approach is to translate results of near field simulations into input (sources of fresher/brine/warm water) for the far field model (Morelissen et al., 2013).

To describe the behavior of a discharge, there are three types of physical and mathematical models: models based on a dimensional analysis of the phenomenon, models based on integration of differential equations along the cross section of flow and Hydrodynamics models (Doneker and Jirka, 2001).

In most models, the following simplifying assumptions are used: incompressible fluid, Reynolds decomposition (mean and turbulent components); Boussinesq approximation (density differences are negligible with the exception of the terms of the buoyancy force); molecular diffusion is neglected; a turbulent diffusion closure model based on Boussinesq eddy viscosity theory and no (other) sources or drains apply (Jenkins et al., 2012).

2.8.1 Numerical Modelling of Near Field Jet Discharging Processes

The mixing processes occurring within the near-field can be determined with so called integral models (Niepelt, 2007). The integration models are mainly used for jets and gravity current modelling. Governing equations of flow are in this case integrated over the cross section, transforming them into simple ordinary differential equations which are easily solved with numerical methods, as Runge Kutta formula (Palomar and Losada, 2011).

Integral models use hydrodynamic equations governing conservation of volume, mass, momentum, buoyancy and of other quantities as temperature and salinity which are solved stepwise along the jet trajectory (Figure 2.11). The actual cross-sectional distribution is fixed a priori mostly as a Gaussian distribution. The solution yields values for the trajectory position and of the centerline concentrations of these quantities. Integral models assume an infinite receiving water body neglecting any boundary effects as jet attachment (Doneker and Jirka, 2007).

Discharge characteristics primarily dominate the mixing behavior in the near-field region which extends from tens of meters up to few hundred meters from the outfall location. The initial volume flux Q_o, the initial momentum flux M_o, the buoyancy flux J_o and outfall configurations significantly influence the jet trajectory and the intensity of mixing of submerged brine discharges. For the discharging phenomenon, the main fluxes are (Niepelt, 2007; Palomar and Losada, 2011):

- **Kinematic flux of mass**: represents effluent flow discharged into the receiving environment.

$$Q_o = \frac{\pi}{4} D^2 U_o \qquad (2.1)$$

- **Kinematic flux of momentum**: represents the energy transmitted during the discharge of the effluent.

$$M_o = Q_o U_o \qquad (2.2)$$

- **Kinematic flux of buoyancy**: represents the effect of gravity on the effluent discharge.

$$J_o = g'_o Q_o \qquad (2.3)$$

Where U_o is the discharge velocity, D is diameter of the orifice, ρ_o is the discharge density, ρ_a is the ambient density and $g'_o = g (\rho_a - \rho_o)/\rho_o$ is the discharge buoyancy.

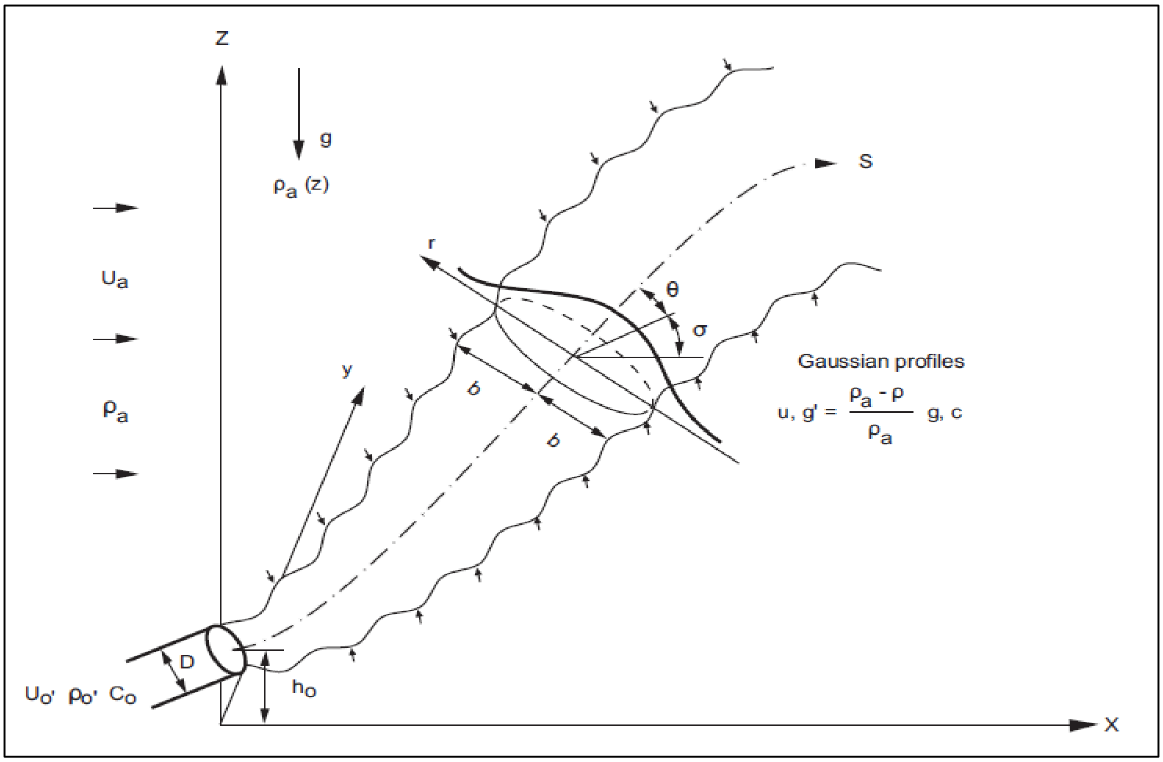


Figure (2.11): General trajectory for a submerged jet (Doneker and Jirka, 2007)

2.8.2 Numerical Modelling of Far Field Jet Discharging Processes

The further away from the source the less important the discharge characteristics. In the far-field extended from hundreds of meters to tens of kilometers the ambient conditions are dominating the mixing processes. The established plume is transported through passive advection by a generally unsteady ambient current. Large scale motions as buoyant spreading processes and passive diffusion control the slow mixing and the trajectory of the plume. Buoyant spreading motions only occur for positively or negatively buoyant discharges. Buoyant forces caused by density differences spread the mixed effluent flow over large distances in lateral direction. A plume of substantial thickness can thereby decrease essentially to a thin but wide layer. The transverse spreading flow is a density current like motion with rather small mixing processes due to entraining ambient fluid at the frontal head of the current.

Passive ambient diffusion is a far-field mixing process which arises due to existing ambient turbulence. The strength of passive diffusion depends mainly on ambient flow characteristics and the degree of stratification. In case of open coastal areas the plume size affects the diffusivities leading to accelerative plume growth (Doneker and Jirka, 2007).

The effluent flow and the effluent mixing in the far field region are described by the continuity equation and the Navier-Stokes equation stating conservation of mass and conservation of momentum and forces (Niepelt, 2007):

Continuity equation - conservation of mass:

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u_i)}{\partial x_i} = 0 \tag{2.4}$$

Where ρ = density, u_i = velocity vector, t = time, x_i = location vector

Momentum equation - conservation of momentum and forces:

$$\frac{\partial (\rho u_i)}{\partial t} + \frac{\partial (\rho u_i u_j)}{\partial x_j} + 2\rho\Omega_i \times u_i = -\frac{\partial P}{\partial x_i} - \rho g_z + \mu \frac{\partial^2 u_i}{\partial x_i^2} + F_{e,i} \tag{2.5}$$

Where Ω = earth rotation vector, p = pressure, g = gravitational acceleration, μ = dynamic viscosity, $F_{e,i}$ = external forces

Transport equation:

$$\frac{\partial c}{\partial t} + \frac{\partial (c u_i)}{\partial x_i} = D_m \frac{\partial^2 c}{\partial x_i^2} + kc \qquad (2.6)$$

Where c = substance concentration, D_m= molecular diffusion coefficient and k = decay/growth function.

2.8.3 Commercial Tools for Brine Discharge Simulations

The quality of a discharge assessment strongly depends on a good knowledge of the receiving waters. In contrast to the near field assessment, a far-field analysis needs much more detail on ambient currents and turbulence than the time, depth, and spatial averaged values used for the near field. This holds especially for the description of stratified coastal waters (Bleninger and Jirka, 2010).

To accurately determine the dispersion, recirculation and environmental impacts of outfall plumes, it is important to be able to model the different characteristics of the outfall plume in detail from the near field to the far field. The solution for engineering practice is to combine different types of models (near and far field models) that each focus on specific scales, with corresponding optimized resolutions and processes. However, to adequately describe the hydrodynamic processes on these different scales, it is essential to couple these models in a dynamic and comprehensive way. This coupled modelling system is able to use the computed far field ambient conditions in the near field computations and, conversely, to use the initial near field dilution and mixing behavior in the far field model (Morelissen et al., 2013). Table (2.4) demonstrates some of the near and far field models.

Table (2.4): Commercial tools for near and far fields simulations

Types of Models	**Model**	**Developer**
Near Field Models	CORMIX	Doneker and Jirka
	VisJet	Lee and Cheung
	Visual Plumes	Frick
Far Field Models	Delft3D	Delft Hydraulics
	MIKE3	Danish Hydraulics Institute
	POM/ ECOM-si	Princeton Ocean Model - Princeton University
	Telemac 3D	EDF, Electricité de France, and Wallingford

CORMIX software, Cornell Mixing Zone Expert System is a commercial model which was developed in the 1980s at Cornell University (USA) as a project subsidized by the Environmental Protection Agency (EPA). Supported by the EPA, it became one of the most popular programs for discharge modelling. CORMIX contains four core hydrodynamic simulation models and two post-processor simulation models. The simulation models are simulation models for single port discharges (CORMIX1), simulation models for submerged multiport diffusers (CORMIX2), simulation models for buoyant surface discharges (CORMIX3), and simulation models for dense brine and/or sediment discharges from single port, submerged multiport, or surface discharges in laterally unbounded coastal environments (DHYDRO) (Doneker and Jirka, 2007).

The hydrodynamic flow classification schemes in the CORMIX system use the length scale concepts, as a measure of the influence of each potential mixing process due to momentum flux and buoyancy of the discharge in relation to boundary interactions, to predict steady-state mixing zone characteristics and plume dynamics such as free jets, shoreline-attached jets, wall jets and upstream intruding plumes (Jones et al., 2007).

Boundary interaction analysis on mixing processes, from laboratory and field experiments, provide a rigorous and robust expert knowledge base that distinguishes among these many complex flow patterns that may occur (Jirka, 2004). For every flow class, CORMIX assembles and executes a sequence of appropriate computational modules. Efficient algorithms provide simulation results in seconds for mixing zone problems with space scales of meters to kilometers and time scales of seconds to hours (Jones et al., 2007).

Loya-Fernández and et al. (2014) compared the model predictions of CORMIX1, CORJET, MEDVSA and VISUAL PLUME (UM3) with field salinity measurements obtained directly inside the brine jet. In general, each model was quite conservative in its results, except UM3, whose prediction presented the best approximation to measured data.

The CORMIX model is the only modeling suite containing a jet model coupled to intermediate field models, being able to predict outfall performance under different limiting conditions. The far field models instead are not necessarily required for showing compliance with outfall related mixing zones, but more for water body related general effects of the outfall on the coastal ecosystem (Bleninger et al., 2009).

MixZon Inc., highlights the features of CORMIX system as follows:

- Makes a complete simulation for near field and far field plume trajectory, shape, concentration, and dilution predictions and visualizations.
- Includes plume boundary interactions, including dynamic near-field attachments.

- Predicts current behavior, buoyant upstream wedge intrusion and stagnation points.
- Provides a documented analysis, complete with all rules used in classification and conclusions reached during a session.
- Models conservative, non-conservative, and heated pollutant types.
- Alerts the user in special conditions, when plume encounters regulatory mixing zone constraints, including Toxic Dilution Zone CMC and CCC values.
- Application to steady and unsteady ambient currents, or stagnant ambient conditions.
- Predicts stratified atmospheric plumes with skewed wind velocity.

For every flow class, CORMIX assembles and executes a sequence of appropriate hydrodynamic simulation modules. Additional features of CORMIX are contemporary 3D plume and diffuser visualizations, a comprehensive documentation and help system, GIS linkage, a benchmarking analysis and validation database, a far field locator post processor, sensitivity analysis and a batch running mode and time series, all fully linked within the expert system interface. CORMIX results include design recommendations, flow class descriptions and reporting oriented on discharge zone analysis (Bleninger and Morelissen, 2015).

Many researchers employed CORMIX model to evaluate the efficiency of brine disposal system for example, Purnama (2012) demonstrated the potential impacts of surface discharges of brine ($12m^3/s$) from the Al-Ghubrah power-desalination plant in the Omani coastal marine environment using Cornell mixing zone model expert system (CORMIX) simulation model. Sensitivity analysis was also carried out using iterative simulations by varying the ambient current velocity (to evaluate the effect of uncertainty in sea conditions), the water depth at the discharge channel (to evaluate the effect of model parameters), the effluent discharge density (to evaluate the effect of uncertainty on the brine characteristic) and the effluent flow rate (to evaluate the effect of uncertainty on the plant's operation).

Alameddine and El-Fadel (2007) studied the dispersion of the brine plume in the marine environment by considering the effluent from a desalination power plant in the Gulf region. Various scenarios were defined and simulated using the CORMIX model to compare the mixing behavior and efficiency of surface, submerged single-port as well as submerged multi-port outfalls taking temperature variations as an indicator. The simulations capitalized on the inadequacy of widely used surface channel discharges in achieving the required dilution rates capable of minimizing potential environmental impacts on the Gulf. For the multiport diffusers, they simulated the brine disposed through vertical, staged and alternating multiport diffuser with a diffuser lengths of 1,464m, 813m, and 1,342m, respectively. They concluded that it's more environmental to adopting a perpendicular alignment of a multiport diffuser line with respect to the ambient velocity to enhance the dilution process.

CHAPTER (3): GENERAL CHARACTERISTICS OF GAZA COASTAL AREA

3.1 Location and Geography

Gaza Strip is located along the coast of the eastern Mediterranean Sea, stretching over a distance of approximately 45km from Beit Hanoun, a town in the north, to Rafah, a city in the south, with width of 7 to 12km (Ghbn, 2010). Figure (3.1) depicts the location of Gaza Strip.

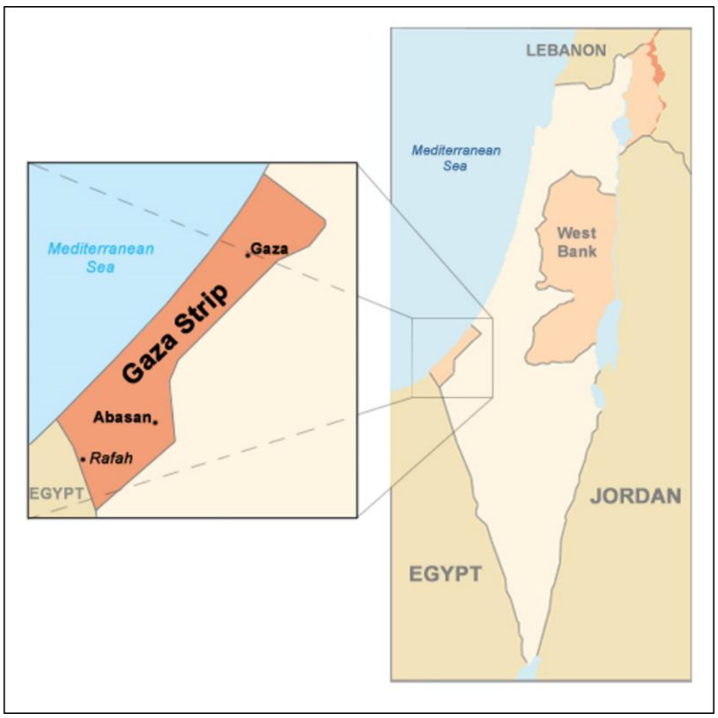


Figure (3.1): Gaza Strip`s location map

Gaza Strip, with a total area of 365 square kilometers, borders Egypt on the southwest for 11km and Israel on the east and north along a 51km border (Wikipedia, 2015). Sand dunes are dominant along the shoreline with elevations up to 40m above mean sea level, while a brown clay (mix with) loamy soil extends at east Gaza city and at north-eastern of Gaza Strip. Three Wadis are crossing Beit Hanoun, Gaza, and Salga areas forming the hydrological feature of the area. The Wadi of Gaza is the biggest one, it runs in the central part of the Gaza Strip and discharges into the Mediterranean Sea. Israel has retained and changed the course of the three Wadis and they became dry Wadis (Ismail, 2003).

3.2 Population

Gaza Strip is considered as one of the most densely area in the world (Aufleger and Mett, 2011). Based on the Palestinian Central Bureau of Statistics (PCBS) data for the year of 2014, the population of Gaza strip for the year of 2014 is 1.76 million inhabitants and the sensitivity of population growth has been evaluated using growth rate of 3.44% (PCBS, 2015).

Figure (3.2) shows the population growth until the year of 2016, it is estimated that the population of Gaza Strip will increase from 1 million to 1.88 million inhabitants by the year of 2016.

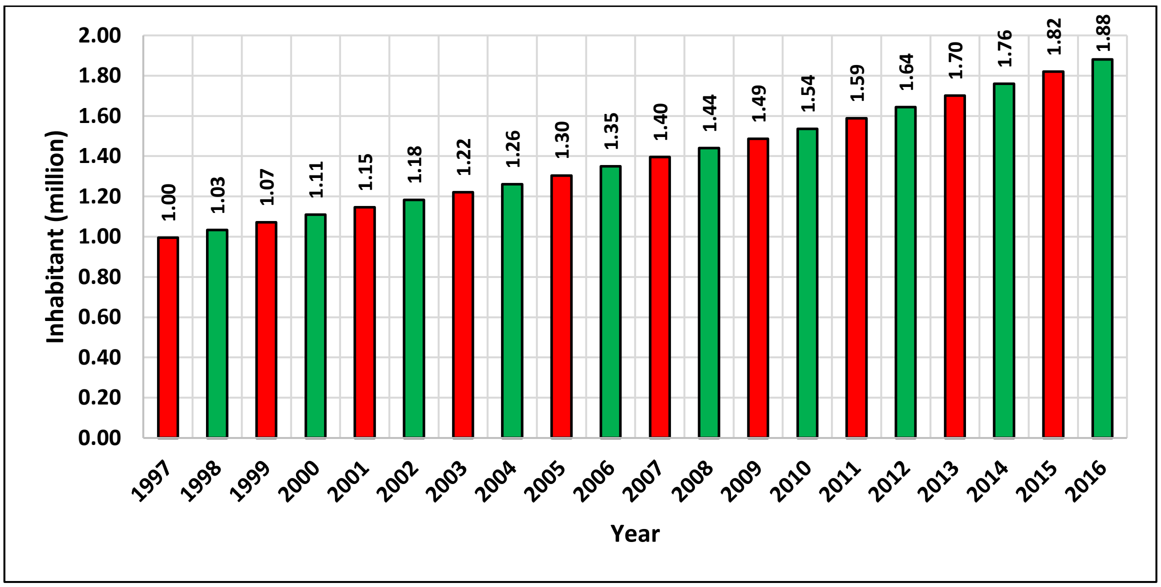


Figure (3.2): Population growth for Gaza Strip until 2016 (PCBS, 2015)

This rapid population growth will exhaust the natural resources found in the Gaza Strip and would weaken the local governments and municipalities to provide the minimum basic needs to the inhabitants from the limited resources.

The economic situation in the Gaza Strip in particular and in Palestine in general is directly affected by the political situation. Israeli procedures like closures, prohibition of export and import from and to the Palestinian area are other significant factors that have resulted in a deceasing trend of the income per capita. The Gross Domestic Product (GDP) has dropped to US$ 600 per capita by year in 2002 and it was expected to be much less than this figure due to the continuous instability of the political situation (PCBS, 1999).

3.3 Climate of Gaza Strip

Gaza Strip has a semi-arid Mediterranean climate, with average daily mean temperature ranges from 25ºC in summer to 13ºC in winter. The daily relative humidity fluctuates between 65% in the day time and 85% at night in summer, and between 60% and 80% respectively, in winter. While the mean daily evaporation varies from 2.1 to 6.3mm per day in December and July respectively (Madi, 2006). The average rainfall in the area based on 20 years' records amounts to 335mm/y (PWA, 2000).

In general, the wind directions in Gaza Strip are west through northwest and hardly ever exceed 15m/s (Smaling, 1996). According to data of Palestinian Meteorological Authority of 2007, wind climate at Gaza can be presented using a wind-rose chart in Figure (3.3).

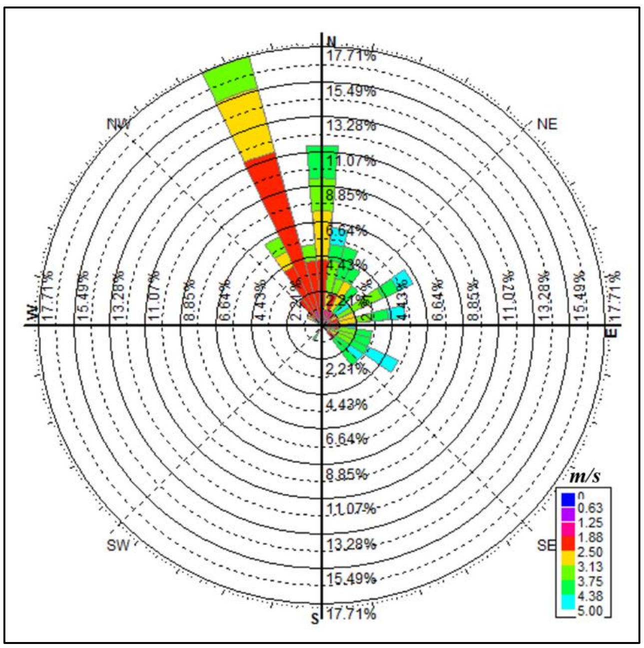


Figure (3.3): Wind rose of Gaza Strip (based on data of Palestinian Meteorological Authority, 2007)

3.4 Oceanography of Waves, Currents and Water-levels

At the location of (31.75°N and 33.94°E) 50km off the coast of the Gaza Strip, Delft Hydraulics (1994) gathered measurements for wind, sea waves and swell waves. This database consists of 8720 measurements taken every three hours between 1-1-1992 and 1-2-

1995. Waves (wind generated waves and swell) 50km offshore are generally not higher than approximately 3.25m and come mostly from a direction between 30° and 240° (through north). The general current pattern in the East Mediterranean is a counterclockwise flow around Cyprus. However, when winds from unusual directions are strong and persistent, local drift opposed to the general circulations may develop. A number of reports on the current speed in the east Mediterranean come to a maximum velocity of 0.50m/s (Grabowsky & Poort Consulting Engineers, 1994, Carmel et al., 1985 cited in Smaling, 1996).

The astronomical tidal range in the Mediterranean is very small. From the Admiralty tide tables of 1988 the highest and lowest beside the mean water levels can be shown in Table (3.1)

Table (3.1): Water levels (Smaling, 1996)

H.A.T	M.H.W.S	M.H.W.N	M.S.L	M.L.W.N	M.L.W.S	L.A.T
+0.45m	+0.35m	+0.15m	0m	-0.15m	-0.25m	-0.35m

In other publications, a water level of 1m above MSL was derived for the design level which corresponds approximately with a once in 50 year water level. Such an extreme water level may coincide with the occurrence of the highest waves, since strong westerly winds cause both the wind setup and the waves. Therefore this extreme water level was used in the determination of the extreme wave height near the coast (Smaling, 1996).

3.5 Coastal Morphology

The sea bed bathymetry of the Gaza coast follows depth contours more or less parallel to the coast. Depth contours are found between 500m and 1200m out of the coast. For the 20m depth contour distances are found between 1500 and 2000m. From the 20m depth contour the water gradually deepens 100m at a distance of 20-25km from the coast. Then the sea bed steepens and deeper water occurs (600m and deeper). Between 4-6m water depth a flat area is found (Smaling, 1996).

Going from sea to land, the coastal profile can be divided into the seabed, the beach, the dune face or kurkar cliffs, and the adjacent body of the dune or cliff plateau. The coastal profile does not only consist of sand, but locally also erosion-resistant formations of rock and kurkar protrude, on the seabed, on the beach, and in the cliffs. The geophysical survey for the Port of Gaza demonstrated the presence of non-erodible layers at a mean distance of about 3m below the alluvial seabed. Further, a detailed bathymetric survey of the area where the Gaza Sea Port is planned revealed that between the shoreline and 10m depth the seabed is characterized by areas of rock outcrops and linear features of sand bars. On the beach and near the waterline of the Gaza shoreline on many places kurkar outcrops and rocky ridges can be seen (MEnA, 2010).

3.6 Marine and Coastal Ecosystem of Gaza

According to the Gaza Coastal and Marine Environmental Protection and Management Action Plan report, the coastline of the Gaza strip forms only a small section of a larger concave system (a “litoral cell”) that extends from Alexandria at the west side of the Nile Delta, via Port Said, Bardawil Lagoon, El Arish, Gaza, Ashqelon, and Tel Aviv to the Bay of Haifa. This litoral cell forms the south east corner of the Levantine Basin. This entire coastline, including the coastline of the Gaza Strip, has been shaped over the last 15,000 years by the Nile River and especially its sediment yield originating from Africa’s mountains (MEnA, 2001).

3.6.1 Seawater Quality and Characteristics

Abualtayef et al. (2014) described the results of 94 microbial analysis samples conducted during summer and autumn on two types of fecal indicators (fecal coliform and fecal streptococci), in addition to a single type of bacteria (pseudomonas) for the Mediterranean coast of the Gaza Strip over an area extended from the proposed Khan Younis fishing port to Gaza fishing port, with a length of about 23km. The result showed that peak bacterial counts of 40,000 CFU per 100mL, and 1200 CFU per 100mL for fecal coliform and fecal streptococci were respectively indicated during autumn season, while peak bacterial count of 60 CFU per 250mL was recorder for Pseudomonas aeruginosa during summer season.

As Gaza coastline is a part of the Mediterranean Sea, the physical and chemical properties of Gaza seawater is in general similar to that properties of the Mediterranean. Faragallah et al. (2009) investigated the physical and chemical characteristics of the Mediterranean Seawater at about 60km from Damietta harbor, Egypt. Table (3.2) shows some these physical and chemical properties.

Table (3.2): Physical characteristics of seawater (Faragallah et al., 2009)

Item	Unit	Value
Temperature	°C	23.1
PH	-	7.94
EC	mS/cm	58.5
TDS	ppm	39000

3.6.2 Marine Life

Most of the 201 fish species that have been recorded in Gaza strip waters are distributed at a depth between 20 and 200 meters, in particular the highest rate of abundance is between 100 and 200 meters this make the marine area of Gaza strip between 20 and 200 meters is the zone of most of the fishing activities, where the abundance of fish in deep waters (>200 meters) becomes declining. The majority of the species are bony fishes 163 species consisting (81%) of the fish population, moreover the presence of cartilaginous fishes as sharks, rays and other forms is 19% of the observed fish fauna. The fish distribute in different types of habitats, the most important habitat for bony fishes in the Gaza Strip is the rocky substrate, while the majority of cartilaginous fishes use the soft bottoms, muddy and sandy substrates (MEnA, 2001).

The fish of Pakala (*Merluccius hubbsi*), Jaraa (*Micropogonias*), Danese (*Sparus aurata*), and Bory (*Mugil cephalus*) are commonly caught in the coastal waters of Mediterranean sea of Gaza Strip (Elnabris et al., 2013).

3.7 Water Sources in Gaza Strip

The water crisis is fundamentally a product of overpopulation relative to the available resources as populations grow, so the finite resource base becomes more and more stretched, and so crisis ensure, globally, world population growth is outrunning water supply, while the Middle East as a whole is close to the ceiling in terms of its very high number of people per flow unit of water (Selby, 2003).

The current situation in the water sector of Gaza Strip has been characterized by various parties as a humanitarian crisis. The primary source of freshwater is the underlying groundwater that is grossly contaminated and at present yields almost no flow of acceptable quality for domestic use (PWA, 2012). At its present rate of deterioration, over 95% of the underlying portion of the coastal aquifer on which the Gaza Strip relies on for its water needs is contaminated with unacceptable high levels of either nitrate (NO_3) or chloride (Cl), posing significant health risks to Gaza’s 1.8 million residents (PWA, 2014).

The sustainable yield of the aquifer within the geographical boundary of Gaza Strip is widely quoted as 55 million cubic meters (MCM) annually, however, more than 1.8 million Palestinians in Gaza consume in excess of 200 MCM/y from the aquifer, thus taking approximately four times as much as the aquifer can sustainably recharge each year (PWA, 2015). Yaqubi (2015) stated that the aquifer currently has a water deficit of about 120 million cubic meters per year (MCM/y) and the water table has dropped 15-20 meters below sea level, this has caused seawater to intrude into the aquifer.

As the coastal aquifer is the only natural source of freshwater in the Gaza Strip, Desalination of water through reverse osmosis (RO) has become the most realistic option to meet a rapidly growing water demand (Ghabayen et al., 2004). Currently in Gaza Strip, six large brackish water and one seawater reverse osmosis desalination plants providing 4% of the total water demand of the Gaza population owned and operated by the Palestinian Water Authority (PWA) and different municipalities. In addition, there are many small desalination units owned and operated by private investors for commercial purposes (Mogheir et al., 2013; Baalousha, 2006).

Moreover, the Palestinian in Gaza Strip purchase nearly 5 million m^3/y of freshwater from the Israel's national water company (Mekorot) which is the quantity that agreed on in Oslo II in the interim agreement (Aufleger and Mett, 2011).

3.8 Desalination Future Prospective in Gaza Strip

The Municipal Coastal Water Utility (MCWU) has estimated that aquifer failure is likely to eventuate in Gaza in 2016. In the worst case, the groundwater will become totally salinized, and all potable water will need to be provided from another source. This implies the loss of about 55MCM/year of otherwise usable flows (PWA, 2011).

In response to this worsening water crisis and in order to maintain the water balance to the positive condition and to fulfill the domestic water demand in terms of quality and quantity, the Government of Norway funded the Comparative Study of Water Supply Options for the Gaza Strip (CSO-G) led by international consultants and validated by consultations with the main stakeholders in the Palestinian Water Sector leading to a consensus water supply strategy. The CSO-G strategy has become the Government of Palestine´s strategic framework for addressing the water crisis through a "rolling schedule of interventions involving nine projects that are inter-linked and in combination form a coherent program to address the critical issues in the water sector in Gaza (PWA, 2015).

The CSO-G highlights that large scale desalination is the priority project stating. The major intervention driving the most important changes involves high-volume regional desalination. If this is not introduced and on the assumption that other high volume options remain elusive due to the political environment and/or their technical difficulty, the groundwater will not be protected adequately and the aquifer will fail totally (PWA, 2011).

The CSO-G team recommends the construction of two regional desalination plants: the first of 55 MCM/year at the site originally selected in middle Gaza; and the second (initially) of 22 MCM/year in either southern Gaza, or northern Egypt (PWA, 2011).

3.9 Environmental Legislative in Palestine

Palestinian Authority legislates and regulates the activities and projects concerned water and costal zones. The Palestinian Environmental Law presents the following articles to regulate the activities concerned with coastal zone as follows (PEL no. (7), 1999):

- Article (31): The Ministry (Environmental Quality Authority), in coordination with competent agencies, shall set standards for the quality of seawater specifying the norms, directives and conditions necessary to control sea pollutants.
- Article (32): It shall be forbidden for anyone to perform any action which may cause pollution of seawater in a manner that contradicts with the standards, directives or conditions prescribed for the purposes of marine environment protection against pollution.
- Article (33): The Ministry, in coordination with the competent agencies, shall specify the necessary environmental conditions required for the establishment of any coastal or offshore buildings or facilities.
- Article (34): It shall be forbidden to perform any action, which may affect the natural track of the beach, or adjust it inside or far from the sea unless an environmental approval is obtained from the Ministry.
- Article (35): The Ministry shall prescribe rules and regulations for the prevention of pollution, preservation and control of the marine environment, against what is generated by the different activities that occur in the free economic zone, continental drifting or the sea bottom which are all subject to the jurisdiction of Palestine.

Moreover in Article (4) of Palestinian Water law, it is prohibited to drill or explore or extract or collect or desalinate or treat waters for commercial purposes or to set up or operate a facility for water or wastewater without obtaining a license (PWL no. (3), 2002).

The Palestinian Cabinet of Ministers on (13/05/2014) issued a decree No. (14) For the year 2014 relating to the Water Law.

- Article (2): this law aims to develop and manage the water resources in Palestine, to increase their capacity, to improve their quality, to preserve and protect them from pollution and depletion, and to improve the level of water services through the implementation of integrated and sustainable water resources management principles.
- Article (2): all water resources in Palestine shall be considered public property, and the Authority has the power to manage these resources in a manner that ensures justice and efficiency in distribution.

- Article (5): every person has the right to obtain his needs of suitable quality drinking water for utilization at specific prices set in accordance with the Tariff Regulation issued by the Cabinet of Ministers. Water Service Providers shall take the necessary measures to ensure this right and prepare the plans required for the development of services in this regard, in accordance with the General Water Policy.
- Articles (7 and 8): The Water Authority is a public institution and enjoys a Legal personality. Its budget is part of the General Budget of the State of Palestine. The authority has the full responsibility for managing Water Resources in Palestine, applying principles of integrated and sustainable management of water resources and Licensing and development of Water Resources utilization, in cooperation and coordination with the relevant authorities.
- Article (50): Protection of Water Resources from Pollution with due regard to the provisions of the Environmental Law, and in coordination and cooperation with the authorities specialized in the protection of water resources and the prevention of their pollution, the Authority shall carry out the following:

    1. Partake in regulating the use of industrial and agricultural materials that may cause the contamination of water resources or water supply systems.
    2. Partake in the committees responsible for conducting environmental impact assessments with regards to any activity related to water resources or water supply systems.
    3. Partake in the development of special mechanisms for crisis management in the event of drought, floods, epidemics that spread through water, or general pollution.
    4. Partake in the preparation of a list of pollutants, which require licensing, and compensation for damages resulting from them.

- Article (51): The Authority shall order the suspension of water extraction or water supply in cases of a water source or supply system pollution, and may order the closure of the source or supply system if the pollution persists. The Authority shall notify the concerned authorities and dispose of contaminants as a matter of urgency.
- Article (53): Any natural or legal person that causes pollution to any Water Resource or water supply system shall remove the pollution affecting the Water Resource or water supply system. In case of refusal or failure to do so, the Authority shall remove the pollution and carry out the required cleansing operations at the expense of the party causing the pollution following written notification to that end, irrespective of the costs, which shall be collected from him in accordance with the Collection of Public Monies Law.

CHAPTER (4): DESCRIPTION OF GAZA CENTRAL SEAWATER DESALINATION PLANT

4.1 Introduction

It is clear that the trend in Gaza Strip to overcome the problem of water crisis is to exploit the advances in desalination technologies to treat seawater to the potable uses. GCDP was set up as a solution to Gaza's growing demand for freshwater.

The main principle of this chapter is to highlight on the general information of GCDP, its design configuration, technical data, plant capacity, feed seawater's characteristics, rejected brine's properties, desalination technology used, location, brine disposal modeling and etc.

4.2 Overview of GCDP

An area of land equivalent to 80 dunums has been allocated to build Gaza central desalination plant, an area will be sufficient to build the first phase, Phase (I), of 55 MCM/y capacity with the potential to expand the capacity later, and also to include allow the construction of a dedicated power plant or some other infrastructure relevant for selected power supply options (PWA, 2015).

During the 12 July 2012 FEMIP-ECOFIN Ministerial Meeting in Brussels, the EIB (European Investment Bank) was requested and accepted to support a landmark project aiming to improve water supply in Gaza. In particular, the EIB accepted to commission and to manage a technical assistance operation aimed at developing the conceptual design and the tendering documents for GCDP. The Promoter is PWA and the corresponding consultancy services have been contracted to a consortium composed of Fichtner GmbH & Co. and Madar Consulting Engineers led and represented by Fichtner. The technical assistance operation is financed under the support from the FEMIP Fund. This fund utilizes non-repayable aid granted by the European Commission in support of EIB investment activities in the eastern and southern Mediterranean countries, assisting promoters during different stages of the project cycle (PWA, 2015).

In the future, long term, GCDP will be expanded by adding another desalination stage, Phase (II), with a desalination capacity of 150,000m^3/d (55Mm^3/y). So in the long term the production capacity of freshwater, total from Phase (II), from GCDP will reach 300,000m^3/d (110Mm^3/y) (PIC, 2014).

The desalination plant of Ashkelon with a production capacity of ($100Mm^3/y$) is one of the largest in the world, and the largest in the Levant Basin (Einav and Lokiec, 2003). GCDP with its long term production capacity will be larger than Ashkelon plant and will become the largest in the Levant Basin.

The site of GCDP lies on the Mediterranean beach of the middle area of Gaza Strip at coordinates of 31°24'11.96"N, 34°18'59.54"E as shown in Figure (4.1).

Figure (4.1): GCDP's location

The surface land features can be described as flat with a sandy strip parallel to the coastline. Ground surface elevations vary typically from 1.5 to 5m above mean sea level, and the coastal zone is covered by finer sediments (i.e. sand and silt). The coastline is relatively flat with an average slope of 1:100.

The nearest residence areas of Deir Al Balah refugee camp and Deir Al Balah city locate approximately 3.5km north and north east from the plant site, and the community uses the beach along the plant site for recreation. The beachfront area west of the site is active and open. The beach is used by fishermen for fishing and related activities, such as boat landing and loading of fishes into the transport vehicles. There are no other major industries in the area, and the main significance feature situated near the GCDP site includes Deir Al Balah seawater desalination plant, which is situated approximately 4.5km north of the site.

GCDP desalinates water from sea using reverse osmosis (RO) technology. The desalination plant´s needs 25MW installed power. About 10% of this power can be generated by Photovoltaic cells (peak load) as a source for renewable energy on site, and additional renewable energy sources could be secured from offsite interventions. The designers recommend grid connection with additional Energy Supplies from neighboring countries or expanding Gaza Power Generation Plant capacity. In addition, a 100% back up onsite reciprocating duel fuel fired engines that can be operated in the future on Gas supplies (PWA, 2015).

4.3 Configuration of GCDP

The project components include a seawater intake, a brine rejection outfall, desalination plant facilities, and 2km pipeline to connect with Gaza Regional Carrier (Ismail, 2003). Figure (4.2) depicts the components of GCDP.

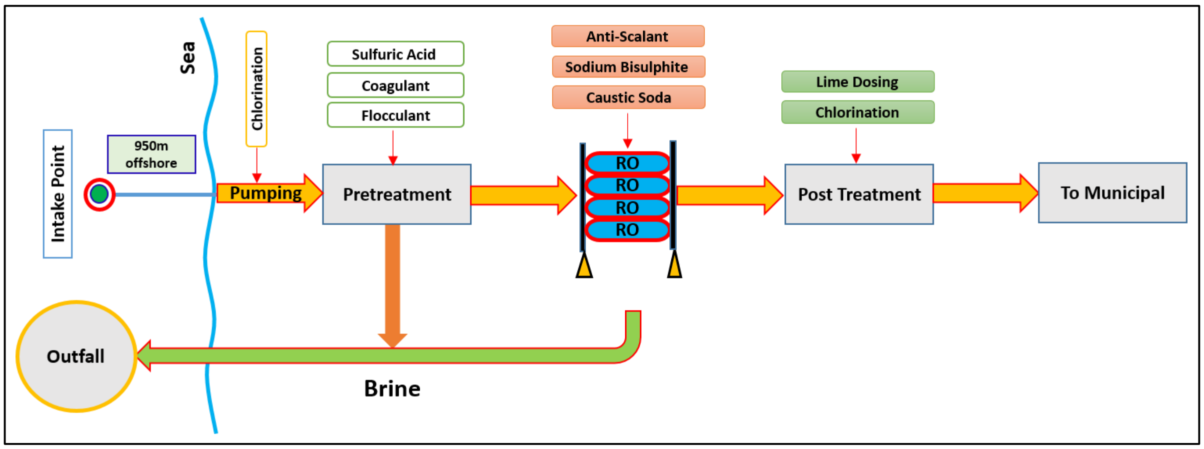


Figure (4.2): Configuration of GCDP

The maximum proposed capacity of the seawater intake system for GCDP is 18,900m^3/h for each phase (total of Phase II is 37,800m^3/h), each phase of GCDP desalinates 6,700m^3/h (total 13,400m^3/h) at a recovery ratio of 35.5%, and thus the remaining flow rate of 12,200m^3/h (total 24,400m^3/h) could be brine. The brine water from GCDP is discharged into the sea through an outfall pipeline. Figure (4.3) demonstrates the intake and outfall systems of GCDP.

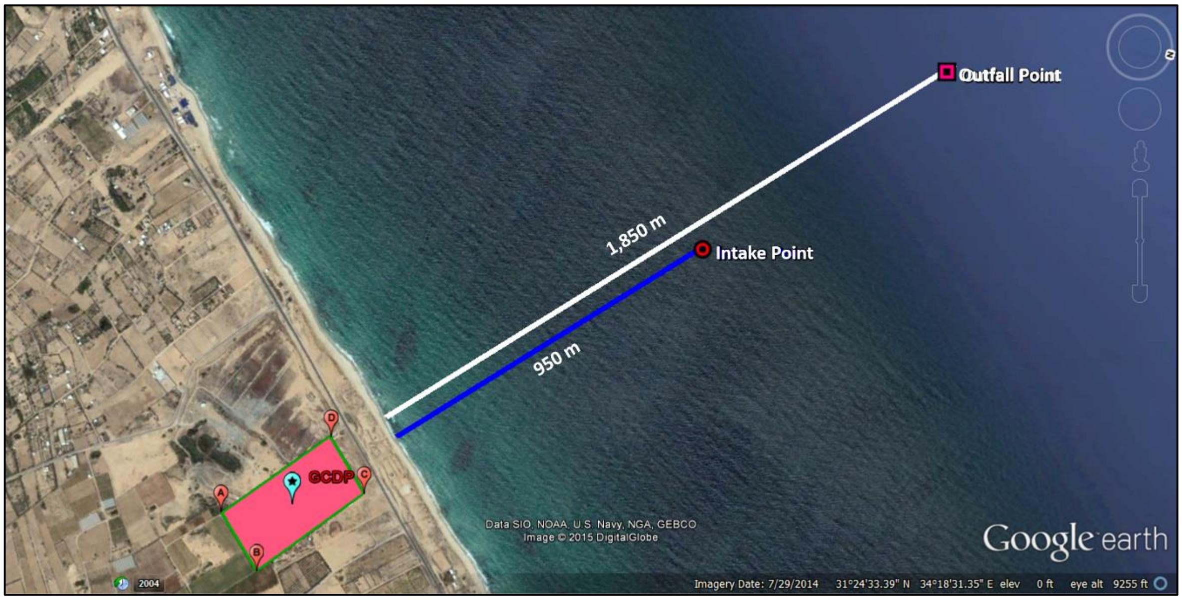


Figure (4.3): GCDP's intake and outfall systems

The seawater intake system consists of three submerged pipes manufactured from high-density polyethylene (HDPE) material with a diameter of 1600mm extends to 950m offshore at 10m seawater depth. The intake section will provide two pipes for the first phase of 55Mm³ per year, each pipe will accommodate 50% of the seawater intake flow at a flow velocity of 1.33m/s. in the long term when the plant operated in its maximum capacity of 110Mm^3 per year the third pipe will be constructed and operated. Each pipe is capable to deliver 66% of the seawater intake at fully fouled conditions or 75% at partially fouled conditions (Abualtayef, 2015).

The outfall facilities are designed to discharge the brine reject from the desalination plant. To avoid the circulation of concentrated brine discharges to the intake system, the proposed sea outfall discharge point is constructed at a distance of 850m from the intake point as shown in Figure (4.3). A quantity of 12,20m^3/h of brine from Phase (I) in the short term, and a total quantity of 24,400m^3/h of brine from Phase (II) in the long term will be discharge through one discharge pipe in order to minimize the cost of redesign, reinstallation and reconstruction. The discharge pipe is a multiport which terminates in a diffuser section consisting of four risers (vertical shafts), each vertical shaft equipped by a turret that has four discharge ports (nozzles) spaced evenly around its circumference. Figure (4.4) presents a general schematic view for an outfall and diffuser.

Onshore, the seawater intake structure is equipped with the screening and pumping systems. The screening system consists of bar and travelling band screens to remove any debris that may be sucked in through the pipelines. The intake seawater is chlorinated to control marine biological growth in the intake structures. The design will allow for shock chlorination (around 10ppm for around 1h at several times a week) and pulse chlorination (up to 1ppm at irregular intervals of in average around 10 minutes).

In the pretreatment process, the seawater feed is cleared from suspended solids like e.g. silt, organic matter or biomass, which otherwise would cause biofouling on the reverse osmosis membranes. For GCDP two alternatives of pretreatment processes are considered to be adequate. Conventional pretreatment of coagulation (flocculation) followed by dual media filtration and final cartridge filtration to safeguard downstream equipment, and advanced membrane filtration based Ultrafiltration (UF) uses porous membranes with nominal pore sizes of 0.01–0.1µm.

4.4 Average Characteristics of Brine Produced from GCDP

As a starting point for more detailed environmental impact studies and process modelling, the initial brine effluent characteristics should be computed, and the type of the flow should be classified. In order to characterize the properties of brine that produced from GCDP, it is necessary to know the seawater conditions at the intake location.

A field survey in the vicinity of the intake and outfall systems was conducted between April and June 2014 to characterize the intake seawater quality (Abualtayef, 2014). Table (4.2) demonstrates the seawater quality measurements for five days in the months of April, May, and June.

Table (4.1): Seawater quality measurements

Parameter	Unit	10th April	20th April	1st May	20th May	1st June	Avg.
Temperature	*ºC*	21	22	23	24	26	**23.2**
PH	-	8.21	8.28	8.23	8.21	8.16	**8.22**
EC	*ms/cm*	57	56.9	56.7	56.9	58.2	**57.14**
TDS	*ppt*	37.9	37.7	37.7	37.8	39.2	**38.06**
Boron	*mg/l*	3.8	3.7	3.3	3.6	3.6	**3.6**
Turbidity	*NTU*	0	0	0	0.5	0.71	**0.24**

MEDAR (Mediterranean Data Archeology and Rescue) offers typical field data measurements (Appendix B) for more than 70 years in the South East corner of the Levantine Sea, the average temperature and salinity for the measurements at a seawater depth of 10m (GCDP`s seawater intake depth) during autumn, spring, summer, and winter is demonstrated in Figure (4.5).

At the intake location 950m offshore (10m depth), according to the field survey data, it can be concluded that the average seawater temperature and salinity in a duration between spring and summer are 23.2^{o}C and 38.06ppt respectively while according to MEDAR`s data, the average seawater temperature and salinity for the readings taken in spring and summer seasons are 23.63^{o}C and 39.1ppt respectively. The difference in average temperature and salinity are 0.43^{o}C and 1.04ppt, respectively. This gives an indication that the typical seasonal data offered by MEDAR are somewhat identical to be used in characterizing the seawater parameters at the intake location.

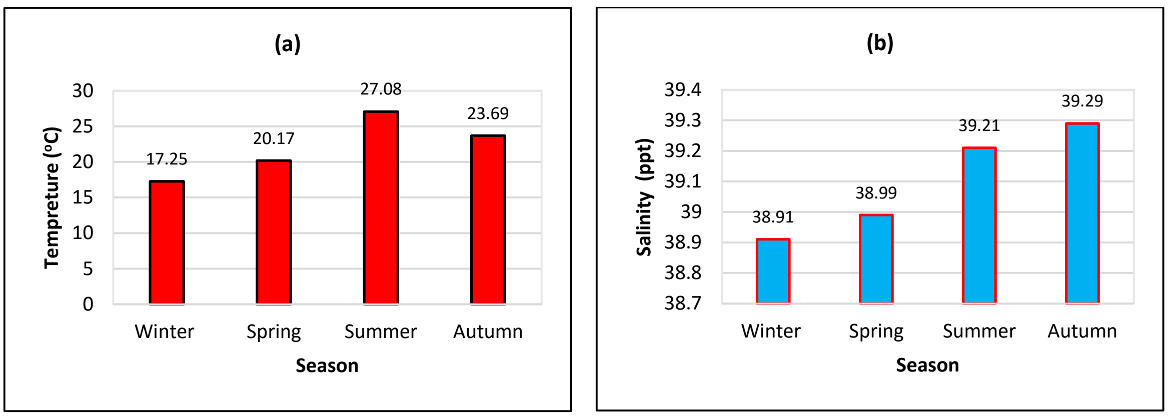


Figure (4.4): Average Seasonal, (a) Temperature, and (b) Salinity at the Intake Location (10m Depth)

Based on the field survey data, demonstrated in Figure (4.6a), the brine's salinity changes between the minimum value of 58.45ppt measured in the 20th of April/1st of May and the maximum value of 60.78ppt measured in the 1st of June.

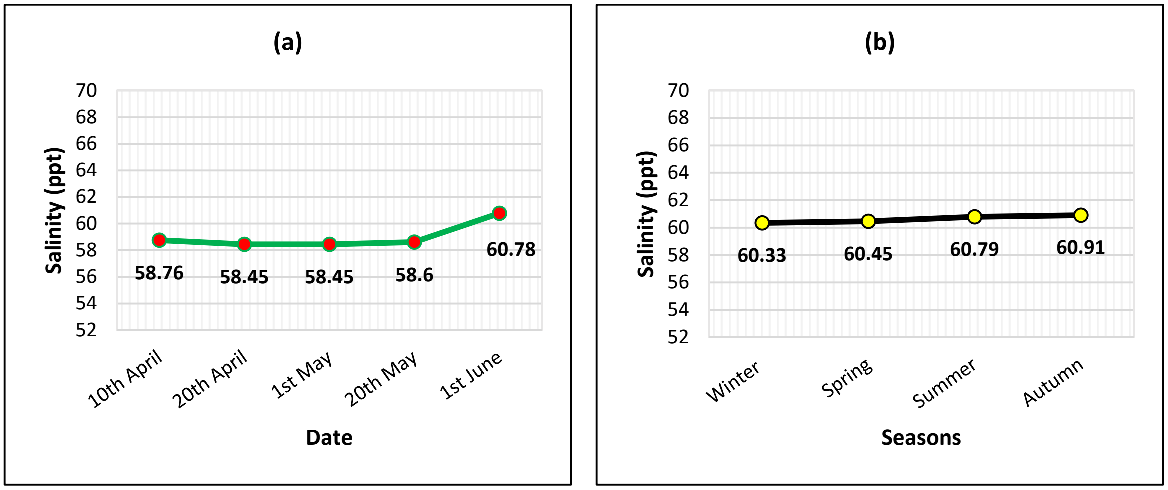


Figure (4.5): Brine salinity (a) according to field survey, and (b) MEDAR`s data

While MEDAR data show that the brine salinity varies between a minimum value of 60.33ppt observed in winter and a maximum value of 60.91ppt inspected in autumn.

In this research in order to take into consideration the variations in seawater parameters over a presentative period, the average temperature and salinity for each of the four seasons at the intake location (10m seawater depth) were employed to specify the characteristics of the rejected brine from GCDP. The average temperature at the intake point is 22.05^{o}C while the average salinity is 39.1ppt.

Bleninger et al. (2010) developed a desalination plant discharge calculator that computes the effluent properties and the ambient characteristics at the discharge point by coded nomograms and screening equations. The calculator is programmed in an MS Excel spreadsheet, and already includes design considerations regarding the discharge geometry and allows to compute a first set of design alternatives. These alternatives then need to be studied within the numerical model applications. By using the MS Excel spreadsheet designed for dense discharges that called the RO discharge calculator shown in Figure (4.7). A sample of brine effluent characteristics computed by discharge calculator is summarized in Table (4.3). For RO desalination technology it is obvious that the effluent temperature is usually the same as ambient temperature while the effluent salinity is more than the ambient salinity by 1.5 to 2 times. The buoyant acceleration for RO effluent that is a measure for density induced motions is almost negative that indicates that the effluent is a negatively buoyant (sinking down).

Table (4.2): Average brine characteristic for GCDP

Parameter	Phase (I)	Phase (II)	Remarks
Seawater intake temperature (ºC)	22.05	22.05	Average of four seasons
Seawater intake salinity (ppt)	39.1	39.1	Average of four seasons
Seawater intake density (kg/m^3)	1,027.02	1,027.02	
Seawater kinematic viscosity (m^2/s)	$1.01 x 10^{-6}$	$1.01 x 10^{-6}$	
Desalination plant`s capacity (m^3/d)	150,685	301,370	
Recovery rate (%)	35.5	35.5	
Brine flowrate (m^3/d)	292,800	585,600	
Brine temperature (ºC)	22.05	22.05	Usually ambient
Brine salinity (ppt)	60.62	60.62	Salinity (drink) = 0ppt
Buoyant acceleration (m/s^2)	-0.15606	-0.15606	Negatively buoyant
Brine density (kg/m^3)	1,043.36	1,043.36	
Brine kinematic viscosity (m^2/s)	$1.04 x 10^{-6}$	$1.04 x 10^{-6}$	

Flowrates & Effluent Characteristics *RO*

				annotations/limitations:
- ambient characteristics (seawater)				
ambient temperature	T_a =	22.05	°C	T = 10 to 180°C
ambient salinity	Sal_a =	39.10	ppt	Sal = 0 to 160 ppt (ppt = g/kg)
ambient density	ρ_a =	1027.02	kg/m³	allowed ranges for viscosity calculation:
ambient kin. viscosity	ν_a =	1.01E-06	m²/s	Sal = 0 to 130 ppt, T = 10 to 180°C (El-Dessouky, Ettouny (2002))
- fresh water (permeate)				
flowrate	Q_{drink} =	1.87	m³/s	recovery rate:
recovery rate	r =	36	%	percentage of intake water converted into permeate;
intake flowrate	Q_{in} =	5.25	m³/s	plant characteristic; following Lattemann: r = 40-65%
- brine characteristics (effluent from desalination process)				
plant effluent flowrate	Q_{desal} =	3.39	m³/s	
temperature	T_{desal} =	22.05	°C	usually ambient or 1°C above
salinity	Sal_{desal} =	60.62	ppt	with Sal_{drink} = 0 ppt
density	ρ_{desal} =	1043.36	kg/m³	
substance concentratio	c_{desal} =	20.00	ppm	e.g. coagulants, anti-scalants, ... (has no effect on density or mixing characteristics)
- blended effluent - external - (e.g. waste water or others)				
flowrate	$Q_{eff,ex}$ =	0.00	m³/s	
temperature	$T_{eff,ex}$ =	20.00	°C	
salinity	$Sal_{eff,ex}$ =	0.00	ppt	
density	$\rho_{eff,ex}$ =	998.40	kg/m³	Sal = 0 to 160 ppt, T = 10 to 180°C
Final effluent characteristics:				
flowrate	Q_o =	3.39	m³/s	
effluent temperature	T_o =	22.05	°C	mean average
effluent salinity	Sal_o =	60.62	ppt	mean average
effluent density	ρ_o =	1043.36	kg/m³	
buoyant acceleration	g_o' =	-0.15606	m/s²	$g_o' = g \cdot (\rho_a - \rho_o)/\rho_a$
-> negatively buoyant, ok!				g_o' < 0: negatively buoyant, g_o' > 0: positively buoyant
kin. viscosity	ν_o =	1.04E-06	m²/s	allowed ranges for viscosity calculation: Sal = 0 to 130 ppt, T = 10 to 180°C (El-Dessouky, Ettouny (2002))
substance concentratio	c_o =	20.00	ppm	

Figure (4.6): RO discharge calculator (Bleninger et al., 2010).

CHAPTER (5): MODEL SETUP of GCDP

5.1 Introduction

As a final destination, the produced brine from GCDP will be disposed into the coastal area of the middle governorate of Gaza Strip. Two alternatives of brine discharge into coastal areas were modeled in this research. The first alternative is dealing with direct discharge of brine at coastline, while the second alternative concerns in brine discharging by submerged pipe far into the sea.

The main point of interest to this research is to study the disposal behavior of brine discharged through an onshore and an offshore disposal system, therefore it is recommended to numerically modeling the brine disposal in conjunction with a sensitivity analysis for different scenarios consider different design configurations and ambient conditions in order to specify the best disposal scenario so that to minimize the negative effects of brine on marine life and to meet the environmental standards.

To investigate the alternative of onshore disposal for the brine discharged from GCDP, numerical simulations were applied to different surface open channel design configurations (Appendix C). Moreover, the second alternative for disposing the brine produced from GCDP is concerned with an offshore submerged disposal system. Different design configurations for single and multiport diffusers were prepared in Appendix (C) to verify the optimal configuration at the optimal dilution.

Due to inherent uncertainty in the input data, sensitivity analysis was also carried out using iterative simulations by varying the ambient current velocity to evaluate the effect of uncertainty in sea conditions, the water depth at the discharge to evaluate the effect of model parameters, the wind velocity to evaluate the effect of uncertainty in the atmosphere conditions and ambient density. The sensitivity analysis for the seasonal variations in ambient current, density and wind were evaluated over winter, spring, summer and autumn.

5.2 CORMIX v9.0

In this study Cornell Mixing Zone Expert System, CORMIX, has been applied to modelling the impact of the disposed brine from GCDP. CORMIX computes the plume characteristics in the mixing zone within which the fluid motion, turbulent field and saline dispersion are dominated by the discharge properties such as mass flux and buoyancy flux of outfall jet. Depending on type and shape of outfall, there are three different models in CORMIX software:

- **CORMIX 1** for submerged single port discharges
- **CORMIX 2** for submerged multiport discharges
- **CORMIX 3** for buoyant surface discharge

Figure (5.1) illustrates the inputs and outputs data for CORMIX, as well as the three cores of COMIX.

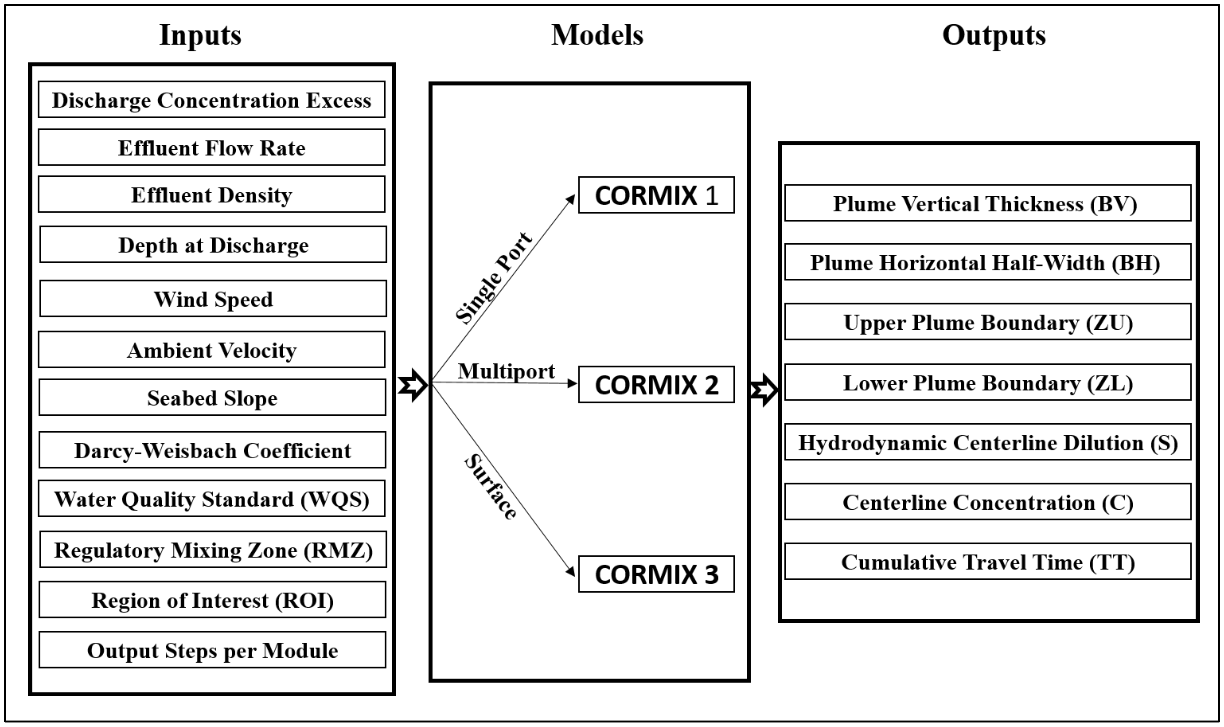


Figure (5.1): Configuration of CORMIX system

5.3 Data Collection

To assist the modelling of brine disposal of GCDP, oceanographic field data at GCDP location should be gathered. These measurements and data include bathymetric, seawater properties, wind speed and direction, and current speed and direction.

5.3.1 Bathymetric Field Survey

The regional bathymetry of GCDP coastline has been measured by marine cruises. A grid of 64 points, covered an area of 6km^2, at 350 meters interval located on Google Earth is illustrated in Figure (5.2), the coordinates for each point has been tracked in the sea field using a GPS device. Seawater depth at each point has been measured using sonar (Abualtayef and Ghabayen, 2014).

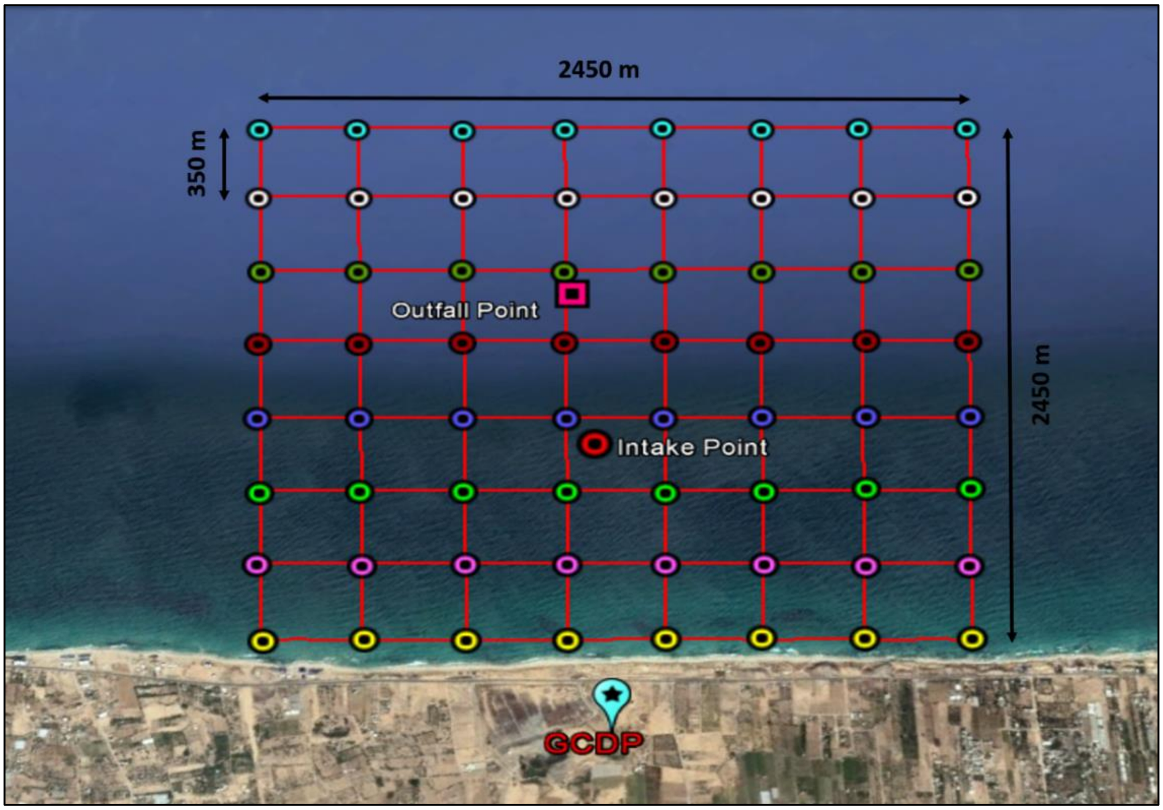


Figure (5.2): Grid points for bathymetric survey

Figure (5.3) depicts the bathymetric counter map for the surveyed grid. The figure shows that the depth contour lines are relatively straight and parallel to the coastline. As the bathymetry of the GCDP`s coastline shows, near the plant site, the water depth reaches nearly 20m at the designed plant`s outfall point at about 1850m offshore and 10m at about 950m offshore at the designed intake point. The contour maps demonstrate that the average offshore slope at the coastal region of GCDP is approximately **1: 95**.

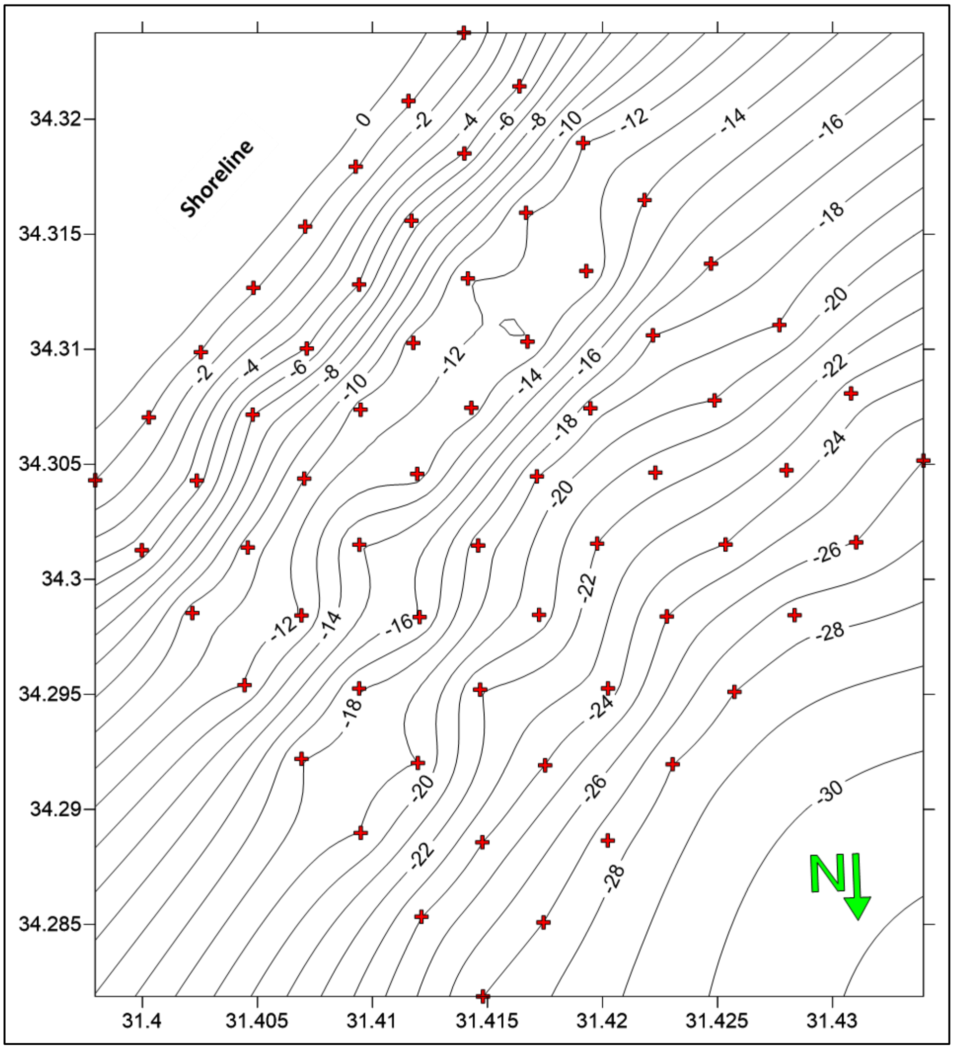


Figure (5.3): Bathymetric of GCDP (Almashrawi, 2014)

5.3.2 Seawater Properties

In this research and due to the variation in the characteristics parameters of seawater, the average seawater salinity, temperature and density for each of the four seasons of winter, spring, summer and autumn were specified in order to carry out the sensitivity analysis for the uncertainty in the characteristics of the receiving waterbody.

Appendix (B) presents filed data measurements for the physical properties of seawater. The data collected by MEDAR (Mediterranean Data Archeology and Rescue) present the average seawater temperature and salinity for more than 70 years in the South East corner of the Levantine Sea, the data provide measurements during autumn, spring, summer, and winter.

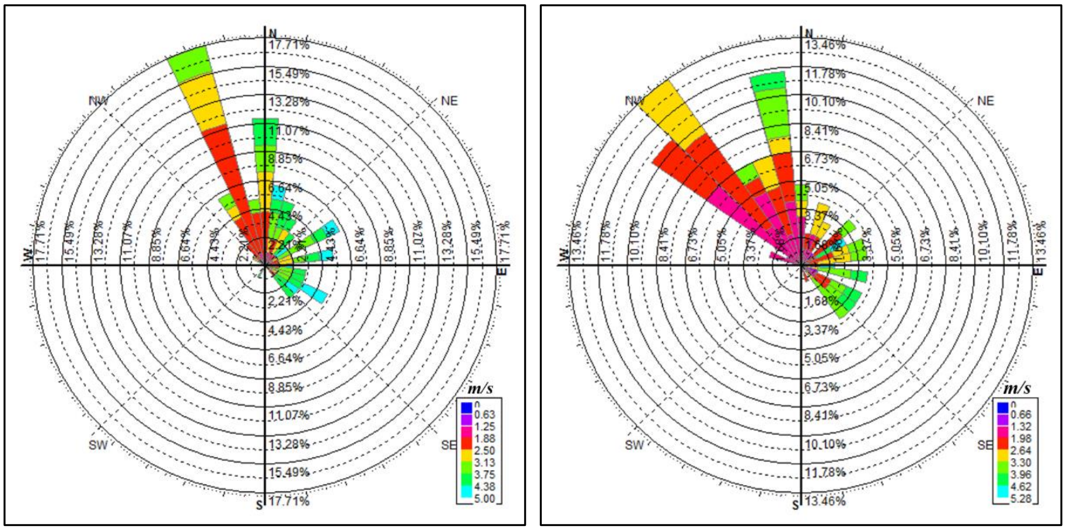
The area of study is confined between shoreline and a depth of 50m, therefore the seawater parameters that were employed in this study are the average temperature, salinity and density between depths of 0 and 50m over the seasons of winter, spring, summer and autumn. Table (5.1) demonstrates the seawater parameters which used in this study.

Table (5.1): Used seawater parameters (based on MEDAR's data).

Season	Layer (m)	Temperature (ºC)	Salinity (ppt)	Density (kg/m^3)
Winter	Surface: 0m	17.21	38.91	1028.26
	Layer (1): 5m	17.16	38.90	1028.27
	Layer (2): 20m	17.24	38.94	1028.28
	Bottom: 50m	17.12	38.98	1028.34
Spring	Surface: 0m	20.52	38.99	1027.39
	Layer (1): 5m	20.25	38.99	1027.47
	Layer (2): 20m	19.35	38.97	1027.71
	Bottom: 50m	17.45	38.95	1028.22
Summer	Surface: 0m	27.26	39.21	1025.46
	Layer (1): 5m	27.18	39.21	1025.48
	Layer (2): 20m	26.36	39.08	1025.66
	Bottom: 50m	19.08	38.83	1027.68
Autumn	Surface: 0m	23.40	39.27	1026.73
	Layer (1): 5m	23.39	39.27	1026.73
	Layer (2): 20m	23.50	39.31	1026.73
	Bottom: 50m	20.77	39.17	1027.45

5.3.3 Wind

GCDP locates in the city of Deir El-Balah in the middle Governorate of Gaza Strip. Appendix (B) provides metrological data for winds measured by the Palestinian Metrological Authority in the year of 2007 at Gaza and Khanyounis metrological stations. Figure (5.4) depicts the wind rose for the wind speeds and directions in Gaza and Khanyounis metrological stations.



(a) (b)

Figure (5.4): Wind rose, (a) Gaza (b) Khanyounis metrological stations (based on data of Palestinian Meteorological Authority, 2007)

As GCDP locates in Deir El-Balah city that locates between Gaza city and Khanyounis city the average wind speeds and directions in winter, spring, summer and autumn from the metrological stations of Gaza and Khanyounis were exploited in this research. After looking at the graphs and tables that show the wind speed and direction in the year of 2007 for Gaza and Khanyounis cities, the average wind speed at the location of GCDP can be illustrated in Table (5.2) for the seasons of winter, spring, summer and autumn.

Table (5.2): Average wind speed and direction at GCDP`s location

Season	Gaza Station		Khanyounis Station		Location of GCDP	
	m/s	(º)	m/s	(º)	m/s	(º)
Winter	3.47	187	3.10	170	3.28	178
Spring	3.17	213	2.87	204	3.02	208
Summer	2.79	240	2.33	230	2.56	234
Autumn	2.94	194	2.22	186	2.58	190

5.3.4 Current

Many researchers described the currents circulation at the south earthen corner of Levantine basin of the Mediterranean Sea. Appendix (B) provides detailed literature about the current circulation in the Levantine basin and in the coast of Palestine. According to data summarized in Appendix (B), the average seasonal current velocities during winter, spring, autumn and summer that were employed in this study can be illustrated in Figure (5.5).

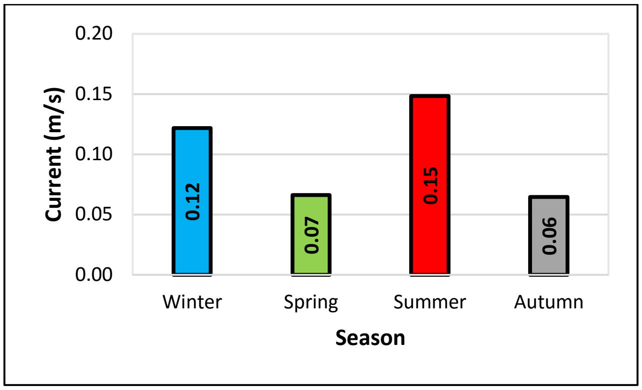


Figure (5.5): Current seasonal variation

As shown in Figure (5.5), in summer due to the generation of the Shikmona Eddy a maximum current velocity was observed (Menna et al., 2012) while in autumn the minimum seasonal current was observed.

5.4 Seasonal Characteristics of GCDP's Brine

GCDP seawater intake point is located at 950m offshore at a seawater depth of 10m. According to data presented in Appendix (B), the characteristics of the desalination feed seawater is mainly related to the seawater properties at that location of 10m depth. The seasonal variation in the seawater properties at the intake depth is demonstrated in Figure (5.6).

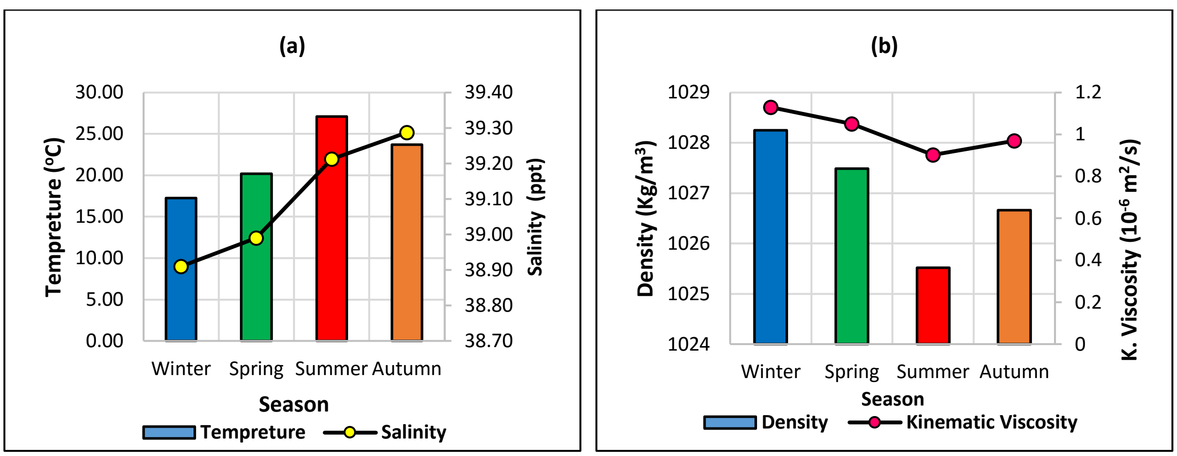


Figure (5.6): Seasonal variation in seawater at 10m depth for (a) tempreture and salinity, (b) density and kinematic viscosity.

Accordingly, due to the variation in the properties of feed seawater, the brine properties can also vary from season to season. Table (5.3) depicts the seasonal variation in the brine produced from GCDP.

Table (5.3): Seasonal characteristics of brine rejected from GCDP

Season	Temperature (ºC)	Salinity (ppt)	Density (Kg/m^3)	K. Viscosity (10^{-6} m^2/s)	B. Acceleration (m/s^2)
Winter	17.25	60.33	1044.59	1.17	-0.15592
Spring	20.17	60.45	1043.81	1.09	-0.15586
Summer	27.08	60.79	1041.82	0.935	-0.15595
Autumn	23.69	60.91	1043.05	1.01	-0.15663

5.5 Regulatory Mixing Zone

There are many regulations related to mixing zone but there is no specific regulation about mixing zone in Palestine.

Also in the Mediterranean countries, according to the author knowledge, there is no specific regulations characterize the mixing zone region in some specific manner.

Accordingly, in this research the Omani regulatory mixing zone regulations were employed. According to Omani regulations on the discharge of liquid waste into the marine environment, the salinity should not deviate from the surrounding average for more than 2 units on a daily basis in a circular area of 300m diameter around the point of discharge (Sultanate of Oman, 2005).

According to Omani regulations the salinity at the boundary of a circle with a diameter equal to 300 m in the seasons of winter, spring, summer and autumn is shown in Figure (5.7)

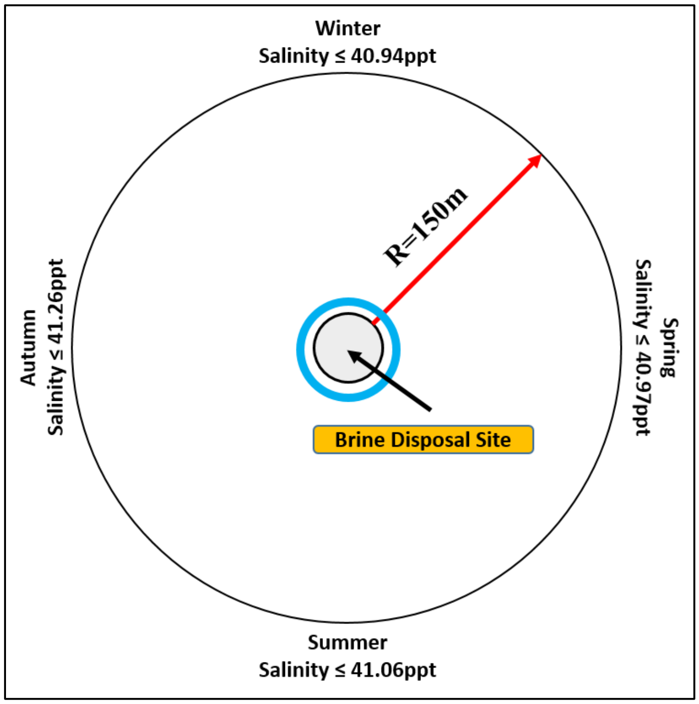


Figure (5.7): RMZ's seasonal requirements at GCDP disposal site

The regulation requirements at the boundary of RMZ vary from season to season in accordance to the variation in the brine properties which associate to the change in the characteristics of feed seawater.

5.6 GCDP's Brine Disposal Modeling and Sensitivity Analysis

Brine behavior on discharge could vary according to the ambient conditions and discharge characteristics. The design configuration of a disposal system can influence the dilution of the brine disposal. Therefore, discharging system should be designed to ensure the required dilutions are achieved in the near filed region where strong initial mixing occurs.

In this study where that to predict how the design configuration for the brine disposal system can affect the dilution, a sensitivity analysis in accordance with simulations for disposal systems of onshore surface open channel, offshore submerged single port diffuser and offshore multiport diffuser were implemented. Detailed design scenarios for the three disposal systems were illustrated in Appendix (B).

Table (5.4) summarizes the characteristics of the simulated disposal configurations as well as the design parameters for sensitivity analysis for GCDP's disposal systems.

Table (5.4): Characteristics of the simulated disposal systems

Parameter	Type of Disposal System			
	Onshore	Offshore		
	Surface	Single Port	Multiport [a]	Multiport [b]
Diffuser`s Configuration	-	-	Alternating	Alternating
Angle of Discharge (^{o})	-	50	50	50
Alignment Angle (^{o})	-	90	0-90	50-90
Inclination angle (^{o})	-	90	30-90	30-90
Number of ports	-	1	16	144
Port(s) diameter (m)	0.5-6.5[c]	0.4-1	0.1	0.1
Port height (m)	-	0.75	0.75	0.75
Discharge depth (m)	1.5-5.5	2.5-21	2.5-21	2.5-21

(a) General Configuration
(b) Design of Study
(c) Channel Width

The parameters of angle of discharge and port height have been kept constants at 50^o and 0.75m respectively, where there changes don`t affect the dilution process in a significant manner. The sensitivity analysis considers moreover the seasonal variation in ambient conditions, as long as the seasonal variation in the intake seawater and produced brine.

5.7 Model Validation

One very simple interpretation of calibration is to adjust a set of parameters associated with a computational science and engineering code so that the model agreement is maximized with respect to a set of experimental data. One very simple interpretation of validation is to quantify our belief in the predictive capability of a computational code through comparison with a set of experimental data (Trucano et al., 2006).

Exhaustive validation of CORMIX has been done by Palomar et al. (2012a), using published experimental data. The validation focuses on the near field region of dense single port jets discharged into both stagnant and dynamic environments.

In this study, a validation for CORMIX model which is used for brine discharge modeling by comparing numerical results with experimental data has been executed according to the experimental results presented by Diaz et al. (2011).

Diaz et al. (2011) have been designed and built a pilot plant to perform brine discharge testing. These tests have been designed to maintain both geometric similarity and dynamic similarity between the pilot plant and a brine discharge from a seawater reverse osmosis desalination plant.

To validate the model of CORMIX the data of tests Group No.1 (Table 5.5) has been exploited in this study.

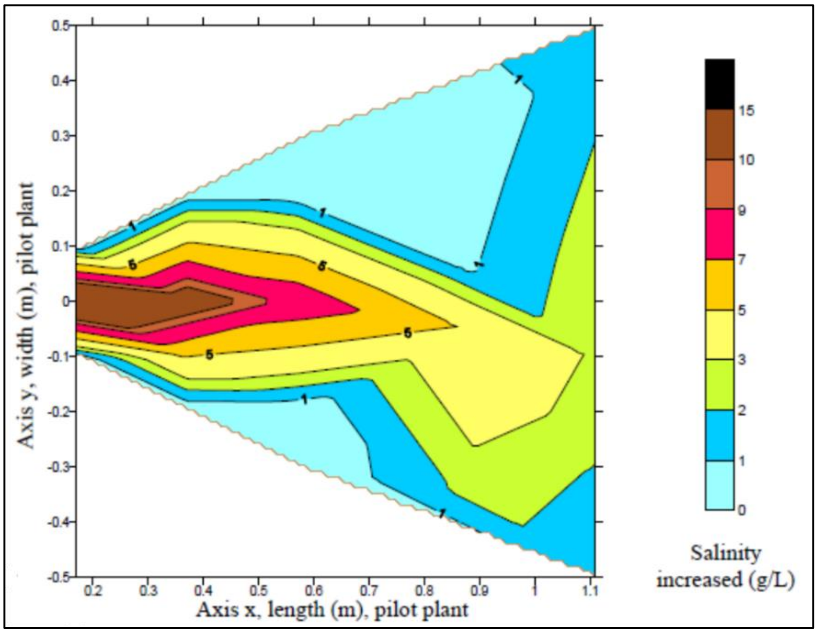
Table (5.5): Tests group No. 1 data (Diaz et al., 2011)

TESTS GROUP No. 1			
Ambient and discharge fluent data on the pilot plant (N_L = 1/6)			
Ambient	Desalinated water	Discharge	Ionized salt solution
Density differential	0.025 kg/L	Concentration differential	31.3 g/L
Discharge flow rare	4,593 L/h	Discharge velocity	0.65 m/s
Ambient geometry data on the pilot plant (N_L = 1/6):			
Ambient velocity	0 m/s	Depth at discharge	1.63 m
Wind speed	2 m/s	Slope and roughness of the ambient	0%, smooth f= 0.015
Discharge geometry data on the pilot plant (N_L = 1/6):			
Discharge angles	45º angle measured counterclockwise from the axis x to the plane z-x projection of the diffuser. 0º angle measured from the axis x to the plane y-x projection of the diffuser.		
Discharge diameter	50 mm.		
Discharge depth	1.5 m.		

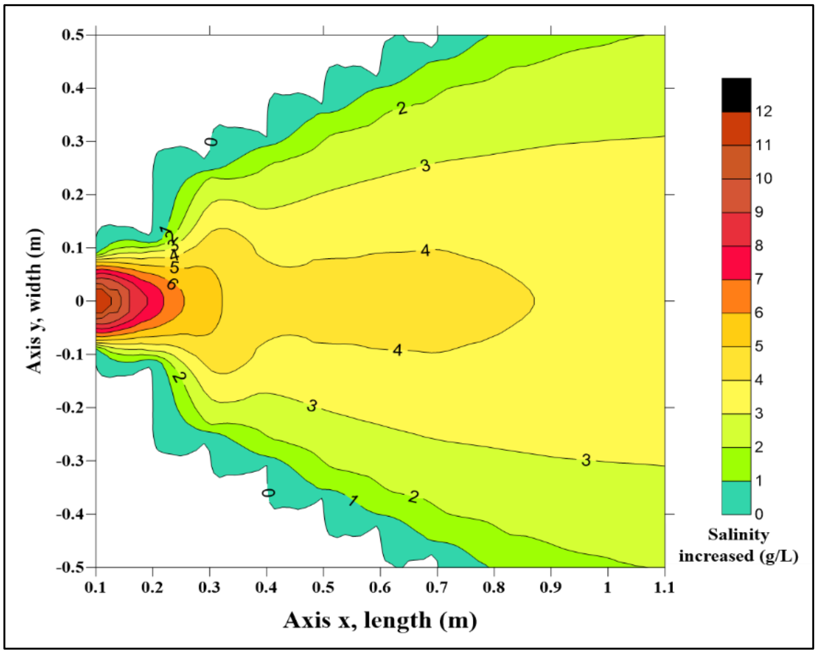
The experimental results for tests Group No.1 data is illustrated in Figure (5.8a). The same inputs data have been simulated using CORMIX model, the modeling results is shown in Figure (5.8b).

The results shown in Figure (5.8) demonstrate convergent plumes, for example the plumes widths at a length of 0.1m are nearly identical for the experimental and CORMIX results.

Moreover, it can be concluded that the plume of CORMIX is wider than that of the physical model plume and it spreads over a large area, this indicates that the results of dilution rate of brine from CORMIX is larger than that of experimental results.



(a)



(b)

Figure (5.8): (a) Diaz et al. (2011)'s experimental results, (b) CORMIX results

CHAPTER (6): RESULTS ANALYSIS AND DISCUSSION

6.1 Introduction

This chapter presents the simulations outputs for the process of brine disposal from GCDP into the coastal area of Deir El-Balah governorate. Brine disposal simulations in accordance with sensitivity analysis for different ambient conditions and design configurations were carried out to three discharging scenarios of onshore open channel, offshore jetting single port and offshore jetting multiport.

This chapter demonstrates the results for each scenario for two cases:

- **1st Case:** brine produced from GCDP in its short term Phase (I), in this case the brine is discharged at a flow rate of 12,200m^3/h.
- **2nd Case:** this second case concerns in brine produced from GCDP in its long term, Phase (II), in this case the brine is discharged at a flow rate of 24,400m^3/h.

This chapter summarizes the dilution outputs from CORMIX v9.0 base simulations at the end of RMZ. Iterative CORMIX simulations are carried out to address model performance due to inherent uncertainty in the input data. These simulations were conducted by varying one parameter at a time while keeping the other input parameters the same as the base simulation specified in Table (6.1).

Table (6.1): Ambient conditions and brine properties

Season	Ambient Conditions					Brine Properties		
	Temperature (ºC)	Salinity (ppt)	Density (kg/m^3)	Wind (m/s)	Current (m/s)	Temperature (ºC)	Salinity (ppt)	Density (kg/m^3)
Winter	17.2	38.94	1028.29	3.28	0.12	17.25	60.33	1044.59
Spring	19.2	38.97	1027.75	3.02	0.07	20.17	60.45	1043.81
Summer	24.33	39.06	1026.32	2.56	0.15	27.08	60.79	1041.82
Autumn	22.90	39.26	1026.88	2.58	0.06	23.69	60.91	1043.05

The features of mixing zone can be characterized to the following criteria: Water quality standard (WQS) of salinity is 2ppt above ambient, regulatory mixing zone (RMZ) is 150m downstream and region of interest (ROI) is 3000m.

6.2 Onshore Disposal by Surface Open Channel

This scenario is used to simulate the brine discharged through open channel into seawater, the brine characteristics are differ over the four annual seasons in coincidence to the variation in the characteristics of the feed seawater. The sensitivity analysis for the effect of channel`s width, slope and seawater depth at the disposal location (distance into waterbody) were modeled for the onshore disposal of GCDP`s brine.

Under the effect of a continuous discharge of brine via an open channel at a flow rate of 12,200m^3/h rejected in the short term and a flow rate of 24,400m^3/h produced in the long term, the seasonal variation in the dilution process can be related to seasonal variation in the ambient properties which also reflects the seasonal variation in the brine properties and variation in the channel geometry.

The simulation and sensitivity analysis` results presented in Appendix (D) show that the onshore disposal for the brine produced from GCDP via a surface open channel can be applicable in the case of Phase (I) at some geometric designs from the view of achieving the discharging regulations at the end RMZ over the four seasons, while in operating the plant at its full capacity of Phase (II), it can be say that the onshore disposal through surface open channel is not applicable from the views of:

a. Failing to achieve the discharging regulations at the edge of RMZ during some seasons or over the four annual seasons,
b. Due to the inapplicability of the channel design where the channel depth to width aspect ratio is out of [0.05-5], or the water`s depth at the disposal point is less than twice the water`s depth in the channel.

Whilst it do not satisfy the discharging regulations at the end of RMZ when the plant rejecting the brine at flow rate of 24,400m^3/h, the results demonstrate that the most applicable design for discharging the brine from GCDP in its short term and long term capacities is at a channel`s width of 4m at a channel`s slope of 3%. Table (6.2) illustrates the concentrations at the RMZ for the channel design of 4m width and 3% slope.

The results show that the concentrations at the RMZ start to meet the discharging regulations at a water depth between 2.5 and 3.5m in the case of Phase (I), while in the case of Phase (II) the regulations were met at a disposal depth between 4.5 and 5.5m just in the seasons of winter and summer. In order to specify the range of disposal depths at which the disposal process of brine can be considered as surface disposal, according to the disposal system of SHOAIBA desalination plant in KSA, the brine is discharged through an open channel to sea at a discharge depth between 2.5 to 4m (www.water-technology.net).

Table (6.2): Phase (II) simulation results at a channel of 4m width and a slope of 3%.

Season			Winter	Spring	Summer	Autumn
Channel		Disposal Depth (m)	Conc. RMZ (ppm)	Conc. RMZ (ppm)	Conc. RMZ (ppm)	Conc. RMZ (ppm)
Width (m)	Slope (%)					
4	3	1.5	5004	5096	4985	5150
		2.5	3525	3624	3515	3696
		3.5	2734	2828	2694	2893
		4.5	2231	2382	2196	2398
		5.5	1904	2045	1781	2075

Generally, while keeping the other parameters constant, the results show that as the width of channel increased the bine dilution increase accordingly. Moreover at the same channel`s width the bine dilution is increased by increasing the channel`s slope, also at the same channel`s width and slope, the brine dilution can be improved by increasing the depth of waterbody at the disposal location.

Figure (6.1a) demonstrates the relationship between the channel width and the corresponding brine concentration above ambient at a slope of 3% at disposal depth of 5.5m at RMZ in summer in the case of Phase (II) in operation. Figure (6.1b) depicts the pattern of change in the brine dilution as a result of change in the slope of channel at RMZ in summer for channel width equal to 4m at a disposal depth equal to 5.5m.

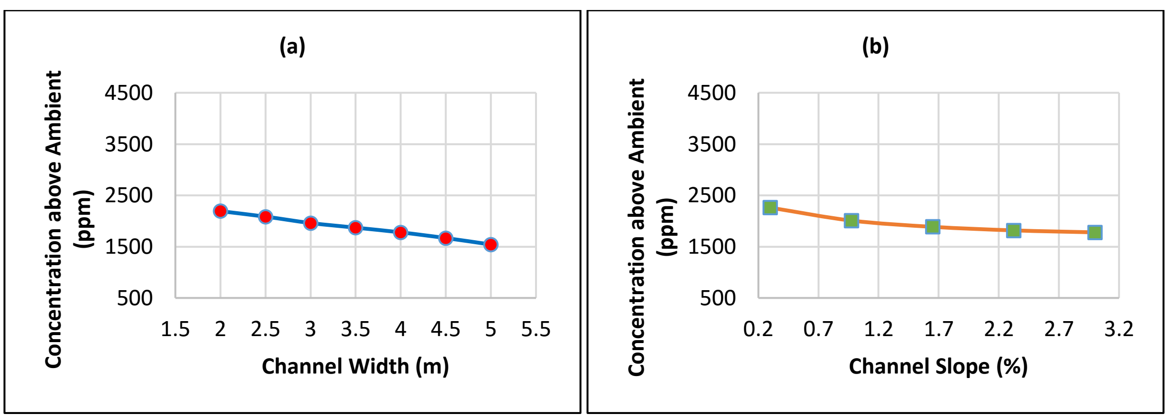


Figure (6.1): Phase (II) in operation in summer at RMZ (a) relationship between brine concertation and channel width at a slope of 3% at a disposal depth of 5.5m, (b) relationship between brine concentration and channel slope at a channel width equal to 4m at a disposal depth of 5.5m

Figure (6.2) presents the simulation output for the open channel design of 4m width, 3% slope and a disposal depth of 5.5m in the case of Phase (II) in summer.

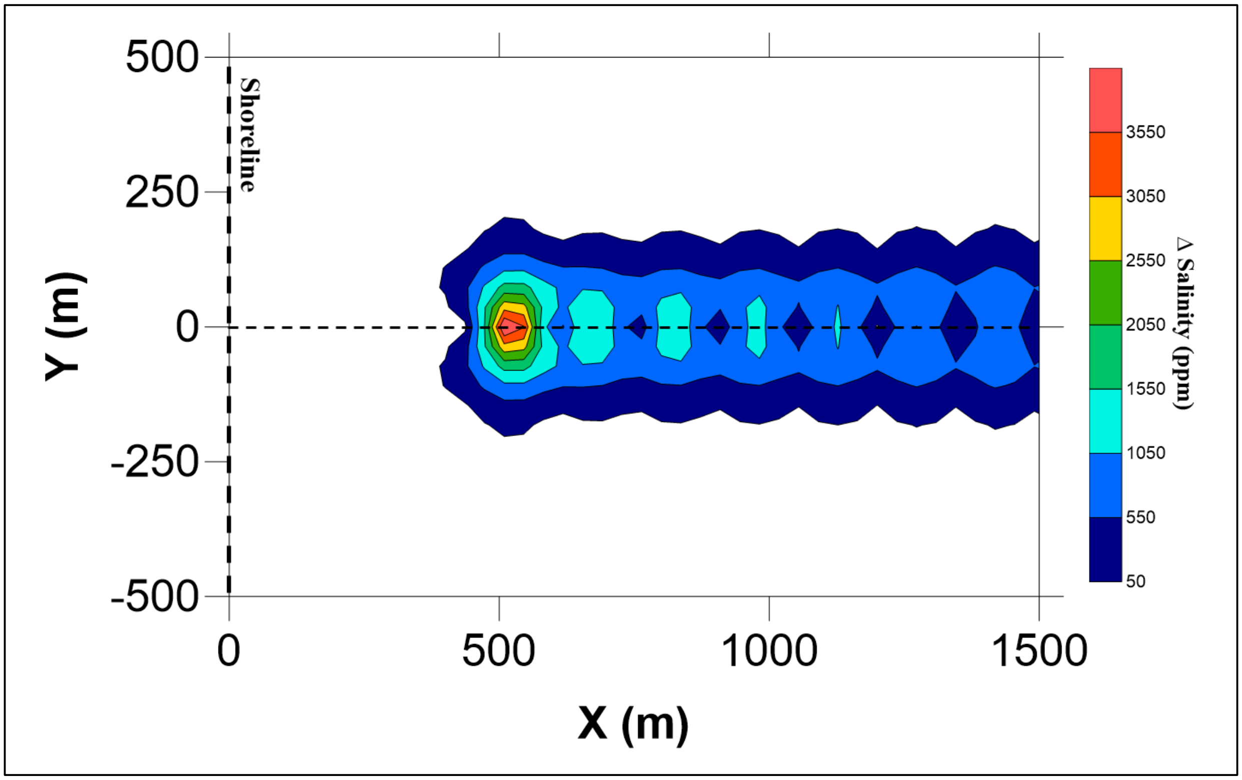


Figure (6.2): Phase (II) simulation outputs for channel of 4m width, 3% slope at a disposal depth of 5.5m in summer

6.3 Offshore Disposal by Submerged Single Port Diffuser

According to the detailed results presented in Appendix (D), this scenario illustrates the simulations of the disposal process for the brine produced from GCDP into seawater through a device consists of feeder pipe (main pipe) ends with a single port. The sensitivity analysis for the effect of port`s diameters, disposal locations (distance into waterbody), and seasonal variation in the ambient (waterbody) characteristics were taken into consideration in modelling the behavior of brine`s diffusion.

Based on the modelling`s results for the single port, it can be concluded that the discharging regulations at the end of RMZ are met willingly in the case of Phase (I) if these regulations are met in the case of Phase (II). Accordingly this study concerns in exploring the optimal design that can serve GCDP in achieving a more environmental discharging for the brine of GCDP in its short term and long term operations.

The simulation results for the brine`s dilution process prove that as the discharging velocity was reduced the brine dilution increased where the rise height (penetration depth) also decreased. This match the results of the experimental investigation conducted by Abou-Elhaggag et al. (2011).

Figure (6.3) illustrates the simulation results of Phase (I) at port`s diameters of 0.4m and 1m in winter and spring respectively at the RMZ.

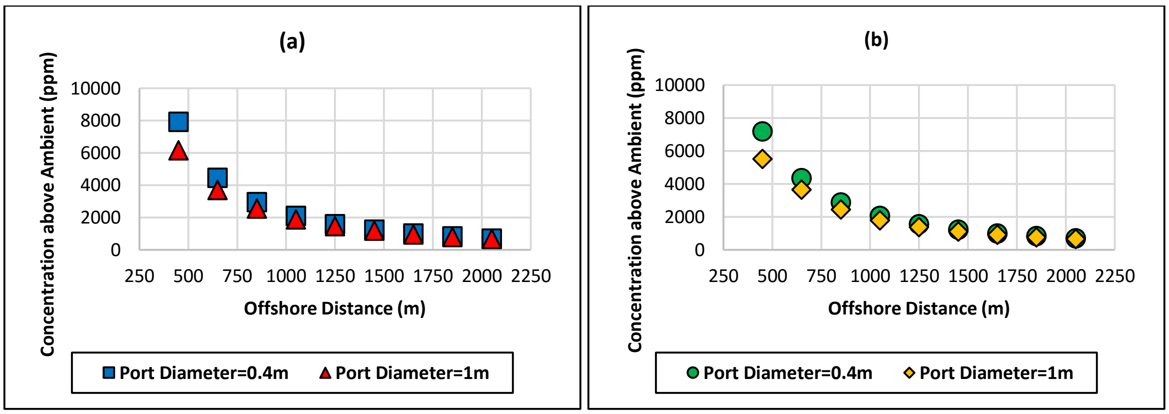
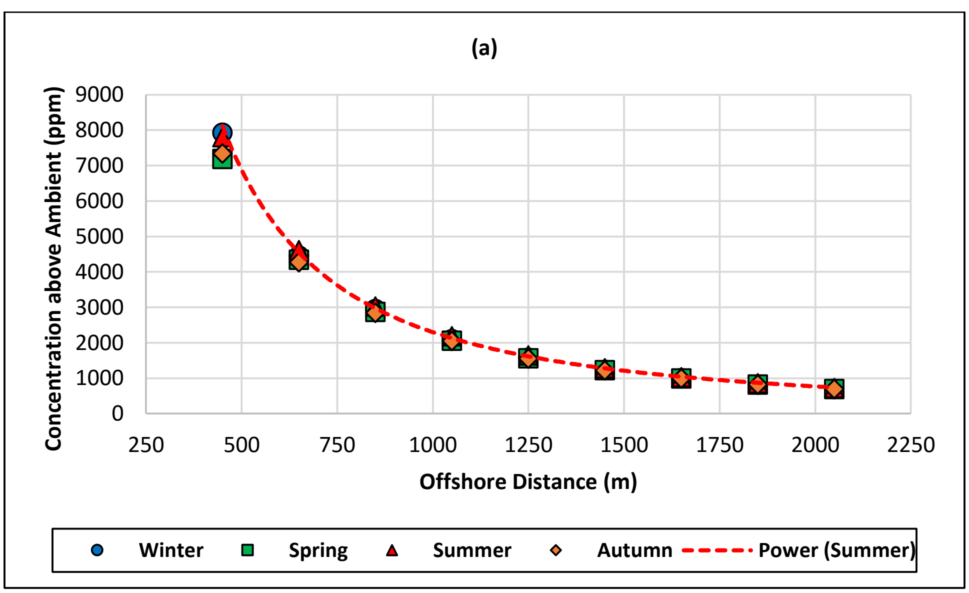


Figure (6.3): Phase (I) simulation results at RMZ in: (a) winter and (b) spring

The seasonal variation in the brine dilution for the brine disposed from Phase (I) at port`s diameters of 0.4m and 1m respectively at RMZ is demonstrated in Figure (6.4).



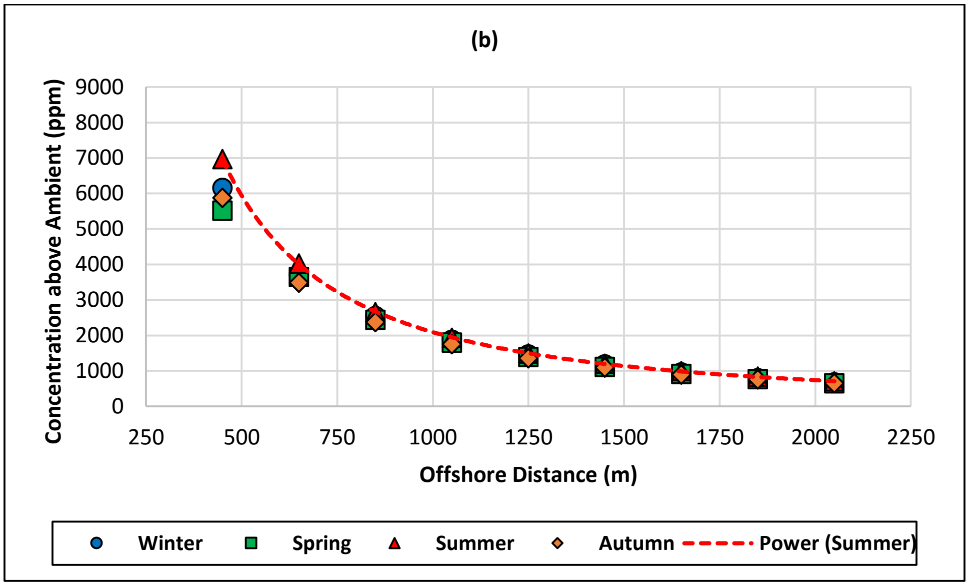


Figure (6.4): Phase (I) seasonal simulation results at port diameter: (a) 0.4m, (b) 1m at RMZ

The results of simulation outputs and sensitivity analysis for Phase (I) over the four seasons show that the regulations of brine disposal at RMZ can be met at an offshore distance more than 1250m in the case of 0.4m single port diffuser while at 1m single port diffuser the regulations at RMZ can be satisfied at an offshore disposal distance of more than 1050m.

The downstream concentration for Phase (I) `s brine plume in the season of summer at a port diameter equal to 1m is presented in Figure (6.5).

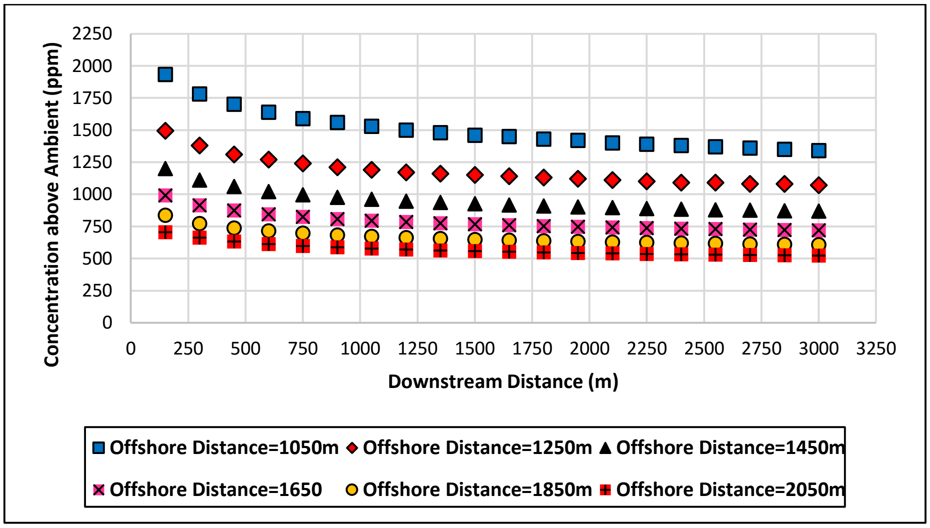


Figure (6.5): Phase (I) downstream concentration of brine for single port of 1m in summer

When Phase (II) operates the quantity of brine that rejected from GCDP will be twice that of Phase (I), while the salinity is the same, the dilution of brine for Phase (II) is less than that of Phase (I). Figure (6.6) illustrates the simulation results for Phase (II) at port`s diameters of 0.4m and 1m at the RMZ in the seasons of summer and autumn, respectively.

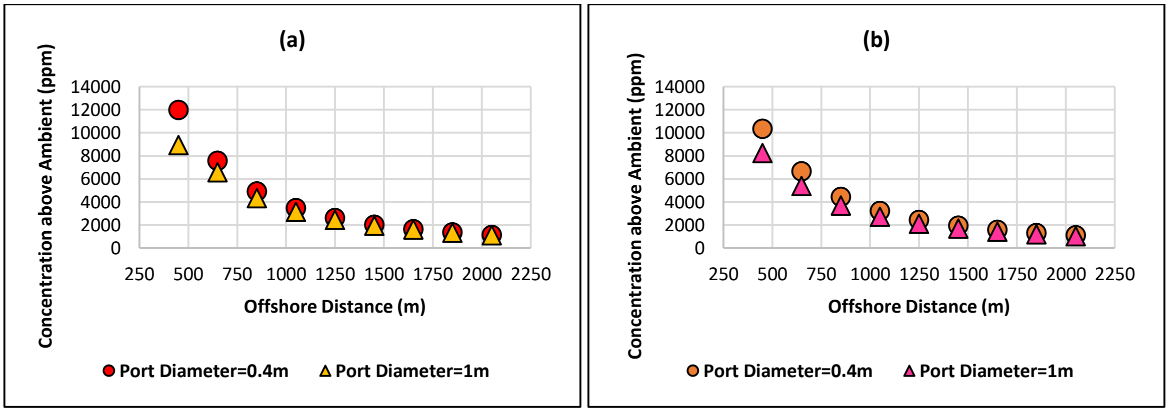


Figure (6.6): Phase (II) simulation results at RMZ in: (a) summer and (b) autumn

Figure (6.6) confirms the findings of Abou-Elhaggag and et al. (2011), where the dilution pattern in the case of doubling the brine`s flow rate (Phase II) is also better for a port diameter of 1m than a diameter of 0.4m. The seasonal variations in brine dilution versus the offshore distance at RMZ for Phase (II) single port's diameters of 0.4m and 1m are presented in Figure (6.7).

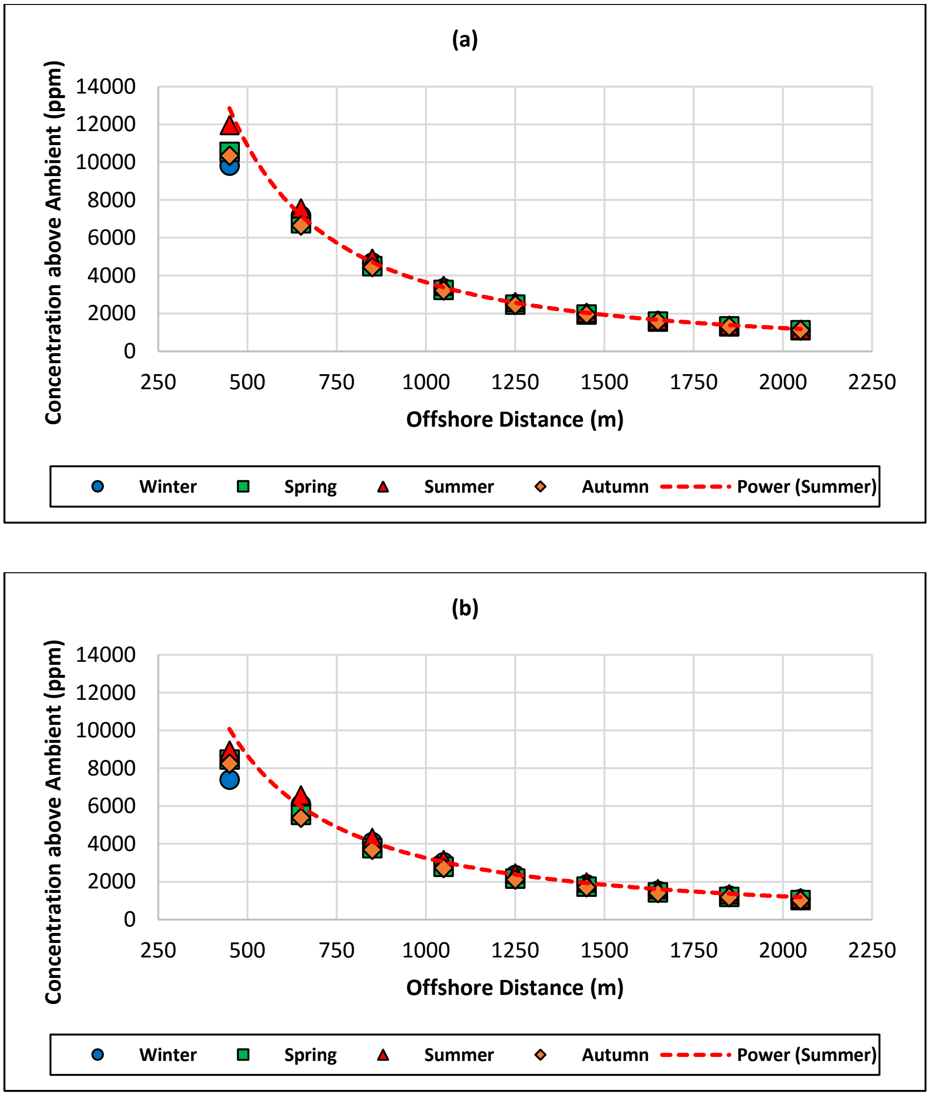


Figure (6.7): Seasonal simulation results of Phase (II): (a) 0.4m and (b) 1m port diameter at RMZ

The results of seasonal simulation and sensitivity analysis for Phase (II) show that the regulations of brine disposal at RMZ can be met at an offshore distance more than 1650m in the case of 0.4m single port diffuser while at 1m single port diffuser the regulations at RMZ can be satisfied at an offshore disposal distance of more than 1450m. The downstream concentration for Phase (II) brine plume in the season of summer at a port diameter equal to 1m in summer is illustrated in Figure (6.8).

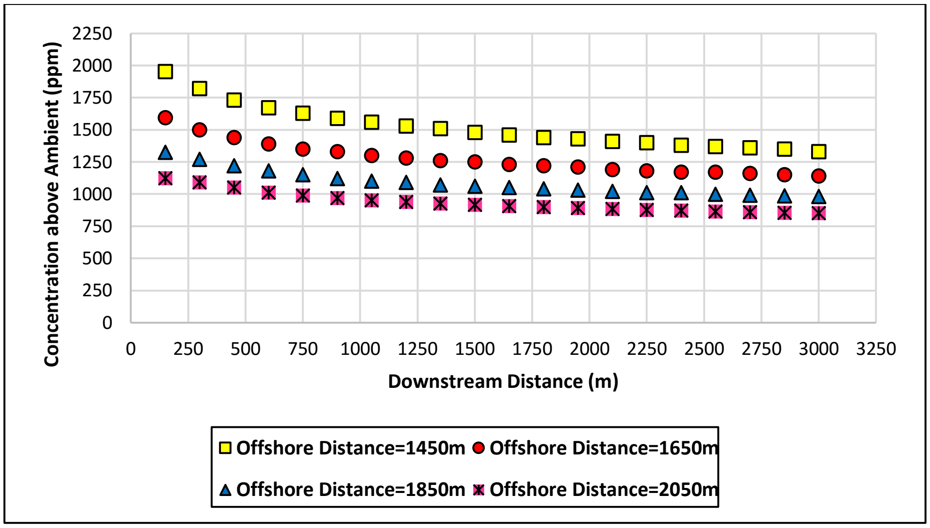


Figure (6.8): Phase (II) downstream concentration of brine for single port of 1m in summer

The simulation results and sensitivity analysis of brine disposal through submerged single port diffuser for GCDP in its short term and long term capacities show that the most viable port diameter that satisfies the environmental requirements and design criteria presented in Appendix (C) is 1m. Although the current speed in summer is the maximum, the results show that the worst dilution for the brine was inspected in that season. This can be interpreted due to faster current spread the brine over a much larger area downstream per unit time also faster current are often more turbulent and increases the diffusion of brine. According it can be concluded that the faster current speed leads to faster moving of the brine plume without sufficient contact with the ambient water and this reflects the lowest brine dilution in summer. There is better offshore transport of the mixed effluent during weak ambient current condition. Higher dilution rates are reached at the near field, due to the turbulence effects created by the shear layer because of the differences of velocity between the jet and the ambient body (Bleninger and Jirka 2008; Palomar and Losada, 2011).

Figure (6.9) depicts the simulation outputs of 1m single diffuser discharges brine from Phase (II) at a disposal distance of 1850m offshore in summer.

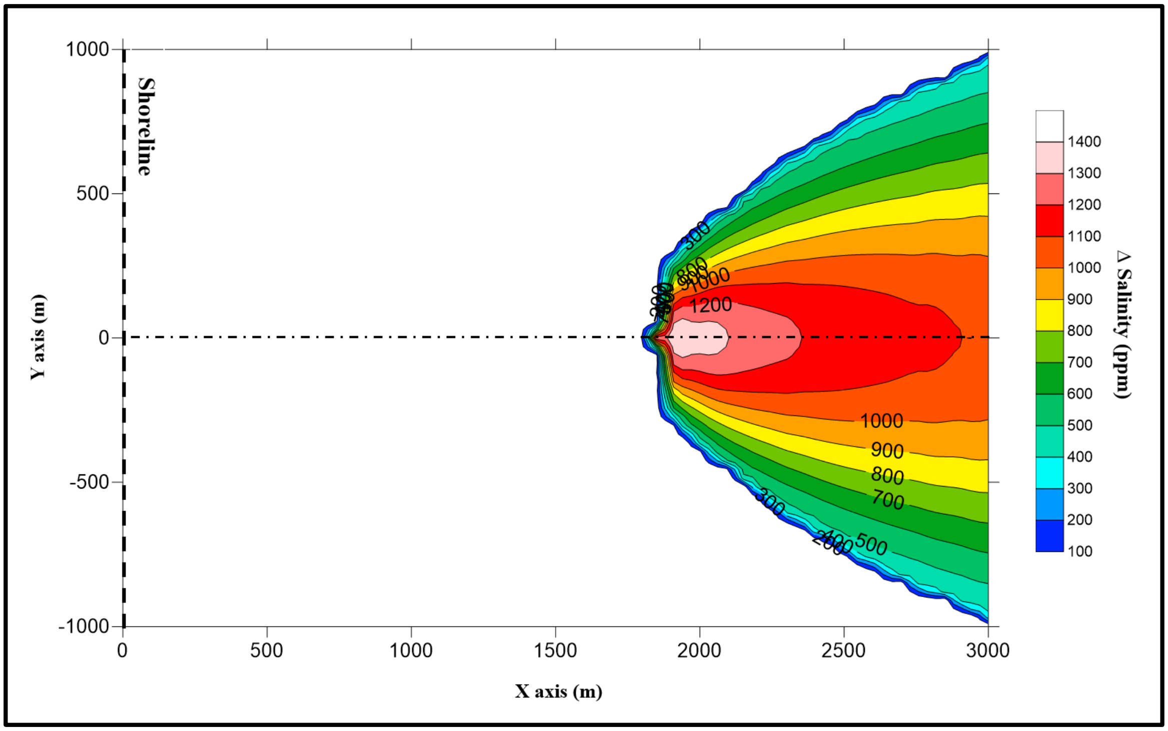


Figure (6.9): Phase (II) simulation outputs for 1m single port diffuser at 1850m offshore in summer

It is clear, in this study, that the disposal of brine via a single port achieves the regulatory requirements at RMZ, for example in the case of Phase (II), the brine concentration at RMZ at 1850m offshore disposal location for 1m single port diffuser is 1326ppm above ambient in the worst case. But in this study the major point that the research aims to achieve is to guarantee the quality of seawater at intake point by ensuring that the brine`s plume will not reach the intake point in any case.

According to the previous, it can be concluded that no single port diffuser configuration was found suitable to be operated in the boundaries of ROI can guarantee the quality of seawater at the intake point. So for GCDP, it is urgent to design and simulate the behavior of brine discharged through an offshore multiport diffuser as to guarantee the quality of seawater to be desalinated at the intake point.

6.4 Offshore Disposal by Submerged Multiport Diffuser

The general description given to GCDP`s disposal system specifies that it`s configuration is a multiport disposal system consists of an outfall pipe ends with an alternating submerged multiport diffuser (Figure 6.10) consists of many risers, each riser is capped by a turret that has four discharge ports spaced evenly around its circumference.

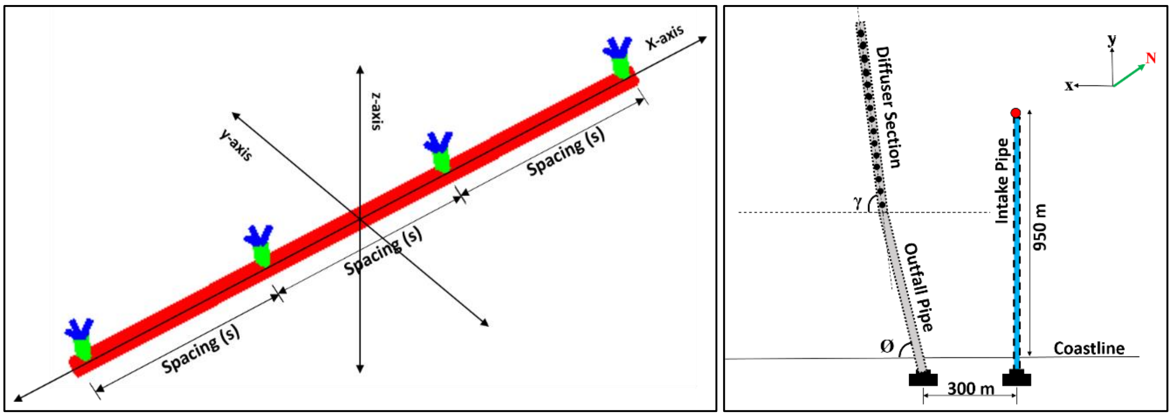


Figure (6.10): Configuration view for GCDP multiport diffuser system

Since there is no complete design for the disposal system, in this study a detailed design in conjunction with a sensitivity analysis for the multiport disposal system have been detailed in Appendices (C) and (D). The sensitivity analysis simulates the seasonal variations in the brine dilution due to the change in the parameters of outfall length, spacing between ports, ports diameters, the alignment angles between diffuser line, inclination angle of outfall pipe to the shoreline and ambient current direction.

This part of the study is interested in investigating the feasibility of the general configuration design prepared to the disposal system of GCDP. The configuration demonstrates that the outfall`s inclination angle (ø) to coastline is 90^o, moreover the alignment angle (γ) between diffuser line and current direction is also 90^o.

the sensitivity analysis and simulation results presented in Appendix (D) for the worst case in the season of autumn show that the most suitable port diameter which can serve the desalination plant in the two cases of Phase (I) and Phase (II) is 10cm (4inch). This diameter will prevent the intrusion of seawater into port diameter at a disposal depth of 19.425m or more as well as it provides an unstable discharging of brine. Figure (6.11) illustrates the relationship between the outfall length and its inclination angles to shoreline for Phase (II) and Phase (I) at the worst case in autumn.

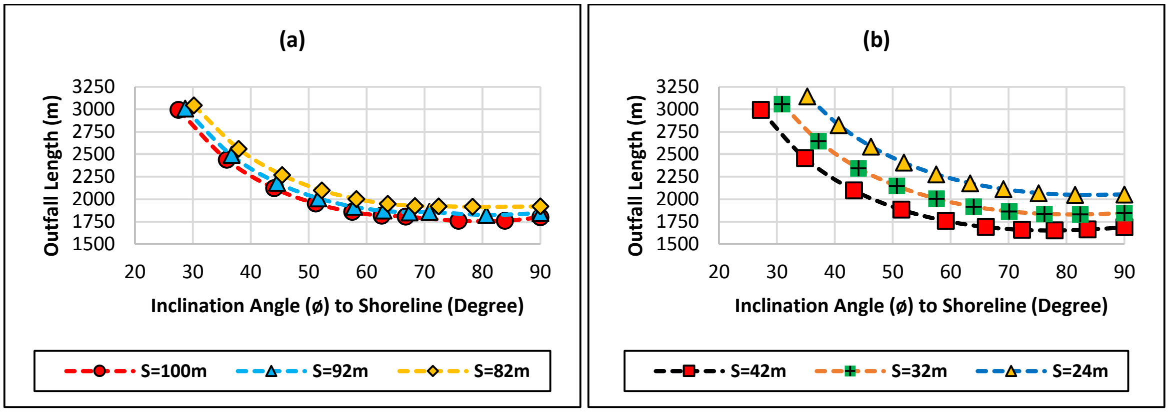


Figure (6.11): Relationship between outfall lengths and inclination angles to coastline at ports spcing of 100, 92 and 82m for (a) Phase (II) and ports spacing of 42, 32 and 24m for (b) Phase (I)

In order to select the spacing between ports that can serve GCDP in its long term of Phase (II) as well as in its short term of Phase (I) at inclination angle (ø) of 90^{o} to shoreline, Figure (6.12) demonstrates the pattern of spacing variation in contrast to the variation in the length outfall line.

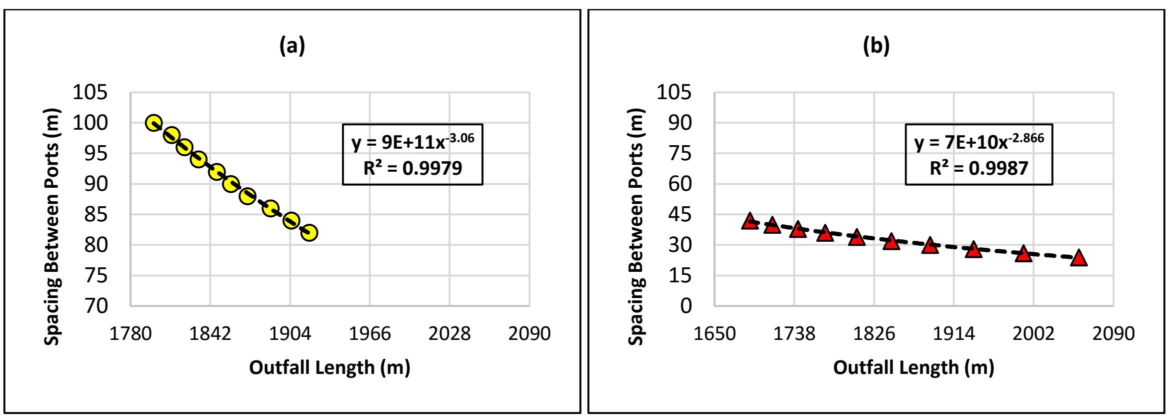


Figure (6.12): Outfall length vs. port spacing at inclination angle (ø) 90^{o} to shoreline: (a) Phase (II), (b) Phase (I)

The results show that at an offshore outfall length of 1850m at inclination angle (ø) of 90^{o} to shoreline, the most environmental spacing between diffuser's ports is 31.7m (30.3m trend line) in the case of Phase (I) in operation, while in the case of Phase (II) in operation the spacing between ports should be increased to 91m (90.5m trend line).

The ports` spacing of 31.7m can serve GCDP in Phase (I) and Phase (II), but in the case of Phase (II) the quantity of discharged brine is twice the quantity of Phase (I) and the dilution process in this case meets the regulations at RMZ but don`t guarantee the quality of seawater at the intake point, so this necessitates to increase the spacing to 91m.

This phenomenon can be intercepted according to the findings of the experimental results prepared by Abessi and Roberts (2014) the results states that as the port spacing was reduced, the rise height and other geometrical variables decreased and the dilutions also decreased. These were caused by Coanda effects and merging. The Coanda effect caused an under pressure on the interior jet surfaces which caused them to curve more sharply inwards. This shortened their trajectories, reducing the external surface area available for entrainment. Jet merging restricted entrainment of clear water to the inner surfaces and exacerbated the Coanda effect.

Optimizing the length of outfall in order to minimizing the operation and installation costs is an advantageous in locating the disposal system. Figure (6.13) illustrates the optimum outfall length for Phase (II) at a spacing of 91m between ports in accordance to the variation in the inclination angle (ø) to coastline.

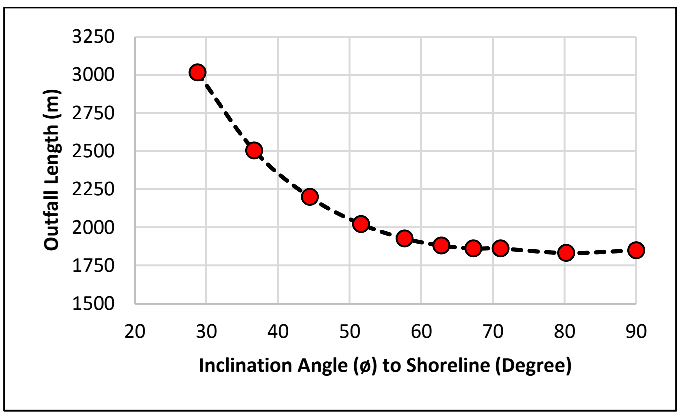


Figure (6.13): Inclination angle vs. outfall length in for Phase (II) at spacing of 91m

The results show that the optimal outfall length that can serve GCDP in Phase (II) is 1830m at inclination angle (ø) of 79.61^{o} (trend line: 1833m, 81.58^{o}).

Similarly, Figure (6.14) illustrates the optimum outfall length for Phase (I) at a spacing of 31.7m between ports in accordance to the variation in the inclination angle (ø) to coastline.

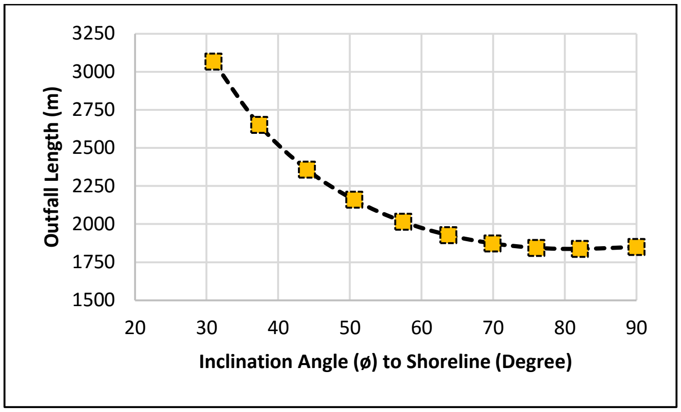


Figure (6.14): Inclination angle vs. outfall length for Phase (I) at spacing of 31.7m

The results shows that the optimal outfall length that can serve GCDP in Phase (I) is 1836m at inclination angle (ø) of 82.08^o according to the equation of trend line.

It is convenient to confirm that the regulations at RMZ are met and it is critical to guarantee that the salinity of seawater in the vicinity of the intake point don`t rise toward shifting the quality of the freshwater outside the WHO drinking water guideline.

Figure (6.15) and Figure (6.16) demonstrate the brine`s concentrations above ambient for Phase (II) and Phase (I) at RMZ and at the intake point, which is far away to about 1059m from the disposal point for the design of diffuser spacing, outfall length, and outfall inclination (ø) are 91m, 1830m and 79.61^o, respectively.

These Figures illustrate the pattern of decreasing in the brine`s concentrations with increasing the alignment angles (γ) between the centerline of diffuser line and the direction of ambient current direction. Moreover, the results at RMZ (in the region of near field) show that at alignment angles ranges from 0^o to nearly 45^o the best dilution found at lowest current speed in autumn and for alignment angles between 45^o and 90^o the best dilution is related with the faster the current speed in summer, while far away from the near field zone at the intake point (in the region of intermediate field or far field) the best dilution process occurs at the faster current speed in summer at all alignment angles. It can be concluded that the faster evacuation of the mixing zone in the near filed can reflect a better dilution in the intermediate of far field.

According to MixZon Inc. (2015) the alternating diffuser in parallel alignment is generally not advantageous for mixing. So it can be concluded according to the presented results that it is advantageous to allocate the diffuser line in at an alignment angle somewhat above 50^o in order to improve the dilution process.

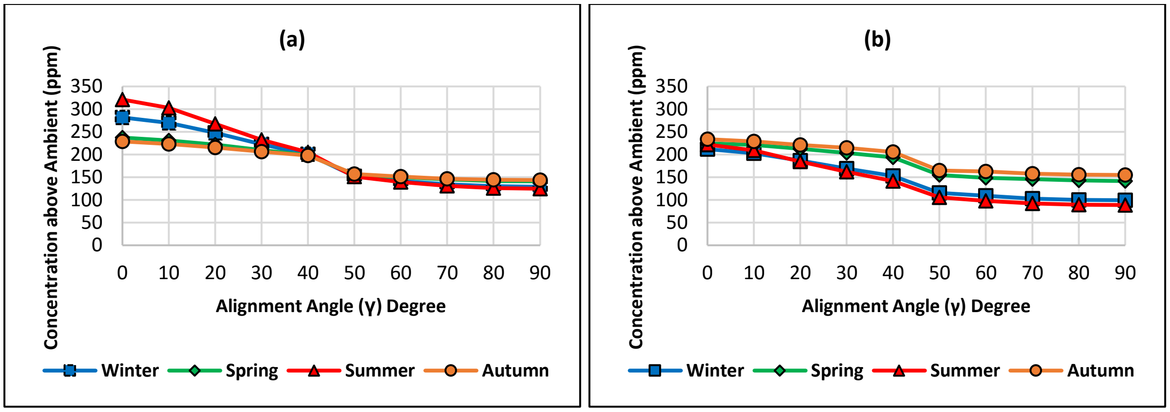


Figure (6.15): Brine concentration above ambient vs. alignment angles (γ) in the case of Phase (II) at: (a) RMZ, (b) intake Point

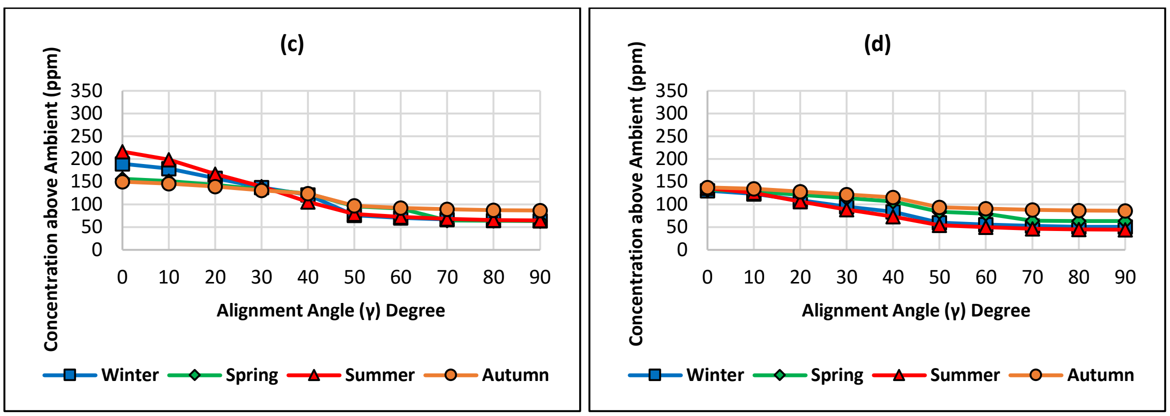


Figure (6.16): Brine concentration above ambient vs. alignment angles (γ) in the case of Phase (I) at: (a) RMZ, (b) intake Point

Similarly, Figure (6.17) demonstrate the brine`s concentrations above ambient for Phase (I) alone at RMZ and at the intake point, which is far away to about 1030m from the disposal point for the design of diffuser spacing, outfall length, and outfall inclination (ø) are 31.7m, 1836m and 82.08^o, respectively. This configuration design is suitable in the operation of Phase (I) for GCDP.

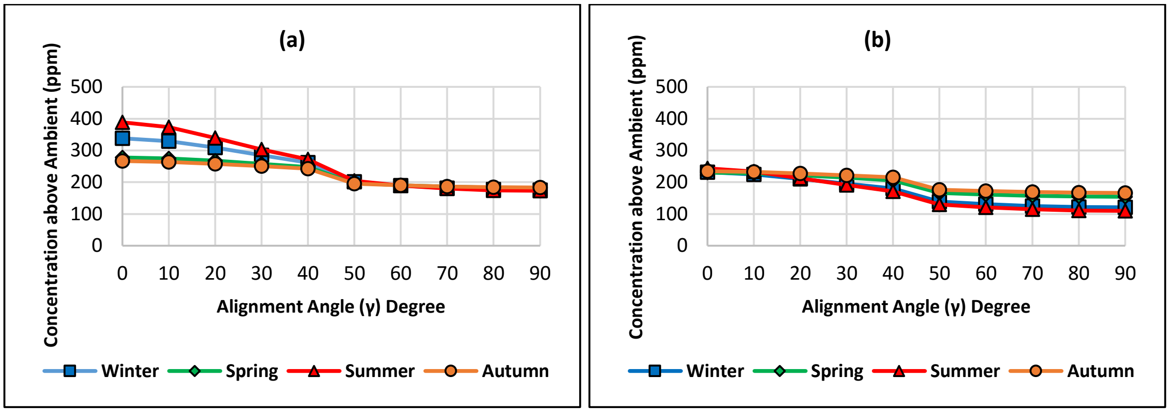


Figure (6.17): Brine concentration above ambient vs. alignment angles (γ) in the case of Phase (I) alone in operation at: (a) RMZ, (b) intake Point

The designs that have been presented above are mainly related to a disposal point locates at 1850m offshore, these designs archive the design’s requirements stated in Appendix (C) but the jetting velocities for these configuration are 26.99m/s and 53.98m/s in the cases of Phase (I) and Phase (II), respectively. Purnama (2015) stated that in the regulations, discharging velocity is not a parameter that is regulated and monitored. But some regulations state that it is recommended to keep the discharging velocities less than 6m/s in order to avoid possible adverse conditions for sensitive fish populations (Bleninger and Jirka, 2008; Bleninger and et al., 2009).

In order to satisfy the design recommendations for a multiport disposal system as well as to optimize the disposal system of GCDP so that to minimize the installation, maintenance and operation costs, this study present its own design configuration for GCDP`s alternating multiport diffuser system.

Here a redesign was prepared for GCDP`s alternating multiport diffuser system in order to serve the plant in its short term and long term operation states. Further the new design undertakes to satisfy the design recommendations, the environmental regulations, as well as the optimum length for the entire brine`s disposal system.

The main design recommendations demonstrated in Appendix (C) states that the port diameter should be in the range of 0.1 to 1m, the Froude number and Reynold number should be greater than 10 (recommended greater than 20) and 4000, respectively; and the discharging velocity should be less than or equal 6m/s (Bleninger and Jirka, 2008; Bleninger and et al., 2009).

In order to select the suitable diameter that can achieve the design recommendations at a discharging velocities of $V_I = 3m/s$ in the case of Phase (I) in operation and $V_{II} = 6m/s$ in the case of Phase (II) in operation, a sensitivity analysis studying the effect of varying port`s diameters on the parameters of number of risers (number of nozzles) and on the seasonal variation in Froude number (F_r) and Reynold number (R_e) was prepared in Table (6.1).

Table (6.3): Design sensitivity analysis

Port Diameter (m)	V_I (m/s)	V_{II} (m/s)	No. of Nozzles	No. of Risers	Integer Number of Riser	Average Quarterly			
						Phase (I)		Phase (II)	
						F_r	R_e (10^6)	F_r	R_e (10^6)
0.1	**3**	**6**	**143.88**	**35.97**	**36**	**23.99**	**0.29**	**47.98**	**0.57**
0.2	3	6	35.97	8.99	9	16.96	0.57	33.93	1.15
0.3	3	6	15.99	4.00	4	13.85	0.86	27.70	1.72
0.4	3	6	8.99	2.25	3	9.00	0.86	17.99	1.72
0.5	3	6	5.76	1.44	2	7.73	1.03	15.45	2.07
0.6	3	6	4.00	1.00	1	9.79	1.72	19.59	3.45
0.7	3	6	2.94	0.73	1	6.66	1.48	13.32	2.95
0.8	3	6	2.25	0.56	1	4.77	1.29	9.54	2.58
0.9	3	6	1.78	0.44	1	3.55	1.15	7.11	2.30
1	3	6	1.44	0.36	1	2.73	1.03	5.46	2.07

The sensitivity analysis results show that the most suitable diameter is 0.1m where the Froude number is greater than 20 in the case of Phase (I) and Phase (II). Accordingly, the corresponding number of risers for the diffuser section is 36 (144 nozzles).

This study interests in modeling the brine`s behavior discharged into coastal area, the major point that should be taken into consideration in selecting the length of diffuser section and the location of disposal point is to avoid the stable disposal of the brine flows where as to save the discharging classification in the class of unstable flows in the cases of Phase (I) and Phase (II).

The assessment of near field stability (i.e. the distinction of stable or unstable conditions) is a key aspect of effluent dilution analyses. It is especially important for understanding the behavior of the two dimensional plumes resulting from multiport diffusers. Near field stability reflects the amount of local recirculation and re-entrainment of already mixed water back into the buoyant jet region. Stable discharge conditions are associated with weak momentum and deep water and are also sometimes called deep water conditions. Unstable discharge conditions have localized recirculation patterns and are also called shallow water conditions. If the buoyancy of the effluent flow is weak or its momentum is very high, unstable recirculation phenomena can occur in the discharge vicinity, this local recirculation leads to re-entrainment of already mixed water back into the buoyant jet region. When a multiport diffuser represents a large source of momentum with a relatively weak buoyancy effect such a diffuser will have an unstable near-field with shallow water conditions (Doneker and Jirka, 2007).

The critical flow which is sensitive to stability and instability flows is in the case of Phase (I) of 3.39m^3/s. Figure (6.18) presents the flow classification in the case of Phase (I).

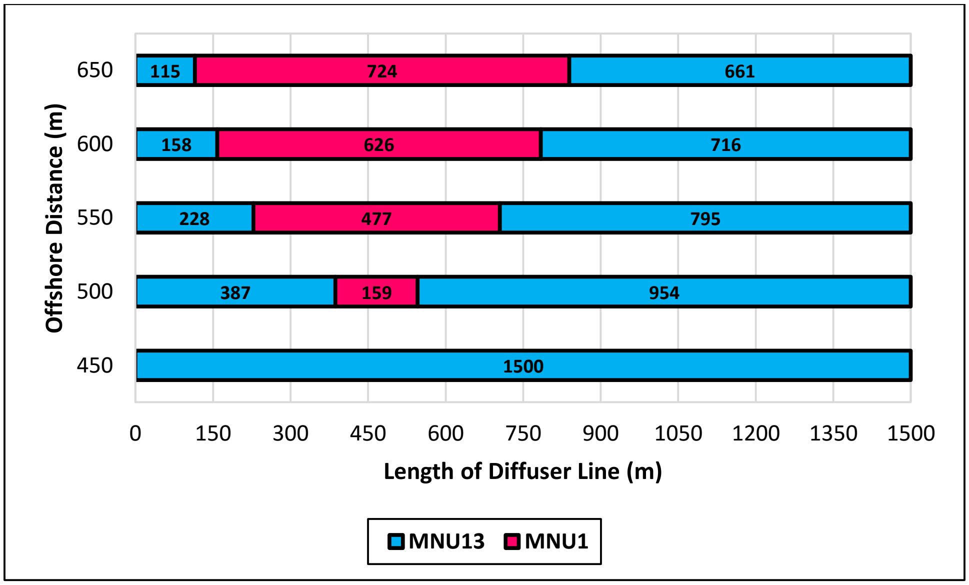


Figure (6.18): Flow classifications for Phase (I) flow rate

Figure (6.18) shows that at an offshore disposal distance equal to 450m or less the class of the flow is unstable at any diffuser length, while for any offshore disposal distance equal to or greater than 500m the stable class stats to appear between two unstable classes, for example at 500m offshore the stable class can be confined between diffuser`s lengths of 387m and 546m. In this study the sensitivity analysis, presented in Appendix (D), at 650m offshore shows that the optimal diffuser length is 680m this length locates the flow in the case of Phase (I) in the class of stable flow, accordingly this choice was ignored.

The maximum offshore distance that can satisfy an unstable flow classification for Phase (I) and willingly for Phase (II) is 550m. In order to optimize the length of the entire disposal system, a sensitivity analysis at a disposal point of 550m offshore was prepared for the parameters of diffuser length and the inclination angle (ø) of outfall to shoreline according to the autumn`s ambient properties. Figure (6.19) depicts a general configuration for the disposal system.

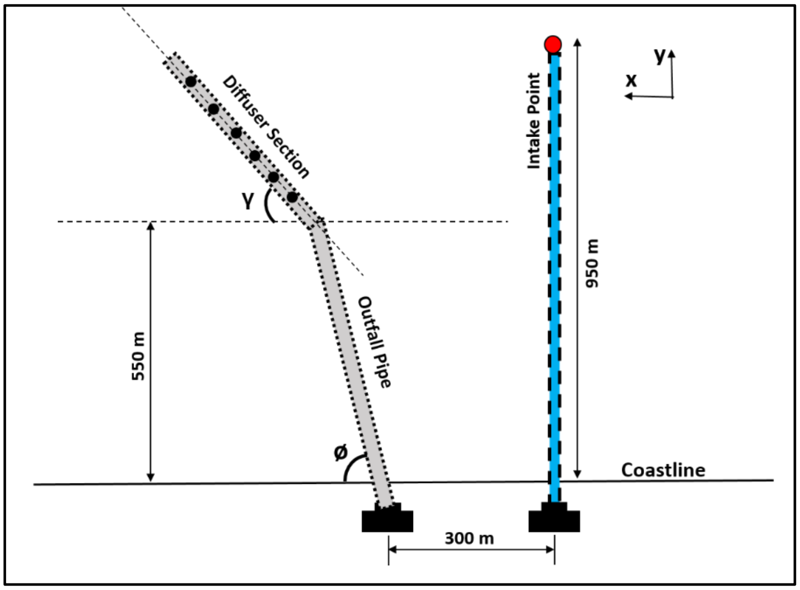


Figure (6.19): Disposal system`s general configuration

Figure (6.20) demonstrates the relationship between diffuser length, outfall length and entire system length (sum of diffuser length and outfall length) and outfall inclination angle to coastline.

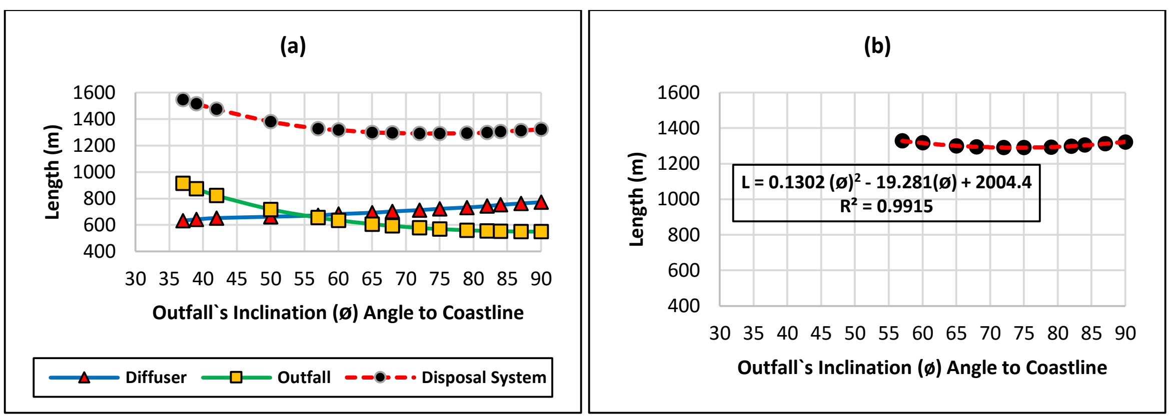


Figure (6.20): Optimum length for the disposal system: (a) interaction between diffuser, outfall and entire system lengths, (b) trend line for the entire disposal system lengths corresponding to the outfall`s inclination angle

The optimizing results show that the optimum length for the disposal system is 1291m at inclination angle (ø) of 74^{o} to coastline with a diffuser length of 719m (2.4m ends+717m diffuser c/c from fist riser to last riser) and an outfall length of 573m. By using a spacing of 20.5m between ports the diffuser`s designed length is 717.5m from the center of first port to the center of last port. Accordingly the length of the entire disposal system become 1293m. Figure (6.21) demonstrates the seasonal variation in the brine`s concentrations in the case of Phase (II) and Phase (I) at RMZ and at the intake point for the final design of disposal system.

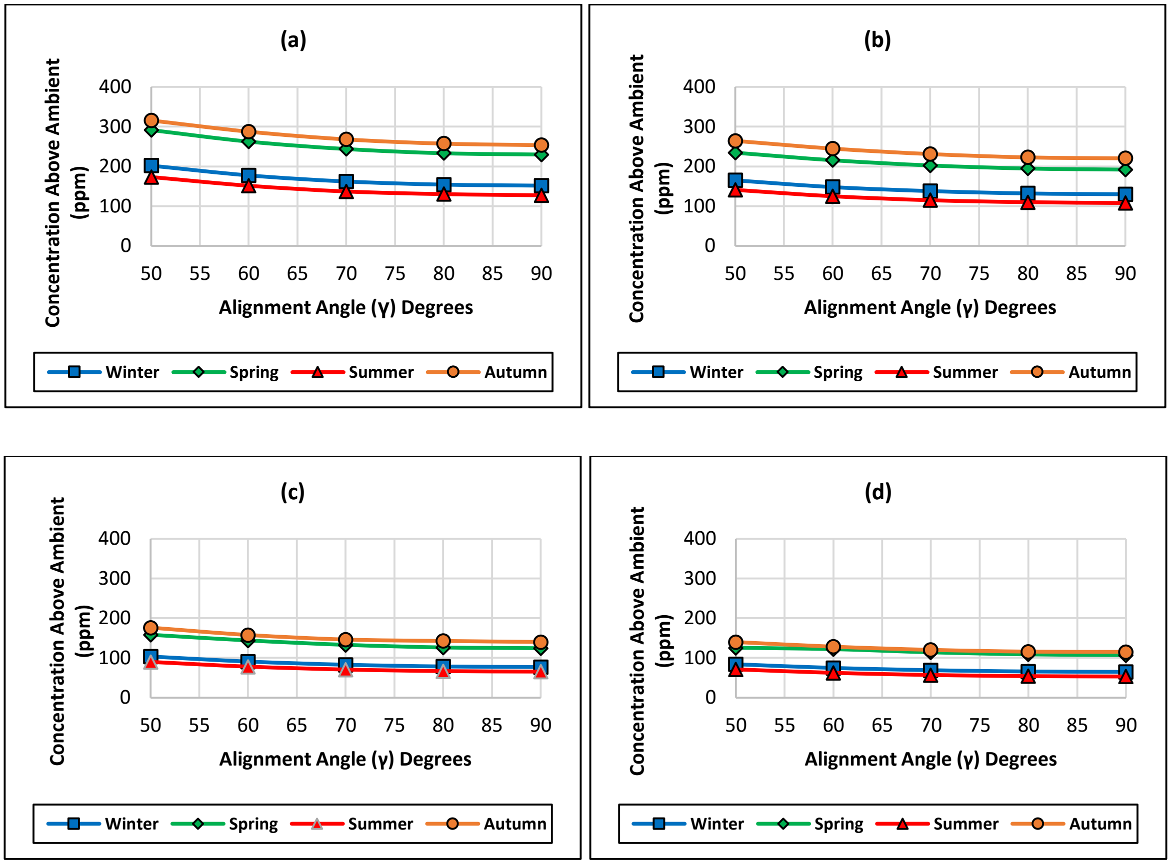


Figure (6.21): Seasonal variations in brine dilutions at RMZ and at the intake point for: (a), (b) Phase (II) and (c), (d) Phase (I)

Tidal currents in coast of Palestine are in general weak, in the order of about 5cm/second. The general circulation, due mainly to the geostrophic current and shelf waves, is oriented counter clockwise most of time (Rosen, 2001). The monthly mean current velocity from two current meters located in the center of the coast of Palestine has been measured at 18 m below the surface in water depth of 26 m for several years. The observed mean currents are directed northward, except in September when it is close to zero. Typical mean velocities are 5–10 cm/s, and there is a clear bimodal seasonal signal, with the strongest mean northward flow in February and July and the weakest northward flow in May and September

(Brenner, 2003). According to Abualtayef (2015) the average current speed in June 2015 is 0.123m/s in the direction of 130^o from north to south. The coordinates of the disposal point is (31.407032^{o}N, 34.304380^{o}E), to maximize the alignment angle of the diffuser line it is urgent to half the angle between the current directions, accordingly the alignment angle for the diffuser of GCDP should be oriented at 65^o to north. Figure (6.22) demonstrates the optimum configuration design for GCDP, this design can serve the disposal process of brine from GCDP in its short term, 12,200m^3/h, as well as in its long term, 24,400m^3/h. Moreover the design can save the quality of seawater and the intake point at different ambient conditions, especially in the cases of changing in the current ambient directions regarding to the orientation of the diffuser section.

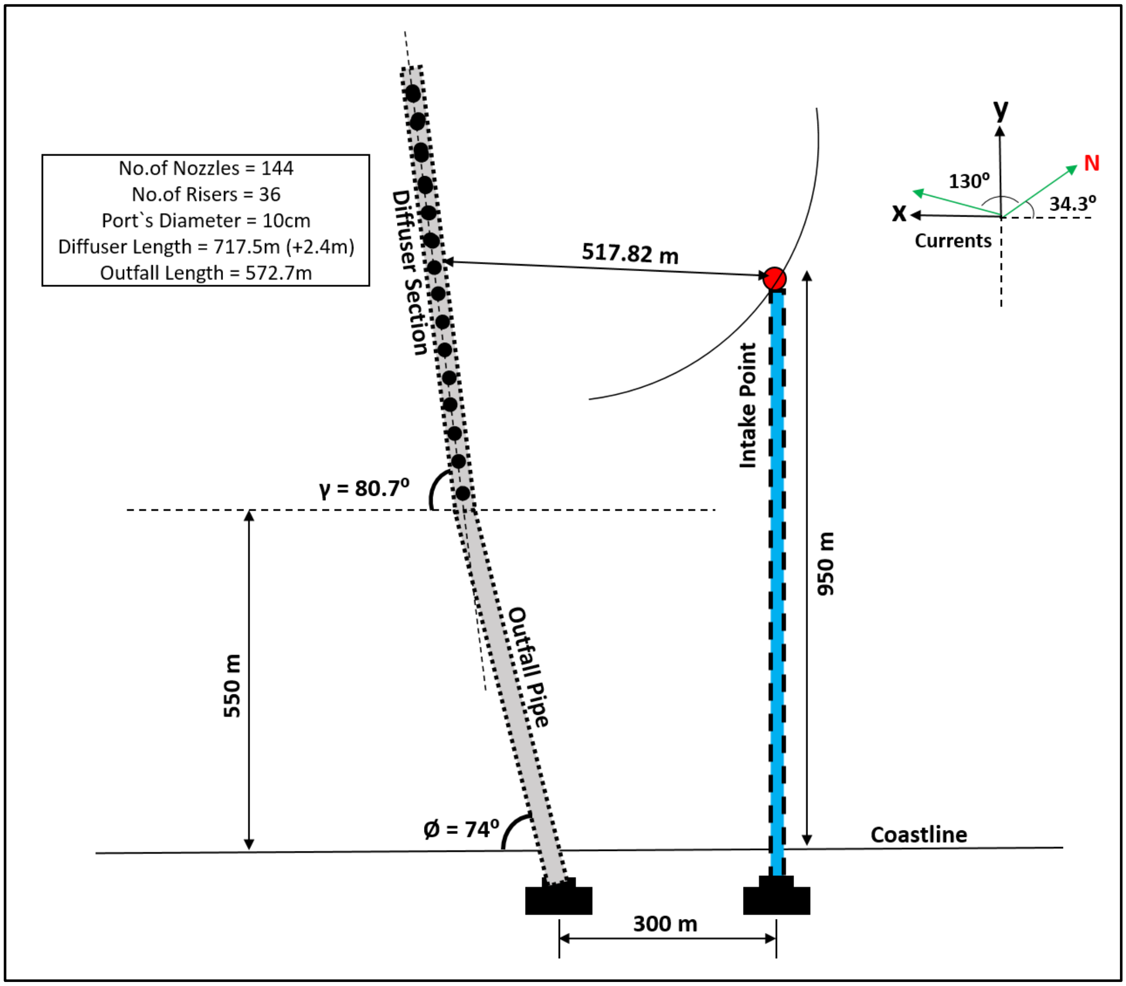


Figure (6.22): Configuration of GCDP brine disposal system

As the model trend to take the shape of power function where it doesn’t provide a zero concentration above ambient, previously in characterizing the properties of rejected brine from GCDP, the salinity of produced freshwater was suggested as zero. This mean that the concentration of the brine plume if it reaches the intake point is not zero, and it will rise slightly the salinity of the intake seawater. Figure (6.23) illustrates the concentrations of brine`s plume at RMZ and at the intake point

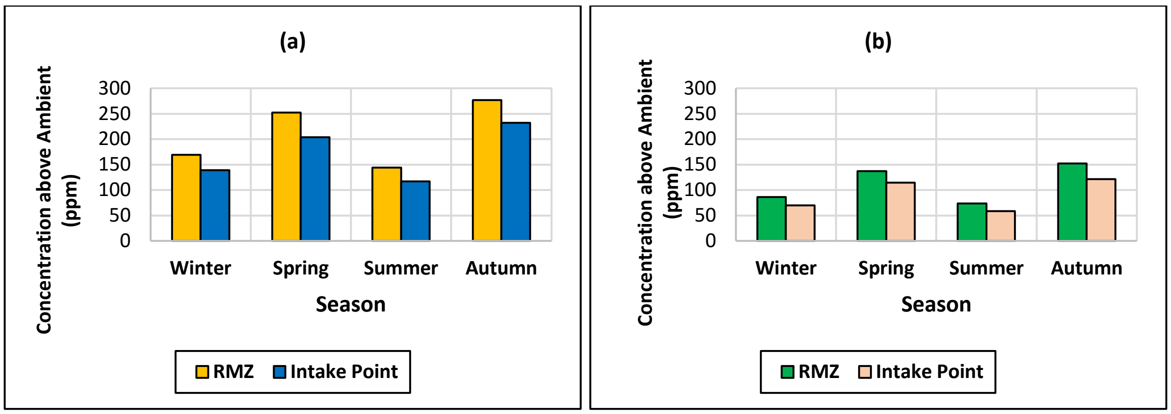


Figure (6.23): Concentrations of brine plume at RMZ and intake point for: (a) Phase (II), (b) Phase (I)

If the scenario of reaching the brine plume to the intake point is taken into consideration, Figure (6.23) demonstrates that the concentrations of brine at the intake point in the case of Phase (II) in the seasons of winter, spring, summer and autumn are 139, 204, 117 and 232ppm, respectively.

While in the case of Phase (I) the concentrations above ambient are 70, 115, 59 and 122ppm in the seasons of winter, spring, summer and autumn respectively. The maximum concentration of brine above ambient observed at the intake point is 232ppm in the case of Phase (II) in the season of autumn. Accordingly the corresponding salinity of the permeate water is 492ppm, this salinity meets the WHO drinking water guidelines.

Accordingly, the simulation results for brine disposed from GCDP in the case of Phase (II) in autumn through the study`s design submerged multiport diffuser can be illustrated in the Figure (6.24).

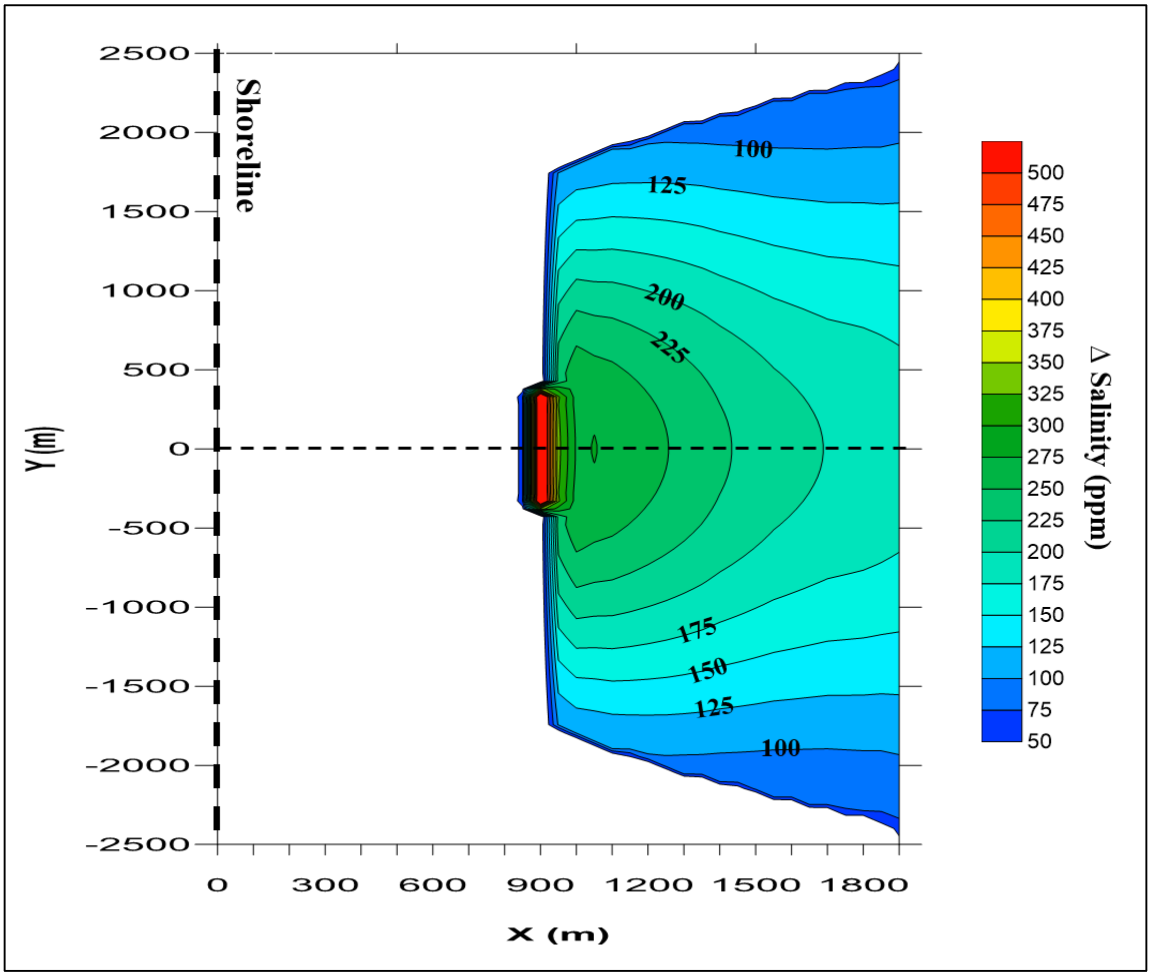


Figure (6.24): View of simulation results of Phase (II) in autumn

CHAPTER (7): CONCLUSION AND RECOMMENDATIONS

The reverse osmosis desalination plants account for the highest share in global seawater desalination capacity. The effluents of these plants have a variety of physical properties and chemical constituents which can be harmful for the marine environment.

Seawater desalination plants mainly discharge a high salinity concentrated brine effluent into coastal waters. Modern, large capacity plants require submerged discharges, in form of a negatively buoyant jet, that ensure a high dilution in order to minimize harmful impacts on the marine environment. The various density differences between the brine and the receiving water represented by the buoyancy flux causes different flow characteristics of the discharge. The dense RO effluent flow has the tendency to fall as a negatively buoyant plume.

7.1 Conclusion

CORMIX simulations for three disposal scenarios of surface, submerged single port and submerged multiport discharges were carried out to assess the compliance of brine discharge from GCDP within the regulations for discharging effluents in the Omani marine environment. Based on the simulation results presented in this study, the adoption of surface channels for brine discharge in shallow areas with limited circulation is not adequate to achieve acceptable mixing and dilution rates. Mitigation of adverse impacts of the direct surface discharge of brine on the local marine environment can be achieved either by the construction of several long single port outfalls or a multiport diffuser.

The results show that the optimal discharging scenario that can meet the regulations at RMZ as well as save the quality of intake seawater at the intake point is using a multiport diffuser device. Salinity rise due to concentrated brine discharges from GCDP is found to be around 277ppm in the worst case of Phase (II) in the season of autumn (above ambient) within the regulatory mixing zone of 150m radius from the center of diffuser center. This value is well below the maximum permissible limit set by the Omani government, which is 2ppt above ambient.

CORMIX has several inherent limitations. One major limitation results from the use of hydro dynamically significant length scales to determine the flow class of the effluent and its subsequent dilution. For example in this study, changing in the flow rate from Phase (I) to Phase (II) leads to a sharp shift in flow class from stable to unstable moreover at the same flow rate for example Phase (I), changing the diffuser length in the multiport device shifts the flow from unstable to stable to unstable at an offshore distance greater than 550m.

The main conclusions of this study can be summarized in the following points:

- The study provide a validate model for the brine`s diffusion behavior disposed through different discharges devices (surface channel, single port and multiport) representing the onshore and offshore disposal processes.
- The study presents a cost optimizing design for the disposal system in order to save the costs of installation, operation and maintenance.
- The study offer a most environmental configuration design for the disposal system of GCDP that can serve the plant in its short and long term capacities in the worst ambient conditions with a least environmental impacts on the marine ecosystem.
- Finally this study present an applicable design for the disposal system of GCDP, where the study recommends to use a multiport diffuser with 36 risers (144ports) with a spacing of 20.5m between ports in order to meet the regulatory requirement.

7.2 Recommendations

In order to support the findings as well as to enhance the viability of this study to manipulate the engineering and environmental issues, it is recommended for the researchers to cover the following issues:

1. While CORMIX provides a good indication on the behavior of brine in the far field, it is recommended to enhance the study with a far field modelling using a pure far field model like Delft3D, MIKE3, POM/ECOM, Telemac 3D, and etc., moreover it is more advantageous to implement a coupling interface linking the near field model with the far field model.
2. Bioassay studies for salinity tolerance and toxicity studies: salinity tolerance investigations must be conducted to evaluate the effects of increased salinity on species commonly found in the discharge site of the proposed desalination project and species considered to be sensitive to environmental stress and those species.
3. Long term field measurements need to be undertaken to validate the presented results on a large scale, and including local, and regional features.

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APPENDIX (A)

An Overview of Some Desalination Plants around the World

In order to get a better understanding on the practical applicable geometries for the intake systems and brine disposal systems, it is feasible to review the intake and outfall systems for existing desalination plants. This Appendix offers a literature on a number of desalination plants around the world.

A.1 CYPRUS: LARNACA Reverse Osmosis Seawater Desalination Plant

A seawater reverse osmosis desalination plant with a capacity of 54,000m^3/day, 18million cubic meters a year, cost 47million ($) was completed in 2001 on the South-East coast of Cyprus near the Larnaca airport. An intake pipeline from HDPE with a diameter of 1.2m capable of supplying the plant with 80,000m^3/day was installed at a water depth of 11m at approximately 1.1km offshore to ensure clean seawater feed for the desalination plant. The RO brine stream with a concentration double that of seawater is discharged by 1m diameter of HDPE pipeline at 1.5km offshore at a water depth of 18m (www.water-technology.net).

A.2 JAPAN: FUKUOKA Seawater Desalination Plant

During 2005 the largest seawater desalination plant in japan was completed and is located on the northern area of Hakata bay in the Fukuoka district. The intake system consists of one 1.8m diameter HDPE main pipe constructed approximately 1.2km offshore at 11.5m water depth. After the filtration process, the brine stream, which has about double the salt concentration than that of seawater, is diluted 50:50 with secondary treated municipal sewage before being discharged to the sea in order to minimize the effect on the marine environment (HAMANO, 2004).

A.3 SAUDI ARABIA: SHOAIBA Desalination Plant

In 2003, the second phase of a MSF facility in Saudi Arabia near SHOAIBA was completed. This second phase was increased the plant capacity from 74,000m^3/d to 450,000m^3/d. At that time, the facility was ranked as the largest in the world. The feed seawater is collected by three pipes of 3.7m diameter prepared from GRP material located 500m offshore. The brine is discharged through an open channel to sea by gravity at a discharge depth between 2.5 to 4m (www.water-technology.net).

A.4 ABU DHABI: UMM AL NAR Desalination Plant

UMM AL NAR desalination plant, located on the Umm Al Nar Island, about 20km to the east of Abu Dhabi city, consists of five 57,000m³/day MSF units which desalinate seawater. The brine is discharged to the sea by gravity open channel through a concrete box culvert that is located onshore. The onshore length of the channel is 1km (www.water-technology.net).

A.5 ISRAEL: ASHKELON Desalination Plant

On the western coast of Ashkelon (Israel), the construction of a 110Mm^3/year reverse osmosis desalination plant was completed in 2005 with a total cost of project reaches 212million ($). Due to site constraints and hydro-geological limitations, a direct subsurface intake type was constructed which consists of three parallel HDPE pipes, which are simple to clean (pigging) and relatively resistant to biological growth, therefore minimizing maintenance costs. The intake pipes with a diameter of 1.6m stretch offshore to 1km. The most environmental and financial feasible method to discharge the brine stream from the desalination plant, was to dilute it with the hot water which is discharged from the adjacent power station to the ocean. The brine is discharge onshore by surface open channel at a dilution ratio of at least 1:10 between the brine and cooling water of the power plant is achieved (www.water-technology.net).

A.6 UAE: FUJAIRAH Desalination Plant

Currently, the Fujairah plant, completed in 2003 is the largest desalination hybrid plant in the world which consists of MSF units coupled with the adjacent power plant, as well as a seawater reverse osmosis component. The capacity of MSF units is 454,000m^3/d (62.5%) while the capacity of RO component is 170,500m^3/d (37.5%). The direct seawater intake system is located about 400 meters offshore at 10m water depth (6m above seabed) and comprises of three individual circular intakes connected to GRP pipes. Approximately 133,000m^3/h of seawater is transported through the intake pipes into the desalination plant, of which 110,000m^3/h is pumped to the MSF plant and 22,000m^3/h to the RO plant. The produced brine is disposed onshore by open channel (SANZ et al., 2007).

A.7 AUSTRALIA: PERTH Seawater Desalination Plant

In April 2007 the construction of the largest SWRO plant which is powered by renewable energy in the world was completed (first water commence November 2006). The plant is located at Kwinana (approximately 40km South of Perth) with a daily capacity of 150,000m^3, supplying 17% of Perth's freshwater needs. Feed water is extracted from a direct sub-surface intake structure about 200m offshore at 10m water depth and the extraction flow rate (4m^3/s) at the intake head works was designed low enough to ensure fish can easily swim against the flow. The intake system contains one GRP pipe with 2.4m diameter and 400m length. Brine with a salinity of approximately 65ppt, the salinity of the ambient receiving waters approximately 37ppt, is discharged under gravity via a diffuser which is designed to reduce the salinity to 0.8ppt above ambient concentrations within a radius of 50 meters of the diffuser (www.water-technology.net). The brine outfall system is summarized in Table (A.1)

Table (A.1): PERTH`s Parameters of Brine Disposal System

Discharge design flow	2.4m^3/s
Offshore Distance	300-500m
Discharge Depth	More than 15m
Discharge Structure	Diffuser
No. of Ports	40
Ports Diameter	150mm
Port Height from Seabed	0.5m
Ports Orientation	60^o to horizontal
Diffuser length	160m
Outfall pipe material	GRP
Outfall pipe Diameter	1.6m

A.8 AUSTRALIA: SYDNEY Seawater Desalination Plant

Sydney's seawater reverse osmosis desalination project located at Kurnell (New South Wales) delivers up to 15% of Sydney's water supply. The plant production capacity is 250,000m^3/d. The intake system consists of one main intake pipe with 4m diameter and 2.5km length from lined concrete, the pipe contains four risers each with 1.5m diameter located 300m offshore. The design of the outfall pipe, shafts and outlets is about the same as for the intake structures, where the outfall main pipe diameter is 4m (TS-01A, 2005).

A.9 OMAN: BARKA Desalination Plant

The Barka power generation and seawater desalination plant is located 65km north-west of Muscat (Oman). It was the first plant in Oman to be built, operated in 2003. The Barka I plant has three MSF desalination units installed, each with a capacity of 30,400m^3/d. The current independent water and power project, Barka II plant, is located adjacent to the existing Barka I plant. The Barka II power generation and seawater desalination plant has commenced its operation in November 2009. The addition of the Barka II plant with a capacity of 120,000m^3/d produced through RO technology will bring the total desalination capacities for Muscat to 393,000m^3/d. There are two sets of existing intake and outfall pipelines. The Barka I and II plants share only one set of intake and outfall pipelines. The maximum capacity of the seawater intake systems is 126500m^3/h: currently, the Barka I plant uses up to a maximum flow rate of 67500m^3/h, and thus the remaining flow rate of 59000m^3/h could be used for cooling purposes in the Barka II plant. The cooling water from the power generation Barka I and Barka II plants are mixed with reject brine (and other effluents) from Barka I (MSF) and Barka II (RO) plants and are discharged into the sea through the existing outfall pipelines. The outfall system is designed for a maximum discharge flow rate of 122100m^3/h: currently, the brine discharge from Barka I plant is up to a maximum flow rate of 61500m^3/h, and thus the remaining up to a maximum flow rate of 60600m^3/h of discharges can be used for the Barka II plant. The seawater intake system consists of four parallel pipes of 1.2km in length and a diameter of 2.2m. The pipes are spaced 2m apart, buried under the seabed (not visible on the surface). The intake structure opens at 1.5m above the seabed at a water depth of 10m. Each intake is equipped with a riser and velocity cap designed to convert vertical to horizontal water flow (Bleninger and Jirka, 2010).

The old (currently in use by the existing Barka I and II plants) outfall pipe length is about 650m, while the new (not yet been used) outfall pipe length is about 1200m, and the distance between the two discharge points is 1000m. The old outfall system comprises of four parallel pipes angled at 62 degrees to the coastline, each with a diameter of 2.5m, buried at 5m below the seabed (not visible on the surface) and spaced equally at 4.8m apart. Each pipe has a 62.4m long multiport diffuser, consisting of nine ports equally spaced at 7.5m apart, installed at the end of each outfall pipe. The multiport diffusers are arranged in two nested V shapes, and each pair diverges at an angle of 30 degrees on either side of the outfall pipeline. The two internal pipes of length 653m have its end at a depth of 9m below the mean sea level, while the other two shorter external pipes of length 582m end at a depth of 8.4m. The ports of each diffuser are oriented in an alternating way each with an angle of 20 degrees to the diffuser pipe. The port diameter is 0.7m and located at 1m above the seabed, and the ports are oriented upwards with an angle of 10 degrees against the horizontal (Purnama, 2012).

A.10 Conclusion about Desalination Plants around the World

The presented technical relevant information about intake and outfall systems from several desalination plants can be helpful to mainly design the outfall system of GCDP. The desalination plants that have been covered in this Appendix were mainly RO plants with direct offshore subsurface seawater intakes. The water depths of the seawater intake headwork were all in the order of 10 meters and the brine discharge location varied from discharge at the shoreline to 18 meters water depth. The main intake or outfall pipe diameters takes the values of 1, 1.2, 1.6, 1.8, 2.2, 2.4, 2.5, 3.7, and 4m.

APPENDIX (B)

Oceanographic and Climatological Data

To assist the design of the seawater intake and outfall systems for desalination plants, a field exploration and marine survey should be conducted. Appendix (B) provides oceanographic and climatological data from monitoring stations located in the vicinity of Gaza Strip.

B.1 Properties of Seawater`s Temperature, Salinity, and Density

MEDAR (Mediterranean Data Archeology and Rescue) gathered field measurements over more than 70 years in the South East corner of the Levantine Sea. The data provide mean measurements for the seasonal variation in seawater`s temperature and salinity. Figure (B.1) presents the changes in seawater parameters over depths of water reach to 100m.

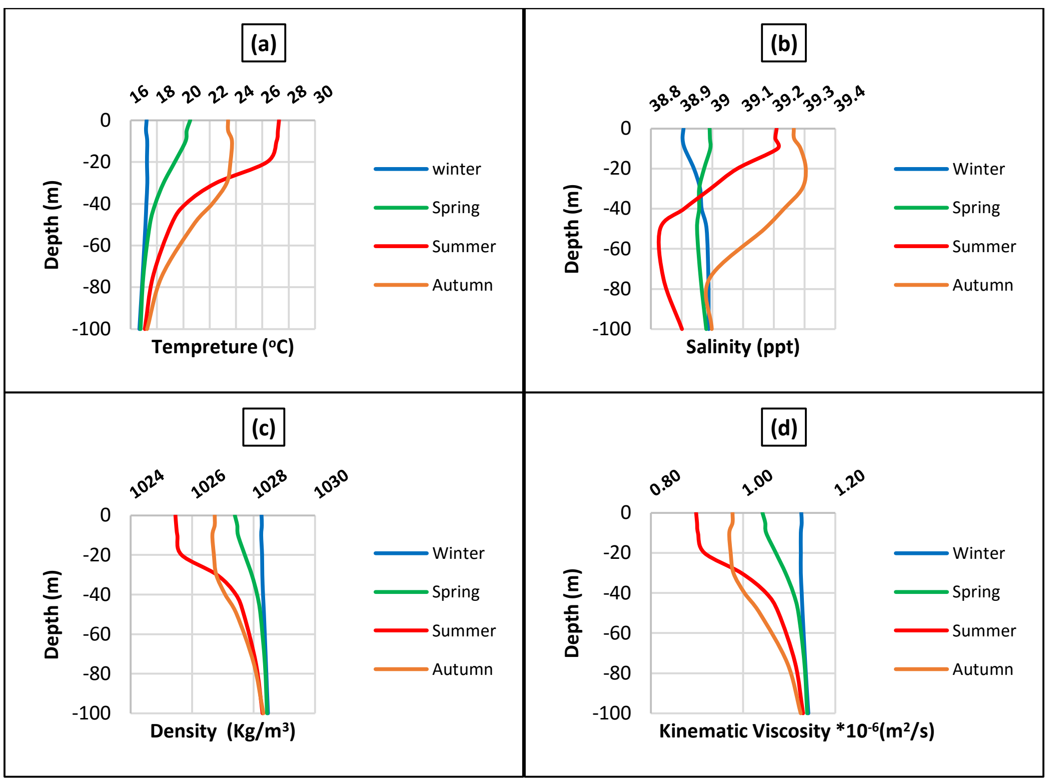

Figure (B.1): (a) average temperature of seawater (b) seawater average salinity (c) seawater average density, and (d) seawater average kinematic viscosity (modified from http://doga.ogs.trieste.it).

Figure (B.1) shows that the maximum recorded seawater temperature is 27.26^oC in summer while the minimum seawater temperature of 16.66^oC is measured in winter. Maximum salinity of 39.31ppt has been recorded in autumn and a minimum salinity of 38.83ppt has been noted in summer. According to the records the maximum seawater density of 1028.47kg/m^3 has been recorded in winter season and a minimum density of 1025.46kg/m^3 was measured in summer. Based on that and as expected the kinematic viscosity that is the ratio of density to dynamic viscosity recoded a maximum average value of $1.14*10^{-6}m^2/s$ has been measured in winter while the minimum value of $0.9*10^{-6}m^2/s$ has been observed in summer.

The Figures also show that the mean temperatures for the whole depth from 0 to 100m are around 17.11^oC, 18.56^oC, and 22.7^oC, 21.77^oC for winter, spring, summer, and autumn respectively. This indicate that the temperature is maximum in the summer season. The average seasonal salinity flocculates from 39.95ppt in winter, 38.97ppt in spring, 39.02ppt in summer, and 39.2ppt in autumn. From the view of seawater density the Figures show that the maximum average density is measured in season of winter with 1028.32kg/m^3, followed by 1027.91kg/m^3 noted in spring. In the autumn the average density reached 1027.16kg/m^3 while in the summer a seawater density of 1026.71kg/m^3 has been recorded. Seawater density in the winter is the maximum this is because that the temperature in winter is the lowest among the other seasonal temperatures. The kinematic viscosity that is the ratio of density to dynamic viscosity recoded a maximum average value of $1.13*10^{-6}m^2/s$, and a minimum average value of $0.99*10^{-6}m^2/s$ has been observed in summer.

B.2 Wind

According to the Palestinian Meteorological Authority the magnitude of wind speeds and directions representing eight days (1st , 3rd ,6th ,9th ,12th ,15th ,18th , and 21st) from each month of the year of 2007 have been summarized in Tables (B.1) and (B.2) for data from Gaza and Khanyounis metrological stations respectively.

The records show that in the 12th of February the maximum wind speed of 5m/s in the direction of 230^o has been read in Gaza metrological station, while in the 1st of April, June, and August Gaza station recorded the same minimum wind speed reading of 1.67m/s at directions of 160^o, 210^o, and 190^o for April, June, and August respectively.

In the metrological station of Khanyounis the maximum recorded wind speed was inspected in the 5th of February at a speed of 5.28m/s at a direction of 238^o. A minimum wind speed of 1.39m/s has been read in the 1st of June, July, August, and September at directions of 171^o, 160^o, 133^o, and 134^o respectively. Also the minimum wind speed has been inspected in the 3rd of June at 127^o, in the 12th of June and October at 304^o, and 168^o respectively, in the 21st of June, July, September, and October at directions of 197°, 190°, 201°, and 168° respectively.

Table (B.1): Wind speeds and directions of Gaza station (Based on data of Palestinian Meteorological Authority, 2007)

Month/Day	1st		3rd		6th		9th		12th		15th		18th		21st	
Speed/Direction	m/s	(°)	m/s	(°)	m/s	(°)	m/s	(°)	m/s	(°)	m/s	(°)	m/s	(°)	m/s	(°)
January	3.33	150	3.61	160	3.33	160	2.78	180	3.33	240	3.33	240	2.78	180	2.50	160
February	4.17	200	4.17	180	4.17	180	4.44	190	5.00	230	4.72	240	4.17	190	4.17	210
March	3.33	200	3.61	190	3.61	180	3.89	220	4.44	260	4.44	270	3.89	240	3.33	190
April	2.22	200	2.50	170	2.78	190	3.06	250	3.61	280	4.17	220	3.89	200	2.78	150
May	1.67	160	1.94	140	1.94	160	2.50	260	3.33	290	3.89	290	3.06	210	2.22	180
June	1.67	210	1.94	160	1.94	180	2.50	280	3.61	300	4.44	310	3.33	310	2.22	250
July	1.94	170	2.22	160	2.22	170	2.78	260	3.61	290	4.17	310	3.33	260	1.94	180
August	1.67	190	2.22	170	2.22	150	2.22	270	3.89	300	4.72	320	3.89	320	2.22	220
September	2.22	160	2.50	160	2.50	150	2.22	260	3.89	300	4.44	320	3.89	300	2.78	230
October	2.22	160	2.50	160	2.78	160	2.22	240	3.33	300	4.17	280	3.89	200	2.50	160
November	1.94	130	2.50	140	2.22	150	2.22	170	3.61	25	4.17	240	3.61	150	2.22	120
December	2.78	160	3.06	160	3.06	160	2.78	180	3.33	210	3.06	180	2.78	180	2.50	160

Table (B.2): Wind speeds and directions of Khanyounis station (Based on data of Palestinian Meteorological Authority, 2007)

Month/Day	1st		3rd		6th		9th		12th		15th		18th		21st	
Speed/Direction	m/s	(°)	m/s	(°)	m/s	(°)	m/s	(°)	m/s	(°)	m/s	(°)	m/s	(°)	m/s	(°)
January	2.22	135	2.5	137	2.78	140	2.78	139	1.94	184	3.61	225	2.50	251	1.94	127
February	3.33	175	3.61	172	3.61	167	4.17	170	3.06	199	5.28	238	4.17	243	3.06	178
March	2.5	169	2.78	167	3.06	157	3.33	165	2.50	210	5.00	273	3.89	276	2.50	191
April	1.94	179	2.22	158	2.5	141	3.06	157	2.50	254	4.17	279	3.33	245	2.50	161
May	1.67	158	1.94	136	1.94	147	2.78	254	1.94	306	3.89	303	2.50	229	1.94	177
June	1.39	171	1.39	127	1.67	142	2.5	264	1.39	304	3.89	319	2.50	298	1.39	197
July	1.39	160	1.67	149	2.22	160	3.33	262	1.11	290	4.17	312	3.06	315	1.39	190
August	1.39	133	1.67	147	1.94	133	2.22	269	4.17	300	3.89	315	2.22	334	1.11	222
September	1.39	134	1.94	134	1.94	134	2.50	234	2.78	260	3.61	320	2.22	306	1.39	201
October	1.67	154	1.94	139	2.22	139	2.50	173	1.39	168	3.33	308	2.22	240	1.39	168
November	1.94	123	2.22	133	2.22	133	2.50	143	1.67	111	3.06	282	1.94	212	1.67	111
December	2.5	137	2.78	139	3.06	139	3.89	150	2.50	131	3.06	205	2.22	171	2.50	131

The average wind speed and direction recorded at Gaza and Khanyounis stations for the months from January to December for the year of 2007 have been presented in Figure (B.2).

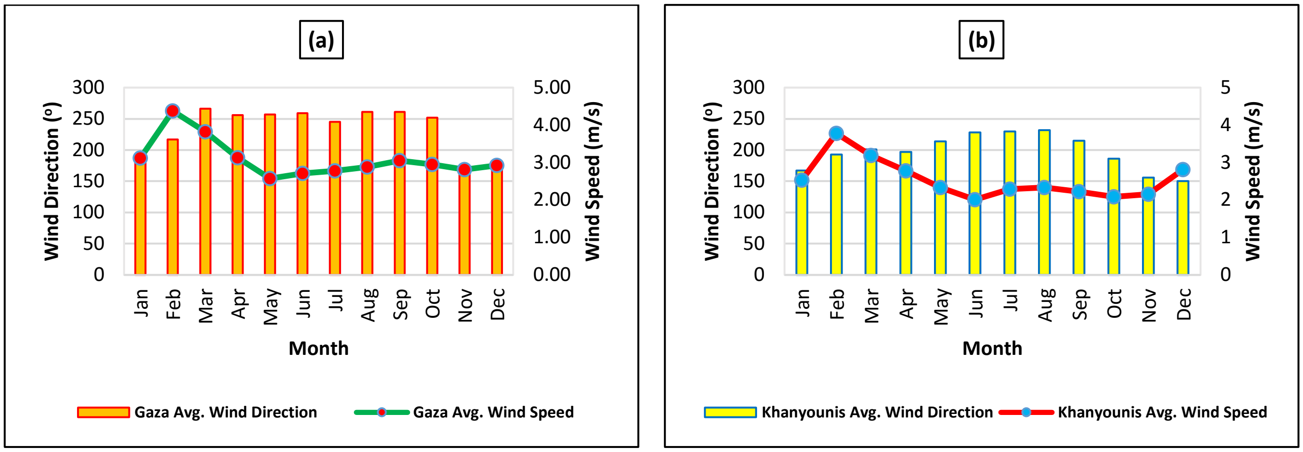

Figure (B.2): Wind speed and direction at (a) Gaza, (b) Khanyounis stations

It can be concluded from Figure (B.2) that the average wind speed of 4.38m/s in February is the maximum among other average wind speeds in another months of the year at Gaza station while the maximum average wind speed of 3.78m/s is depicted also in May in Khanyounis station. Minimum average wind speeds of 2.57m/s and 2.01m/s have been depicted for Gaza and Khanyounis stations respectively.

B.3 Oceanography of Current

Tidal currents in coast of Palestine are in general weak, in the order of about 5 cm/second. The general circulation, due mainly to the geostrophic current and shelf waves, is oriented counter clockwise most of time. The currents in most case have low speeds of about 10 cm/s. the vertical distribution is almost uniform, but decays towards the bottom in summer. The speed decreases towards the shore. In certain instances, currents of about 2 knots were measured. (Rosen, 2001).

The monthly mean current velocity from two current meters located in the center of the coast of Palestine has been measured at 18 m below the surface in water depth of 26 m for several years. The observed mean currents are directed northward, except in September when it is close to zero. Typical mean velocities are 5–10 cm/s, and there is a clear bimodal seasonal signal, with the strongest mean northward flow in February and July and the weakest northward flow in May and September (Brenner, 2003). Figure (B.3) shows the mean current velocity in coast of Palestine for a year. It is clear that the maximum mean current velocity is 0.13 m/s in February while the minimum mean current velocity is zero in September. The average yearly current velocity is 0.06m/s.

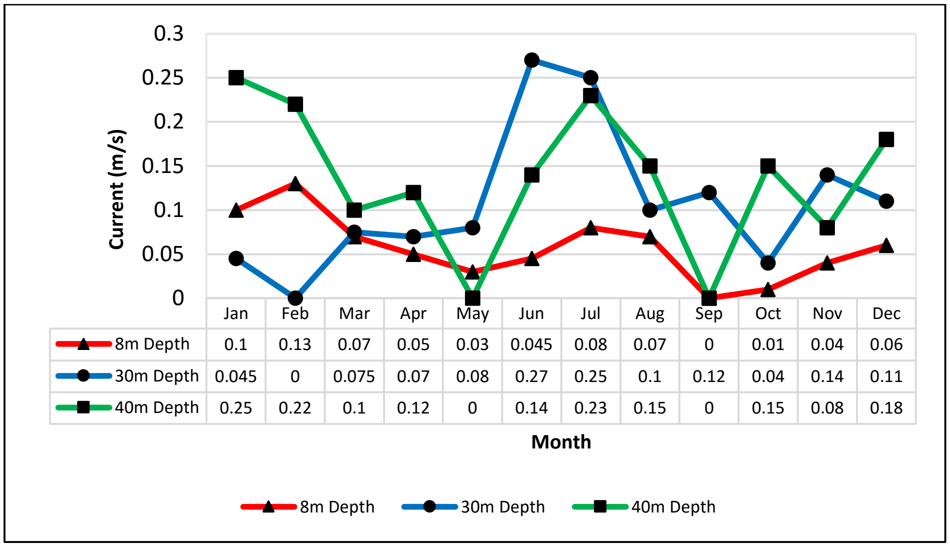

Figure (B.3): Yearly mean observed current velocity (modified: Brenner, 2003)

Menna et al. (2012) described the surface currents of the Levantine sub-basin (Mediterranean Sea) using 18 years (1992–2010) of drifter data and satellite-derived sea level anomalies. The mean field velocity depicts the well-known anticlockwise circulation around the whole basin. The eastern Levantine sub-basin is dominated by two recurrent anticyclonic eddies: the Cyprus Eddy and Shikmona Eddy.

In summer, drifter tracks depict the generation of the Shikmona Eddy as a pinched off meander from the instability of the northward current along the Palestinian-Lebanese coast (speeds of 15–20 cm/s); in the same weeks a drifter deployed south of Cyprus is captured by the Shikmona Eddy circulation and moves in the neighborhood of the eddy core. The Shikmona Eddy rotates steadily (speeds between 20 and 33 cm/s) and drifters carry out 7 full cycles around the eddy core (diameter of 100 km). In early fall 2009, drifters leave the Shikmona Eddy and are driven by the currents in southward and westward directions. In late fall 2009 and winter 2009-2010, drifters deployed along the south Palestinian coast follow an anticyclonic meander (speeds of 25-30 cm/s; diameter of 120 km), continue somewhat northward. In spring 2010, the drifter tracks follow an anticyclonic eddy, which could be identified as the Shikmona Eddy (speeds of 20–35 cm/s; diameter of 100-120 km), and a cyclonic secondary lobe (eddy core (speeds of 15–30cm/s; diameter of 80 km). The Shikmona Eddy main anticyclonic lobe reaches a bin-averaged speed of 20 cm/s, whereas the velocities of a secondary cyclonic lobe, south of the main eddy, are weaker less than 10 cm/s. The along slope current flows off the Egypt, Palestine and Lebanon coasts with mean speed of 15–20 cm/s; its velocity increases in the Cyprus–Syria Passage and in the northern Levantine sector (Cilician and Antalya basins), with mean values exceeding 25 cm/s (Menna et al., 2012).

APPENDIX (C)

Detailed Design of GCDP Brine Disposal Systems

Ocean outfalls are classified according to their location (onshore surface discharges / offshore submerged discharges), their mixing features (single port / multiport) and their effluent characteristics (positively buoyant, or negatively buoyant). Onshore surface discharges have traditionally been installed due to their low costs. However, such discharges should be analyzed carefully and generally be avoided due to their limited mixing characteristics, high visibility, their need for large scale coastal constructions, and thus generally larger impacts. Shoreline discharges may cause shoreline impacts by causing high concentrations accumulating in the near-shore region due to the limited mixing characteristics of these discharges. Further direct impacts are caused by the often necessary large scale discharge and protection structures (wave protection, stilling basins, etc.), and their effect on coastal currents and sediment transport characteristics. Therefore, it is recommended to apply modern efficient mixing devices, which overcome the limitations of the traditional surface onshore discharges. Such single or multiport submerged diffuser systems are characterized by their flexible location and their high mixing rates. These discharge technologies follow two main principles, aiming for enhanced effluent dispersion in the receiving environment and providing an adequate discharge siting to avoid pollutant accumulation, to protect sensitive regions and to utilize natural purification processes (Bleninger and Bleninger, 2010).

This Appendix contains the design geometries for the onshore surface open channels, the offshore submerged single port diffusers, and the offshore submerged multiport diffusers that were employed in this research.

C.1 Configuration Design of the Onshore Disposal System

One of the brine disposal scenarios for the produced brine from GCDP studies the simulation of the brine dispersion in the case of surface (onshore) discharge. The general design configuration for the brine disposal system of GCDP is mainly based on a submerged multiport diffuser system. In order to put in our hands a model for the onshore discharge it is obvious to provide a specific design for the surface disposal system.

In Ashkelon, the RO negatively buoyant brine is discharged through an open channel, Figure (C.1), at the coast into the Mediterranean (Einav and Lokiec, 2003).

Figure (C.1): Ashkelon`s onshore open channel disposal system

Kish Island (Iran) Seawater Desalination Plant discharges the returned water (brine) through one open surface channel with 2m width, 1.5m depth and 30m length. The discharge of outflow is 10929.6m^3/h and its salt concentration is 1540 mg/l higher than the intake water concentration (36800mg/l). Water depth in outfall position is 2.5m (Vaselali, A., and Vaselali, M., 2009). Moreover a surface open channel with a width of 4m and a depth of 0.3m discharges brine with a flow rate of 12m^3/s at a discharge depth of 0.5m is used in Al-Ghubrah Desalination Plant in Oman (Purnama, 2012).

Figure (C.2): Surface Open Channel Locations of Al-Ghubrah Plant, Oman (Purnama, 2012)

In this study, the modelling of the onshore disposal for the negatively buoyant brine that produced form GCDP has been stand on the discharging through an open channel at the coast into the Mediterranean. For that it is urgent to prepare a hydraulic design for that channel to accommodate the brine produces from Phase (I) in the primarily stage and to accommodate the total quantity of brine produces from Phase (II).

According to manning formula for uniform flow, the open channel design can be summarized in the following equations (Hwang and Houghtalen, 1996).

$$\mathbf{v = \frac{1}{n} . R_h^{\frac{2}{3}} . S_e^{\frac{1}{2}}} \qquad (\mathbf{C.1})$$

$$\mathbf{Q = \frac{1}{n} A . R_h^{\frac{2}{3}} . S_e^{\frac{1}{2}}} \qquad (\mathbf{C.2})$$

Where, v: flow velocity (m/s), Q: flow rate (m^3/s), n: manning`s coefficient of the channel roughness, A: water area (m^2), R_h: hydraulic radius (m), and S_e: channel slope (m/m).

The design of an open channel subjects to specific considerations. The Road Design Drainage Technical Subcommittee (2013) specified a slope of 0.3% may be regarded as the minimum practical slope for construction and it is recommended that design achieves a Froude Number less than 0.9 (subcritical flow).

The maximum permissible velocity is not usually a consideration in the design of rigid boundary channels if the flow does not carry large amounts of sediments. However, if the sediment load is large, then flow velocities should not be too high to avoid erosion of the channel. The minimum flow velocity should be such that sediment is not deposited, aquatic growth is inhibited, and sulfide formation does not occur. The lower limit for the minimum velocity depends upon the practical size and the specific gravity of sediments carried in the flow. The channel size does not have significant effect on the lower limit. Generally, the minimum velocity in a channel is about 0.6 to 0.9 m/s. flow velocities of 12 m/s have been found to be acceptable in concrete channel if the water is not carrying large concentrations of sediment (Chaudhry, 2008). The maximum permissible velocities refer to the velocities that can be safely allowed in the channel without causing scour or erosion of the channel material. A permissible maximum velocity of 6 m/s can safely be adopted for concrete material channel (Subramanya, 2009). The Code of Federal Regulations (1994) specified that the maximum and minimum velocities for the concrete open channels are 25 feet/s and 3 feet/s respectively.

Since the hydraulic design of the surface open channel is affected by the changes in the parameters of channel width and slope at a specified flow rate. Many designs were conducted by varying one parameter at a time while keeping the other input parameters constant. The rejected brine from GCDP is disposed at a flow rate of 12,200m^3/h (3.39m^3/s) in the Phase (I) while in long term when operating Phase (II) the brine flow rate will reach 24,400m^3/h (6.78m^3/s), from Phases (I) and (II) together.

C.1.1 Open Channel`s Hydraulic Design for Phase (I) of GCDP

In this case the brine quantity that disposes from GCDP is 12,200m^3/h from Phase (I) only. Table (C.1) summarizes the open channel`s design scenarios over several channel widths, and slopes.

Table (C.1): Hydraulic design scenarios for the surface open channel in the case of brine flow rate of, 12,200 m^3/h, Phase (I).

Width (m)	Slope (%)	Depth (m)	Velocity (m/s)	Depth /Width	Froude No. (Fr)	Friction Factor	Width (m)	Slope (%)	Depth (m)	Velocity (m/s)	Depth /Width	Froude No. (Fr)	Friction Factor
0.5	0.3	4.21	1.61	8.428	0.25	0.0223	3.5	0.3	0.45	2.13	0.130	1.01	0.02
	0.975	2.40	2.82	4.806	0.58	0.0227		0.975	0.31	3.12	0.089	1.79	0.0217
	1.65	1.88	3.61	3.758	0.84	0.0227		1.65	0.26	3.69	0.075	2.30	0.0223
	2.325	1.60	4.23	3.208	1.07	0.0227		2.325	0.24	4.11	0.067	2.71	0.0233
	3	1.43	4.75	2.856	1.27	0.0233		3	0.22	4.46	0.062	3.05	0.0237
1	0.3	1.54	2.20	1.540	0.57	0.02	4	0.3	0.41	2.06	0.103	1.02	0.0205
	0.975	0.94	3.60	0.941	1.19	0.0205		0.975	0.28	3.00	0.071	1.80	0.022
	1.65	0.76	4.45	0.762	1.63	0.021		1.65	0.24	3.54	0.060	2.31	0.0233
	2.325	0.67	5.09	0.666	1.99	0.0213		2.325	0.22	3.94	0.054	2.71	0.0237
	3	0.60	5.61	0.604	2.31	0.0217		3	0.20	4.26	0.050	3.05	0.0243
1.5	0.3	0.96	2.36	0.637	0.77	0.0195	4.5	0.3	0.38	1.99	0.084	1.03	0.021
	0.975	0.61	3.68	0.409	1.50	0.0205		0.975	0.26	2.88	0.058	1.80	0.0223
	1.65	0.51	4.45	0.338	2.00	0.021		1.65	0.22	3.40	0.049	2.31	0.0237
	2.325	0.45	5.03	0.299	2.40	0.0213		2.325	0.20	3.78	0.044	2.70	0.024
	3	0.41	5.50	0.274	2.74	0.0217		3	0.18	4.09	0.041	3.04	0.0247
2	0.3	0.72	2.36	0.360	0.89	0.0195	5	0.3	0.35	1.92	0.070	1.04	0.021
	0.975	0.47	3.57	0.237	1.65	0.021		0.975	0.24	2.78	0.049	1.80	0.0227
	1.65	0.40	4.27	0.198	2.16	0.0213		1.65	0.21	3.28	0.041	2.30	0.024
	2.325	0.35	4.79	0.177	2.57	0.0217		2.325	0.19	3.64	0.037	2.70	0.0247
	3	0.32	5.22	0.162	2.92	0.022		3	0.17	3.94	0.034	3.03	0.025
2.5	0.3	0.59	2.29	0.237	0.95	0.0195	5.5	0.3	0.33	1.87	0.060	1.04	0.0213
	0.975	0.40	3.41	0.159	1.73	0.021		0.975	0.23	2.69	0.042	1.80	0.0233
	1.65	0.33	4.06	0.134	2.24	0.0217		1.65	0.19	3.17	0.035	2.29	0.0243
	2.325	0.30	4.54	0.119	2.65	0.0223		2.325	0.18	3.52	0.032	2.69	0.025
	3	0.27	4.93	0.110	3.00	0.0227		3	0.16	3.81	0.029	3.02	0.0258
3	0.3	0.51	2.21	0.170	0.99	0.02	6	0.3	0.31	1.81	0.052	1.04	0.0213
	0.975	0.35	3.26	0.115	1.77	0.0213		0.975	0.22	2.61	0.036	1.79	0.0237
	1.65	0.29	3.87	0.097	2.28	0.022		1.65	0.18	3.07	0.031	2.29	0.0247
	2.325	0.26	4.31	0.087	2.69	0.0227		2.325	0.17	3.41	0.028	2.68	0.0254
	3	0.24	4.68	0.081	3.04	0.0233		3	0.15	3.69	0.026	3.01	0.0262
							6.5	0.3	0.30	1.76	0.045	1.04	0.0217
								0.975	0.21	2.54	0.032	1.79	0.0237
								1.65	0.17	2.98	0.027	2.28	0.025
								2.325	0.16	3.31	0.024	2.67	0.0258
								3	0.15	3.58	0.022	3.00	0.0266

C.1.2 Open Channel`s Hydraulic Design for Phase (II) of GCDP

As the Phase (II) is operated beside Phase (I), the brine quantity that is disposed from GCDP is 24,400m^3/h from Phase (II). Table (C.2) summarizes the open channel`s design scenarios over several channel widths, and slopes in the case of Phase (II).

Table (C.2): Hydraulic design scenarios for the surface open channel in the case of brine flow rate of, 24,400 m^3/h, Phase (II).

Width (m)	Slope (%)	Depth (m)	Velocity (m/s)	Depth /Width	Froude No. (Fr)	Friction Factor	Width (m)	Slope (%)	Depth (m)	Velocity (m/s)	Depth /Width	Froude No. (Fr)	Friction Factor
0.5	0.3	8.27	1.64	16.546	0.18	0.022	3.5	0.3	0.72	2.69	0.206	1.01	0.0185
	0.975	4.66	2.91	9.317	0.43	0.0223		0.975	0.49	3.99	0.139	1.83	0.02
	1.65	3.62	3.75	7.232	0.63	0.0223		1.65	0.41	4.73	0.117	2.36	0.0205
	2.325	3.07	4.42	6.139	0.81	0.0223		2.325	0.37	5.29	0.105	2.79	0.021
	3	2.72	4.99	5.439	0.97	0.0223		3	0.34	5.74	0.096	3.16	0.0213
1	0.3	2.85	2.38	2.846	0.45	0.0195	4	0.3	0.65	2.62	0.162	1.04	0.019
	0.975	1.68	4.02	1.685	0.99	0.02		0.975	0.44	3.85	0.110	1.85	0.02
	1.65	1.34	5.04	1.345	1.39	0.02		1.65	0.37	4.56	0.093	2.39	0.021
	2.325	1.16	5.82	1.164	1.72	0.0205		2.325	0.33	5.09	0.083	2.81	0.0213
	3	1.05	6.47	1.048	2.02	0.0205		3	0.31	5.52	0.077	3.18	0.0217
1.5	0.3	1.67	2.71	1.110	0.67	0.0185	4.5	0.3	0.59	2.54	0.132	1.05	0.019
	0.975	1.04	4.36	0.691	1.37	0.0195		0.975	0.40	3.72	0.090	1.87	0.0205
	1.65	0.85	5.34	0.564	1.85	0.0195		1.65	0.34	4.40	0.076	2.40	0.0213
	2.325	0.74	6.08	0.496	2.25	0.02		2.325	0.31	4.90	0.068	2.82	0.0217
	3	0.68	6.69	0.451	2.60	0.0205		3	0.28	5.31	0.063	3.19	0.022
2	0.3	1.20	2.82	0.602	0.82	0.0185	5	0.3	0.55	2.47	0.110	1.07	0.019
	0.975	0.78	4.37	0.388	1.59	0.0195		0.975	0.38	3.60	0.075	1.88	0.0205
	1.65	0.64	5.28	0.321	2.11	0.02		1.65	0.32	4.26	0.064	2.41	0.0213
	2.325	0.57	5.96	0.284	2.52	0.02		2.325	0.29	4.74	0.057	2.83	0.022
	3	0.52	6.52	0.260	2.89	0.0205		3	0.26	5.13	0.053	3.19	0.0223
2.5	0.3	0.97	2.81	0.386	0.91	0.0185	5.5	0.3	0.51	2.41	0.093	1.07	0.0195
	0.975	0.64	4.27	0.254	1.71	0.0195		0.975	0.35	3.50	0.064	1.88	0.021
	1.65	0.53	5.11	0.212	2.24	0.02		1.65	0.30	4.12	0.054	2.41	0.0217
	2.325	0.47	5.74	0.189	2.67	0.0205		2.325	0.27	4.59	0.049	2.83	0.022
	3	0.43	6.26	0.173	3.03	0.021		3	0.25	4.97	0.045	3.18	0.0223
3	0.3	0.82	2.76	0.273	0.97	0.0185	6	0.3	0.48	2.34	0.080	1.08	0.0195
	0.975	0.55	4.13	0.182	1.78	0.0195		0.975	0.33	3.40	0.055	1.88	0.0213
	1.65	0.46	4.92	0.153	2.32	0.0205		1.65	0.28	4.00	0.047	2.41	0.022
	2.325	0.41	5.51	0.137	2.75	0.021		2.325	0.25	4.45	0.042	2.82	0.0223
	3	0.38	5.99	0.126	3.11	0.021		3	0.23	4.82	0.039	3.18	0.0227
							6.5	0.3	0.46	2.29	0.070	1.08	0.0195
								0.975	0.32	3.31	0.049	1.88	0.0213
								1.65	0.27	3.89	0.041	2.40	0.022
								2.325	0.24	4.33	0.037	2.82	0.0227
								3	0.22	4.68	0.034	3.17	0.0233

C.2 Configuration Design of the Offshore Disposal Systems

Designing a submerged discharge system is mainly concerned in the design of the diffuser section and the disposal main pipe. The diffuser section of any submerged jetting disposal system can mainly be divided into single port or multiport diffuser.

The design of the diffuser section is mainly related to the design of the risers and the ports (nozzles) that capped them. The design of diffuser section can be done by achieving determinants and recommendations for discharge angle (port orientation), port diameter, Froude Number (F_r), and Reynolds number (R_e). These determinants and recommendations were specified by Jirka (2008) for improving discharge configuration for brine effluents from desalination plants.

A. Discharge Angle

Jirka (2008) specified an acceptable range for the orientation angle of the port in order to getting a trajectory jetting discharge, the angle of the ports should be between $0^o \leq \theta_o \leq 90^o$ to the horizontal. While Christodoulou et al. (n.d) stated that the practical range for the port angle is between 30^o and 75^o.

B. Froude Number

The Froude Number, F_r, is an index of the ratio of the force due to the acceleration of a fluid particle (inertial force) to the force due to gravity (weight). The Froude number, F_r, is expressed as follow (Young et al., 2011):

$$\mathbf{F_r} = \frac{\mathbf{u_o}}{\sqrt{|\mathbf{g'_o}|.\,\mathbf{D}}} \qquad (\mathbf{C.3})$$

In the case of pipe flow, D is the pipe diameter, u_o is the mean velocity, and $g_o{}'$ is the buoyant acceleration.

The Froude number, F_r, for the port, equation (C.3), must at least be equal to 10. Moreover it is recommend that the Froude number be more than 20 (Jirka, 2008).

C. Reynolds Number

At the end of 19th century the British engineer Osborne Reynolds performed a very carefully pipe flow experiment to specify the parameters that contribute in the transition from laminar to turbulent flow in a pipe. Reynolds found that the flow velocity, pipe diameter, and the fluid viscosity actually affect the flow transition from laminar to turbulent flow. The relationship can be described by the ratio of the inertial force to viscous force in the pipe. The ratio is commonly known as the *Reynolds number*, N_R, and it can be expressed as follow (Hwang and Houghtalen, 1996):

$$\mathbf{N_R = \frac{DV}{\nu}} \qquad (\mathbf{C.4})$$

In the case of pipe flow, D is the pipe diameter, V is the mean velocity, and ν is the kinematic viscosity of the fluid.

Flow can be classified into three types according to N_R, laminar, transition, and turbulent flow. For Reynolds number N_R less than 2100 the flow classified as laminar, the transition flow type is considered for N_R between 2100 and 4000, while for N_R more than 4000 the flow is classified as turbulent (Dhaubhadel, 2000).

D. Port Spacing

Comprehensive laboratory experiments on multiport diffusers for dense effluents such as brine reported that the effect of port spacing is described by (Abessi and Roberts, 2014):

$$\mathbf{\frac{S}{D.F_r}} \qquad (\mathbf{C.5})$$

Where S is the port spacing, D the nozzle diameter, and F_r the jet Froude number.

For S/ $(D.F_r) > 2$, the jets don`t merge, and the results followed expected asymptotic solutions for single jets. While for S/ $(D.F_r) < 2$ the jets merged, but don`t follow expected asymptotic line source solutions. As the port spacing was reduced, the rise height and other geometrical variables decreased and the dilutions also decreased. These were caused by Coanda effects and merging. The Coanda effect caused an under pressure on the interior jet surfaces which caused them to curve more sharply inwards. This shortened their trajectories, reducing the external surface area available for entrainment. Jet merging restricted entrainment of clear water to the inner surfaces and exacerbated the Coanda effect. To prevent reduction in dilution attributable to restricted entrainment, it is recommended to maintain adequate port spacing so that S/ ($D.F_r$) be more than 2.

E. Port Height

It is recommended that the height of ports either in the case of single port diffuser or multiport diffuser to be in the range between 0.5 and 1 m above the bottom of seabed (Bleninger et al., 2009)

F. Discharging Velocity and Diameter

The discharge calculator recommended that the discharge velocity to be in the range of 4 to 6 m/s. CORMIX recommended that the discharge velocity should be less than 2.5 m/s in order to avoid possible adverse conditions for sensitive fish populations. Purnuma (2015) stated that there are no specific regulations specify limits for the discharge velocity.

Design flows must be discharged satisfactorily through the ports to ensure continuity of flow. Generally, the total cross-sectional areas of the ports should be less than 0.7 times the cross sectional area of the main pipe at any point in the diffuser. A port diameter of less than 75 mm is susceptible to blockage (Le Roux, 2010). A port diameter range between 0.1 and 1m are required in the discharge calculator sheet.

G. Design of the Pressure Lines

The optimization of the pressure pipe diameter depends on the present and future flow conditions and available or practical head (pump). The design should ensure that a pressure pipe velocity of greater or equal to 0.7 m/s is maintained to prevent deposition of solids and provide scouring abilities. However, based on regular monitoring at South African abalone farms, it was concluded that no marine growth will occur inside pipelines with flow velocities of 3 m/s. (Le Roux, 2010).

C.2.1 Design of the Main (Feeder) Pipe

In GCDP and to minimize the construction, installations, and maintenance costs one main pipe in the brine disposal system will be constructed to accommodate the brine stream produced from Phase (I) in the short term and that produced from Phase (II) in the long term case.

In the short term when Phase (I) in operation the main pipe will carry the brine at a flow rate of 12,200m^3/h (3.39m^3/s) while in operating the desalination plant in its full capacity the main pipe should accommodate brine stream with a flow rate of 24,400m^3/h (6.78m^3/s) produced from Phase (II).

It is insist to maintain a velocity not less than 0.7m/s inside the pipe to prevent deposition of solids and provide scouring abilities more. Figure (C.3) depicts the relation between pipe diameters and velocities for Phase (I) and Phase (II) brine flow rates.

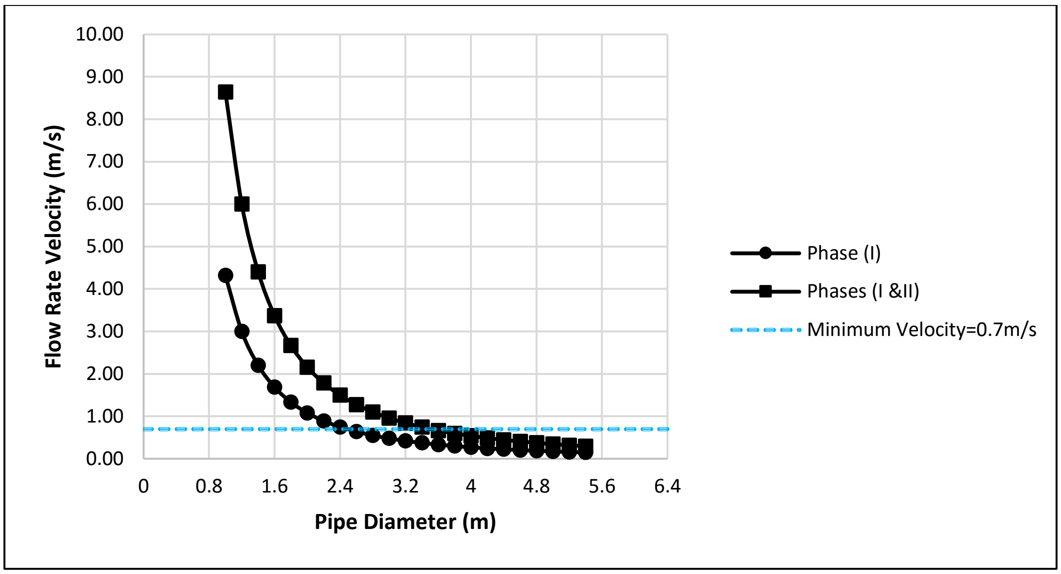

Figure (C.2): Pipe diameters vs. pipe flow velocities for Phase (I) and Phase (II).

The chosen pipe diameter for GCDP was selected as <u>1.6m</u>. The brine flow rate velocity when Phase (I) in operation is 1.69m/s, while in operating Phase (II) together the velocity inside the pipe will reach 3.37m/s. In the long term the velocity of 3.37m/s can prevent marine growth inside pipeline.

In Perth seawater desalination plant the main pipe diameter of the brine outfall system is 1.6m from GRP material. Moreover the velocity of greater than 3m/s is applicable in South Africa to prevent marine growth inside the pipe (Le Roux, 2010).

C.2.2 Design of Single Port Diffuser

Selecting the suitable diameters range for a single port diffuser are mainly related to the design criteria stated previously. The design criteria for the diffuser section specified that the Froude number should not be less than 10, beside that the minimum Reynold number should be not less than 4000. Table (C.3) demonstrates the relation between a range of port`s diameters and their Froude and Reynold numbers in the case of Phase (I).

Table (C.3): Design of Single Port Diffuser for Phase (I)

Diameter (m)	Velocity (m/s)	Winter		Spring		Summer		Autumn	
		F_r No.	R_e No.	F_r No.	R_e No.	F_r No.	R_e No.	F_r No.	R_e No.
0.1	431.85	3458.43	36910011	3459.10	39619003	3458.10	46186859	3450.58	42757142
0.15	191.93	1255.02	24606674	1255.26	26412669	1254.90	30791239	1252.17	28504761
0.2	107.96	611.37	18455006	611.49	19809502	611.31	23093430	609.98	21378571
0.25	69.10	349.97	14764005	350.04	15847601	349.93	18474744	349.17	17102857
0.3	47.98	221.86	12303337	221.90	13206334	221.84	15395620	221.36	14252381
0.35	35.25	150.91	10545718	150.94	11319715	150.89	13196245	150.56	12216326
0.4	26.99	108.08	9227503	108.10	9904751	108.07	11546715	107.83	10689285
0.45	21.33	80.51	8202225	80.53	8804223	80.50	10263746	80.33	9501587
0.5	17.27	61.87	7382002	61.88	7923801	61.86	9237372	61.73	8551428
0.55	14.28	48.75	6710911	48.76	7203455	48.75	8397611	48.64	7774026
0.6	12.00	39.22	6151669	39.23	6603167	39.22	7697810	39.13	7126190
0.65	10.22	32.11	5678463	32.11	6095231	32.10	7105671	32.03	6578022
0.7	8.81	26.68	5272859	26.68	5659858	26.67	6598123	26.62	6108163
0.75	7.68	22.45	4921335	22.45	5282534	22.45	6158248	22.40	5700952
0.8	6.75	19.11	4613751	19.11	4952375	19.10	5773357	19.06	5344643
0.85	5.98	16.42	4342354	16.42	4661059	16.42	5433748	16.38	5030252
0.9	5.33	14.23	4101112	14.23	4402111	14.23	5131873	14.20	4750794
0.95	4.79	12.43	3885264	12.44	4170421	12.43	4861775	12.40	4500752
1	4.32	10.94	3691001	10.94	3961900	10.94	4618686	10.91	4275714
1.05	3.92	9.68	3515239	9.68	3773238	9.68	4398748	9.66	4072109
1.1	3.57	8.62	3355456	8.62	3601728	8.62	4198805	8.60	3887013
1.15	3.27	7.71	3209566	7.71	3445131	7.71	4016249	7.69	3718012
1.2	3.00	6.93	3075834	6.93	3301584	6.93	3848905	6.92	3563095
1.25	2.76	6.26	2952801	6.26	3169520	6.26	3694949	6.25	3420571
1.3	2.56	5.68	2839232	5.68	3047616	5.68	3552835	5.66	3289011
1.35	2.37	5.16	2734075	5.17	2934741	5.16	3421249	5.15	3167196
1.4	2.20	4.72	2636429	4.72	2829929	4.72	3299061	4.71	3054082
1.45	2.05	4.32	2545518	4.32	2732345	4.32	3185301	4.31	2948768
1.5	1.92	3.97	2460667	3.97	2641267	3.97	3079124	3.96	2850476
1.55	1.80	3.66	2381291	3.66	2556065	3.66	2979797	3.65	2758525
1.6	1.69	3.38	2306876	3.38	2476188	3.38	2886679	3.37	2672321

Table (C.4) provides designs for a single port diffuser in the case of brine quantity of 24,400m^3/h produced form Phase (II).

Table (C.4): Design of single port diffuser for Phase (II)

Diameter (m)	Velocity (m/s)	Winter		Spring		Summer		Autumn	
		F_r No.	R_e No.	F_r No.	R_e No.	F_r No.	R_e No.	F_r No.	R_e No.
0.1	863.69	6916.86	73820023	6918.19	79238006	6916.20	92373718	6901.17	85514284
0.15	383.86	2510.04	49213349	2510.53	52825337	2509.80	61582479	2504.35	57009523
0.2	215.92	1222.74	36910011	1222.98	39619003	1222.62	46186859	1219.97	42757142
0.25	138.19	699.94	29528009	700.07	31695202	699.87	36949487	698.35	34205714
0.3	95.97	443.72	24606674	443.80	26412669	443.67	30791239	442.71	28504761
0.35	70.51	301.81	21091435	301.87	22639430	301.78	26392491	301.13	24432653
0.4	53.98	216.15	18455006	216.19	19809502	216.13	23093430	215.66	21378571
0.45	42.65	161.02	16404450	161.05	17608446	161.00	20527493	160.65	19003174
0.5	34.55	123.73	14764005	123.76	15847601	123.72	18474744	123.45	17102857
0.55	28.55	97.50	13421822	97.52	14406910	97.49	16795222	97.28	15548052
0.6	23.99	78.44	12303337	78.45	13206334	78.43	15395620	78.26	14252381
0.65	20.44	64.21	11356927	64.23	12190462	64.21	14211341	64.07	13156044
0.7	17.63	53.35	10545718	53.36	11319715	53.35	13196245	53.23	12216326
0.75	15.35	44.90	9842670	44.91	10565067	44.90	12316496	44.80	11401905
0.8	13.50	38.21	9227503	38.22	9904751	38.21	11546715	38.12	10689285
0.85	11.95	32.84	8684709	32.84	9322118	32.83	10867496	32.76	10060504
0.9	10.66	28.46	8202225	28.47	8804223	28.46	10263746	28.40	9501587
0.95	9.57	24.87	7770529	24.87	8340843	24.86	9723549	24.81	9001504
1	8.64	21.87	7382002	21.88	7923801	21.87	9237372	21.82	8551428
1.05	7.83	19.36	7030478	19.37	7546477	19.36	8797497	19.32	8144218
1.1	7.14	17.24	6710911	17.24	7203455	17.23	8397611	17.20	7774026
1.15	6.53	15.42	6419132	15.43	6890261	15.42	8032497	15.39	7436025
1.2	6.00	13.87	6151669	13.87	6603167	13.86	7697810	13.83	7126190
1.25	5.53	12.52	5905602	12.52	6339040	12.52	7389897	12.49	6841143
1.3	5.11	11.35	5678463	11.35	6095231	11.35	7105671	11.33	6578022
1.35	4.74	10.33	5468150	10.33	5869482	10.33	6842498	10.31	6334391
1.4	4.41	9.43	5272859	9.43	5659858	9.43	6598123	9.41	6108163
1.45	4.11	8.64	5091036	8.64	5464690	8.64	6370601	8.62	5897537
1.5	3.84	7.94	4921335	7.94	5282534	7.94	6158248	7.92	5700952
1.55	3.59	7.31	4762582	7.31	5112129	7.31	5959595	7.30	5517051
1.6	3.37	6.75	4613751	6.76	4952375	6.75	5773357	6.74	5344643

In order to keep a minimum value of 10 for Froude number a maximum port diameter of 1m should not exceeded in the case of Phase (I) and Phase (II). A range of port diameters of [0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1m] were selected to study the sensitivity analysis of port diameter on the brine dilution process. The discharging velocity is confined between 4.32 and 8.64m/s in the case of Phase (I), while in the case of Phase (II) the velocity is range between 26.99 and 53.98m/s.

The selected port diameters have Froude numbers above 10, moreover the Reynold numbers for these diameters are more than 4000.

The angle of the port orientation was specified as 50^o as specified by the general description of the disposal system for GCDP. Moreover the chosen port height above seabed is 0.75m.

C.2.3 Design of Multiport Diffuser

In this research the design for the multiport diffuser is mainly based on the general description given to GCDP`s brine disposal system. The general configuration for the brine disposal system of GCDP consists of a main discharge pipe which terminates in a diffuser section consisting of four risers (vertical shafts), each vertical shaft equipped by a turret that has four discharge ports (nozzles) spaced evenly around its circumference. Table (C.5) demonstrates the relation between a range of port`s diameters and their Froude and Reynold numbers in the case of Phase (I).

Table (C.5): Design of multiport port diffuser for Phase (I)

Diameter (m)	**Velocity (m/s)**	**Winter**		**Spring**		**Summer**		**Autumn**	
		F_r No.	R_e No.	F_r No.	R_e No.	F_r No.	R_e No.	F_r No.	R_e No.
0.1	26.99	216.15	2306876	216.19	2476188	216.13	2886679	215.66	2672321
0.15	12.00	78.44	1537917	78.45	1650792	78.43	1924452	78.26	1781548
0.2	6.75	38.21	1153438	38.22	1238094	38.21	1443339	38.12	1336161
0.25	4.32	21.87	922750.3	21.88	990475.1	21.87	1154671	21.82	1068929
0.3	3.00	13.87	768958.6	13.87	825395.9	13.86	962226.2	13.83	890773.8
0.35	2.20	9.43	659107.3	9.43	707482.2	9.43	824765.3	9.41	763520.4
0.4	1.69	6.75	576718.9	6.76	619046.9	6.75	721669.7	6.74	668080.3
0.45	1.33	5.03	512639	5.03	550263.9	5.03	641484.2	5.02	593849.2
0.5	1.08	3.87	461375.1	3.87	495237.5	3.87	577335.7	3.86	534464.3
0.55	0.89	3.05	419431.9	3.05	450215.9	3.05	524850.7	3.04	485876.6
0.6	0.75	2.45	384479.3	2.45	412697.9	2.45	481113.1	2.45	445386.9
0.65	0.64	2.01	354904	2.01	380952	2.01	444104.4	2.00	411126.4
0.7	0.55	1.67	329553.7	1.67	353741.1	1.67	412382.7	1.66	381760.2
0.75	0.48	1.40	307583.4	1.40	330158.4	1.40	384890.5	1.40	356309.5
0.8	0.42	1.19	288359.5	1.19	309523.5	1.19	360834.8	1.19	334040.2
0.85	0.37	1.03	271397.1	1.03	291316.2	1.03	339609.3	1.02	314390.7
0.9	0.33	0.89	256319.5	0.89	275132	0.89	320742.1	0.89	296924.6
0.95	0.30	0.78	242829	0.78	260651.3	0.78	303860.9	0.78	281297
1	0.27	0.68	230687.6	0.68	247618.8	0.68	288667.9	0.68	267232.1

Table (C.6) provides designs for a multiport port diffuser in the case of brine quantity of 24,400m^3/h produced form Phase (II).

Table (C.6): Design of multiport diffuser for Phase (II)

Diameter (m)	Velocity (m/s)	Winter		Spring		Summer		Autumn	
		F_r No.	R_e No.	F_r No.	R_e No.	F_r No.	R_e No.	F_r No.	R_e No.
0.1	53.98	432.30	4613751	432.39	4952375	432.26	5773357	431.32	5344643
0.15	23.99	156.88	3075834	156.91	3301584	156.86	3848905	156.52	3563095
0.2	13.50	76.42	2306876	76.44	2476188	76.41	2886679	76.25	2672321
0.25	8.64	43.75	1845501	43.75	1980950	43.74	2309343	43.65	2137857
0.3	6.00	27.73	1537917	27.74	1650792	27.73	1924452	27.67	1781548
0.35	4.41	18.86	1318215	18.87	1414964	18.86	1649531	18.82	1527041
0.4	3.37	13.51	1153438	13.51	1238094	13.51	1443339	13.48	1336161
0.45	2.67	10.06	1025278	10.07	1100528	10.06	1282968	10.04	1187698
0.5	2.16	7.73	922750.3	7.73	990475.1	7.73	1154671	7.72	1068929
0.55	1.78	6.09	838863.9	6.09	900431.9	6.09	1049701	6.08	971753.2
0.6	1.50	4.90	768958.6	4.90	825395.9	4.90	962226.2	4.89	890773.8
0.65	1.28	4.01	709807.9	4.01	761903.9	4.01	888208.8	4.00	822252.7
0.7	1.10	3.33	659107.3	3.34	707482.2	3.33	824765.3	3.33	763520.4
0.75	0.96	2.81	615166.9	2.81	660316.7	2.81	769781	2.80	712619
0.8	0.84	2.39	576718.9	2.39	619046.9	2.39	721669.7	2.38	668080.3
0.85	0.75	2.05	542794.3	2.05	582632.4	2.05	679218.5	2.05	628781.5
0.9	0.67	1.78	512639	1.78	550263.9	1.78	641484.2	1.77	593849.2
0.95	0.60	1.55	485658	1.55	521302.7	1.55	607721.8	1.55	562594
1	0.54	1.37	461375.1	1.37	495237.5	1.37	577335.7	1.36	534464.3

The design should keep a minimum Froude number value of 10. So in the case of multiport diffuser it is urgent to take into consideration that the Froude number is above 10 in the case of Phase (I) and in the other case of Phase (II).

The applicable range for port diameters that specify the condition in the two cases is [0.1, 0.15, 0.2, 0.25, and 0.3]. The selected port diameters have Froude numbers above 10, and the Reynold numbers for these diameters are more than 4000.

The angle of the port orientation was also specified as 50^{o} as specified by the general description of the disposal system for GCDP. Moreover the chosen port height above seabed is 0.75m.

In order to avoid possible adverse conditions for sensitive fish populations it is recommended to specify a discharging velocities as less as possible, in this study the most applicable port diameter of 0.3m that achieves the least applicable velocity was selected to the multiport diffuser system, where the discharging velocities are 3m/s in Phase (I) and 6m/s in Phase (II).

APPENDIX (D)

Detailed Results Analysis

This appendix provides a detailed presentation for the simulations and sensitivity analyses results for the three disposal scenarios.

Dilution parameter, S, is defined as a representative for pollutant material concentration (water salinity in this study) in CORMIX outputs and is calculated as below (Vaselali, A., and Vaselali, M., 2009):

$$\mathbf{S} = \frac{\mathbf{D_o}}{\mathbf{D}} \times \mathbf{100\%} \qquad (\mathbf{D.1})$$

In which, D_o is salt concentration of discharged flow in outfall position and D is salt concentration in the end of near field zone.

In this study the simulation has been executed over the four seasons of winter, spring, summer, and autumn in order to gain an imagination about the seasonal variation in the brine dilution.

The seasonal climatological and metrological data that have been used in this study are demonstrated in Table (D.1).

Table (D.1): Used seasonal climatological and metrological data

Season	Ambient Current (m/s)	Ambient Wind (m/s)
Winter	0.12	3.28
Spring	0.07	3.02
Summer	0.15	2.56
Autumn	0.06	2.58

In simulating the onshore brine disposal via surface open channel ambient stratification has been encountered in the analysis to accurate model in selecting the suitable applicable layer. The surface discharging was analyzed at a range of water ambient depths from 1.5m to 5.5m.

Table (D.2) demonstrates the ambient characteristics that have been employed in the simulation of the onshore disposal of brine.

Table (D.2): Ambient characteristics used in the simulation of the onshore disposal.

Season	Layer (m)	Temperature (°C)	Salinity (ppt)	Density (kg/m^3)
Winter	Surface: 0m	17.21	38.91	1028.26
	Layer (1): 5m	17.16	38.90	1028.27
	Layer (2): 20m	17.24	38.94	1028.28
	Bottom: 50m	17.12	38.98	1028.34
Spring	Surface: 0m	20.52	38.99	1027.39
	Layer (1): 5m	20.25	38.99	1027.47
	Layer (2): 20m	19.35	38.97	1027.71
	Bottom: 50m	17.45	38.95	1028.22
Summer	Surface: 0m	27.26	39.21	1025.46
	Layer (1): 5m	27.18	39.21	1025.48
	Layer (2): 20m	26.36	39.08	1025.66
	Bottom: 50m	19.08	38.83	1027.68
Autumn	Surface: 0m	23.40	39.27	1026.73
	Layer (1): 5m	23.39	39.27	1026.73
	Layer (2): 20m	23.50	39.31	1026.73
	Bottom: 50m	20.77	39.17	1027.45

On the other hand, in simulating the offshore brine disposal via submerged devices, the average ambient parameters have been encountered in the analysis to avoid model`s inconsistency. Table (D.3) demonstrates the ambient and brine characteristics that have been employed in the simulation of the offshore disposal of brine.

Table (D.3): Used ambient and brine characteristics

Season	Ambient Properties			Brine Properties		
	Temperature (°C)	Salinity (ppt)	Density (kg/m^3)	Temperature (°C)	Salinity (ppt)	Density (kg/m^3)
Winter	17.2	38.94	1028.29	17.25	60.33	1044.59
Spring	19.2	38.97	1027.75	20.17	60.45	1043.81
Summer	24.33	39.06	1026.32	27.08	60.79	1041.82
Autumn	22.90	39.26	1026.88	23.69	60.91	1043.05

D.1 Tables of Result Analysis

Tables (D.1) to **(D.13)** demonstrates the results of sensitivity analysis for surface discharge. While **Tables (D.14**) to **(D.20)** illustrates the results of single port. In contrast **Tables (D.21)** to **(D.25)** are for the results of the general configuration multiport diffuser.

Table (D.1): Open surface with 0.5m chanel's width

Season			Winter	Spring	Summer	Autumn
Channel Width (m)	**Slope (%)**	**Disposal Depth (m)**	**Concentration at [a] RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**
0.5	0.3	1.5	[b] N/A	N/A	N/A	N/A
		2.5	N/A	N/A	N/A	N/A
		3.5	N/A	N/A	N/A	N/A
		4.5	N/A	N/A	N/A	N/A
		5.5	N/A	N/A	N/A	N/A
	0.975	1.5	N/A	N/A	N/A	N/A
		2.5	N/A	N/A	N/A	N/A
		3.5	N/A	N/A	N/A	N/A
		4.5	N/A	N/A	N/A	N/A
		5.5	2229.05	2729.91	2191.47	2768.56
	1.65	1.5	N/A	N/A	N/A	N/A
		2.5	N/A	N/A	N/A	N/A
		3.5	N/A	N/A	N/A	N/A
		4.5	2565.54	2710.84	2383.41	2770.42
		5.5	2145.00	2474.35	2122.29	2535.41
	2.325	1.5	N/A	N/A	N/A	N/A
		2.5	N/A	N/A	N/A	N/A
		3.5	2711.01	2853.85	2710.18	2902.38
		4.5	2403.73	2518.94	2269.85	2567.76
		5.5	2044.27	2299.52	2029.55	2349.07
	3	1.5	N/A	N/A	N/A	N/A
		2.5	N/A	N/A	N/A	N/A
		3.5	2586.28	2709.80	2585.73	2749.03
		4.5	2291.96	2388.53	2180.75	2432.39
		5.5	1968.33	2180.27	1954.27	2225.71

[a] **RMZ:** Regulatory Mixing Zone 150m downstream from the disposal point.
[b] **N/A:** Not Applicable due to: Channel`s depth to width aspect ratio out of the range [0.05-5] or, Depth at the discharge location is less than twice the depth in the channel.

(D.2) Season			Winter		Spring		Summer		Autumn	
Phase			I	II	I	II	I	II	I	II
Channel Width (m)	Channel Slope (%)	Disposal Depth (m)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)
1	0.3	1.5	NA	NA	NA	NA	NA	NA	NA	NA
		2.5	NA	NA	NA	NA	NA	NA	NA	NA
		3.5	3307.51	NA	3690.76	NA	3285.11	NA	3429.03	NA
		4.5	2929.30	NA	3080.90	NA	2499.90	NA	2894.19	NA
		5.5	2130.84	NA	2697.47	NA	2037.67	NA	2639.12	NA
	0.975	1.5	NA	NA	NA	NA	NA	NA	NA	NA
		2.5	3363.97	NA	3440.25	NA	3360.12	NA	3487.29	NA
		3.5	2792.76	3835.09	2994.53	4038.43	2787.09	3824.92	3061.14	4098.72
		4.5	2466.57	3362.81	2622.65	3548.58	2269.15	3346.61	2696.77	3619.22
		5.5	2031.91	3054.59	2381.75	3217.83	2004.89	2859.84	2448.59	3287.35
	1.65	1.5	NA	NA	NA	NA	NA	NA	NA	NA
		2.5	3036.51	NA	3147.54	N/A	3031.35	NA	3189.74	NA
		3.5	2554.94	3432.89	2706.95	3524.20	2548.15	3448.23	2768.14	3577.93
		4.5	2242.92	3063.87	2372.34	3209.48	2114.89	3058.62	2428.99	3259.50
		5.5	1889.92	2787.16	2154.47	2907.81	1870.83	2654.38	2207.45	2959.14
	2.325	1.5	3911.72	NA	4011.62	NA	3927.28	NA	4060.99	NA
		2.5	2880.19	3894.27	2973.71	3991.54	2876.13	3917.89	3012.76	4036.85
		3.5	2410.28	3236.14	2548.22	3308.90	2410.00	3241.44	2598.39	3359.47
		4.5	2114.34	2863.75	2233.74	2997.01	2015.18	2871.76	2285.59	3041.87
		5.5	1800.57	2616.13	2023.90	2718.35	1790.51	2513.07	2073.14	2765.64
	3	1.5	3720.88	NA	3828.93	NA	3736.31	NA	3876.17	NA
		2.5	2744.57	3734.07	2830.11	3809.67	2741.45	3743.29	2867.52	3853.16
		3.5	2294.17	3096.10	2338.28	3162.99	2293.52	3101.92	2377.37	3211.26
		4.5	2012.56	2704.76	2114.64	2772.49	1927.37	2745.04	2158.20	2806.32
		5.5	1724.03	2473.46	1916.02	2592.75	1710.13	2412.43	1958.15	2631.38

(D.3) Season			Winter		Spring		Summer		Autumn	
Phase			I	II	I	II	I	II	I	II
Channel Width (m)	Channel Slope (%)	Disposal Depth (m)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)
1.5	0.3	1.5	NA	NA	NA	NA	NA	NA	NA	NA
		2.5	3877.15	NA	4259.86	NA	3827.86	NA	4332.73	NA
		3.5	3164.93	4321.94	3491.41	4686.56	3140.30	4253.11	3335.01	4567.10
		4.5	2749.25	3742.69	2899.72	3974.60	2367.62	3707.07	2804.24	3796.34
		5.5	2015.82	3319.05	2540.71	3454.76	1925.49	2933.14	2530.33	3324.07
	0.975	1.5	4409.02	NA	4550.24	NA	4401.69	N/A	4608.81	N/A
		2.5	3257.51	4338.47	3331.48	4453.56	3252.22	4341.94	3388.92	4505.86
		3.5	2685.17	3637.41	2884.74	3827.89	2672.00	3612.15	2956.94	3893.41
		4.5	2341.12	3165.53	2515.31	3347.15	2157.53	3142.55	2588.78	3411.28
		5.5	1916.56	2860.00	2258.98	3013.63	1869.90	2677.07	2302.61	3077.26
	1.65	1.5	4089.10	N/A	4196.79	NA	4082.89	NA	4270.30	NA
		2.5	2977.22	3992.09	3088.49	4076.46	2970.53	3996.74	3129.75	4122.99
		3.5	2485.35	3271.56	2646.41	3371.07	2477.75	3287.31	2708.50	3410.91
		4.5	2165.47	2903.41	2306.25	3041.60	2023.04	2891.47	2362.74	3096.24
		5.5	1799.55	2623.44	2073.64	2744.78	1775.66	2492.46	2130.98	2801.57
	2.325	1.5	3874.61	5082.91	3973.37	5232.25	3868.82	5121.75	4022.23	5266.82
		2.5	2821.25	3745.34	2913.60	3838.78	2815.43	3767.83	2964.34	3882.95
		3.5	2346.87	3083.76	2487.48	3161.61	2338.71	3099.41	2536.60	3213.38
		4.5	2041.00	2711.30	2161.04	2852.25	1928.74	2717.51	2212.94	2903.72
		5.5	1714.24	2463.29	1947.65	2573.16	1694.46	2359.47	1996.17	2619.30
	3	1.5	3705.73	4889.34	3796.53	4974.73	3720.37	4927.62	3864.60	5061.08
		2.5	2700.50	3611.73	2797.51	3682.39	2694.88	3634.41	2834.77	3741.78
		3.5	2242.96	2979.82	2371.01	3053.53	2234.06	2983.73	2418.14	3089.77
		4.5	1949.38	2580.66	2058.77	2652.80	1848.37	2583.88	2108.41	2685.07
		5.5	1643.51	2346.61	1848.79	2466.94	1623.93	2282.59	1895.56	2510.71

(D.4) Season			Winter		Spring		Summer		Autumn	
Phase			I	II	I	II	I	II	I	II
Channel Width (m)	Channel Slope (%)	Disposal Depth (m)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)
2	0.3	1.5	5160.77	NA	5357.94	NA	5147.00	NA	5431.58	NA
		2.5	3813.12	5153.88	4212.24	5169.86	3762.35	5082.93	4163.49	5232.88
		3.5	3089.66	4195.83	3320.19	4547.38	3065.51	4127.06	3211.26	4406.73
		4.5	2611.90	3619.54	2779.28	3801.41	2233.62	3581.72	2711.70	3693.37
		5.5	1904.88	3155.80	2432.40	3299.44	1814.87	2787.99	2432.29	3219.30
	0.975	1.5	4387.04	NA	4530.98	NA	4375.80	NA	4589.43	NA
		2.5	3212.27	4276.28	3283.49	4390.80	3193.74	4277.17	3340.98	4442.12
		3.5	2626.25	3566.40	2836.81	3770.40	2604.45	3537.95	2903.09	3836.49
		4.5	2262.52	3086.80	2423.95	3278.25	2059.80	3060.97	2428.71	3342.29
		5.5	1755.39	2775.41	2093.67	2944.53	1693.91	2590.75	2126.27	3008.09
	1.65	1.5	4096.75	5365.45	4205.12	5465.41	4086.16	5404.72	4282.59	5566.28
		2.5	2950.60	3921.05	3063.11	4023.96	2928.53	3943.25	3104.38	4069.67
		3.5	2437.48	3205.14	2609.35	3304.55	2421.55	3205.89	2674.77	3343.59
		4.5	2103.51	2830.36	2255.66	2979.23	1938.94	2816.97	2267.97	3033.54
		5.5	1650.71	2544.59	1944.12	2671.75	1606.99	2409.65	1993.65	2718.60
	2.325	1.5	3859.92	5091.90	3958.60	5245.59	3849.36	5093.19	4032.99	5275.98
		2.5	2775.59	3715.70	2881.83	3811.51	2767.71	3737.75	2919.54	3854.90
		3.5	2279.81	3049.10	2440.19	3127.38	2271.27	3049.52	2499.85	3180.49
		4.5	1967.34	2660.95	2098.39	2808.27	1835.62	2666.87	2155.59	2859.88
		5.5	1569.04	2405.37	1814.86	2515.64	1530.46	2294.57	1861.42	2560.83
	3	1.5	3691.02	4882.54	3806.98	4967.58	3704.52	4885.52	3854.77	5053.49
		2.5	2658.40	3573.37	2757.17	3641.95	2649.29	3575.30	2794.26	3704.38
		3.5	2188.60	2924.43	2329.10	2996.75	2178.03	2925.78	2376.59	3032.41
		4.5	1878.95	2512.61	2002.40	2582.73	1764.33	2503.23	2053.22	2614.07
		5.5	1509.90	2268.63	1740.42	2401.11	1468.25	2194.65	1782.89	2444.57

(D.5) Season			Winter		Spring		Summer		Autumn	
Phase			I	II	I	II	I	II	I	II
Channel Width (m)	Channel Slope (%)	Disposal Depth (m)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)
2.5	0.3	1.5	5116.66	NA	5314.94	NA	5100.50	NA	5411.90	NA
		2.5	3752.31	5114.95	4058.87	5444.52	3699.44	5039.98	3936.92	5190.50
		3.5	2955.83	4143.89	3145.43	4430.65	2880.50	4072.84	3052.91	4284.55
		4.5	2444.95	3547.25	2632.84	3673.49	2075.78	3472.10	2586.16	3560.91
		5.5	1768.80	3039.73	2311.73	3184.84	1682.28	2674.20	2326.04	3120.52
	0.975	1.5	4421.16	5820.32	4569.37	5972.89	4406.65	5858.60	4628.74	6094.36
		2.5	3199.37	4236.03	3471.53	4350.77	3178.49	4234.47	3497.39	4424.49
		3.5	2577.57	3516.69	2749.34	3724.77	2522.00	3484.83	2726.00	3793.75
		4.5	2101.08	3027.72	2268.05	3221.14	1882.76	2987.97	2270.31	3249.68
		5.5	1608.56	2668.56	1948.71	2816.15	1543.18	2457.37	1993.20	2816.01
	1.65	1.5	4056.63	5363.67	4191.33	5463.89	4041.84	5401.91	4244.26	5605.78
		2.5	2884.74	3892.70	3011.55	3996.83	2859.75	3914.13	3051.72	4066.40
		3.5	2360.85	3161.90	2519.31	3261.70	2316.70	3160.83	2512.85	3299.61
		4.5	1924.77	2768.58	2069.44	2930.49	1761.69	2752.83	2100.91	2984.94
		5.5	1499.62	2467.06	1788.92	2593.67	1444.88	2283.04	1827.11	2628.04
	2.325	1.5	3900.57	5079.54	4030.26	5171.55	3885.88	5117.67	4080.50	5304.72
		2.5	2758.21	3698.35	2881.65	3797.44	2748.37	3696.68	2919.62	3839.86
		3.5	2247.20	2994.35	2400.36	3090.49	2218.14	2994.09	2405.00	3125.91
		4.5	1831.39	2598.08	1978.93	2747.72	1697.56	2591.73	2003.81	2812.07
		5.5	1444.44	2330.79	1702.42	2452.24	1393.14	2171.75	1748.07	2476.21
	3	1.5	3730.13	4893.89	3823.76	4978.97	3714.61	4889.36	3870.61	5033.20
		2.5	2638.10	3536.36	2740.55	3627.24	2627.48	3557.22	2792.90	3668.99
		3.5	2147.55	2864.06	2295.34	2952.20	2114.88	2862.73	2286.16	2987.49
		4.5	1746.56	2481.22	1881.79	2531.91	1628.10	2485.59	1916.76	2563.04
		5.5	1386.62	2155.78	1622.33	2335.39	1344.84	2087.86	1663.96	2368.82

(D.6) Season			Winter		Spring		Summer		Autumn	
Phase			I	II	I	II	I	II	I	II
Channel Width (m)	Channel Slope (%)	Disposal Depth (m)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)
3	0.3	1.5	5093.38	NA	5293.62	NA	5050.05	NA	5392.71	NA
		2.5	3691.54	5050.70	3827.44	5409.81	3588.62	4991.86	3718.94	5293.36
		3.5	2770.43	4084.18	2977.36	4238.90	2699.37	3996.99	2900.49	4121.83
		4.5	2294.05	3384.32	2497.63	3514.24	1919.86	3318.42	2482.84	3431.95
		5.5	1633.58	2904.85	2210.82	3049.82	1548.37	2533.78	2241.59	3005.43
	0.975	1.5	4389.45	5842.65	4566.85	5957.50	4398.25	5837.54	4626.53	6023.89
		2.5	3151.98	4194.91	3320.25	4334.23	3116.33	4190.66	3263.69	4384.76
		3.5	2403.18	3465.59	2569.18	3693.29	2360.29	3414.94	2557.13	3677.84
		4.5	1964.11	2940.26	2114.73	3066.99	1734.21	2861.62	2139.44	3047.08
		5.5	1476.97	2515.91	1829.93	2653.65	1410.38	2289.42	1873.09	2665.97
	1.65	1.5	4053.93	5372.00	4191.46	5518.44	4063.69	5409.03	4275.26	5578.33
		2.5	2851.87	3869.13	2978.95	4000.89	2825.12	3889.82	3035.52	4046.39
		3.5	2211.31	3122.42	2372.09	3222.51	2175.46	3102.58	2359.39	3278.61
		4.5	1802.05	2717.03	1949.04	2836.59	1630.04	2631.74	1971.83	2848.01
		5.5	1386.84	2307.97	1676.80	2448.31	1331.34	2138.97	1715.52	2468.39
	2.325	1.5	3863.20	5139.93	3994.52	5234.13	3875.01	5130.59	4076.27	5290.05
		2.5	2712.87	3682.12	2836.61	3782.56	2685.88	3676.92	2891.51	3824.83
		3.5	2105.37	2960.86	2248.74	3056.99	2064.16	2958.21	2244.64	3092.42
		4.5	1717.67	2533.14	1848.20	2693.38	1560.87	2490.70	1878.88	2691.02
		5.5	1330.49	2196.52	1588.33	2316.97	1282.90	2031.70	1634.37	2352.17
	3	1.5	3749.52	4929.62	3877.29	5015.48	3730.78	4964.39	3925.31	5118.70
		2.5	2622.17	3565.98	2743.69	3633.06	2610.69	3558.26	2797.36	3702.57
		3.5	2039.67	2849.54	2179.22	2940.13	2012.76	2844.50	2183.48	2994.52
		4.5	1664.72	2430.64	1798.53	2595.20	1520.56	2407.79	1822.29	2605.91
		5.5	1298.24	2068.75	1538.77	2237.82	1252.75	1963.30	1580.76	2262.00

(D.7) Season			Winter		Spring		Summer		Autumn	
Phase			I	II	I	II	I	II	I	II
Channel Width (m)	Channel Slope (%)	Disposal Depth (m)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)
3.5	0.3	1.5	5033.40	6802.90	5232.63	6988.12	4986.73	6837.43	5332.78	7069.73
		2.5	3464.90	4996.55	3618.99	5228.98	3371.14	4934.49	3532.43	5052.52
		3.5	2599.76	3948.09	2828.95	4033.93	2533.66	3837.42	2775.97	3931.85
		4.5	2157.74	3223.57	2385.87	3356.68	1774.84	3148.50	2257.41	3277.40
		5.5	1515.57	2763.00	2122.12	2922.59	1430.37	2402.85	2078.17	2877.23
	0.975	1.5	4364.01	5846.17	4544.51	5960.45	4343.29	5881.31	4604.05	6073.77
		2.5	2979.44	4165.91	3146.43	4305.82	2924.07	4157.63	3072.94	4357.26
		3.5	2255.25	3408.01	2406.69	3538.84	2194.75	3327.48	2398.20	3470.07
		4.5	1834.19	2789.06	1998.02	2934.70	1604.77	2721.90	2016.33	2909.69
		5.5	1364.47	2381.03	1730.15	2520.15	1298.88	2153.08	1769.56	2523.28
	1.65	1.5	4054.93	5402.77	4194.74	5505.08	4033.74	5439.00	4281.12	5614.71
		2.5	2783.58	3856.83	2877.09	3963.69	2720.12	3849.84	2940.39	4008.78
		3.5	2088.29	3072.60	2252.35	3171.17	2045.32	3047.84	2242.19	3227.49
		4.5	1699.54	2559.09	1848.28	2705.41	1512.74	2506.96	1859.34	2705.77
		5.5	1291.26	2182.88	1584.44	2315.23	1231.91	2010.57	1626.99	2344.06
	2.325	1.5	3936.47	5156.52	4072.95	5251.60	3915.13	5192.50	4124.46	5359.51
		2.5	2658.92	3670.17	2777.78	3771.98	2621.22	3662.37	2840.59	3843.51
		3.5	2028.42	2935.84	2174.83	3030.26	1981.37	2904.52	2165.21	3085.87
		4.5	1656.53	2411.55	1789.31	2568.53	1479.29	2398.21	1812.40	2583.94
		5.5	1261.01	2097.53	1532.89	2215.30	1207.59	1926.46	1578.11	2237.09
	3	1.5	3767.25	4968.25	3930.19	5058.17	3778.99	5004.46	3977.94	5111.79
		2.5	2574.28	3532.26	2695.00	3630.65	2535.97	3553.22	2719.77	3700.92
		3.5	1964.72	2822.16	2106.88	2916.31	1927.09	2818.74	2102.67	2970.21
		4.5	1600.45	2308.38	1720.71	2481.44	1437.66	2292.17	1748.43	2479.86
		5.5	1224.05	1969.37	1473.02	2136.19	1177.18	1872.75	1514.69	2170.96

(D.8) Season			Winter		Spring		Summer		Autumn	
Phase			I	II	I	II	I	II	I	II
Channel Width (m)	Channel Slope (%)	Disposal Depth (m)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)
4	0.3	1.5	4951.59	6782.86	5225.08	6969.94	4932.88	6815.53	5273.50	7097.16
		2.5	3283.90	4955.16	3469.94	4979.73	3183.61	4834.82	3363.49	4859.03
		3.5	2463.23	3794.63	2719.69	3864.53	2396.09	3664.46	2521.08	3767.12
		4.5	2045.29	3070.20	2307.01	3211.16	1655.48	2991.19	2244.53	3141.66
		5.5	1411.88	2634.23	2058.76	2797.94	1329.93	2262.93	2080.94	2774.14
	0.975	1.5	4331.87	5788.27	4455.63	5951.77	4257.77	5822.73	4571.10	6017.97
		2.5	2830.46	4092.54	2965.69	4233.02	2780.27	4083.32	2919.82	4310.69
		3.5	2129.62	3226.37	2289.80	3358.56	2067.99	3149.61	2291.00	3297.60
		4.5	1733.24	2621.09	1896.20	2757.24	1495.52	2563.01	1924.69	2759.51
		5.5	1275.11	2245.36	1649.62	2392.67	1209.80	2011.27	1699.42	2395.12
	1.65	1.5	4033.14	5414.40	4217.12	5517.58	4004.45	5397.69	4254.96	5577.60
		2.5	2664.45	3799.16	2784.99	3934.35	2605.96	3789.64	2748.51	3979.12
		3.5	2007.68	2979.04	2153.83	3045.37	1958.99	2944.11	2155.39	3110.24
		4.5	1635.22	2429.60	1772.60	2573.52	1431.14	2385.38	1794.52	2564.81
		5.5	1219.71	2077.27	1528.16	2220.20	1159.33	1889.21	1571.39	2221.33
	2.325	1.5	3889.44	5126.09	4069.76	5220.87	3917.43	5160.98	4100.44	5332.41
		2.5	2547.75	3608.09	2679.44	3739.27	2543.14	3627.04	2735.04	3781.72
		3.5	1952.02	2786.40	2078.79	2912.58	1911.65	2746.16	2073.11	2939.90
		4.5	1589.55	2276.64	1707.58	2438.14	1398.19	2265.37	1731.90	2445.63
		5.5	1187.29	1977.90	1464.66	2095.67	1135.62	1819.87	1505.83	2131.03
	3	1.5	3639.15	5004.24	3742.68	5095.83	3611.13	4984.84	3770.66	5150.06
		2.5	2352.79	3524.82	2484.90	3624.34	2321.12	3515.02	2507.03	3696.08
		3.5	1807.60	2734.23	1925.07	2827.62	1765.28	2693.46	1920.11	2892.58
		4.5	1467.08	2230.64	1583.94	2381.50	1302.07	2196.28	1596.69	2397.99
		5.5	1105.02	1903.93	1349.81	2049.96	1056.87	1781.36	1391.42	2074.78

(D.9) Season			Winter		Spring		Summer		Autumn	
Phase			I	II	I	II	I	II	I	II
Channel Width (m)	**Channel Slope (%)**	**Disposal Depth (m)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**
4.5	**0.3**	1.5	4728.53	6757.81	4977.82	6946.19	4654.83	6743.12	5088.54	7027.48
		2.5	3102.12	4815.99	3312.36	4795.52	3018.34	4612.42	3062.94	4670.93
		3.5	2343.90	3627.67	2626.99	3725.64	2273.32	3482.72	2478.14	3612.76
		4.5	1944.25	2943.85	2239.54	3087.29	1545.73	2856.70	2326.81	3033.79
		5.5	1319.84	2511.35	1920.49	2699.27	1253.05	2148.25	2198.40	2689.44
	0.975	1.5	4147.35	5770.73	4308.97	5937.08	4052.66	5803.91	4419.01	6003.14
		2.5	2706.48	3996.79	2871.36	4130.77	2640.31	3978.89	2807.84	4226.42
		3.5	2033.39	3087.06	2205.90	3192.20	1972.76	3017.33	2213.40	3142.34
		4.5	1654.63	2506.70	1831.85	2642.63	1400.76	2439.73	1865.48	2628.18
		5.5	1201.63	2137.07	1601.56	2271.20	1130.81	1904.91	1649.36	2277.90
	1.65	1.5	NA	5373.07	NA	5531.13	NA	5403.97	NA	5591.46
		2.5	NA	3731.04	NA	3876.18	NA	3703.41	NA	3909.75
		3.5	NA	2842.80	NA	2981.32	NA	2811.39	NA	2970.32
		4.5	NA	2307.59	NA	2462.87	NA	2267.54	NA	2473.62
		5.5	NA	1990.24	NA	2124.96	NA	1796.34	NA	2137.10
	2.325	1.5	NA	5206.00	NA	5303.81	NA	5184.04	NA	5361.03
		2.5	NA	3610.95	NA	3699.80	NA	3590.34	NA	3795.60
		3.5	NA	2713.36	NA	2828.75	NA	2675.79	NA	2890.57
		4.5	NA	2226.06	NA	2383.88	NA	2198.70	NA	2380.68
		5.5	NA	1922.72	NA	2050.04	NA	1747.54	NA	2073.78
	3	1.5	NA	4952.15	NA	5041.86	NA	4929.07	NA	5094.12
		2.5	NA	3384.34	NA	3534.16	NA	3365.26	NA	3560.99
		3.5	NA	2567.90	NA	2685.83	NA	2531.57	NA	2708.87
		4.5	NA	2126.00	NA	2240.87	NA	2094.22	NA	2249.74
		5.5	NA	1809.72	NA	1922.42	NA	1670.53	NA	1957.54

(D.10) Season			Winter		Spring		Summer		Autumn	
Phase			I	II	I	II	I	II	I	II
Channel Width (m)	Channel Slope (%)	Disposal Depth (m)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)
5	0.3	1.5	4533.00	6724.77	4768.71	6913.20	4465.48	6706.55	4873.92	7044.62
		2.5	2944.66	4647.09	3187.55	4611.45	2856.80	4449.11	2939.35	4504.62
		3.5	2227.04	3485.59	2539.50	3582.24	2155.13	3351.12	2477.12	3490.82
		4.5	1849.24	2823.69	2087.09	2992.95	1449.94	2738.55	2382.25	2948.33
		5.5	1236.78	2412.88	2038.95	2619.55	1219.24	2044.39	2157.67	2629.55
	0.975	1.5	NA	5793.24	NA	5961.96	NA	5824.86	NA	6084.50
		2.5	NA	3899.32	NA	4023.10	NA	3832.04	NA	4113.85
		3.5	NA	2996.38	NA	3098.21	NA	2907.42	NA	3067.06
		4.5	NA	2429.01	NA	2573.28	NA	2354.97	NA	2556.93
		5.5	NA	2072.15	NA	2219.33	NA	1829.47	NA	2224.57
	1.65	1.5	NA	5413.45	NA	5575.18	NA	5389.29	NA	5636.31
		2.5	NA	3598.85	NA	3732.47	NA	3580.36	NA	3823.08
		3.5	NA	2755.15	NA	2898.07	NA	2724.11	NA	2848.78
		4.5	NA	2255.72	NA	2392.17	NA	2204.69	NA	2401.62
		5.5	NA	1925.95	NA	2064.80	NA	1731.77	NA	2074.48
	2.325	1.5	NA	5174.01	NA	5328.65	NA	5204.59	NA	5384.66
		2.5	NA	3515.11	NA	3595.06	NA	3435.50	NA	3682.12
		3.5	NA	2639.60	NA	2742.22	NA	2626.07	NA	2797.56
		4.5	NA	2172.83	NA	2296.86	NA	2131.41	NA	2310.53
		5.5	NA	1849.74	NA	1974.67	NA	1673.82	NA	2005.82
	3	1.5	NA	4826.72	NA	4999.68	NA	4895.03	NA	5033.08
		2.5	NA	3203.12	NA	3282.98	NA	3185.63	NA	3366.01
		3.5	NA	2394.75	NA	2528.91	NA	2362.38	NA	2550.68
		4.5	NA	1987.61	NA	2099.43	NA	1960.99	NA	2122.93
		5.5	NA	1683.51	NA	1815.46	NA	1544.12	NA	1826.24

(D.11) Season			Winter		Spring		Summer		Autumn	
Phase			I	II	I	II	I	II	I	II
Channel Width (m)	Channel Slope (%)	Disposal Depth (m)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)
5.5	0.3	1.5	4418.62	6580.95	4553.95	6829.10	4278.95	6526.32	4652.30	6883.98
		2.5	2832.95	4438.56	3098.96	4451.20	2741.20	4243.77	2775.98	4320.60
		3.5	2133.15	3335.45	2483.66	3446.87	2065.39	3189.39	2577.15	3380.88
		4.5	1779.61	2695.17	2062.48	2882.52	1369.31	2607.64	2381.72	2882.39
		5.5	1169.59	2305.81	2044.67	2532.25	1195.62	1929.61	2153.60	2451.85
	0.975	1.5	NA	5676.76	NA	5837.51	NA	5742.02	NA	6016.81
		2.5	NA	3724.51	NA	3890.90	NA	3660.06	NA	3925.56
		3.5	NA	2854.83	NA	2969.58	NA	2775.50	NA	2929.39
		4.5	NA	2313.43	NA	2460.82	NA	2249.91	NA	2445.40
		5.5	NA	1975.70	NA	2120.57	NA	1737.33	NA	2138.91
	1.65	1.5	NA	5413.62	NA	5582.67	NA	5347.39	NA	5631.62
		2.5	NA	3501.43	NA	3681.00	NA	3481.03	NA	3714.05
		3.5	NA	2702.01	NA	2824.15	NA	2649.65	NA	2786.95
		4.5	NA	2178.88	NA	2325.34	NA	2131.94	NA	2318.76
		5.5	NA	1871.13	NA	2004.74	NA	1665.54	NA	2015.92
	2.325	1.5	NA	NA	NA	NA	NA	NA	NA	NA
		2.5	NA	NA	NA	NA	NA	NA	NA	NA
		3.5	NA	NA	NA	NA	NA	NA	NA	NA
		4.5	NA	NA	NA	NA	NA	NA	NA	NA
		5.5	NA	NA	NA	NA	NA	NA	NA	NA
	3	1.5	NA	NA	NA	NA	NA	NA	NA	NA
		2.5	NA	NA	NA	NA	NA	NA	NA	NA
		3.5	NA	NA	NA	NA	NA	NA	NA	NA
		4.5	NA	NA	NA	NA	NA	NA	NA	NA
		5.5	NA	NA	NA	NA	NA	NA	NA	NA

(D.12) Season			Winter		Spring		Summer		Autumn	
Phase			I	II	I	II	I	II	I	II
Channel Width (m)	Channel Slope (%)	Disposal Depth (m)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)
6	0.3	1.5	4213.87	6411.58	4345.42	6538.33	4126.63	6364.33	4533.12	6704.95
		2.5	2709.87	4264.84	3016.81	4295.68	2617.78	4081.64	2717.63	4196.77
		3.5	2046.51	3191.95	2369.58	3353.19	1984.18	3062.74	2626.06	3306.72
		4.5	1714.74	2590.31	2143.44	2803.91	1297.86	2498.57	2374.37	2704.31
		5.5	1117.54	2218.66	2011.40	2464.15	1169.43	1842.01	2150.76	2419.44
	0.975	1.5	NA	5539.38	NA	5694.25	NA	5483.14	NA	5740.29
		2.5	NA	3618.24	NA	3774.45	NA	3554.19	NA	3858.15
		3.5	NA	2770.47	NA	2896.59	NA	2697.52	NA	2853.38
		4.5	NA	2231.89	NA	2380.05	NA	2164.48	NA	2387.21
		5.5	NA	1911.46	NA	2056.36	NA	1665.30	NA	2082.67
	1.65	1.5	NA	NA	NA	NA	NA	NA	NA	NA
		2.5	NA	NA	NA	NA	NA	NA	NA	NA
		3.5	NA	NA	NA	NA	NA	NA	NA	NA
		4.5	NA	NA	NA	NA	NA	NA	NA	NA
		5.5	NA	NA	NA	NA	NA	NA	NA	NA
	2.325	1.5	NA	NA	NA	NA	NA	NA	NA	NA
		2.5	NA	NA	NA	NA	NA	NA	NA	NA
		3.5	NA	NA	NA	NA	NA	NA	NA	NA
		4.5	NA	NA	NA	NA	NA	NA	NA	NA
		5.5	NA	NA	NA	NA	NA	NA	NA	NA
	3	1.5	NA	NA	NA	NA	NA	NA	NA	NA
		2.5	NA	NA	NA	NA	NA	NA	NA	NA
		3.5	NA	NA	NA	NA	NA	NA	NA	NA
		4.5	NA	NA	NA	NA	NA	NA	NA	NA
		5.5	NA	NA	NA	NA	NA	NA	NA	NA

(D.13) Season			Winter		Spring		Summer		Autumn	
Phase			I	II	I	II	I	II	I	II
Channel Width (m)	Channel Slope (%)	Disposal Depth (m)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)
6.5	0.3	1.5	NA	6199.72	NA	6426.55	NA	6153.94	NA	6479.34
		2.5	NA	4148.66	NA	4193.51	NA	3964.86	NA	4086.03
		3.5	NA	3115.26	NA	3278.97	NA	2972.14	NA	3160.43
		4.5	NA	2513.95	NA	2754.65	NA	2423.42	NA	2672.00
		5.5	NA	2153.63	NA	2429.64	NA	1768.31	NA	2436.62
	0.975	1.5	NA	NA	NA	NA	NA	NA	NA	NA
		2.5	NA	NA	NA	NA	NA	NA	NA	NA
		3.5	NA	NA	NA	NA	NA	NA	NA	NA
		4.5	NA	NA	NA	NA	NA	NA	NA	NA
		5.5	NA	NA	NA	NA	NA	NA	NA	NA
	1.65	1.5	NA	NA	NA	NA	NA	NA	NA	NA
		2.5	NA	NA	NA	NA	NA	NA	NA	NA
		3.5	NA	NA	NA	NA	NA	NA	NA	NA
		4.5	NA	NA	NA	NA	NA	NA	NA	NA
		5.5	NA	NA	NA	NA	NA	NA	NA	NA
	2.325	1.5	NA	NA	NA	NA	NA	NA	NA	NA
		2.5	NA	NA	NA	NA	NA	NA	NA	NA
		3.5	NA	NA	NA	NA	NA	NA	NA	NA
		4.5	NA	NA	NA	NA	NA	NA	NA	NA
		5.5	NA	NA	NA	NA	NA	NA	NA	NA
	3	1.5	NA	NA	NA	NA	NA	NA	NA	NA
		2.5	NA	NA	NA	NA	NA	NA	NA	NA
		3.5	NA	NA	NA	NA	NA	NA	NA	NA
		4.5	NA	NA	NA	NA	NA	NA	NA	NA
		5.5	NA	NA	NA	NA	NA	NA	NA	NA

(D.14) Season			Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Phase			**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**
Port Diameter (m)	**Offshore Distance (m)**	**Water Depth (m)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**
0.4	**250**	2.625	8982.87	9816.96	6275.56	10544.19	11277.32	11976.89	9958.26	10349.36
	450	4.725	7928.76	9816.96	7187.56	10544.19	7803.40	11976.89	7348.76	10349.36
	650	6.825	4460.59	7169.85	4342.73	6766.55	4617.03	7561.79	4274.51	6656.97
	850	8.925	2958.58	4678.92	2876.26	4501.64	3029.54	4900.86	2845.69	4450.04
	1050	11.025	2108.69	3327.22	2063.92	3240.53	2187.74	3468.27	2049.75	3215.43
	1250	13.125	1584.40	2504.16	1562.76	2459.11	1644.27	2603.25	1556.23	2446.81
	1450	15.225	1240.63	1962.95	1230.09	1938.68	1285.72	2037.08	1227.33	1932.87
	1650	17.325	1001.97	1586.50	997.10	1573.27	1037.43	1644.48	996.28	1570.88
	1850	19.425	828.91	1313.15	827.06	1306.09	857.70	1360.03	827.27	1305.57
	2050	21.525	699.04	1107.81	698.84	1104.34	722.82	1146.69	699.59	1104.85

(D.15) Season			Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Phase			**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**
Port Diameter (m)	**Offshore Distance (m)**	**Water Depth (m)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**
0.5	**250**	2.625	8278.99	8977.34	5965.67	10042.24	10522.88	11181.24	9437.31	9830.41
	450	4.725	7456.73	8977.34	6448.29	10042.24	7801.79	11181.24	6985.37	9830.41
	650	6.825	4296.38	6984.76	4180.56	6492.24	4516.50	7324.89	4097.41	6363.88
	850	8.925	2877.57	4597.45	2793.01	4356.42	2950.67	4801.78	2750.90	4288.34
	1050	11.025	2087.98	3285.77	2018.01	3158.69	2139.80	3441.16	1995.68	3121.14
	1250	13.125	1572.97	2481.27	1535.83	2410.46	1640.00	2588.62	1523.75	2389.30
	1450	15.225	1233.85	1949.47	1213.45	1908.36	1281.43	2028.59	1206.88	1896.32
	1650	17.325	997.72	1578.13	986.35	1553.60	1034.71	1639.26	982.87	1546.79
	1850	19.425	826.12	1307.73	819.86	1292.88	855.87	1356.67	818.16	1289.17
	2050	21.525	697.13	1104.18	693.87	1095.20	721.44	1144.44	693.22	1093.36

(D.16) Season			Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Phase			**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**
Port Diameter (m)	**Offshore Distance (m)**	**Water Depth (m)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**
0.6	**250**	2.625	7803.49	8440.16	5773.79	9621.09	9897.53	10516.05	9017.30	9402.05
	450	4.725	7073.62	8440.16	6094.13	9621.09	7806.81	10516.05	6685.35	9402.05
	650	6.825	4146.81	6789.64	4032.79	6247.63	4423.56	7055.04	3940.62	6109.22
	850	8.925	2800.15	4516.87	2711.19	4217.18	2878.11	4695.05	2660.58	4138.24
	1050	11.025	2048.58	3239.37	1969.93	3074.86	2092.38	3384.27	1940.88	3027.84
	1250	13.125	1559.26	2454.53	1506.17	2357.91	1609.94	2571.02	1489.05	2329.12
	1450	15.225	1225.40	1933.15	1194.38	1874.20	1275.94	2018.02	1184.13	1856.33
	1650	17.325	992.22	1567.68	973.63	1530.64	1031.06	1632.57	967.45	1519.45
	1850	19.425	822.38	1300.77	811.09	1277.00	853.31	1352.24	807.40	1269.97
	2050	21.525	694.49	1099.39	687.65	1083.92	719.46	1141.40	685.52	1079.56

(D.17) Season			**Winter**	**Spring**	**Summer**	**Autumn**	**Winter**	**Spring**	**Summer**	**Autumn**
Phase			**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**
Port Diameter (m)	**Offshore Distance (m)**	**Water Depth (m)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**
0.7	**250**	2.625	7452.15	8061.16	5640.34	9264.99	9394.95	9984.70	8720.00	9044.43
	450	4.725	6770.51	8061.16	5878.40	9264.99	7580.97	9984.70	6434.45	9044.43
	650	6.825	4014.61	6589.47	3901.88	6033.40	4331.49	6405.84	3804.18	5889.75
	850	8.925	2728.43	4422.92	2634.04	4088.62	2812.24	4592.54	2577.69	4002.67
	1050	11.025	2002.67	3190.28	1922.14	2993.57	2047.54	3319.75	1887.94	2939.67
	1250	13.125	1543.85	2425.13	1475.36	2304.68	1578.65	2552.60	1454.00	2269.80
	1450	15.225	1215.53	1914.64	1173.77	1838.25	1265.04	2005.80	1160.27	1815.35
	1650	17.325	985.57	1555.52	959.48	1505.74	1026.52	1624.63	950.74	1490.52
	1850	19.425	817.71	1292.49	801.09	1259.32	850.01	1346.85	795.44	1249.12
	2050	21.525	691.10	1093.58	680.40	1071.09	716.82	1137.62	676.76	1064.23

(D.18) Season			Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Phase			**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**
Port Diameter (m)	**Offshore Distance (m)**	**Water Depth (m)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**
0.8	**250**	2.625	7185.07	7783.71	5539.93	8960.65	8984.92	9556.53	8377.50	8740.04
	450	4.725	6526.80	7783.71	5726.35	8960.65	7359.40	9556.53	6220.59	8740.04
	650	6.825	3898.52	6402.93	3830.00	5845.77	4219.47	6816.54	3685.06	5699.65
	850	8.925	2662.66	4304.13	2563.77	3971.98	2752.62	4495.79	2503.33	3881.94
	1050	11.025	1959.41	3150.00	1876.14	2916.99	2005.72	3257.92	1838.18	2858.40
	1250	13.125	1519.36	2394.26	1444.52	2252.68	1548.56	2510.32	1419.71	2213.23
	1450	15.225	1204.53	1894.62	1152.53	1802.00	1242.59	1992.24	1136.04	1775.01
	1650	17.325	977.91	1542.04	944.40	1479.91	1020.00	1615.59	933.31	1461.22
	1850	19.425	812.15	1283.11	790.10	1240.55	845.97	1340.58	782.66	1227.44
	2050	21.525	686.93	1086.85	672.27	1057.19	713.50	1133.12	667.20	1047.96

(D.19) Season			**Winter**	**Spring**	**Summer**	**Autumn**	**Winter**	**Spring**	**Summer**	**Autumn**
Phase			I	II	I	II	I	II	I	II
Port Diameter (m)	Offshore Distance (m)	Water Depth (m)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)	Concentration at RMZ (ppm)
0.9	**250**	2.625	6974.12	7562.91	5461.07	8697.03	8659.58	9215.96	8125.76	8477.39
	450	4.725	6328.19	7562.91	5608.84	8697.03	7155.56	9215.96	6036.15	8477.39
	650	6.825	3795.96	6234.45	3740.00	5680.70	4115.35	6702.02	3580.45	5533.45
	850	8.925	2603.69	4196.68	2499.82	3867.05	2698.98	4405.24	2436.73	3774.64
	1050	11.025	1919.41	3092.34	1833.68	2846.16	1967.46	3199.57	1792.68	2784.19
	1250	13.125	1489.85	2362.80	1414.30	2202.97	1520.07	2469.23	1386.97	2160.05
	1450	15.225	1192.79	1873.71	1130.91	1766.37	1220.76	1980.00	1112.15	1736.13
	1650	17.325	969.42	1527.58	928.63	1453.91	1009.01	1605.68	915.66	1432.24
	1850	19.425	805.79	1272.82	778.39	1221.23	841.27	1333.55	769.32	1205.56
	2050	21.525	682.02	1079.34	663.39	1042.58	709.52	1127.96	657.01	1031.22

(D.20) Season			Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Phase			**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**
Port Diameter (m)	**Offshore Distance (m)**	**Water Depth (m)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**
1	**250**	2.625	6802.48	7391.36	5396.45	8465.48	8381.87	8930.44	7960.00	8247.83
	450	4.725	6160.30	7391.36	5512.41	8465.48	6972.20	8930.44	5874.23	8247.83
	650	6.825	3704.89	6084.25	3650.00	5534.00	4024.47	6571.09	3487.80	5386.95
	850	8.925	2549.39	4099.93	2441.68	3772.62	2650.39	4320.55	2376.50	3678.56
	1050	11.025	1882.83	3032.26	1794.35	2781.00	1933.21	3144.92	1751.09	2716.88
	1250	13.125	1462.94	2340.00	1386.55	2155.97	1493.67	2430.12	1356.99	2110.75
	1450	15.225	1179.81	1852.09	1109.86	1731.85	1199.85	1953.19	1089.22	1699.19
	1650	17.325	960.29	1512.32	912.54	1428.09	992.07	1595.07	897.85	1404.17
	1850	19.425	798.75	1261.79	766.15	1201.63	835.99	1325.87	755.63	1183.93
	2050	21.525	676.40	1071.13	653.87	1027.53	704.97	1122.22	646.29	1014.35

(D.21) Port's Diameter (m)		**0.1**		**0.2**		**0.3**	
Phase		**I**	**II**	**I**	**II**	**I**	**II**
Offshore Distance (m)	**Water Depth (m)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**	**Concentration at RMZ (ppm)**
1850	19.425	500.23	766.00	500.81	766.40	5466.45	766.67
		398.35	609.85	2043.03	610.26	5006.85	610.47
		339.28	518.84	1920.61	519.18	4706.54	2653.41
		299.12	457.97	1831.21	458.21	4486.90	2528.58
		269.97	413.16	1761.59	413.32	4315.32	2431.54
		247.66	378.86	1704.97	379.20	4175.58	2352.68
		230.19	351.50	1657.45	351.71	4037.12	2286.62
		214.82	328.99	1616.74	329.16	3881.61	2230.05
		202.95	309.94	1581.21	310.04	3747.59	2180.68

Table (D.22)

Offshore (m)	Alignment	Ld	Away From Intake	Angle to Shoreline	Diffuser Length	Outfall length	Total Pipe Length
450	50	750	1020.32	54	752.40	556.23	1308.63
500	50	710	933.42	52	712.40	634.51	1346.91
550	**50**	**670**	**889.13**	**57**	**672.40**	**655.80**	**1328.20**
600	50	620	954.70	53	622.40	751.28	1373.68
650	50	580	951.70	54	582.40	803.44	1385.84

Table (D.23)

Offshore (m)	Alignment	Ld	Away From Intake	Angle to Shoreline	Diffuser Length	Outfall length	Total Pipe Length
650	50	620	1067.35	49	622.40	861.26	1483.66
650	50	635	928.20	57	637.40	775.04	1412.44
650	50	650	855.44	62	652.40	736.17	1388.57
650	50	665	784.32	67	667.40	706.13	1373.53
650	50	680	739.25	71	682.40	687.45	1369.85
650	50	695	693.37	75	697.40	672.93	1370.33
650	50	710	650.08	79	712.40	662.17	1374.57
650	50	725	616.73	83	727.40	654.88	1382.28
650	50	740	583.67	86	742.40	651.59	1393.99

Table (D.24)

	Phase (I)							
	Winter		Spring		Summer		Autumn	
Alignment	RMZ	Intake	RMZ	Intake	RMZ	Intake	RMZ	Intake
50	103.54	84.10	158.31	125.63	89.99	71.20	176.19	139.92
60	90.86	74.80	143.98	122.09	78.12	62.50	157.78	128.29
70	82.85	69.10	132.92	114.12	70.83	57.10	146.27	120.28
80	78.51	65.90	126.36	108.88	66.86	54.20	142.68	115.89
90	77.09	64.90	124.48	107.10	65.60	53.30	140.16	115.12

Table (D.25)

	Phase (II)							
	Winter		Spring		Summer		Autumn	
Alignment	RMZ	Intake	RMZ	Intake	RMZ	Intake	RMZ	Intake
50	201.98	165.00	291.46	234.55	173.36	141.00	315.64	264.30
60	177.46	148.00	262.42	215.59	151.42	125.00	287.46	244.85
70	162.13	138.00	243.80	202.45	137.00	115.00	268.02	231.11
80	154.25	132.00	233.17	194.70	130.32	110.00	257.37	222.77
90	151.70	130.00	229.90	192.02	127.43	108.00	253.51	220.32