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Optimal Selection of the Desalination Intakes and Outlets Considering the Environmental and Hydrodynamic Conditions Prevailing in the UAE Western Coastal Water

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OPTIMAL SELECTION OF THE DESALINATION INTAKES AND OUTLETS CONSIDERING THE ENVIRONMENTAL AND HYDRODYNAMIC CONDITIONS PREVAILING IN THE UAE WESTERN COASTAL WATER

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ABSTRACT

A multi-layered hydrodynamic model is developed for the coastal area of Ruwais, an industrial petroleum compound located about 230 Km west of Abu Dhabi City that has a medium size desalination plant. The simulation is carried out using Delft3D model, which considers a curvilinear grid model with sigma layers in the vertical direction, and incorporates the transport of salt and temperature interactively with water dynamics. The study investigates the impact of the of brine and warm cooling water released from the desalination plant as well as other nearby industrial facilities using three-dimensional advection-dispersion surface formulation. The model output is used to determine suitable locations and configurations for water intakes as well as outlets to maintain the temperature and salinity of the water introduced to the plant at optimum acceptable levels, so that maximum efficiency and minimum operation cost are achieved.

A number of optional scenarios are considered to fully assess the problem. This includes extreme desalination operation scenarios in the summer and winter, possible maximum release of warm water by other industrial facilities, and scenarios of future expansion of the plant production. Three alternatives are investigated including shifting intake to new offshore locations, moving the outfall away from intake area, and having the outfall discharge its effluent to deeper zone. Cost analysis is carried out for two scenarios to evaluate the impact operation cost in terms of chemical and energy cost. The first alternative that involves shifting the intake location about one kilometer offshore is found the be best option as it achieved the maximum reduction of chemical and energy costs for all tested scenarios when compared with the existing configurations. A 2.5% of the total annual cost; that is equivalent to 1,193,000 USD, is saved considering major expansion to the existing industrial facilities; that is 10 times the present existing effluent levels.

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LIST OF ABBREVIATIONS

BPE	Boiling Point Elevation
BRO	Brackish Reverse Osmosis
BRP	Brine Recirculation Pump
DC	Direct Cost
GH	Gate Height
GUI	Geographical User Interface
GUP	General Utilities Plant
HGS	Heat Gain/Recovery Section
HRS	Heat Rejection Section
LMTD	Logarithmic Mean Temperature
MDF	Master Definition File
MED	Multi Effect Distillation
Mg	Milligram
MGD	Million Gallons per Day
MSF	Multi Stage Flash
MW	Mega Watt
NEA	Non Equilibrium Allowance
ppm	Part Per Million
ppt	Part Per Trillion
PR	Performance Ratio
RO	Reverse Osmosis
SPDP	Sitra Power and Desalination Plant
SWRO	Seawater Reverse Osmosis
TDS	Total Dissolved Solids
USD	United States Dollars

CHAPTER (1)
INTRODUCTION

1.1 Background

Natural water resources consist of limited quantities of run-off resulting from floods, groundwater in the alluvial aquifers, and extensive groundwater reserves in the deep sedimentary aquifers. The supplementary non-conventional sources include desalination of sea and brackish water, and renovated wastewater. Water availability is governed by rainfall distribution in time and space, in relation to run-off generation, as well as topographic and geological features that influence water movement and storage.

The countries of the Arabian Peninsula have similar physiographic, social, and economic characteristics, including extremely arid climates, space natural vegetation, and fragile soil conditions (Badr et al., 1992). The peninsula is largely desert with the exception of the coastal strips and mountain ranges. The climate is characterized by long, hot, and dry summers and short, and cool winters for the interior regions and hot, somewhat more humid, summers and mild winters for coastal regions. For the major part of the peninsula, rainfall is low and erratic.

In predominantly arid regions of the world, and especially in the Middle East, where conventional sources of fresh water (e.g., rivers, lakes, reservoirs, or groundwater) are not readily available, seawater desalination will continue to supply most drinking water demands. In some countries, desalinated water may also be used for government subsidized agricultural operations where self-sufficiency and national security are primary objectives. The scarcity of natural resources and the growing gap between demand and available supply of potable water in most of Gulf region is a major challenge. Maintaining economic prosperity with limited water supply, finding enough capital to increase supply, mastering advanced water technologies, securing supplies under all conditions, reducing negative impacts to the environment, and coordinating the efforts of existing water institutions are additional challengers that have to be faced. Fortunately, the region has the financial resources and the ability to turn these challenges into opportunities for economic growth and expansion.

The continuous stress pressure on the region's water resources due to population growth and economic expansion made it necessary to develop both the conventional water resources (surface and ground water), and the unconventional one (desalination of seawater and treated wastewater).

Imbalances between increasing water demand and existing limited water resources are being experienced by the countries of the Arabian Peninsula. During the last decade, water demand in all sectors has increased dramatically as a result of high population growth, improvement in the standard of living, efforts to establish self-sufficiency in food, and promotion of industrial development. Domestic and industrial water requirements for the UAE are satisfied through desalination and a limited amount of groundwater from both shallow and deep aquifers. Most of this desalinated water is produced from MSF (Multi Stage Flash) process.

1.2 Problem Statement

Desalination plants usually take sufficient precautionary measures to transform seawater to safe drinking water by maintaining maximum operation efficiency. However, depending on the local marine environment and layout of the inflow outflow water lines, the performance of the plant can be considerably affected. In the costal water of the UAE, the natural level of salinity is very high (more than 40,000 ppm), while the water temperature in the shallow areas rises up to more than 30° C during the summer. The discharge of brine wastewater and warm cooling water from the plants increases the water salinity and temperature in the vicinity of the plants intakes.

The coastal flow dynamics and their associated circulation pose a great influence upon the water quality of raw water drawn by the desalination plants and eventually upon their performance and efficiency. Natural processes like evaporation, diffusion and dispersion, and mixing are all affecting the transport of warm and brine water in seawater subjected to tides, winds, and locally generated eddies. The presence of oil refineries and other industrial facilities near many of the desalination plants in the

UAE can add another dimension to the problem. Other than the generated oily wastes, such facilities use seawater for cooling purposes that usually cause localized increase of water temperature. A careful selection of intakes and outlets of the desalination plants should therefore take into account the above considerations by studying the coastal flow hydraulics and their effect on the water quality variation.

1.3 Objectives

The objective of the study is to determine the fate of brine and warm cooling water released from the desalination plants as well as other nearby facilities using a three-dimensional advection-dispersion surface model. The model output will be used to determine suitable locations and configurations for water intakes as well as outlets to maintain the temperature and salinity of the water introduced to the plant at optimum acceptable levels, so that maximum efficiency and minimum operation cost are achieved.

1.4 Methodology

A multi-layered hydrodynamic model is developed for the coastal area of Ruwais, an industrial petroleum compound located about 230 Km west of Abu Dhabi City that has a medium size desalination plant. The study is conducted using Delft3D model, which considers a curvilinear grid model with sigma layers in the vertical direction, and incorporates the transport of salt and temperature interactively with water dynamics. The boundary conditions of the model are obtained from the simulation results of a regional model that simulates the dynamics of the entire Arabian Gulf.

The bathymetry information is collected from available universal charts are "Admiralty Chart". Meteorological and other oceanographic information is collected from various relevant authorities and literature. Average rate of water intake and discharge in the sea is collected from Ruwais Desalination Plant Authority in addition to estimating of any missing data. The simulation is carried out for summer and winter seasons by considering the change in solar radiation, variation of wind pattern, and warm water discharges from other nearby industries.

Field measurements for salinity and temperature are collected at a number of locations in Ruwais area provided by recent studies. Water level and currents measured at selected locations for a reasonable period of time are employed into the model. The hydrodynamic and transport models are calibrated against the measured data. Comparison is made with water level data, current data, time-dependent salinity and temperature data.

A number of optional scenarios are considered to fully assess the problem. This includes extreme desalination operation scenarios in the summer and winter, possible maximum release of warm water by other industrial facilities, and scenarios of future expansion of the plant production. Other scenarios assess various intakes and outlets configuration including their locations, depths, coastal angels, and cross sections.

The salinity and temperature at the intake of the desalination plant calculated from each scenario are utilized in estimating the operation cost of the MSF plant using an EXCEL sheet program. The calculated costs for the considered scenario allow identifying the best configuration for intake and outlets that satisfies maximum operation at minimum operation cost

CHAPTER (2)
LITERATURE REVIEW

This chapter focuses on the importance of selecting the desalination plant intake and outfall configuration as well as highlights the environmental considerations for the disposal of desalination concentrates. Selecting the best and practical location for outfall system usually has positive impact on the intake area since the discharged brine might be directed away form the intake location. That enhances the desalination plant performance and reduces the plant operational cost. The chapter illustrates several case studies related to intake systems and impact assessment of brine disposal from coastal desalination plant. Case study carried out in Saudi Arabia highlights the importance of selecting the intake location and the requirements of detailed physical oceanographic modeling of the region before extra load is placed on the existing intake bay. Another study carried out in Oman highlights the significance impact of brine discharge of MSF desalination plant on the near by coastal area, where the coastal ground water aquifers are affected. Other study in Bahrain highlights the importance of conducting a detailed hydrodynamic and design model of any water structure near a desalination plant that may affect adversely the surrounded environment. There are many ways of considerations to be made in order to reduce the impact of disposal desalination concentrates, such as addition processing / treatment in order to remove/dilute the chemical & discharged brine, changing operation conditions, change of material, alternative intake and outfall configuration. This can be achieved by conducting a comprehensive feasibility studies in order to mitigate all the area of concerns that could impact adversely the environment.

2.1 Seawater Intakes of Desalination Plants

The seawater intake has to ensure sufficient seawater in terms of quantity and quality independently from the type of desalination plant (Reverse Osmosis- RO, Multi Effect -MED, Multi Stage Flash-MSF) installed downstream. (Detlef Gille, 2003)
A good intake system guaranteeing the stability of the quality and quantity of the raw water supply is an important factor in improving the desalination process efficiency

and the plant overall reliability. The design of the intake system for coastal plants is much more elaborate and more critical. Figure 2.1 illustrates the function of bar grates and traveling screens.

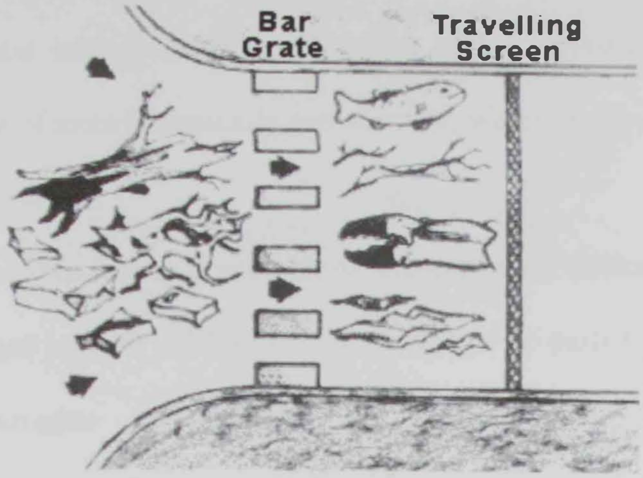

Figure 2.1 Function of bar grates and traveling screens

Large floating debris is kept out of the inlet by the bar grates. Water velocity through the bar grates must be kept low enough so that fish and trash are not held against the screens, thereby reducing the flow area and increasing the velocity through screens. Any increase in water velocity simply hold more trash and fish, further reducing flow area and further increasing water velocity. The traveling screens downstream of the bar grates are designed to screen out fish, crab, claws, sea shells, twigs, polythylene bags and similar trash. These screens are designed to discharge accumulated trash as they slowly rotate. Traveling screens must be maintained in good operating order. The hole size in the traveling screens is on the order of ½ inch or less.

The best seawater quality can be usually reached by beach wells, but in these cases the amount of water which can be extracted from teach well is limited by the earth formation, and therefore the amount of water available by beach well is very often far below the demand of the desalination plant. In theses cases the developer has the choice between:

- An intake from deep seawater with the advantage to have less polluted seawater and the disadvantage of high investment cost which normally limits this type of seawater intake to 20,000 m^3/h
- Open seawater intakes with the advantage of low investment cost but the disadvantage of more biologically active water, which requires more efforts to treat the seawater.

Offshore seawater intakes require a submerged pre-screening device minimizing the amount of sand sucked into the pipeline and ensuring that no particles able to damage or block the pump can enter.

Most of the desalination plants are fed with surface water extracted from the sea in depths of 1-6 m which is highly polluted with sand, fish, seaweed, algae jelly fish and Microorganisms. A much better seawater quality can be extracted from the depth below 35 m because the debris load in such depths is by at least 20 times smaller than in surface water, and therefore it is practically clean.

Seawater intake, as a natural surface/subsurface structure or artificial structures studded to the coast, is an important part of any desalination plant, and its efficient operation has a significant bearing on the overall efficiency and productivity of the plants. Because inland water is either too scanty or already dedicated to other uses, coastal seawater offer the best option as source water for desalination plants. Appropriate design is a prerequisite for making intakes cost effective and environmentally sustainable and it is emphasized that any once-through intake system should take into account the present and prospective uses of selected site by communities of people in region. Environmental effects such as change in the velocity field, seawater, local current pattern, transport of suspended and bottom sediment and seawater stratification has to be reported and studied. The effects of the marine environment on the plant are recognized primarily as befouling of the intake structure, pumps and various plant structures. Events in the marine environment have a definite bearing on operation and maintenance of desalination plants, so that a high quality feed water is a prerequisite for their successful operation. (D.Gille, 2003)

2.1.1 Conventional Water Intakes

The water intakes are designed to provide the required quantities at all times. Many different configurations and designs have been developed in the early stages. The different types of water intakes can be divided into two general categories; shallow seawater intake and Deep seawater intake depending on the plant location, sea bed formation which are onshore and offshore systems. The intake systems consist of either a conveying channel or pipeline and equipped with simple or complex mechanical screening systems. These systems depend on the quantity and type of suspended matter.

2.1.2 Shallow seawater intake

In reality, most of the locations for desalination plants are in the so-called shallow water areas where water depths of 35 m can be reached to distances more than 500 m from the shoreline. The cost of pipelines on or under the sea can be extremely high, and therefore the designer consider an off-shore pipeline length of more than 500 m only if the process requires extremely cool seawater which cannot be extracted form the surface.

2.1.3 Deep seawater intake

The best location for desalination plants are so-called deep water locations where the depths of 35 m can be reached with 50 m from the shore line, since the requirement for additional pre-treatment of such water are low. This type of intake is common where shallow water or high concentrations of weeds are present near the shoreline. Theses intakes usually extend as far as local conditions require. The controlling factors of the offshore distance are the:

- Topography of the bottom of water body
- Size of waves and depth of wave disturbances
- Weed/particles concentrations and movements patterns

The topography of the seabed indicates the bottom slope and the water depth at selected distances. The size of the waves during major storms would indicate the depth of wave disturbance, turbulence can be determined and the type and size of structure can be selected. Weed concentration and their patterns of movement are the most difficult of all. The buoyancy of weeds is variable according to the ambient atmospheric conditions. They travel over the whole range of water depth, therefore the determination of the weed colonies movement patterns becomes extremely difficult to evaluate since the submarine current weeds can travel in any direction according to the prevailing current conditions. (D.Gille, 2003)

The offshore intake head can be located in a seaweed free area but that is only a matter of time before the weeds move in. The most common water depths that satisfy requirements of intake, range between eight meters and fifteen meters and extend offshore to about five kilometers. With this system, the problems involved are similar to those of the onshore systems but with less severity and lower frequency.

2.1.4 Improved Intake Head System

Offshore intake system can be upgraded and highly improved by a balanced designed intake head system that fully utilizes the potential flow theory in guiding water particles in smooth, uniform streamlines into the intake head for the following four flow stages: (Elarbash, 1991)

Approach Stage:

The water particles start to move toward the intake head in radial direction with a final entrance velocity equals about 0.14 m/sec and vanishes down to 0.06 m/sec only one meter away from the head entrance. Currents generated by thermal and density differentials tend to have velocities much higher than approach velocities.

That makes the pressure drop around the intake head due to the suction caused by the head differential at the intake basin negligible and do not cause suspended matter to travel toward the intake head, thus making it virtually nonexistent as a sink point and hydraulically invisible to this matter. Refer to Figure 2.2

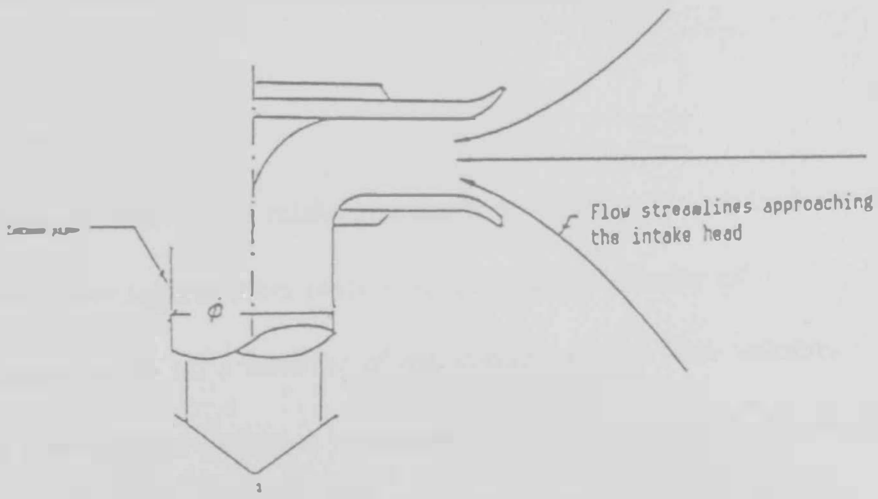

Figure 2.2 Flow to Intake Basin

The Stabilizing Stage:

This stage expands from 1.0Va to 2.6Va, where Va is the entrance velocity. In this stage, flow freedom is provided throughout the entrance ports into the intake head by having the entrance portion of the flow guiding vanes perforated to provide flow flexibility and hence stability and to give access to flow streams created by thermal and density differentials to give more security against suspended matter flow and to smoothly divide and direct the flow into the intake pipe. (Elarbash, 1991)

Acceleration Stage:

This stage extends from the down stream end of the guiding vane perforated portion to the inlet of the intake pipeline. In this stage the flow proceeds smoothly toward the inlet and accelerates to 11Va from 2.6Va with no eddies or vorticities created, thus reducing pressure losses and in turn contributing to smaller intake pipes and shallower settling basin, hence reducing initial operation, and maintenance cost.

The Steady Flow Stage:

This stage start from the inlet of the intake pipeline to its outlet at the intake basin. In this stage, a steady flow regime takes place with an average velocity of 11Va. The intake head dimensions are all a function of the average steady flow velocity (Vp) (Figure 2.3). In conventional design, a reasonable velocity is chosen, with the flow rate known, then area of the flow inlet of the intake head is calculated using the continuity equation. By assuming either the height or the diameter/width, the other dimension is found.

With minor modification applied to the intake head system, it can be easily converted to work as an effluent disperser of effluent water. The system can disperse the effluent in such a manner that it is not allowed to be waved back and washed off on the beach. The dispersed effluent mixes with the ambient water and retains the same

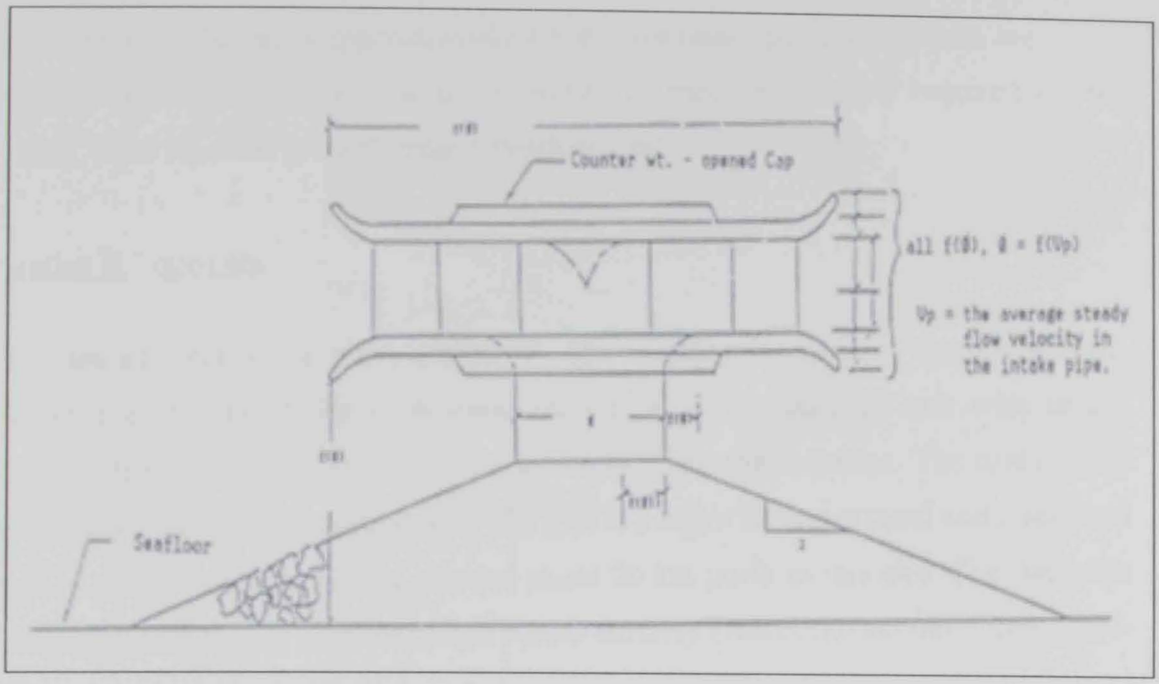

Figure 2.3 Section of the intake head showing the various dimensions as function of the intake pipe

physical and chemical conditions of the surrounding seawater in a short time in which it is allowed to stay below the surface.

2.1.5 Case study of seawater intake facilities in Arabian Gulf

A study was carried out in the Arabian Gulf, bordering Al Jubail desalination and power plant in Saudi Arabia. (Abdul Azis et al., 2000). This is the largest desalination facility in the world producing 246 MGD of water and 1585 MW of power. A new 24 MGD seawater reverse osmosis (SWRO) is being commissioned.

Station I: intake bay

This is a man-made structure studded to the coastline. It is protected by two breakwater sea walls. The intake lagoon, with a 330 m wide entrance, begins 1.8 km away from the shore and taps the clean open seawater of the Gulf. The lagoon broadens quickly to 700 m for about 1.5 km and then declines to 300 m width. The mean depth of the bay is approximately 4.6 m. Five intake pumping stations are located on the shore to provide uninterrupted seawater feed supply required for the plants. Feed seawater is taken from a depth of 3 m.

Station II." open sea

The sea adjacent to the plant is shallow. The coastline is relatively straight and the seaward extension of the continental shelf is a gently slopping one with depths ranging from 1 to 10 m up to a distance of 6 km from the shoreline. The study site is shallow with a depth of around 3 m. The area is a major fishing ground and a seaweed bed. A huge industrial city is situated about 20 km north to this site. The materials required for the study were collected during monthly cruises carried out during 1997-98.

Intake issues and management strategies

Many of the issues of source water characteristics identified above constitute the effect of environment on the plant. The marine environment being a unique ecosystem and the seawater being in a state of perpetual motion, the feed seawater quality and marine life are prone to frequent changes and are unpredictable. Desalination plants require a thorough understanding of their intakes for evolving suitable management strategies. The seawater reverse osmosis plants are susceptible to fouling caused by bacteria and colloidal particles. Intake system effectiveness has become a matter of greater interest recently because of the fouling related problems increasingly being noticed in many desalination plants. Pollution of intake from other sources and from the plants own discharges are suspected to reduce the effectiveness of intakes.

Al-Jubail experience with a segregated Intake Bay has been a great success story. A redeeming feature observed was that the water quality did not show any deviation from that of the open sea. In contrast to the open sea site (Station II) characterized by turbulent waves and shallow depths the intake bay was calmer and deeper. The intake bay mouth situated at about 1.7 km from the seashore accords the benefit of clear offshore seawater. The intake pumps withdrew water from a depth of 2.4 m making it typically a coastal subsurface intake. Besides the entrainment effect, the enclosed nature of the intake system unavoidably has created an embayment effect also in the form of elevated TSS values and planktonic abundance. The intake bay serves as a shelter for the phytoplankton and zooplankton providing greater residence time and increased bio fouling potential. The intake water chlorination and sub-sequent in-plant chlorination has been found to be quite effective. The intake zone is free from contamination from the disposed brine.

Desalination plants in the Middle East, where the intake zone is not segregated from the discharge zone have experienced contamination of the feed by the discharged brine. In such plants, the intake zones were found to be affected by the elevated temperature and salinity of the receiving waters, apparently due to spreading and re-circulation of the effluent-mixed layer. This underlines the need for a carefully segregated intake and discharge bays for all desalination plants located in the region. Al- Jubail experience in this regard has been found to be most successful in keeping the feed water free from discharged brine. (Abdul Azis et al., 2000).

In Jubail, intakes 13 and 14 for the new SWRO plant will be at about 2-4 m depth in the Intake Bay. The intake 14 has been observed already as having high biological potential and suspended solids. The width of intake basin at Intake 14 is only about 150 m whereas in other areas it is greater than 300 m. The sensitive nature of Intake 14 is due to its interior most position in the lagoon. The area being relatively shallow, the problem of biofouling and colloidal fouling could be significant to the new SWRO plant in Al-Jubail and preventive measures are therefore needed.

Summary

From this study, the following findings and recommendation are concluded as follows:

* AL-Jubail experience with a segregated and protected coastal intake bay has been found to be a great success. The source water quality remained impressively good through out the period of study and did not show any sign of contamination either from the discharge area or from the region of the Al- Jubail industrial city.

* At AL-Jubail, the sea adjacent to the plant is shallower than the intake basin. The drag of seawater maintained by intake pumps and the break water walls of the bay creates an entrainment and embayment effect.

* Whereas elevated total suspended solid load, incidence of planktonic blooms and ingress of biofouling organisms have the potential of creating serious colloidal and biofouling situations in the seawater RO plant, the ingress of jellyfish and sea grass could render the intake bar/traveling screens ineffective and decrease the efficiency and increase the maintenance operation cost.

* As the sea adjacent to the plant is very shallow, a detailed physical oceanographic modeling of the region is needed before extra load is placed on the existing intake bay.

* In order to reduce the potential of colloidal and biological fouling in the new SWRO plant in Al-Jubail from the presently used intake 14, a suitable alternate intake may be identified for drawing the needed feed seawater. An effective filtration and pretreatment system taking into account the uncertainties regarding suspended solids and planktonic blooms also may be incorporated in the plant.

* AL-Jubail plant has to be in a state of preparedness to meet the ingress of jellyfish into the intake bay. Fixing of jellyfish scooping device in front of the bar screen, putting up a jellyfish prevention boom and fixing of electronic repellers at the bay entrance are some proposed measures to control ingress of jellyfish.

* The northern breakwater wall of the intake bay needs a modification at its entrance to prevent a direct access of invasive species into the intake bay.

2.2 Seawater Outfalls of Desalination Plants

Desalination of seawater leaves brine containing a high salt concentration to be disposed into the environment. For coastal desalination plants, the most practical and least expensive brine disposal operation is to discharge it into the sea. However, the location of the outfall may affect the salinity and temperature conditions at the intake, and as a result, adversely affects the desalination plant performance.

Because of the rapid development of industry, cities and agriculture, especially along the coastal areas of Oman, not only the ground water is intensively pumped out but also its quality is deteriorating as a result of seawater intrusion. The need for seawater and for access makes it a practical choice for locating a desalination plant in coastal areas. It seems natural and practical for coastal

desalination plants to dispose of their brine waste into the sea, via outfalls at some distance from the shoreline/beach. (Anton Purnama et al., 2003). There are several types of disposal methods, among which the following three methods:

- Ocean Outfall
- Disposal Ponds
- Basalt Aquifer Injection Wells

An ocean outfall is a long pipe that is laid along the seafloor. At a certain depth and distance form the shore, the pipe is perforated to allow a waste stream to diffuse through the pipe into the ocean. Due to concerns with environment impact and cost, the ocean outfall disposal method was ranked low. However, this method is still in use in many desalination plants with increasing the distance of locating these outfalls (range from 1000m to 3000m).

Disposal ponds can be used as a method for disposing of brine. The brine is pumped into the ponds where it evaporates, leaving behind salts and other dissolved solids. Brine ponds can also be used to hold the brine solution until it can be disposed of in another way. The injection well method inject the waste streams to deep injection wells within aquifer and 300 feet below the source well locations. The injection wells should be deep enough to eliminate potential of waste brine seeping into the offshore coastal waters.

2.3 Impact of Brine and Temperature on Marine Environment

The problems of thermal discharge are becoming more and more critical as the demand for electricity and desalinated water is increasing in the Arabian Gulf countries. Thermal discharge may cause three major changes in the natural ecosystems. The first change is the thermal enrichment of the receiving water; secondly, alteration of the chemical make-up of the water may be detected; and thirdly, the biotic structure may be modified. In arid climate regions, as it is the case with most of the Arabian Gulf countries, it is no longer possible to rely solely on limited underground water resources. To meet the growing demands for potable water and its reliable supplies, several desalination plants have been constructed in many parts of Gulf countries.

The impact of brine disposal operations on coastal and marine environment is still largely unknown; however, it is commonly thought that the brines discharged must ultimately be diluted and transported into the ocean. Nevertheless, for each coastal seawater desalination plant, care has always been taken to determine the optimum site of water intakes and brine waste outfalls. One factor affecting dispersion of brines discharged is the water depth variations. In deeper water, the mixing is stronger as the current tends to be stronger, and there is a greater depth over which to dilute brine waste.

2.3.1 Case study of impact assessment of brine disposal from coastal desalination plants in Oman

There are two main types of seawater desalination plants: multi-stage flash (MSF) and reverse osmosis (RO). MSF distillation is the leading seawater desalination processes in terms of its capacity. RO process uses high pressure to remove dissolved salts through a membrane; and the concentrated brine produced may have salinities up to 2.5 times higher than the ambient seawater. The total amount of brine produced in Oman through MSF plants is much larger than that of its RO plants (Table 2.1). (Anton Purnama et al., 2003)

Table 2.1 The existing coastal desalination plants in Oman

Location	Water source	Plant type	Capacity, m^3
Shisah	SW	VC	300
Kumzar	SW	RO	200
Limah	SW	RO	100
Ghubrah	SW	MSF	159,000
Sur	SW	RO	4,545
Ras Al-Hadd	SW	RO	100
Al-Ruwais	SW	RO	272
Aseelah	SW	RO	195
Masirah	SW	MSF	1,150
Mahout	BGW	RO	100
As-Saadanat	BGW	RO	50
Al-Zahar	BGW	RO	50
Madrakah	SW	RO	100
Suqarah	SW	RO	100
Al-Halaaniyat	SW	RO	60

The first and largest MSF coastal desalination plant in Oman is in Ghubrah, supplying demands for the capital Muscat areas (Al Sajwani, 1998). Seawater is drawn from an intake of about 2 km offshore, and the outfall for brine waste discharges is at the beach. There are also many other smaller RO coastal desalination plants in Oman that dispose of their brine waste into the sea (Table 2.1). Other coastal desalination plants in the Arabian Gulf countries have also been reported to discharge of their brine waste into the sea.

Oman has a coastline stretching for more than 1700 km from the Gulf of Oman to the Arabian Sea. Beginning at the northern end of Oman, the Musandam coast is characterized by precipitous slopes that continue below water to depths exceeding 40 m. Only a few of these shores are accessible by land. The northern coastline of Oman is a predominantly sandy beach, which follows south from Ghubrah to Sur with sandy beaches and rocky coastal cliffs. The coastline shows a quite steep bathymetry to depths greater than 2000 m within 8 km offshore. The southern part of the Omani coastal water faces the Arabian Sea and extends to the Yemeni border. The coast is a mostly sandy beach; but further south to the border of Yemen, the shore is characterized by low metamorphic rocks and cliffs with steep slopes descending into the sea. The imaginable environmental impact most commonly associated with brine disposal operations from coastal desalination plants are attributed to discharges of hot concentrated brine, its subsequent mixing and transport, and its effects on marine habitats. The brine plumes due to continuous discharges into the sea are observed drifting parallel to the shoreline and slowly heading towards the beach (Figure 2.4).

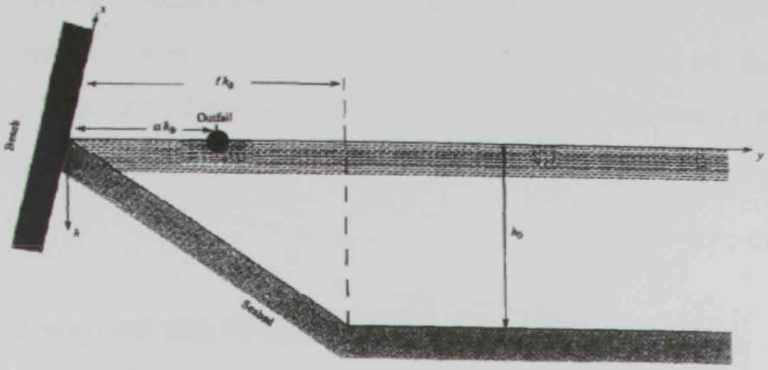

Figure 2.4 Seabed depth profile of a sloping beach.

In order to meet the growing demands for water, underground water resources have been intensely exploited, in particular through abstraction from wells. However, as replenishment of the aquifer is very low due to the shortage of rainfall, coastal areas of Oman face the critical problem of seawater intrusion. In order to ease the groundwater contamination by saline water, many coastal desalination plants have been constructed (see table 2.1).

Coastal desalination plants in Oman discharge the brine waste containing high salt concentration into the sea. The results reflected that the continuous discharging brine wastes directly on the shoreline would result in the salinity increased along the coastline. Unfortunately, such an increased in salinity will intensify, instead of improving, the critical problems of seawater intrusion into coastal groundwater aquifers. The impact of brine disposal operations on coastal and marine environments can be avoided by extending the outfalls further offshore to the sea. (Anton Purnama et al., 2003)

2.3.2 Case study of impact assessment of Desalination Plant on the Physical properties of seawater in Bahrain

The magnitude of the effects of the thermal discharge varies with the temperature of the effluents, the topography of the system and the dispersion rate of the receiving water. Signs of thermal effects on marine ecosystem could be seen through the alteration in the water quality, marine organisms and habitats.

The most obvious chemical alteration may include an increase in the salinity and a decrease in the dissolved oxygen. The effects of these changes on the marine ecosystem depend on the rate of dispersion of the effluent. As the rate of dispersion increased, the effects of the effluent are decreased. (Winters et al., 1979).

Study Area

The site is located at the north side of Sitra Island, Bahrain (Figure 2.5).

The island is surrounded by a shallow bay. The average depth of the by is 1m. The Sitra Power and Desalination Plant "SPDP" is a thermal plant located on the island and produces a bout 28 MGD of desalinated water and 125 MW of electric power. The plant has four cooling water conduits. These conduits are located on the north side of the plant. The seawater inlet flow has an average rate of 66,000 m^3/hr. There are four effluent outlets, three from the distillers and one from the condenser. The hot effluent is discharged at an average rate of about 12,000 m^3/hr.

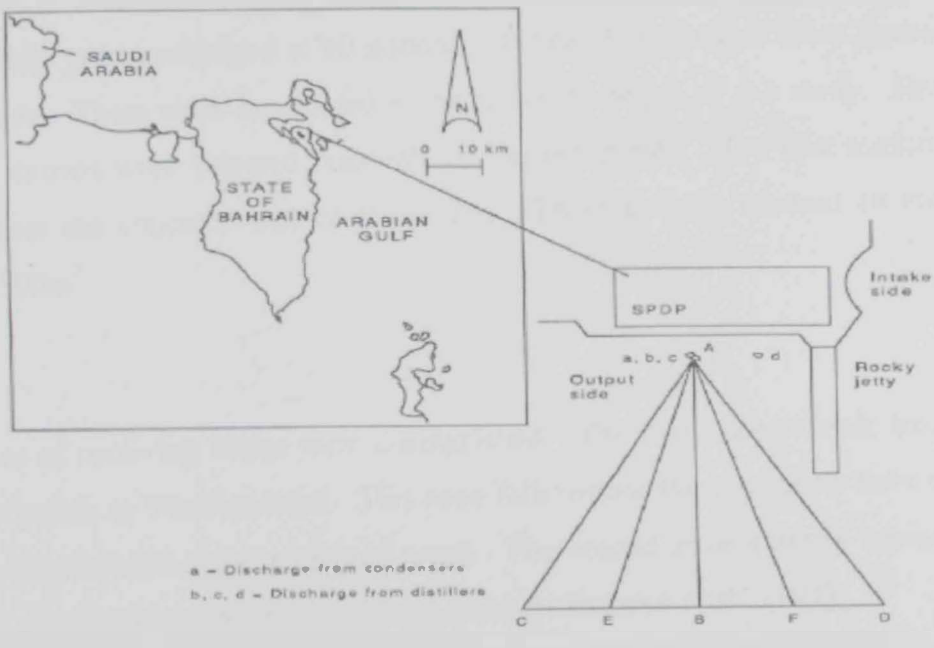

Figure 2.5 Location of coastal desalination plants in Bahrain. (Ahmed Al Tayaran, I. Madany, 1991)

In order to prevent the spillover of warm effluent into intake surface water, a rocky jetty has been constructed. The length and width of the jetty are 70 and 2 m, respectively. The water temperatures of site range from 10 to 20 °C in winter months, December-February (Price et al., 1984) and may reach to about 40°C during summer months. Coastal air temperature during winter months normally drops to 12°C and regularly exceeds 40°C in summer (Issa et al., 1989). During the winter months, the salinity of surface water of the site may drop to about 37ppt, and may reach 45 ppt during summer. The dissolved oxygen levels of the surface water range from 6.0 to about 4.0 mg/l during winter and summer, respectively, (Al-Alawi, 1983)

The Field Study

The effects of thermal discharge from the SPDP on the surface water temperature and salinity were monitored. An electric thermometer was used to measure water temperature. A refractometer was used to determine the salinity. Measurements were conducted twice a week for a period of 2 months (February and March). These 2 months are a transition period between the winter and summer months. The measurements were conducted at 90 stations. Fifteen (15) stations were located on the inlet side. These were considered as the reference points of this study. Seventy five (75) stations were selected randomly on the outlet side. The first station was selected near the concrete wall of the outlets. These stations covered an area of approx. 1500m^2.

Results

Two zones of receiving water were distinguished. The first zone extends from the discharge points to 70m seaward. This zone falls within the protection limit of the jetty (hereinafter called the protected zone). The second zone extends beyond the protected zone to about 150m seaward. (Ahmed Al Tayaran et al., 1991)

The temperature and salinity of the stations of the protected zone were significantly higher than those of the control stations.

Beyond protected zone limit, there were various responses. The significant differences in water temperature between the receiving and control stations continued, but significant differences in the water salinity of the receiving and control station were also observed. Heated water dispersion is strongly affected by the presence of the jetty. The jetty restricts water currents and circulation within the protected zone.

Within the protected zone, the dispersion of the heated effluent was strongly restricted and depressed. The dispersion of temperature in the protected zone was also affected by the jetty, whereas, the dispersion of temperature returned to normal beyond the jetty. At about 30m beyond the protected zone, and where the jetty effect is lifted, the control stations were affected by the change of the temperature of the receiving water. The size of the mixing zone was estimated as 160m (exceeds jetty by about 90m). (Ahmed Al Tayaran et al., 1991)

Effluent water is directly discharged into the shallow coastline water body at a temperature of 10 to 15 °C above the naturally occurring equilibrium water temperature during winter and summer. The water discharged into the natural water body from the SPDP caused the effluent to spread over the surface and avoid excessive mixing. The warmed water is directly exposed to the atmosphere for heat dissipation. This type of dissipation relies on the rate at which warmed water moves to the surface.

It appears that the jetty is not working in the way in which it was designed. The effluent was detected to cause changes in the water temperature and salinity beyond the jetty area. It also appears that with the jetty area, water circulation was affected. These effects were reflected in the increasing levels of the temperature and salinity in receiving water and the limited mixing efficiency of the water.

The mixing zone of the receiving water was extended to approx. 160m from the outlet point. This distance is between 50 and 60m beyond the effective designed limit of the jetty and exceeds the limit recommended by the U.S. Atomic Energy Commission (1971). The mixing zone size, according to U.S. A.C recommendation, should not exceed 90m for a plant with similar specification as SPDP. The jetty is effectively reducing the dissipation of the effluent.

The author recommended rectifying this deficiency by extending the intake to deeper water, extending the jetty, or by changing the method of discharge of the effluent. The first measure may not be possible due to the heavy traffic of Sulman Port near the

SPDP and the restricted depth of the area that makes this alternative unfeasible. Increasing the length of the jetty causes further water restriction and may not be suitable for decreasing the size of the mixing zone. Underwater effluent discharge may be the best alternative. Sending the SPDP effluent 100m offshore through underwater pipes provide enough protection to the intake and reduce the effect of restricted water circulation. However, a further feasibility study was still recommended to evaluate the commercial side of this alternative. (Ahmed Al Tayaran et al., 1991)

2.4 Environmental Considerations for the Disposal of Desalination Concentrates

For negative environmental impacts, the industry needs to recognize this trend and determine ways of mitigating the problems. More generally, the industry needs to be proactive in addressing these issues that may, if not addressed, slow or limit realization of the tremendous potential for desalination to meet the growing needs for alternative water sources in an environmentally safe and cost-effective way (Mike M., 1992).

The following sections review the characteristics of membrane (reverse osmosis) and thermal concentrates and the environmental concerns associated with each method of concentrate disposal. Particular attention is paid to the surface discharge of concentrates since it is the most frequently used method of concentrate disposal, both for seawater and brackish processes.

2.4.1 Characterization of Desalination Concentrates

Factors affecting concentrate characteristics include:

- Raw water quality
- Pre-treatment chemicals
    - polymer additives
    - acid
    - chlorination
    - corrosion inhibitors
    - dechlorination

- Water recovery
    - temperature
    - process production of corrosion products
- Post-treatment chemicals
- Concentrate blending
- Addition of cleaning or other wastes to concentrate

Concentrate characteristics are summarized in Table 2.2 for the various desalting processes considered. Unlike most industrial processes, the major waste stream produced by the desalting processes - the concentrate - is not characterized by intentionally added process chemicals. Rather, the concentrate reflects the raw water characteristics, and the composition at a more concentrated level. Raw source water is pretreated with additives to control scaling, fouling, and corrosion of process components, all of which compromise system performance. The level of these added chemicals is relatively low in most cases (typically less than 10 ppm), so that concentrate is overwhelmingly defined by the constituents present in the raw water. An exception to the low level of added chemicals is the use of acid to reduce scaling potential from carbonate species. Acid may be added in amounts up to a few hundred mg/L. Besides lowering the pH, the addition of acid increases the concentration of the acid anion species such as sulfate in the case of sulfuric acid addition. Such anions, however, are not of toxic concern.

Thus the feed water to the processes is slightly modified raw water. In the process itself most or all of the raw water constituents get concentrated depending on the particular process. Typical concentration factors, different for the various processes, are given in Table 2.2.

Due to the much higher processing temperatures in thermal processes, the potential for corrosion is significant. The industry has shifted towards the use of more corrosion resistant materials as well as away from the continuous use of acid. Consequently, corrosion potential has decreased. Where acid and chlorine are used, good control of chemical levels is important. Post-treatment of concentrate is usually minimal. Brackish reverse osmosis (BRO) concentrates that originate from groundwater sources may be low in dissolved oxygen and high in dissolved CO_2 and even H_2S.

Post-treatment may consist of aeration for oxygen, degasification to get rid of CO_2 and H_2S, and pH adjustment to bring the pH back up to neutral levels that minimizes corrosion potential and be compatible with receiving water life forms. Seawater reverse osmosis (SWRO) processes may have only pH control as post-treatment.

Concentrate from thermal processes, such as multistage flash evaporation (MSF) and multi effect distillation (MED), is typically mixed with once-through cooling water prior to discharge. The cooling water usually contains a certain amount of free chlorine that is dependent on the sophistication and effectiveness of chemical control. The dilution of concentrate results in a final discharged effluent that is rarely more than 15% higher in salinity than the receiving water. In larger thermal desalination plants that are sited along with steam turbine power plants, the concentrate may be further diluted with condensate water. SWRO concentrate, on the other hand, can be 100% higher in salinity than the receiving water.

Other wastes produced by the desalination plant, such as cleaning wastes, may be mixed with the concentrate and discharged together. The intermittently produced cleaning wastes may be stored and continuously blend into the concentrate or discharged to the sewer. Membrane chemical cleaning agents include acids, bases, complexing agents, enzymes, detergents, and disinfectants. The wastes also contain the scaling and fouling materials that are cleaned from the membrane system. In thermal processes, the fairly standard acid cleaning produces a waste that may also contain elevated levels of metals due to tube corrosion/etching. In summary, while desalting concentrate depends on the particular process involved, there are several important shared characteristics. Desalting concentrate may be described as having low levels of process-added chemicals so that raw water characteristics determine final concentrate characteristics. The concentrates are characterized by few parameters other than high total dissolved solids (TDS) relative to the raw water and higher temperature in the case of thermal process concentrates. Membrane concentrates may be further characterized by low pH and thermal process concentrates (frequently) by the presence of trace metals and residual chlorine. It is important to realize that, in the absence of corrosion products and with good chemical control and use of non-toxic additives, desalting processes do not produce more pollutant material or mass; they redistribute (concentrate) what is present in the raw water. (Mount et al., 1992)

2.4.2 Concentrate Disposal and Environmental Concerns

There are several means of disposal of concentrate that are practiced worldwide. These include:

- Surface water discharge
- Disposal to front end of sewage treatment plants
- Deep well disposal
- Land applications
- Evaporation ponds
- Brine concentrators

First is the discharge to the effluent end of a sewage treatment plant. This option avoids hydraulic overloading of the sewage treatment plant. The combination of discharges offers dilution for both waste streams. Second is the further concentration of the concentrate by a brine concentrator. This is typically an expensive option; however, feasibility needs to be viewed on a site-specific basis. The brine from the concentrator may be converted to solids (zero discharge option) by further processing by spray dryer or crystallizer. Alternatively, the brine may be added to lime settling ponds where the solids end up as sludge. Another alternative is to haul the brine to a centralized multipurpose wastewater treatment center for final treatment and disposal. The environmental concerns associated with the disposal of concentrate center on the contamination of surface and ground waters, soil, and air by individual chemical components and the salinity level of the concentrate. The source of the chemical contaminants can be from raw water, added chemicals, and corrosion.

By far, most concentrates are discharged to available and adjacent surface waters. In the United States, regulation of effluents (including concentrates) has evolved from a few bulk physical and chemical parameters of pH, total suspended solids, biological oxygen demand, etc. to include many chemical inorganic and organic parameters. Further, the allowable level of many chemical species has decreased over that last ten years. More recently, surface water discharge permits have also required a more direct demonstration of effluent non-toxicity in the form of whole effluent toxicity tests (WET tests). Here, various organisms, ideally common to the receiving water, are exposed to the effluent for a period of time. In acute tests, the survival of species is monitored. In chronic tests, the effect of the effluent on growth and reproducibility is monitored. Periodic testing to monitor effluent quality is required after permit issuance. In some even more recent permitting instances, bioinventory study of the receiving water life forms has been required - a direct indication of the environmental effect.

The discharge of concentrate to the front end of a sewage treatment plant raises practical concerns about the effect of the concentrate TDS and possible heavy metals on the process bacteria, as well as the effect of the added concentrate load on plant capacity. The primary environmental concern is for the increase in TDS of the sewage plant effluent due to the concentrate.

Land application of concentrates includes spray irrigation and percolation ponds. Allowable salinity and specific chemical levels are dictated both by vegetation tolerance and salinity of underlying aquifers. Water quality limitations frequently dictate blending of the concentrate with a lower salinity water (such as sewage plant effluent) prior to discharge. This disposal option is typically limited by climate and by the availability of land. Permits may require monitoring of soil and groundwater conditions.

Disposal by deep well injection is disposal to a non-drinking water aquifer that is structurally isolated from overlying drinking water aquifers. Monitoring of disposal well integrity and of the water quality of nearby monitoring wells is typically required in the disposal permit. This disposal option is not possible in most locations, and where possible, it can be costly. Evaporation ponds are most appropriate for relatively warm, dry climates with high evaporation rates, level terrain, and low land costs. Monitoring of pond integrity is typically required in disposal permits. In the zero discharge case, the concentrate is taken to dry solids as a result of further treatment. The environmental concern is with the disposal of the solid waste and specifically with the leaching of chemical components from the landfill site and eventually into nearby surface and underground waters. Table 2.3 lists the particular environmental concerns for each of these disposal options as well as possible mitigation methods. (Mike M., 1992).

2.4.3 Surface Water Discharge of Concentrate

Surface water discharge is the most frequent disposal method used for brackish water plants and is the disposal method for nearly all seawater plants. The environmental effects from surface water discharge are more readily apparent than those from other disposal options. Consequently, there has been more focus and research on environmental effects of this disposal method. Several environmental concerns that are raised by the discharge of concentrate to surface waters have to do with the chemical makeup of the concentrate and its temperature relative to that of the receiving water. Table 2.4 lists the various specific environmental concerns, the processes they are associated with, and the possible mitigation approaches.

Seawater is much more uniform in composition than groundwater. The variable nature of groundwater quality can lead to environmental concerns associated with the raw water. The raw ground water may contain contaminants that when concentrated become toxic to some aquatic organisms. Some mitigation is possible through limiting the degree of concentration directly in the process or by blending of the concentrate with any available and suitable dilution water. Treatment of concentrate for removal of specific chemical species is generally not economically feasible - with the following exceptions. Groundwater may contain low levels of dissolved oxygen and high levels of other dissolved gases such as CO_2 and H_2S. Routinely encountered levels of CO_2 and H_2S are directly toxic to many organisms. Concentrate levels of these gases can be corrected by treatment of the concentrate prior to discharge. Within the last few years, it has been determined that some groundwaters, when concentrated (and some when they are not concentrated) are toxic to various organisms used in the whole effluent toxicity (WET) tests. The cause of the toxicity is the unusual relative amounts of essential ions present (Na, K, Ca, Mg, Cl, SO_4, HCO_3, etc.). More specifically, the toxicity occurs when the relative amounts of these common ions are 'unbalanced' as compared to the relative amounts of these common ions in a 'balanced' water, such as seawater diluted to the same salinity level. This toxicity most frequently occurs in situations where waters are less sodium chloride dominated and more calcium carbonate or calcium sulfate dominated (or dominated by some other species). This essential or common ion toxicity is being determined to be a factor in several cases of failed WET tests in Florida brackish reverse osmosis plants. Current research is underway to better define the nature of this type of toxicity.

It appears that the common ion toxicity is not a linear function of concentration like most forms of toxicity, but sharp thresholds exist so that toxicity occurs above certain concentrations and toxicity disappears sharply once the amount of a specific common ion is diluted past its threshold. This unusual nature allows for an efficient application of blending, of the use of diffusers that assure a certain immediate level of dilution in the receiving water, and of mixing zones. The term mixing zone is used here to mean a regulatory concept, which defines a limited area or volume of the receiving water where the initial dilution of a discharge is usually allowed to occur.

Some environmental concerns arise from the pretreatment of desalting process feedwater. Anti-scalant additives, corrosion inhibitors, acid, and chlorine may be added during pretreatment and be present in the feedwater and thus the concentrate. Obviously, any pretreatment additives that remain in the concentrate are concentrated along with other feedwater species. The use of non-toxic additives and post-treatment of the concentrate to increase pH and limit chlorine residuals are typical mitigation approaches. Some environmental concerns are directly due to the processing. Thermal processes produce a concentrate of elevated temperature relative to the feed water source, which is typically also the receiving water for the concentrate discharge. The impact of temperature differences between discharge and receiving water can be reduced by blending with lower temperature waters prior to discharge and by the use of diffusers. Mixing zones for temperature may also be granted by regulatory agencies. Depending on the materials of construction, thermal processes may give rise to metal ions of corrosion origin (Cu, Ni, Fe, Cr, Zn) in the concentrate. Toxic levels of these metals may be reduced or avoided by using different materials, through improved chemical control, and through dilution or blending of the concentrate. Where intermittent acid cleaning wastes are added to concentrate, a holding tank and continuous blend of the cleaning wastes into the concentrate can lower instantaneous levels. Where feasible, separate disposal of cleaning wastes may be considered.

For an SWRO concentrate of 70 ppt, a dilution of about 35 to 40 times would be required to achieve an effluent stream salinity of one ppt above the receiving water (assumed to be 35 ppt). Recently, brine disposal in oceans has been modeled to take into account these considerations. Thus a tool is available to assist the design of a proper dispersion and discharge system for this situation. This addresses the mitigation method of diffusers. Other mitigation methods include blending and the assignment of mixing zones. Since thermal process concentrates are typically mixed with cooling water prior to discharge, effluent salinity levels are much lower than those from SWRO plants.

2.4.4 Technical Solutions

From the discussion, it may be seen that the mitigation methods involve both technical and regulatory approaches. In general, the technical and regulatory solutions mentioned include:

Technical solutions:

- Additional processing (treatment or blending to remove or dilute the chemical of concern)
- Changing of operating conditions (changing recovery to limit concentrate salinity)
- Changing of materials (use of non-toxic additives, non-corrosive materials to reduce or eliminate the problems)
- Reducing effluent impact on receiving waters (use of diffusers to afford an immediate dilution factor)
- Better chemical control (of chlorine to reduce residual levels; of acid to avoid excessive corrosion; of other process additives to limit their level)
- Continuous blending of cleaning wastes and concentrate or separate disposal of cleaning wastes and concentrate

Regulatory solutions:

- Granting a mixing zone for specific chemicals, for certain toxicity situations, and for temperature

Author concluded that not all of these 'solutions' are presently possible. In some cases more research needs to be conducted to provide better scientific understanding and therefore a more appropriate basis for acceptance of these solutions by regulatory agencies. In other cases, the economic feasibility of mitigation methods is questionable. This feasibility must be evaluated on a site-specific basis and be part of the design or redesign process associated with determining feasible concentrate disposal options. (Mike M., 1992)

Table 2.2: Characterization of Desalting Processes and their Concentrates (Mike M., 1992).

Process	BRO	SWRO	MSF/MED
Raw Water	Brackish	Seawater	Seawater
Recovery based on feed	60 to 85%	30 to 50%	15 to 50%
Temperature	Ambient	Ambient	10 to 15°F above ambient
Concentrate blending	Possible, not typical	Possible, not typical	Typical, with cooling water
Final concentration factor	2.5 to 6.7	1.25 to 2.0	<1.15

Pretreatment

- Similar schemes may be used in all processes
- Chlorination where biological may be present (more for surface waters)
- Polymer additives used for scale control
- Acid sometimes used in addition to additives (particularly for RO)
- Corrosion inhibitors used in thermal processes
- Decolourisation for some membrane processes where chlorination is used

Post-treatment

- Degasification for CO_2, H_2S (BRO) aeration for adding O_2 (BRO)
- pH adjustment for corrosion protection (RO)

where BRO = brackish water reverse osmosis
SWRO = seawater reverse osmosis
MSF = multistage flash evaporation
MED = multiple effect distillation

Table 2.3: Environmental concerns for different disposal options and possible mitigation method, membrane processes (Mike M., 1992).

Disposal option	General environmental concern	Mitigation method
1. Surface water	Contamination of receiving water (See table 2.4)	See table 2.4
2. Sewer system blending;	Contamination of eventual receiving water	Reduce recovery; membrane type selection
3. Land application	Contamination of underlying; groundwater, and of soil	Reduce recovery, blending; membrane type selection
4. Deep well injection	Contamination of overlying drinking water aquifers due to well leakage	Move disposal location or change means of disposal
5. Evaporation ponds	Contamination of underlying higher quality aquifers due to pond leakage	Double lining with leach ate collection system
6. Zero discharge	Contamination of underlying higher quality aquifers due to land fill leakage	Double lining with leachate collection system

Note: in every case the contamination may be due to the TDS level, specific chemical specie's level, or both

Table 2.4: Surface water discharge: Environmental concerns and possible mitigation methods (Mike M., 1992)

Environmental Concern	Process	Mitigation method
From raw water		
1. Contaminants present in raw water	BRO (others)	Limit degree of concentration, blending; mixing zones; post-treatment
2. 'Imbalance' in essential ions (from many groundwater)	BRO	Diffusers; blending; mixing zones
3. Low dissolved oxygen, high H2S, etc. (from many groundwater)	BRO	Aerate, degasify, or otherwise treat prior to discharge
From pretreatment		
4. Toxicity of additives	All	Use non-toxic additives
5. Low pH (due to acid addition)	RO	Raise pH prior to discharge
6. Chlorine in concentrate	Thermal	Dechlorination prior to discharge, improved chemical control
From the process		
7. Temperature	Thermal	Blending; diffusers; mixing zones
8. Metal ions of corrosion	Thermal	Different equipment materials, blending; improved chemical control; continuous discharge of cleaning wastes with concentrate, separate disposal of cleaning wastes
From the concentrate salinity		
9. Different salinity than receiving water	RO more than thermal	Diffusers; blending; mixing zones

2.5 Hydrodynamic Modeling for Arabian Gulf

The oceanic region comprised of the Gulf, Strait of Hormuz, and Gulf of Oman is one of the most important waterways in the world. The maximum width of Gulf is 338 km, and the length to its northern coast is nominally 1000 km. The surface area of Gulf is approximately 2.39×10^5 km^2, and a mean depth of 36 m implies an average volume of 8.36×10^3 km^3. The bathymetry of the Gulf shallows to the northwest and to the west coasts. An isolated trough extends northward from the Strait of Hormuz along the Iranian coast approximately 100 km. The trough collects denser bottom water and impedes exiting bottom flow. The possibility exists that a weak bottom circulation into these depressions cold lead to a buildup of pollutants. The board region of shallow water off the coast of the United Arab Emirates (UAE) features many small islands and lagoons where it is extremely difficult to operate oceanographic vessels. This area is a region of intense evaporation, and a significant contribution to the deep circulation of the Gulf is made here.(Reynolds 1993)

Probably no other body of water of comparable size and economic importance is so under investigated as Gulf region. Modeling efforts have been carried as far as they can with the present, spotty data base. Winds and hydrography and the resulting currents are highly seasonal, and alack of data sets for all seasons adds another dimension to the problem. An extensive modeling effort is one mean of bridging the data gap. Modeling efforts can be divided between tidal models and estuarine circulation models. Three comprehensive models of the estuarine circulation currently exist: 1. US Naval Oceanographic Office (Horton et al., 1992); 2. The Catholic University of America (Chao et al., 1992); and 3. King Fahd University of Petroleum and Minerals (KFUPM) (Lardner et al., 1991). The Navy model is a three-dimensional, primitive-equation circulation model with complete thermodynamics and imbedded turbulent-closure sub models. It uses terrain following vertical coordinates and has a horizontal grid size of approximately 8 km and 14-22 levels in the vertical. The Catholic University model uses 20 km grid size and 11 levels in a diagnostic formulation. The KFUPM model covers the Gulf with a rectangular grid of approximately 10 km size. It is three-dimensional, but has the option of being a two-dimensional, vertically-integrated mode. The algorithm uses a mode-splitting method by which the depth-averaged equations are first solved for the barotropic mode, then the momentum equations are stepped forward to compute the velocity profiles. The bottom friction and advective terms are computed for use in the depth-averaged equation on the next step. These models all produce similar large-scale patterns. There are several excellent tidal models for the Gulf, and the paper by (Le Provost, 1984) is a good review. Tides are oscillatory and contribute little ot the residual current flow. Thus, for scales beyond the tidal excursion (< 10 km), they contribute little to advection processes. They do contribute to horizontal and vertical mixing mainly by production of mechanical turbulence over the sea bed and around obstacles. The KFUPM has developed a detailed tide model of the Gulf (Lardner et al., 1982)

2.6 Hydrodynamic Modeling for Ruwais Area (UAE)

With the rapid development of the coastal zone, the environmental issues in UAE are drawing significant attention in recent days. It is important to understand the nature of the mixing and variation of these parameters for precise investigation the local water quality. The shallow coastal shelf of the UAE is known as dense water formation zone. Denser water formed in the shallower water moves towards the deeper part as density current (Chao et al., 1992; Reynolds 1993). Temperature-salinity distribution in this part of the southern Arabian Gulf influences the water quality. Resolving the physical dynamics of the coastal water of Ruwais, an industrially developed segment of UAE coast, is important for the assessment of ecological health of the area. Typically, in the southern Arabian Gulf, the salinity gradually decreases in the seaward direction as the depth increases (Reynolds 1993). The coastal water temperature is higher in the summer and the trend reverses in the winter. Such horizontal gradients can potentially develop three dimensional residual flow (Elshorbagy et al., 2004b). In Ruwais coast, the shoreward density variation is more pronounced as a number of industries discharging warm and/or brine water close to the shore line affect the temperature-salinity distribution of the area.

(Elshorbagy et al., 2004b) demonstrated through a series of tests of mathematical model that density gradient and wind are the most important forces for generating mean circulation in the Arabian Gulf. The density current is more prominent in the north and in the central region whereas the wind governs the current along the coast of Saudi-Arabia and UAE. The wind also influences the density current and plays a regulating role on the fresher water influx from the Arabian Sea.

2.7 Summary and Recommendation

The location and configuration of the intake as well as the outfall of the desalination plant are considered one of the most important factors that should be well investigated and deeply studied. Conducting several scenarios of the intake and outfall location is considered a practical process in order to achieve the best location that has minimum impact of temperature and salinity of brine produced from the nearby desalination plants. Intake and outfall configurations should be evaluated in terms of vertical alignment, pipeline angle, ...etc, in order to reach to the most suitable configuration considering full compliance with technical and commercial requirements.

The present study investigates the alternatives by focusing on Ruwais Desalination Plant (GUP) in United Arab Emirates. The intake and outfall configurations will be evaluated through hydrodynamic simulation and results will be utilized to asses the desalination plant in terms of performance and operation cost. Scenarios will consider the expected expansion of existing petrochemical and other nearby industrial facilities. The evaluation of extending the outfall away from the shoreline will be investigated through the simulated model, in order to study the effect of this proposal on the salinity and temperature at intake location. Other scenarios will be considered as well to improve the feed water characteristics at intake in terms of salinity and temperature.

There are several environmental concerns associated with the disposal of desalting concentrates. In most cases their mitigation is straightforward in a technical sense. The choice of disposal method and mitigation methods, however, is dependent on acceptance by the regulatory group(s) involved in the permitting of the desalting plant. In addition to the costs associated with addressing such environmental concerns, the time and effort involved in interacting with regulatory agencies, in researching disposal options, and in generating and providing data for regulatory agencies should be accounted for.

As just discussed, there are capital costs associated with each disposal method and mitigation approach. Disposal permits typically involve monitoring and reporting requirements with their associated operating costs.

Regulation of environmental effects impacts the capital and operating costs of desalting plants and thus the plant feasibility. Consequently, environmental issues need to be considered at an early stage of the plant design. Likewise existing plants subject to new regulations, must also consider the environmental issues.

CHAPTER (3)
EFFECT OF INTAKE SALINITY & TEMPERATURE ON MSF PERFORMANCE

Water is the most important chemical compound for the use of mankind. It has an essential role in all organic life due to its solvent properties. It is a precondition for improvement in health standards. Water is closely associated with the progress man has made. The demand for steady, economical supply of water is constantly increasing all around the world. Often it does not match the available supply. It does not seem possible that supply will equal demand in the near future. Therefore, sound water resources development is and will be a constant challenge. In many countries, water policy will have to be an essential ingredient of economic policy.

There are many solutions to water problem. Alternatives include control of water consumption, conservation, improved distribution and storage, reclamation, purification and reuse, planting or growing crops that use less water, tapping of new sources, etc. Desalination is seriously considered only when all the other possibilities have been ruled out for various reasons.

The MSF process with brine circulation is one of the major processes of the desalination industry. At present, this process is considered the most suitable for large scale production capacity, where the conventional capacity of a single unit amounts to 25,000 m^3/d. (Hisham Ettouney et al., 1999)

This chapter focuses on the process of Multi Stage Flash Desalination plant. Single stage system is presented as introduction to thermal process. Detailed description of MSF process is presented in terms of flashing flow system considering re-circulation process. Then, the chapter highlights the energy requirements and chemical treatment process including polyphosphate chemical treatment, acid treatment, and high temperature additives. MSF simulation is presented by creating a detailed design example using EXCEL for MSF simplified model in order to obtain required design data, and evaluate the system performance and assess the effect of salinity and temperature on MSF. Finally, cost evaluation is carried out illustrating the impact of salinity and temperature increase on MSF overall performance and operational cost in terms of chemical and energy cost.

3.1 Single Stage Flash Process

Feedwater is preheated in a condenser. It then flows to a brine heater where low pressure steam is introduced from an external source. The feed water is maintained under pressure conditions, which do not permit vapor formation. No boiling takes place in the pipe leading to the flash chamber. Hot feed water from the brine heater is introduced into the flash chamber, which is maintained under vacuum by an ejector. The temperature in the stage is slightly below the boiling point (or saturation temperature) of the feed at that pressure. When feed enters the stage, it is already at the saturation temperature for higher pressure. It becomes superheated and has to give off vapor (flash) to become saturated again. Transfer of latent heat from brine to vapors causes brine to cool down to the saturation temperature equivalent to the stage pressure. The vapor, after passing through demister, is condensed on the condenser tubes. The heat of condensation supplies a large part of the heat required to raise the feed to its boiling point. Distillate is collected in the distillate storage. Un-evaporated brine is rejected to the sea. Fresh seawater is added continuously. Refer to Figure (3.1).

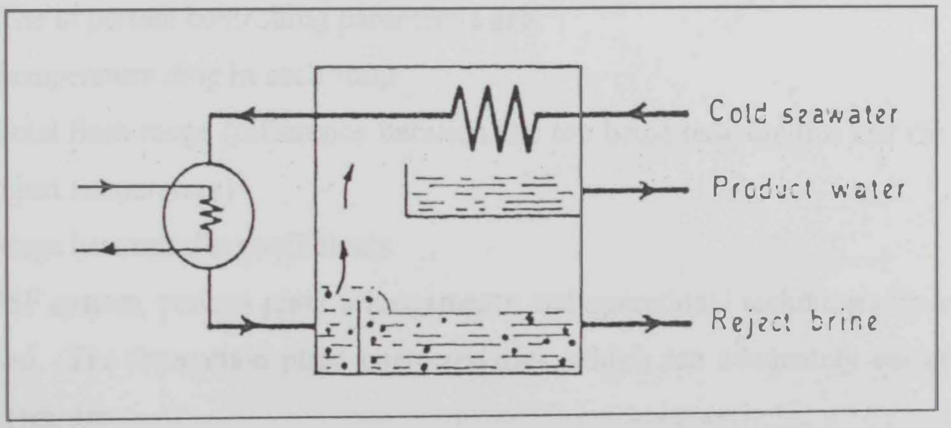

Figure 3.1 Single Stage Flash

3.2 Principles of Flash Distillation

In order to increase the heat recovery efficiency of a single unit, the number of flash stage is increased. The modified system recovers a considerable part of the wasted energy and is know as the Multistage Flash Process (MSF). An MSF evaporator can be visualized to be a single stage unit extended to N stages (usually 16-50) in series. For a given performance ratio, an increase in the number of stages reduces the expensive heat transfer area (the cost of relatively cheap partitions between stages).

The pressure in each stage is lower than the pressure in the preceding stage. The minimum pressure and temperature in the last stage are fixed by vapor volume and heat rejection considerations. This temperature is usually in the range of 37-40 °C. The addition of multiple stages reduces the amount of heat that has to be removed from the process. The number of stages controls the amount of heat recovery possible and this determines the amount of external energy required. Brine is not rejected from the first stage as is done in the single stage flash process. It is sent to the second stage instead. When brine enters the second stage, it flashes again. Vapors are condensed on the condenser at the top of stage 2. The temperature of un-flashed brine drops to a value corresponding to the second stage pressure. This brine flows into the third stage where it again undergoes flashing (as in the first two stages). This continues till the n^{th} stage. Concentrated brine form this stage is rejected (once through process) or recycled (re-circulation process).

In each stage, distillate is produced. The amount of distillate produced in each stage varies. The important controlling parameters are:

1. Temperature drop in each stage
2. Total flash range (difference between the top brine temperature and the brine reject temperature)
3. Stage heat transfer coefficients

In the MSF system, various plant arrangements and operational techniques have been established. The three main plant characteristics, which can adequately describe an MSF system, are:

1. Flashing flow system
    a. Once through
    b. Re-circulation

2. Type of chemical pretreatment
    a. Polyphosphate
    b. Acid
    c. High Temperature Additives
3. Condenser Tubes configuration
    a. Cross
    b. Long
    c. Vertical

3.3 Flashing Flow System: MSF- Once through

A plant which does not re-circulate a portion of the brine is knows as a "Once Through" plant. In this process, seawater is fed to the last stage of the evaporator by the seawater supply pump. It flows through the condenser tubes of all the stages up to the brine heater. In each stage, it condenses vapor produced in the flash chamber of that stage. Therefore, it gets preheated.

On leaving the first stage condenser tubes, seawater is heated up to the top temperature in the brine heater by low pressure steam. The hot feed is then introduced into the first stage flash chamber. It flashes and the vapors produced are condensed on the condenser tubes. Un-flashed brine is sent to the next flash chamber (for which it is superheated feed), where it again flashes due to the lower pressure maintained there. This process is repeated till the last stage. The vapors produced are salt free. Any entrained brine droplets are removed with the help of knitted wire mist separators (better known as demister). Refer to Figure (3.2)

Un-evaporated brine in the last stage is sent back to the sea. It is extracted by the brine blow down pump. The amount of blow down is equal to the feed less than distillate produced. Blow down is usually around 90% of the feed. About 10% of the feed is recovered as distillate. Due to the relatively low percentage of distillate recovery and greater amount of chemicals required (than in re-circulation plants), once through plants are not widely used. Their advantage is that operation is relatively simple, especially during startup. Balancing flows through all the stages is easier than in a re-circulation type plant. This type of plant is exposed to low brine concentrations because brine is not re-circulated. Hence, scaling problem is limited.

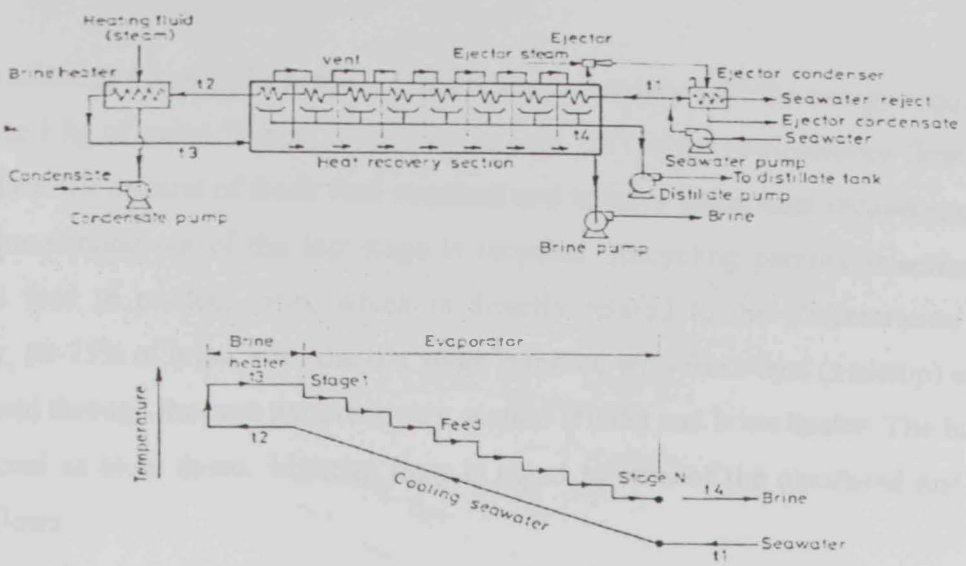

Figure 3.2 Multi-stage flash with no circulation (Arshad Kahn, 1986)

The important features of this process are:

1. Low brine concentration decreases danger of scaling.
2. Brine concentration at the top temperature is low. This allows a higher top temperature. This means increased flash range and less chance of scaling.
3. No circulation pump required.
4. Large amount of non condensable gases released through flashing.
5. High corrosion due to large amount of released gases.
6. Reduction in heat transfer coefficients due to gas blanketing.
7. Large ejector capacity.
8. Very large raw seawater requirements.
9. Variation of seawater temperature can affect the flash range, thus affecting distillate and steam quantity.
10. Easy startup and operation.

However, as mentioned earlier, once through system is not used widely and most common practical and capacity is the re-circulation system. (Arshad Kahn, 1986)

3.4 Flashing Flow System: MSF- with re-circulation

This is a modification of the once through process. In the once through process, the latent heat required for flashing is supplied by the sensible heat change of the liquid. Suppose brine temperature is 100°C in the first stage and 30°C in the last stage. This is equivalent to a loss of 70 kcal/kg. This is approximately 1/8th the energy required to vaporize 1 kg of water. Hence, production is only 1/8th of the re-circulation flow.

To reduce the amount of fresh feed required and to have better heat recovery, part of the brine coming out of the last stage is recycled. Recycling permits selection of a desired feed to product ratio, which is directly related to the concentration ratio, usually, 50-75% of brine from the last stage is mixed with fresh feed (makeup) and re-circulated through the heat gain/recovery section (HGS) and brine heater. The balance is rejected as blow down. Makeup flow is equal to sum of the distillated and blow down flows.

The ratio of makeup to blow down flow is called the concentration ratio and usually varies in the 1.3-2 range. It is affected by the raw seawater salinity and the maximum temperature selected for flashing brine. The scale deposition process is dependent on the concentration ratio. In general, a value of 1.7 should not be exceeded. To keep the concentration ratio within safe limits, seawater makeup is continuously added to brine in the last stage. If the concentration ratio is too low, it will mean using larger feed water rates. Consequently, energy and chemicals costs will be adversely affected.

Compared to the once through process, which comprises only two sections (brine heater and heat recovery section), the re-circulation process consists of three sections. The additional third section is the heat rejection section (HRS). The recovery and rejection sections are enclosed in a single long vessel. This is divided into compartments, which are separated by thin walls.

The function of the HRS is to remove excess heat from flashing brine. It does this by heat exchange with a coolant (raw seawater). The HGS and HRS together usually consist of 16-50 stages, each operating at a lower pressure than the preceding stage. Each stage is divided into evaporation and condensation compartments.

Cold seawater is pumped to the inlet of the last HRS stage. It flows through the condenser tubes. Heat gained by seawater in the tubes is equal to the latent heat of condensation of the vapors. The seawater extracts an amount of heat equal to the heat added in the brine heater. This allows a continuous cycle of operation to take place. Condensed vapors are collected on distillate trays.

On leaving the tubes of the final HRS stage, most of the seawater is rejected to the sea. A portion, equal to the makeup, is chemically treated for scale prevention and then sent to a decarbonator (if acid dosed) for removing gaseous carbon dioxide. It is then sent to the deaerator. Deaeration helps prevent corrosion by oxygen and eliminates accumulation of non-condensable gases on the condenser tubes. Makeup is then introduced into the flash side of the last HRS stage where it mixes with concentrated brine.

After mixing, brine in the last flash chamber is extracted by the brine re-circulation pump. A part is rejected as blow down and the rest is pumped into the condenser tubes of the last HGS stage. This brine acts as the coolant in the condenser section of each stage. It becomes progressively hotter as it gains the latent heat of condensation (from the last to the first stage of the HGS). The warming recycle brine stream condenses vapors generated at successively higher temperatures and maintains the temperature and pressure profile over the plant. Brine circulates in the plant in a countercurrent manner. This establishes a temperature profile with the maximum temperature at the brine heater outlet and the lowest temperature at the outlet of the last HRS stage. Across the flash chambers, a pressure profile is established corresponding to the saturation temperature.

From the HGS section, brine flows to the brine heater, where its temperature needs to be raised by only a few degrees up to the top temperature. This temperature depends on the type of feed chemical treatment. Heating in the brine heater is done by low pressure steam. Hot seawater from the brine heater passes through a flow control valve, which maintains the pressure required to avoid boiling. On entering the flash chamber of the first (hottest) stage, part of the seawater flashes into vapors. These condense on the condenser tubes.

Each stage is maintained at a specified vacuum by ejectors. They remove air and non-condensable gases. The pressure difference is controlled in each stage by brine, which acts as a seal. The pressure in each stage is controlled so that incoming heated brine flashes instantaneously and violently. After flashing, brine cools down and passes into the next lower pressure stage. It again flashes. This flashing process continues, at progressively lower temperature and pressure, till brine reaches the last (coldest) stage of the HRS.

Distillate from each stage is collected in a common distillate through. As distillate cascades, from one higher pressure stage to the next lower pressure stage, it flashes and subsequently cools down. Vapors from distillate flashing condense on the condenser tube bundle and drop back as liquid into the product tray. Heat liberated thus is used to combine mass of the flashing brine and product. The process continues, with brine and distillate passing in parallel from stage to stage, till the last stage from where distillate is channeled to the distillate pump. (Arshad Kahn, 1986)

3.5 Chemical Treatment

MSF plants require seawater as the primary feed. It is required for cooling the HRS and ejector condenser. Part of this is used as makeup. Typically seawater has a temperature of 20-35°C and salinity around 42,000 ppm. Its various constituents and pollutants like suspended matter and gases (hydrogen sulfide, ammonia, etc..) can cause scaling and corrosion. Therefore, pretreatment of feed water is a very important step in the MSF distillation process. Without pretreatment, there will be frequent interruptions in plant operation. Pretreatment usually consists of filtration, chlorination, antiscalant chemical dosing, deaeration and/or decarbonation.

3.5.1 Polyphosphate Chemical Treatment

Feedwater treatment with polyphosphates causes the formation of sludge (instead of harmful hard scales) in condenser tubes. With polyphosphates, the top brine temperature is restricted to 91°C. Typical heat transfer coefficients are in the 2800-3000 W/m^2 °C range. Cleaning frequency can be as low as once every two years. However, typically it is done every 4-6 months even if an on line ball cleaning system is used. (Andrew Porteous, 1983)

3.5.2 Acid

The addition of HCl or H_2SO_4 to the makeup in stoichimetric quantities reduces the seawater alkalinity. This prevents the formation of scales. A disadvantage of acid dosing is that it accelerates corrosion if pH control is not strictly maintained. Cleaning frequency with acid is less- about once a year.

3.5.3 High Temperature Additives

Plants using high temperature additives (HTA) like Blegard EV can be operated at temperature higher than is possible with polyphosphates. HTA prevents scale formation and produce crystal distortion. This prevents individually precipitated particles from adhering to each other or to the metal surface. (Andrew Porteous, 1983)

3.6 Energy Requirements

An MSF plant requires energy in the form of heat to raise the brine temperature in the brine heater. Mechanical power is required for driving the pumps and auxiliaries. The power required for pumps and auxiliaries depend on the output and performance ratio. For a plant with a performance ratio of 9, the power required will be about 3.7 kwh/m3 (if an electric drive is used for the brine re-circulation pump-BRP).

Low pressure steam is required in the brine heater and high pressure steam is required for operating the ejectors. Heat consumption depends on the temperature difference between the flashing and re-circulation of brine streams. This difference is a function of heat transfer surface areas, overall heat transfer coefficients, fouling, and temperature losses due to boiling point elevation.

The performance ratio can be varied by varying the heat transfer surface area and stage design. A large performance ratio means a large number of stages and hence, higher capital cost. (Arshad Kahn, 1986)

3.7 Advantages and Disadvantages of MSF Process

3.7.1 Advantages of MSF Process

- Can be constructed in very large capacities.
- Considerable operating experience.
- Boiling does not take place on the tube surface. Therefore, less susceptible to fouling.
- Performance ratio not directly related to the number of stages. When tubes are fouled, there is choice between decrease in product output and increase in energy consumption (steam).
- Scale prevention is less hazardous because threshold chemicals are extensively used (acid treatment not being preferred). There is less likelihood of corrosion due to overdosing.
- Very pure product water is obtained.

- Economies of scale work well

3.7.2 Disadvantages of MSF Process

- Performance ratio limited. Upper temperature is limited to 121 °C.
- Cannot operate below 60% of design capacity.
- Lack of high/qualified skilled staff.
- Slow start up. Requires considerable care.
- Leaks in tubes can cause serious product contamination.
- Large amount of seawater required compared to the production. Large pumping power required.
- Very large intake structure required due to large requirements of seawater.
- Large capital cost.
- Improper materials selection has lead to problems in the past.
- Noise of pumps, ejectors, steam production system...etc.
- Considerable cost for continuous maintenance and spare parts.

However, in light of the above, MSF process proofs strongly to be the most suitable system in large scale and will remain the main desalination process, especially in Middle East. This is due to the following facts in addition to what have been mentioned above:

- The conservative nature of the desalination owner.
- The product is a strategic life-supporting element.
- Extensive experience in construction and operation
- Process reliability
- Limited experience, small database and unknown risks with new technologies.

3.8 MSF Simulation

MSF process with brine re-circulation is shown in Figure 3.3. Detailed of MSF processes are described below (Hisham Ettouney et al., 1999):

- The intake seawater stream ($M_f + M_{cw}$) is introduced into the condenser tubes of the heat rejection section, where its temperature is increased to a higher temperature by absorption of the latent heat of the condensing fresh water vapor.
- The warm stream of intake seawater is divided into two parts: the first is cooling seawater (M_{cw}), which is rejected back to the sea and the second is the feed seawater, which is deaerated, chemically treated and then mixed in the brine pool of the last flashing stage in the heat rejection section.
- The brine recycle stream (M_r) is extracted from the brine pool of the last stage in the heat rejection section and is introduced into the condenser tubes of the last stage in the heat recovery section. As the stream flows in the condenser tubes cross the stage it absorbs the latent heat of condensation from the flashing vapor in each stage.
- The brine recycle stream (M_r) enters the brine heater tubes where the heating steam (M_s) is condensed on the outside surface of the tubes The brine stream absorbs the latent heat of condensing steam and its temperature increases to its maximum design value know as the top brine temperature (T_o).

- The hot brine enters the flashing stages in the heat recovery section and then in the heat rejection section, where a small amount of fresh water vapor is formed by brine flashing in each stage. The flashing process takes place due to decrease in the stage saturation temperature and causes the reduction in the stage pressure.

- In each stage of the heat recovery section, the flashed off vapors condenses on the outside surface of the condenser tubes, where the brine recycle stream (M_r) flows inside the tube from the cold to the hot side of the plant. This heat recovery improves the process efficiency because of increase in the feed seawater temperature.

- The condensed fresh water vapor outside the condenser tubes accumulates across the stages and forms the distillate product stream (M_d). This stream cascades in the same direction of the flashing brine from stage to stage and withdrawn from the last stage in the heat rejection section.

- The flashing process and vapor formation is limited by an increase in the specific vapor volume at lower temperature and difficulties encountered for operation at low pressure. Common practice limits the temperature of the last stage to range of 30 to 40°C, for winter and summer operation respectively. Further reduction in these temperature results in drastic increase of the stage volume and its dimensions.

- In MSF, most of flashing stages operation at temperature below 100°C have vacuum pressure. This increases the possibilities of in-leakage of the outside air. Also, trace amounts of dissolved gases in the flashing brine, which are not removed in the deaerator or formed by decomposition of $CaHCO_3$. At such conditions, air and other gases are non-condensable and their presence in the system may result in severe reduction in the heat rates within the chamber, increase of tendency for corrosion, and reduction of the flashing rates. This condition necessitates proper venting of the flashing stages to enhance the flashing process and to improve the system efficiency.

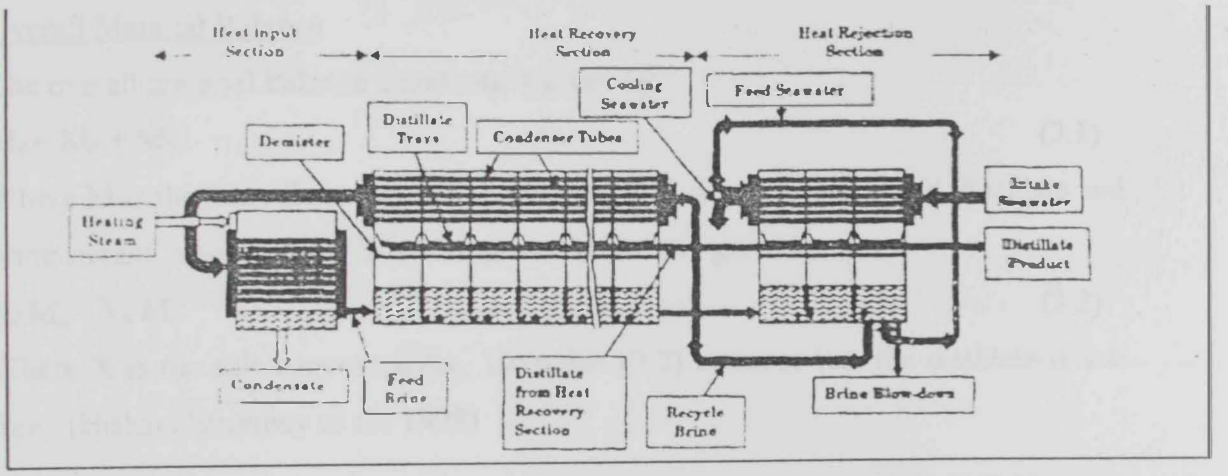

Figure 3.3 Multi-stage flash desalination process (Hisham Ettouney et al., 1999)

Treatment of the intake seawater ($M_f + M_{CW}$) includes screening and filtration. On the other hand, treatment of the feed seawater stream is more extensive and it includes deaeration, and addition of chemical to control scaling, foaming and corrosion which may affect the operation process and as a result the efficiency of the plant production. (Hisham Ettouney et al., 1999)

3.8.1 Model Description

The MSF simplified model is a very useful tool for obtaining quick design data, evaluating the system performance, and developing a good initial guess for more detailed mathematical models. Model assumptions include the following:

- Constant and equal specific heat capacity for all liquid streams.
- Equal temperature drop per stage for the flashing brine.
- Equal temperature drop per stage for the feed seawater.
- The latent heat of vaporization in each stage is assumed equal to the average value for the process.
- The non-condensable gases have negligible effect on the heat transfer process.
- Effects of the boiling point rise and non-equilibrium losses on the stage energy balance are negligible; however, their effects are included in the design of the condenser heat transfer area.
- The temperature of the feed seawater leaving the rejection section is equal to the brine temperature in the last stage.

<u>Overall Material Balance</u>

The overall material balance equations is given by

$$M_f = M_d + M_b \tag{3.1}$$

Where M is the mass flow rate and the subscripts f, d and b define feed, distillate and brine stream, respectively. The overall salt balance is given by

$$X_f M_f = X_b M_b \tag{3.2}$$

Where X is the salt concentration. Equation (3.2) assumes that the distillate is salt free. (Hisham Ettouney et al., 1999)

Using equations (3.1) and (3.2), so

$$M_b = M_d (X_f / (X_b - X_f) \tag{3.3}$$

$$M_f = M_d (X_b / (X_b - X_f) \tag{3.4}$$

<u>Evaporator and Condenser Energy Balances:</u>

- The energy balance of the evaporator is given as follows:

$$Q_e = M_f C_p (T_b - T_f) + M_d \lambda_v = M_s \lambda_s \tag{3.5}$$

Where Q_e is the thermal load of the evaporator, C_p is the specific heat at constant pressure of the brine, and λ is the latent heat of evaporation

- The energy balance of the condenser is given as follows:

$$Q_c = (M_f + M_{cw})\, C_p\, (T_f - T_{cw}) = M_d\, \lambda_v \qquad (3.6)$$

- The overall energy balance of the system is given as follows:

$$M_s\, \lambda_s = M_b\, C_p\, (T_b - T_{cw}) + M_d\, C_p\, (T_v - T_{cw}) + M_{cw}\, C_p\, (T_f - T_{cw}) \qquad (3.7)$$

Equation (3.6) is used in order to eliminate the last term in equation, so the overall energy balance will be:

$$M_s\, \lambda_s = M_b\, C_p\, (T_b - T_f) + M_d\, C_p\, (T_v - T_f) + M_d\, \lambda_v \qquad (3.8)$$

The vapor temperature T_v is then defined in terms of the boiling temperature (T_b) and boiling point elevation (BPE)

$$T_b = T_v + BPE \qquad (3.9)$$

Substitution of Eq. 3.9 into Eq. 3.8 gives:

$$M_s\, \lambda_s = M_b\, C_p\, (T_v + BPE - T_f) + M_d\, C_p\, (T_v - T_f) + M_d\, \lambda_v \qquad (3.10)$$

Equation 3.10 is arranged to give

$$M_s\, \lambda_s = M_b\, C_p\, (T_v - T_f) + M_b\, C_p\, BPE + M_d\, C_p\, (T_v - T_f) + M_d\, \lambda_v \qquad (3.11)$$

The flow rate of rejected brine, M_b is eliminated in Eq. 3.11 by using the relation given in Eq. 3.3 .

$$M_s\, \lambda_s = M_d\, C_p\, (T_v - T_f) + M_d\, (X_f / (X_b - X_f)\, C_p\, (T_v - T_f) + M_d\, (X_f / (X_b - X_f)\, C_p\, BPE + M_d\, \lambda_v \qquad (3.12)$$

Eq. 3.12 is simplified to

$$M_s\, \lambda_s = M_d((1 + X_f / (X_b - X_f)\, C_p\, (T_v - T_f) + (X_f / (X_b - X_f))\, C_p\, BPE + \lambda_v) \qquad (3.13)$$

Eq. 3.13 is then written in terms of the flow rates ratio of the distillate and heating steam, or the performance ratio , PR. This gives,

$$PR = \frac{M_d}{M_s} = \frac{\lambda_s}{(\lambda_v + C_p (T_v - T_f) \dfrac{X_b}{X_b - X_f} + \dfrac{X_f}{X_b - X_f} C_p BPE)} \qquad (3.14)$$

Equation 3.14 is used to determine the system performance ratio as a function of the temperatures of the feed and condensed vapor, the salinity of feed and rejected brine, the boiling point elevation, the latent heats of heating steam and condensing vapor and the heat capacity of water.

Equation 3.6 is arranged to obtain the specific cooling water flow rate. The derivation of this relation proceeds as follows:

$$M_{cw} C_p (T_f - T_{cw}) = M_d \lambda_d - M_f C_p (T_f - T_{cw}) \quad (3.15)$$

The seawater feed flow M_f is eliminated in the above equation by use of the relation given in Eq. 3.4. This gives

$$M_{cw} C_p (T_f - T_{cw}) = M_d \lambda_d - M_d (X_b / (X_b - X_f)) C_p (T_f - T_{cw}) \quad (3.16)$$

Further arrangement of Eq.3.16 gives the specific flow rate of water cooling:

$$sM_{cw} = \frac{M_{cw}}{M_d} = \frac{\lambda_d - (X_b /(X_b - X_f))C_p (T_f - T_{cw})}{C_p (T_f - T_{cw})} \quad (3.17)$$

<u>Evaporator and Condenser Heat Transfer Area:</u>

The dimensions of the required heat transfer surface area in the evaporator A_e are obtained from :

- The amount of the heat to be transferred Q_e.
- The overall heat transfer coefficient U_e.
- The difference between the condensation temperature of the steam, T_s and the boiling temperature of the seawater T_b

So, this relation is given by

$$A_e = Q_e / (U_e (T_s - T_b)) \quad (3.18)$$

Substituting the value of Qe from Eq. 3.15 into the above

$$A_e = \frac{M_f C_p (T_b - T_f) + M_d \lambda_v}{U_e (T_s - T_b)} \quad (3.19)$$

The flow rate of the feed seawater, M_f is eliminated in Eq. 3.19 by the use of Eq. 3.4, which relates M_f, M_d, and salinity of the feed and rejected brine.

$$A_e = \frac{M_d \left[\frac{X_b}{X_b - X_f} \right] C_p (T_b - T_f) + M_d \lambda_v}{U_e (T_s - T_b)} \quad (3.20)$$

Equation 3.20 is arranged to obtain the specific heat transfer area for evaporator, which is defined as the ratio of the heat transfer area to the distillate product flow rate. So the relation will be

$$\frac{A_e}{M_d} = \frac{\left[\frac{X_b}{X_b - X_f}\right] C_p (T_b - T_f) + \lambda_v}{U_e (T_s - T_b)} \qquad (3.21)$$

Reference to Eq. 3.21, it is noticed that the increase in the (BPE) would reduce the temperature driving force and hence increases the specific heat transfer area. In other words, the (BPE) represents an extra resistance to heat transfer.

The heat transfer between the condensing vapor and the feed water in the condenser can be written in terms of the condenser load, the overall heat transfer coefficients U_c, the condenser heat transfer area Ac, and the logarithmic mean temperature difference, $(LMTD)_c$, thus

$$A_c = \frac{Q_c}{U_c (LMTD)_c} = \frac{M_d \lambda_d}{U_c (LMTD)_c} \qquad (3.22)$$

From fig. 2

$$(LMTD)_c = \frac{(T_f - T_{cw})}{\ln \frac{(T_d - T_{cw})}{(T_d - T_f)}} \qquad (3.23)$$

The specific heat transfer area in the condenser is then given by

$$\frac{A_c}{M_d} = \frac{\lambda_d}{U_c (LMTD)_c} \qquad (3.24)$$

The following example demonstrates the mathematical calculations of the MSF system performance parameters. This model will be used to compare all the hydrodynamic scenarios in terms of salinity and temperature at desalination intake and the effect of these scenarios on the feed seawater, cooling seawater with respect to pumping requirement, chemical dosages and the commercial impact on the plant operation. Numerical results utilized later (section 3.10) are obtained from solving the present example. Also, proposals for future expansion of Ruwais existing facilities and the proposed recommendations relevant to the intake and outfall configurations will be based on the calculations made by this model.

3.8.2 MSF Design Calculation (Hisham Ettouney et al., 1999)

Example Calculation for PR at MSF BR :

Mathematical Formulation	Results
Assumed Design Parameters:	
Top Brine Temperature T_o (°C) =	106
Brine Temperature at last stage T_n (°C) =	40
Temperature of motive steam , T_s (°C) =	116
Temperature of intake seawater, T_{cw} (°C) =	25
Product Flow Rate , M_d (kg/s) =	378.8
Intake seawater Salinity , X_f (ppm) =	42000
Salinity of brine reject , X_b (ppm) =	70000
Number of Flashing stages =	24
Specific heat at constant pressure , C_p (kJ/kg °C) =	4.18
Heat Recovery/Gain Stages =	21
Heat Rejection Stages =	3
Vapor Velocity in the last stage V_v (m/s) =	6
Brine mass flow rate per stage width V_b (kg/ms)=	180
Weir friction coefficient, C_d =	0.5
Calculations:	
The flow rate seawater flow rate is calculated:	
$M_f = X_b / (X_b - X_f) M_d$ =	947
The flow rate of blow-down brine is calculated:	
$M_b = M_f - M_d$ =	568.2
The temperature drop in each effect is obtained:	
$\Delta T = (T_o - T_n) /n$ =	2.75
Temperature at the first and second stages T1 & T2:	
$T_1 = T_o - \Delta T$ =	103.25
$T_2 = T_1 - \Delta T$ =	100.5
The temperature of seawater leaving the condensers	
in the first and second stages are calculated:	
$T_{r1} = Tn + (n-j)\Delta T$ =	97.75
$T_{r2} = T_{r1} - \Delta T$ =	95
Calculation of the y ratio is preceded by evaluation of	
T_{av} and λ_{av} :	

$T_{av} = (T_o + T_n) / 2 =$	73
At $T_{av} =$ 73 °C , λ_{av} (Table A.2) =	2330
$y = C_p \Delta T / \lambda_{av} =$	4.933×10^{-3}
The brine recycle flow rate is obtained:	
$M_r = M_d / (1 - (1-y)^n) =$	3384.5
The steam flow rate is obtained:	
$M_s = M_r C_p (T_o - T_{r1}) / \lambda_s =$	52.52
The heat transfer area for the brine heater , A_b, is calculated:	
Logarithmic Mean Temperature Difference $(LMTD)_b =$	
$((T_s - T_o) - (T_s - T_{r1})) / \ln((T_s - T_o)/(T_s - T_{r1})) =$	13.71
Overall heat transfer coefficient (Ub) =	
$1.7194 + 3.2063E-3 * T_s + 1.5971E-5 * (T_s)^2 + 1.9918E-7 * (T_s)^3$	1.99
Brine Heater area (A_b) = $M_s \lambda_s / (U_b (LMTD)_b) =$	4274.8
The condenser area in the heat recovery section, A_r, is calculated for the first stage :	
Vapor condensation temperature (T_{v1}) =	
$T_1 - BPE_1 - NEA_1 - \Delta T_{d1} =$	
From Appendix (table A.3)	
$X_r = (X_f M_f + (M_r - M_d) X_n - M_b X_b) / M_r =$	62165
The values of B and C in the correlation for BPE are calculated:	
$B = ((6.71 + 6.34E-2 * T1 + 9.74E-5 * (T1)^2) * 10^{\wedge}-3 =$	0.0143
$C = ((22.238 + 9.59E-3 * T1 + 9.42E-5 * (T1)^2) * 10^{-8} =$	2.223×10^{-7}
Substitute B and C in BPE correlation:	
$BPE_1 = X_r (B + (X_r) C)) 10^{-3} =$	1.75
The non-equilibrium allowance, NEA1, in the first stage is calculated from the correlation given in the appendix for the MSF system. This involves calculations of the gate height, GH, the height of the brine pool , the stage width W, the stage pressure drop, P1-P2, and brine density.	

$W = M_r/V_b$ =	18.80
The stage length is calculated for the last stage, where	
D_{24} = 14.904 kg/s	14.9
ρ_{vn} = 0.0512 kg/m^3 =	0.0512
$L = D_n/(\rho_{vn} * V_{vn} * W)$ =	2.58
The brine density in the first stage is 1002.413 kg/m^3, which is obtained from from the correlation given in the appendix (Table A.1) with salinity is 62473.9 ppm and temperature of 103.25 °C. The pressure of the first and second stage are obtained form saturation pressure correlation, where, T_1=103.25, P1=113.72 kPa and at T2= 100.5 °C and P2=103.23 kPa. The resulting gate height in the first stage, GH1, is calculated:	
$GH_1 = M_r(2\ \rho_{b1}\ \Delta P_1)^{(-0.5)} / (C_d\ W)$ =	0.0785
The corresponding brine pool height is obtained by simply adding 0.2m to value of GH_1 :	
$H_1 = 0.2 + GH_1$	0.2785
The non-equilibrium allowance is then calculated using the correlation given in the appendix A.4 :	
$NEA_1 = (0.9784)^{(To)} (15.7378)^{(H1)} (1.3777)^{(Vb*10^{\wedge}-6)}$ =	0.213
The temperature drop in the demister is assumed negligible in comparison with the values of BPE1 and NEA1. Therefore, the vapor temperature in the first stage is	
Vapor condensation temperature (T_{v1}) = $T_1 - BPE_1 - NEA_1 - \Delta T_{d1}$ =	101.289
The vapor temperature T_{v1} is used to calculate U_r and $(LMTD)_r$, where :	
Logarithmic Mean Temperature Difference (LMTD)r= $((T_v - T_{r1}) - (T_v - T_{r2})) / \ln((T_v - T_{r1})/(T_v-T_{r2}))$ =	4.78
$(U_r) = 1.7194 + 3.2063E-3 * T_{v1} + 1.9571E-5 * (T_{v1})^2 + 1.9918E-7 * (T_s)^3$	1.996
$(A_r) = Mr\ Cp (Tr1 - Tr_2) / (U_r (LMTD)_r)$ =	4073.95

The condenser area in the heat rejection section , Aj, is determined for the last stage. Determination of this value requires calculations of the vapor condensation temperature, Tvn, the logarithmic mean temperature difference (LMTD)j, and the overall heat transfer coefficient, Uj. The vapor temperature is given by :	
$T_{vn} = T_n + BPE_n - NEA_n - \Delta T_{dn}$ =	
The values of B and C are calculated as :	
$B = ((6.71+6.34E-2* T_n + 9.74E-5 * (T_n)^2)*10^{\wedge}-3$ =	0.0094
$C = ((22.238+9.59E-3* T_1 + 9.42E-5 * (T_1)^2)*10^{\wedge}-8$ =	2.227×10^{-7}
Substitute B and C in BPE correlation :	
$BPE_n = X_n (B + (X_n)C))10^{\wedge}-3$ =	1.774
The gate height and the height of the brine pool in the last stage are assumed equal to those in the previous stage. The brine density in stage n-1 is 1042.4 kg/m3, which is calculated at a salinity of 69654 ppm and a temperature of 35C. The pressure of stages n-1 and n are P_{n-1} = 8.35 kPa, which are calculated at T_{n-1}=35° C and T_n=40 °C. The resulting gate height in the stage n-1, GH_{n-1} is calculated :	
$GHn-1 = B_n-2 (2 \rho_{bn-1} \Delta P_{n-1})^{(-0.5)} / (C_d W)$ =	0.2113
The corresponding brine pool height is obtained by simply adding 0.2 m to the value of GH, or	
$H_{n-1} = 0.2 + GH_1$ =	0.4113
the non-equilibrium allowance is then calculated using the correlation	
$NEAn = (0.9784)^{(Tn-1)} (15.7378)^{(Hn-1)} (1.3777)^{(Vb*10^{\wedge}-6)}$ =	1.221
The temperature drop in the demister is assumed negligible in comparison with the values of BPEn and NEAn. Therefore, the vapor temperature in the last stage is	
$T_{vn} = T_n + BPE_n - NEA_n - \Delta T_{dn}$ =	37.005
The vapor temperature , Tvn is used to calculate Uj and (LMTD)j, where	

Logarithmic Mean Temperature Difference $(LMTD)_r$=	
$((T_{vn} - T_{jn}) - (T_{vn} - T_{cw})) / \ln((T_{vn} - T_{jn})/(T_{vn}-T_{cw}))$ =	9.28
$(U_j) = 1.7194 + 3.2063E-3 * T_{vn} + 1.9571E-5 * (T_{vn})^2 + 1.9918E-7 * (T_n)^3$	1.87
$(A_j) = (M_f+M_{cw}) C_p (T_{jn} - T_{cw}) / (U_j (LMTD)_j)$ =	2247
The total condenser area is calculated :	
$(A_c) = (n-j) A_r + j A_j$ =	92294
The cooling water flow rate is calculated :	
$M_{cw} = (M_s\lambda_s - MfC_p(T_n - T_{cw})/(C_p(T_n-T_{cw}))$ =	914.5
Performance Parameters :	
$PR = M_d / M_s$ =	7.2
$sA = (A_b + A_c) / M_d$ =	255
$sM_{cw} = M_{cw} / M_d$ =	2.41

3.9 Effect of Salinity and Temperature on MSF Performance

Salinity and temperature at desalination intake are considered one of the playing factors that may affect the operation process of the desalination plant. Change in the salinity may affect the feed water requirements. The change in intake seawater temperature may affect the cooling water requirements. These changes in the feed and cooling water (M_f & M_{cw}) have impact on pumping and chemical treatment requirements.

The increase in the salinity concentration at intake, and the effect of this change on MSF parameters is illustrated using previous EXCEL model, the following relationship was obtained showing that the increase in intake salinity concentration (X_f) will lead to increases in feed water M_f as shown in figure 3.4. The increase in seawater intake temperature will increase the cooling water capacity introduced to the desalination plant, refer to figure 3.5.

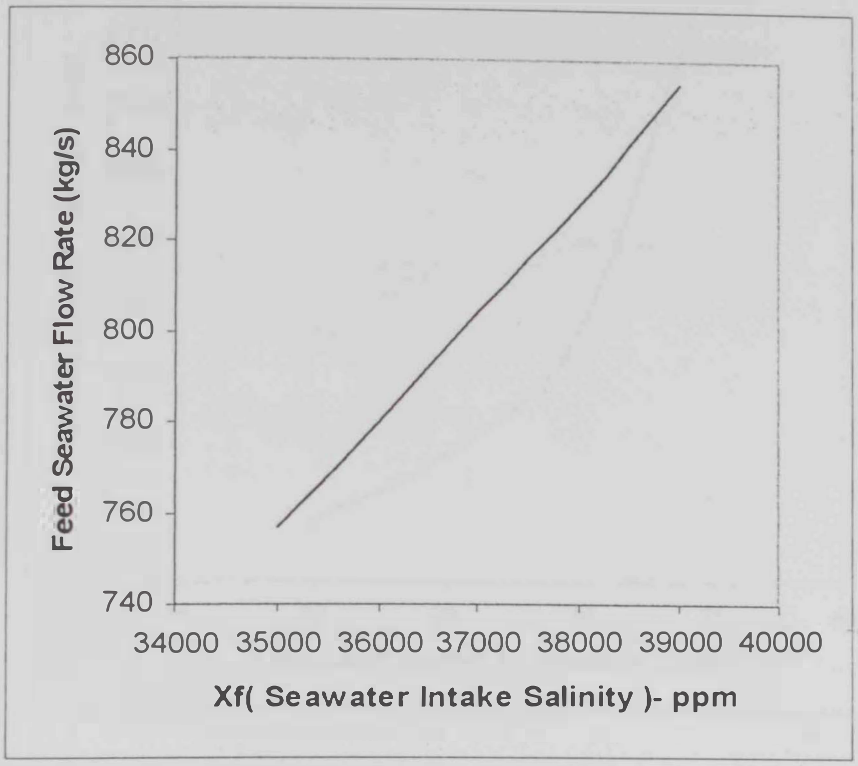

Figure 3.4 Effect of intake seawater Salinity (X_f) on Feed Seawater flow rate (M_f) at constant seawater Temperature (T_{cw}) = 20 °C

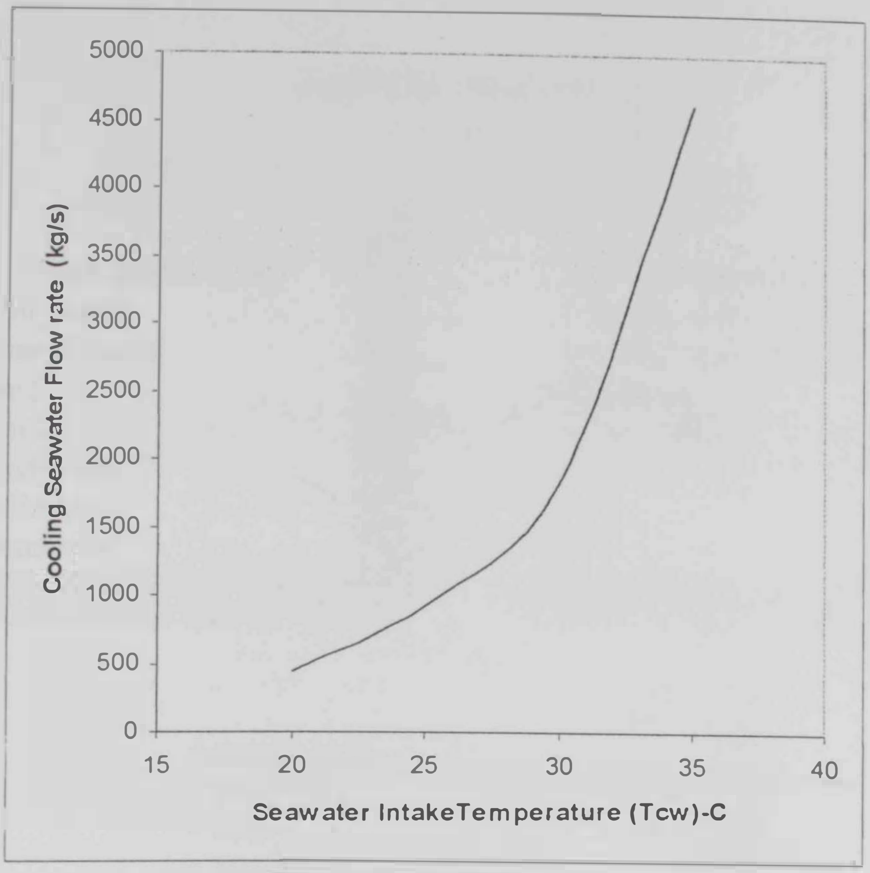

Figure 3.5 Effect of intake seawater Temperature (T_{cw}) on Cooling Seawater flow rate (M_{cw}) at constant seawater intake salinity concentration (X_f) = 35000 ppm.

3.10 Cost Evaluation

Costs can be divided into capital and operation costs. Theses can be very site specific. The performance ratio selected affects not only the investment cost, but also the subsequent operating cost. Calculations of unit product cost depend on the process capacity, site characteristics and design features. System capacity specifies sizes for various process equipment, pumping units, and required membrane surface area. Site characteristics have a strong influence on the type of pretreatment and post-treatment equipment, and consumption rates of chemicals. Process design features affect consumption of electric power, heating steam and chemicals. A summary of the cost elements for desalination processes is shown in Figure 3.6. Production cost is divided into direct and indirect capital costs and annual operating costs.

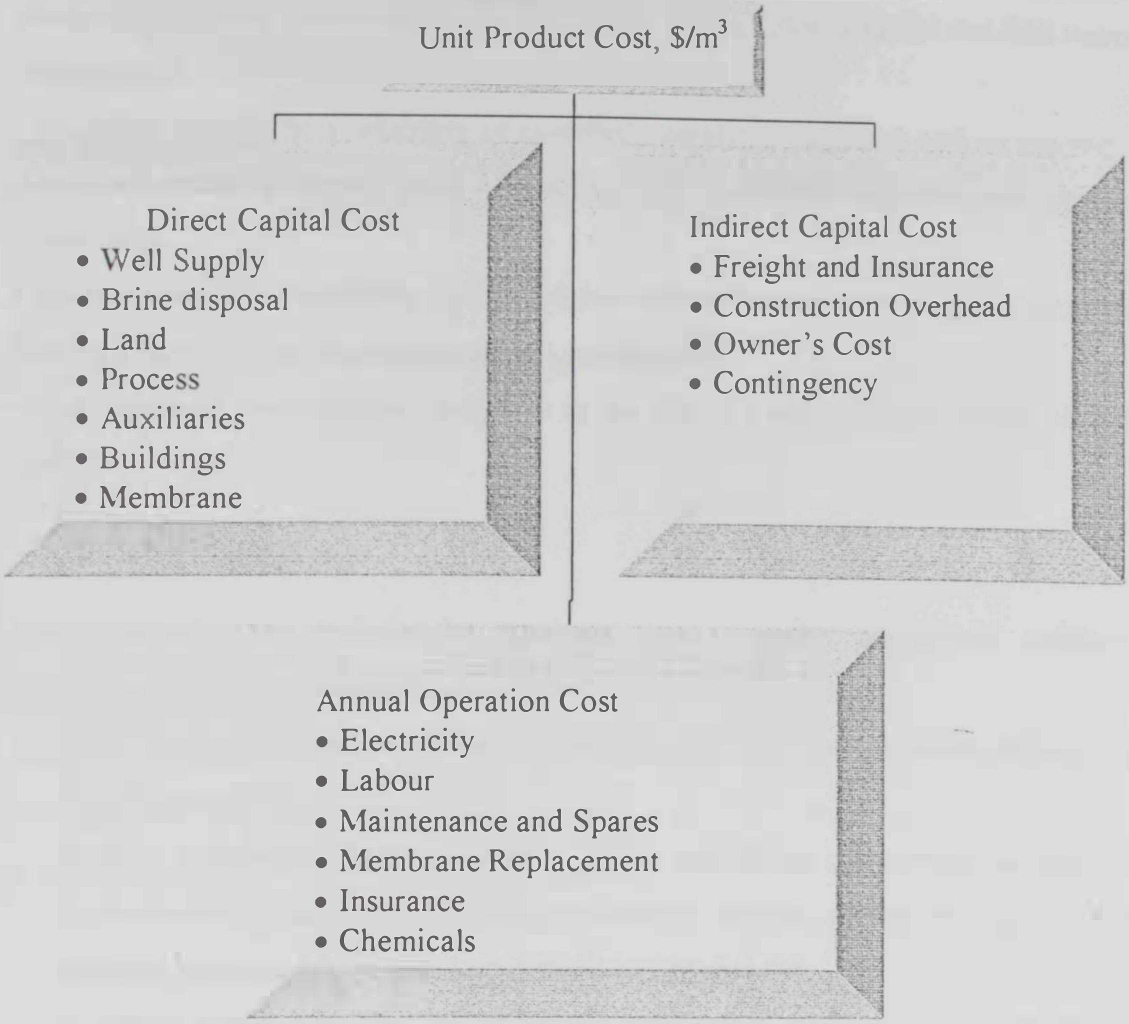

Figure 3.6: Elements of cost analysis for desalination processes (Hisham Ettouney et al., 2002).

3.10.1 Factors affecting Product cost

Unit product cost is affected by several design and operational variables:

• *Salinity and quality of feed water:* Lower feed salinity allows for higher conversion rates. As a result, the plant can operate with lower specific power consumption and dosing of antiscalant chemicals. Also, downtime related to chemical scaling is considerably reduced. (Hisham Ettouney et al., 2002)

• *Plant capacity:* Larger plant capacity reduces the cost per unit product, despite a higher initial capital investment (due to economies of scale).

• *Site conditions:* Installation of new units as an expansion of existing sites eliminates the costs associated with facilities for feed water intake, brine disposal and feed water pretreatment.

• *Qualified labor:* The availability of qualified operators, engineers and management personnel results in higher plant availability and production capacity, and shorter downtimes

• *Energy cost:* The availability of inexpensive sources for low-cost electric power and heating steam has a strong impact on unit product cost.

• *Plant life and amortization:* Increases in the life of a plant reduce product capital costs

3.10.2 Direct Capital Costs

Direct capital costs include the purchase cost of major equipment, auxiliary equipment, land and construction as follows:

Land. The cost of land may vary considerably, from zero to a sum that depends on site characteristics.

Process equipment. This category includes processing equipment, as well as instrumentation and controls, pipes and valves, electric wiring, pumps, process cleaning systems, and pre- and post-treatment equipment.

Auxiliary equipment. The following are considered auxiliary equipment: open intakes or wells, transmission piping, storage tanks, generators and transformers, pumps, pipes and valves

Building Construction. Building cost varies depends on market location, material cost, availability of material, labor cost..etc. This cost is site-specific and depends on the building type. Buildings could include a control room, laboratory, offices and workshops

3.10.3 Indirect Capital Costs

The costs in this category are expressed as percentages of the total direct capital cost

Freight and insurance. This cost is typically equal to 5% of the total direct costs.

Construction overhead. Construction overhead costs include fringe benefits, labor burden, field supervision, temporary facilities, construction equipment, small tools, contractor's profit and miscellaneous expenses. They are about 15% of direct material and labor costs (which depend on the plant's size).

Owner's costs. These include engineering and legal fees, and are approximately 10% of direct material and labor costs.

Contingency costs. These are generally estimated at 10% of the total direct costs.

3.10.4 Annual Operating Costs

Annual operating costs are those expenditures incurred after plant commissioning and during actual operation. These include labor, energy, chemicals, spare parts and miscellaneous items.

Electricity. Electricity costs vary over the range of $0.04--0.09/kWh. The upper end of the range is characteristic of European countries, while the lower value can be attained in the Gulf States and the U.S.

Labor. Labor costs are site-specific and depend on plant ownership (*i.e.*, public or private). In addition, recent trends in plant operations point to more outsourcing of plant operation and maintenance duties. This often reduces the number of required full-time employees, such as managers, engineers and technicians. It could suffice to have one plant manager and a small team of experienced engineers and technicians.

Membrane replacement. The replacement rate may vary between 5% per year for membranes treating low-salinity brackish water supported by proper operation and pretreatment systems to 20% per year for membranes treating high-salinity seawater (*e.g.*, Arabian Gulf seawater). The higher costs may also reflect generally inefficient operations and/or inefficient pretreatment systems.

Maintenance and spare parts. This is typically less than 2% of the total capital cost on an annual basis.

Insurance. Insurance is 0.5% of the total capital cost.

Amortization or fixed charges. This item accounts for annual interest payments for direct and indirect costs. It is obtained by multiplying these costs by an amortization factor, which is given by:

$$a = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{3.25}$$

where i is the annual interest rate and n is plant life (in years). Experience in the desalination industry indicates that an amortization life of 30 yrs is adequate. An interest rate in the range of 5–10% is common for economic analyses.

Chemicals. The chemicals frequently used to clean desalination plants include sulfuric acid, caustic soda, various antiscalants and chlorine. The cost of these items may be affected by availability of nearby manufacturing plants and by global market prices. In addition, chemical treatment differs for thermal and membrane processes, with higher specific costs for the latter. Also, treatment depends on the top brine temperature and feed salinity. Table 3.1 provides estimates for the unit cost of chemicals used in thermal and membrane desalination, dosing rates and specific rates per unit volume of product water.

Table 3.1 Estimated chemical costs and dosing rates (H. Ettouney et al 2002)

Chemicals	Unit Cost, $/kg	Dosing Rate, g/m^3	Specific Cost $/ m^3 water
Sulphuric Acid	0.504	0.242	0.0122
Caustic Soda	0.701	0.140	0.0098
Anti-scalant	1.9	0.050	0.0095
Chlorine	0.482	0.040	0.00193

3.10.5 Equations used for Cost Calculations

Following are several equations used to evaluate the economic calculations of MSF plant based on the available information as well as the hydrodynamic results that affecting the MSF plant performance. (H. Ettouney et al, 2002):

Annual fixed charges: $A_{fixed} = (a)(DC)$ (3.26)

Annual steam costs: $A_{steam} = (s)(\lambda)(f)(m)(365)/[(1000)(PR)]$ (3.27)

Annual electric power costs: $A_{electric} = (c)(w)(f)(m)(365)$ (3.28)

Annual chemical cost: $A_{chemical} = (k)(f)(m)(365)$ (3.29)

Annual labor cost: $A_{labor} = (\gamma)(f)(m)(365)$ (3.30)

Total annual costs: $A_{total} = A_{fixed} + A_{steam} + A_{electric} + A_{chemical}$

$$+ A_{labor} + A_{membrane} \quad (3.31)$$

Unit product cost in terms of production:

$$A_{unit,p} = A_{total} / [(f)(m)(365)] \quad (3.32)$$

Unit product cost in terms of capacity:

$$A_{unit,c} = A_{total} / (m) \quad (3.33)$$

where,

c = electric cost, \$/m3
DC = direct capital cost, \$
f = plant availability
i = interest rate
k = specific chemicals cost, \$/m³
m = plant capacity, m3/d
n = plant life, yr
PR = performance ratio, kg product/kg steam
s = heating steam cost, \$/MkJ
w = specific consumption of electric power, kWh/m³
γ = specific cost of operating labor
λ = average latent heat of steam , kJ/kg

The following example illustrates a sample calculation of the capital and operation cost of MSF process. All calculations are based on recent economic data extracted from actual field data and from design studies in the literature. (H. Ettouney et al 2002).

- Interest rate = i = 5%
- Plant life = n = 30 yrs
- Amortization factor (from eq. 1) = = 0.0651 yr^{-1}
- Plant availability = f = 0.9
- Performance Ratio = PR= 8 kg product / kg steam
- Average latent heat of heating steam = λ = 2,200 kJ/kg
- Electric Cost = c = \$0.05 / kWh
- Heating steam cost = s = \$ 1.466/MkJ
- Specific chemical cost = k =\$0.025/m^3
- Specific cost of operating labor = γ = \$0.1/m^3
- Direct Capital Cost = DC = \$64,000,000
- Plant Capacity = m = 32,732 m^3/d
- Electric Power consumption = w = 5 kWh/m^3

Annual fixed charges = A_{fixed} = *(a) (DC)*	$ 4,163,292	/ yr
Annual steam cost = A_{steam} = *(s).(λ) (f) (m) (365) / [1000 * PR]*	$4,334,855	/ yr
Annual electric power cost = $A_{electric}$ = *(c) (w) (f) (m) (365)*	$2,688,116	/ yr
Annual chemical cost = $A_{chemical}$ = *(k) (f) (m) (365)*	$268,812	/ yr
Annual labour cost = A_{labour} = *(γ) (f) (m) (365)*	$1,075,246	/ yr

Total Annual Cost = $A_{total} = A_{fixed} + A_{steam} + A_{electric} + A_{chemical} + A_{labour}$ = $12,530,320 / yr

Unit product cost in terms of production = $A_{unit\,p.} = A_{total} / [(f) (m) (365)]$ = $1.17 / m^3

Unit product cost in terms of capacity = $A_{unit\,c.} = A_{total} / (m)$ = $383 / m^3 / d

3.10.6 Cost Results

Reference to the Figures 3.4 and 3.5 and by utilizing example calculation of MSF model (section 3.8.2), the following results are obtained :

Table 3.2: Effect of increase of intake salinity on pumping and chemical cost at constant T_{cw}:

Scenario	Salinity (ppt)	Feed Water (Mf) (kg/s)	Cooling Water (Mcw) (kg/s)	Blow down Brine (Mb) (kg/s)	M_{Total} (kg/s)	Difference % of pumping cost	Difference % of Chemical Cost
SN1	30	663	1200	285	2148	10.2	33.5
SN2	40	885	977	505	2367		

From table 3.2, the increase in salinity by about 33% leads to an increase in feed water by about (33.5%) and increase in rejected blow down brine by about (77%). However, the cooling water flow rate required decreased by about (23%). Additional pumping cost increased by about 10.2%. Also, the cost of chemical treatment requirements is estimated to increase by about 33.5 %.

Table 3.3 shows that the increase in feed intake temperature by about (20%) requires additional pumping requirements that have an additional cost impact by about 77.5%.

It is noticed that, the change in seawater temperature at intake (T_{cw}), has no impact on feed water (M_f)

Table 3.3: Effect of increase of intake Temperature on electrical power cost:

Col.1	Col.2	Col. 3	Col. 4
Scenario	Temperature (°C)	Cooling Water (Mcw) (kg/s)	Difference % of pumping cost
SN1	25	1200	77.5
SN2	30	2130	

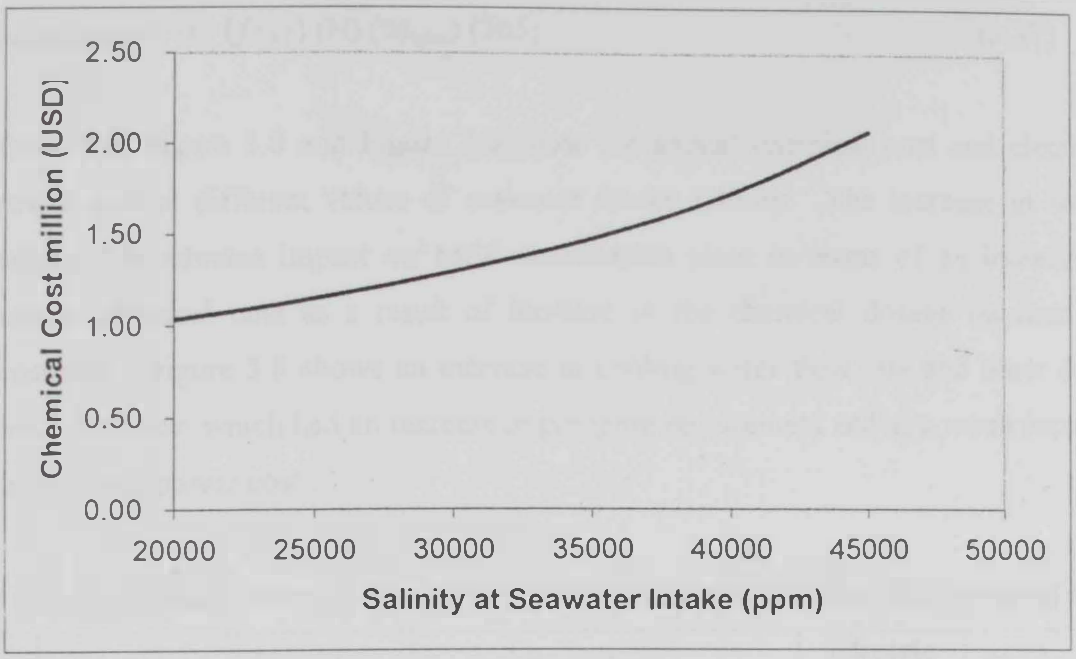

Figure 3.7 The impact of increase in seawater intake on the chemical cost of Feed seawater

The study emphasizes on the effect of intake salinity and temperature on the performance of MSF plant, and the associated operational cost. Therefore, the study focuses on the relationship between intake feed water, Cooling water and the associated chemical and electrical power cost. The equations of annual chemical cost and annual electric power cost are as follows:

$A_{chemical} = (k)\,(f)\,(M_f)\,(365)$ (3.34)

$Power = \gamma\, Q\, H / \eta$ (3.35)

$A_{electric\ power} = (c)\,(w)\,(f)\,(M_f)\,(365)$ (3.36)

Reference to equations 3.34, and table 3.1, and considering the escalation in UAE market, the average estimated chemical cost is estimated to be \$0.06/ m^3. The electric cost (c) can be estimated as 0.05 \$/kWh. The electric power cost (for pumping) is calculated considering 100% efficiency and 16 operating hours per day. The flow rate (Q) in equation 3.35 represents the required amount of total feed water and cooling water to be pumped at relevant pumping head. So, equation 3.36 can be rearranged as follows:

$$A_{electric\ power} = (c)\ (f)\ (\gamma)\ (H)\ (M_{total})\ (365) \qquad (3.37)$$

Table 3.4, Figure 3.8 and Figure 3.9 show the annual chemical cost and electrical power cost at different values of seawater intake salinity. The increase in intake salinity has adverse impact on MSF desalination plant in terms of an increase in annual chemical cost as a result of increase in the chemical dosage required for treatment. Figure 3.8 shows an increase in cooling water flow rate and blow down brine flow rate, which had an increase in pumping requirement and as a result increase in electrical power cost.

Table 3.4 Effect of increase of seawater intake salinity on chemical and pumping cost

SN	Sal. (ppt)	M_f kg/s	M_{cw} kg/s	M_b kg/s	M_{total} kg/s	Pumping (KWh) for H (m)	Pumping Head (m)	Electric power (Pumping)cost (\$/yr)	Chemical Cost (M\$/yr)
SN1	30	663	1200	285	2148	339	25	139	1,14
							40	223	
							50	279	
SN2	40	885	977	505	2367	374	25	154	1,52
							40	246	
							50	307	

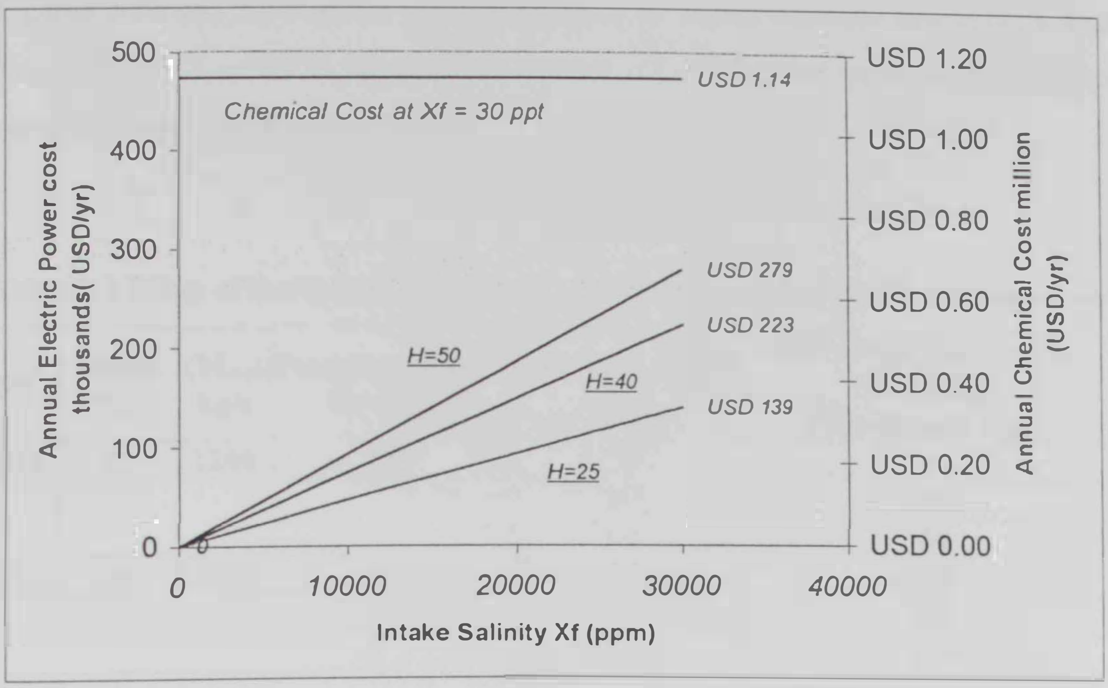

Figure 3.8 Annual chemical and electrical power cost at intake salinity $X_f = 30$ ppt

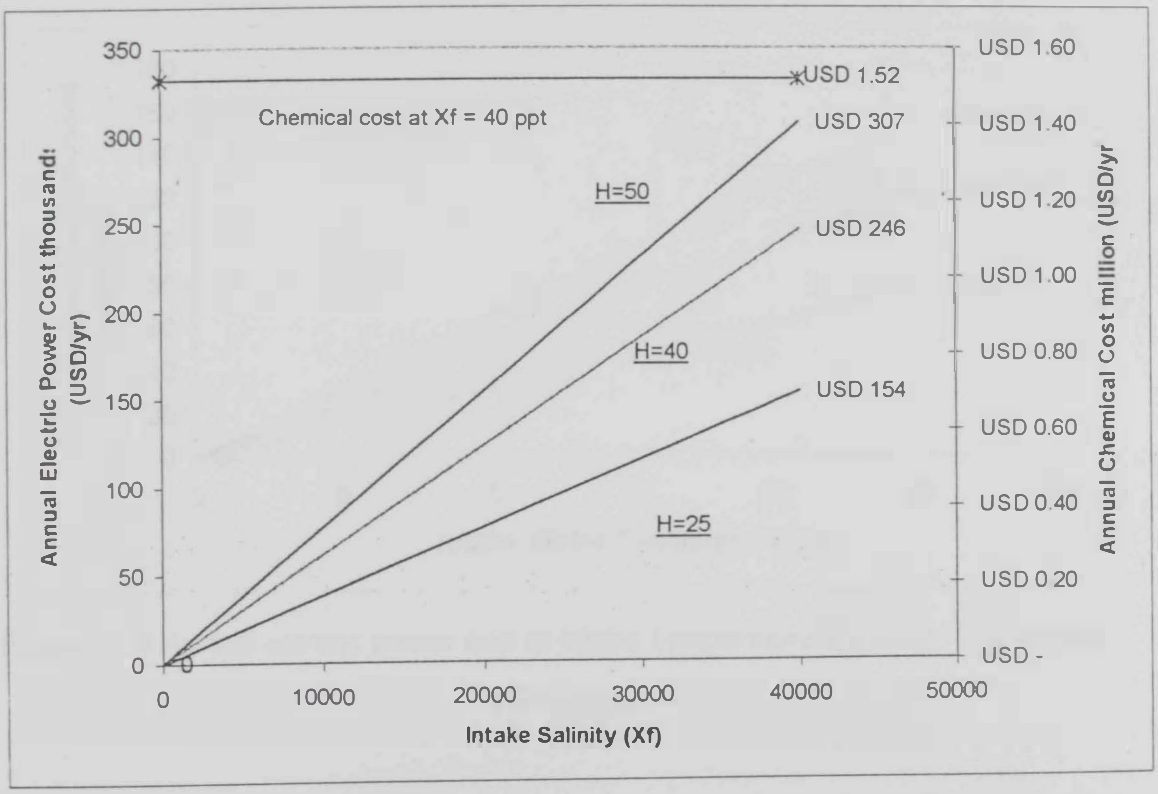

Figure 3.9 Annual chemical and electric power cost at intake salinity $X_f = 40$ ppt

Figures 3.10 and 3.11 shows that the increase in intake seawater temperature from T_{cw1}=25°C to T_{cw2}=30°C increases in cooling water pumping requirements and as a result increases electrical power cost.

Table 3.5 Effect of increase of seawater intake Temperature on electrical power cost

SN	Temp. (°C)	(M_{cw}) kg/s	Pumping (KWh) for H (m)	Pumping Head (m)	Electrical Power Cost (Pumping) (Thousands $/yr)
SN1	25	1200	190	25	78
				40	125
				50	156
SN2	30	2130	337	25	138
				40	221
				50	276

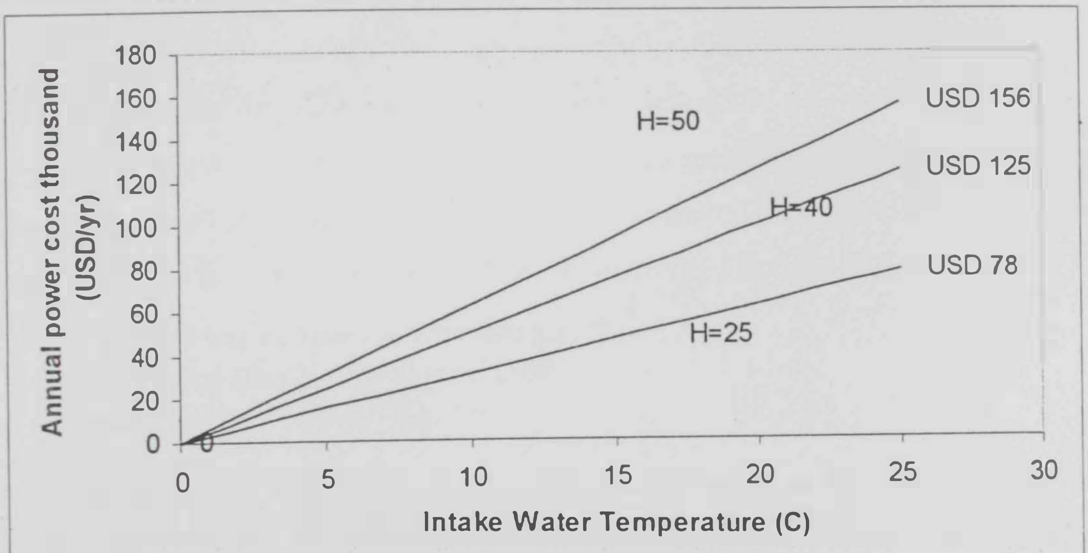

Figure 3.10 Annual electric power cost at intake Temperature T_{cw} = 25 °C at constant X_f = 30 ppt

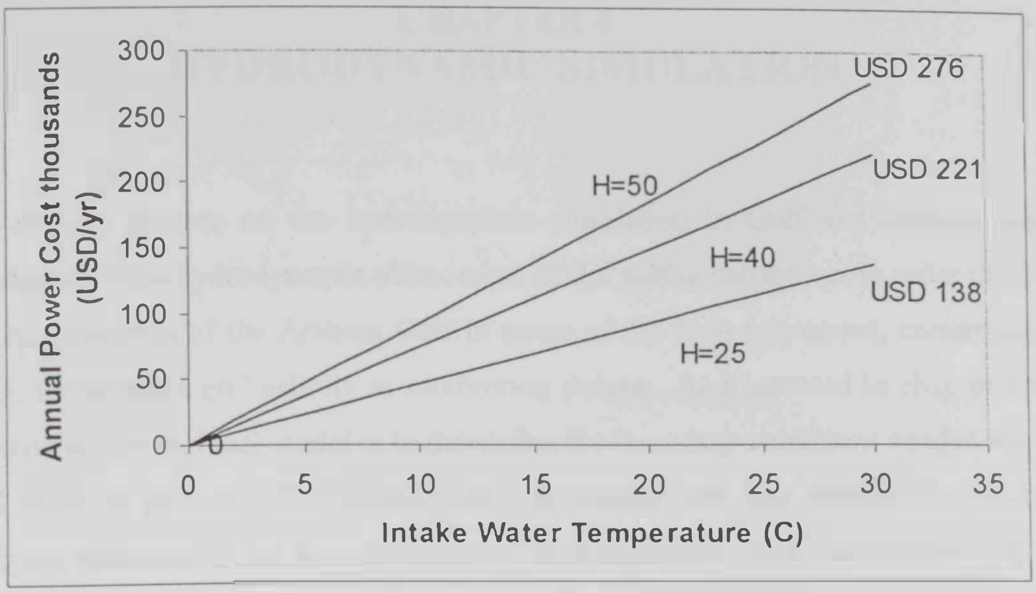

Figure 3.11 Annual electric power cost at intake Temperature T_{cw} = 30 °C at constant X_f = 30 ppt

CHAPTER 4
HYDRODYNAMIC SIMULATION

This chapter focuses on the hydrodynamic simulation in Gulf and Ruwais areas. Simulation of the hydrodynamic phenomena of the gulf is carried out in order to study the characteristics of the Arabian Gulf in terms of the Tide movement, current, wind effect, temperature and salinity at monitoring points. As illustrated in chapter 1 the objective of the regional model is to determine the boundary conditions needed for the local model at Ruwais. The hydrodynamic simulation will then elaborate in tracking the brine effluents in the Ruwais area to the desalination intake and inspecting the temperature and salinity there under several effluents scenarios.

4.1 Theoretical Background

Delft3D-FLOW solves the Navier Stokes equations for an incompressible fluid, under the shallow water and the Boussinesq assumptions. In the vertical momentum equation the vertical accelerations are neglected, which leads to the hydrostatic pressure equation. In 3D-models, the vertical velocities are computed from the continuity equation. The set of partial differential equations in combination with an appropriate set of initial and boundary conditions is solved on a finite difference grid; In the horizontal direction Delft3D-FLOW offers the opportunity to use:

- Cartesian rectangular co-ordinates (x, y).
- Orthogonal curvilinear co-ordinates (η,ξ)
- Spherical co-ordinates (λ,ϕ)

The used model, DELFT3D, is a sigma-layer model that solves the classical equations of mass and momentum equations after being transformed from rectilinear into curvilinear system so that the model grids better fit the natural land boundaries. The rectilinear forms of continuity and momentum equations are shown below.

$$\frac{\partial \eta}{\partial t}+\frac{\partial uh}{\partial x}+\frac{\partial vh}{\partial y}=0 \tag{4.1}$$

Momentum equation in x-direction is:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial \sigma}=-g\frac{\partial \eta}{\partial x}+\frac{1}{h^2}\frac{\partial}{\partial z}(\nu_v\frac{\partial u}{\partial z})+F_x+fv+\frac{\rho_a}{\rho_w}C_W W W_x \tag{4.2}$$

Momentum equation in y-direction is:

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-g\frac{\partial \eta}{\partial y}+\frac{1}{h^2}\frac{\partial}{\partial z}(\nu_v\frac{\partial v}{\partial z})+F_y+fu+\frac{\rho_a}{\rho_w}C_w WW, \quad (4.3)$$

where u, v and w (m^3/s/m) are velocities in x-, y- and z-directions, respectively. t (s) is time, x, y and z (m) are Cartesian co-ordinates, h (m) is water depth, g (9.81 m/s^2) is acceleration due to gravity, η (m) is the sea surface elevation, ν_v is eddy viscosity, ρ_w and ρ_a (kg/m^3) are the air and water densities, respectively, C_W is the wind friction factor, W (m/s) is the wind speed, f (~5.2 10^{-5} s^{-1}) is Coriolis parameter. F_x and F_y are the imbalance of horizontal Reynold's stress.

The vertical velocity is computed from the continuity equation represented by

$$\frac{\partial w}{\partial z}=h(q_{in}-q_{ut}) \quad (4.4)$$

where q_{in} and q_{out} are ingoing and outgoing discharges of local sources per unit volume (1/s), respectively. The momentum balance in the vertical direction is introduced into the model by equating the pressure gradient with hydrostatic pressure i.e. vertical acceleration is neglected, as the horizontal scale is much larger than the vertical scale.

The advection-dispersion transport equation is formulated in a conservative form in three directions and considering the sigma 'σ' vertical axis as:

$$\frac{\partial c}{\partial t}+\frac{\partial uc}{\partial x}+\frac{\partial vc}{\partial y}+\frac{\partial wc}{\partial \sigma}=\frac{\partial}{\partial x}\left(h\cdot D_x\cdot\frac{\partial c}{\partial x}\right)+\frac{\partial}{\partial y}\left(h\cdot D_y\cdot\frac{\partial c}{\partial y}\right)+\frac{\partial}{\partial \sigma}\left(h\cdot D_\sigma\cdot\frac{\partial c}{\partial \sigma}\right)+c_S \quad (4.5)$$

where C_S is a source/sink. The horizontal diffusion coefficients (D_x and D_y) are defined as the superposition of two parts, i.e. a part due to turbulence and a part due to molecular diffusion. The vertical eddy diffusivity (D_s) is the combination of three-dimensional turbulence-generated diffusivity and molecular diffusivity. A first order turbulent closure scheme, k-L model (Horton et al 1994) is used to compute vertical diffusivity. The mixing length (L) is prescribed analytically. The model formulates the conservation of turbulent kinetic energy k using the following relation.

$$\frac{\partial k}{\partial t}+u\frac{\partial k}{\partial x}+v\frac{\partial k}{\partial y}+w\frac{\partial k}{\partial \sigma}=\frac{1}{h^2}\frac{\partial}{\partial \sigma}\left(\cdot\left(\nu_m+\frac{\nu}{\sigma_k}\right)\frac{\partial k}{\partial \sigma}\right)+P_k+B_k-\varepsilon \quad (4.6)$$

where P_k is a production term, B_k is a buoyancy term and E is a dissipation term.

In the heat flux model, the short wave radiation is transmitted to deeper water. The longer waves are absorbed at the water surface. Therefore the incoming radiation is separated into two portions, i.e., the longer wave portion and the remainder part. The absorption of the heat in the water column is an exponential function of the distance from the water surface and given by:

$$Q_{sn}(z) = (1-\beta)Q_{sn}e^{-\gamma} \quad (4.7)$$

with, γ= extinction coefficient (m), z = distance to the surface (m).

$$Q_{br} = 30 + 5.2\,(T_s - 273.1) \quad (4.8)$$

T_s is the surface water temperature in K.

The evaporation rate E defined as the volume of water evaporated per unit area per unit time is computed using Dalton's law of mass transfer:

$$E = f(U_{w10})\,(e_s - e_a) \quad (4.9)$$

The saturated vapor pressure e_s and the actual vapor pressure e_a are given by the following relations:

$$e_s = 23.38e^{(18.1-5303.3/T_a)} \quad (4.10)$$

$$e_a = r_{hum}e_s \quad (4.11)$$

U_{w10} is the wind velocity at 10 m above the surface. The wind speed function $f(U_{w10})$ is estimated as follows (RSMAS 2000):

$$f(U_{w10}) = \left(\frac{5.010^6}{S_{area}}\right)(3.5+2.0U_{w10}) \quad (4.12)$$

S_{area} is the total surface area. To estimate C_w, the wind shear on the surface is determined by the quadratic expression:

$$|\tau_s| = \rho_a C_d U_{10}^2 \quad (4.13)$$

where ρ_a (kg/m3) is the density of air, U_{10} (m/sec)is the wind speed 10 m above the surface and C_d is the wind drag coefficient, which is 0.00063 for non-storm condition. The wind shear and bed shear are introduced in to the model as boundary conditions.

4.2 Regional Model (Gulf Model)

The hydrodynamics of the southern Arabian Gulf plays a significant role on the coastal environment of United Arab Emirates. The large cities and industries are located in the coastal zone. The coastal waters are also busy with movements of oil tankers and their loading-unloading operations. Understanding the coastal flow

dynamics is essential for investigation of environmental processes of this region The high rate of evaporation, water exchange with the Arabian Sea at the east and seasonally varying wind field, all significantly contribute to the flow dynamic of the sea which is subject to tidal forcing through the straits of Hormuz However the present knowledge on hydrodynamic behavior of the southern gulf and its response to meteorological and oceanographic forces is considerably poor The present study employs a three dimensional numerical model to examine the sensitivity of the flow at the UAE coast to tides, wind field, salinity, and temperature
The strategy is to simulate the entire Gulf and conduct a reasonable level of its calibration, and then the local model (at Ruwais) is nested from that regional model Since, there are no available time-dependant data at the local boundary, the boundary conditions for the Ruwais model is extracted from the Gulf model
The Arabian Gulf (approximately 1000 km by 200–300 km) slopes from the shallow United Arab Emirates Coast to Iran, 80–100 m deep The sea, which is located within the latitude of 24°N to 30°N, is shallow with a constricted entrance at the Straits of Hormuz (Figure 4 1) The peninsular of Qatar constricts the Gulf between north and south Oceanographic features in the two regions are remarkably different

Figure 4.1 The Arabian Gulf

A complex physical dynamic phenomenon is evidenced from a number of modelling and survey studies carried out in the Arabian Gulf The high solar radiation and the exchange of fresher water and circulation driven by wind and astronomical forces are the main contributory factors for such phenomenon. The excessive evaporation occurs in the shallow coastal region of UAE leading to formation of highly saline water (up to 46 ppt). A principal feature of the central-gulf is an existence of cyclonic circulation (Horton, et al., 1994). Such flow enhances the advective transport of temperature from the shallower region to the deeper region and contributes to a horizontal mixing process. Wind-driven circulation is also apparent in the shallow northwest regions adjacent to the Iraqi-Kuwaiti-Saudi Arabian coasts. The prevailing winds are along the axis of the Gulf to the southeast and drive a south-eastward coastal current along the Kuwaiti-Saudi Arabian coasts. However the winds are quite variable, especially during winter.

Straits of Hormuz maintains an exchange process between saline water of the Arabian Gulf and less saline water from the Gulf of Oman (Johns et al., 1998). Stratified upper layer of warmer and less saline water was found in the straits during a survey carried out in 1997-1998. The salinity and temperature both increased up to 38 ppt and 33° C, respectively during the summer, in particular months of July and October.

4.2.1 Gulf Model Setup

A curvilinear model grid is prepared for the whole Arabian Gulf with higher resolution for the coast of UAE. The model area is extended up to the Straits of Hormuz. The generated grid sizes at the north-western gulf are larger with maximum dimension of 6500 m×3000 m and grids are smaller in the constricted channel of Hormuz with dimension of about 500m×500 m. Such distribution of grids develops a numerical array of size 385×120.

The model grid is generated using Delft-RGFGRID module. Curvilinear girds are applied in finite difference modeling to provide a high grid resolution in the area of interest and to better represent the boundaries of irregular shape. Curvilinear grids should be smooth in order to minimize errors in the finite difference approximations.

The program allows for an iterative grid generation process, starting with a rough sketch of the grid by splines. Then, the splines are transformed into a grid that can be smoothly refined by the program. Various grid manipulation options are provided in order to put the grid lines in the right position with right resolution. Existing grids may be modified or extended using this program. Grids can be locally refined by insertion of grid lines.

4.2.2 Data Input and Simulation

In order to set up a hydrodynamic model, an input file must be prepared. All parameters to be used originate from the physical phenomena being modeled. Also from the numerical techniques being used to solve the equations that describe these phenomena, and finally, from decisions being made to control the simulation and to store its results. Within the range of realistic values, it is likely that the solution is sensitive to the selected parameter values, so a concise description of all parameters is required. The input data defined is stored into an input file called the Master Definition Flow file or MDF-file. The input parameters that define a hydrodynamic scenario are grouped into Data Groups. Upon starting the FLOW GUI, a menu is displayed with the Data Group Description selected and displayed. The area to the right of the Data Groups is called the canvas area. A data group is a coherent set of input parameters that together define a certain type of input data. For instance, in the Data Group Discharges one can define all aspects related to a discharge, such as its name, its location, its discharge rate, if the momentum of the discharge is to be taken into account and if so in which direction and last but not least, the concentration of all substances released. Several of these items can be specified as a function of time, where the time-series can be specified manually or read from a file. Some data groups are organized in sub-data groups, such as the Data Group Domain, that consists of four sub-data groups: Grid Parameters, Bathymetry, Dry Points and Thin Dams.

During the simulation, many files are created as well as some data are gathered from different literature in order to finalize the model needed to be studied. As illustrated in section 4.3.2, the model grids and bathymetry are created with the help of several resources such as Admiralty Charts and data sampling. The initial conditions are required for dependent variables such as salinity and temperature. Due to some disturbance that propagates into the model, the simulation is conducted originally by using the collected samples for initial conditions, and the output files of this run was re-considered as initial conditions for the second simulation run in order to reach to a stabilized model. Also, smooth interpolation was carried out around the area showing blowing up current vectors, in order to eliminate this instability during the simulation. Most of rivers inflow into Gulf occur in the northern end, primarily on the Iranian side (Figure 4.2). The Shatt Al Arab is a nexus of three major rivers: Tigris and Euphrates rivers together provide an annual average of 708 m^3/s and Karun adds 748 m^3/s. Thus, the total average outflow of the Shatt Al Arab is 1456 m^3/s. Other major rivers are the Hedijan (203 m^3/s), The Hilleh (444 m^3/s), and Mand (1387 m^3/s). (Mt Mitchell). All the above mentioned rivers are used as input parameters into the Gulf model.

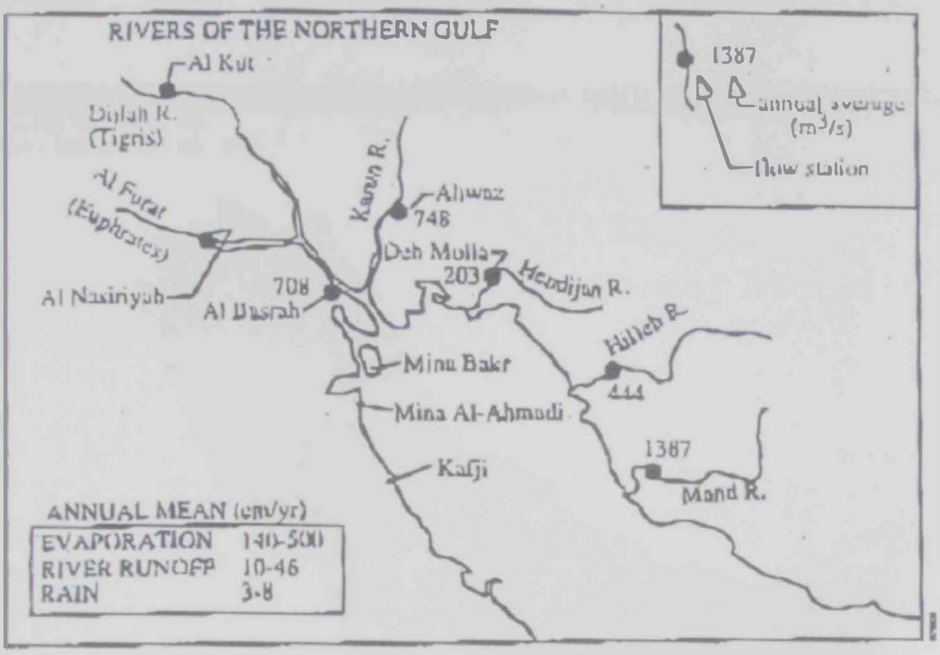

Figure 4.2 Map showing major rivers into the northern Gulf

Tidal constituent for the boundary at the straits of Hormuz is obtained from the Admiralty Tide Table (ATT, Admiralty Tide Table, 2001) and from a report published on marginal seas (Kantha et al., 1994). The main astronomic tidal constituents for open boundary conditions used for tidal prediction are found in all relevant studies as M2, S2, K1, and O1. The astronomical components that boundary (strait of Hormouz) at two locations A1, and B1 are described in table 4.1 and figure 4.3:

Table 4.1: Astronomic Tidal Constituents.

Boundary-1A		
A0	0.000000	0.000000
M2	0.660000	299.000
S2	0.190000	335.000
K1	0.290000	57.0000
O1	0.200000	55.0000

Boundary-1B		
A0	0.000000	0.000000
M2	0.760000	299.000
S2	0.190000	332.000
K1	0.370000	66.0000
O1	0.270000	57.0000

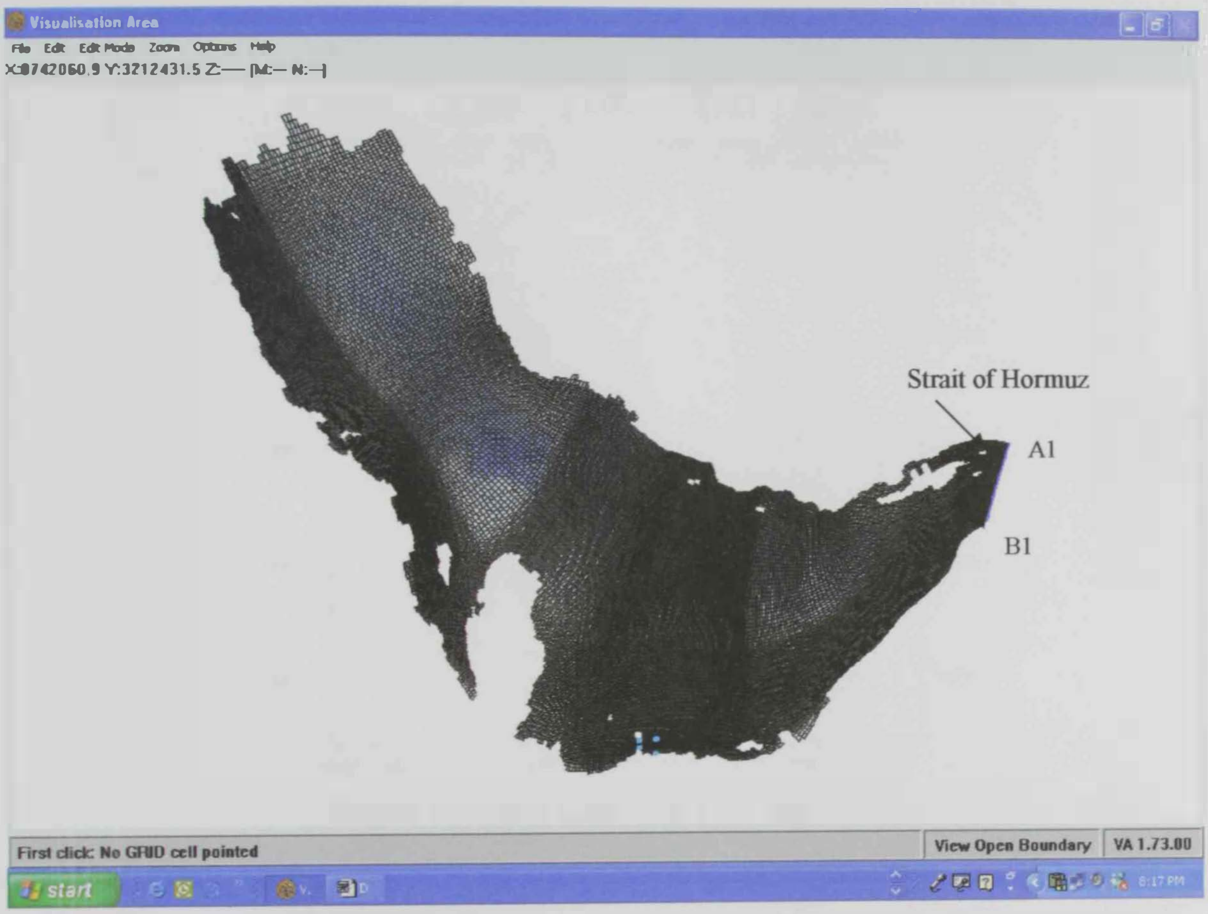

Figure 4.3 Boundary locations at Strait of Hormuz

An initial salinity map is produced on the basis of available descriptions from number of sources (RSMAS, 2000), (Kantha et al., 1994). Since a good depth varying information on salinity in the Straits of Hormuz is available (Johns et al., 1998), (John et al., 1990), the model is executed for sufficiently time period to have greater influence from the boundary on the salinity field and a modified initial map is prepared. The salinity in the shallow southern coast is 45 ppt and it decreases up to 37 ppt in the deeper north (Figure 4.4). The temperature model considers constant radiation, humidity and cloud coverage through out the modeling period. The magnitude of net radiation is 140 W/m^2 with 50% humidity and 0.1% cloud coverage.

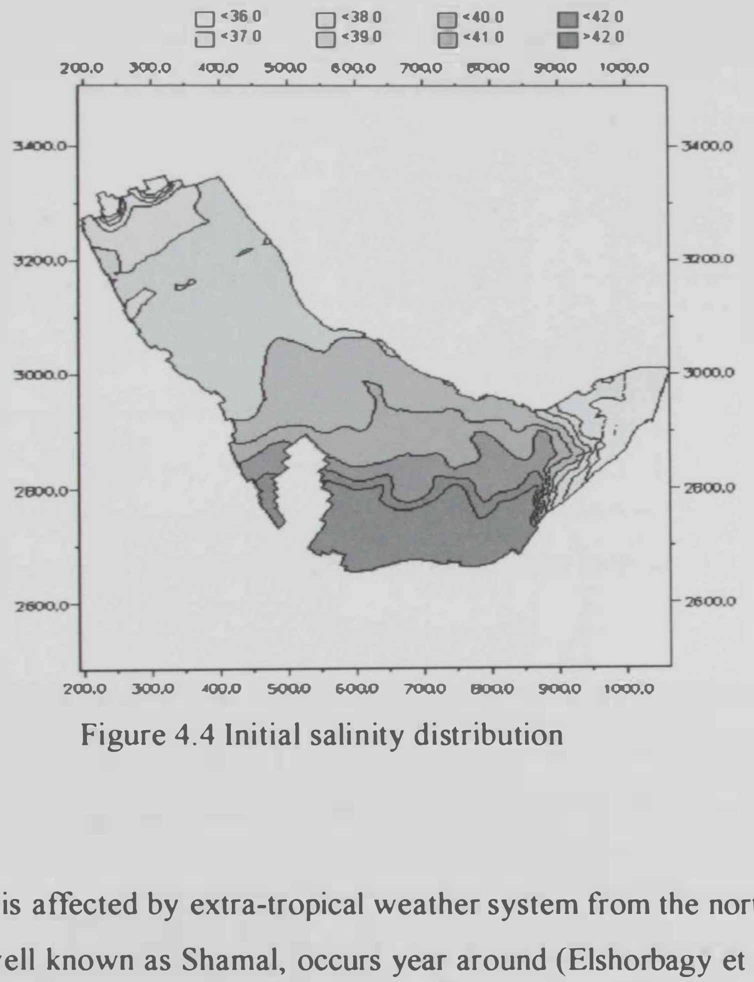

Figure 4.4 Initial salinity distribution

The Arabian Gulf is affected by extra-tropical weather system from the northwest. A NW wind, more well known as Shamal, occurs year around (Elshorbagy et al 2004a). The winter Shamal brings some of the strongest winds and highest seas to the gulf region. It seldom exceeds 10 m/s (< 5% frequency) but lasts several days. The summer Shamal is usually continuous from early June through July.

4.2.3 Calibration and Results

As an initial calibration effort, the model results were favorably calibrated against measured water level at Abu Dhabi coast (ElShorbagy et al 2004a). The calibration simulation is done for two weeks, from 1st of May to 15th of May, 1997.Comparison of measured and simulated water level at Abu Dhabi coast is shown in Figure 4.5. The comparison shows good agreement for the tidal phase and magnitude over the most of the considered simulation period except for some deviation in the magnitude of high neap tides. Present unavailability of data in other locations limits the calibration effort. In the coastal water of UAE, as shown by the simulation, the tide induces weak oscillatory motions not exceeding the magnitude of 0.8 m within a complete spring-neap cycle.

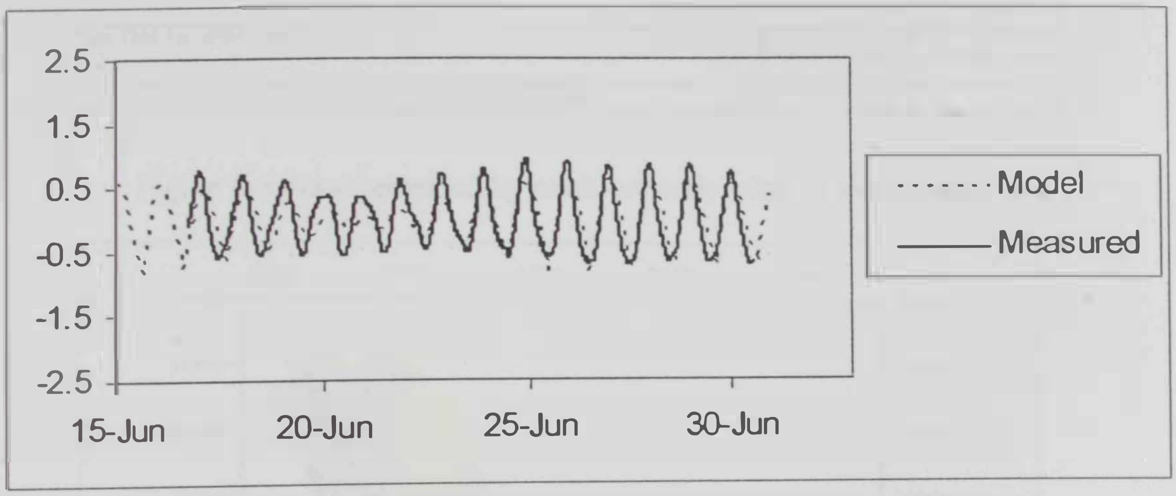

Figure 4.5 Comparison of measured and simulated water level at Abu Dhabi

A map plot of the flow pattern generated by 5 m/s northwest wind at the end of two week simulation is shown in Figure 4.6. Result shows that a net flow (not shown here) is generated along the coast of UAE towards east as the wind blows to southeast.

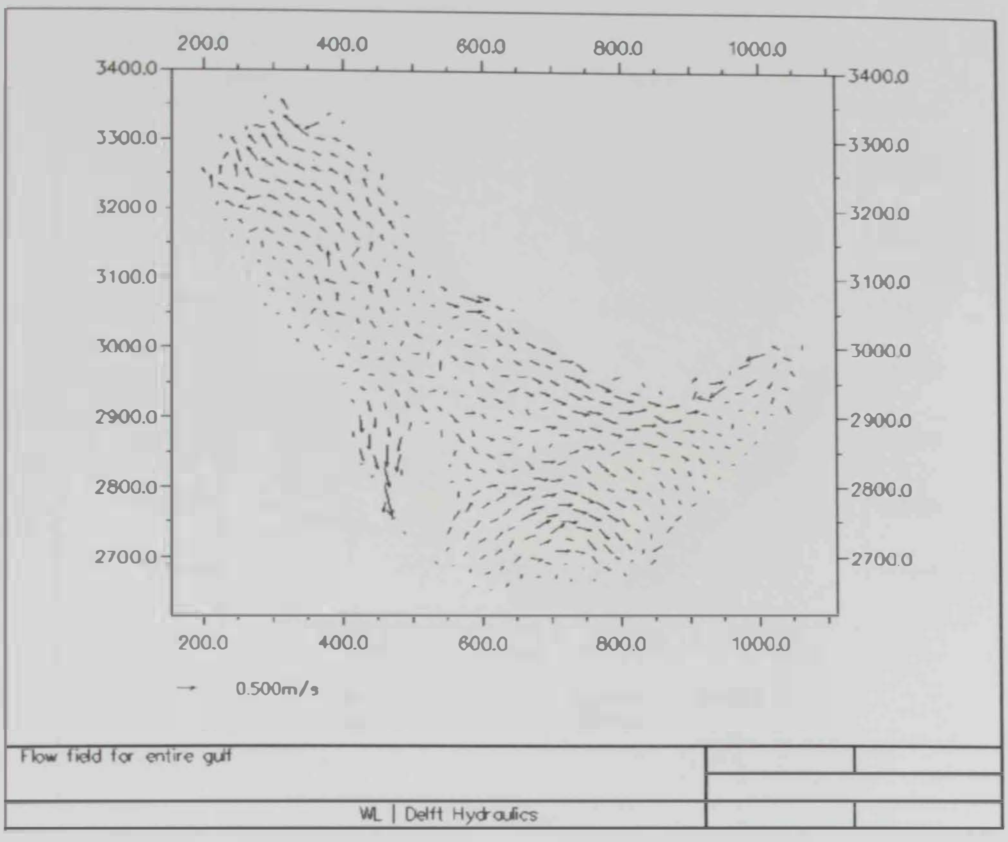

Figure 4.6 Flow generated by north-westerly wind of magnitude 5 m/s.

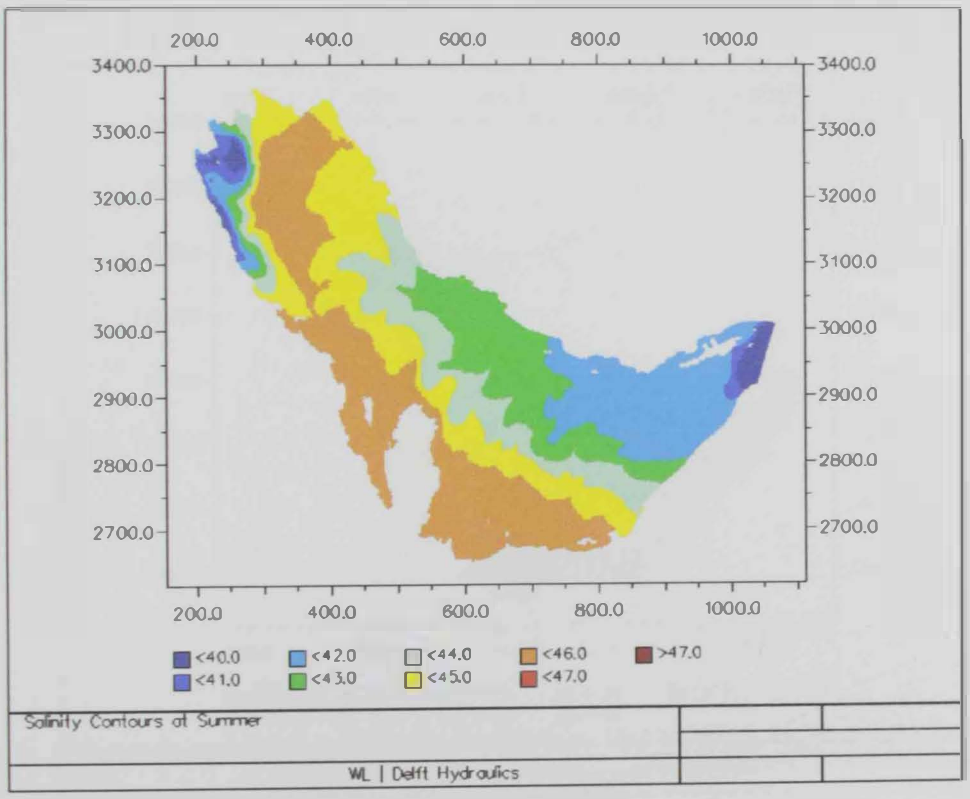

Figure 4.7 Salinity distributions at summer for entire gulf

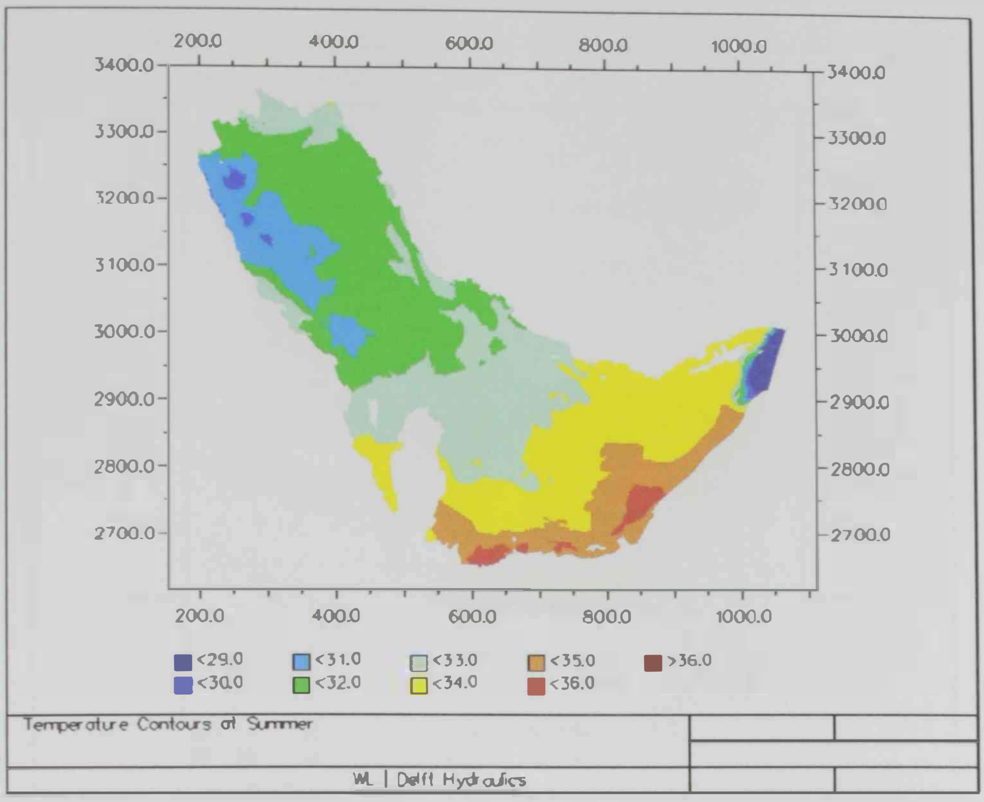

Figure 4.8 Temperature distributions at summer for entire gulf

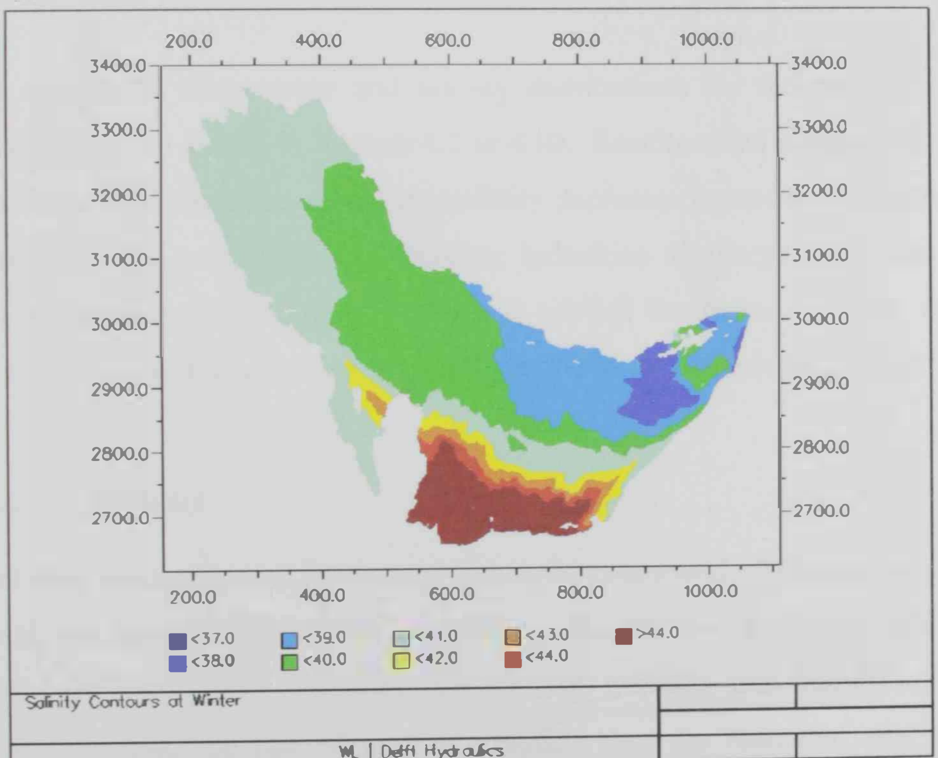

Figure 4.9 Salinity distributions at winter for entire gulf

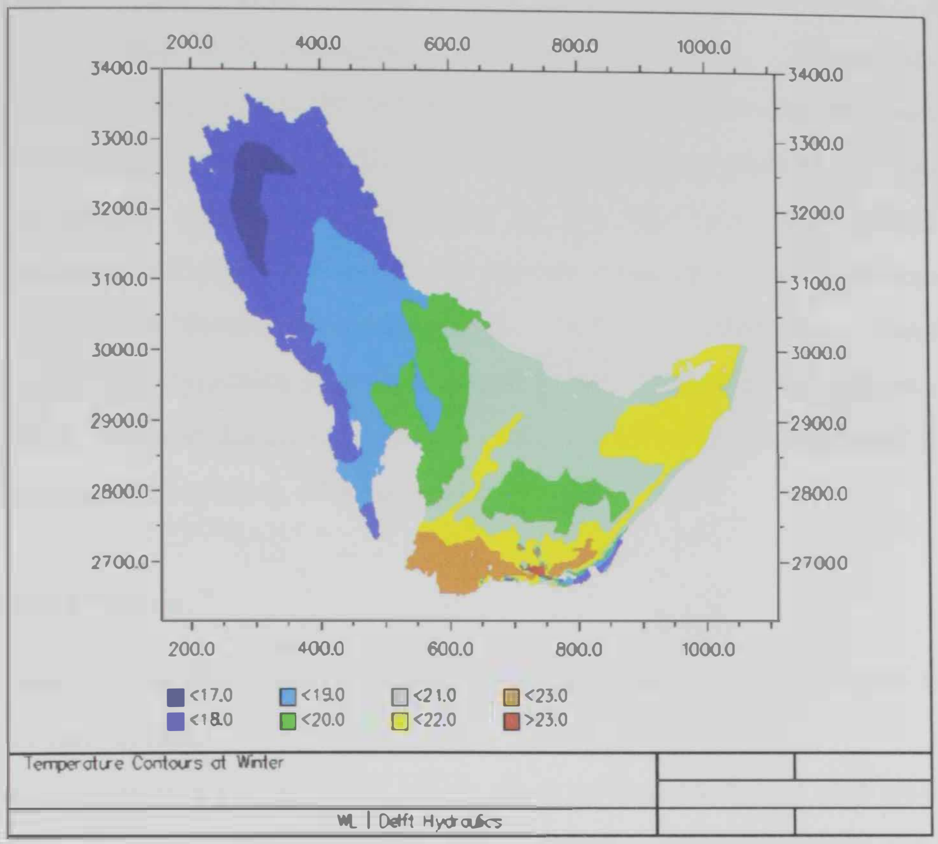

Figure 4.10 Temperature distributions at winter for entire gulf

Simulation results for temperature and salinity distributions for the entire gulf at summer and winter are shown in Figures 4.7 to 4.10. Results show a higher level of salinity near the UAE coastline, where the salinity decreases towards the deeper sea zones at north. The contribution of existing industries discharge influences the increase in the salinity at shoreline. The same is applied for the temperature, where the temperature increases at shoreline, especially at the areas of the industries outfalls.

4.3 Ruwais Local Model

The coastal flow pattern around the coastal industrial compound of Ruwais has been studied using the same 3-D hydrodynamic model. The study area is about 264 km² and partially sheltered from the open sea by salt marches and islands. Such configuration increases the risk of marine pollution near the industrial site. The industrial compound encompasses a major port and other industrial facilities such as

Ruwais Desalination Plant, Takreer refinery and Borooj Petrochemical facilities as well as small workshop with amenities and municipal facilities. The obvious implication of such development is the increased potential threat to coastal ecosystem as well as the effect of the produced effluent of MSF desalination plant in particular with regard to salinity and temperature effect on the MSF plant performance. Discharge of industrial effluents, spillage in the port and released of brine and warm water may have considerable impact on the marine environment. Hence, understanding the hydrodynamics is a pivotal task for assessment of the impact of ongoing activities. A three-dimensional model study is conducted to understand the baseline hydrodynamic conditions of the coastal study area.

4.3.1 Ruwais Model Setup

In order to establish the local model, a nesting process was carried out from the original overall Gulf model.

Nesting process is simply a process used where the boundary conditions of a model are generated by a larger (overall) model to a nested model. In principle, the nested boundary conditions are generated by bi-linear interpolation of computational results at monitoring stations of the overall model.

The study area for the model is selected from the south of Sir Baniyas Island as illustrated in (Figure 4.11). The seaward extent of the model is about 15 kilometers.

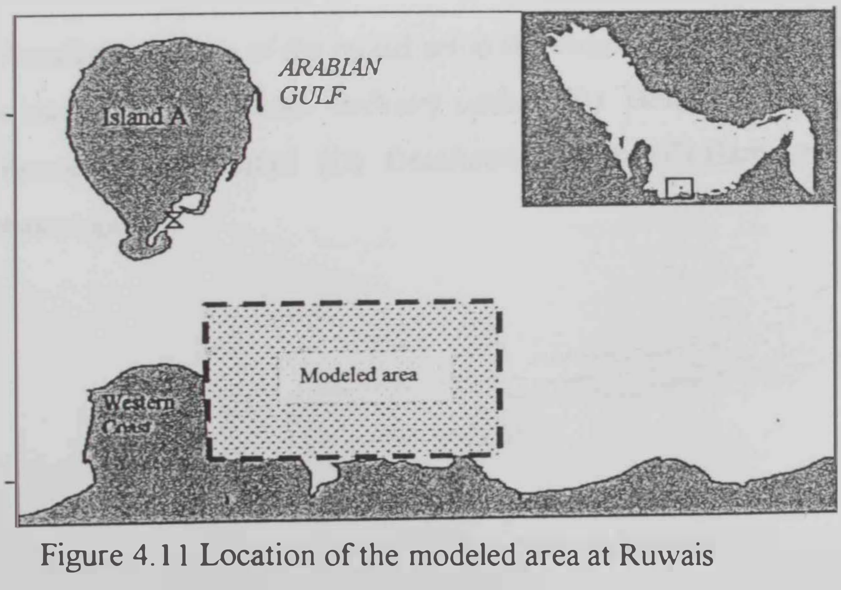

Figure 4.11 Location of the modeled area at Ruwais

The study area is focused on the shoreline where several industrial facilities are located such as Ruwais Desalination Plant (Intake and Outfall locations), Borooj Petrochemical Facilities, and Takreer Refineries. As stated earlier, most of simulation results are reported near the intake of the desalination plant for evaluation purpose. Reference to Figure 4.12, several petrochemical establishments are entered in the model as discharge/outfall points in addition to the intake of the desalination plant. Tables 4.2 and 4.3 illustrate the estimated discharge flow for each industrial facility at summer and winter, and the assumed related characteristics for each flow in terms of salinity and temperature.

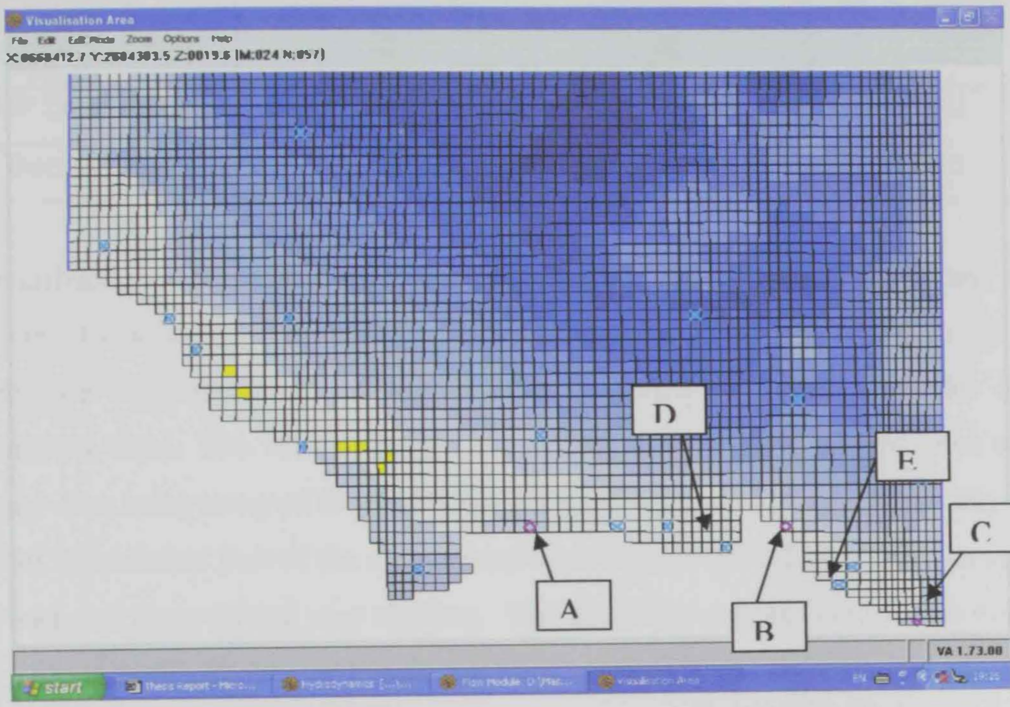

Figure 4.12 Visualization Area of the model setup showing the observation points and the discharge locations: (A) Takreer Refinery outfall (B) Desalination Plant outfall (C) Borooj Petrochemicals outfall (D) Desalination Intake (E) Harbour (for water level measurement gauge)

Table 4.2 Estimated effluent discharge characteristics for industrial facilities at summer (Elshorbagy et al 2004b)

Facility	Flow (m^3/s)	Salinity (ppt)	Temperature (°C)
Takreer Refinery	10	45.21	42
GUP Desalination	4	60	43
Borooj Plant	14	46	43

Table 4.3 Estimated effluent discharge characteristics for industrial facilities at winter (Elshorbagy et al 2004b)

Facility	Flow (m^3/s)	Salinity (ppt)	Temperature (°C)
Takreer Refinery	10	46	25
GUP Desalination	4	60	30
Borooj Plant	35	48	35

The utilized model has an overall grid size of 87x60 and employs a curvilinear sigma system. Curvilinear grids should be smooth in order to minimize errors in the finite difference approximations. A k-L module estimates the depth variation of the turbulence field. The vertical dimension is modeled in sigma co-ordinates with 3 layers. The bathymetry of the model is digitized from a navigational Admiralty Chart #3780. The central part of the area is deep with a depth up to 22m while, the areas at the east and the west are very shallow. The deep sections provide suitable entrance for large tankers. The model is calibrated against water level and current data.

4.3.2 Data Input and Simulation

Coastal winds in the UAE are dominant between west and north directions. The landward winds are driven by the intense temperature difference between land and water surface. The salinity and temperature in the Arabian Gulf are highest in the coastal waters of the UAE and Qatar. The temperature is found to vary over the study area between 20 and 34 C and salinity changes from 44 to 46 ppm over one year.

An earlier study (Fischer et al., 1981) showed hydrodynamic results and conducted sensitivity tests to show the effect of different parameters on the model results. It was shown that the salinity gradient generated an anticlockwise net circulation in the central gulf. The flow was found to decrease with the introduction of radiation induced temperature into the model.

The Master Definition Flow (MDF) file was created for the Ruwais model by creating the grid and bathymetry files. The boundary conditions were nested from overall model in terms of flow boundary conditions (time-series), and transport boundary conditions.

4.3.3 Calibration & Results

The model is calibrated by adjusting parameters within practical ranges to attain agreement with measured hydrodynamic data. All measurements are obtained from recent studies (Elshorbagy et al., 2004b). Comparison of the measured and simulated water level data at coastal location (harbour location) is shown in Figure 4.13 where a satisfactory agreement can be noticed. The match of the estimated water level with observation appears to be satisfactory. The surface currents for the summer conditions obtained after 14 days of simulation is shown in Figure 4.14. The current is generated under the influence of tidal forcing on the bathymetric variation, wind force and density gradient. As indicated in figure 4.14, a stream enters the local study area from the west towards the center, south and east of the study area at the near shoreline. An outflow occurs in the east and northeast. As the tidal force and the gradient of temperature-salinity remain almost unchanged in both seasons (summer and winter), seasonal variation of wind force is apparently the prime source of such flow pattern (Elshorbagy et al., 2004b). It was observed that the current flow pattern is dominated by the wind direction. Fig.4.14 shows the vector direction towards southeastward, as it indicates the most prevailing wind direction. Harmonic generated in figure 4-13 due to shallow water effect and disturbance of moving vessels at jetty.

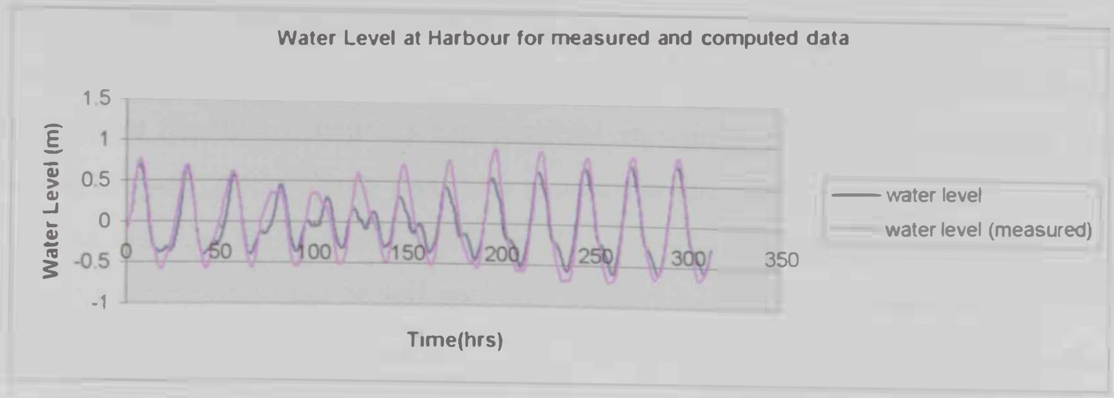

Figure 4.13 Comparison of measured and simulated water level at Harbour

Figure 4.14 Flow Field Pattern for Ruwais model at summer

The temperature-salinity dynamics is a three-dimensional process as the atmospheric heat exchanges with the water-mass, the evaporation occurs at the surface and the evolved density variation moves water under the influence of gravity. It was observed that the higher salinity and temperature near eastern shoreline are intensified due to the brine discharge and effluents from industries especially the eastern Borooj effluent

The calibrated results are compared with the salinity and temperature data utilized in a recent study Recent study done by (Elshorbagy et al , 2004b) carried out field survey to measure the flow conditions and temperature-salinity distribution of Ruwais area during the year 2002 Water level was measure at three locations i.e Bani Yas, Jabal Dhanna and Abu Dhabi Port (ADPOC) The water level records at the ADPOC port covered nearly one year period and was used in this study Current profiles were measured using Acoustic Doppler Current Profiler Temperature and salinity profiles were measure at 10 locations (figure 4 15) both in the summer and winter Simulated and observed distributions of salinity and temperature at summer and winter are shown in Figures 4 16 to 4 19, respectively Highest temperature and salinity are observed close to the shore in the east where the GUP and Borooj outfalls are located. The alignment of the salinity-temperature contours exhibits the progression of the flow towards deeper north Density force, convection and dispersion generate such movement of the warm and high saline water While the tidal circulation brings fresher water from the west mixing with central basin water before leaving through north (Elshorbagy et al , 2004b), water close to the outfalls moves relatively slowly as almost no exchange occurs from the east.

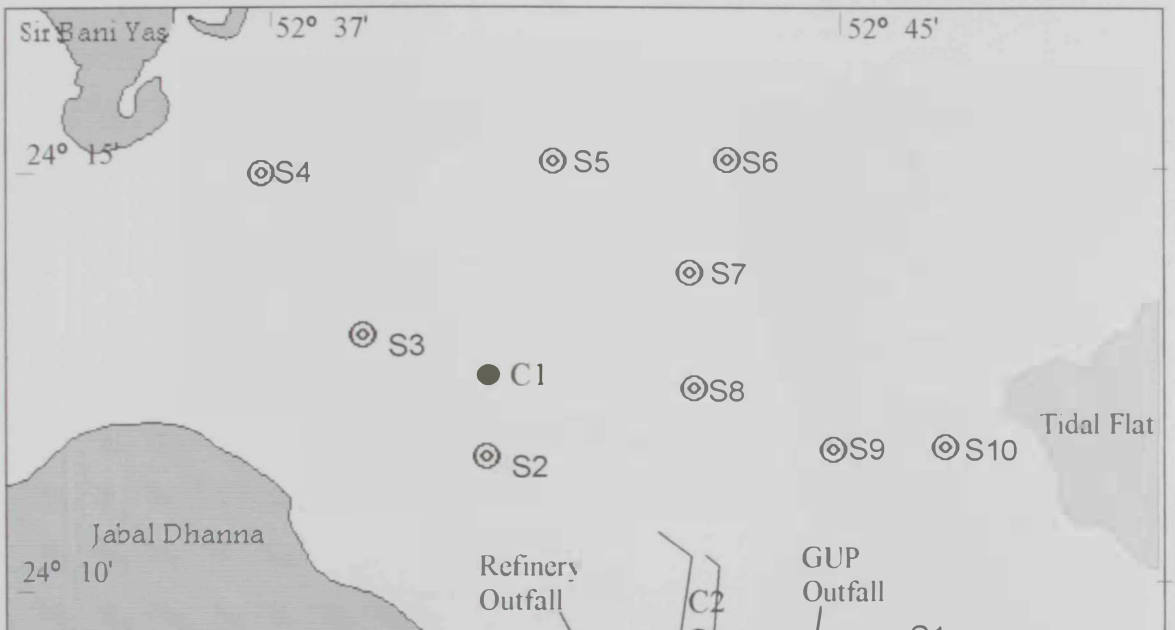

Figure 4 15 Ruwais coast and locations of measurements

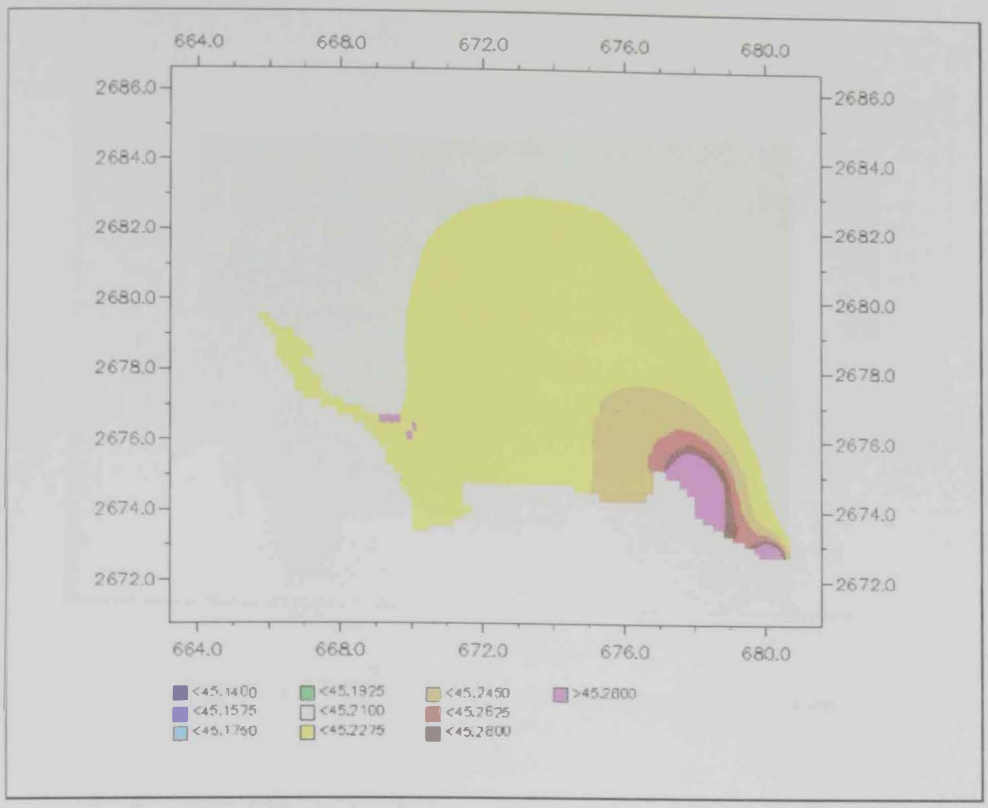

Figure 4.16 Salinity model results at summer

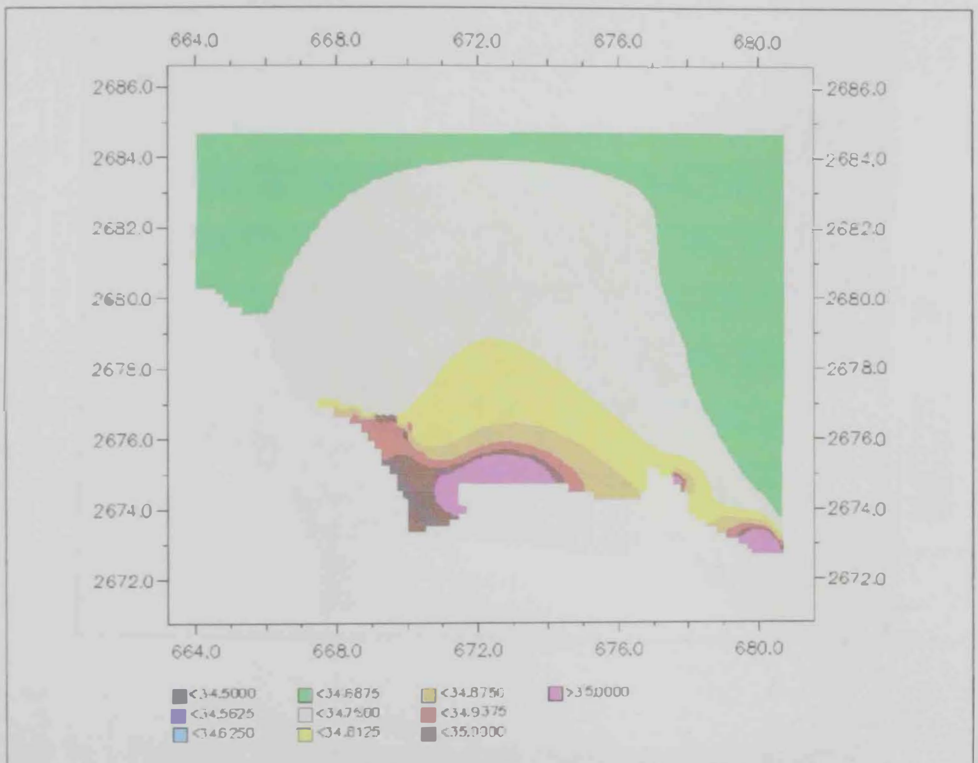

Figure 4 17 Temperature model results at summer

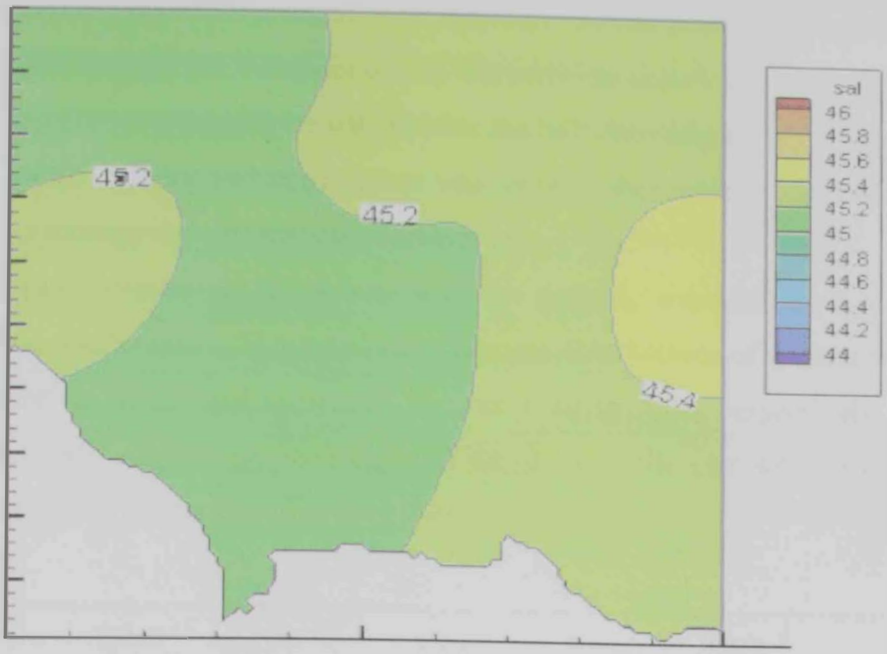

Figure 4.18 Salinity field measurements at summer

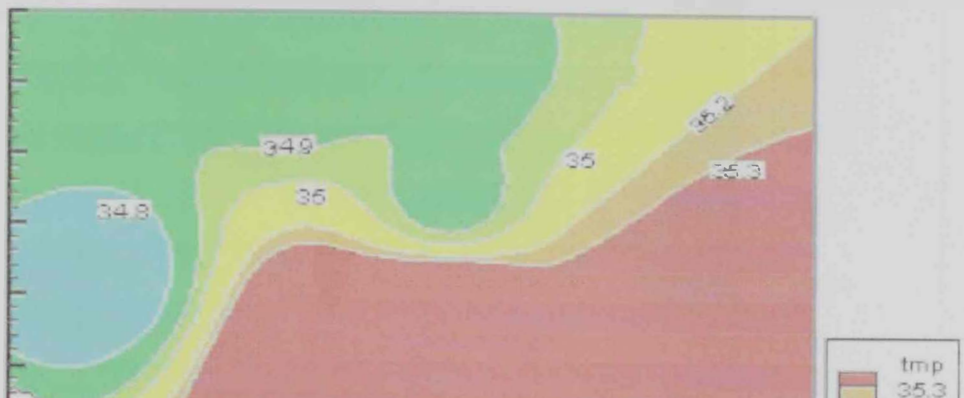

Figure 4.19 Temperature field measurements at summer

The temperature-salinity dynamics is a three-dimensional process as the atmospheric heat exchanges with the water-mass, the evaporation occurs at the surface and the evolved density variation moves water under the influence of gravity It was observed that the higher salinity and temperature near eastern shoreline are intensified due to the brine discharge and effluents from industries

The calibrated results are compared with the existing available data in terms of salinity and temperature. Simulated and observed distributions of surface salinity and temperature at winter are shown in Figures 4 20 to 4 23, respectively Highest temperature and salinity are seen close to the shore in the east where the GUP and Borooj outfalls are located with a range between 21-23°C

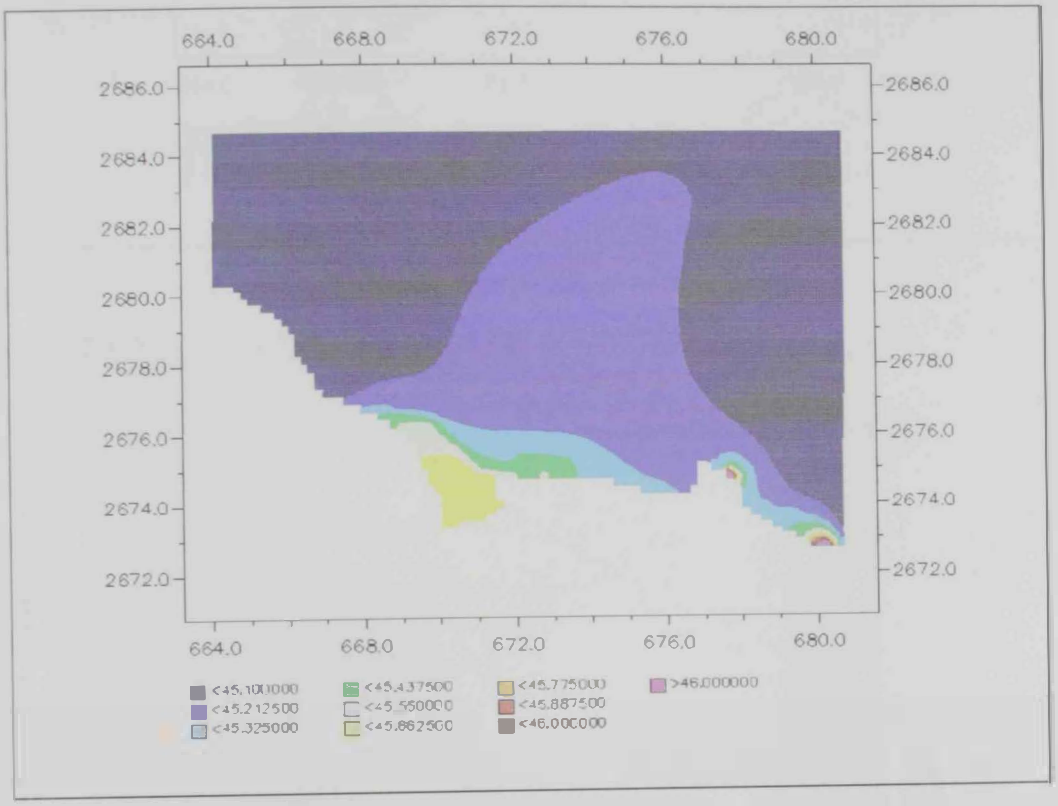

Figure 4 20 Salinity model results at winter.

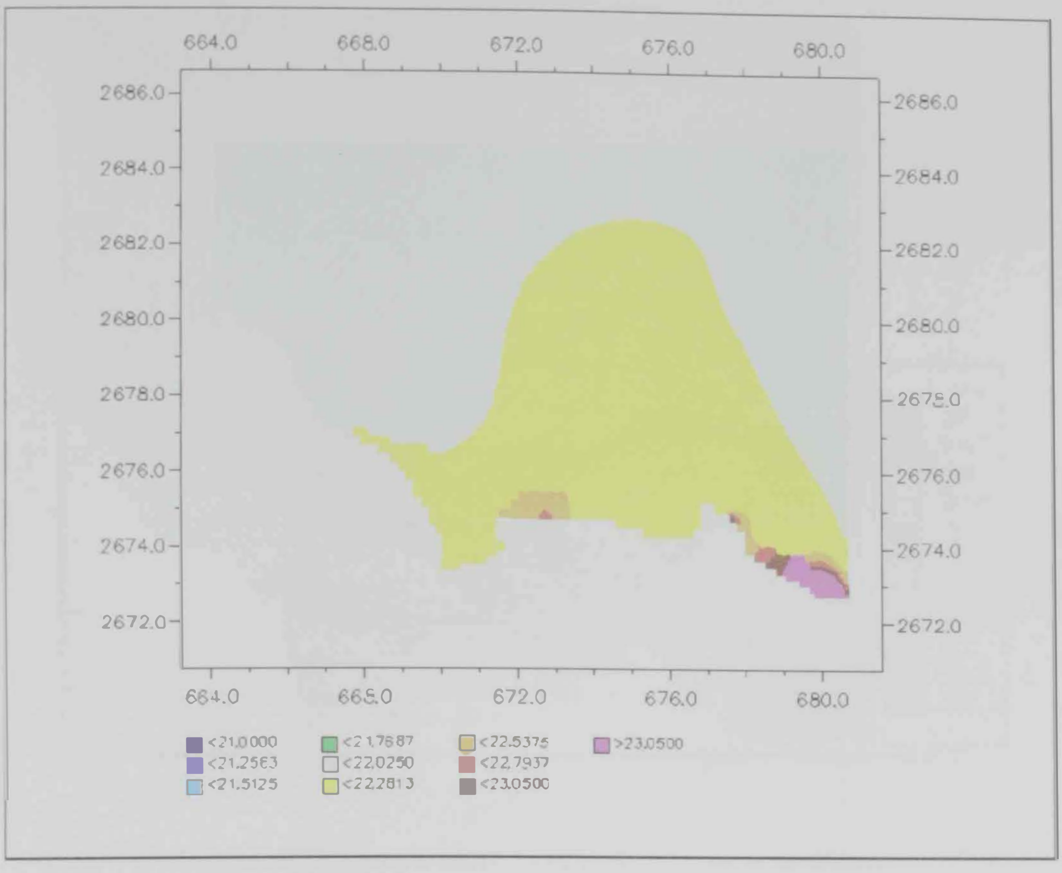

Figure 4.21 Temperature model results at winter.

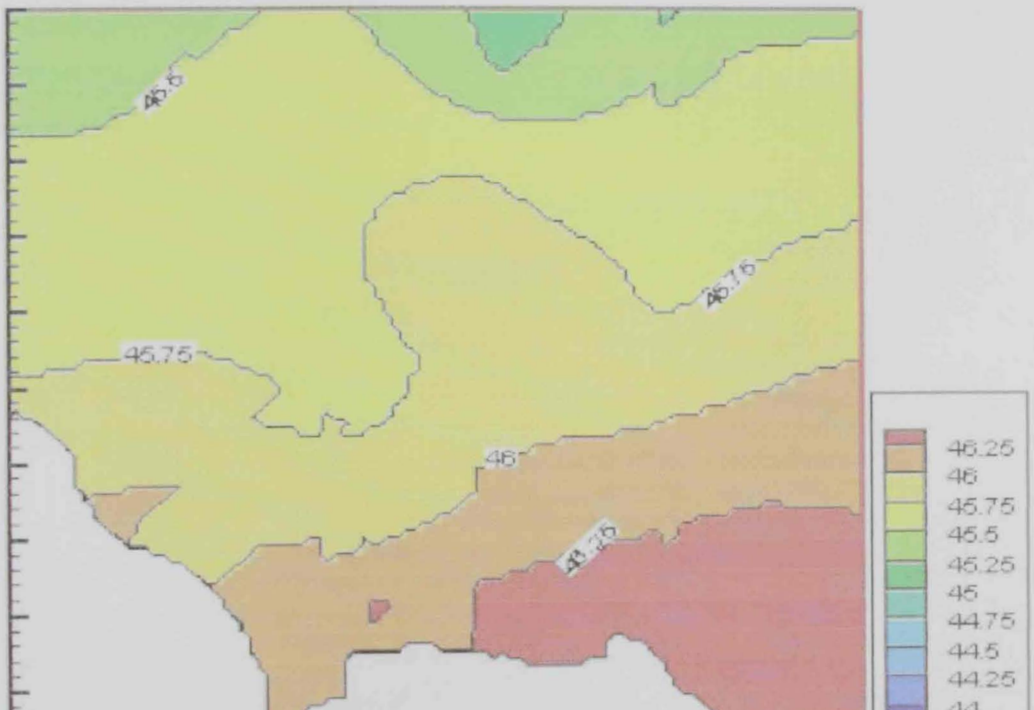

Figure 4. 22salinity field measurements at winter

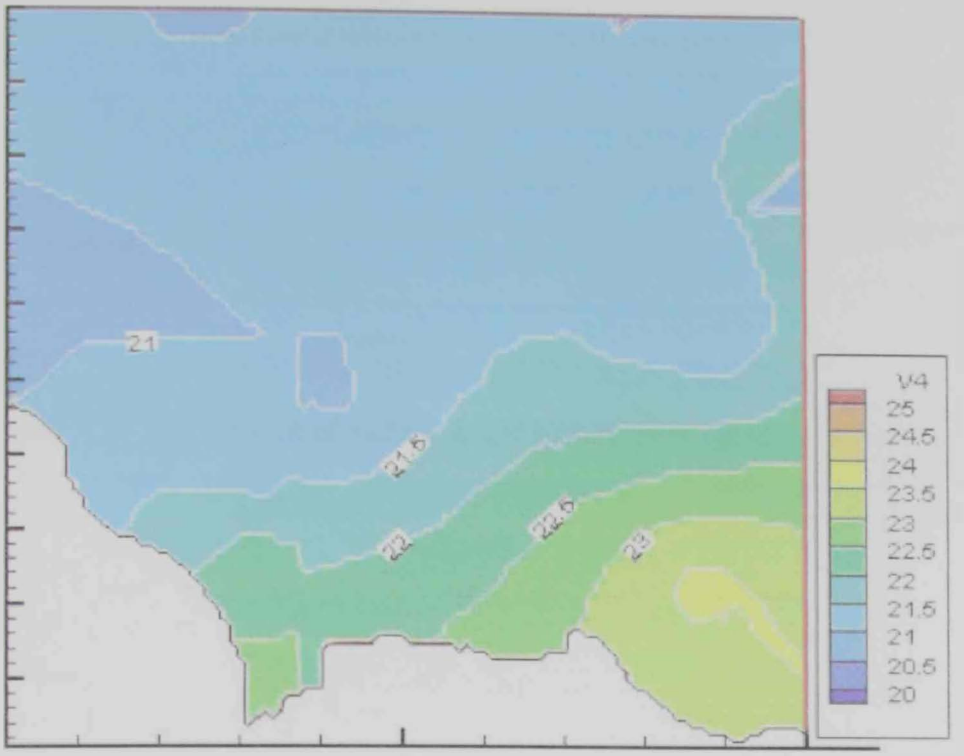

Figure 4 23 Temperature field measurements at winter

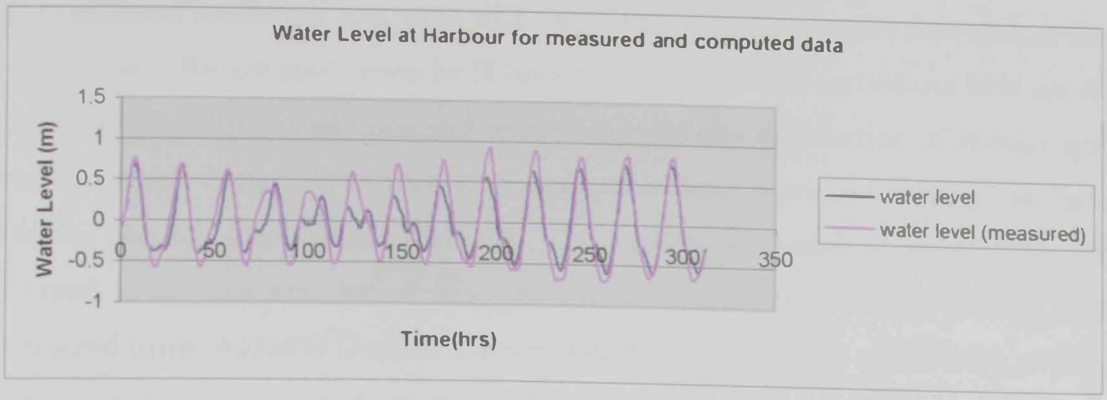

Figure 4.13 Comparison of measured and simulated water level at Harbour.

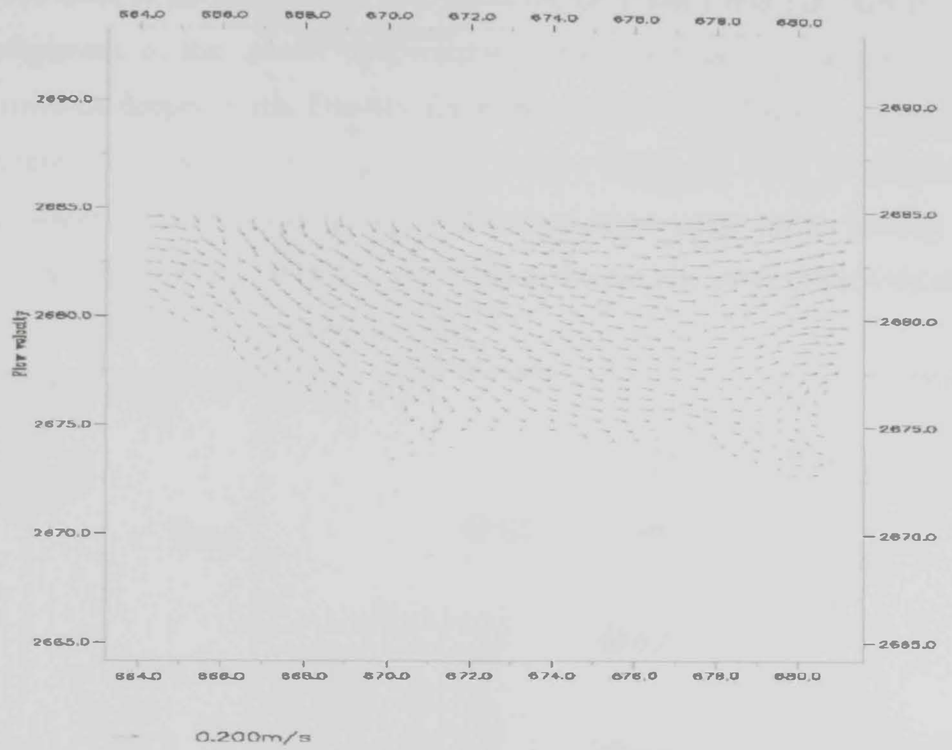

Figure 4.14 Flow Field Pattern for Ruwais model at summer

The temperature-salinity dynamics is a three-dimensional process as the atmospheric heat exchanges with the water-mass, the evaporation occurs at the surface and the evolved density variation moves water under the influence of gravity. It was observed that the higher salinity and temperature near eastern shoreline are intensified due to the brine discharge and effluents from industries especially the eastern Borooj effluent.

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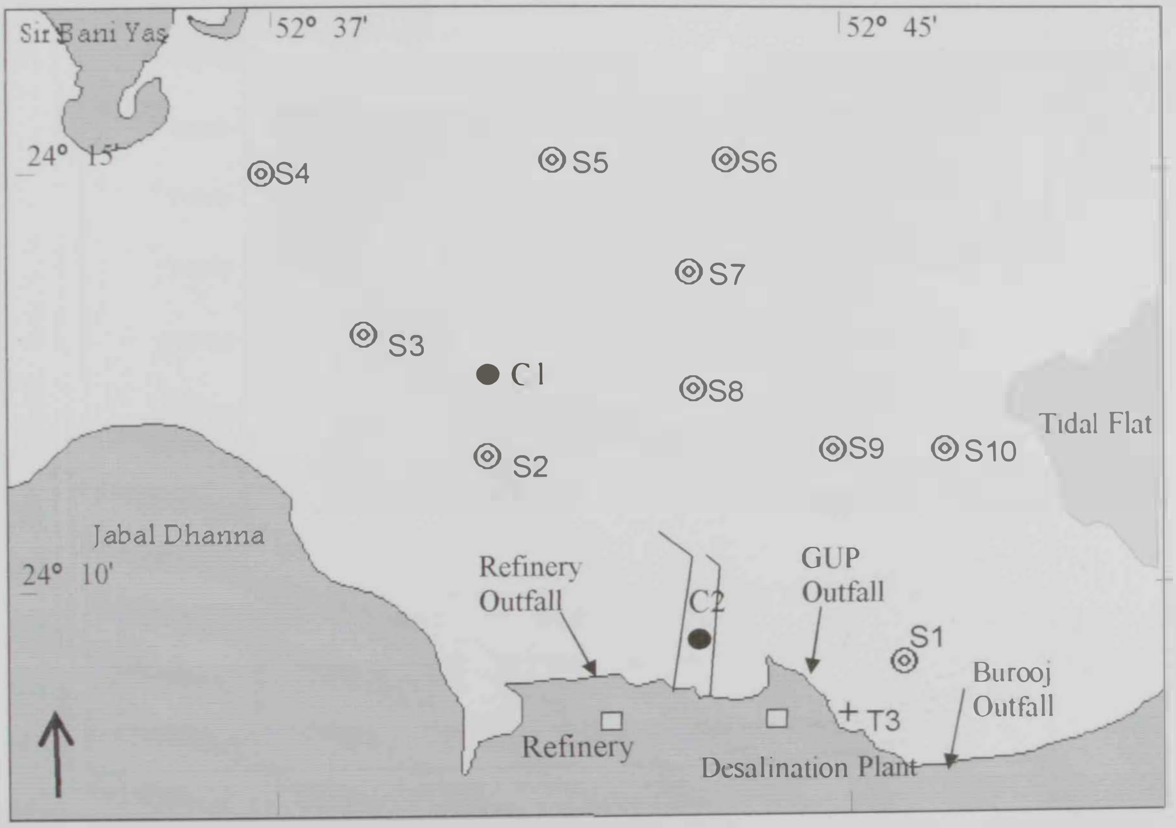


Figure 4 15 Ruwais coast and locations of measurements

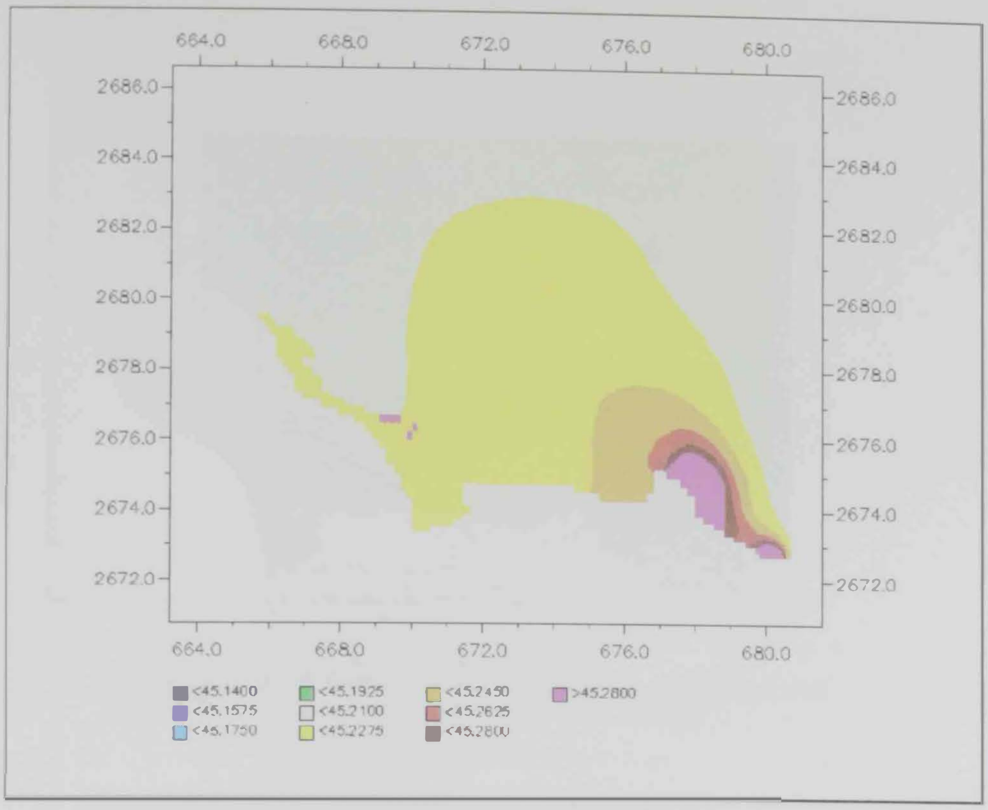


Figure 4.16 Salinity model results at summer

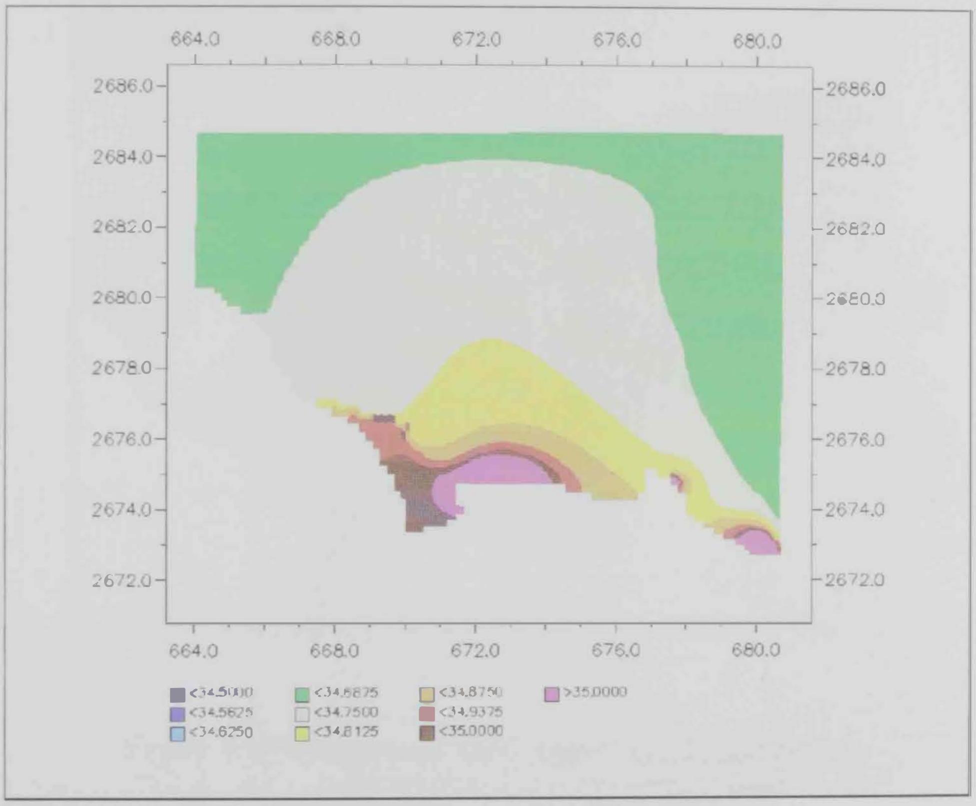


Figure 4.17 Temperature model results at summer

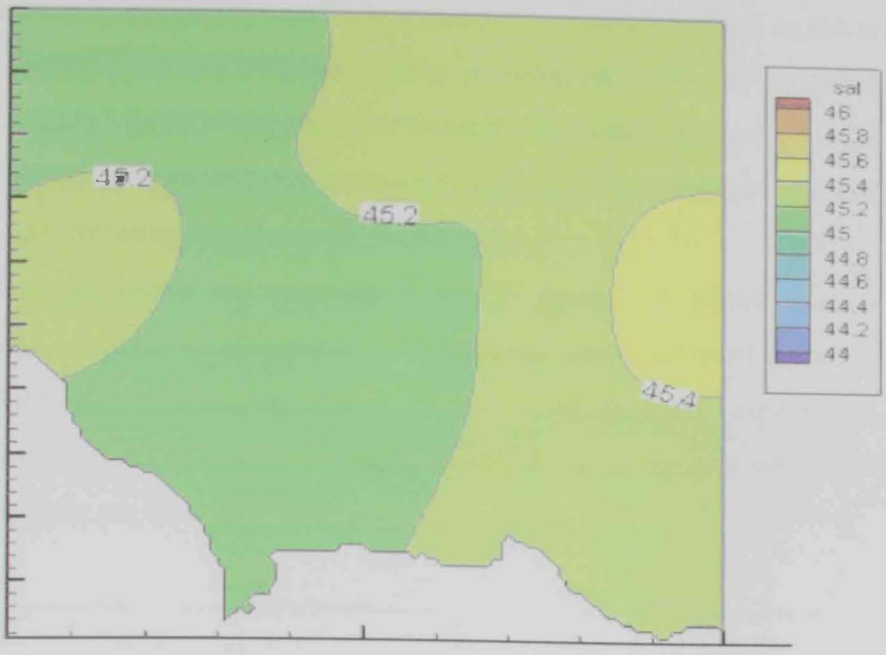


Figure 4.18 Salinity field measurements at summer

Figure 4.19 Temperature field measurements at summer

The temperature-salinity dynamics is a three-dimensional process as the atmospheric heat exchanges with the water-mass, the evaporation occurs at the surface and the evolved density variation moves water under the influence of gravity. It was observed that the higher salinity and temperature near eastern shoreline are intensified due to the brine discharge and effluents from industries.

The calibrated results are compared with the existing available data in terms of salinity and temperature. Simulated and observed distributions of surface salinity and temperature at winter are shown in Figures 4.20 to 4.23, respectively. Highest temperature and salinity are seen close to the shore in the east where the GUP and Borooj outfalls are located with a range between 21-23°C.

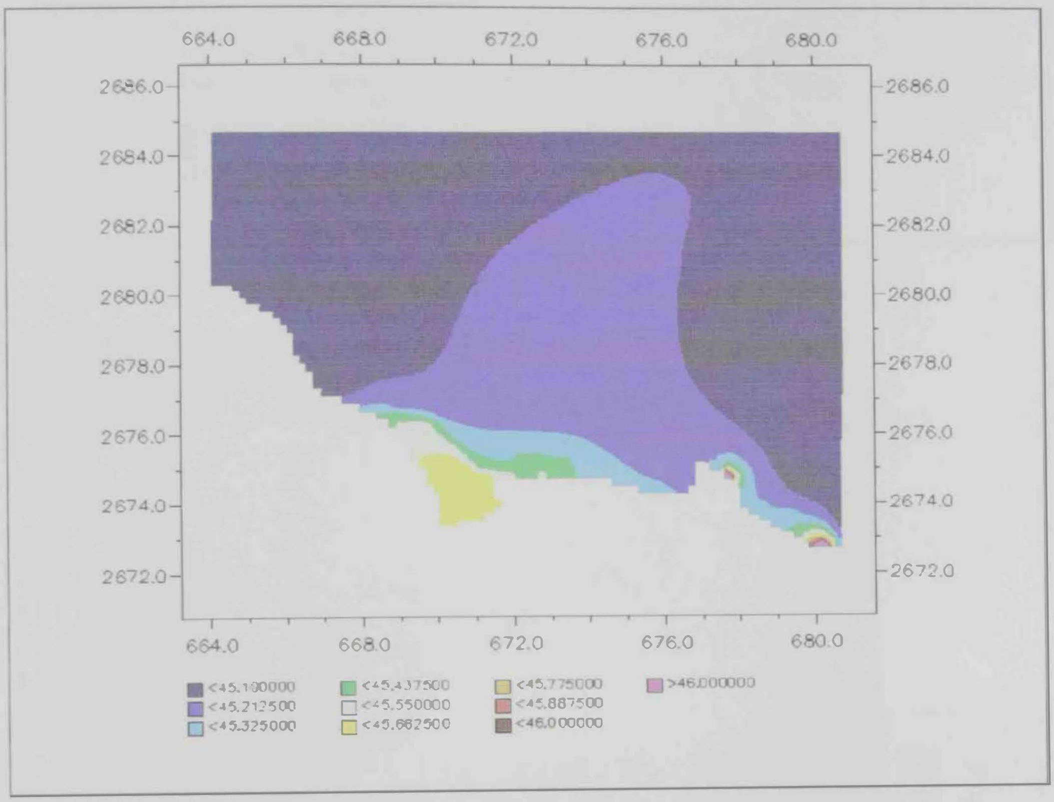


Figure 4.20 Salinity model results at winter.

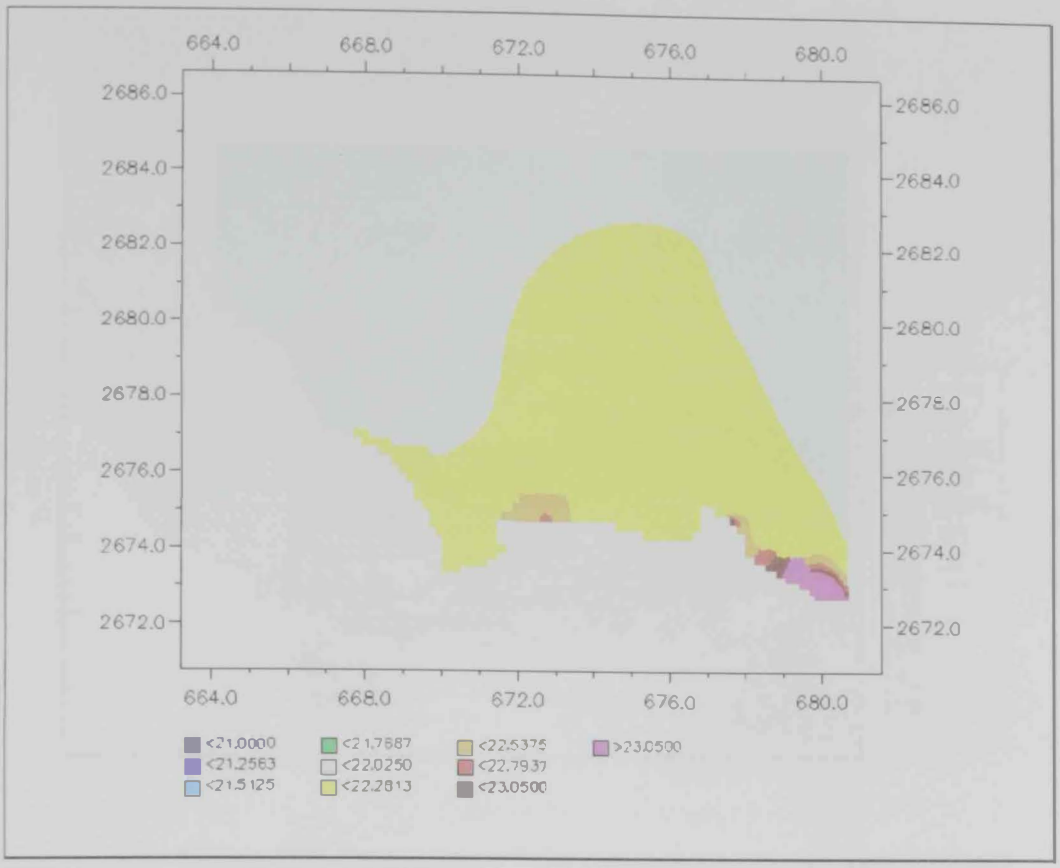


Figure 4.21 Temperature model results at winter.

Figure 4.22salinity field measurements at winter

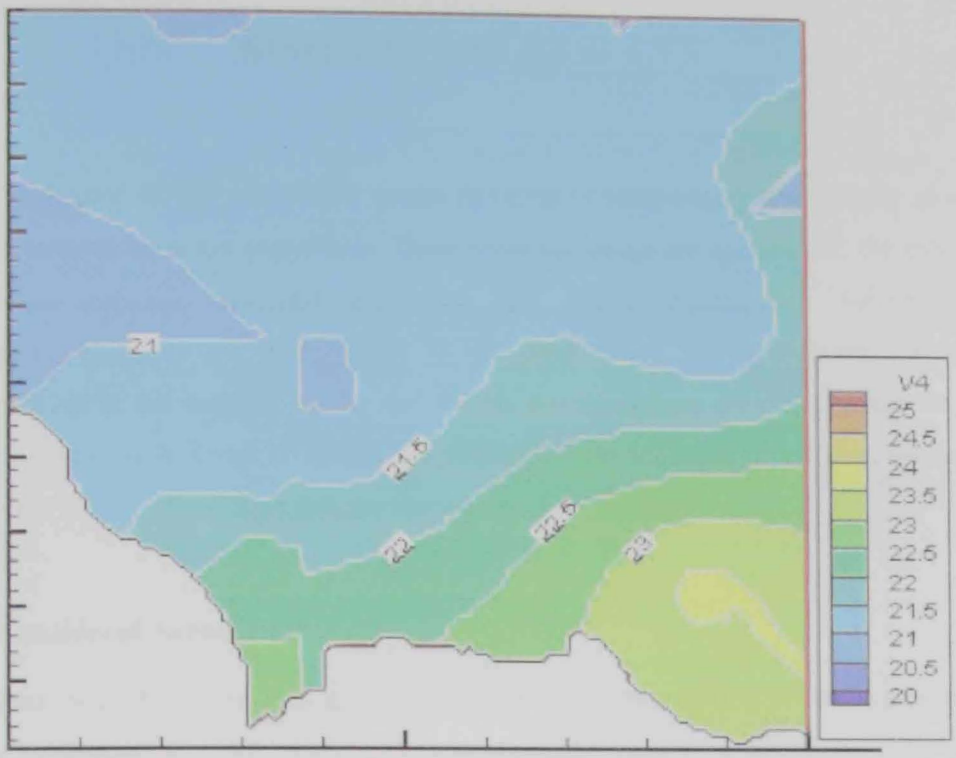


Figure 4.23 Temperature field measurements at winter

CHAPTER (5)
SIMULATION RESULTS

In this chapter, all the simulation results in terms of temperature and salinity as well as operational costs are presented. Three main scenarios are considered; the existing facilities scenario, moderate expansion and major expansion. Salinity and temperature results are investigated at the desalination intake location. Several alternatives to the existing intake and outfall configurations are investigated for the entire scenarios in order to assess the impact of the increase of effluent discharge upon the MSF performance and the corresponding operational costs.

5.1 Considered Scenarios

In simulation, the considered wind is constant value representing the most prevailing wind conditions at UAE coats, which is west and northwest direction. The wind direction is defined according to the nautical definition, i.e. relative to true North and the positive is measured clockwise. In figure 5.1, the wind direction is about +60 degrees i.e. a Northeast wind.

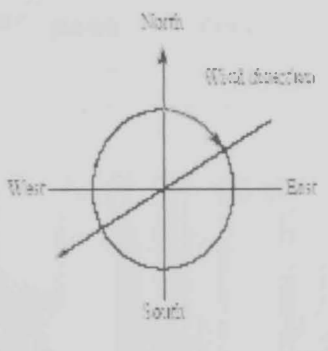
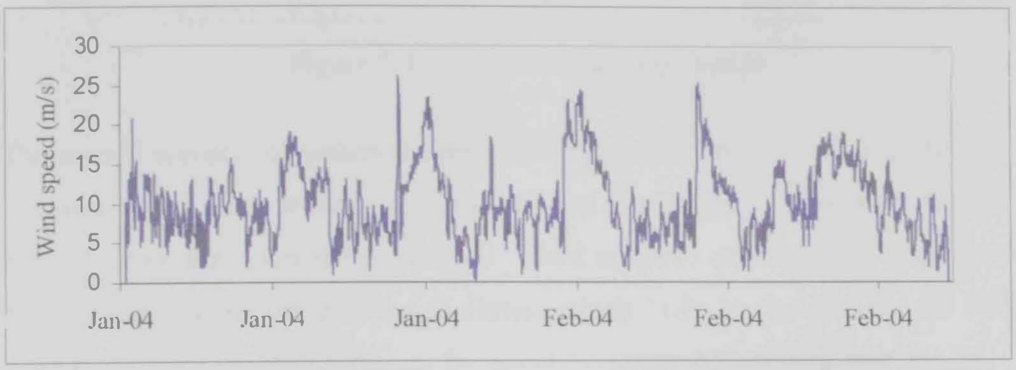


Figure 5.1 Nautical definition wind direction

The wind exerts a strong influence on the mixing and the circulation of the Gulf. Like the tide and density gradient, wind is another source of energy that creates water motion in the Arabian Gulf (Reynolds 1993). For the present study, winter wind data are obtained from measurements conducted in a recent study (Elshorbagy et al., 2004b) while the summer data are collected from nearby islands as reported in (Elshorbagy et al., 2004a). Plot of measured wind speed and direction are shown in

Figure 5.2. A wind speed ranging from 5-10 m/s dominates the most part of the record, but stronger wind exceeding 20 m/s and sustaining for 4 days occurs mostly in cyclic fashion from the end of January. The weaker wind mostly flows from the east and shows diurnal oscillation. All strong winds, which are regionally well known as 'Shamal', come from northwest. The time averaged wind speed for this period is 5.2 m/s and mean direction is between north and northwest. For the summer season, wind data were collected from three offshore islands of the Southern Gulf. The summer wind is much weaker than the winter wind, but mostly blows from northwest direction. The speed rarely exceeds 10m/s limit and the stronger wind does not sustain for long duration. Reference to Figure 5.2, and with simple calculation, it was noticed that among the measured period, 77% of the overall period has direction between north and northwest, and 23% has the reverse direction (east direction), Figure 5.3.



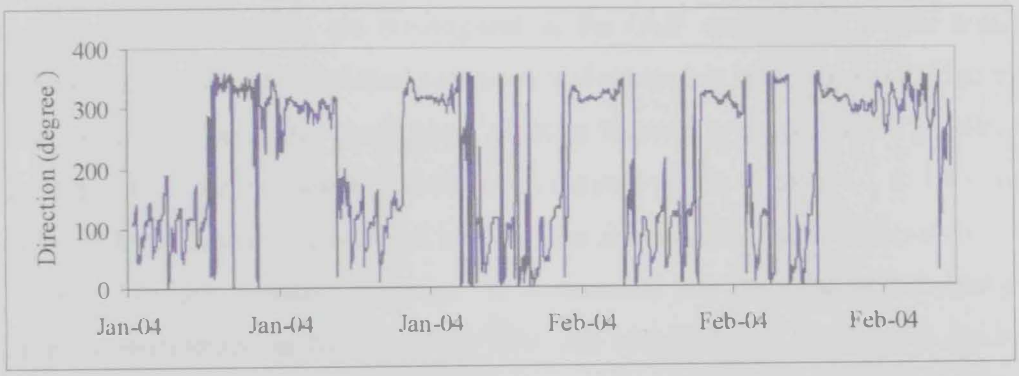


Figure 5.2 Winter measurements of wind speed and direction in Ruwais, 2004

The study shall evaluate the salinity and temperature at desalination intake from several scenarios, and the effect of wind's magnitude and direction on the simulation results and the impact on the MSF plant performance in terms of technical and commercial perspectives.

There are three main scenarios to be considered in both season's summer and winter. First scenario shall consider the existing facilities including all the basic data/information created to formulate the basic design model considering the wind effect as the most prevailing wind direction (north & north-west).

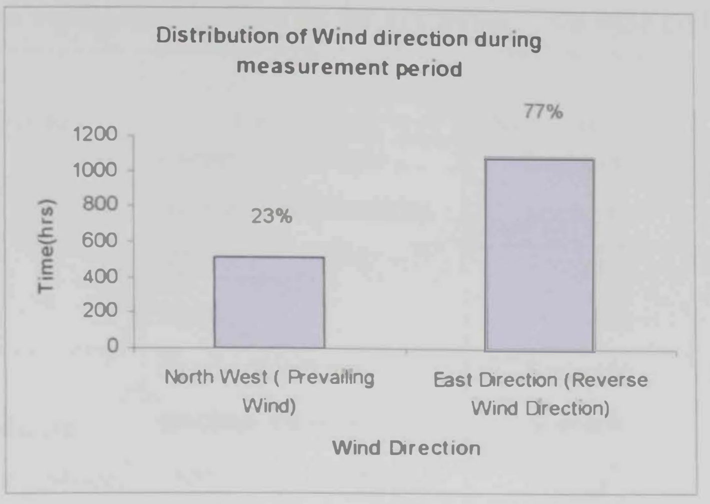
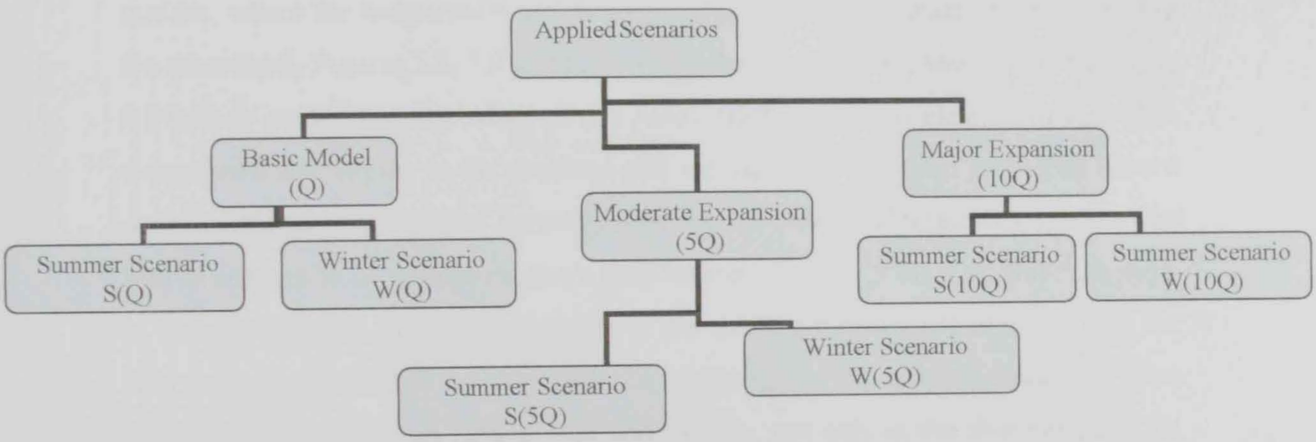


Figure 5.3 Wind Direction Distribution

The second scenario considers the assumption of moderate expansion to the existing facilities, which leads to increase in the effluent discharge of the existing facilities by about 5 times the original base model. Third scenario considers the assumption of major expansion to the existing facilities, which leads to increase in the effluent discharge of the existing facilities by about 10 times the original base model. The salinity and temperature are investigated at the GUP desalination intake area. A summary of the above mentioned scenarios is illustrated in table 5.1 and in Figure 5.4. The capacity of existing desalination plant at Ruwais is about 64,000 m^3/day that corresponds to the estimated effluent levels defined earlier (Tables 4.2 & 4.3 Chapter 4) in the basic scenario considered herein. The discharge increases relatively with the increase in plant distillate capacity. It is assumed that the relation between plant capacity represented as M_d (Distillate flow rate required) and the effluent discharge representing the salinity and temperature is almost leaner. On the other word, the increase in distillate (water need) in addition to the expansion of adjacent industrial facilities increases the effluent discharge from all these industrial facilities into the sea. Consequently, this will lead to an increase in temperature and salinity at the shoreline area. Having the effect of "No Discharge" scenario was not considered in the study since, this scenario will only evaluate the environmental impact of existing facilities on the Ruwais ecosystem. This is somewhat different from the objective of the thesis, where the study of the potential impact of existing facilities on MSF performance in terms of temperature and salinity.

Table 5.1 List of considered scenarios for the evaluation of the MSF performance

S/N	Scenario	Description	Sub Scenarios	Remarks
A	Basic Model	Current discharges from existing facilities **(Q).**	Summer Scenario	S(Q)
			Winter Scenario	W(Q)
B	Moderate Expansion Model	Discharges from existing facilities increased 5 times (**5Q)**	Summer Scenario	S(5Q)
			Winter Scenario	W(5Q)
C	Major Expansion Model	Discharges from existing facilities increased 10 times **10Q)**	Summer Scenario	S(10Q)
			Winter Scenario	W(10Q)



S(Q) = Summer with discharge Q
S(5Q) = Summer with discharge 5Q
S(10Q) = Summer with discharge 10Q

W(Q) = Winter with discharge Q
W(5Q) = Winter with discharge 5Q
W(10Q) = Winter with discharge 10Q

Figure 5.4 Diagram showing different considered scenarios

5.2 Hydrodynamic Results for dominant wind

5.2.1 Summer Results

The results of the three scenarios are presented in Figures 5.5 to 5.13. The summer temperature and salinity that cover the majority of the year (about 7months) ranges from 34.5 to 35.2 °C and from 45.5 to 46 ppt, respectively. The contour profile shows higher temperature in the southern close to shoreline. The temperature in the west is the lowest. Similarly, the salinity is slightly higher in the southern and becomes lower in the west. Such findings indicates that the basin receives less saline and cooler water from the north and the west near the open boundaries, while the warmer and saline water formed of the shallower eastern side where the industrial facilities contribution by discharge of brine water with high temperature and more saline water. Highest temperature and salinity are observed close to the shore in the east where the GUP and Borooj outfalls are located. Density force, convection and dispersion generate such movement of the warm and high saline water. While the tidal circulation brings fresher water from the west and western north and mixes with central and lower basin water before leaving through north, the tidal flow close to the east helps in mixing with industrial facilities effluent and propagate toward the north of the basin (refer to Figure 5.7). Figures 5.5, 5.6 and 5.7 show that the impact of industrial facilities is clearly noticed at the close area that surrounds the facilities outfalls, where the temperature and salinity concentration increased in that area. On the other hand, Figures 5.8, 5.9 and 5.10 where the moderate expansion to the existing facilities is considered, the effect of this moderate expansion is clearly noticed. The temperature and salinity in the southern east are increased and even propagate toward north, where the possibility of harming/affecting adversely the desalination intake (the area of concern to be studied) is more pronounced. Figures 5.11, 5.12 and 5.13 show an extreme scenario of major expansion of the existing industrial facilities, where the discharge was increased by 10 times the discharge of all exiting facilities. This scenario shows very high temperature and salinity, not only at the shoreline, but the effect of this scenario covers the majority of the coastal shoreline and even propagates toward north at centre of the basin, yielding minimum success to the opportunity of proposing alternative intake and outfall configurations to overcome such situation.

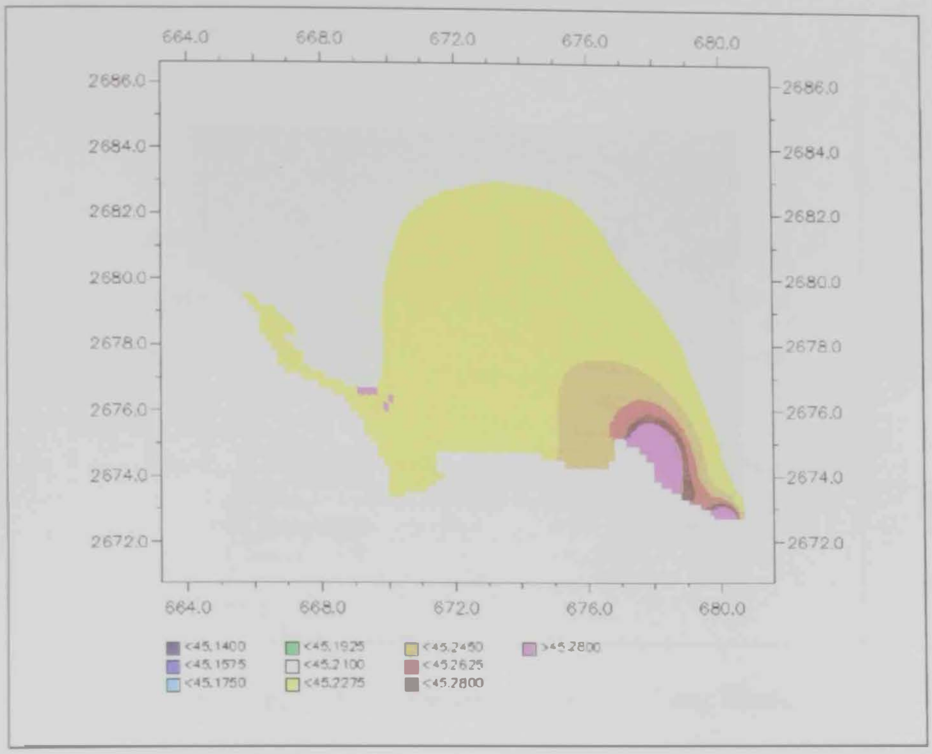


Figure 5.5 Salinity Contours at summer (Basic Model)

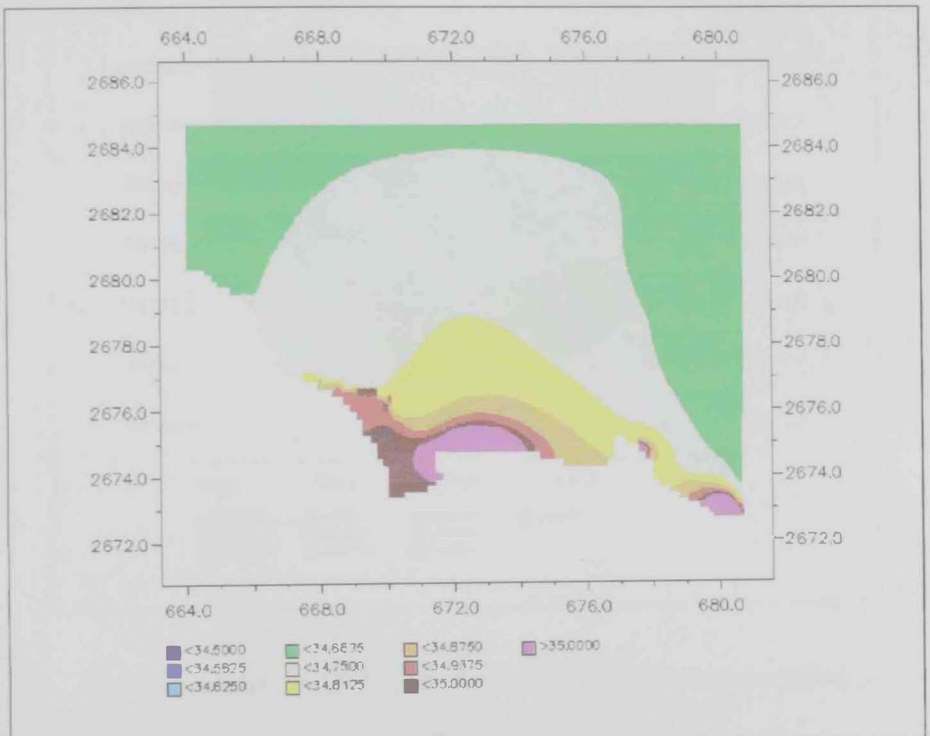


Figure 5.6 Temperature Contour at summer (Basic Model)

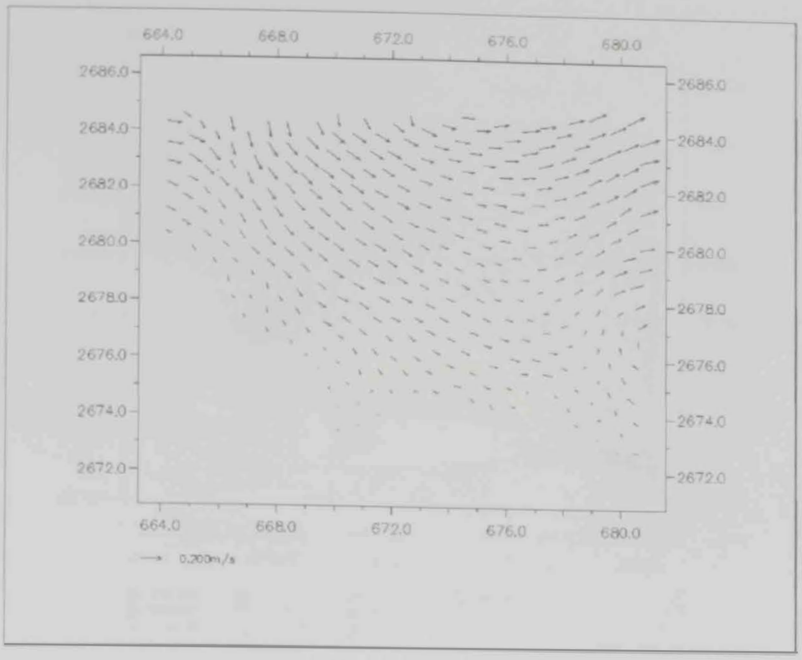


Figure 5.7 Flow Field Pattern at Summer (Basic Model)

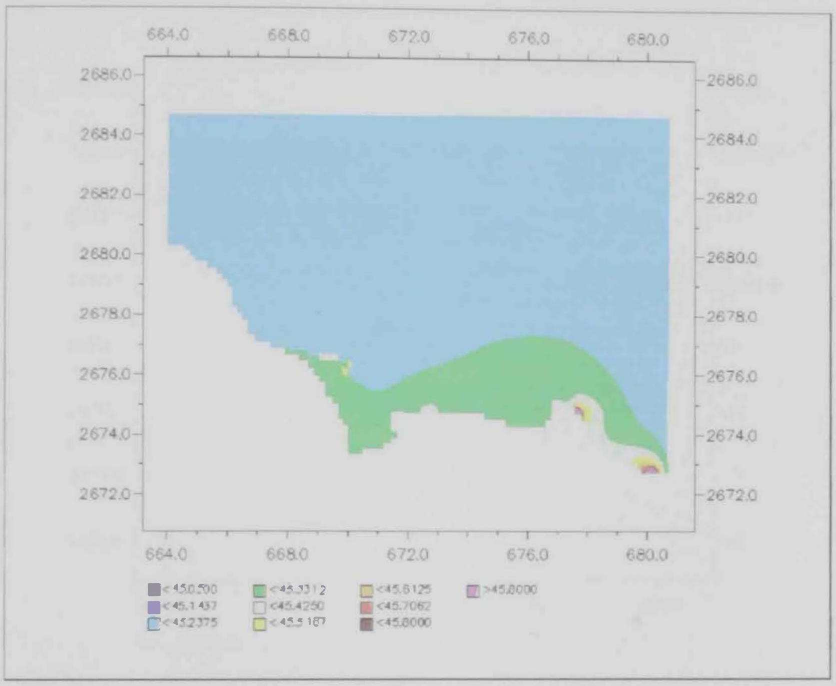


Figure 5.8 Salinity Contours at summer (Moderate expansion).

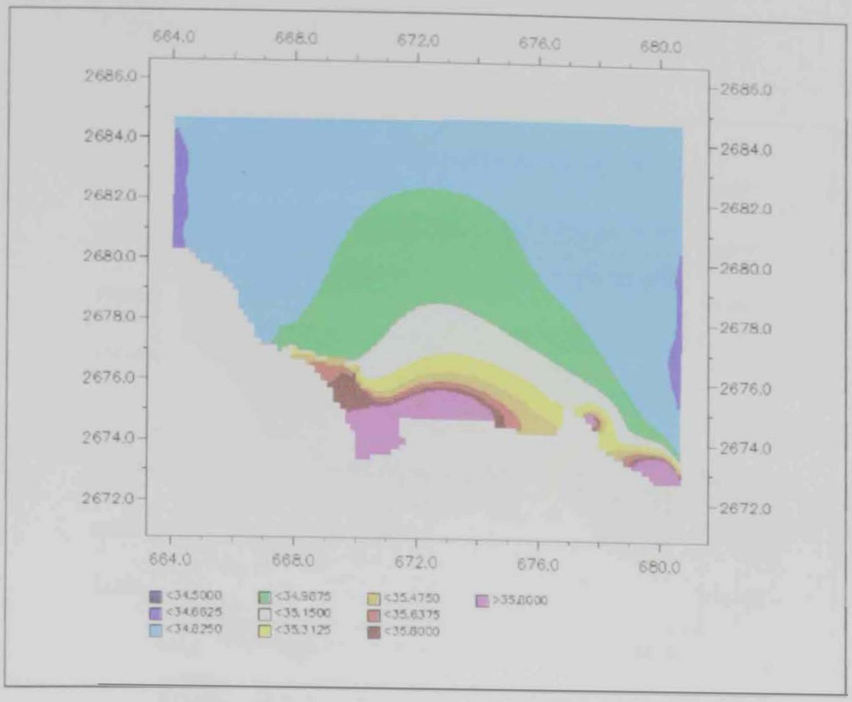


Figure 5.9 Temperature Contour at summer (Moderate expansion).

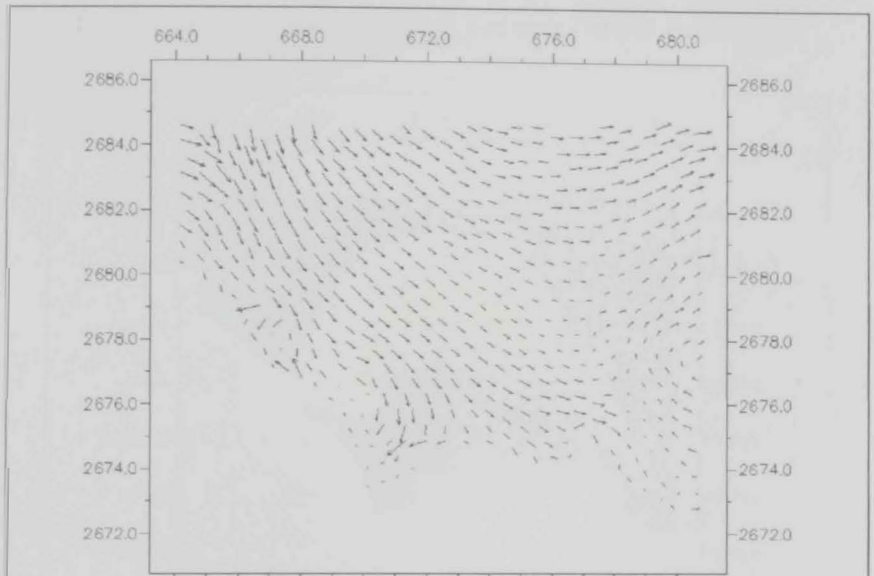


Figure 5.10 Flow Filed Pattern at Summer (Moderate expansion)

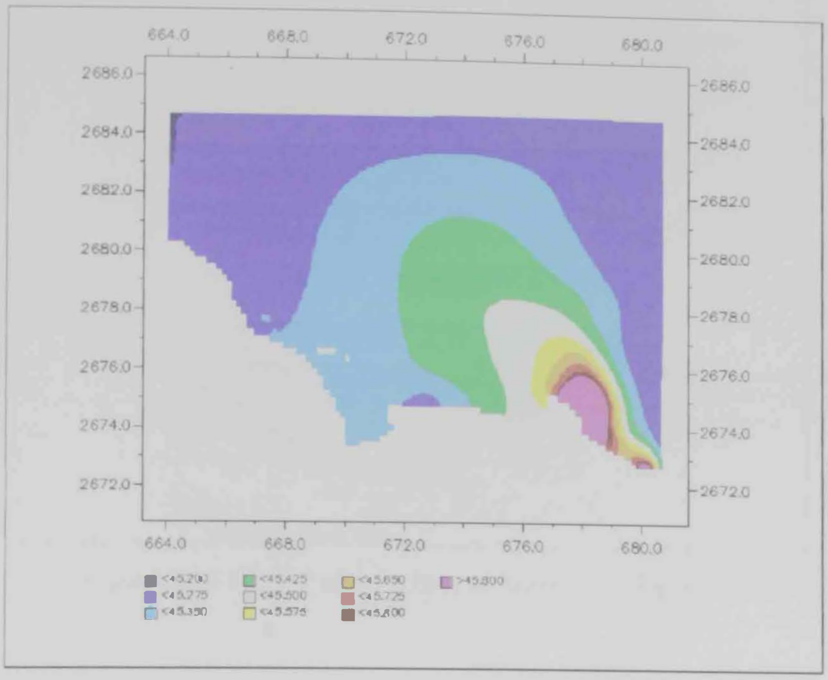


Figure 5.11 Salinity Contour at summer (Major expansion).

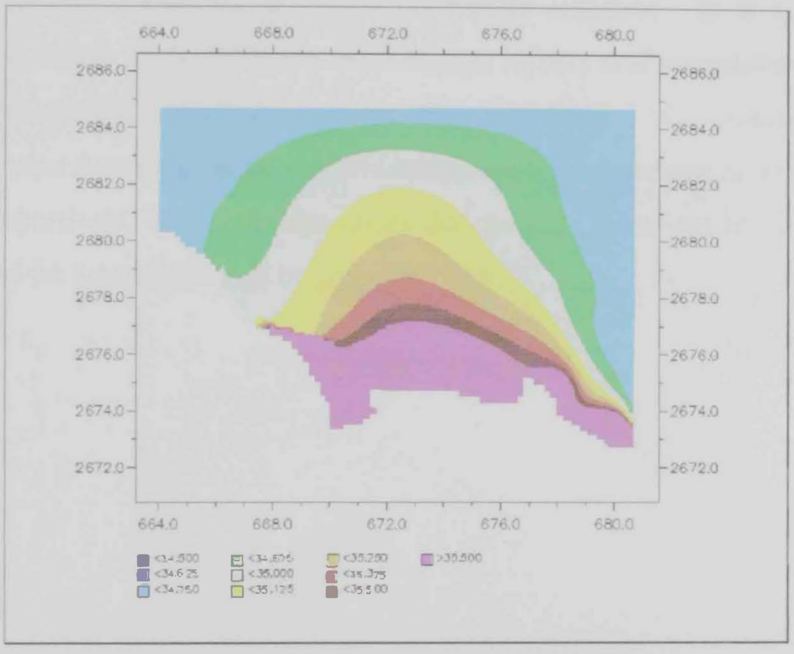


Figure 5.12 Temperature Contour at summer (Major expansion)

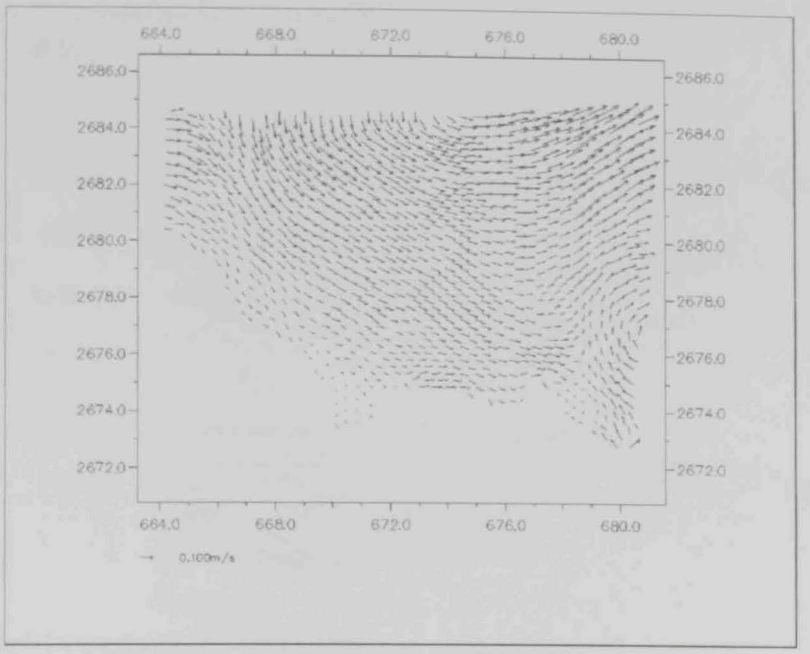


Figure 5.13 Flow Field Pattern at Summer (Major expansion)

Figures 5.14 and 5.15 show the summer salinity and temperature variation with time at the desalination intake for the three considered scenarios. It is noticed that moderate expansion of the facilities increases the salinity and temperature at intake from an average of 45.24 to 45.36 ppt and from 34.8 to 35.3 °C, respectively. The major expansion increases the salinity and temperature to an average of 45.48 ppt and 35.9 °C, respectively. That increase raises the chemical treatment cost and energy cost required for pumping as will be presented later.

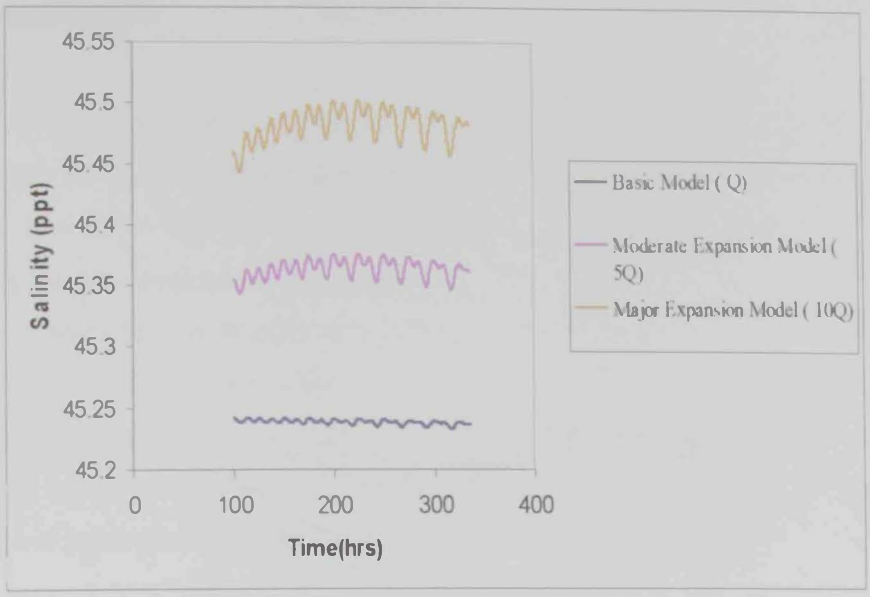


Figure 5.14 Comparison of the salinity results considering the three different scenarios at desalination intake in summer

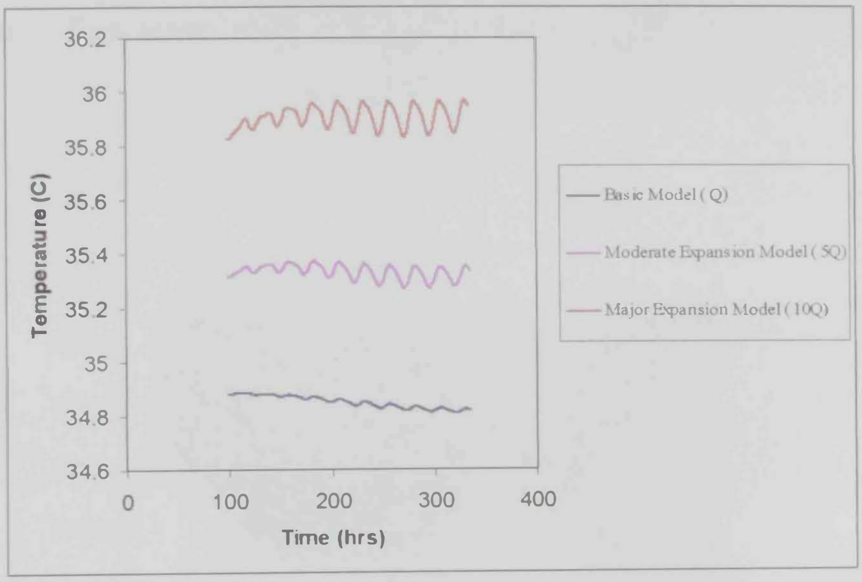


Figure 5.15 Comparison of the temperature results considering the three different scenarios at desalination intake in summer

5.2.2 Winter Results

Winter results of the three scenarios are presented in Figures 5.16 to 5.24. The winter temperature and salinity, which spans over about 30% of the year, ranges from 21.8 to 23.2 °C and from 45.0 to 46 ppt, respectively. Again, the western side shows relatively lower temperature and salinity as the case of summer. As illustrated previously with the case of summer conditions, the existing industrial facilities had an influence on the salinity/temperature distribution especially at the surface level of the shoreline. The wind plays a significant role in the mixing process, especially the prevailing northwestern wind. The overall circulation is greatly enhanced under the influence of northwesterly wind (refer to figures 5.18, 5.21 and 5.24).

In the case of moderate and major expansion to the existing facilities, higher brine is introduced to the sea, which increases the salinity and temperature near the eastern shoreline. This denser water mass propagates northward under the influence of gravity.

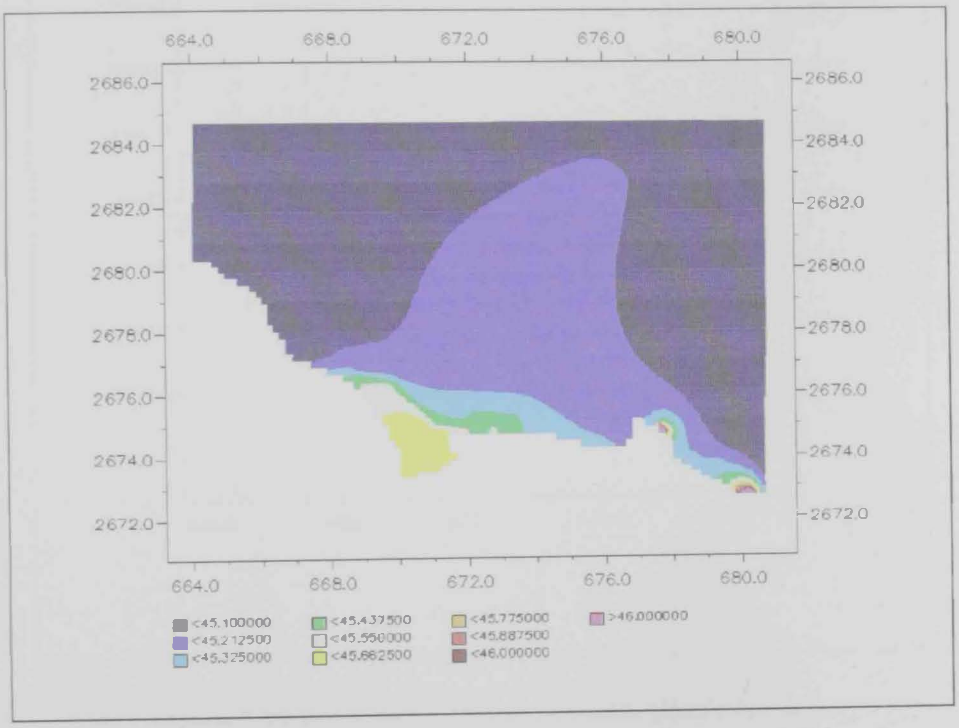


Figure 5.16 Salinity Contours at winter (Basic Model)

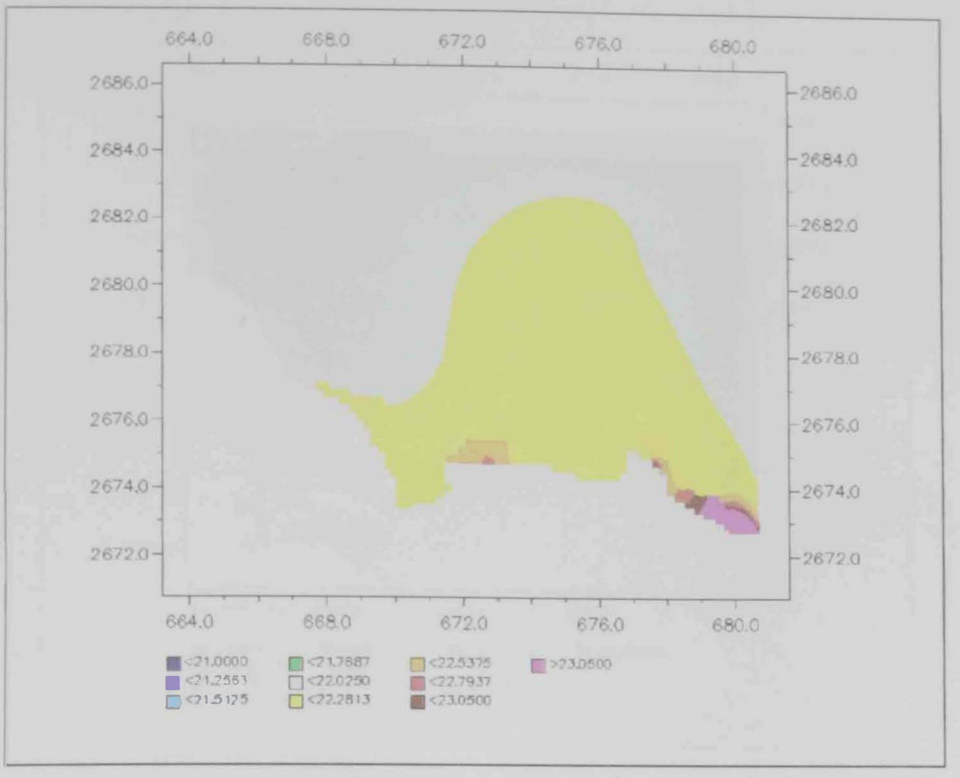


Figure 5.17 Temperature Contours at winter (Basic Model)

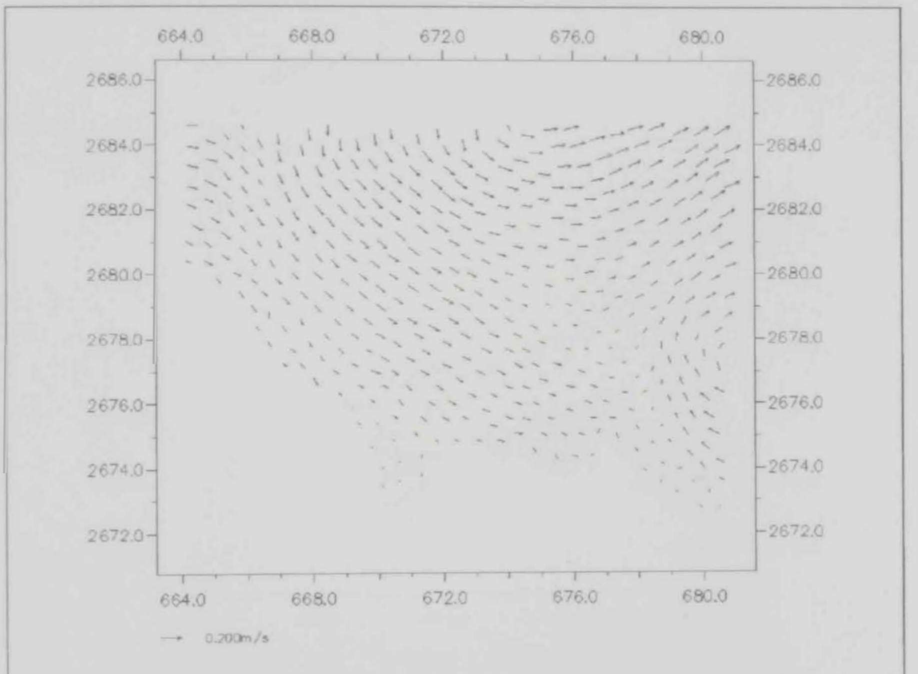


Figure 5.18 Flow Field Pattern at winter (Basic Model)

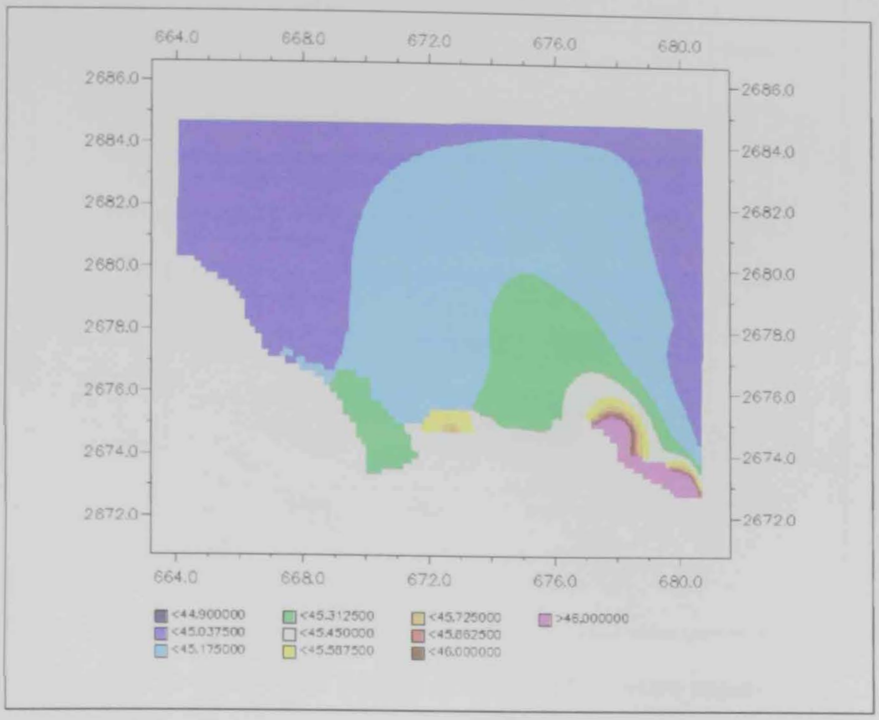


Figure 5.19 Salinity Contours at winter (Moderate expansion).

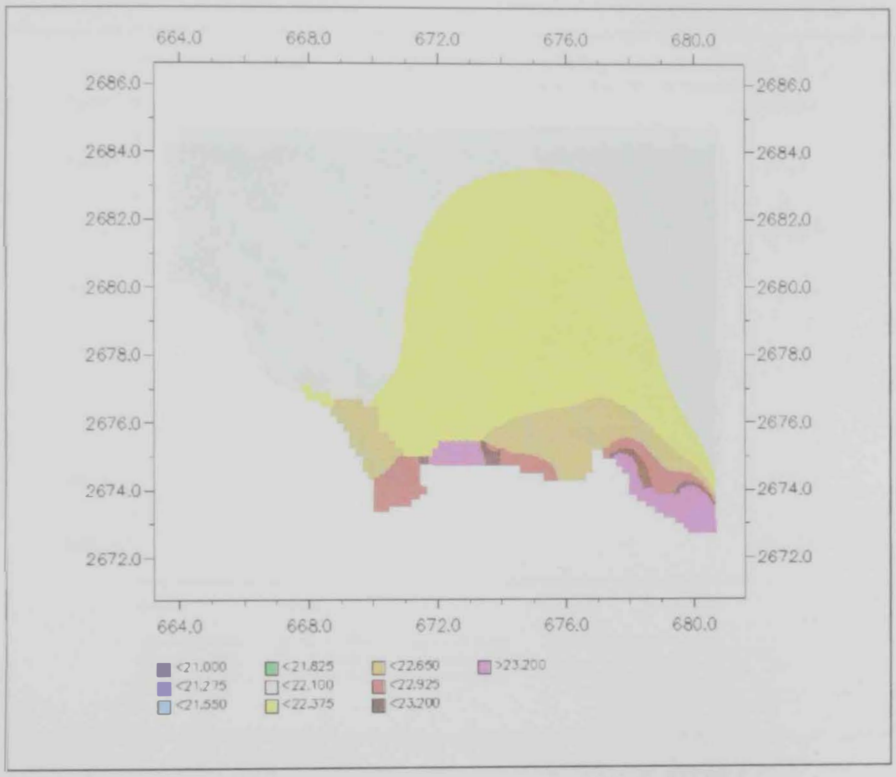


Figure 5.20 Temperature Contours at winter (Moderate expansion).

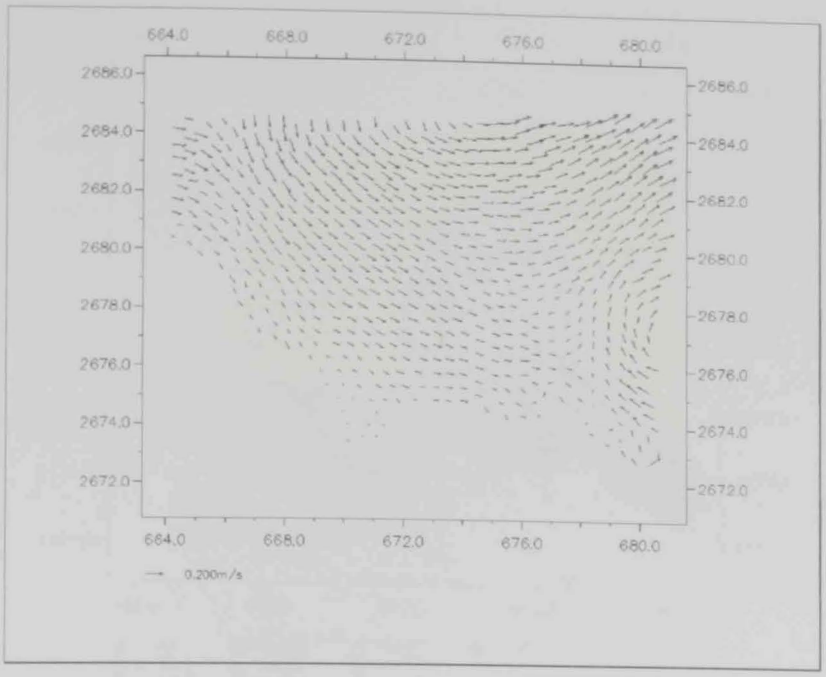


Figure 5.21 Flow Filed Pattern at winter (Moderate expansion)

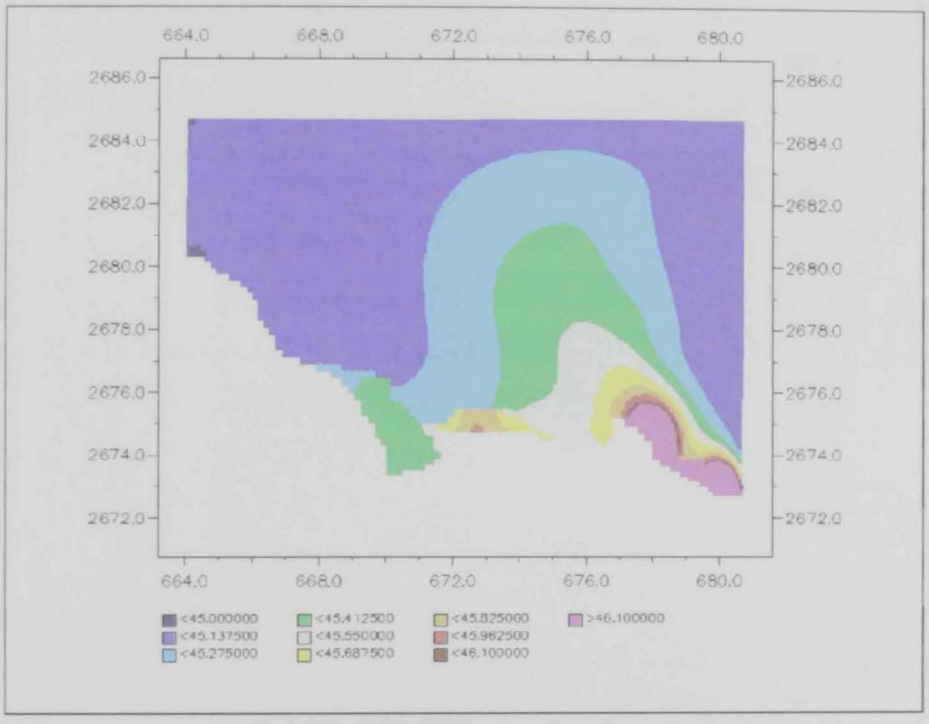


Figure 5.22 Salinity Contours at winter (Major expansion).

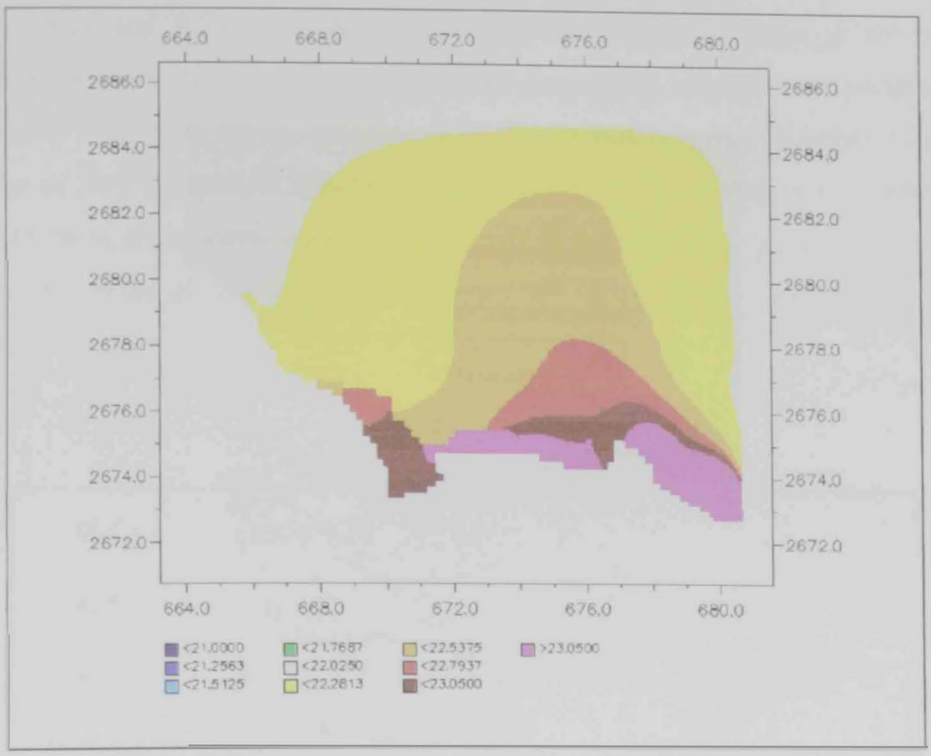


Figure 5.23 Temperature Contours at winter (Major expansion)

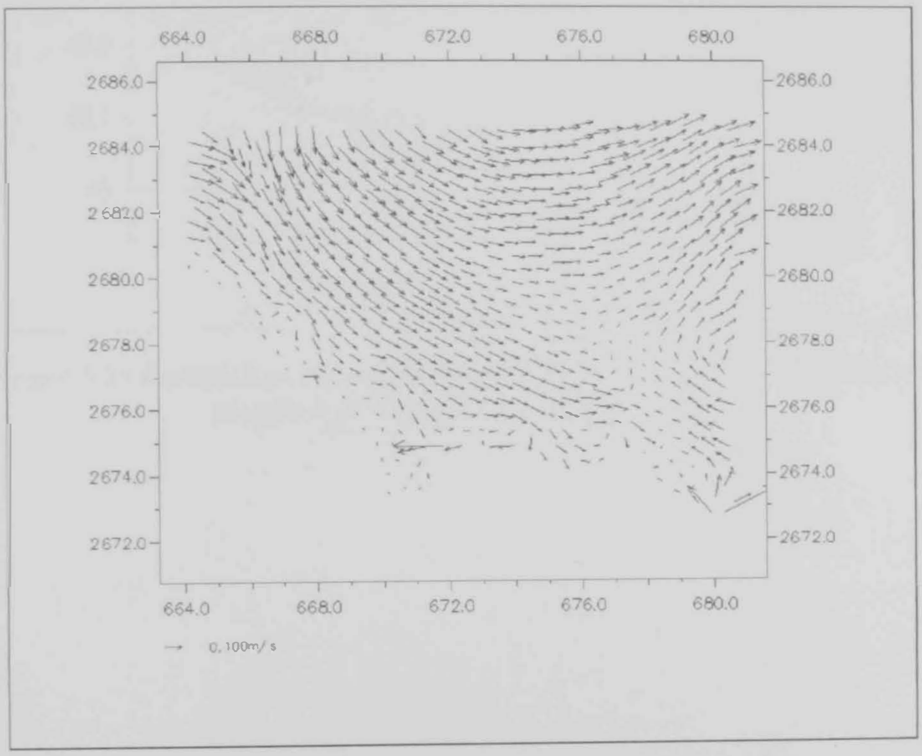


Figure 5.24 Flow Filed Pattern at winter (Major expansion)

Figures 5.25 and 5.26 show the salinity and temperature variation at the intake desalination plant, respectively. The change in salinity among three scenarios is minimum. However, the temperature at intake desalination area increased from an average of 22.1°C (existing facilities) to an average of 23 °C. The salinity increased from 45.10 to 45.65 considering the basic and major expansion models. Table 5.2 shows the results of salinity and temperature for summer and winter for the three different scenarios.

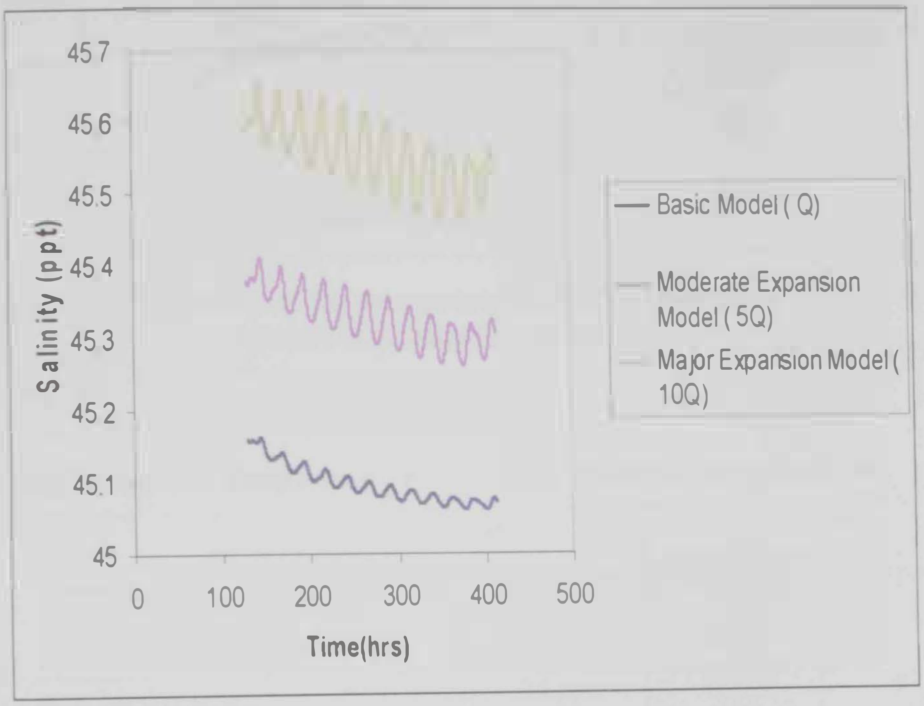


Figure 5.25 Comparison of the salinity results considering the three different scenarios at desalination intake in winter

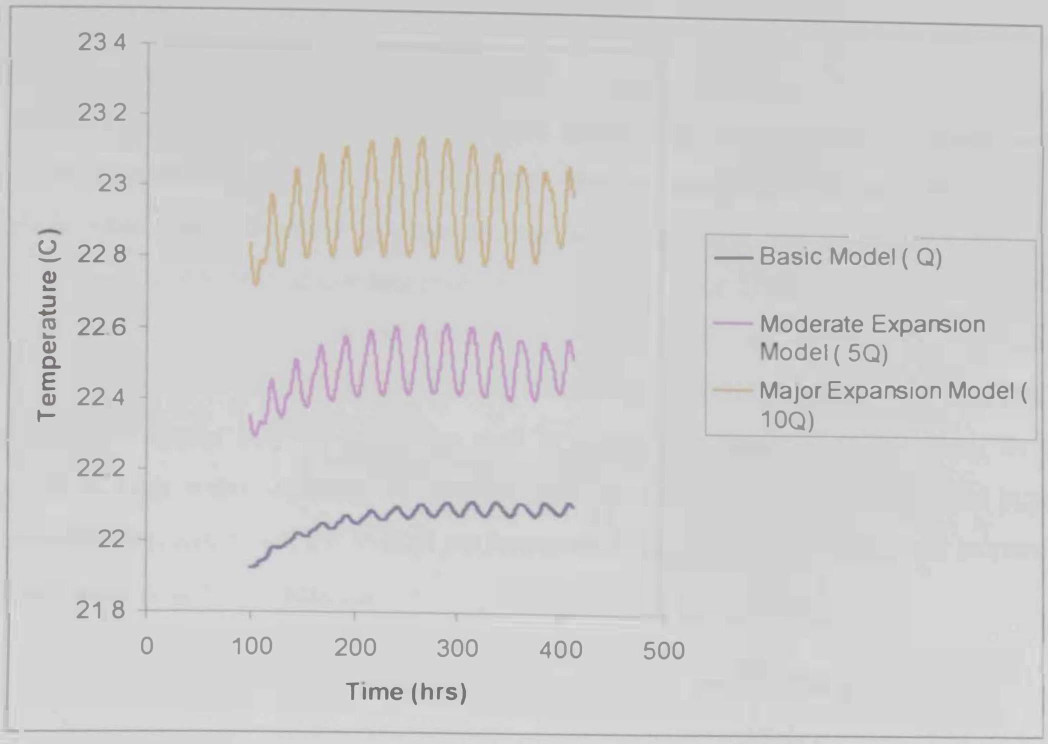


Figure 5.26 Comparison of the temperature results considering the three different scenarios at desalination intake in winter

Table 5.2 Salinity and Temperature results at plant intake for three scenarios

Scenario	Summer		Winter	
	Salinity (ppt)	Temperature (°C)	Salinity (ppt)	Temperature (°C)
Basic Model	45.24	34.8	45.07	22.1
Moderate Expansion	45.36	35.3	45.30	22.5
Major Expansion	45.48	35.9	45.60	23

5.3 Estimates of Operational Costs

Referring to the cost calculation example introduced in chapter 3, and using the salinity and temperature results obtained from the hydrodynamic simulation in summer and winter for the three different scenarios, the operational costs for the MSF desalination plant are similarly calculated and reported in table 5.3. The results prove that the proposed moderate and major expansion have a cost impact on some of the annual operation cost related to chemical treatment and electric power cost (assuming constant pumping head)

Table 5.3 and Figure 5.27. present the total annual cost with respect to summer and winter considering that summer and winter seasons represent 70% and 30% of the whole year, respectively. At summer, the annual electric and chemical costs for moderate expansion facilities increases to about 6.8 Million USD and 18 Million USD respectively, where the annual electric and chemical cost for major expansion increases to about 15.2 Million USD and 36.2 Million USD, respectively. The cost calculation shows that the operation cost in summer is higher than in winter, as a result of high water temperature as well as an increase in air temperature and high humidity that will affect the overall performance of the desalination plant and increase the operation and maintenance cost.

Table 5.3 MSF desalination plant annual chemical and electric cost at summer and Winter

Scenario	Basic Model		Moderate Expansion		Major Expansion	
	Summer	Winter	Summer	Winter	Summer	Winter
Intake Salinity (ppt)	45.24	45.07	45.36	45.30	45.48	45.60
Temperature °C	34.8	22.1	35.3	22.5	35.9	23.1
(M_f) kg/s	2092	2077	10511	10485	21125	21229
(M_{cw}) kg/s	8397	970	48778	5098	111914	11046
(M_b) kg/s	1352	1337	6811	6785	13725	13829
M_{total} kg/s	11841	4384	66100	22368	146764	46104
Power (KWh) for H (m)	1871	692.89	10447	3535	23196	7287
Pumping cost (M$/yr)	1.23	0.46	6.86	2.32	15.24	4.79
Chemical Cost (M$/yr)	3.59	3.56	18.02	17.98	36.22	36.40
Sub Total (M$/yr)	4.82	4.02	24.89	20.30	51.46	41.19
Total (M$/yr)	**4.58**		**23.51**		**48.38**	

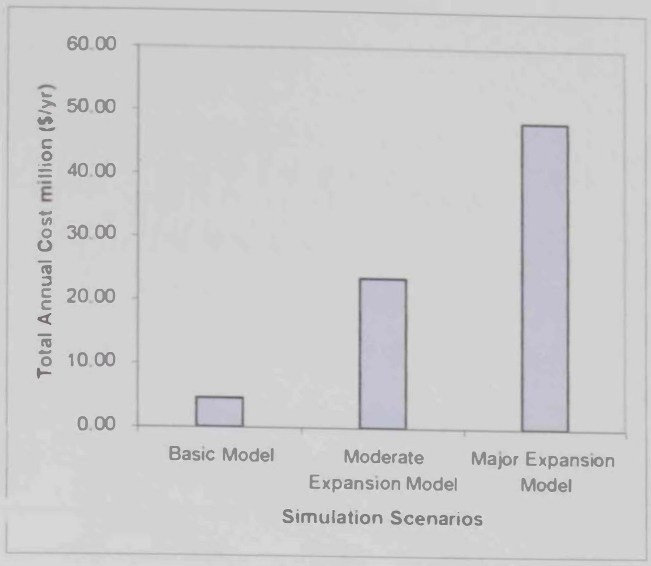


Figure 5.27 Total annual cost considering 70% of summer annual cost and 30% of winter annual cost for basic scenario.

5.4 Reverse Wind Scenario

Eastward wind direction is considered in this scenario as east wind direction (90 Deg). The objective of this scenario is to evaluate the effect of the reverse direction of the wind on the desalination plant operation cost

Figures 5.28, 5.29,5.30 and 5.31 show the variation with time in temperature and salinity for the three scenarios considering both prevailing (dominant) and reverse wind directions during summer and winter. It is noticed that the temperature and salinity at intake increased slightly in reverse wind direction. This is attributed to the wind direction that plays a major role in transporting the effluent of Borooj and GUP facilities toward the intake location. However, the increased flow coming from the eastern boundary helps in diluting that effluent and alleviates the effect of brine discharge of industrial facilities on the intake. The reverse wind direction does also reduce the impact of Takreer effluent on intake condition

Since the effect of reverse wind direction is limited, as the occurrence is about 23% over the whole year, the alternative proposed scenarios discussed later will consider only for the most dominant wind direction, that represents the most prevailing conditions during the year. Tables 5.4 and 5.5 show the cost calculations for three scenarios considering reverse wind direction

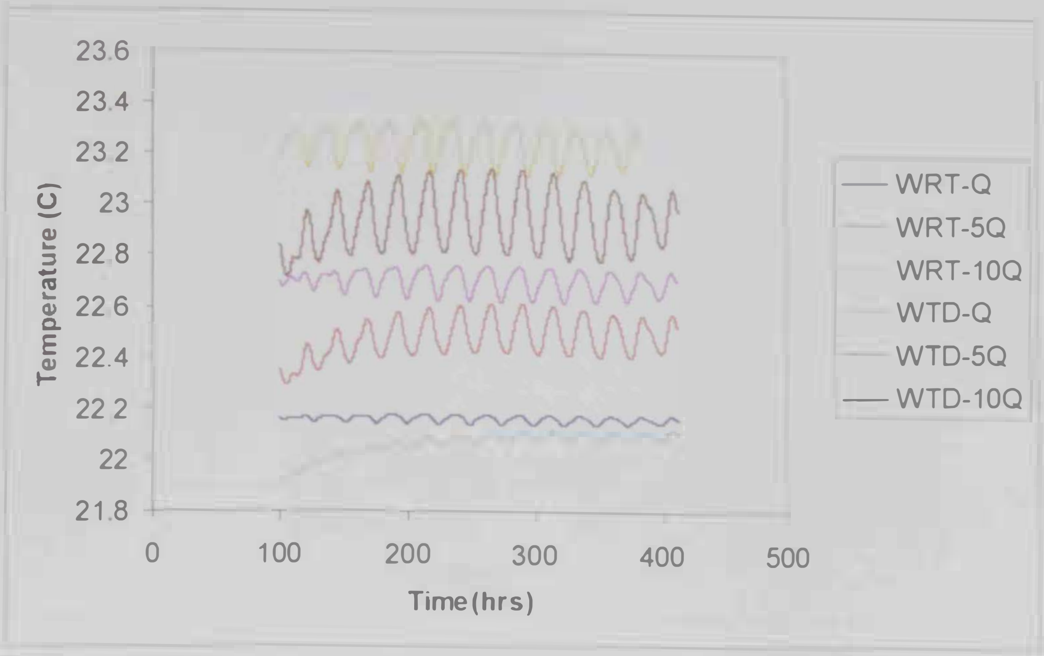


Figure 5.28 Comparison of temperature for three scenarios considering prevailing and reverse wind direction at Winter. WRT = Winter Reverse Temperature, WDT = Winter Dominant Temperature

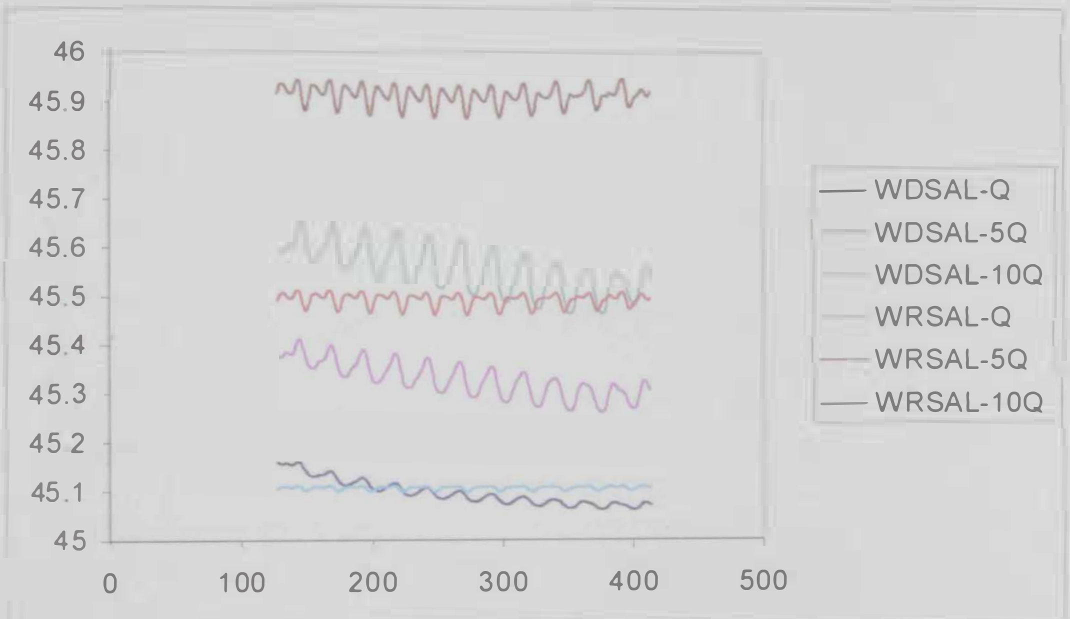


Figure 5.29 Comparison of salinity for three scenarios considering prevailing and reverse wind direction at Winter. WRSAL = Winter Reverse Salinity.

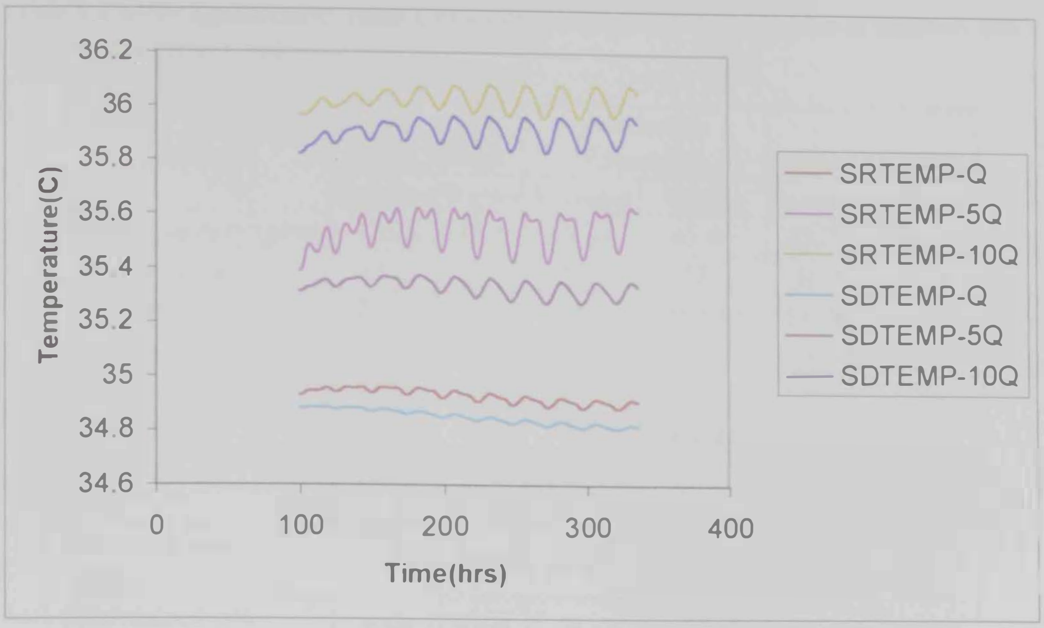


Figure 5.30 Comparison of temperature for three scenarios considering prevailing and reverse wind direction at Summer. SRTEMP = Summer Reverse Temperature and SDTEMP = Summer Dominant Temperature

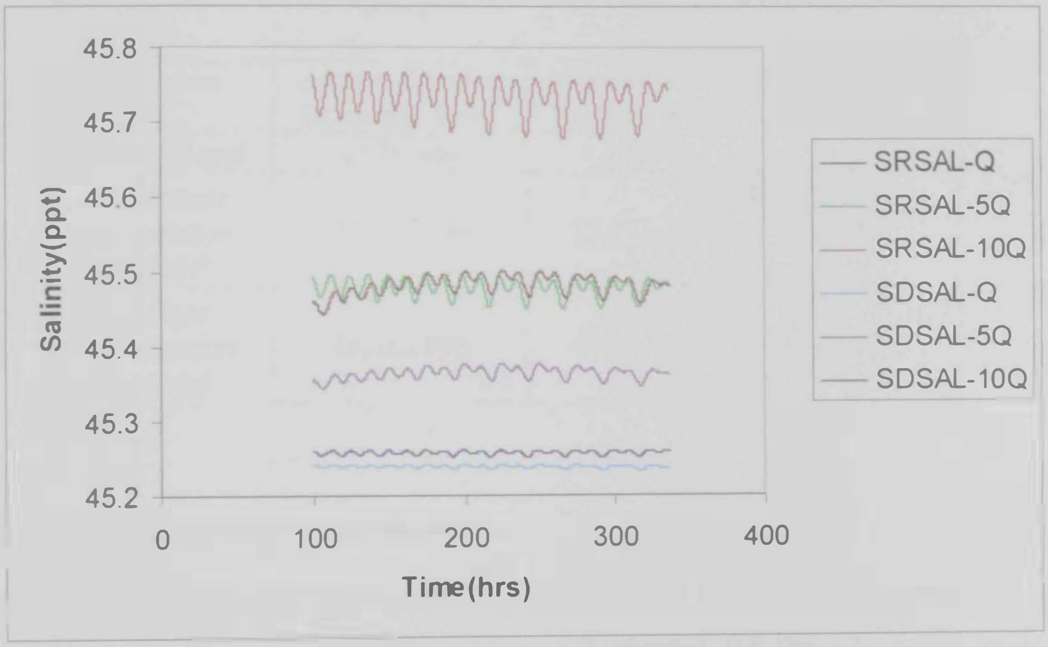


Figure 5.31 Comparison of salinity for three scenarios considering prevailing and reverse wind direction at Summer. SRSAL = Summer Reverse Salinity and SDSAL = Summer Dominant Salinity

Table 5.4 MSF desalination plant annual chemical and electrical cost at summer and winter for reverse wind direction.

Scenario	Basic Model		Moderate Expansion		Major Expansion	
	Summer	Winter	Summer	Winter	Summer	Winter
Intake Salinity (ppt)	45.26	45.1	45.48	45.45	45.75	45.75
Temperature °C	34.9	22.1	35.5	22.7	36.1	23.2
(M_f) kg/s	2093	2080	10562	10549	21360	21360
(M_{cw}) kg/s	8601	967	50044	5215	118502	11107
(M_b) kg/s	1353	1340	6862	6849	13960	13960
M_{total} kg/s	12047	4387	67468	22613	153822	46427
Power (KWh) for H (m)	1904	693	10663	3574	24312	7338
Pumping cost (M$/yr)	1.25	0.46	7.01	2.35	15.97	4.82
Chemical Cost (M$/yr)	3.59	3.57	18.11	18.09	36.63	36.63
Sub Total (M$/yr)	4.84	4.02	25.12	20.44	52.60	41.45
Total (M$/yr)	**4.59**		**23.71**		**49.25**	

Table 5.5 Comparison of Total annual costs for dominant and reverse wind direction

Scenario	Annual Cost for Dominant Wind	Annual Cost for Reverse Wind	Increase in Cost (%)
Basic Model	4,576,840	4,594,651	0.39
Moderate Expansion Model	23,511,996	23,713,205	0.86
Major Expansion Model	48,382,096	49,254,655	1.80

5.5 Proposed alternative configurations

In order to minimize the negative impact of brine circulation toward the intake for the proposed scenarios, several proposals are investigated for the intake and outfall configurations. These proposals can be summarized as follows:

Alternative 1 (Alt.1): Change the intake configuration by extending the intake location offshore to an area receiving cooler and less saline water (about 1000)

Alternative 2 (Alt.2): Change the outfall configuration by extending the desalination outfall in a location that has lower impact on the intake location

Alternative 3 (Alt.3). Change the outfall configuration to discharge the effluent in deeper zone

In addition to the above alternatives, the salinity and temperature at different depths close to intake location are evaluated. Figure 5.32 shows the location of existing desalination intake, existing desalination outfall, alternative location for intake and alternative location for outfall

The hydrodynamic simulation was conducted considering these alternatives

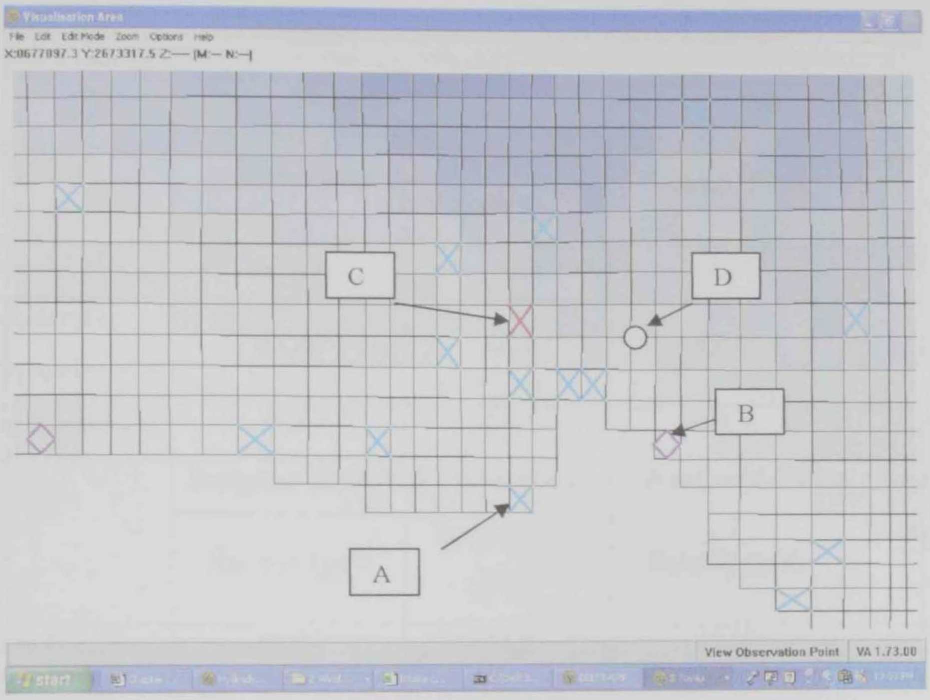


Figure 5.32 Map of Ruwais area showing (A) existing intake location (B) existing outfall location (C) proposed alternative for intake location (T3) (D) proposed alternative for outfall

Results of Alternative 1 (Summer and Winter)

The simulation results for alternative 1 are shown in Figures B.1 to B.12 (Appendix B) for salinity and temperature considering moderate and major expansion of existing industrial facilities at summer and winter.

As a summary of the results as shown in Appendix B, table 5.6 shows the average salinity and temperature as a result of adopting alternative 1 at existing conditions. Tables 5.7 shows the operation cost calculation for chemical and electrical power expenses for summer and winter. Table 5.8 shows the reduction in cost when Alt.1 is employed for the three scenarios. It is noticed that the reduction in cost is minimum. Salinity and temperature at summer and winter are decreased. However, it is noticed that the reduction in temperature at winter is quite high compared with summer temperature.

Table 5.6 Salinity and Temperature results for Alternative 1 compared with Existing conditions results:

Scenario	**Summer (Alt.1)**		**Winter(Alt.1)**	
	Salinity (ppt)	Temperature (°C)	Salinity (ppt)	Temperature (°C)
Basic Model	*45.23*	*34.6*	*45.06*	*22.06*
Moderate Expansion	*45.32*	*35.1*	*45.25*	*22.3*
Major Expansion	*45.42*	*35.5*	*45.5*	*22.6*
	Summer (Existing Conditions)		**Winter (Existing Conditions)**	
	Salinity (ppt)	Temperature (°C)	Salinity (ppt)	Temperature (°C)
Basic Model	45.24	34.8	45.07	22.1
Moderate Expansion	45.36	35.3	45.30	22.5
Major Expansion	45.48	35.9	45.60	23

Table 5.7 MSF desalination plant annual chemical and electric cost at summer and inter for alternative 1.

Scenario	Basic Model		Moderate Expansion		Major Expansion	
	Summer	Winter	Summer	Winter	Summer	Winter
Intake Salinity (ppt)	45.23	45.06	45.32	45.25	45.42	45.5
Temperature C	34.65	22.06	35.1	22.3	35.5	22.6
(M_f) kg/s	2091	2076	10494	10485	21074	21142
(M_{cw}) kg/s	8103	963	45165	4922	97505	10205
(M_b) kg/s	1351	1336	6794	6785	13674	13742
M_{total} kg/s	11545	4375	62453	22192	132253	45089
Power (KWh) for H (m)	1825	691	9871	3507	20903	7126
Pumping cost (M$/yr)	1.20	0.45	6.49	2.30	13.73	4.68
Chemical Cost (M$/yr)	3.59	3.56	17.99	17.98	36.14	36.25
Sub Total (M$/yr)	4.78	4.01	24.48	20.28	49.87	40.94
Total (M$/yr)	**4.55**		**23.22**		**47.19**	

Table 5.8 Cost comparison for three scenarios considering alternative 1

Scenario	Total Annual Cost (Existing Conditions)	Total Annual Cost (Alternative 1)	Difference In Cost	Percentage in Saving
Basic Model	4,576,840	4,553,330	23,500	0.51%
Moderate Expansion Model	23,511,996	23,221,017	291,000	1.24%
Major Expansion Model	48,382,096	47,189,741	1,193,000	2.46%

Results of Alternative 2 (Summer and Winter)

The results presented in Figures B.13 to B.24 (Appendix B) show that alternative 2; extending outfall location by about 1000m away from the nearby zone at summer and winter, improves slig tly the intake water properties in terms of receiving less saline and cooler water from that location. Althoug , the reduction difference in salinity and temperature is considered insignificance, but that alternative emphasizes on the importance in identifying the right location and configuration for outfall system especially, when there is a planning of new expansion of existing industrial facilities.

The results show that, extending the effluent away from the shoreline, and considering the circulation process, wind direction , and current movement, the new location helped in reducing the intake water salinity and temperature. Although, the reduction is low, but it is quite evidence that the outfall configuration plays an important role in enhancing the MSF overall operation performance by reducing the salinity and temperature at intake location. It is worth mentioning that the bloom that flow from east direction helped in lowering the effect of the brine effluent of the industrial facilities, due to mixing process. Table 5.9 shows the salinity and temperature results for existing and alternative 2.

Table 5.9 Salinity and Temperature results for Alternative 2 and existing conditions

Scenario	**Summer (Alt.2)**		**Winter(Alt.2)**	
	Salinity (ppt)	Temperature (°C)	Salinity (ppt)	Temperature (°C)
Basic Model	45.23	34.8	45.06	21.8
Moderate Expansion	45.36	35.3	45.25	22.35
Major Expansion	45.48	35.9	45.50	22.6
	Summer (Existing Conditions)		**Winter (Existing Conditions)**	
	Salinity (ppt)	Temperature (°C)	Salinity (ppt)	Temperature (°C)
Basic Model	45.24	34.8	45.07	22.1
Moderate Expansion	45.36	35.3	45.30	22.5
Major Expansion	45.48	35.9	45.60	23

Table 5.10 MSF plant annual chemical and electric cost at summer and winter for alternative 2

Scenario	Basic Model		Moderate Expansion		Major Expansion	
	Summer	Winter	Summer	Winter	Summer	Winter
Intake Salinity (ppt)	45.23	45.06	45.36	45.25	45.48	45.50
Temperature °C	34.8	21.8	35.3	22.35	35.9	22.6
(M_f) kg/s	2091	2076	10511	10464	21125	21142
(M_{cw}) kg/s	8397	928	48778	4987	111914	10205
(M_b) kg/s	1351	1336	6811	6764	13725	13742
M_{total} kg/s	11839	4340	66100	22215	146764	45089
Power (KWh) for H (m)	1871	686	10447	3511	23196	7126
Pumping cost (M$/yr)	1.23	0.45	6.86	2.31	15.24	4.68
Chemical Cost (M$/yr)	3.59	3.56	18.02	17.94	36.22	36.25
Sub Total (M$ yr)	4.81	4.01	24.89	20.25	51.46	40.94
Total (M$/yr)	**4.57**		**23.50**		**48.31**	

Table 5.11 : MSF plant annual total cost (chemical and electric cost) at winter for alternative 2.

Scenario	Total Annual Cost (Existing Conditions)	Total Annual Cost (Alternative 2)	Difference in cost	Saving (%)
Basic Model	4,576,840	4,573,609	3231	0.07
Moderate Expansion Model	23,511,996	23,496,427	15569	0.07
Major Expansion Model	48,382,096	48,305,722	76374	0.16

As a summary of the above results, table 5.9 shows the average salinity and temperature as a result of adopting alternative 2. Table 5.10 shows the operation cost calculation for annual chemical and electric power cost for summer and winter. Table 5.11 shows the comparison between existing condition with old outfall location and alternative 2; extending outfall location further offshore away from the shoreline area. Selecting the outfall location is considered as important factor in setting out the MSF location, and by applying the two alternatives (Alt.1 & Alt.2), the effect of the brine discharge will be minimized.

'esults of Alternative 3 (Summer and Winter)

ernative 3; changing the outfall depth to discharge at lower sea water level, had no -ficance impact at the intake location, since the effluent discharge had transported to saturate the full vertical alignment of the water profile especially at coastline area. Changing the outfall location in terms of vertical alignment should be studied carefully, especially at the areas where many industrial facilities do exist and brine discharge is high.

CHAPTER (6)
CONCLUSION AND RECOMMENDATION

The study of the hydrodynamic phenomena in coastal water is considered one of the major factors that influence the design of coastal industrial facilities or expanding the existing ones. Such study is vital to investigate the best and most optimum location/configuration of intake and outfall system. The current study highlights the importance of selecting careful locations for the intake and outfall particularly for the MSF desalination plants. The selection is made so that the effects of environmental conditions of the intake feed water, mainly the salinity and temperature, upon the overall MSF performance is optimized and the operational cost is eventually minimized. Water dynamics and circulation prevailing in the coastal area dictate the status of temperature and salinity of the intake feed water.

To achieve the above goals, two hydrodynamic analyses were conducted in the present study; the first for the entire Arabian Gulf and the second for the local study area of Ruwais. That modeling was carried out using the well-known Delft3D model. The model results were favorably calibrated against water levels at Abu Dhabi coast. The local hydrodynamic model of Ruwais was also calibrated against water observations as well as salinity and temperature field measurements attaining fair agreement between the simulated and observed variables.

The present work did also evaluate the direct effect of intake salinity and temperature upon the operational cost of MSF desalination plant. The operational costs were subdivided into two major groups; chemical costs and energy costs. Chemical costs are associated with the chemicals added at the feed point such as anti-scalant, antifoam, .etc. The energy costs are associated with lifting and pumping the feed and cooling waters throughout various desalination processes. The cost analysis conducted in chapter 3 showed that an increase in salinity of about 33% leads to an increase in the chemical cost by about 33.5% while an increase in the intake water temperature of about 20% leads to an increase in the energy cost by about 78%. Such results indicated that the intake water temperature has more pronounced effect on the annual operational cost of the MSF desalination plants knowing that the energy cost is much higher than the chemical costs.

In order to evaluate the impact of high salinity and temperature on the MSF overall performance and associated operational cost, three scenarios were considered. The first scenario considered the existing conditions while the second and third scenarios assumed moderate and major expansion taking place in the existing facilities as well as their disposed effluents. The moderate and major expansions are represented by effluent discharges increased 5 and 10 times the existing discharges from the current facilities, respectively. Cost analysis was carried out to evaluate the significance of each scenario and its impact on the MSF performance. The annual operational costs estimated for the three scenarios were estimated at about 4.58, 23.5, and 48.4 Million USD. It is worth mentioning that such operational costs were based on hydrodynamic simulation results associated with the most frequent wind conditions prevailing in the area; that is northwestern wind of 5.2 m/s average magnitude.

To decide on the most optimum intake/outfall configuration, three alternative configurations were considered and evaluated. These alternatives are:

Alternative 1: Change the intake configuration by extending the intake location offshore to an area receiving cooler and less saline water.

Alternative 2: Change the outfall configuration by extending the desalination outfall in a location that has lower impact on the intake location.

Alternative 3: Change the outfall configuration to discharge the effluent in deeper zone.

The hydrodynamic simulation results showed little overall reduction in the salinity and temperature achieved with all tested alternatives and considering the three scenarios, especially the first scenario of existing conditions. This indicates that the current existing intake/outfall configuration has been carefully selected in anticipation of various environmental conditions and different future expansions. The sheltered location of the intake minimized the effect of effluent brine discharged from the existing industrial facilities on the desalination intake.

Alternative 1 did, however achieve noticeable savings in the annual operational costs compared to the existing configurations for moderate and major expansions (1.2% and 2.5%). Such percentages even though look small, they represent major annual savings estimated at 291,000 and 1,193,000 USD, respectively. As stated earlier, the success of locating the existing desalination intake caused the savings achieved in case of current effluents to be insignificant (0.5 % or 23,500 USD).

Studying the effect of the less-frequent reverse wind direction upon the MSF performance reflected higher operational cost than the case of dominant wind direction. This was tested for the case of basic scenario (current effluents) and considering the existing intake/outfall configuration. Such result suggests that further savings can be achieved with different alternatives in case of considering the reverse wind direction especially if the future expansion is limited to the western effluent of Takreer only.

The results indicate that locating the intake near the shoreline in case of large discharged effluents is not advisable, since the coastal shore water is shallow and is highly affected by any increase in the temperature and salinity due to slow mixing process and low circulation. Although, extending the intake configuration requires initial capital cost, the savings attained from the running operational cost can definitely cover such cost in few years after which pure savings are achieved.

Finally, the study outcomes strongly recommend a great attention to be paid in studying and investigating the selection of intake and outfall configuration especially when there is a plan for major expansion to the existing facilities. This selection should be made in line with full understanding of the hydrodynamic phenomena prevailing in the area under study as well as awareness of the relevant environmental conditions, bylaws and regulations.

APPENDIX A

Table A.1 Variation in seawater density (kg/m3) as a function of temperature (°C) and salinity (ppm).

	Salinity ppm						
T (°C)	10000	20000	30000	40000	50000	60000	70000
10	1008	1015	1023	1031	1038	1046	1054
15	1007	1014	1022	1030	1037	1045	1053
20	1006	1013	1021	1028	1036	1044	1051
25	1004	1012	1019	1027	1034	1042	1050
30	1003	1010	1018	1025	1033	1040	1048
35	1001	1008	1016	1023	1031	1038	1046
40	999	1007	1014	1021	1029	1036	1044
45	997	1004	1012	1019	1027	1034	1042
50	995	1002	1010	1017	1024	1032	1039
55	993	999.9	1007	1015	1022	1029	1037
60	990	997.5	1005	1012	1020	1027	1034
65	988	994.9	1002	1010	1017	1024	1032
70	985	992.2	999.5	1007	1014	1022	1029
75	982	989.3	996.6	1004	1011	1019	1026
80	979	986.3	993.7	1001	1008	1016	1023
85	976	983.2	990.6	997.9	1005	1013	1020
90	973	980	987.4	994.7	1002	1010	1017
95	969	976.7	984	991.4	998.8	1006	1014
100	966	973.2	980.6	988	995.4	1003	1010
105	962	969.6	977	984.4	991.9	999.3	1007
110	958	965.9	973.3	980.8	988.3	995.7	1003

Table A.2 Variation in latent heat of water evaporation in (kJ/kg) as a function of temperature (°C).

T (°C)	Calculated Latent Heat (kJ/kg)	Latent Heat from Steam Tables (kJ/kg)	Percentage Error
5	2489.89	2489.56	0.013241
10	2477.93	2477.75	0.007259
15	2466.006	2465.93	0.003078
20	2454.106	2454.12	0.000577
25	2442.218	2442.3	0.003365
30	2430.33	2430.48	0.006175
35	2418.43	2418.62	0.007845
40	2406.507	2406.72	0.008854
45	2394.548	2394.77	0.009271
50	2382.542	2382.75	0.008746
55	2370.476	2370.66	0.007767
60	2358.339	2358.48	0.005984
65	2346.119	2346.21	0.00389
70	2333.804	2333.84	0.001563
75	2321.381	2321.37	0.000489
80	2308.84	2308.78	0.002614
85	2296.169	2296.05	0.005166
90	2283.354	2283.19	0.007192
95	2270.385	2270.19	0.008602
100	2257.25	2257.03	0.009743
105	2243.936	2243.7	0.010528
110	2230.432	2230.2	0.010415
115	2216.726	2216.5	0.010206
120	2202.806	2202.61	0.008904
125	2188.66	2188.5	0.007316
130	2174.276	2174.17	0.004888
135	2159.643	2159.59	0.002441
140	2144.748	2144.76	0.00058
145	2129.579	2129.65	0.00334
150	2114.125	2114.26	0.006395
155	2098.373	2098.57	0.009369
160	2082.313	2082.56	0.01187
165	2065.931	2066.21	0.013499
170	2049.216	2049.5	0.013838
175	2032.157	2032.42	0.01295
180	2014.74	2014.95	0.010402
185	1996.955	1997.07	0.005742
190	1978.79	1978.76	0.001499
195	1960.232	1960	0.011812
200	1941.269	1940.75	0.026741

Table A.3 Variation in seawater boiling point elevation (°C) as a function of temperature (°C) and salinity (wt%).

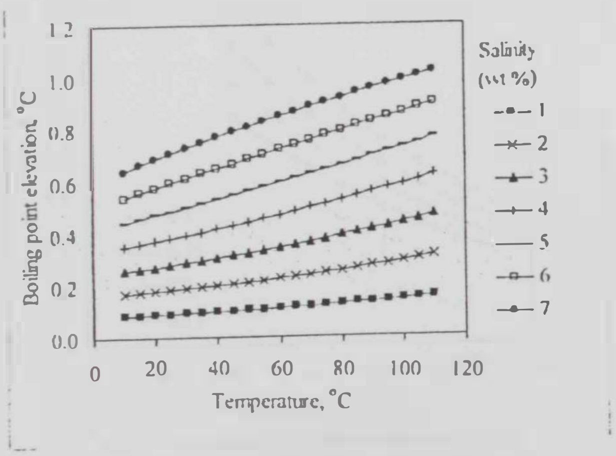
	Salinity (wt%)						
temperature °C	1	2	3	4	5	6	7
10	0.085	0.171	0.258	0.348	0.441	0.538	0.639
15	0.087	0.175	0.266	0.359	0.456	0.556	0.662
20	0.089	0.180	0.273	0.370	0.470	0.575	0.684
25	0.091	0.185	0.281	0.381	0.485	0.593	0.706
30	0.093	0.190	0.290	0.393	0.500	0.612	0.727
35	0.096	0.195	0.298	0.405	0.516	0.630	0.748
40	0.099	0.201	0.307	0.417	0.531	0.648	0.769
45	0.101	0.207	0.316	0.430	0.546	0.666	0.789
50	0.104	0.213	0.326	0.443	0.562	0.684	0.809
55	0.108	0.220	0.336	0.456	0.578	0.703	0.829
60	0.111	0.227	0.346	0.469	0.594	0.721	0.848
65	0.115	0.234	0.357	0.483	0.610	0.739	0.866
70	0.118	0.241	0.368	0.497	0.627	0.756	0.885
75	0.122	0.249	0.379	0.511	0.643	0.774	0.903
80	0.126	0.257	0.391	0.525	0.660	0.792	0.921
85	0.130	0.265	0.402	0.540	0.677	0.810	0.938
90	0.135	0.274	0.415	0.555	0.694	0.828	0.955
95	0.139	0.283	0.427	0.571	0.711	0.845	0.971
100	0.144	0.292	0.440	0.587	0.728	0.863	0.987
105	0.149	0.301	0.453	0.603	0.746	0.880	1.003
110	0.154	0.311	0.467	0.619	0.764	0.898	1.018

The correlation for the boiling point elevation of seawater is

$$BPE = A\,X + B\,X^2 + C\,X^3$$

with

$$A = (8.325\times10^{-2} + 1.883\times10^{-4}\,T + 4.02\times10^{-6}\,T^2)$$
$$B = (-7.625\times10^{-4} + 9.02\times10^{-5}\,T - 5.2\times10^{-7}\,T^2)$$
$$C = (1.522\times10^{-4} - 3\times10^{-6}\,T - 3\times10^{-8}\,T^2)$$



: Variation in boiling point elevation of seawater as a function of temperature and salinity

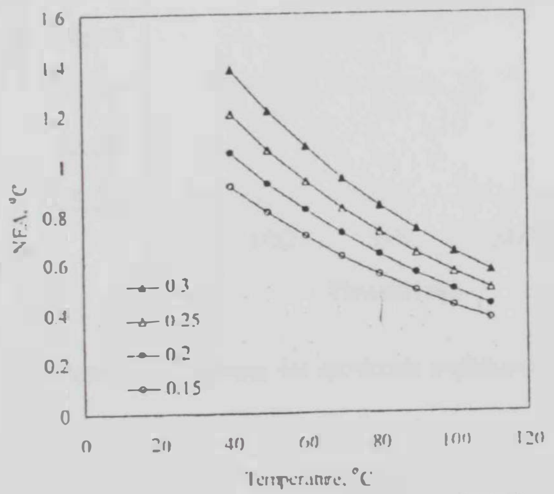
Table A.4 Variation in seawater boiling point elevation (°C) as a function of temperature (°C) and salinity (wt%).

NEA (°C)	T_j (°C)	H (m)	NEA (°C)	T_j (°C)	H (m)
0.63	40	0.15	0.83	40	0.25
0.51	50	0.15	0.67	50	0.25
0.41	60	0.15	0.54	60	0.25
0.33	70	0.15	0.43	70	0.25
0.26	80	0.15	0.35	80	0.25
0.21	90	0.15	0.28	90	0.25
0.17	100	0.15	0.22	100	0.25
0.14	110	0.15	0.18	110	0.25
0.72	40	0.2	0.95	40	0.3
0.58	50	0.2	0.77	50	0.3
0.47	60	0.2	0.62	60	0.3
0.38	70	0.2	0.50	70	0.3
0.30	80	0.2	0.40	80	0.3
0.24	90	0.2	0.32	90	0.3
0.20	100	0.2	0.26	100	0.3
0.16	110	0.2	0.21	110	0.3

$$(NEA)_{10} = (0.9784)^{T_i} (15.7378)^{H} (1.3777)^{V_b \times 10^{-6}}$$

and

$$NEA = (NEA_{10}/(0.5\Delta T + NEA_{10}))^{0.3281L} (0.5\,\Delta T + NEA_{10})$$



[illegible] Variation in non-equilibrium allowance in MSF as a function of brine temperature and brine height for brine weir load of 180 kg/m s and stage length = 10 ft.

APPENDIX B

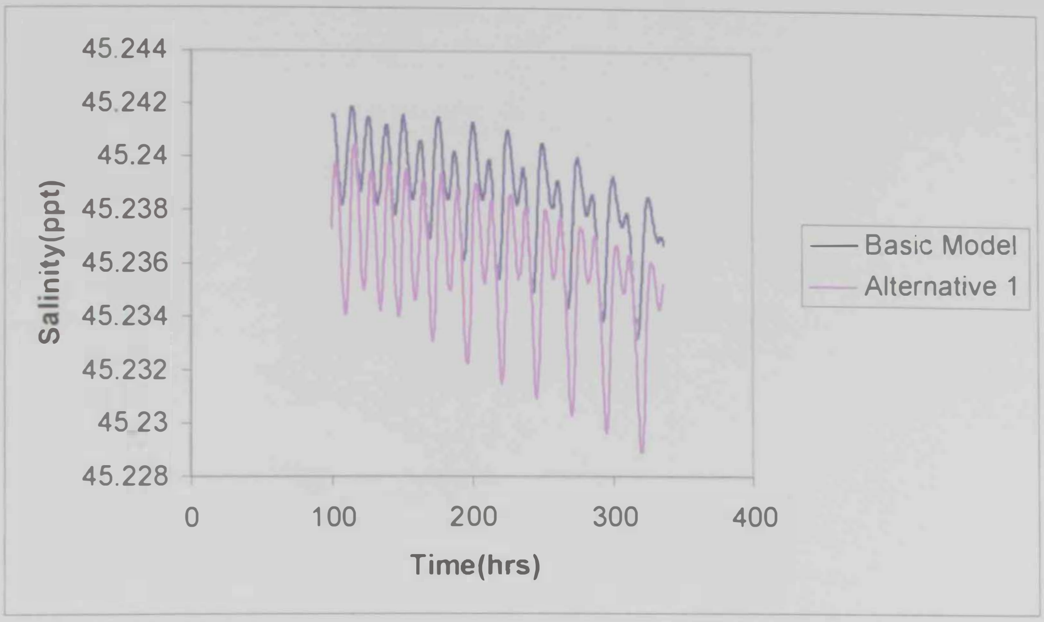


Figure B.1 Salinity for basic model and alternative 1 at summer

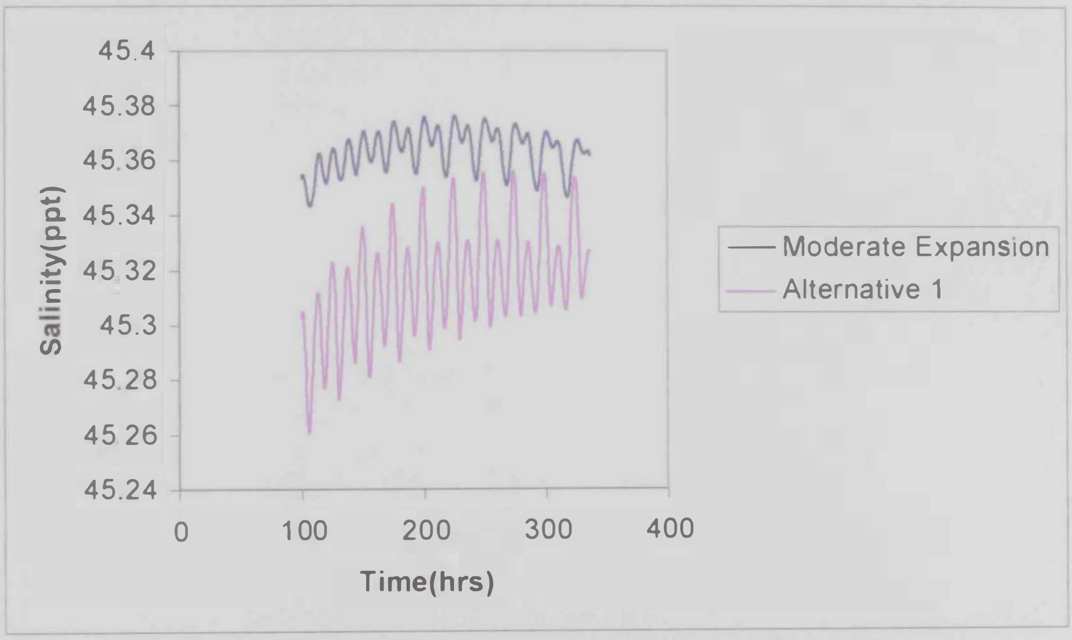


Figure B.2 Salinity for moderate expansion model and alternative 1 at summer

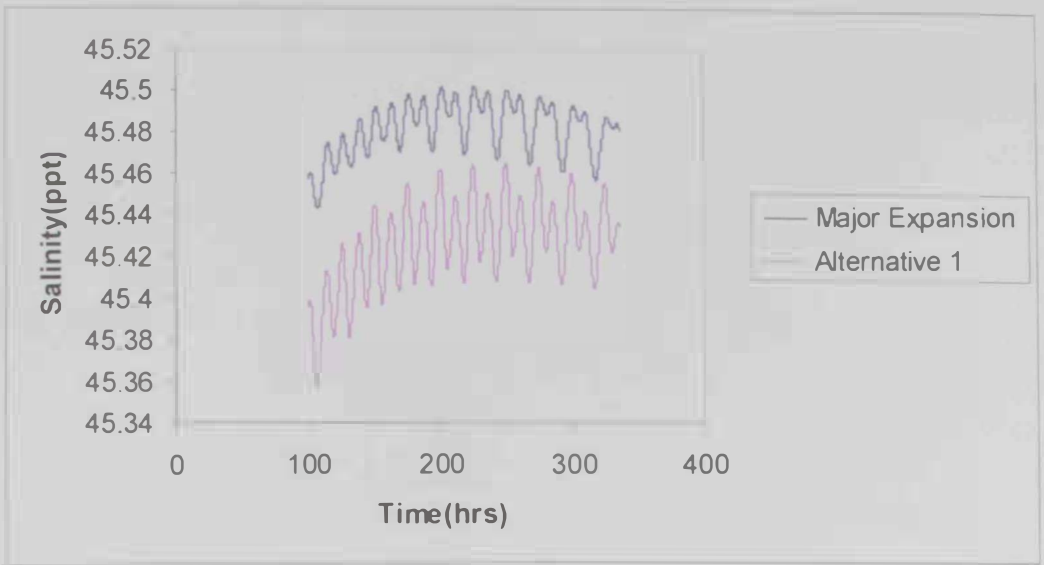


Figure B.3 Salinity for major expansion model and alternative 1 at summer.

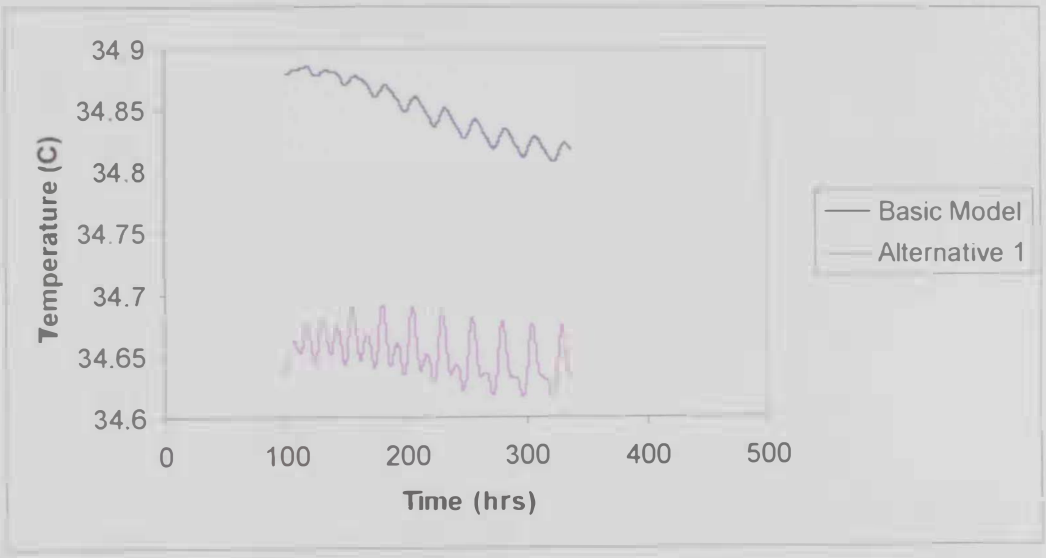


Figure B.4 Temperature for basic model and alternative 1 at summer

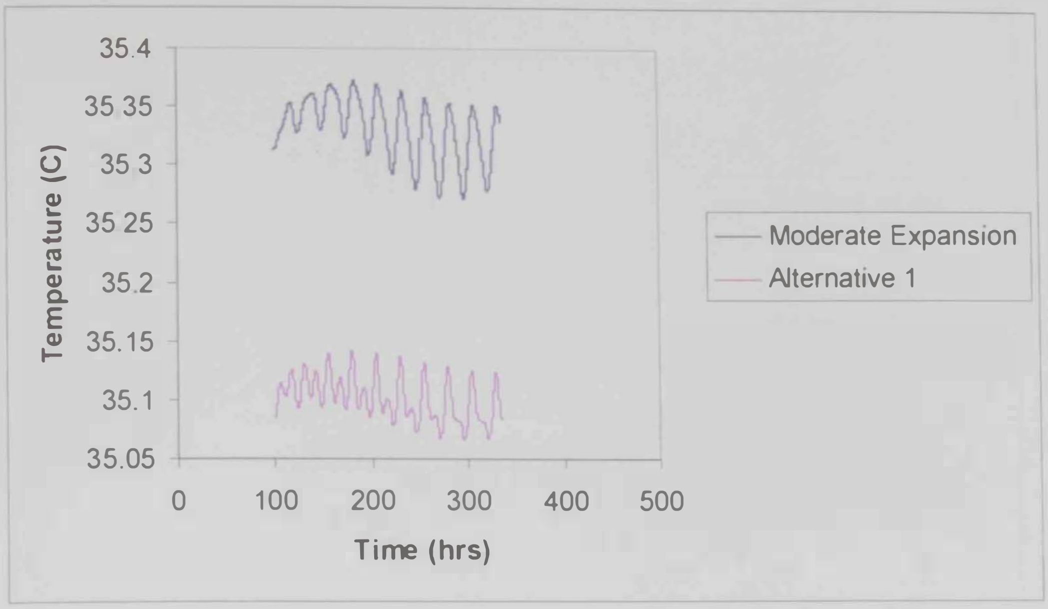


Figure B.5 Temperature for moderate expansion model and alternative 1 at summer

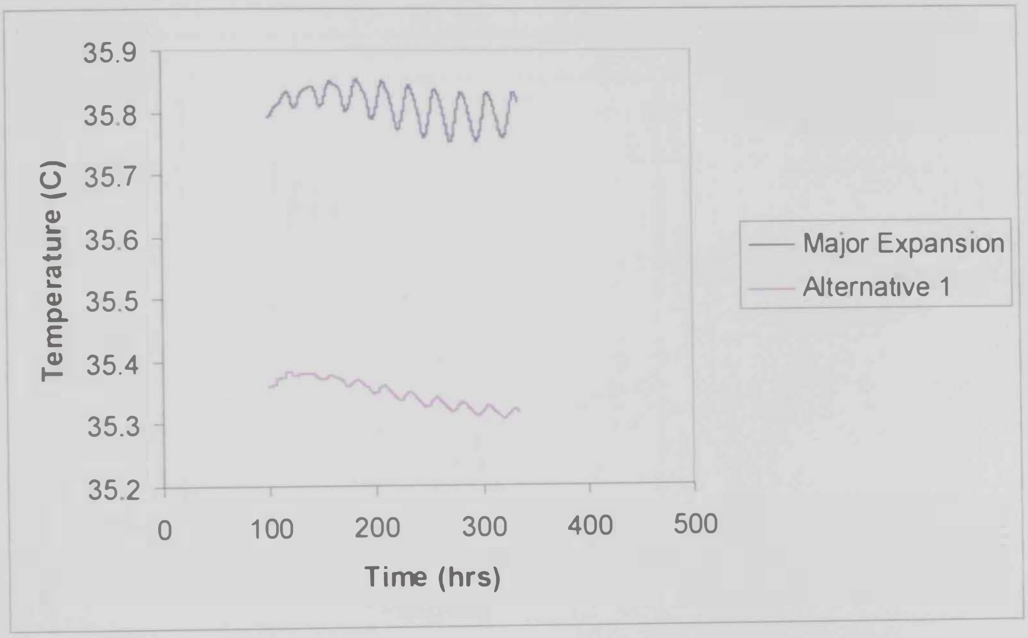


Figure B.6 Temperature for major expansion model and alternative 1 at summer.

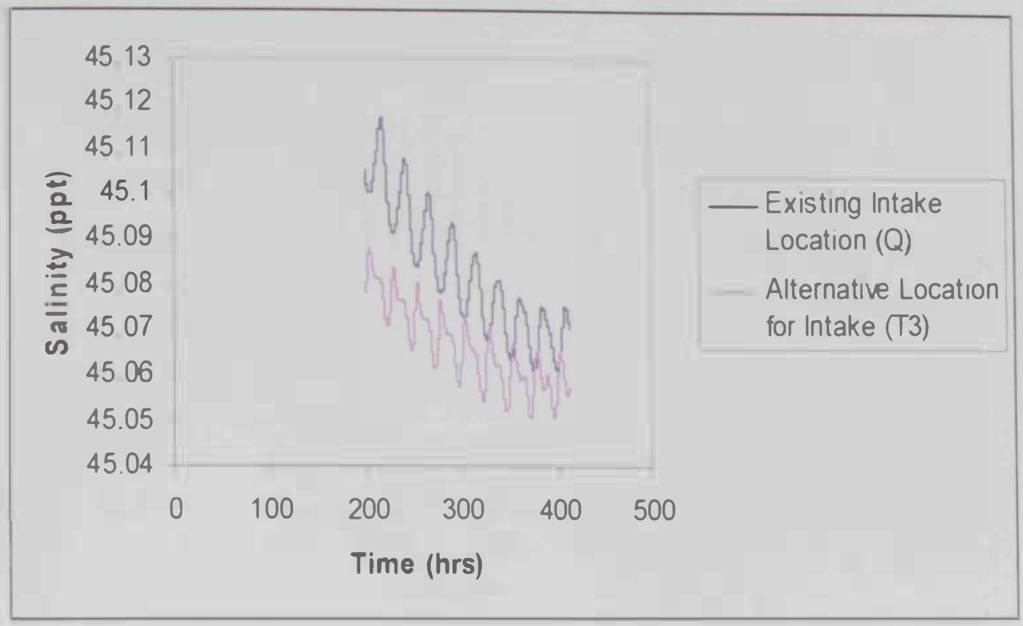


Figure B 7 Salinity for basic model and alternative 1 at winter

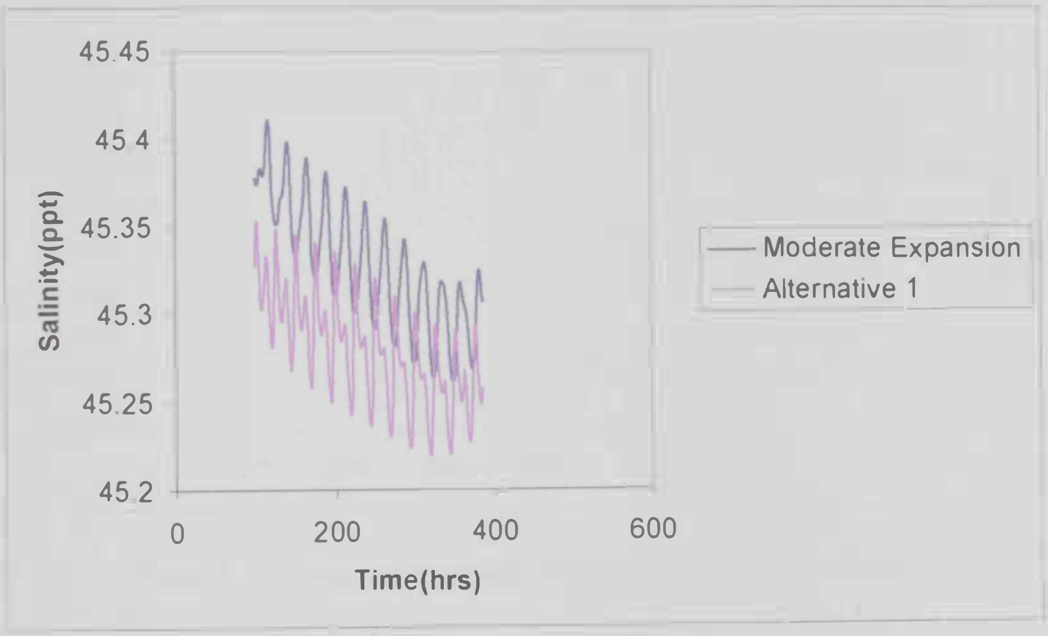


Figure B 8 Salinity for moderate expansion model and alternative 1 at winter.

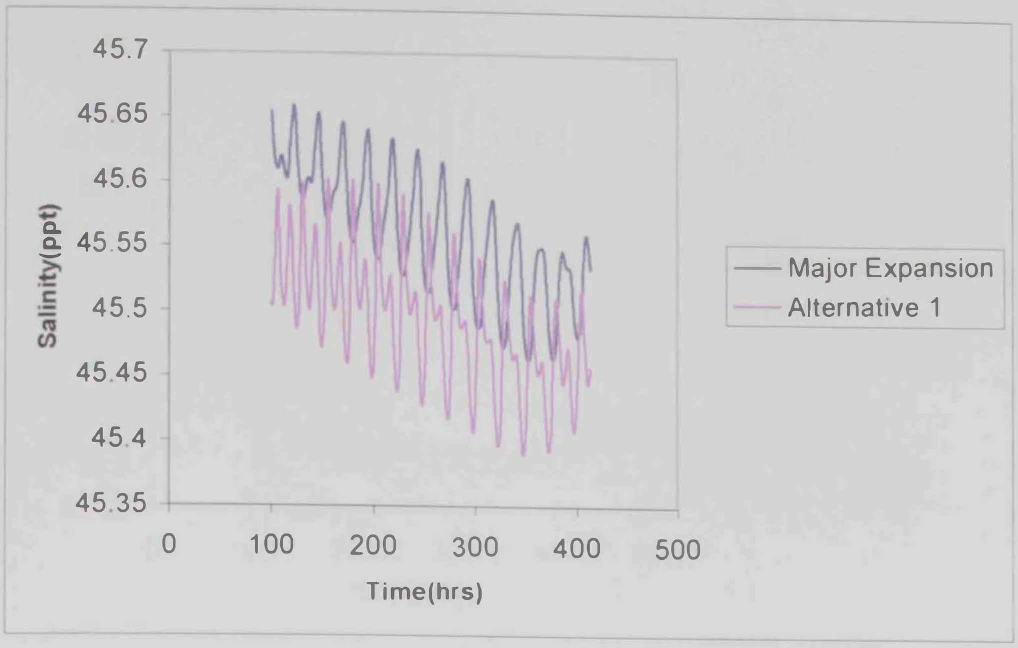


Figure B.9 Salinity for major expansion model and alternative 1 at winter.

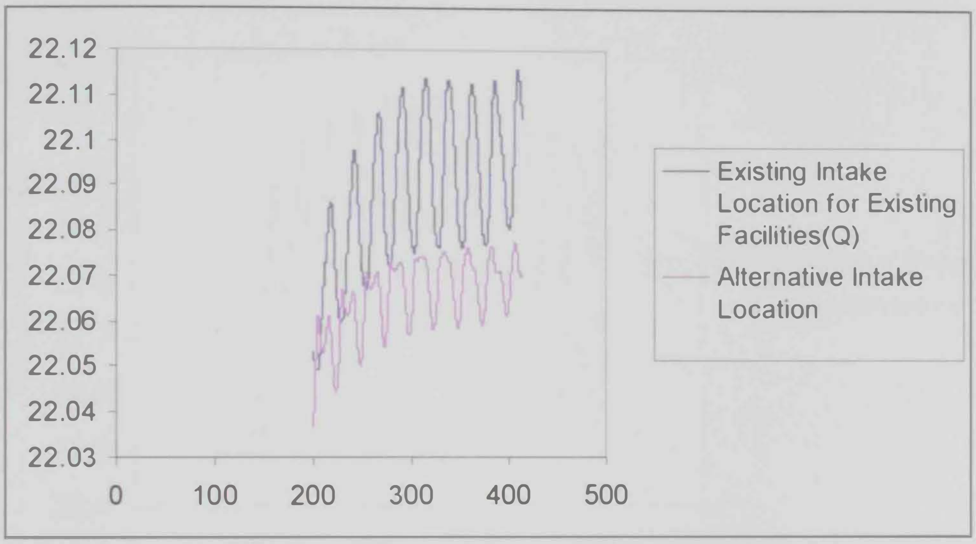


Figure B.10 Temperature for basic model and alternative 1 at winter.

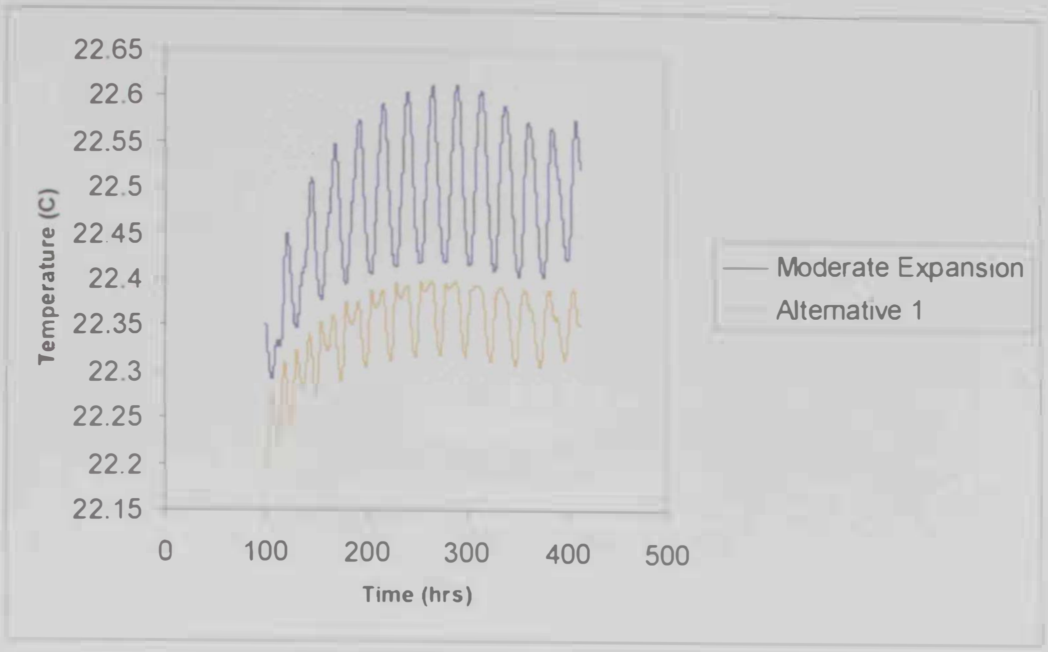


Figure B.11 Temperature for moderate expansion model and alternative 1 at winter

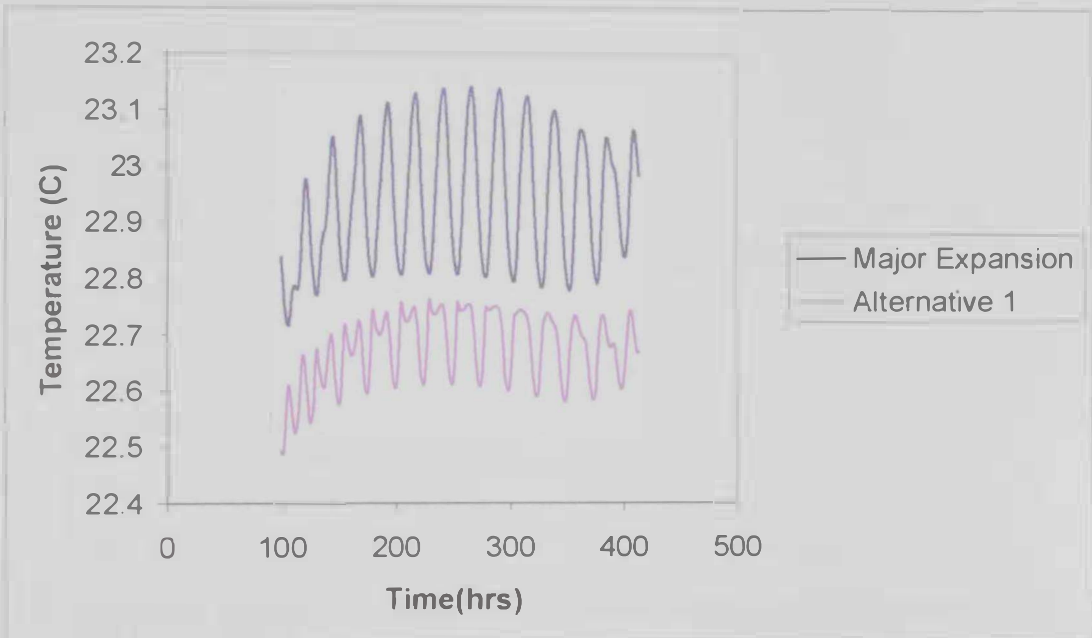


Figure B 12 Temperature for major expansion model and alternative 1 at winter.

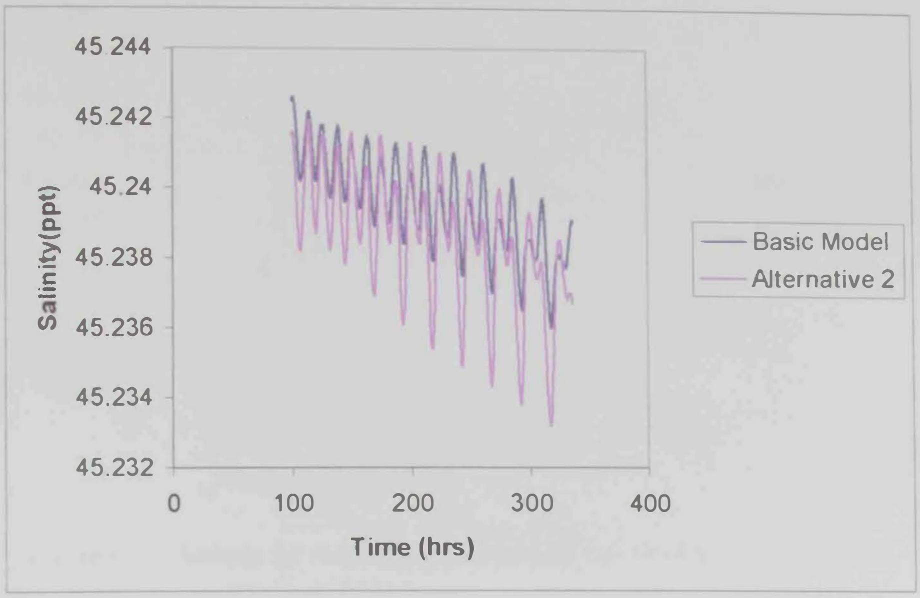


Figure B.13 Salinity for basic model and alternative 2 at summer.

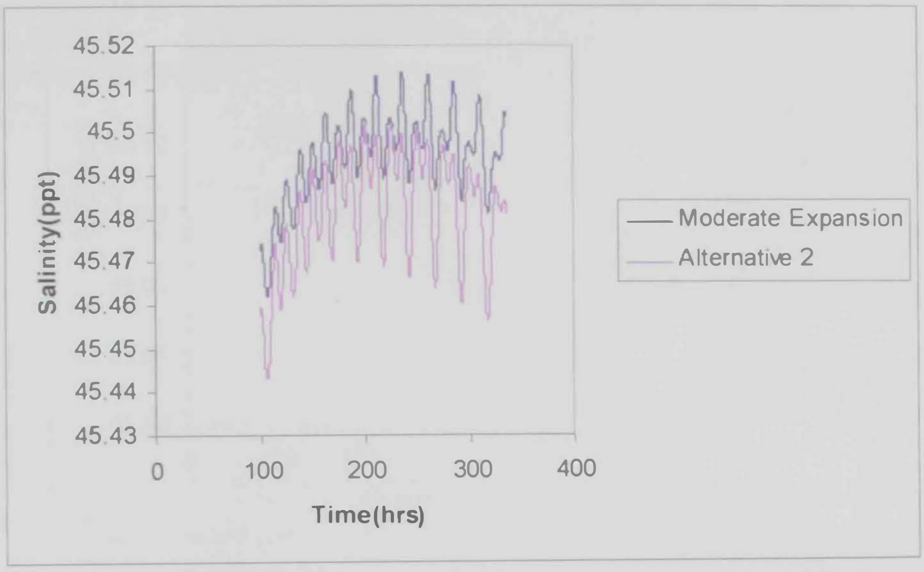


Figure B.14 Salinity for moderate expansion model and alternative 2 at summer.

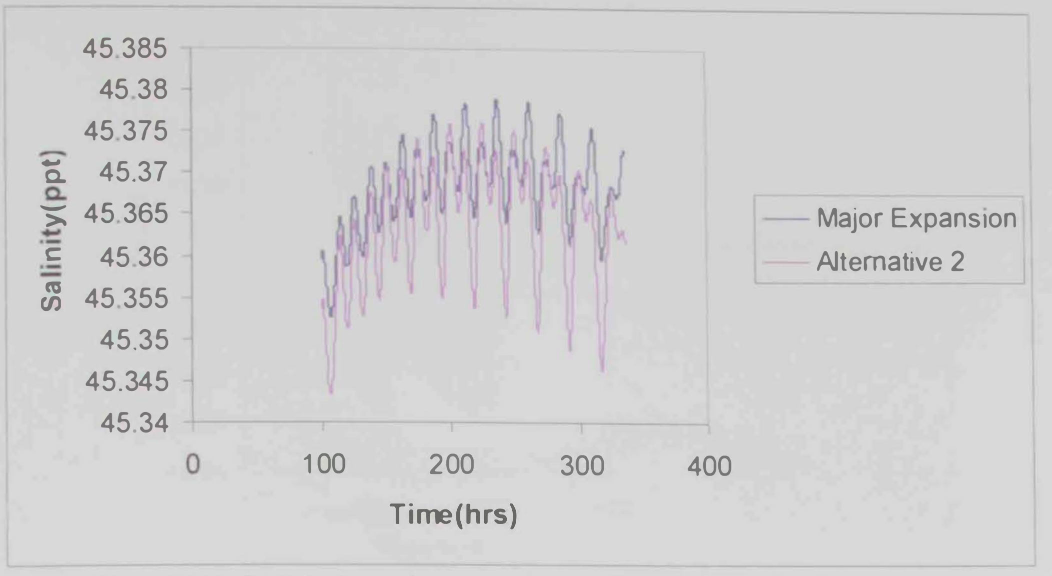


Figure B.15 Salinity for major expansion model and alternative 2 at summer.

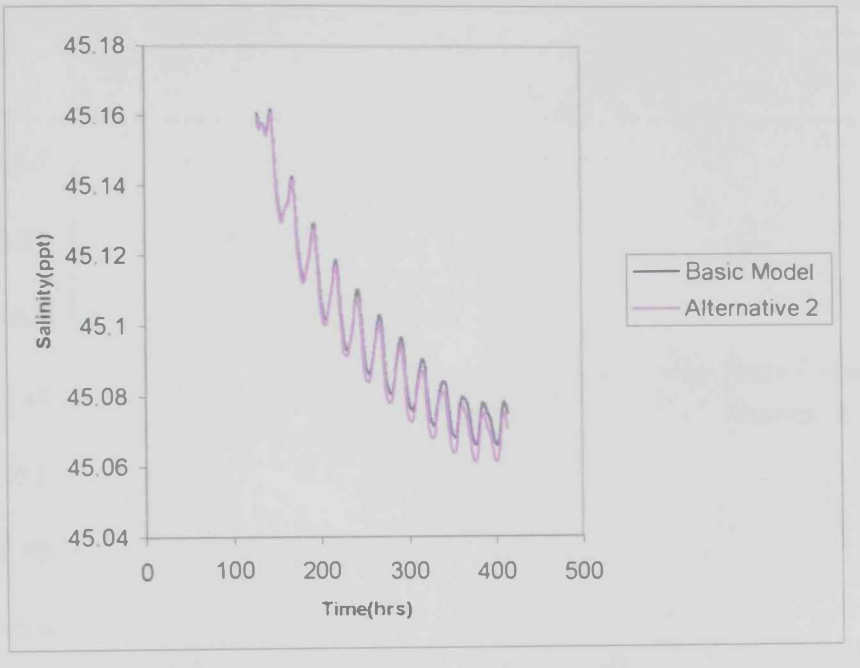


Figure B.16 Salinity for basic model and alternative 2 at winter.

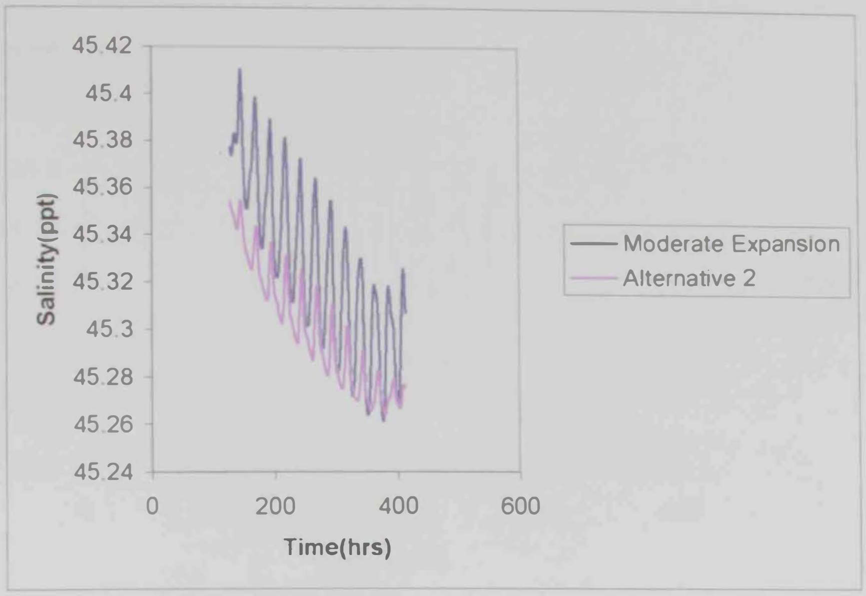


Figure B.17 Salinity for moderate expansion model and alternative 2 at winter.

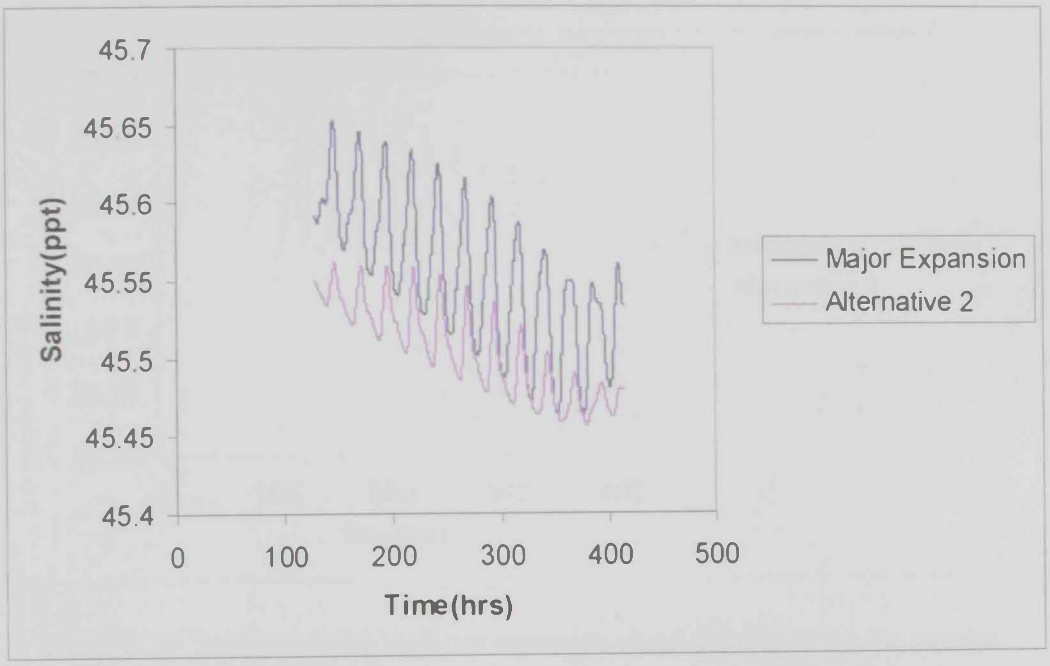


Figure B.18 Salinity for major expansion model and alternative 2 at winter.

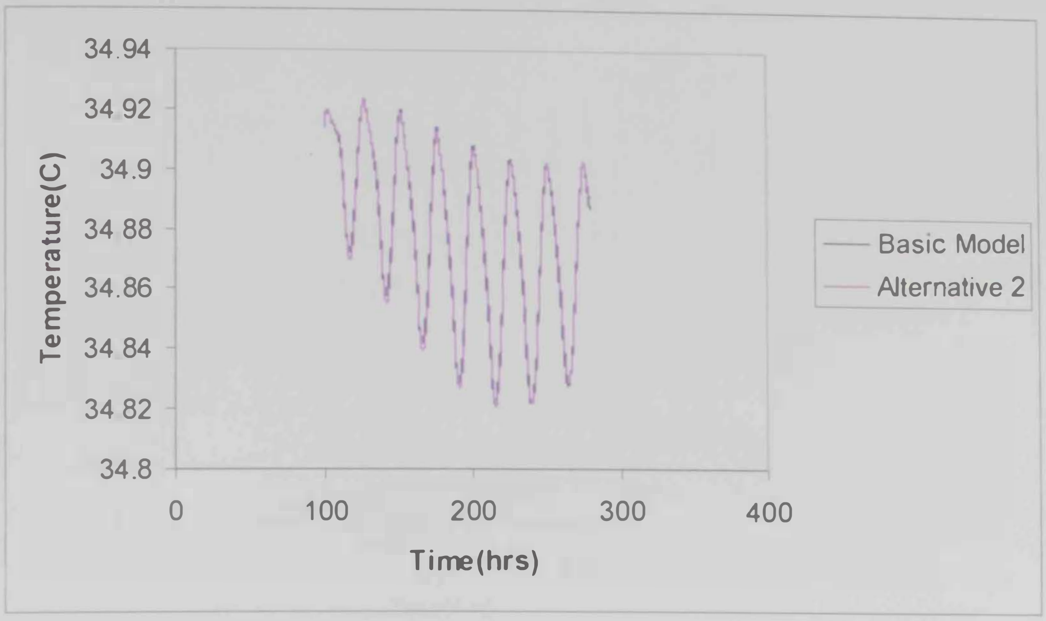


Figure B.19 Temperature for basic model and alternative 2 at summer

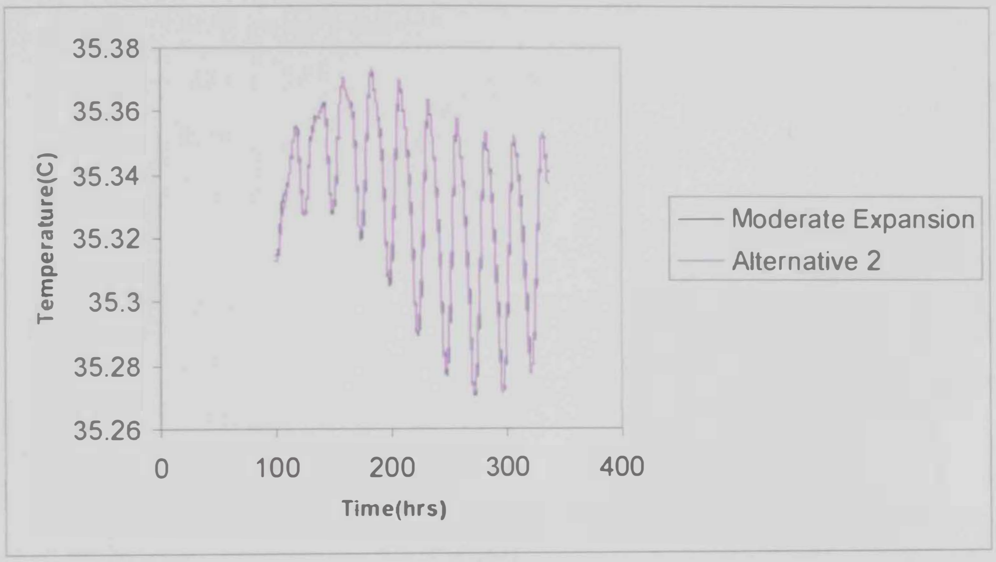


Figure B.20 Temperature for moderate expansion model and alternative 2 at summer

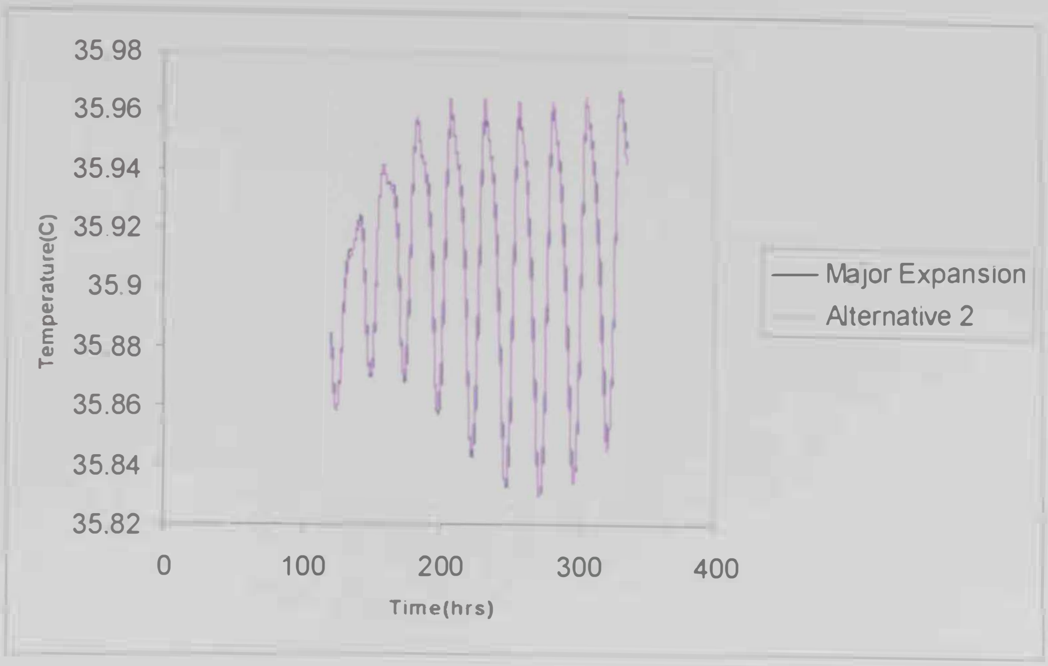


Figure B.21 Temperature for major expansion model and alternative 2 at summer

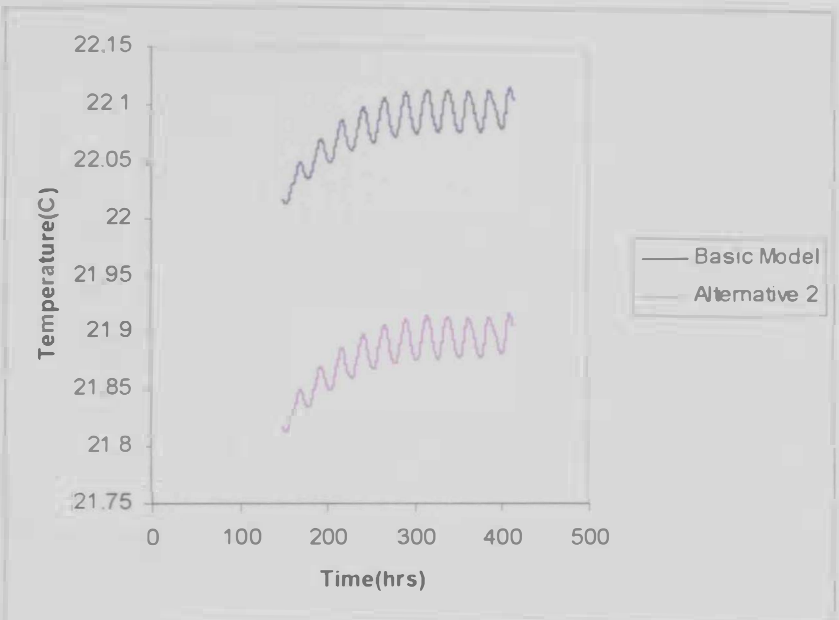


Figure B.22 Temperature for basic model and alternative 2 at winter.

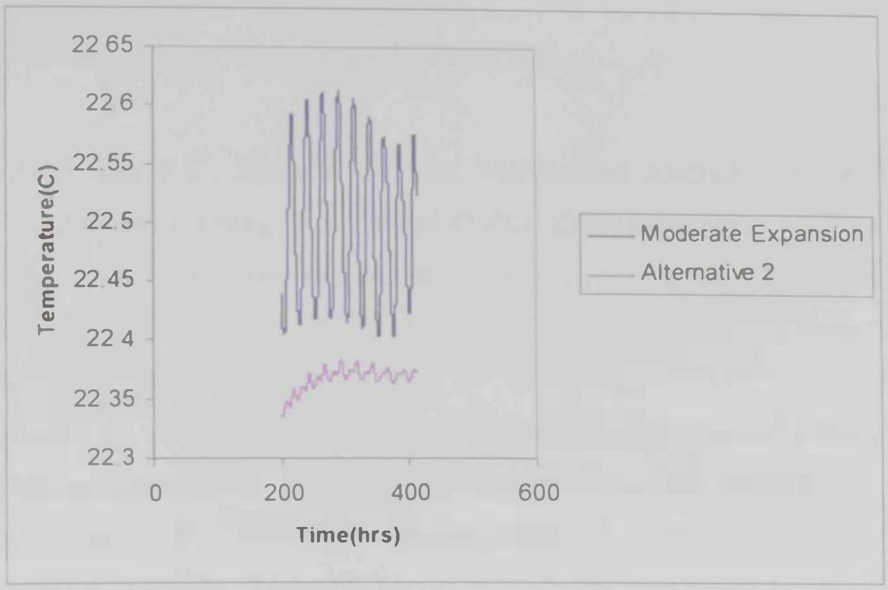


Figure B.23 Temperature for moderate expansion model and alternative 2 at winter

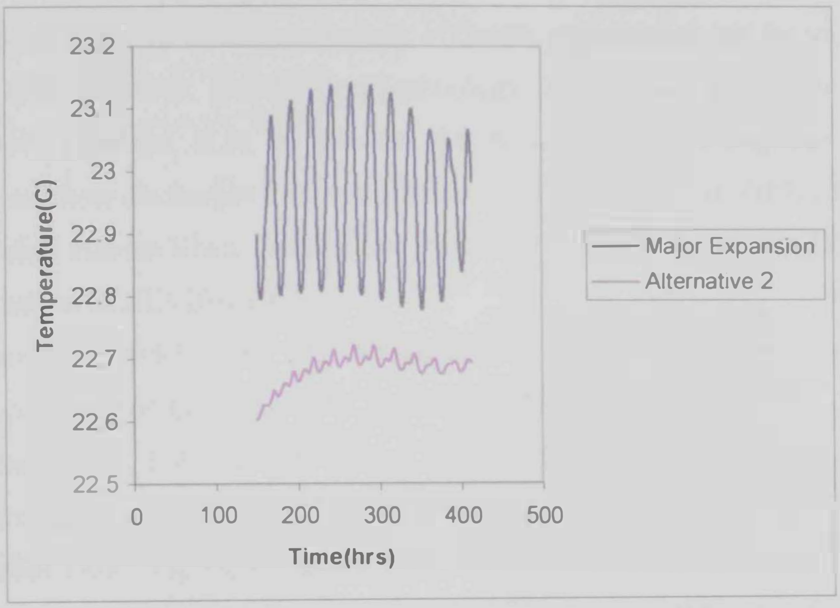


Figure B.24 Temperature for major expansion model and alternative 2 at winter

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ملخص الأطروحة

تعتبر دراسة موارد المياه من المواضيع الهامة. وذلك لما لعنصر الماء من اهمية في حياة جميع الدول . وخاصة دول الخليج العربي ,والتي تعاني من نقص الموارد الطبيعية للمياه . ويشكل اعتمادها على تحلية مياه البحر العنصر الاساسي لتوفير المياه اللازمة للمجالات البشرية والصناعية.

وقد ركزت هذه الدراسة البحثية على دراسة الاختيار الامثل من الناحية الفنية (التقنية) والاقتصادية لمواقع مأخذ مياه البحر وكذلك اماكن تصريف مخلفات محطات التحلية من مياه ساخنة تحتوي على كميات مركزة من الاملاح والمواد العالقة . وقد تم تصميم نموذج محاكاة متعدد الطبقات لدراسة ديناميكا المياه لمنطقة الرويس الصناعية وماتضم من منشآت صناعية الى جانب محطة تحلية مياه البحر. وذلك باستخدام برنامج Delft3D , ودراسة تاثير مخلفات محطة التحلية و المنشآت الصناعية من مياه ذات درجة حرارة عالية و تركيز املاح مرتفع على الكفاءة التشغيلية لمحطة التحلية , و الآثار الاقتصادية الناجمة عن هذا التاثير.

ولذلك تم دراسة سيناريوهات مختلفة تقوم بفرضيات مستقبلية تشمل توسعة كبيرة في المنشآت الصناعية ,وما يترتب على ذلك من زيادة في صرف المخلفات المائية الى مياه البحر,مما يودي الى ارتفاع درجة حرارة المياه وتركيز الاملاح في الاماكن القريبة من المياه الضحلة القريبة من محطة التحلية. وتقوم الدراسة بتقديم اقتراحات وبدائل ما من شانها تقليل تاثير هذه التوسعة على البيئة المائية الضحلة القريبة من محطة التحلية وذلك ما من شانه تقليل هذا التاثير على كفاءة المحطة . وتشمل البدائل نقل اماكن ماخذ المياه الى المياه العميقة على بعد حوالي 1000م بعيدا عن المياه الضحلة القريبة من الشاطىء ,اما البديل الثاني فهو تصريف مخلفات مياه المحطة بعيدا عن الشاطىء ,والبديل الاخير هو صرف مخلفات المياه الى طبقات عميقة في المياه.

من خلال البدائل الثلاث سابقة الذكر ,تم دراسة التاثير الفني والاقتصادي على محطة التحلية ممثلا في التوفير الحاصل في استهلاك الطاقة الكهربائية وتوفير استهلاك المواد الكيميائية اللازم اضافتها لمعالجة مياه البحر المستخدمة في التحلية . وقد جاءت النتائج لتبرز مدى فاعلية البديل الاول وهو نقل ماخذ المياه لتكون على بعد حوالي 1000م من المياه الضحلة , حيث حقق هذا الحل البديل توفيرا لكلفة الصيانة التشغيلية بقيمة 2.5% (حوالي 1,193,000دولار امريكي) وذلك بفرضية حدوث توسعة كبيرة للمنشآت الصناعية القائمة في منطقة الرويس الصناعية.

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عمادة الدراسات العليا

الاختيار الأمثل لمواقع مآخذ وأماكن تصريف محطات التحلية باعتبار عوامل البيئة وديناميكا مياه البحر الواقعة في البيئة الساحلية الغربية لدولة الإمارات العربية المتحدة

أطروحة مقدمة من الطالب
أحمد علي بسيوني

بكالوريوس هندسة مدنية
جامعة الإمارات العربية المتحدة (1998)

استكمالا لمتطلبات الحصول على درجة الماجستير في علوم موارد المياه

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