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# Impact of Reject Brine Chemical Composition from Inland Desalination Plants On Soil

Juma Bin Khalfan Bin Khamis Al-Handhaly

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**UNITED ARAB EMIRATES UNIVERSITY**

**DEANSHIP OF GRADUATE STUDIES**

**IMPACT OF REJECT BRINE CHEMICAL COMPOSITION  
FROM INLAND DESALINATION PLANTS ON SOIL**

**By**

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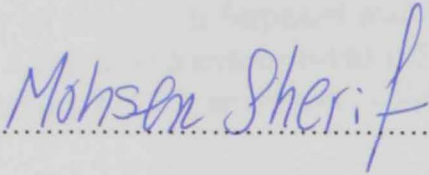
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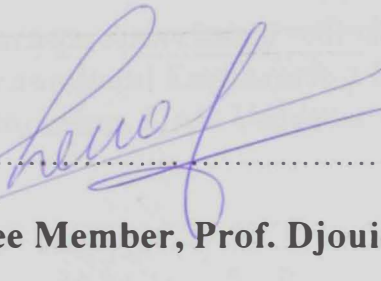
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## ABSTRACT

The impact of reject brine chemical composition and disposal from inland desalination plants on soil in the eastern region of Abu Dhabi Emirate, namely Al Wagan, Al Quaa and Um Al Zumool, was evaluated. Twenty five (25) inland Brackish Water Reverse Osmoses (BWRO) desalination plants (11 at Al Wagan, 12 at Al Quaa, and 2 at Um Al Zumool) were investigated. The average capacity of these plants varied between 26,400 G/d (99.93 m<sup>3</sup>/d) and 61,000 G/d (230.91 m<sup>3</sup>/d). The recovery rate varied from 60 and 70% and the reject brine accounts for about 30 – 40 % of the total water production. The electrical conductivity of feed water and rejects brine varied from 4.61 to 14.70 and 12.90 to 30.30 (mS/cm), respectively. The reject brine was disposed directly into surface impoundment (unlined pits) in a permeable soil with a low clay content, a cation exchange capacity (CEC) and organic matter content. The groundwater table lay at a depth of 100 – 150 m. The average distance between feed water intake and the disposal site was approximately 5 km. A survey was conducted to gather basic information, to determine the type of chemicals used, and determine if there were any current and/or previous monitoring programs. The chemical compositions of the feed, product, reject, and pond water were analyzed for major, minor and trace constituents. Most of the water samples (feed, product, reject and pond water) showed the presence of major, minor and trace constituents. Some of these constituents were above the Gulf Co-operation Council (GCC) and Abu-Dhabi National Oil Company (ADNOC) Standards for drinking water and effluents discharged into the desert. The Total Petroleum Hydrocarbon (TPH) was also analyzed and found to be present, even in product water samples, in amounts that

exceeded the GCC standards for organic chemical constituents in drinking water (0.01 mg/l). Chemical analysis has revealed that the horizontal movement of contaminants was higher than the lateral movement. The fate, and impact of concentrate (reject brine), was studied using batch and column tests. The results obtained from the batch test revealed that the retardation coefficient takes the following order Potassium >Strontium >Sulfate. The results obtained from the leaching column test showed that strontium retardation calculated as the area under the curve and for PV at  $C/C_0 = 0.5$  was higher for in-place (natural) soil than sand dune soil. In addition, the changes in electrical conductivity (EC) were similar to that of an ideal tracer. The outcomes from CXTFIT modeling program indicated that the in-place (natural) soil had a higher dispersion coefficient ( $D$ ), a higher retardation coefficient ( $R$ ) and a greater dispersivity ( $\alpha$ ) than sand dune soil. This suggested a faster movement of contaminants in sand dune. Predictions of field conditions using CXTFIT model showed that Sr required 13-14 days to reach the feeding aquifers of 100 m depth in the case of sand dune soil, whereas it requires 16 days for the In-place soil . Finally the available options that can be implemented to reduce the impact of reject brine on environment were discussed.

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## LIST OF ABBREVIATIONS

BRINE	Brine TDS >5000 mg/l
BW	Brackish Water (TDS 3,000 mg/l - 15,000 mg/l)
M <sup>3</sup> /day	Cubic per Day
GCC	Gulf Cooperation Council
MGD	Million Gallons per Day
RO	Reverse Osmosis
ESCWA	Economic and Social Commission for Western Asia
UN	United Nation
WHO	World Health Organization
mg/l	Milligram per Litter
EPA	(US) Environmental Protection Agency
MCM/yr.	Million Cubic Meters per Year

# CHAPTER 1

## INTRODUCTION

### 1.1 BACKGROUND

Given the importance of water to human and ecosystem survival, water quantity and quality represent important environmental elements. Evidences indicate that the world is facing a growing challenge in maintaining water quality and meeting the rapidly growing demand for water resources (Rosegrant, 1997). However, many regions of the world that are subjected to critical water shortages and contamination are facing famine, economic breakdown, and a potential warfare (Starr, 1999). Within the Middle East, the Gulf Region is suffering water scarcity. Water shortages problems in the United Arab Emirates (UAE) are aggravating by the rapidly growing population, and the expansion of industrial and agricultural activities. The struggle of UAE to meet present and future demands for water resources has shifted attention to the role of desalination technology in alleviating water shortages using sea and brackish water as feed. Desalinated water accounts for approximately 98% of domestic supplies, with a total production of 701.6 mcm/year (UN, 2001). Between 1999 and 2001, the production of the desalination water in the UAE has increased by 30%, due to the remarkable economic and demographic development. Currently, desalination plants produce about 98% of the total drinking water supplies in the UAE (Sommariva and Syambabu., 2001). The degradation of groundwater resources in terms of quality in the eastern region of Abu Dhabi Emirate (Al Wagan, Al Qua'a and

Um Al Zumool) is due to the increase of the total dissolved solids (TDS) of the groundwater. Salinity problems, however, are likely to increase in the future both quantitatively and qualitatively due to brackish groundwater intrusion and low recharge rate. For the aforementioned reasons the reliance on unconventional water resources such as the water produced by Brackish Water Reverse Osmoses (BWRO) Desalination Technology has increased to meet the demographic and economic developments and to fulfill one of the requirements for the settlement of nomadic citizens. Since 1980's the BWRO has gradually increased and become a prime method for solving the pressing water supply problem. The current daily output of inland desalination plants in eastern region is 959,992 G/d (3,633 m<sup>3</sup>/d), with an 30 to 40 % reject brine.

All desalination method have always been limited by the disposal costs of the concentrated waste brines produced and the adverse impact of brine compositions on the environment, particularly in large-scale plants. In coastal regions, disposal of brine water can be accomplished by discharging into the neighboring body of seawater. However, in the eastern part of Abu Dhabi Emirate brine concentrate cannot be discharged to the distant sea. But in some special cases, particularly for small capacity plants, the brine water discharged over the land surface. In the inland desalination plants brackish water is the feed source and the rejected water is disposed of into a surface impoundment (unlined pits).

The major constituents of reject brine are inorganic salts. The brine also contains small quantities of antiscaling additives, corrosion products, and other reaction products. Early desalination plants practices emphasized water production with little consideration for environmental impact. One of the impacts of inland plants is water pollution that results when concentrated brine is discharged back into the feed water

source from unlined ponds or/pits. Over the last 23 years, reject brine in the eastern region has not been utilized and the environmental implications associated with that has not been adequately considered from the higher authorities. Technical, economical and environmental issues of the rejected water have not been addressed properly.

## **1.2 RESEARCH OBJECTIVES**

The objectives of this study are to:

1. Determine the composition of feed/or raw water, product, reject brine, and pond water.
2. Characterize the inland soil at the disposal site in view of its physical, chemical and mineralogical composition.
3. Evaluate the status of inland Brackish Water Reverse Osmoses (BWRO) in the Eastern Parts of Abu Dhabi.
4. Evaluate the transport parameters of major elements in reject brine in inland soil at the disposal site.
5. Predict the distribution of brines constituent as a function of distance and time at the inland disposal site.
6. Evaluate the status of reject brine distribution at specific desalination plants in subsurface soil.

## **1.3 SCOPE AND BOUNDARIES OF THE STUDY**

The current work is limited to inland desalination plants located in the eastern region of Abu Dhabi Emirates. Inland desalination plants in other regions of Abu Dhabi Emirate (i.e., Liwa), and in the Northern Emirates have not been surveyed. A

questionnaire was distributed among the surveyed plants to obtain data about the quality and quantity of feed or/groundwater, product, brine and pond water. Furthermore, water samples were analyzed for the three investigated plants. Soil samples were collected from Al Qua'a disposal site and from two nearby locations. No other soil samples were collected from the other two inland disposal sites. Water samples were analyzed for physical, chemical and Total Petroleum Hydrocarbons (TPH), whereas soil samples were analyzed for physical, chemical and mineralogical composition. No groundwater samples from surrounding areas were collected. Impact of reject brine on soil and groundwater was evaluated using the above-analyzed parameters and other laboratory experiments: including batch, and miscible displacement experiment. CXTFIT modeling program (Version 2.0) was used to simulate reject brine transport through packed soil columns as a function of depth ( $x$ ) and time ( $t$ ).

#### **1.4 THESIS ORGANIZATION**

This thesis consists of seven (7) chapters. Chapter one (1) contains background information on the importance of desalination technologies to reduce the gap between demands and water availability and the environmental impacts of desalination plants. Chapter two (2) is devoted to the review of the current situations of water resources in UAE in general, and Abu-Dhabi Emirate in particular. It highlights the role of desalination technology to overcome water shortages problem. Desalination and brine production, chemistry and the chemical composition, brine disposal methods, impact of reject brine on soil properties and groundwater are discussed. The fate and pollutant movement through soil media and the use of modeling package to predict their transport are reviewed. Chapter three (3) presents

an assessment to the study areas, material characterization and testing techniques. Chapter four (4) includes an evaluation of the status of inland BWRO desalination plants in the eastern part of Abu-Dhabi. Chapter five (5) presents an evaluation of the distribution of reject brine in subsurface soil at the disposal site. Chapter six (6) elaborates the different methods used to evaluate the transport parameters, conduct a sensitivity analysis and predict the potential movement of reject brine in the field. Chapter seven (7) concludes the study and draws recommendations related to reject brine chemical compositions, disposal and mitigations steps to minimize the adverse impacts on environment. The chapter addresses the relevant innovative technologies used to mitigate the problems associated with the reject brine waste, and presents the most favorable technologies to be applied in the GCC and UAE. Supporting documents (Experimental results, GCC drinking quality standards, ADNOC wastewater re-use standards, photos and questionnaires) are included in the appendices.

# CHAPTER 2

## LITERATURE REVIEW

### 2.1 INTRODUCTION

The Abu Dhabi Emirate (Fig. 2.1) is located in a dry arid to semi-Arid region with an average rainfall of less than 100 mm/yr (NDC, 1993). Abu Dhabi Emirate has a population of 1.3 million and has the highest GCC growth rate of +10% per annum (Soyza, 2002). The Emirate has, a low groundwater recharge rate, and a very high evaporation rate (2000 – 3000 mm/yr) no reliable perennial surface water resources, with summer shade temperature frequently exceeding 40 °C (Soyza, 2002). Strong persistent winds are normally encountered in many areas of Abu Dhabi Emirate.



Fig. 2.1: Map of United Arab Emirates (UAE)



Table 2.1 shows the renewable water resources availability in the UAE and the GCC Countries (Al-Hiti and Al-Hadithi, 2001). Total conventional freshwater resources available in UAE is 315 Mm<sup>3</sup>/yr while the total water demand was 2180 Mm<sup>3</sup> in the year 2000. The forecasted demand for the year of 2025 is 3200 Mm<sup>3</sup>/yr (Sommarive and Syambabu, 2001).

Country	Renewable Water Resources (TR)	Total Demand (TD)		TD/TR %	
		2000	2025	2000	2025
Saudi Arabia	6080	17765	24200	292	398
<b>UAE</b>	<b>315</b>	<b>2180</b>	<b>3200</b>	<b>692</b>	<b>1016</b>
Oman	1468	1847	2430	126	169
Kuwait	160.1	590	1400	369	874
Bahrain	100.1	282	609	282	608
Qatar	51.4	347	485	670	943

Table 2.1: Renewable Water Resources (Mm<sup>3</sup>/yr) in the UAE and GCC Countries (Al-Hiti and Al-Hadithi , 2001).

Conventional water resources available in the UAE include groundwater from single wells and central well fields, storage dams, Aflaj, Wadi flow and springs. Unconventional water resources include desalination and recycled water. The contribution of each source to the total water demand for year 2000 is illustrated in Fig. 2.2.

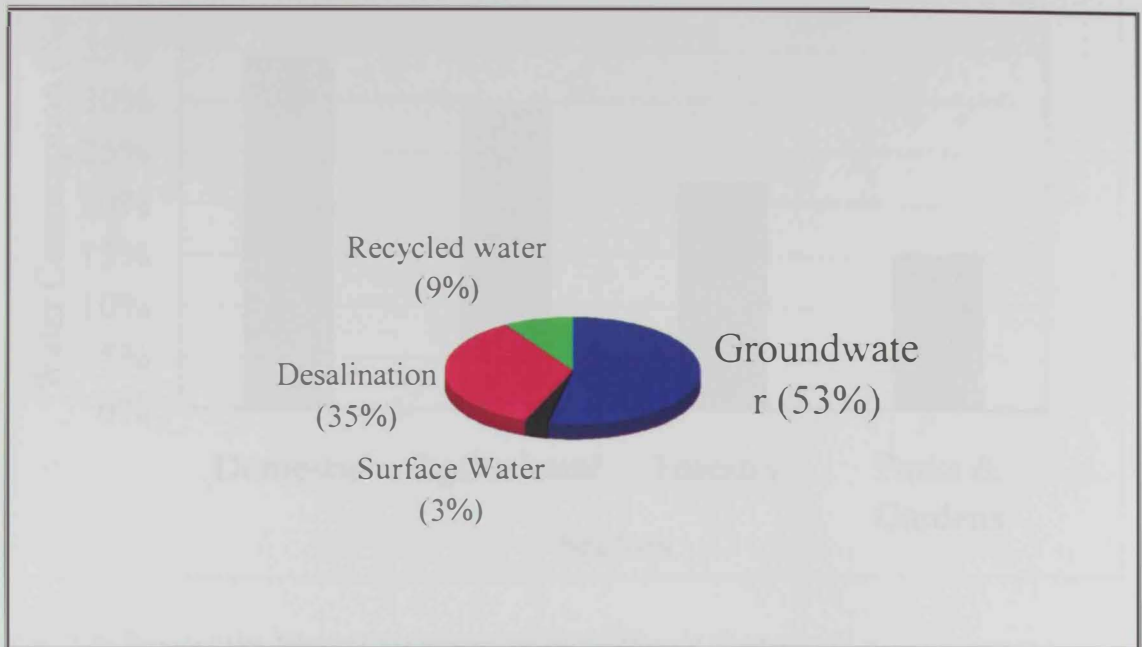


Fig. 2.2: Contribution of the Different Water Resources in the UAE for year 2000 (Maraqa, 2002)

In analyzing the water demand in UAE, there are three major sectors as shown in Fig.2.3. These include the domestic sector (households and drinking demands), the industry and commerce sector and the agricultural, forestry and landscaping sector (ADWEA and FEWA, 2000).

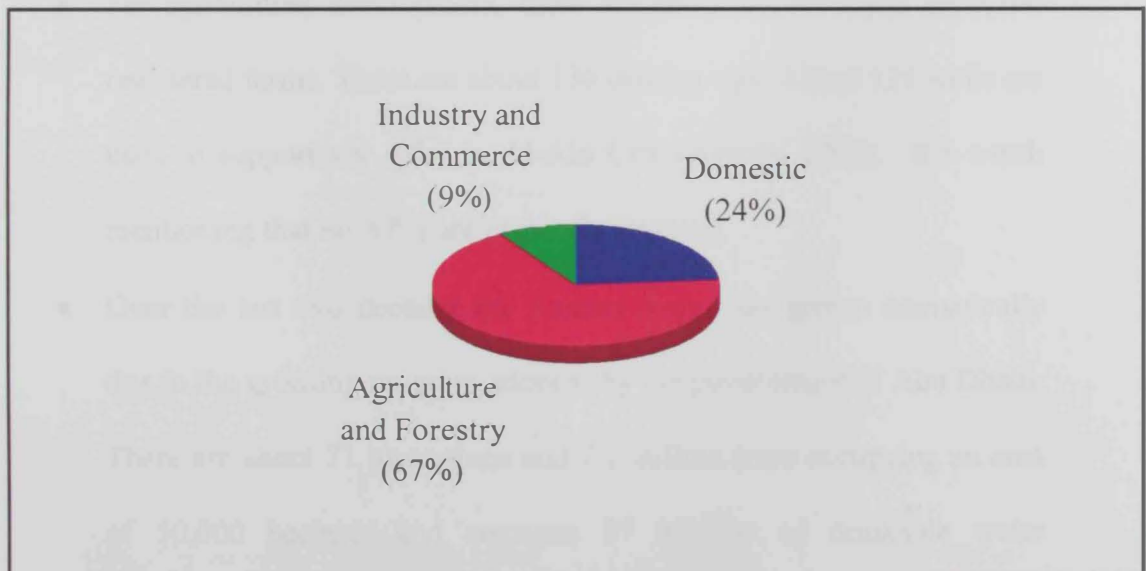


Fig. 2.3: Distribution of Water Uses by Sector in the UAE (Maraqa, 2002)

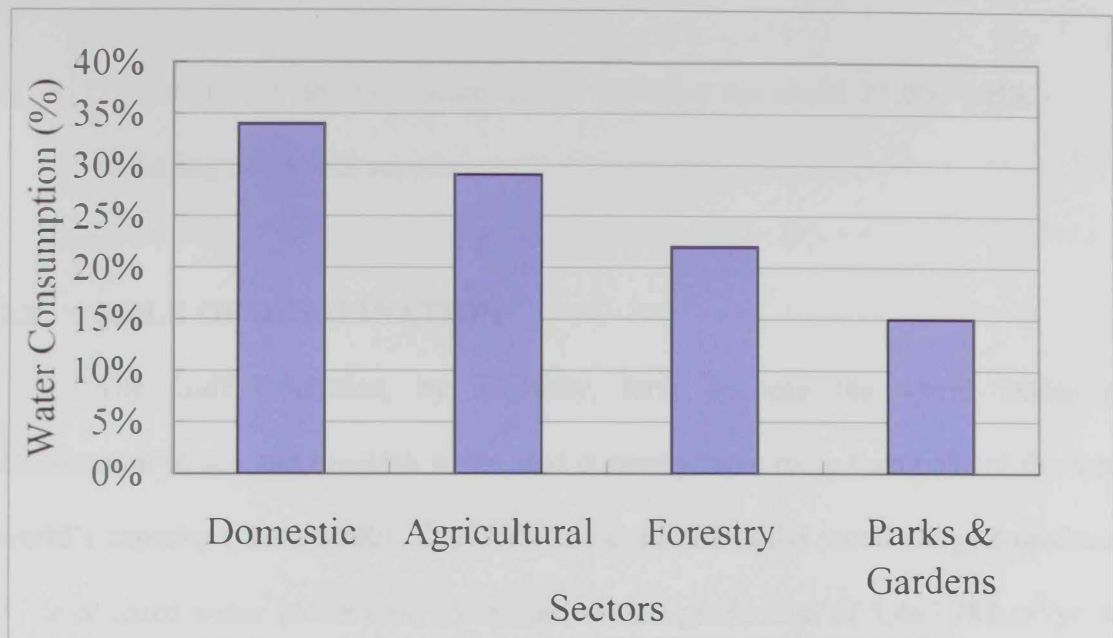


Fig. 2.4: Percentage Water Consumption by Different Sectors

Figure 2.3 shows that 67% of the water demand is used for agriculture, while 24% is used for domestic purposes and 9% for industrial activities. In the Eastern Region of Abu Dhabi Emirate the groundwater statistics indicate a total abstraction of approximately 880 Mm<sup>3</sup>/yr (Soyza, 2002). Distributions are shown in Figs. 2.3 and 2.4 and discussed.

- For agricultural development, there are about 24,000 wells on 9,100 registered farms. There are about 130 drilling rigs. About 124 wells are used to support six Aflaj in Al-Ain City (Amrita, 2002). It's worth mentioning that no Aflaj are presently working.
- Over the last two decades the forestry sector has grown dramatically due to the greening program adopted by the government of Abu Dhabi. There are about 71 plantations and 7.1 million trees occupying an area of 50,000 hectares and consume 97 Mm<sup>3</sup>/yr of drinkable water abstracted from 2,600 wells (Amrita, 2002).

- To satisfy the domestic water demands, there are about 25,000 wells including municipal supplies.

## 2.2 ROLE OF DESALINATION

The Gulf Countries, by necessity, have become the world leader in desalination of sea and brackish water, and currently have more than 65% of the total world's capacity (GWI, 2000). The UAE is considered as the second largest producer of desalinated water in the Gulf Countries, with a production of 5,465,784 m<sup>3</sup>/yr. as shown in Table 2.2.

Country	Number of Units	Total Capacity (m <sup>3</sup> /y)
Saudi Arabia	2074	11,656,043
<b>UAE</b>	<b>382</b>	<b>5,465,784</b>
Kuwait	178	3,129,588
Qatar	94	1,223,000
Bahrain	156	1,151,204
Oman	102	845,507
<b>Total</b>	<b>2986</b>	<b>23,471,126</b>

Table 2.2: Desalination Units in the Six GCC Countries (Global Water Intelligence, 2000)

Abu Dhabi has the highest per capita domestic consumption rate 500 l/d in the GCC, and is ranked worldwide after the USA (UN, 2001). Further development in the UAE can't be satisfied without reliance on unconventional water resources such as desalination of sea and brackish water, which currently account for about 98% of the water supply for drinking purposes. The total production and percentage of

desalinated water (MCM) in the different Emirates for year 2000 are shown in Figs. 2.5 and 2.6, respectively. Abu Dhabi Emirate has the highest percentage and production among the other Emirates. Desalination requirements in UAE will continue to grow. Between 1999 and 2001 the desalinated water production increased by 30% due to the startup of new desalination projects (Sommariva and Syambabu, 2001).

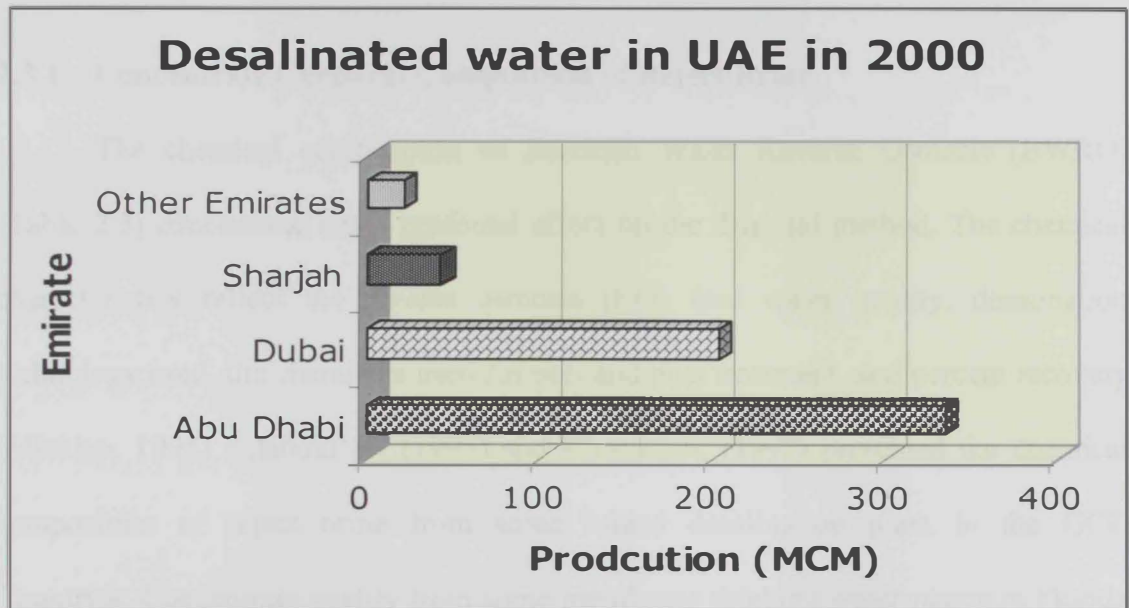


Fig. 2.5: Total Production of Desalinated Water (MCM) in UAE in 2000 (ADWEA and FEWA Report, 2000).

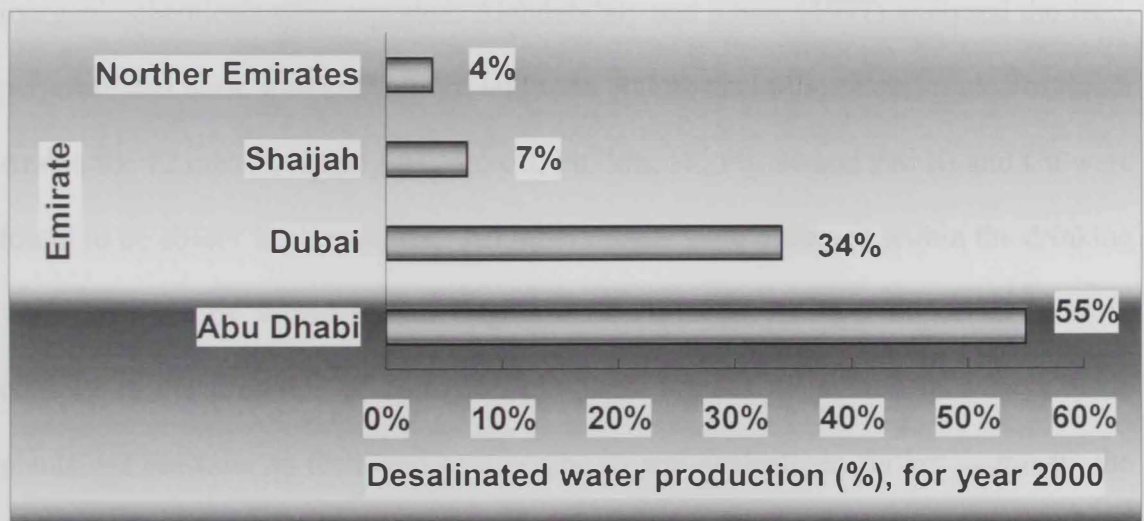


Fig. 2.6: Percentage of Desalinated Water Production in UAE Emirates for Year 2000 (ADWEA and FEWA Report, 2000).

## **2.3 REJECT BRINE**

Reject brine, also referred in the literature as concentrate or wastewater, is a by product of the desalination processes. Brine discharged is more concentrated than brackish water or seawater and contains chemicals like antiscalent, used in the pretreatment of the feed water, washing solutions, rejected backwash slurries from the feed water, and other substances.

### **2.3.1 Concentrate Chemical Composition of Reject Brine**

The chemical composition of Brackish Water Reverse Osmosis (BWRO) (Table 2.3) concentrate has a profound effect on the disposal method. The chemical characteristics reflect the reverse osmosis (RO) feed water quality, desalination technology used, the chemicals used for pre- and post treatment, and percent recovery (Mickley, 1995). Alabdul'aly (1995) and Khordagui, (1997) presented the chemical composition of reject brine from some inland desalination plant in the GCC Countries. Concentrate quality from some membrane drinking water plants in Florida has been reported by Mickley (1993) where the concentrations of 40 different inorganic chemicals were reported. Alabdula'aly and Khan, (1997) analyzed the feed, permeate and brine water of four groundwater RO plants in the central region of Saudi Arabia for 12 metals, namely Al, As, Cd, Fe, Mn, Ni, Pb, Se and Zn. Ni and Cu were found to be absent in all samples. All other metals were observed within the drinking water limit set by World Health Organization (WHO). Another important issue of concern is the presence of corrosion products. Studies conducted in a large scale plants use seawater as feed, and acid dosing as anti-scalent can further aggravate the corrosion problem (Oldfield and Todd, 1995). RO system recovery can influence concentrate characteristics. The system volume recovery is the volume of permeates

produced from the feed water expressed as a percentage. High recovery leads to a concentrating effect of dissolved species in the feed water, the extent of which can be estimated from the following mass balance equation.

$$CF = 1 / (1 - SR) \quad [2.1]$$

Where  $CF$  is the concentration factor of ionic species;  $SR$  is the system recovery expressed as a decimal.

The dilution of concentrate (blended) results in a final discharged effluent that is rarely more than 15% higher in salinity than the receiving water. Concerns over the potential adverse effects are tempered by the total volume of brine being released, the constituents of the brine discharged (i.e., heavy metals, organic and inorganic compounds and also by products from pre-and post-chemical treatment which might include antiscalent, antifoaming agents, polyphosphates, coagulant aids, residual chlorine, and acid).

Parameter	Alssadanat Oman	UmmAl Quwain, UAE	Hamriyah, Sharijah, UAE	Saja'a Sharijah, UAE	Buwaib, Saudi Arabia	Salboukh, Saudi Arabia
Ca <sup>++</sup> , mg/l	923	202	173	188	573	404
Mg <sup>++</sup> , mg/l	413	510	311	207	373	257
Na <sup>+</sup> , mg/l	2780	3190	1930	4,800	2327	1433
K <sup>+</sup> , mg/l	81.5	84.5	50.7	60	NR	NR
Sr <sup>++</sup> , mg/l	28.2	21.10	14.20	40	NR	NR
ΣCation meq/l	203.06	192.98	119.48	NR	NR	NR
pH	7.21	7.54	7.66	7.95	4.1	4.5
Electrical conductivity (mS/cm)	16.8	14.96	127.41	NR	NR	NR
TDS, mg/l	10553	10923	7350	12,239	10800	6920
NO <sub>3</sub> , mg/l	7.2	27.4	15.9	NR	143	142
F <sup>-</sup> , mg/l	-	1.6	1.3	8.0	NR	NR
Cl <sup>-</sup> , mg/l	4532	4108	2933	4,860	2798	1457
SO <sub>4</sub> , mg/l	1552	2444	1537	2,400	4101	2840
SiO <sub>2</sub> , mg/l	NR	164.09	133.71	120	NR	NR
Carbonate, CO <sub>3</sub> <sup>-</sup>	NR	NR	NR	NR	NR	NR
Bicarbonates, HCO <sub>3</sub> <sup>-</sup>	466	656	753	NR	NR	NR
N <sup>-</sup>	1.6	6.2	3.6	NR	NR	NR
Σanions maq/l	167.88	198.05	127.41	NR	NR	NR
Ion Balance	9.48	4.02	-3.21	NR	NR	NR
SAR	19.12	27.20	20.30	NR	NR	NR
SER	59.55	71.91	70.27	NR	NR	NR
LI	1.24	1.04	1.26	NR	NR	NR
RI	4.73	5.46	5.14	NR	NR	NR
Total Ion, mg/l	10781	11245	7719	NR	NR	NR
Total alkalinity	380	538	617	945	NR	NR
Total Hardness	4041	2630	1730	NR	2968	2066
Fe, mg/l	0.06	0.08	0.05	NR	65.5	NR
Mn, mg/l	0.05	0.05	0.05	NR	22.6	NR
Cu, mg/l	0.05	0.05	0.05	NR	10.8	NR
Zn, mg/l	0.05	0.05	0.05	NR	NR	NR
Cr, mg/l	0.02	0.12	0.05	NR	NR	NR
Al, mg/l	NR	NR	NR	NR	182	NR
Ba, mg/l	NR	NR	NR	NR	68	NR
As, mg/l	NR	NR	NR	NR	23.2	NR
Pb, mg/l	NR	NR	NR	NR	5.2	NR
Se, mg/l	NR	NR	NR	NR	7.7	NR

Table 2.3: Chemical Composition of Reject Brine from Inland Desalination Plants in the GCC Countries (after Ahmed 2000 and Alabdul'aly, 1997).

\* NR: Not Reported



Also, it is possible to find corrosion products in brine water resulting from the effect of water flow, dissolved gases and treatment chemicals (acids) on the alloys utilized in the construction of desalination pipes and equipments. The corrosion products may include harmful heavy metals such as Nickel (Ni), Copper (Cu), Molybdenum (Mo), and other less toxic metals such as Iron (Fe) and Zinc (Zn). The amount of these metal ions is directly related to redox potential, pH and the material in contact with water during the desalination process.

### **2.3.2 Reverse Osmoses Concentrate Disposal**

There are many options for concentrate disposal from inland desalination plants (Khordagui, 1997). Some of these are:

1. Discharge into well-engineered solar evaporation pond;
2. Disposal to wastewater system;
3. Land application (includes spray irrigation and percolation ponds);
4. Injection into deep saline aquifers (non-drinking water aquifers);
5. Disposal into land surface, and
6. Disposal into the sea through a pipeline

A Survey was conducted by (Ahmed *et al.*, 2000) on the current status of brine disposal techniques of 23 inland desalination plants in Oman, Jordan, and the UAE. The survey concluded that the disposal practices in the above countries range from evaporation ponds to the utilization of saline water in irrigation after dilution as well as disposal in boreholes, shoreline, wadi beds, and the ocean. Another survey was conducted in the USA at membrane drinking water facilities of size greater than 95 m<sup>3</sup>/day (Squire, 2000). About 73% of the plants were brackish water RO, 11% were

nonfiltration (NF), 11% electro dialysis (ED) and the remaining 5% seawater RO Plants. Table 2.4 summarizes the different methods for disposal of concentrate in the USA.

<b>Method of disposal</b>	<b>(%)</b>
Surface water	48%
Discharged to wastewater treatment plants	23%
Land Application	13%
Deep well injection	10%
Evaporation ponds	6%

Table 2.4: Methods of Concentrate Disposal

The necessity for a special disposal technique could make the system very costly. A report published by (UN, 2002) outlined that the cost plays an important role in selecting a method of reject brine disposal. The cost could range from 5 to 33% of the total cost of desalination (Khordagui, 1997). Evaporation ponds are the most appropriate for relatively warm, dry climates with high evaporation rates. It should be noted that with all types of land disposal procedures, there would always be a potential risk of groundwater contamination.

### **2.3.3 Impact of Reject Brine on Soil and Groundwater**

Disposal of reject brine into unlined pond or/pits from inland desalination plants has a significant environmental consideration. Improper disposal has the potential for polluting the groundwater resources and can have a profound impact on subsurface soil properties if it's discharged by land application. A case study in India indicated that seepage from brine caused groundwater contamination of the source well and resulted in an increase in hardness of the groundwater (Rao *et al.*, 1990).

High salt contents in reject effluent with elevated levels of sodium, chloride, and boron can reduce plants and soil productivity and increase the risk of soil

salinization. It can also alter the electrical conductivity of soil (Maas, 1990), changing the sodium adsorption ratio (SAR), and induce specific ion toxicity. The sodium adsorption ratio (SAR) defines the influence of sodium on soil properties by calculating the relative concentration of sodium, calcium, and magnesium. Higher SAR values can lead to lower permeability (Rhoades and Loveday, 1990). Although sodium does not reduce the intake of water by plants, it changes soil structure and impairs the infiltration of water, affecting plant growth (Hoffman *et al.*, 1990). Additional impacts include increased irrigation and rainwater runoff, poor aeration, and reduce leaching of salts from root zone because of poor permeability. Heavy metals and inorganic compounds build up in the soil and groundwater sources and may cause long-term health problems. There are other impacts caused by desalination, which are summarized in Table 2.5.

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### **Environmental Impacts**

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#### **Energy:**

Burning fossil fuels to generate power for desalination plants impacts:

- Human health
- Climate change

#### **Land-use:**

Land-use impacts related to the loss of the open good agricultural land for construction of inland desalination plants.

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Table 2.5: List of the Most Important Environmental Impacts of Desalination.

## **2.4 ENVIRONMENTAL FATE AND MODELING**

Assessing the extent and rate of pollutant movement through the soil profile from the disposed brine on inland desalination plants is of great importance. It

provides means for addressing the water quality issues associated with the deep percolation of reject brine when this by-product of desalination is discharged in improper way. In addition, understanding the movement of the concentrated brine along with heavy metals is essential in evaluating their negative impacts on the environment and addressing the policies and the regulatory aspects of brine reject discharge.

Models that describe the physical, chemical, and biological processes associated with the movement of solutes in the soil profile have been derived and investigated by many researchers (Burns, 1974, Melaamed *et al.*, Selim *et al.*, 1977, Yong *et al.*, 1992, Mohamed and Antia, 1998, and Fetter, 1999). According to Addiscott and Wagent, 1985, such models range from being deterministic, where individual processes are defined mathematically, to stochastic, where the emphasis is less on the process but more on predicting the statistical distributions of a given characteristics. The former category of models is usually complex in nature as it emphasizes the processes involved and the interactions among these processes.

## CHAPTER 3

### ASSESSMENT OF STUDY AREA

#### 3.1 STUDY AREA

The study area (Fig. 3.1a, b) is located at the eastern region of Abu Dhabi Emirate, about 100 km from Al-Ain City, where a hot arid climate prevails and evaporation greatly exceeds precipitation. The average annual rainfall may only be a few centimeters, which usually occurs seasonally and sometimes only from a single cloudburst. The summer shade temperature is frequently above 40°C. Strong persistent winds are normally experienced. The geological features of the area consist mainly of sand dunes with marine sand and silt. The principal transporting agents of the environment is wind. The superficial deposits overlie interbedded sandstone, limestone, conglomerates, calcites, gypsum, plagioclase and siltstones. The raw water originates from Sayh Al Raheel, Um Al Ash and from Aslab wells with a water table of 100-150 meters below the ground surface. The average brackish water conductivity ranges between 6.5 –15.0 mS/cm.

#### 3.2 PLANTS VISITED

The following (BWRO) plants were visited: Al Wagan, Al Qua'a and Umm Al Zumool, on February 2002. Photos taken during field visit are provided in (Appendix A). A Questioner Survey (Appendix B) has been conducted to gather basic data on the investigated plants and the gathered information is summarized in Table 3.1.

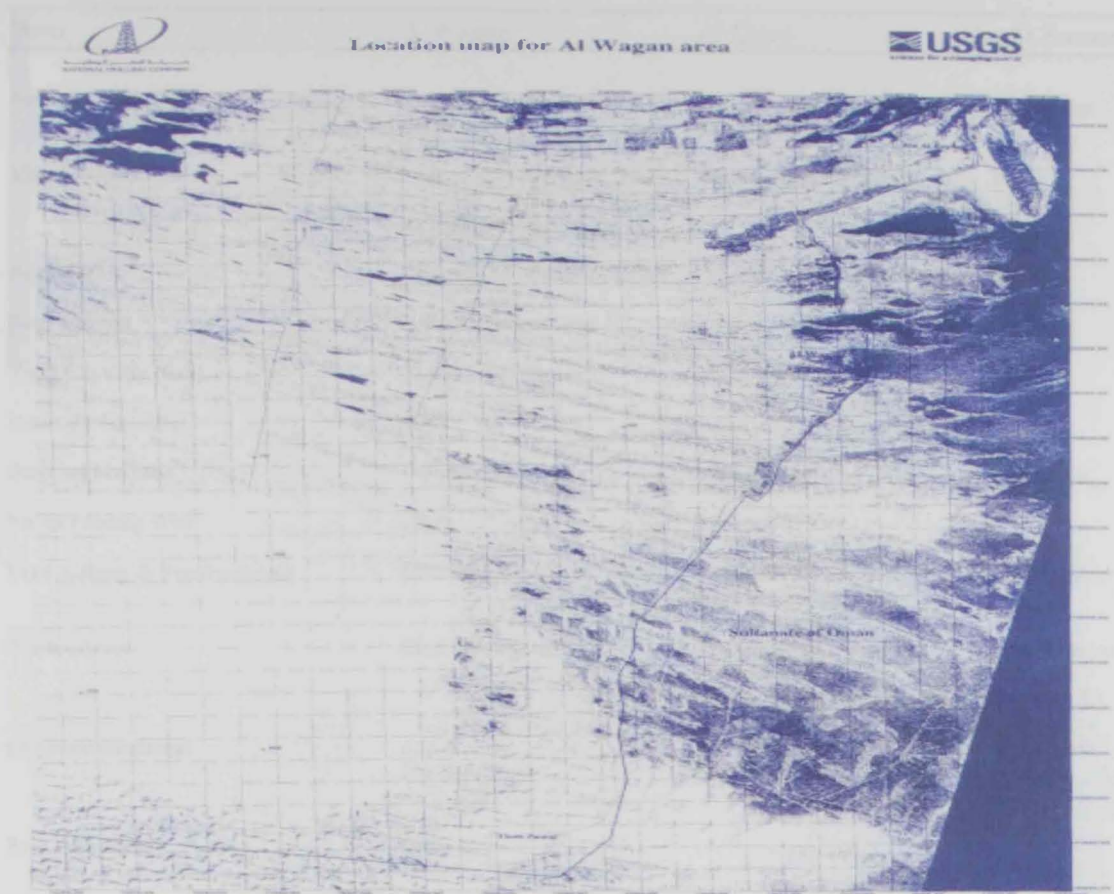


Fig 3.1a: Map of the Study Area

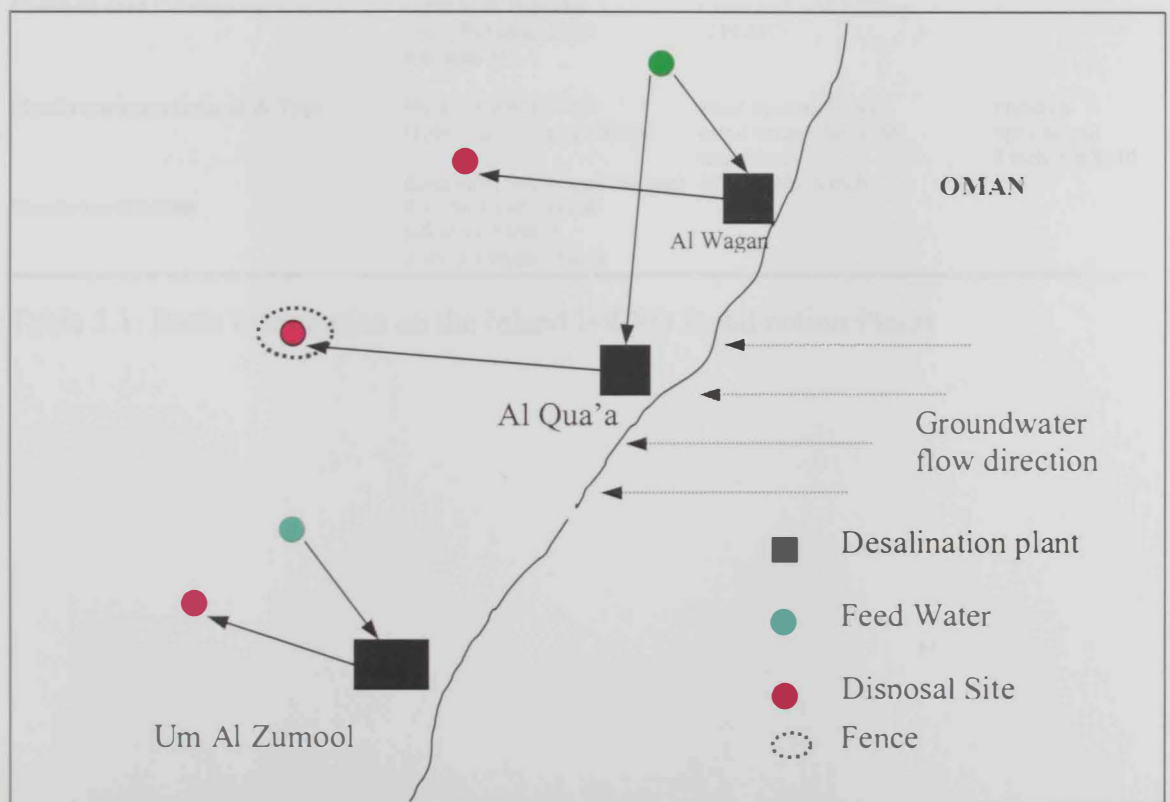


Figure 3.1b: Study Area

Item	AlWagan	Al Quaa	Um Al Zumool
No. of Plants	11 plants (4 mobile and 7 Stationary)	12 plants (6 mobile and 6 stationary)	2 Stationary
Year of Operation	3 plants start operation 1980, 1 in 1991, 1 plant in 1992, 4 plants in 1996 and 2 in 1997	3 plants operated in 1980, 3 in 1991, 3 in 1996, 2 in 1997	1992
Purposes	Domestic and livestock supply	Domestic and livestock supply	Domestic
Feed Method	Brackish Groundwater	Brackish Groundwater	Brackish
Total Capacity (G/d)	25,000 – 50,000	25,000 – 60,000	25,000
Recovery Rate (%)	70%	70%	60%
Disposal Methods	Unlined pit	Unlined pit	Unlined pit
No. of Feeding Well	13	15	8
Feed Salinity & Pre-treatment	6500 mS/cm	6000 mS/cm 9000 mS/cm	17000 mS/cm
Pre-treatment	Sand filtration	Sand filtration Carbon filtration Cartridges filtration	Sand filtration Carbon & Cartridge filt.
Chemical treatment	Anti-scalent, Sulphuric Acid	Anti-scalent, H <sub>2</sub> SO <sub>4</sub>	Anti-scalent Sulphuric Acid
Post Treatment	1u-5u filters	UV System	-
RO membrane cleaning frequency	every 2000 hrs 22 working hrs/d	every 2000 hrs 20 working hrs/d	every 2000 hrs 16 hrs/d
Chemical used for cleaning	Citric acid, Bioclean L607, RO clean L607 Bioclean 511	Citric acid, and Fouling (115,807)	-
Membrane manufactures & Type	Fluid System, Flimtech Hydro matrix. Spiral Wound	Fluid System, Dupont spiral wound, Seawater Membrane	Flimtech Spril wound 8 inch, SW8040
Membrane life time	&Seawater membranes are used 9 yr. for Fluid System 5-6 yr for Flimtech 3 yrs. for Hydro matrix	4(SW4040), 8 inch	

Table 3.1: Basic Information on the Inland BWRO Desalination Plants

### 3.2.1 Feed, Product and Reject Brine Water Production

The reject brine production and total desalinated and rejected water in 1999 and 2002 along with the monthly feed, desalinated, and reject water are shown in Table 3.2 and Figs.3.1, 3.2, 3.3, 3.4 and 3.5. The figures show an increase in feed, product, and reject water over the last four years due to increase in water demands for both domestic and livestock use. The ranges of brine production in 2002 from Al Wagan, Al Qua'a and Um Al Zumool as compared to the 1999 are illustrated in Table 3.2. The data show a dramatic increase in both product and reject water with a brine recovery rate of 30-40 %.

Plants (BWRO)	Year	
	1999	2002
Al Wagan	25,425,605	49,627,511
Al Qua'a	33,129,547	49,749,263
Um Al Zumool	9,675,080	10,584,469

Table 3.2 Reject Brine Water Production (MG/Y), year 1999 and 2002

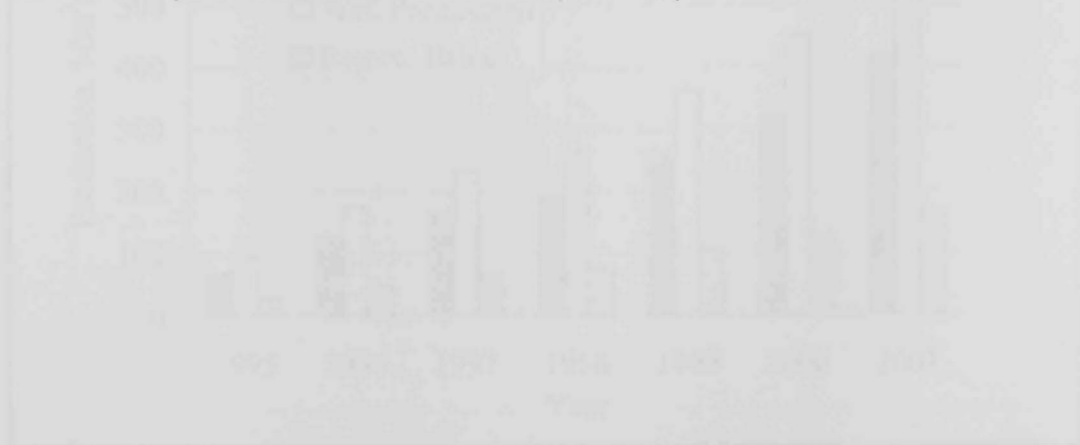


Fig. 3.1 Monthly Range of Brine Production in Al Wagan & Al Qua'a Plants



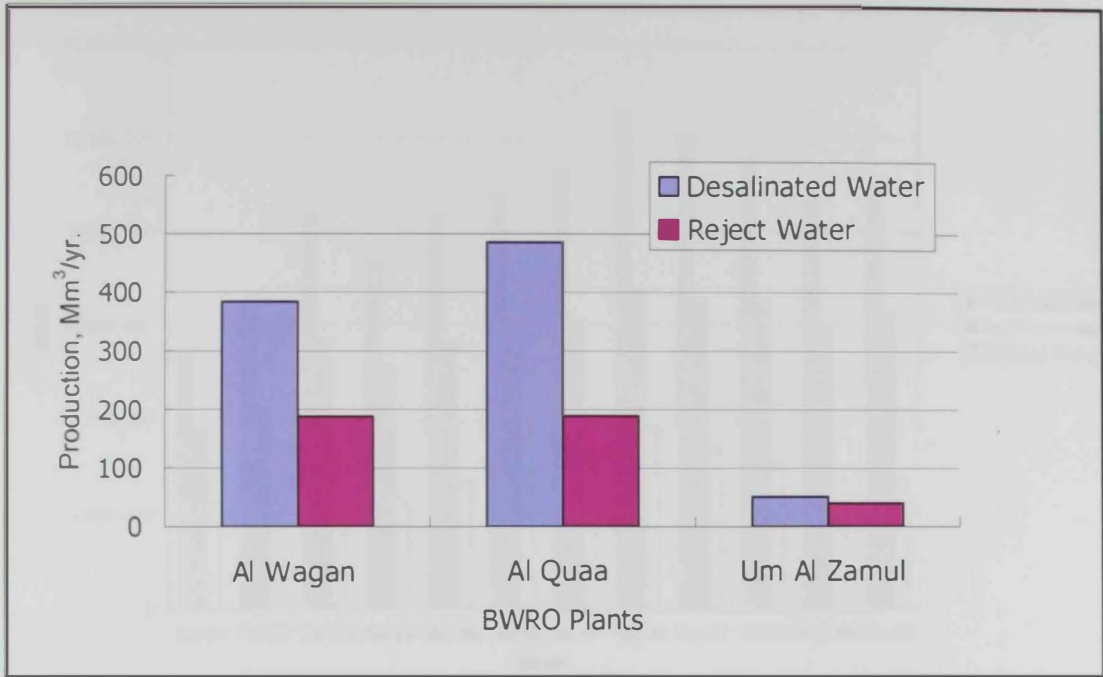


Fig. 3.1: Total Desalinated and Reject water Produced in year 2002 (Mm<sup>3</sup>)

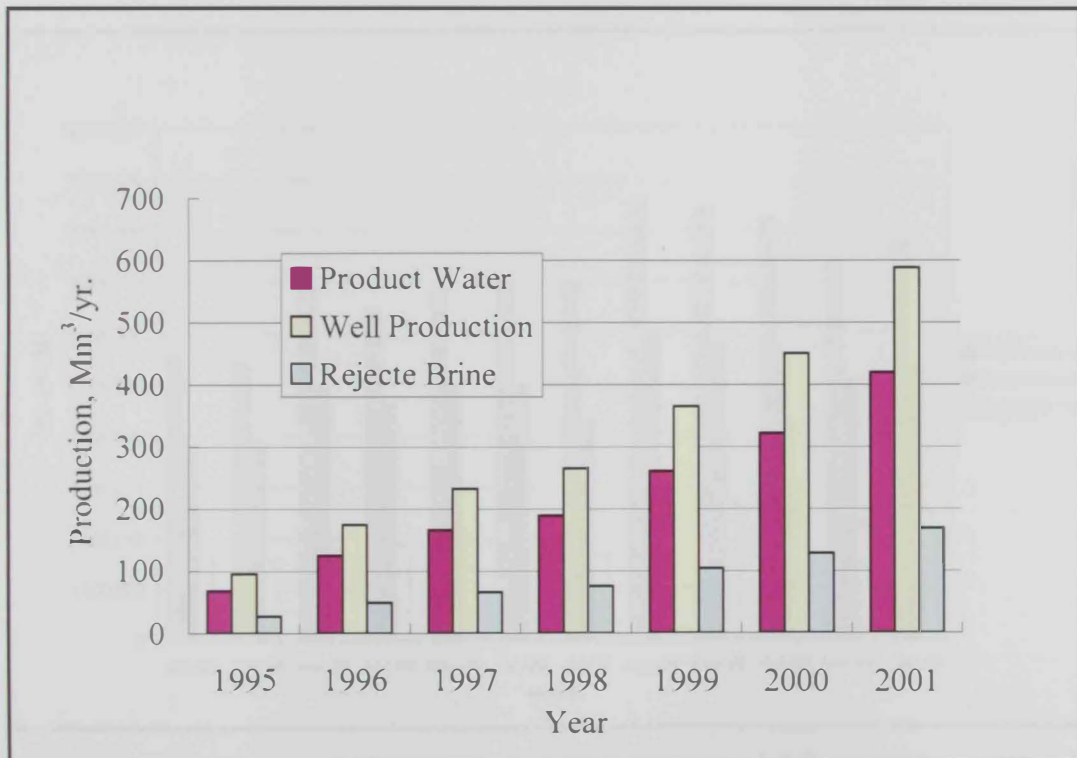


Fig. 3.2: Rate of Change of Water Production, Al Quaa's Desalination Plants

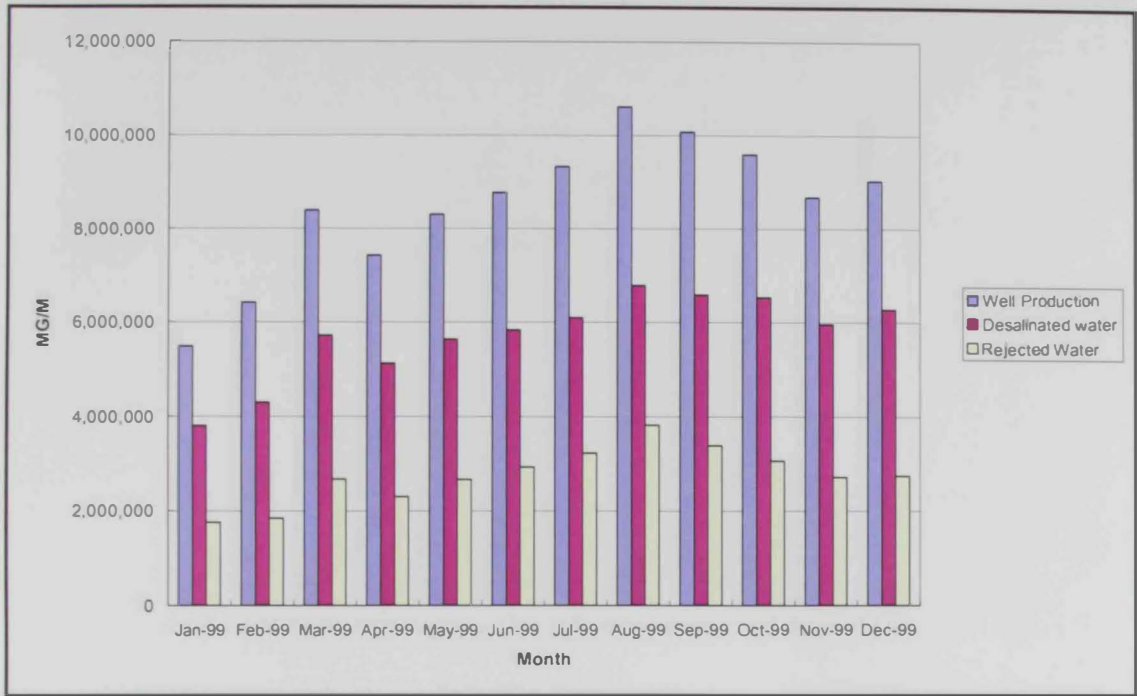


Fig. 3.3: Yearly Feed, Product, and Brine Production (Mm3/yr.), Al Qua'a Desalination plants

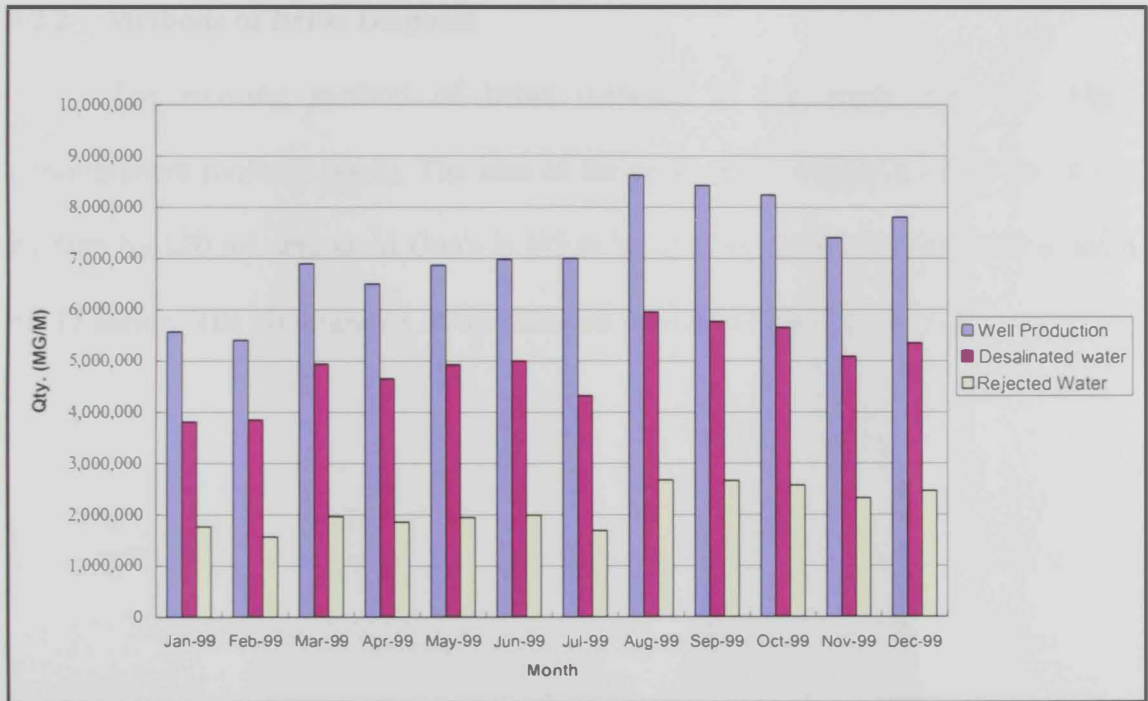


Fig. 3.4: Monthly Desalinated and Rejects Water Produced from Al Wagan Desalination Plants

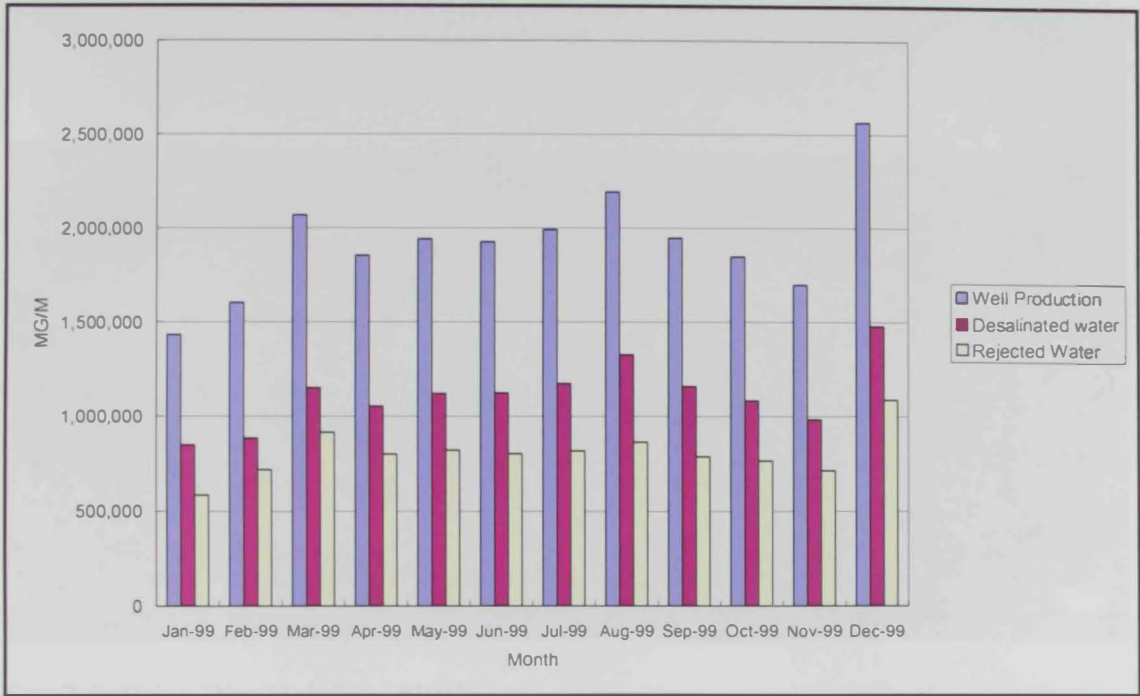


Fig. 3.5: Monthly Desalinated and Rejects Water Produced from Um Al Zumool Desalination Plants

**3.2.2 Methods of Brine Disposal**

The existing method of brine disposal in the study area is surface impoundment (unlined pond). The size of the pond at Al Wagan is (65 m by 100 m by 50m by 120 m), and at Al Qua'a is (45 m by 75m by 40 m by 55 m) with a depth of 17 meter. The photographs of the sites are shown in Figs. 3.6 and 3.7

Fig. 3.6: Brine Disposal Site, Al Qua'a

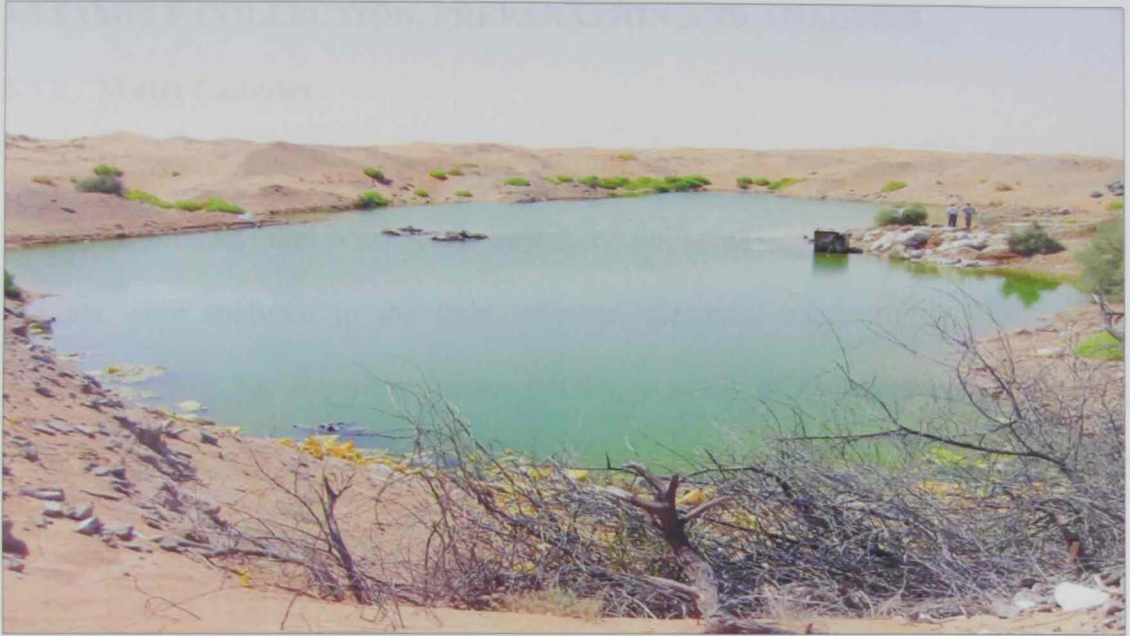


Fig. 3.6: Brine Disposal Site, Al Wagan



Fig. 3.7: Brine Disposal Site, Al Qua'a.

### **3.3 SAMPLE COLLECTION, PREPARATION AND ANALYSIS**

#### **3.3.1 Water Samples**

Representative discharge effluents from three inland desalination plants along with feed, products and pond water have been collected and analyzed. Temperature and pH were analyzed in the field whereas, electrical conductivity, TDS, major cations (Ca, Mg, Na, K), major anions (HCO<sub>3</sub>, SO<sub>4</sub>, Cl, NO<sub>3</sub>), major metals (Al, As, Cu, Fe, Zn, Cd, Cr, Pb, Se, Mn, Sr, V, B and Ba), and TPH were analyzed at the Central Laboratory Unit (CLU), UAE University, using ICP-OES-VISTA-MPX CCD, HACH DR4000U Spectrophotometer, and MAGNA-IR (560), E.S.P Spectrometer, respectively (Appendix C). The water samples analyzed for TPH were collected in 1000 ml; acid washed, and kept in dark brown glass bottles. The samples for trace elements and TPH were acidified at the time of collection with spectroscopy grade nitric acid until the pH was less than 2, brought to the laboratory in ice boxes, and stored at 4°C until analyzed.

#### **3.3.2 Soil Samples**

Soil samples were collected from Al Qua'a disposal site (Fig. 3.8) at each location (i.e., A1, A2, A3, B1, B2, and B3). Five (5) samples were collected from each point. Soil samples were air-dried and sieved using 2mm sieve and analyzed for the followings physical and chemical parameters.

##### **3.3.2.1 Physical Parameters**

A soil specific gravity and grain size distribution has been analysed using pycnometer and dry sieve analysis, respectively.

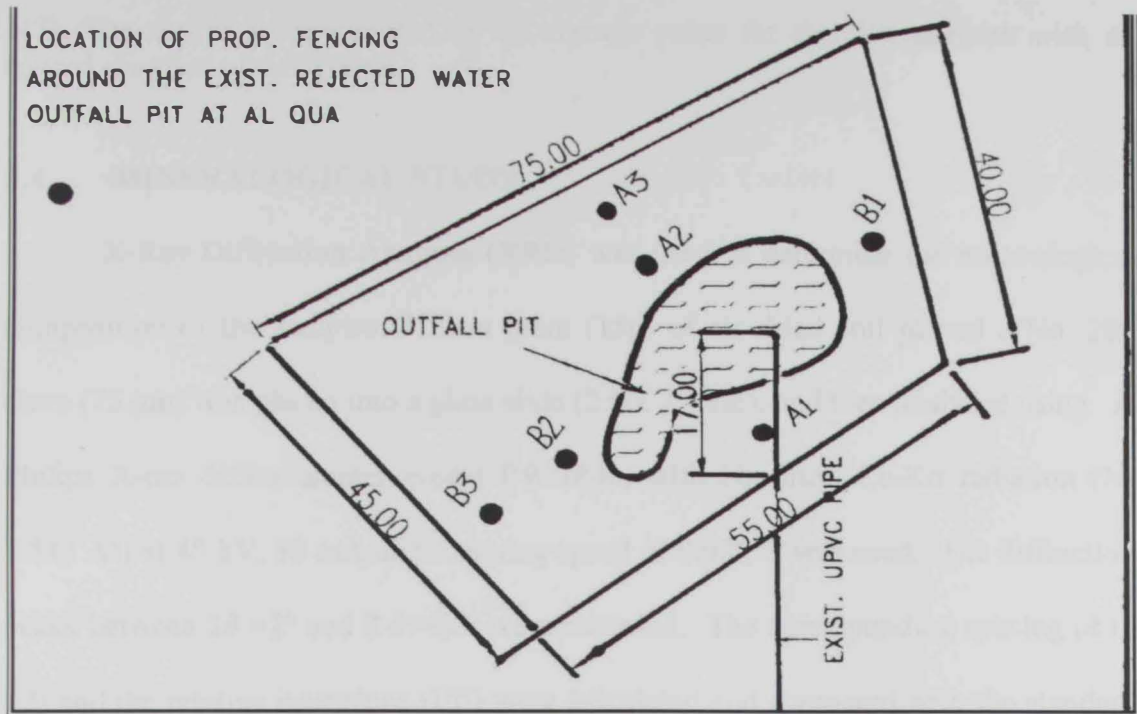


Fig. 3.8: Soil Sampling Location (Al Qua'a Disposal Site)

### 3.3.2.2 Chemical analysis:

Cation exchange capacity (CEC) was determined by using Ammonium acetate method. Cations were then analyzed using Atomic Absorption Spectrophotometer.

The electrical conductivity (EC), TDS, and pH in the 1:2.5 ratio were measured using a Jenway 4020 EC/TDS and Jenway 3020 -pH meter respectively. Readings were taken in the suspension before extraction. Major cations, anions and heavy metals in a suspension of 1:2.5 soils to water ratio were analyzed. Samples were placed in a receptacle shaker for over night and extracted using filter paper. Chloride, Carbonate, and Bicarbonates were determined by titration method. Nitrate was determined by using HACH DR4000 U Spectrophotometer.

For the determination of heavy metals, 1.0g of < 2mm air dry soil was digested in a Aqua Regia Solution 1:3 Ratio (HNO<sub>3</sub> : HCL). Heavy metals and some anions have been analyzed using ICP-OES-VISTA-MPX CCD Simultaneous.

N/B. The results were reported as an average value for the five samples with its related standard of deviations.

### **3.4 MINERALOGICAL STUDY**

X-Ray Diffraction Analysis (XRD) was used to determine the mineralogical composition of the samples. Fifteen gram (15g) of air dried soil passed a No. 200 sieve (75  $\mu\text{m}$ ) was placed into a glass slide (2.6 x 2.3 cm), and then analyzed using A Philips X-ray diffractometer model PW/1840, with Ni filter, Cu-K $\alpha$  radiation ( $\lambda=1.542 \text{ \AA}$ ) at 40 kV, 30 mA and scanning speed of 0.02 $^\circ$ /S was used. The diffraction peaks between  $2\theta = 2^\circ$  and  $2\theta = 60^\circ$  were recorded. The corresponding spacing (d in  $\text{\AA}$ ) and the relative intensities ( $I/I^\circ$ ) were calculated and compared with the standard data.

### **3.5 SAMPLING AND ANALYSIS OF IN-PLACE AND SAND DUNE SAMPLES**

Two soil samples were collected, the first one was taken about 100 m from the Al Qua'a disposal site, and the other was taken about 1.5 km away from the disposal site. It is important to mention that sample were collected from two sites. At the first site, samples were taken from sand dune deposition where the disposal site is located. At the other site, samples were taken from the in-place (original) soil of the area (virgin soil).

Soils were characterized for hydraulic conductivity, using Constant Head Hydraulic Conductivity Test (ASTM) standard method. This method is generally used for sands that contain little silt or fines. The hydraulic conductivity cell was used and the soil specimen was compacted inside the cell. Water flows from a reservoir through the compacted specimens that remains under a constant head. Soil

samples were also characterized for Specific gravity, particle size distribution using standard ASTM D 2487-92, CEC, pH, EC, TDS, cation, anions using 1:2.5 soil to water ratio and heavy metals by using wet digestion method. Cations, anions and heavy trace metals were analyzed using ICP.

Table 3.1 Concentration of the target elements in the Stock Solution

### 3.6 BATCH ISOTHERM EXPERIMENT

The main objectives of this experiment were to study soil attenuation of reject brine at equilibrium, estimate the number of pore volumes required to achieve breakthrough of selected reject brine constituents ( $\text{SO}_4$ , K, and Sr) into the effluent liquid, and finally, to calculate the retardation parameter required in the pollutant transport equations.

*Following the procedures described by Mohamed and Anita, 1998, and Yong R.N. et al., 1992*

Batch adsorption tests were conducted using each soil sand dune and in-place soil to evaluate the sorption isotherm for the target elements/substances. A fixed amount (10 g) of air-dried soil has been placed in 100 ml glass bottles. Stock solutions containing KBr,  $\text{N}_2\text{O}_6\text{Sr}$  and  $\text{Na}_2\text{SO}_4$  with concentrations shown in Table 3.3 were prepared. Hundred milliliters of various initial concentrations of the target elements were added to the glass bottles by making appropriate dilutions from the stock solution.



Chemical	M.Wt.	M.Wt. of target element	Amount g / L.	Concentration of target substance (mg/L)
KBr	119	39	0.149	48.8
N <sub>2</sub> O <sub>6</sub> Sr	211.6	87.6	0.241	100
Na <sub>2</sub> SO <sub>4</sub>	142	96	0.148	100

Table 3.3: Concentration of the Target Elements in the Stock Solution.

Initial concentrations of Sr and SO<sub>4</sub> in the glass bottles were varied over the range of 5-100 ppm while that for K was varied over the range of 0 - 48.8 ppm. A blank bottle contains just the target elements (with no soil) was used to verify no interaction of constituents with the bottle material neither precipitation during the phase of the experiment. The bottles were capped tightly and tumbled end-over-end for 4 days. Phase separation was accomplished by centrifugation. Aqueous samples from the supernatant were collected and analyzed for the target elements. The amount adsorbed by the soil was calculated by difference. Fig. 3.9 illustrates the batch equilibrium procedure. The equation is used to calculate  $q$  (Yong *et al.*, 1992):

$$q = (C_0 - C) * V/M \quad [3.1]$$

Where  $V$  is the volume of liquid in a bottle (100 ml), and  $M$  is the mass of soil in the bottle (10 g). The numerator in the above equation represents the mass of constituent adsorbed onto the solid phase, and it is divided by the mass of the soil to obtain a measure of the relative mass of the constituent adsorbed on the solid phase.

The values of  $q$  are plotted as a function of the equilibrium concentration. For constituents at low or moderate concentrations, the following relationship between  $q$  and  $c$  can expressed as:

$$q = k_d c^b \quad [3.2]$$

Where  $k_d$  and  $b$  are coefficients that depend on the constituents, nature of the porous material and the interaction mechanism between it and the constituents. The above equation is known as the *Freundlich* isotherm. If  $b = 1$ , then  $q$  versus  $c$  data will be straight line (linear). With  $b = 1$  reduced to:

$$dq / dc = k_d \quad [3.3]$$

$k_d$  known as the distribution coefficient, and it is used for pollutant partitioning between liquid and solid. Retardation factor ( $R_f$ ) for liner sorption can be calculated using the following equation:

$$R = 1 + (\rho_d * k_d) / n \quad [3.4]$$

Where  $\rho_d$  is the dry density,  $k_d$  is the distribution coefficient, and  $n$  is the porosity.

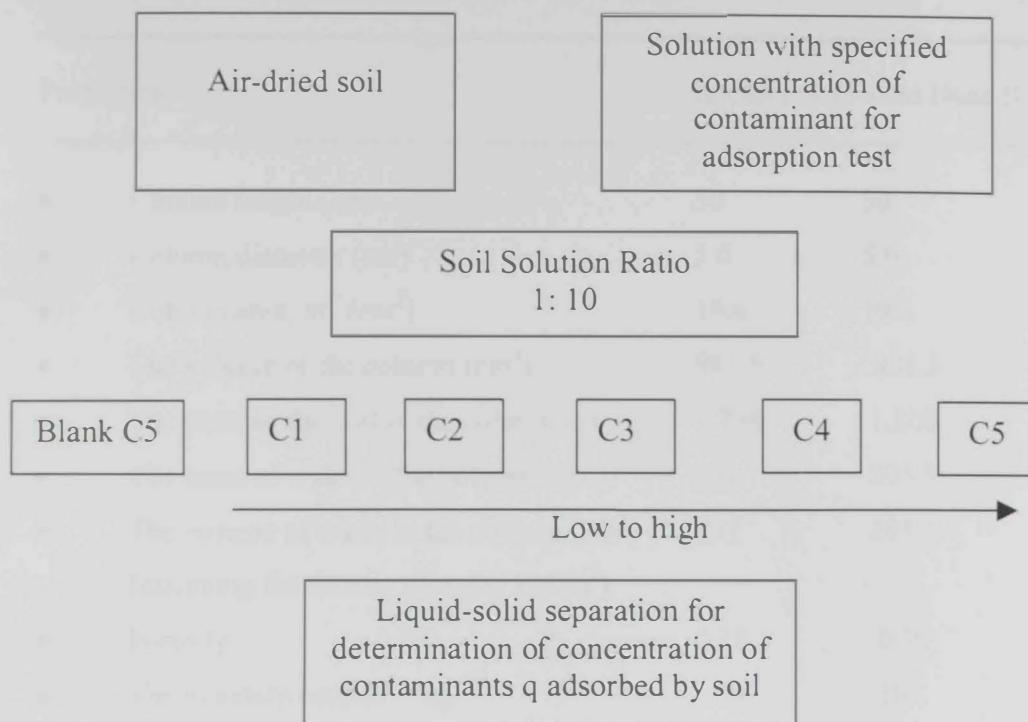


Fig. 3.9: Schematic Diagram Showing Batch Equilibrium Procedure

### 3.7 MISCIBLE DISPLACEMENT EXPERIMENT

The main objectives of this experiment are (Yong *et al.*, 1992, Mohamed and Antia, 1998) to: (1) study pollutant migration and attenuation by soils, and (2) estimate the transport parameters and the mechanisms which control the leaching of pollutants through soils.

Determination of adsorption characteristics of soils requires simulation of passage of the leachate. To that end, two (2) leaching experiments (Fig. 3.10) have been set, with the characteristics detailed in Table 3.4.

Properties	In-place Soil	Sand Dune Soil
• Column length (cm)	50	50
• Column diameter (cm)	5.0	5.0
• Column area, $\pi r^2$ (cm <sup>2</sup> )	19.6	19.6
• The volume of the column (cm <sup>3</sup> )	981.5	981.5
• The mass of the soil in the column (g)	1,738	1,808
• The mass of water in the column (g)	391	295.5
• The volume of water in the column (cm <sup>3</sup> ) (assuming the density of water 1g/cm <sup>3</sup> )	391	295.5
• Porosity	0.38	0.30
• The moisture content (%)	38	30
• Bulk density (g/cm <sup>3</sup> )	1.689	1.75
• Hydraulic conductivity, k (cm/sec)	$6.50 \times 10^{-5}$	$9.0 \times 10^{-5}$
• Specific gravity	2.68	2.59

Table 3.4: Packed columns properties

### ***Test Procedures***

The soil was compacted into two soil columns (Fig. 3.10) and then the leaching columns were assembled. Firstly, the leaching cell has been burg with O<sub>2</sub> to remove excess air. Secondly, after steady state condition has been established using deionized water, the fluid in the effluent reservoir is changed to reject brine solution containing 81 mg/l Sr concentration. The reason for choosing Sr as a target metals was based on previous results which indicated that strontium (Sr) concentration is the highest amongst other heavy metals as well as its concentration in excess of the allowable limits in drinking water standards by various regulatory agencies.

The effluent concentration,  $C_e$ , of the studied chemical species is collected over time and measured using ICP. The results were plotted in the form of solute breakthrough curves, or relative concentration,  $C_e/C_o$ , versus time or pore volumes of flow (PV).



Fig. 3.10: Leaching Column System with a Fraction Collector.

### 3.8 REJECT BRINE TRANSPORT MODELING

The movement of contaminants through soil profile is an active area of research. Models have been developed to simulate leachate migration from disposal sites as other problems such as salt water intrusion. For the purpose of this work, the effects of equilibrium retardation are illustrated through use of **CXTFIT**. This model was developed by the U.S. Salinity Laboratory, USDA, ARS, USA for estimating solute transport parameters from observed concentrations (the inverse problem) or for predicting solute concentrations (the direct problem) using the convection-dispersion equation as the transport model.

In this project, adsorption was simulated. The one-dimensional mass transport through a saturated porous medium that is in column 0.5 m long and internal diameter of 0.05 m was considered. The hydraulic conductivity ( $k$ ) and the porosity ( $\theta$ ) for both columns are  $6.50 \times 10^{-5}$  (cm/sec),  $9.0 \times 10^{-5}$  (cm/sec) and 0.38 and 0.30, respectively. The reject brine injected contains an initial solute concentration of ( $\text{Sr}^{2+}$ ) of 52.2 and 81 mg/L for the sand dune and in-place soil testing, respectively. The solution is injected into the bottom of the soil column and collected from the top by a fraction collector (Figure 3.10), in accordance with the specified time frame (Appendix D). The model yields the solute concentration in the effluent as a function of the number of pore volumes and distance.

## CHAPTER 4

### EVALUATION OF INLAND BWRO

#### DESALINATION PLANTS

##### 4.1 VARIATIONS OF pH, EC, AND MAJOR CATIONS

Analyses of the feed, product reject brine, and pond water are summarized in Table 4.1. The table shows the pH and the electrical conductivity (EC) at Al-Wagan, Al Qua'a, and Um Al Zumool desalination plants. The pH values ranged from 5.64 to 7.02, 6.76 to 7.46, 7.03 to 8.41 for Al-Wagan, Al-Qua'a and Um Al-Zomool, respectively. Whilst, EC ranged from 0.83 to 30.30, 0.22 to 16.90, and 0.34 to 14.00 mS/cm, for the same areas respectively. The concentration  $\text{Na}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  are higher than the allowable limits set by the GCC Countries in all water samples.

##### 4.2 VARIATIONS OF MAJOR ANIONS

The major anions of feed, product, reject and pond water are shown in Table 4.2. The results show that these samples were not contaminated with Nitrate ( $\text{NO}_3^-$ ) and Phosphorus (P), whereas the concentrations of Sulfate ( $\text{SO}_4^-$ ) and Chloride ( $\text{Cl}^-$ ) were exceeding the allowable limits. The higher  $\text{SO}_4^-$  concentration in feed water is attributed to the geological nature of the area, which is classified as Gypsy-ferrous soil (UAEU, 1993); this has been confirmed by the mineralogical analysis.

Plant & Water Sample Name		Cations (mg/l)					
		pH	EC (mS/cm)	Na	Ca	Mg	K
<b>Al Wagan</b>							
	Feed	7.02	14.7	741.59	146.31	112	8.46
	Product	7.02	0.82	55.25	140.00	0.94	1.30
	Reject	5.64	30.3	2248	367.96	282	68.49
	Pond	6.76	26.6	1985	393.25	300	56.60
<b>Al Qua'a</b>							
	Feed	6.67	4.61	451.13	162.36	104	27.24
	Product	7.46	0.22	39.20	1.80	1.16	0.90
	Reject	6.67	16.9	2880	518.86	337	94.64
	Pond	7.14	14.6	1994	366.86	252	61.67
<b>Um Al - Zumool</b>							
	Feed	7.57	5.05	2482	456.40	194	110.1
	Product	7.40	0.34	151.0	18.23	7.75	4.64
	Reject	7.03	12.9	6206	846.78	361	264.0
	Pond	8.41	14.0	5517	782.75	336	245.0

Table 4.1: pH, EC and Major Cations of Water Samples from the Desalination Plants

Plant & Sample Name		Anions (mg/l)				
		Cl <sup>-</sup>	P	NO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	
<b>Al Wagan</b>						
	Feed	3,827		ND	8.99	539.22
	Product	398.0		ND	1.69	5.36
	Reject	8,946		0.40	7.11	1,540
	Pond	9,943		0.30	10.60	1,436
<b>Al Qua'a</b>						
	Feed	6,213		0.14	1.57	394.38
	Product	1,143		ND	0.85	5.62
	Reject	7,212		0.42	5.30	1,979
	Pond	10,437		0.40	5.61	1,456
<b>Um Al-Zumool</b>						
	Feed	9,443		ND	12.70	1,746
	Product	1,243		0.01	1.58	55.56
	Reject	23,856		0.28	17.2	4,179
	Pond	19,880		0.20	14.1	3,622

Table 4.2: Major Anions of Water Samples from the Desalination Plants



### 4.3 VARIATION OF HEAVY METALS

All water samples collected from the three aforementioned desalination plants were analyzed for the presence of 13 heavy metals. These heavy metals include Al, Ba, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sr, V, Zn and B as shown in Table 4.3. The concentrations of Vanadium (V), Chromium (Cr), and Strontium (Sr), have been compared with the GCC drinking water standards of the above three metals (Appendix E), and regulations for effluents discharges (Appendix F). The concentrations were found to be higher in the feed, reject and pond waters. Heavy metals such as Al, Ba, Cd, Cu, Fe, Mn, and Ni were found to be within the allowable limits. The concentration of most of the heavy metals which were analyzed in feed water was below the allowable limits set by the GCC standards except for Sr and B which were found to be above the allowable limits for drinking water. Other metals such Cd, Pb, Fe, Cu were not detected in some water samples as shown in Table 4.3.

Plant & Water Sample Name	Heavy metals Concentration (mg/l)												
	Al	Ba	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Sr	V	Zn	B
<b>AlWagan</b>													
Feed	0.10	0.03	0.01	<b>0.23</b>	ND	0.01	0.01	0.01	ND	<b>5.60</b>	<b>0.04</b>	0.01	<b>1.10</b>
Product	ND	0.01	0.01	0.01	0.01	0.01	ND	ND	ND	<b>0.05</b>	ND	0.01	<b>0.80</b>
Reject	0.02	0.10	ND	<b>0.70</b>	ND	ND	0.01	0.01	ND	<b>21.63</b>	0.11	6.02	<b>1.40</b>
Pond	0.02	0.08	ND	<b>0.63</b>	ND	0.01	0.01	0.01	ND	<b>16.70</b>	0.12	0.01	<b>1.20</b>
<b>AlQua'a</b>													
Feed	0.01	0.03	0.01	<b>0.18</b>	ND	ND	0.01	0.01	ND	<b>5.40</b>	0.03	0.01	<b>0.80</b>
Product	ND	0.01	0.01	0.01	ND	0.01	ND	0.01	ND	<b>0.07</b>	0.01	0.01	<b>0.60</b>
Reject	0.03	0.10	ND	<b>0.63</b>	ND	ND	0.01	0.01	ND	<b>24.22</b>	0.11	0.01	<b>1.92</b>
Pond	0.02	0.07	ND	<b>0.62</b>	ND	ND	0.01	0.01	ND	<b>17.24</b>	0.10	0.01	<b>1.62</b>
<b>Um Al Zumool</b>													
Feed	0.02	0.02	ND	<b>0.05</b>	ND	0.01	0.01	0.03	ND	<b>9.96</b>	0.02	0.02	<b>2.86</b>
Product	ND	0.10	0.01	0.01	ND	0.01	0.01	0.01	ND	<b>0.51</b>	0.01	0.01	<b>1.00</b>
Reject	ND	0.32	ND	ND	<b>0.09</b>	0.01	0.01	0.01	0.01	<b>30.10</b>	<b>0.04</b>	0.10	<b>5.40</b>
Pond	0.03	0.03	ND	<b>0.09</b>	ND	0.01	0.01	0.01	0.01	<b>30.16</b>	<b>0.04</b>	0.10	<b>4.92</b>

Table 4.3: Heavy metals in water samples

#### 4.4 VARIATION OF TOTAL PETROLUM HYDROCARBON (TPH)

It can be seen from Fig. 4.1 that TPH is present in feed, product, reject, and pond water. In some plants the concentration exceeds the standard limits set by the GCC Countries, which is 0.01 mg/l for drinking water. The results should be considered as indicative of TPH presence in water samples. A fingerprint study is required to determine the source of hydrocarbons.

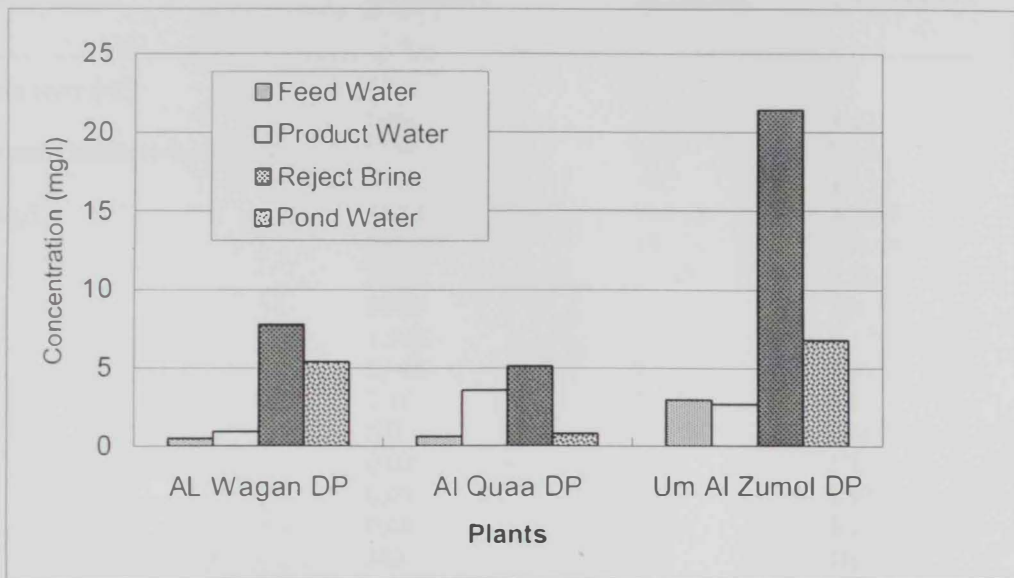


Fig. 4.1: The Level of TPH in Water Samples

#### 4.5 PERFORMANCE OF REJECT BRINE PITS

Table 4.4 indicates that the reject brine from Al Qua'a and Um Al Zumool has higher concentrations compared to reject brine from the Al Wagan plant. Table 4.5 indicates that the desalination plants have led to the enrichment of reject brine with major ions as indicated from the calculated ratios (reject water : feed water). The concentration factor (CF) calculated as the ratio between the concentrations of species in the pond water to that in the reject brine is shown in Table (4.6). This may indicate that there is a leakage problem. Further investigations are needed.

Usually ponds have much higher concentrations than wastewater depending on age of pond, size, and possible dilution. However, these assumptions are made based on one sampling only. For precise conclusions a series of water samples with constant or/ different time intervals should be conducted, and results can be reported based on the average sample number and standard of deviation.

PARAMETER	ALWAGAN	ALQUAA	UMZOMOL
Temperature (°C)	35	35	35
pH	7.03	6.67	5.62
Electrical Conductivity (mS/cm)	12.9	16.9	30.3
TDS	7.77	10.2	18.3
Ca, mg/l	367.96	518.86	846.78
Mg,	282.02	337.26	361.68
Na,	2,248	2,880	6,206
K,	68.44	94.64	264.05
SO <sub>4</sub>	1,540	1,979	4,179
Cl,	8,946	7,212	2,385
NO <sup>3</sup>	7.11	5.30	17.1
F	ND	ND	ND
Al	0.02	0.03	ND
Mn	0.01	0.01	0.01
P	0.40	0.42	0.28
Cu	ND	ND	ND
Zn	0.02	0.01	0.01
Ni	0.01	0.01	0.01
Cr	0.70	0.63	0.09
Cd	ND	ND	ND
Ba	0.10	0.10	0.32
B	1.40	1.92	3.40
V	0.11	0.11	0.04
Se	ND	ND	ND
Pb	ND	ND	0.01
Sr	21.63	30.10	30.10

Table 4.4: Characteristics of Reject Brine from Desalination plants

Location	Constituents (mg/l)				
	Na	Ca	Mg	K	EC
<b>Al Wagan</b>					
Feed water	741.59	146.31	112.41	28.46	5.05
Reject water	2,248	367.96	282.02	66.49	12.90
Ratio	<b>3.03</b>	<b>2.51</b>	<b>2.50</b>	<b>2.34</b>	<b>2.55</b>
<b>AlQua'a</b>					
Feed water	451.13	162.36	103.64	27.24	4.61
Reject water	2,880	518.86	337.26	94.64	16.90
Ratio	<b>6.83</b>	<b>3.19</b>	<b>3.25</b>	<b>3.47</b>	<b>3.66</b>
<b>Um Al Zumool</b>					
Feed water	2,481	456.40	194.50	110.29	14.70
Reject water	6,206	846.78	361.68	264.05	30.30
Ratio	<b>2.50</b>	<b>1.85</b>	<b>1.86</b>	<b>2.40</b>	<b>2.06</b>

Table 4.5: Ratio of Major Ions of Feed water and Reject Brine of the plants

Location	Constituents (mg/l)				
	Na	Ca	Mg	K	EC
<b>Al Wagan</b>					
Reject Brine	2,248	367.96	282.02	68.49	12.90
Pond Water	1,985	393.25	300.95	56.60	14.00
Conc. factor (CF)*	<b>0.88</b>	<b>1.07</b>	<b>1.07</b>	<b>0.82</b>	<b>1.85</b>
<b>Al Qua'a</b>					
Reject Brine	2,880	518.86	337.26	94.64	16.90
Pond Water	1,994	366.86	252.75	61.60	14.60
Conc. Factor (CF)*	<b>0.70</b>	<b>0.70</b>	<b>0.75</b>	<b>0.65</b>	<b>0.86</b>
<b>Um Al Zumool</b>					
Reject Brine	6,206	846.78	361.68	264.05	30.30
Pond Water	5,516	782.75	336.42	245.42	26.60
Conc. Factor (CF)*	<b>0.88</b>	<b>0.92</b>	<b>0.93</b>	<b>0.93</b>	<b>0.87</b>

Table 4.6: Concentration Factor in Disposal Ponds

\* CF = Pond Water/Reject water

# CHAPTER 5

## EVALUATION OF SUBSURFACE POLLUTANT DISTRIBUTION AT AL-QUA'A DISPOSAL SITE

### 5.1 SOIL CHARACTERIZATION

#### 5.1.1 Grain Size and Silt Analysis

The size of the mineral particles profoundly affects the physical properties of the soil, leaching, and the ability to hold water and other constituents. Dry Sieve analysis has been performed to determine soil texture. The textures of soil samples are fine to very fine sand. The grain size distributions for both soils are illustrated in Figures 5.1.

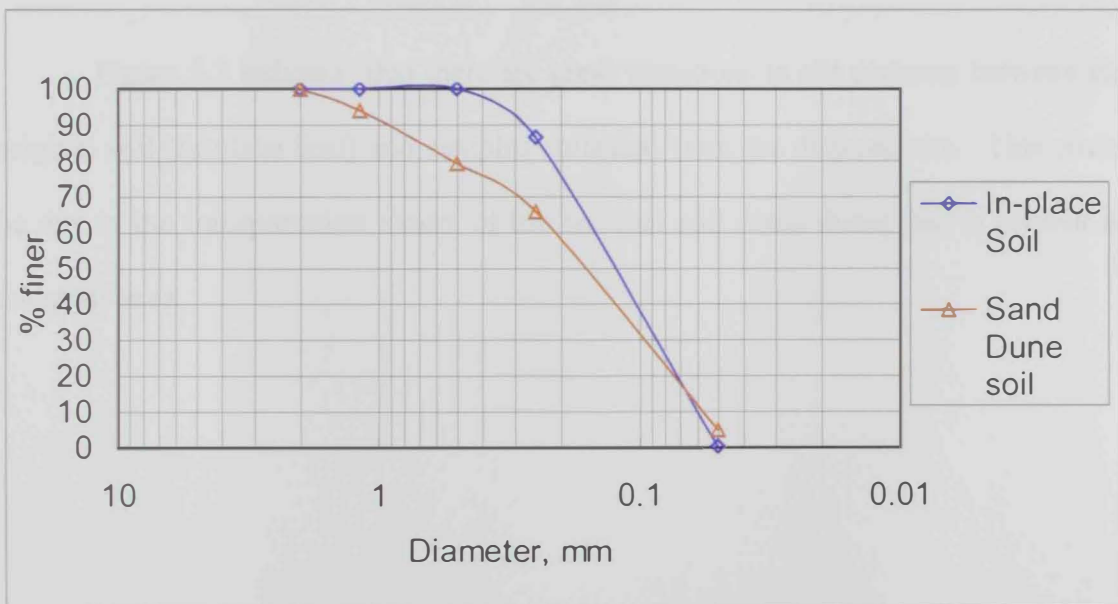


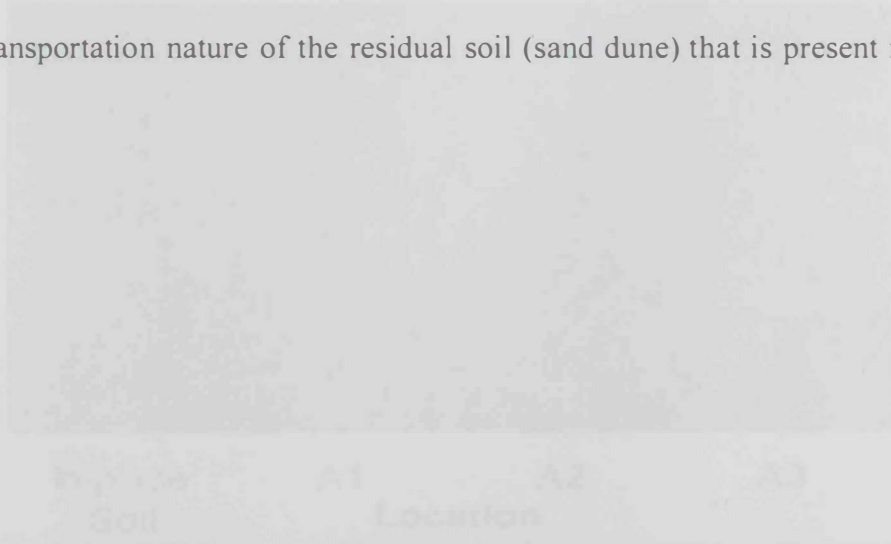
Fig. 5.1: Grain Size Distribution of the In-place and Sand Dune soil, Al Qua'a Disposal Site

Figure 5.1 shows very clearly that the soil contained negligible fines ( soil particles that will pass a 0.25 – 0.05 mm sieve and retained on a < 0.05 mm pan). A Unified Soil Classification System has been used to confirm the soil texture by calculating the  $C_u$  and  $C_c$ .  $C_u$  is the coefficient of uniformity, and  $C_c$  is the coefficient of curvature. The  $C_u$  and  $C_c$  and approximate Hydraulic Conductivity ( $K$ ) values for In-place and sand dune soil are given in Table 5.1

Soil ID.	$C_u$	$C_c$	$K$
In-Place Soil	0.363	0.817	3.6 E-07
Snd Dune Soil	2.5	0.9	3.36 E-07

Table 5.1: Calculated Coefficient of Uniformity ( $C_u$ ), Coefficient of Curvature ( $C_c$ ) and Approximate Hydraulic Conductivity ( $k$ ).

Figure 5.2 indicates that there are great variations in silt contents between the original soil (In-place Soil) and samples collected from the disposal site. This could be due to the transportation nature of the residual soil (sand dune) that is present in the study area.



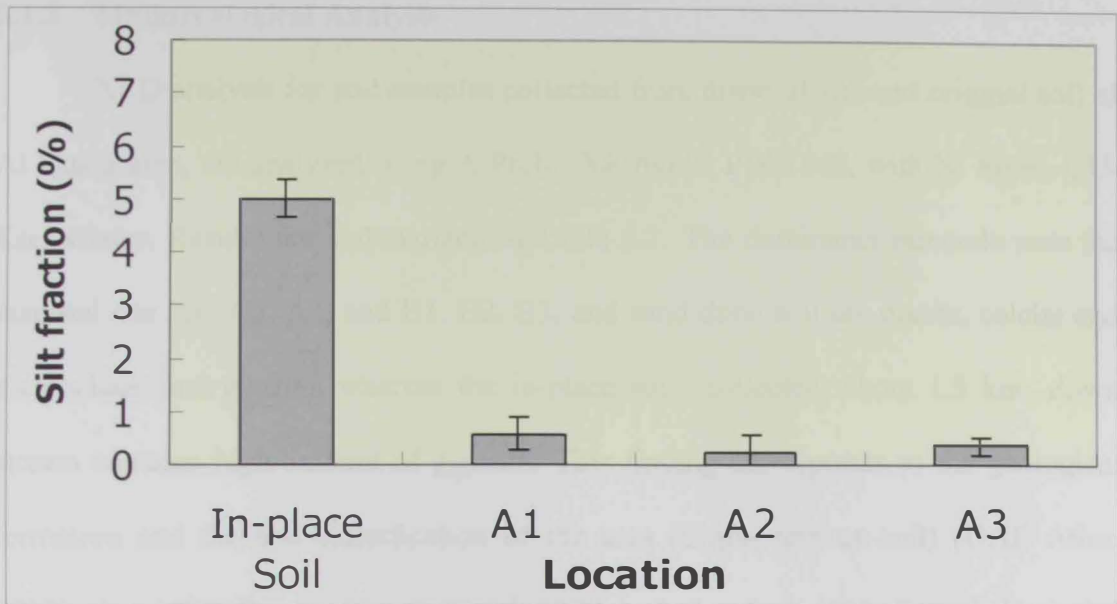


Fig. 5.2: Variation in Silt Content among Sampling Locations

### 5.1.2 Cation Exchange Capacity (CEC)

Figure 5.3 indicates clearly the variation in CEC contents between the original (in-place) soil and the soil collected from Al Qua'a disposal site (A1, A2, and A3). The variation in CEC content is attributed to high fine silt content in the original soil.

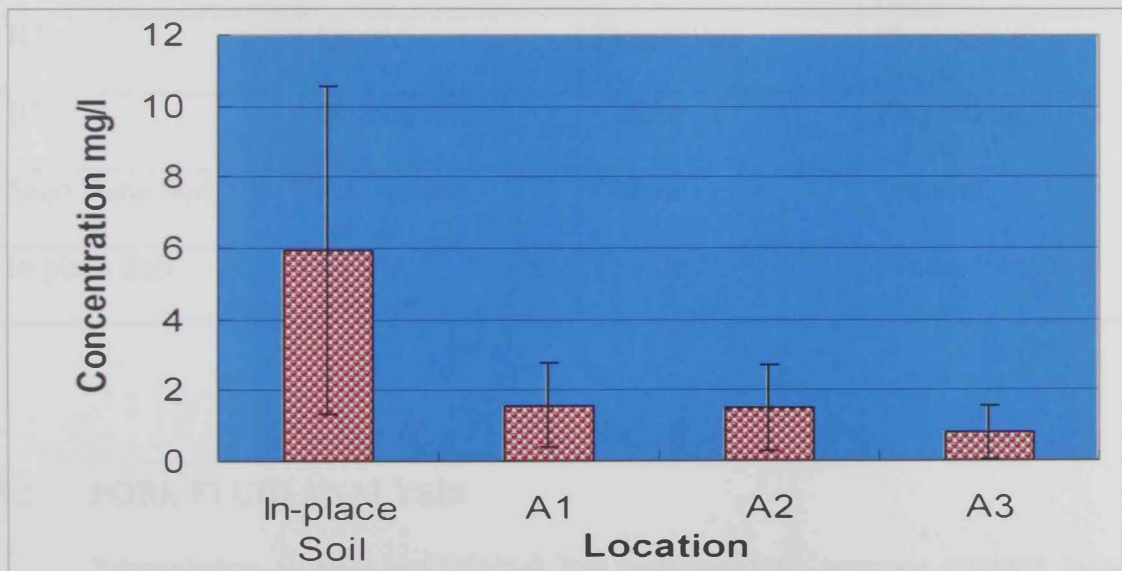


Fig. 5.3: Variation in Soil CEC (cmol/kg dry soil))

### 5.1.3 Mineralogical Analysis

XRD analysis for soil samples collected from disposal site and original soil of Al Qua'a area, are analyzed using A Philip XR model PW/1840, with Ni Filter,  $\text{Cu-K}\alpha$  radiates. Results are summarized in Table 5.1. The dominants minerals near the disposal site A1, A2, A3, and B1, B2, B3, and sand dune soil are quartz, calcite and plagioclase, and gypsum whereas the in-place soil collected, about 1.5 km down stream contains high amount of gypsum. This finding corresponds to the geological formation and the soil classification of the area (Gyps-ferrous soil) (UAE Atlas, 2000). Appendix D summarizes the physical and chemical properties of the tested soil.

Table 5.1: Soil Minerals

Sample I.D	Major minerals	Subordinate minerals	Minor minerals
A1	Quartz, Plagioclase	Plagioclase, calcite	Calcite
A2	Quartz	Plagioclase, calcite	Calcite
A3	Quartz, Calcite	Plagioclase	Gypsum
B1	Plagioclase	Plagioclase, calcite	Plagioclase, calcite
B2	Quartz,	Plagioclase	Plagioclase, calcite
B3	Quartz,	Calcite	Plagioclase, calcite
Sand Dune Soil	Plagioclase, calcite	Calcite	Gypsum
In-place Soil	Quartz, Calcite, Gypsum	Calcite	Plagioclase, calcite

## 5.2 PORE FLUID ANALYSIS

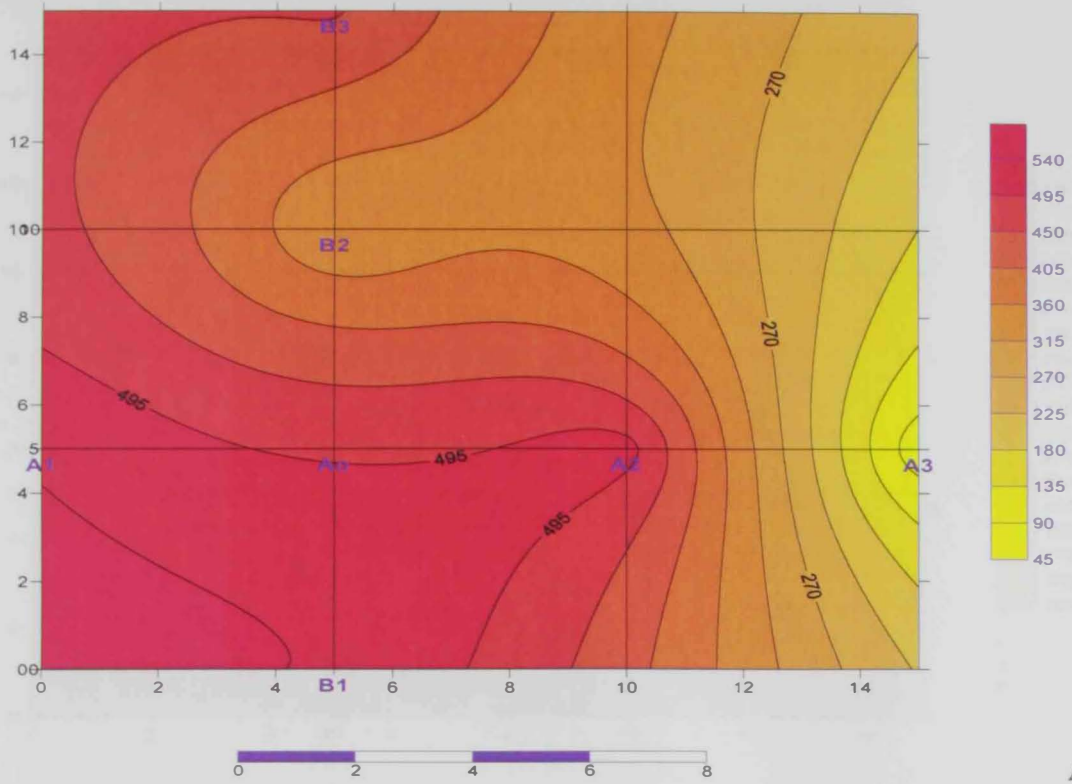
Interpolation technique (Kriging) has been used to generate contour lines using Surfer, version 8.02. The program has been used to illustrate the variation in cations, anion and trace metals distribution as well as flow direction.



### 5.2.1 Anion Distribution

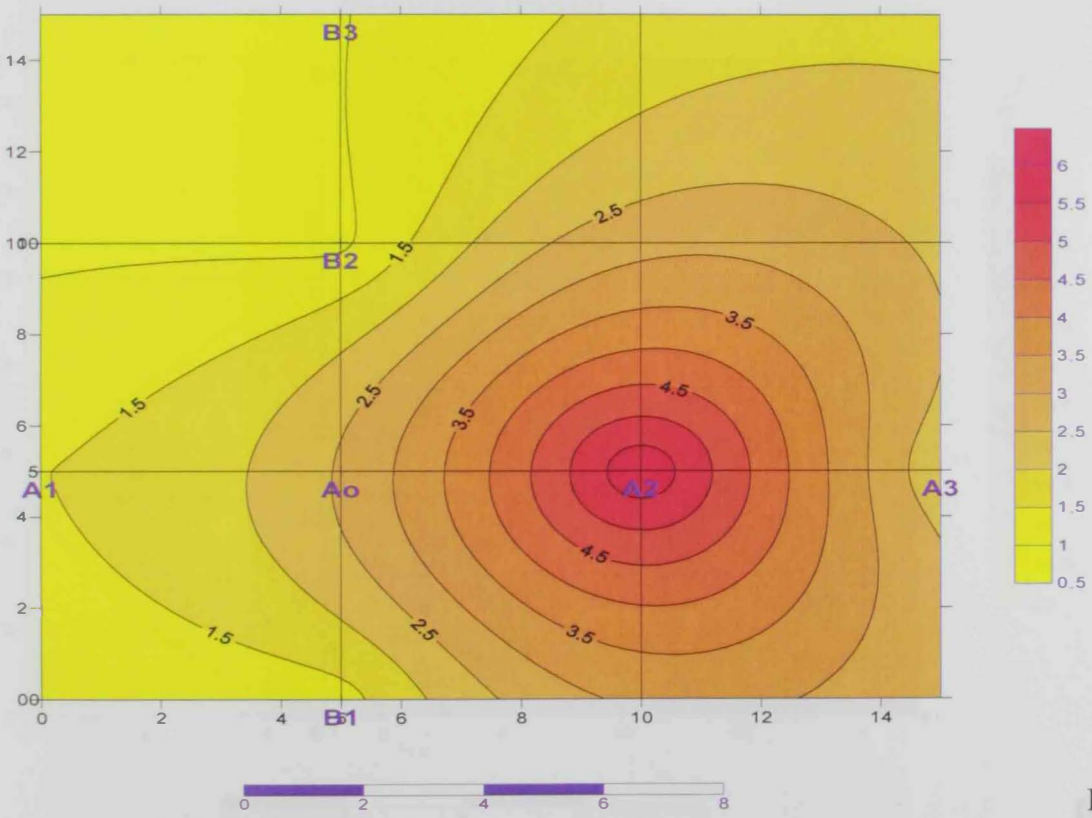
Fig. 5.4 shows that the concentration of chloride is higher at sampling points A1, A2, B1, B2, and B3, whereas the concentration of chloride at point A3 is very low. This indicates that the flow direction is from A1 and B1 to A3 and the chloride migration is the mainly in vertical direction. Nitrate concentration was lower than the maximum allowable limits sets by the GCC standards. The Nitrate graph shows also, that point A3 has the lowest concentration among the other points. Sulfate is concentrated mainly at point A1 and propagates toward A3. The concentration of bicarbonate is high at point A3 (Appendix E).

Chloride (Cl)



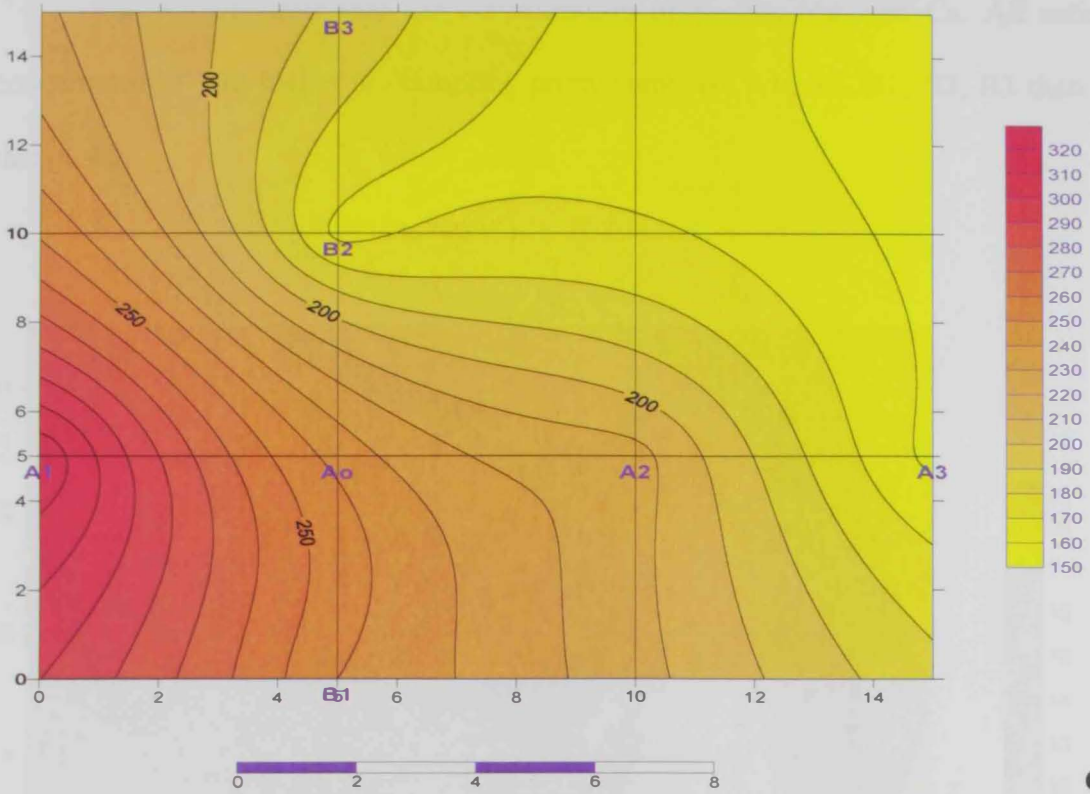
A

Nitrate (NO<sub>3</sub>)



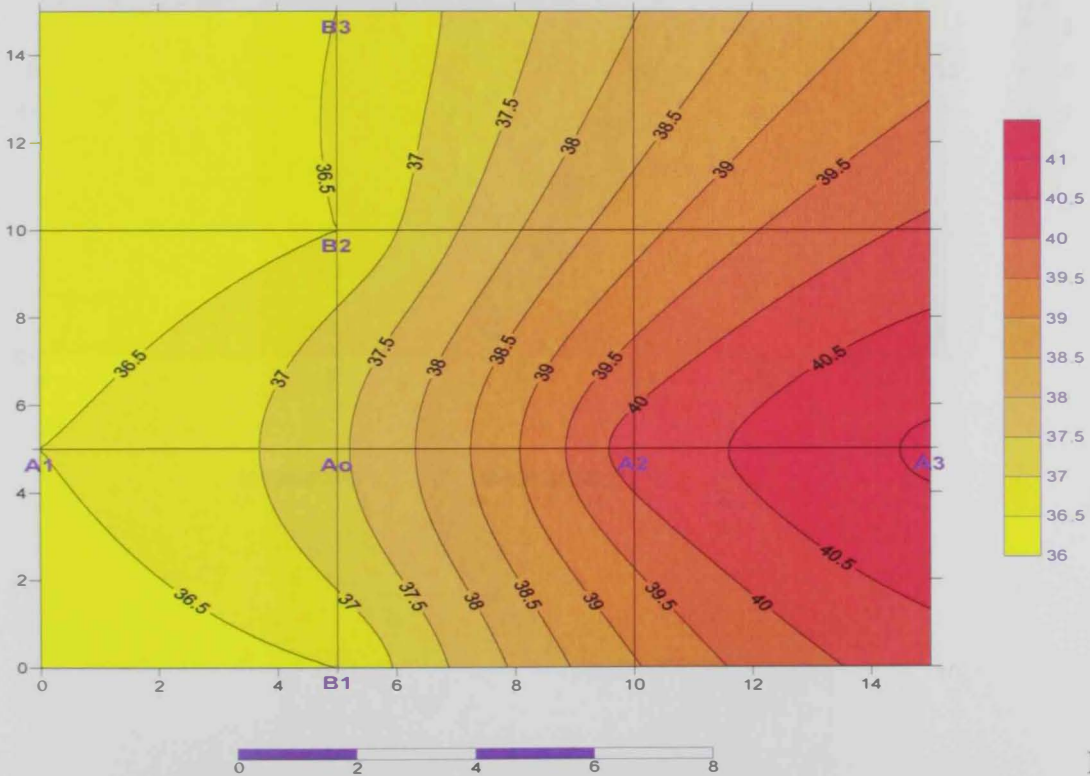
B

Sulphate (SO<sub>4</sub>)



C

Bicarbonate (HCO<sub>3</sub>)

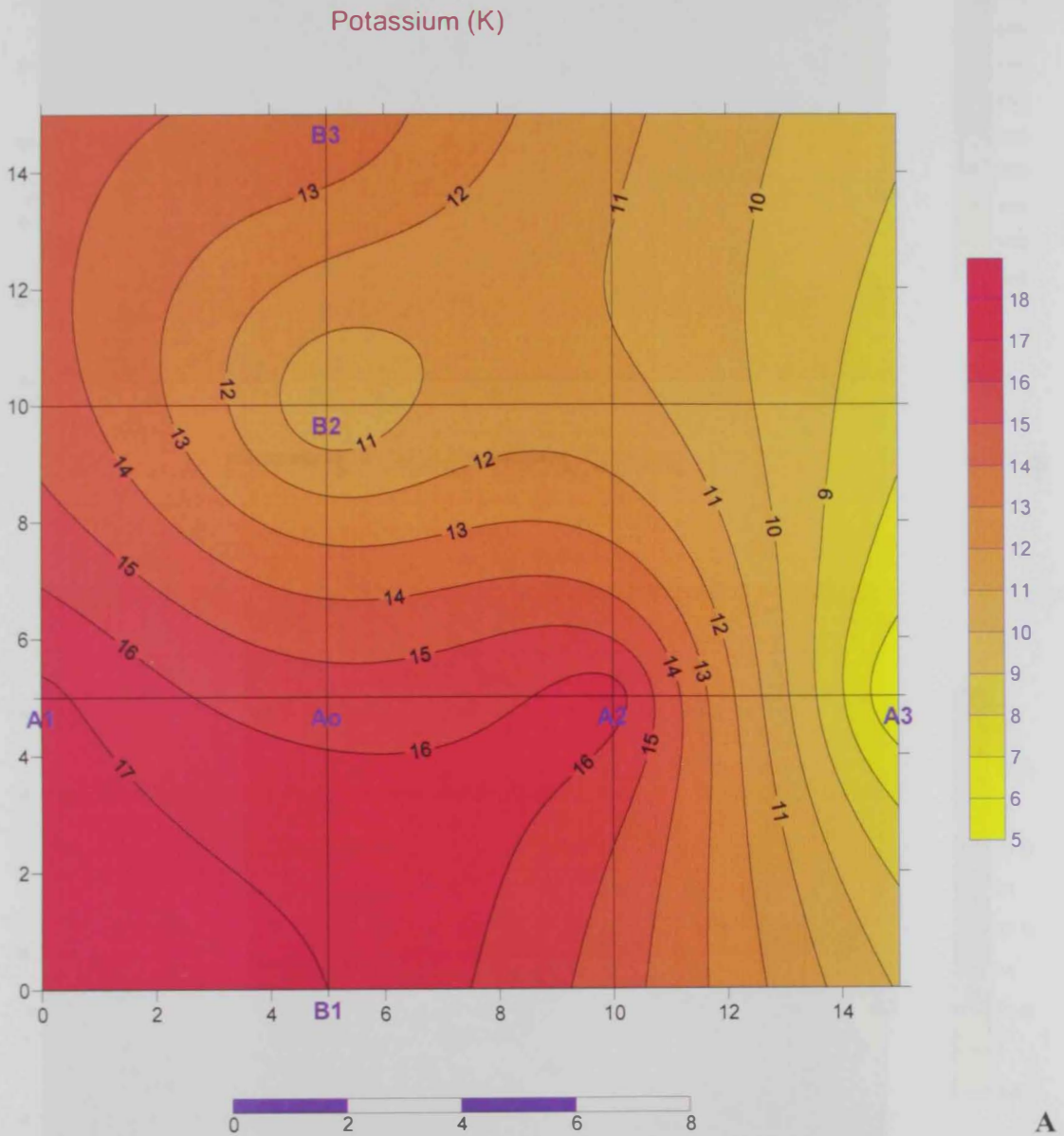


D

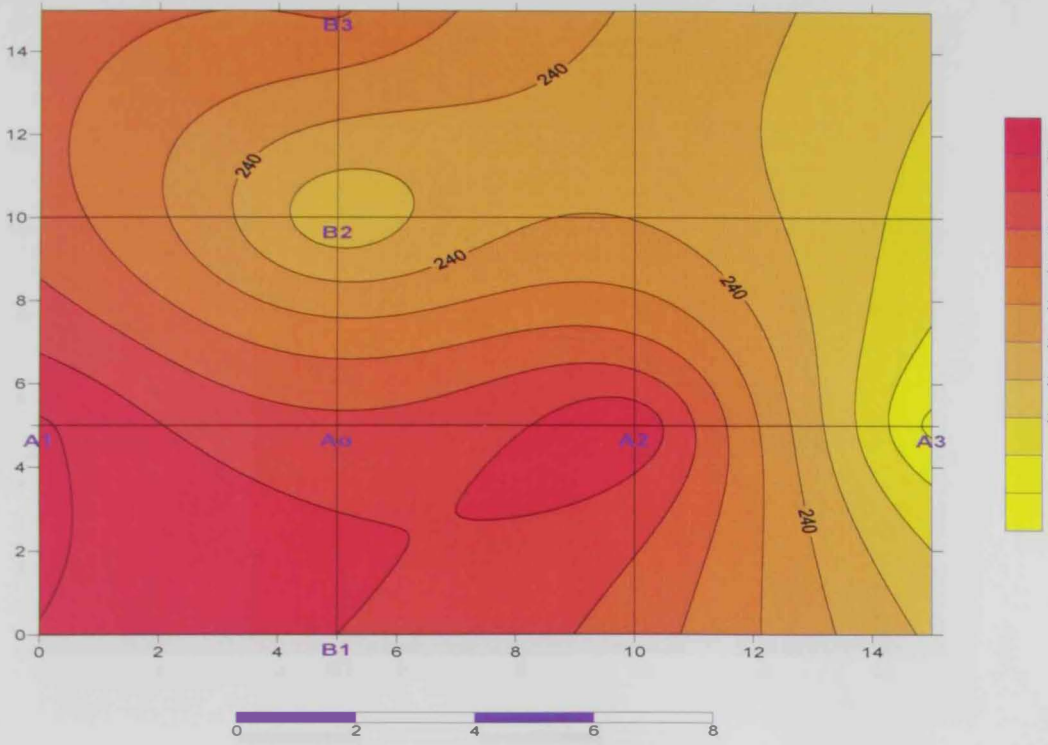
Fig. 5.4: Anion Distribution in Subsurface Soil Below the Disposal Site at an Average Depth of 1.0m: (a) Chloride; (b) Nitrate; (c) Sulfate and (d) Bicarbonate

### 6.2.2 Cation Distribution

Fig. 5.5 illustrate that the concentration of K, Na, Mg, and Ca. All cation concentrations are higher at sampling point numbers A1, A2, B1, B2, B3 than at that at A3.

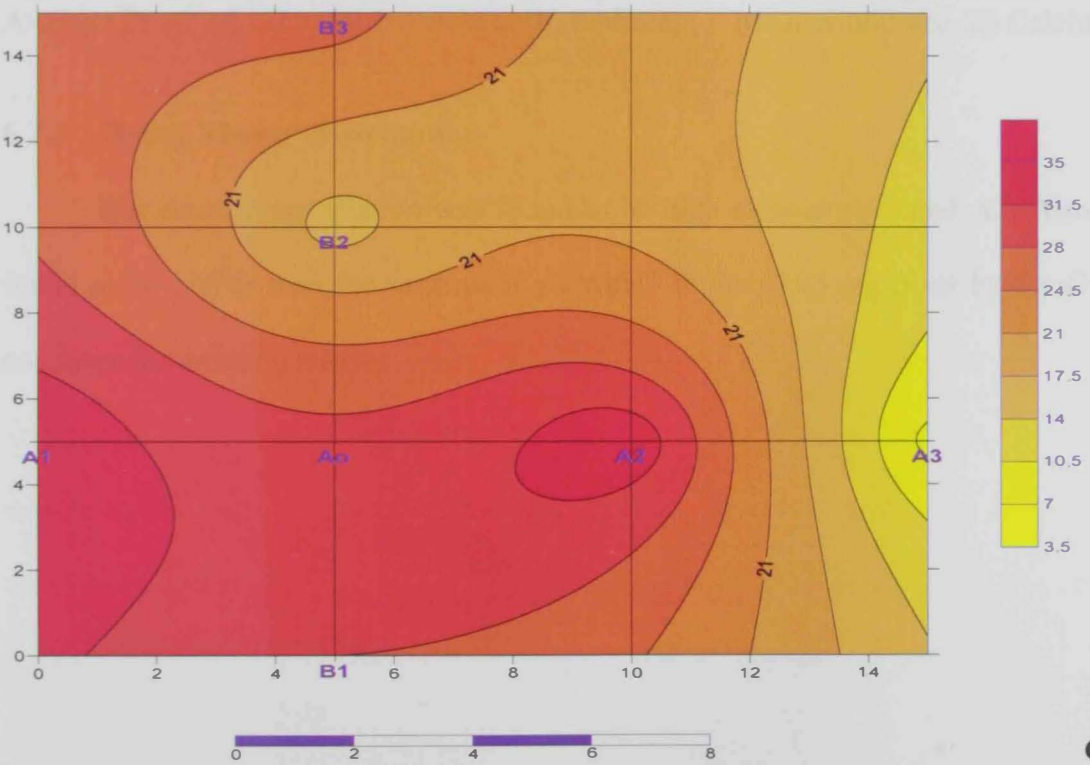


### Sodium (Na)

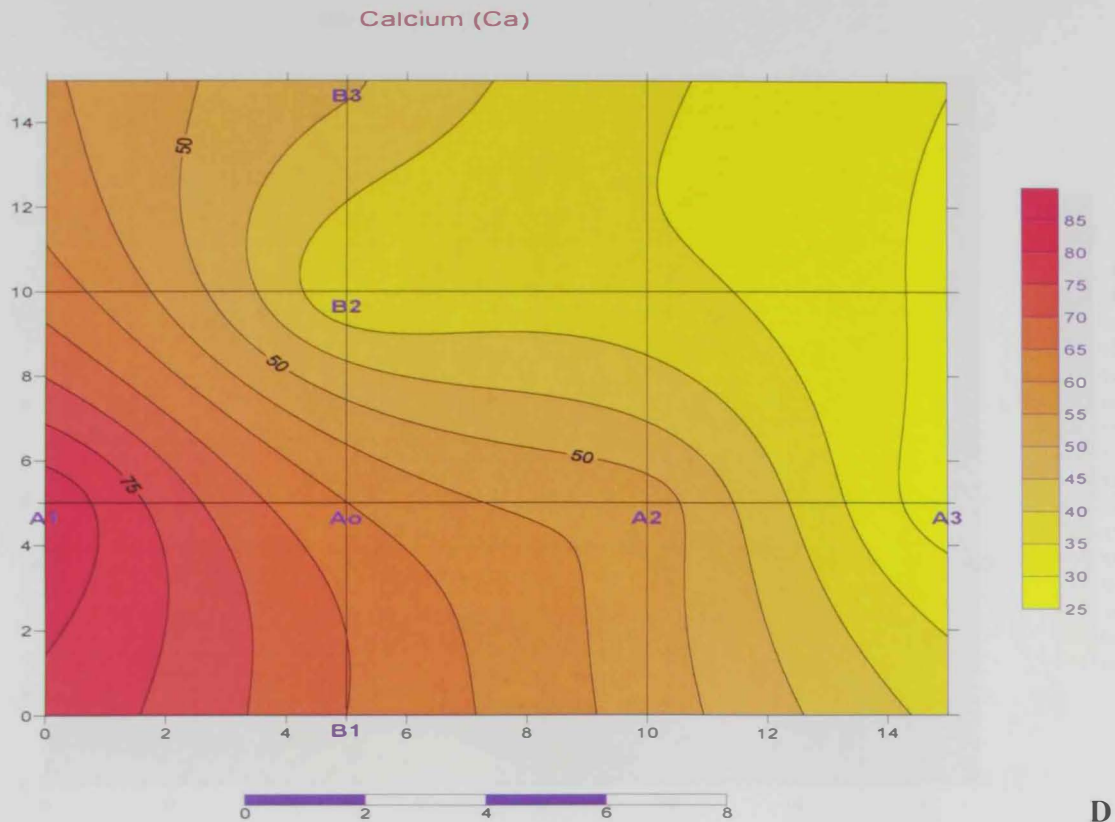


B

### Magnesium (Mg)



C



D

Fig. 5.5: Cation Distribution in Subsurface Soil Below the Disposal Site at an Average Depth of 1.0m: (a) Potassium; (b) Sodium; (c) Magnesium; and (d) Calcium.

### 6.2.3 Heavy Metals Distribution

Strontium concentration was found to be high at points A1 and A3. Also its found to be higher than the maximum allowable limits (0.05 mg/l) set by the GCC countries for drinking water.

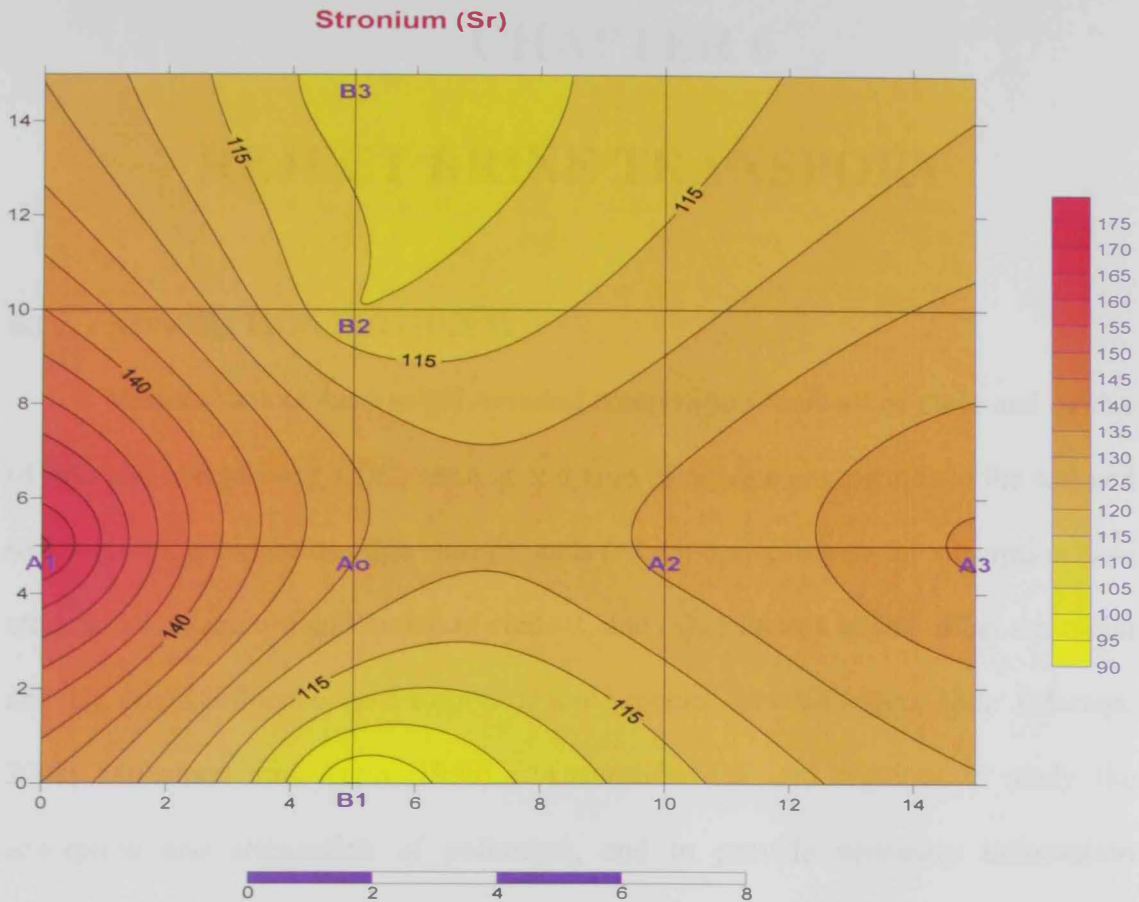


Fig. 5.6: Strontium Distribution in Subsurface Soil Below the Disposal Site at an Average Depth of 1.0m.

In conclusion the graphs suggest that the concentration of the reject brine water decreases by distance from the center of the pond. However, the horizontal movement is very limited suggesting that the main direction for transport is the vertical direction. The concentration of these ions are found to be higher than the maximum allowable limits set by the GCC Drinking Water Standards and also higher than the maximum limits set by ADNOC for the disposal of effluents into the desert (Appendix F).

## CHAPTER 6

# REJECT BRINE TRANSPORT

### 6.1 ADSORPTION ISOTHERM

Various factors such as pH, mineral composition (content of clays and oxides of iron and manganese), CEC, amount and type of organic compounds in the soil and soil solution, presence of other heavy metals (which may compete for adsorption sites etc.), soil temperature and moisture content, and other factors which effect microbial activity, could influence the transport of ionic species into subsurface soils (Maraqa, 2002; Mohamed and Antia, 1998). Adsorption data are required to study the adsorption and attenuation of pollutants, and to provide necessary information required to calculate retardation parameter of the pollutant transport equation. Such information is also needed to determine the diffusion/dispersion coefficient which control the migration of pollutants through soils (Yong *et al.*, 1992). At this stage it is very important to note that adsorption isotherm has been applied to soil suspension, assuming that this situation is one of the completely dispersed soil where all soil particles surface are exposed and available for interaction with the pollutants (Yong *et al.*, 1992).

Adsorption/desorption isotherm for strontium, potassium, and sulfate are shown in Figs. 6.1 to 6.3. At low input concentration, desorption process has taken place. Higher input concentration, adsorption process is dominant. However, for sulfate, desorption process is dominant at all input concentrations indicating that the soil is rich in sulfate.



The original soil showed higher tendency to interact with the above elements as compared to sand dune soil. A major factor that played role in this might be the CEC of the soil. The original soil has the highest CEC's.

The experimental results can be fitted via linear relations as shown in the figures with high regression parameters for strontium and potassium. For the desorption process of sulfate, the desorption process could not be fitted with a high regression. Following the standard procedures (Mohamed and Antia, 1998) for calculating the distribution coefficient ( $K_d$ ) and hence estimating the retardation parameter ( $R$ ), the results shown in Table 6.1 were obtained. The results indicate that the in-place soil has high ability to retard the movement of strontium and potassium by factors 3 and 2, respectively, as that of sand dune. However, for sulfate, since it is mainly desorption process, the two soils gave similar results.

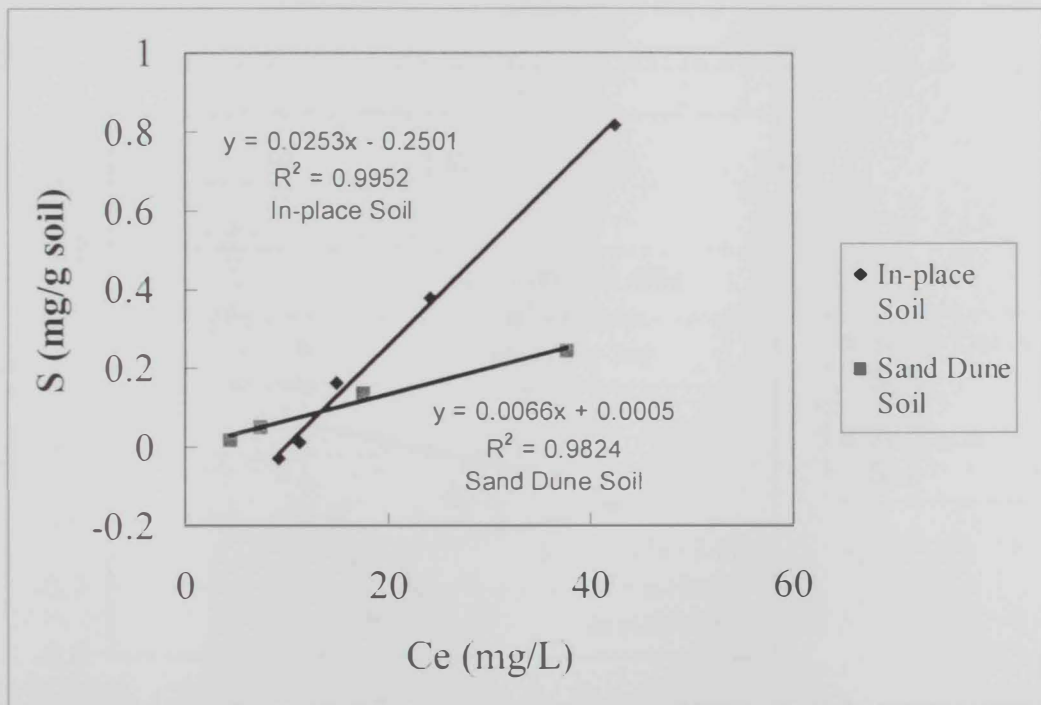


Fig. 6.1: Equilibrium Distribution of Sr,

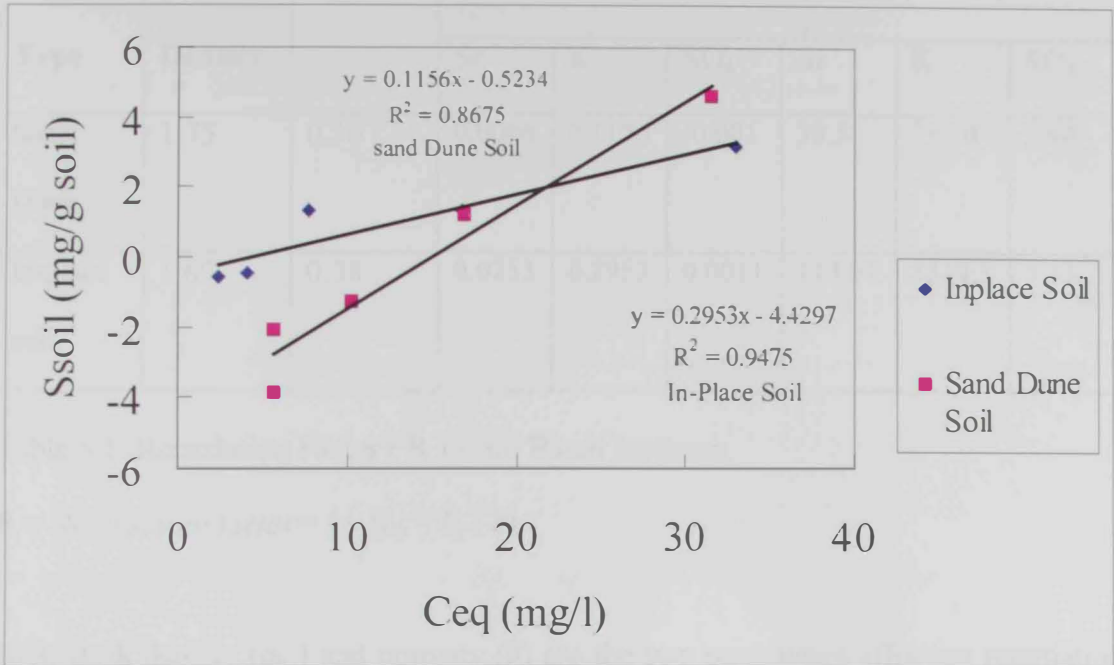


Fig. 6.2: Equilibrium Distribution of  $K^+$

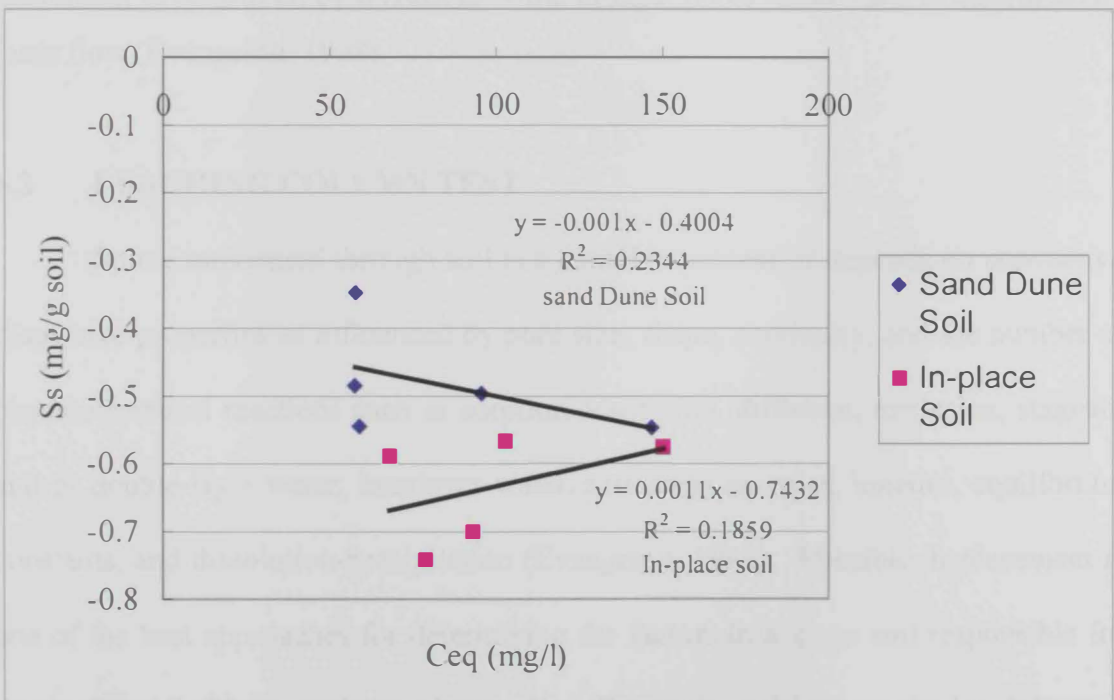


Fig. 6.3: Equilibrium Distribution of  $SO_4$

Soil Type	Bulk Density	Porosity	K <sub>d</sub>			R		
			Sr	K	SO <sub>4</sub>	Sr	K	SO <sub>4</sub>
Sand Dune	1.75	0.30	0.0066	0.1156	-0.001	39.5	710.0	5.90
In-place soil	1.69	0.38	0.0253	0.2953	0.0011	113.51	1314.3	7.13

Table 6.1: Retardation Factor ( R ) from Batch Isotherm.

$$R = \text{Retardation factor} = 1 + (\rho_b * k_d / \theta)$$

N/B. Bulk density ( $\rho_b$ ) and porosity ( $\theta$ ) are the two parameters affecting retardation by producing a wide range of total porosity in soils as well as various pore sizes. Pore size regulates the nature of solute flow. For example, in very small pores, solute movement is controlled by diffusion, while in larger pores solute flow is controlled by mass flow (Evangelou, 1998).

## 6.2 LEACHING COLUMN TEST

Solute movement through soil is a complex process. It depends on convective dispersive properties as influenced by pore size, shape, continuity, and the number of physicochemical reactions such as sorption-adsorption, diffusion, exclusion, stagnant and or double-layer water, interlayer water, activation energies, kinetics, equilibrium constants, and dissolution-precipitation (Evangelou, 1998). Miscible displacement is one of the best approaches for determining the factors in a given soil responsible for the transport behaviour of any given solute. Figs 6.4a and b show the breakthrough curves for electrical conductivity and strontium for in-place soil and sand dune. The experimental results indicate that for in-place soil, the electrical conductivity breakthrough after the passage of about 2.5 pore volume while for strontium, it

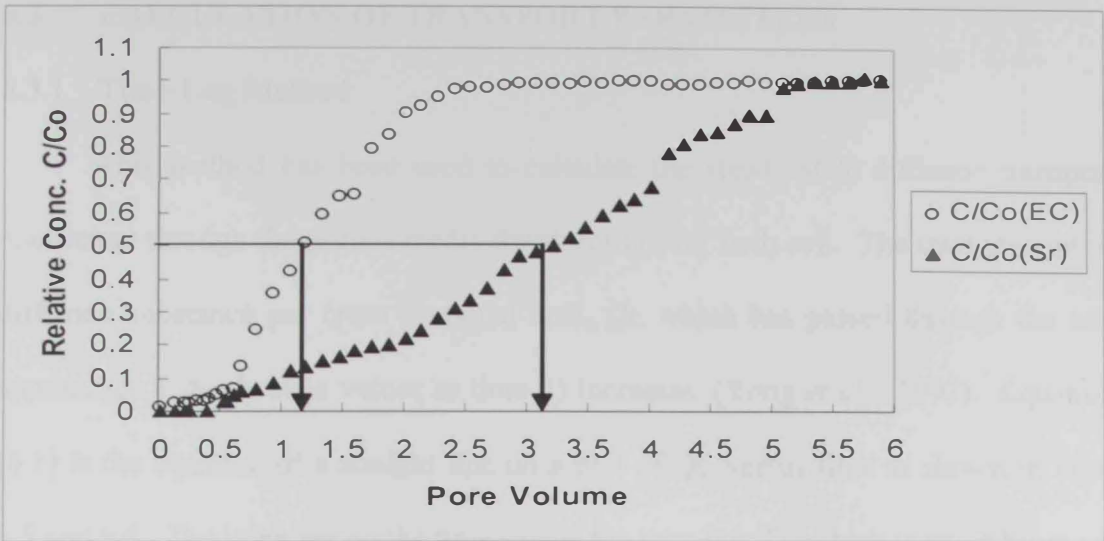
breaks after about 5.25 pore volumes. The results also indicate that the behaviour of electrical conductivity is similar to that of ideal tracer movement in soils.

For sand dune, the experimental results indicate that the electrical conductivity breaks through after about 1 pore volume while for strontium, it breaks after about 3 pore volumes.

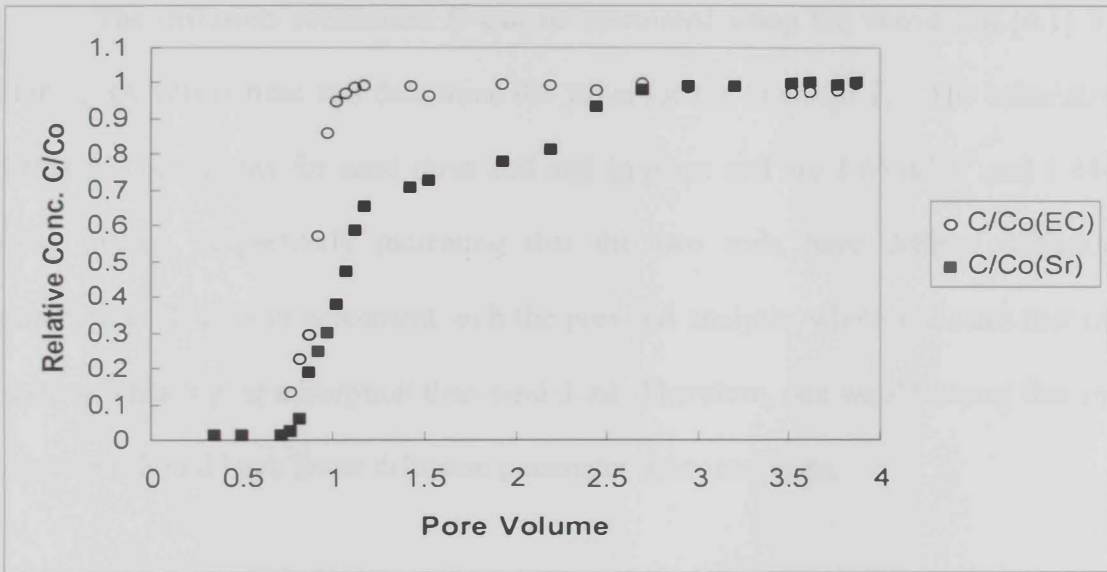
Comparing the experimental results of Figs. 6.4a and 6.4b, one concludes that in-place soil has higher capability for adsorption and retardation of pollutant migration. To verify this statement, one calculates the area under the breakthrough curve to provide a quantitative measure as shown in Table 6.2. The calculated areas, which are a measure of retardation or adsorption, for in-place soil are higher than that of sand dune due to high CEC values.

Soil	Sr	EC
<b>Sand Dune</b>		
- $A_R$ (area under the curve)	<b>1.35</b>	<b>0.92</b>
- $A_R$ (PV at $C/C_0 = 0.5$ )	1.3	0.9
<b>In-place Soil</b>		
- $A_R$ (area under the curve)	<b>2.94</b>	<b>1.28</b>
- $A_R$ (PV at $C/C_0 = 0.5$ )	3.20	1.2

Table 6.2: Retardation Measure ( $A_R$ ) from Miscible Displacement Experiment



**A. In-place Soil**



**B. Sand Dune**

Fig. 6.4: Breakthrough Curves for Electrical Conductivity and Strontium for In-place soil, and Sand Dune soil.

## 6.3 CALCULATION OF TRANSPORT PARAMETERS

### 6.3.1 Time-Lag Method

This method has been used to calculate the steady state diffusion transport coefficient through the porous media for strontium for both soil. The total amount of diffusing substance per cross sectional area,  $Qt$ , which has passed through the soil approaches a steady state values as time ( $t$ ) increases. (Yong *et al.*, 1992). Equation [6.1] is the equation of a straight line on a plot of  $Qt$ , versus time as shown in Figs. 6.5 and 6.6. The intercept on the time axis is the time lag,  $T_L$ , which is given by:

$$T_L = L^2 / 6D \quad [6.1]$$

The diffusion coefficient  $D$  can be calculated using the above Eq. [6.1] by plotting  $Qt$  versus time and determine the value for the intercept  $T_L$ . The calculated diffusion coefficients for sand dune soil and In-place soil are  $1.653 \times 10^{-6}$  and  $1.446 \times 10^{-6}$   $m^2/sec$ , respectively indicating that the two soils have different diffusion parameters. This is in agreement with the previous analysis, which indicates that in-place soil has higher adsorption than sand dune. Therefore, one would expect that in-place soil should have lower diffusion parameter than sand dune.

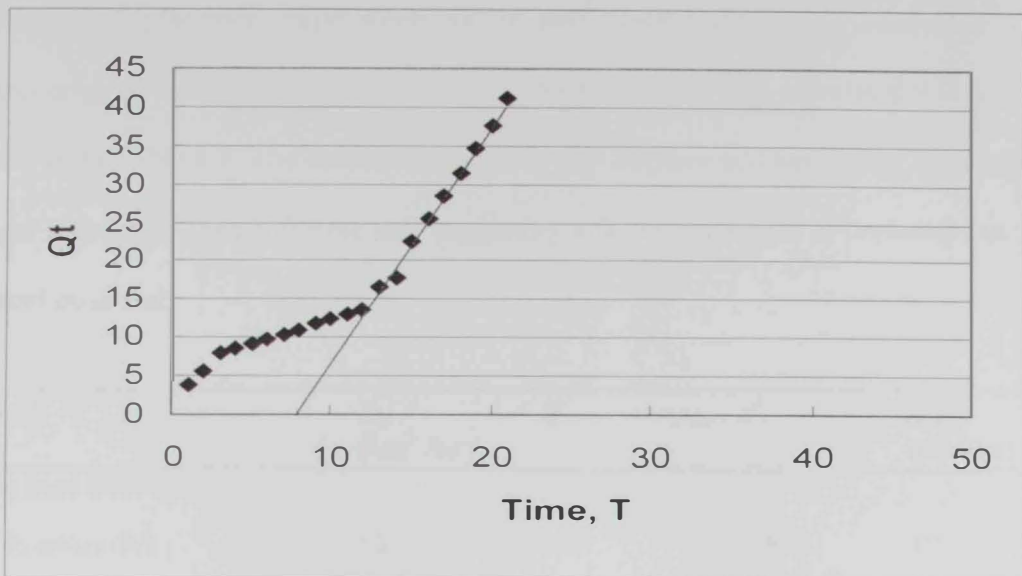


Fig. 6.5: Determination of Diffusion using Time-Lag Method for Sand Dune Soil, Al-Qua'a.

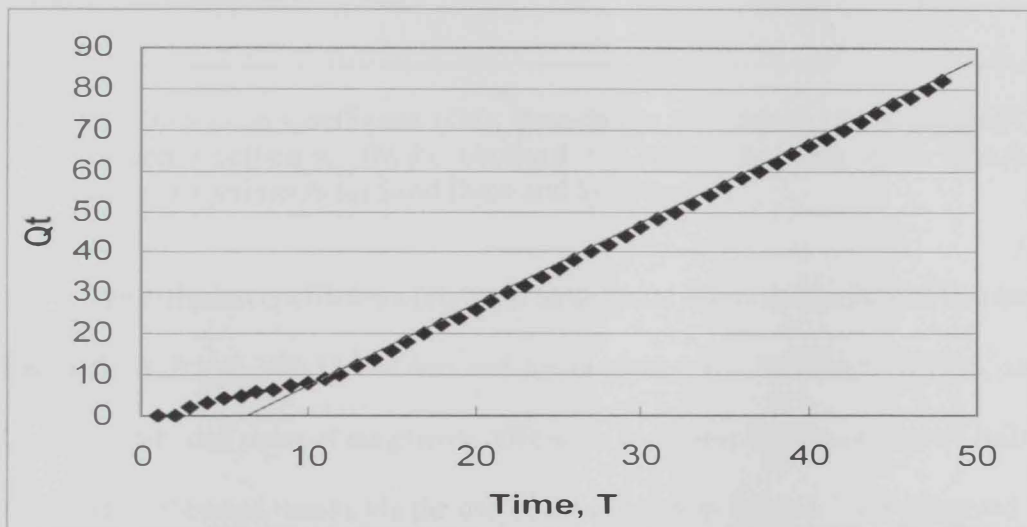


Fig. 6.6: Determination of Diffusion using Time-Lag Method for In-place Soil, Al-Qua'a.

### 6.3.2 CXTFIT MODEL

Effects of equilibrium retardation can be illustrated through the use of a computer model, CXTFIT. The situations being modeled are the inverse situations by fitting mathematical solutions of theoretical transport models, based upon the convection-dispersion equation, to the experimental results obtained from conducted

miscible displacement experiments for the two selected soil namely sand dune soil and original soil collected from Al Qua'a, Al-Ain, UAE. The calculated results are shown in Table 6.3. The results indicate that the in-place soil has higher dispersion, and retardation than soil dune soil suggesting a faster movement of contaminants in sand dune soil.

Soil	$D_d$ ( $\text{cm}^2/\text{hr}$ )	$R$	$r^2$	$D_d/R$ ( $\text{cm}^2/\text{hr}$ )
<b>(a) Sand Dune Soil</b>				
- Strontium (Sr)	6.22	1.25	0.96071	4.976
- Electrical Conductivity (EC)	0.3237	0.9000	0.9949	0.359
<b>(b) In-place Soil</b>				
- Strontium (Sr)	7.88	3.32	0.96591	2.37
- Electrical Conductivity (EC)	5.57	1.57	0.9958	3.55

Table 6.3: Dispersion Coefficient ( $D_d$ ), Retardation Coefficient ( $R$ ) R Square( $R^2$ ), and Diffusion Coefficient ( $D_d/R$ ), obtained by Fitting the Data from Miscible Displacement Experiments for Sand Dune and In-place Soil.

The diffusion coefficients ( $D_d/R$ ) in SI units are calculated as follow. For sand dune soil,  $D_d/R = 1.378 \times 10^{-7} \text{ m}^2/\text{sec}$  and for in-place soil,  $D_d/R$  is  $6.58 \times 10^{-8} \text{ m}^2/\text{sec}$ . Approximately one order of magnitude difference is observed between the two soils.

The calibrated results via the use of data shown in Table 6.2 are presented in figs. 6.7 to 6.10. The figures indicate a very good match between observed and fitted results.



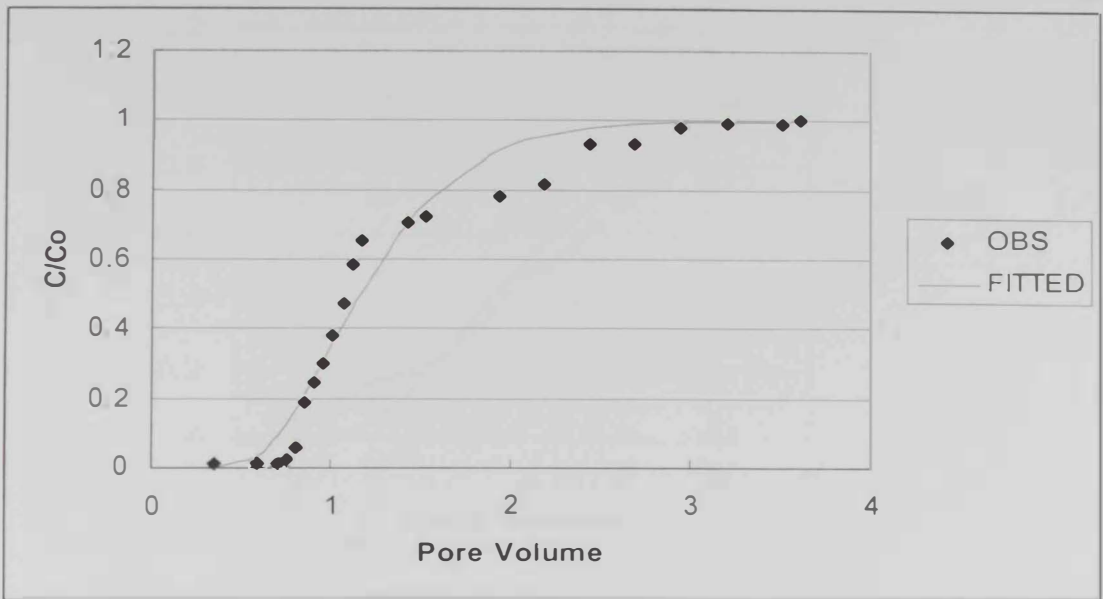


Fig. 6.7: Experimental and Fitted Breakthrough Curves for Strontium in the case of Sandy Dune Soil.

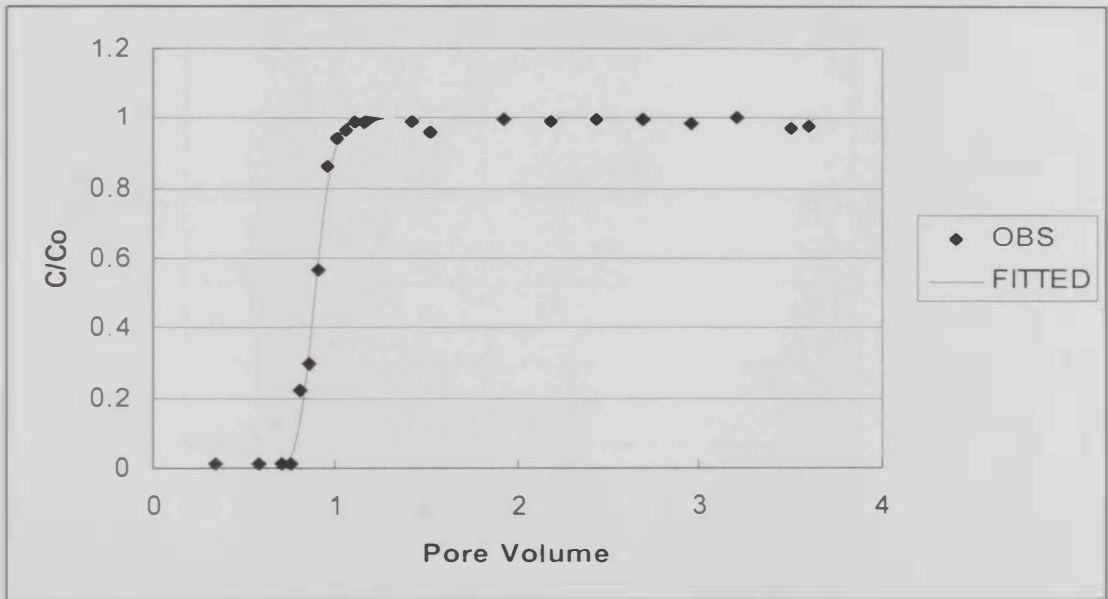


Fig. 6.8: Experimental and Fitted Breakthrough Curves for Electrical Conductivity for the case of Sandy Dune Soil.

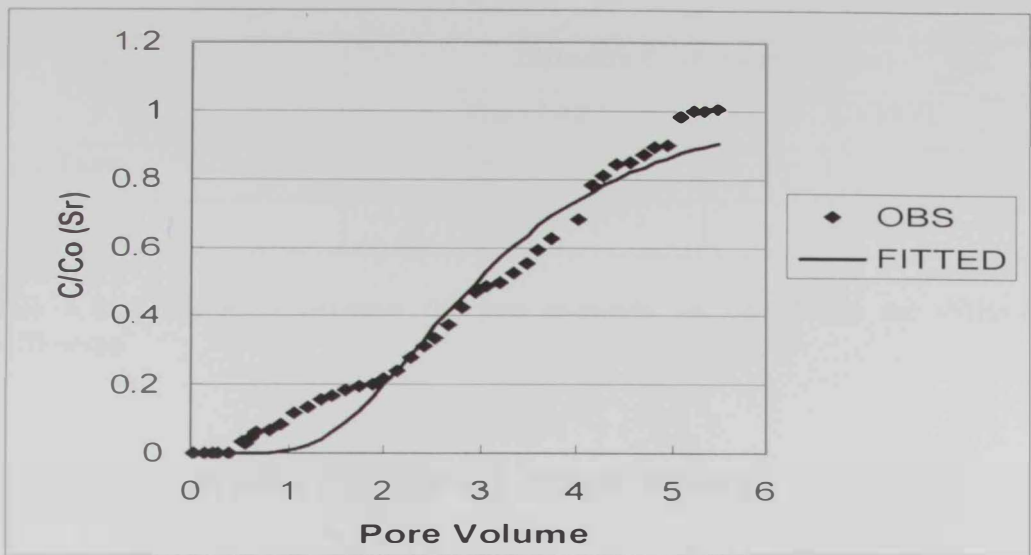


Fig. 6.9: Experimental and Fitted Breakthrough Curves for Strontium in the case of in-place soil.

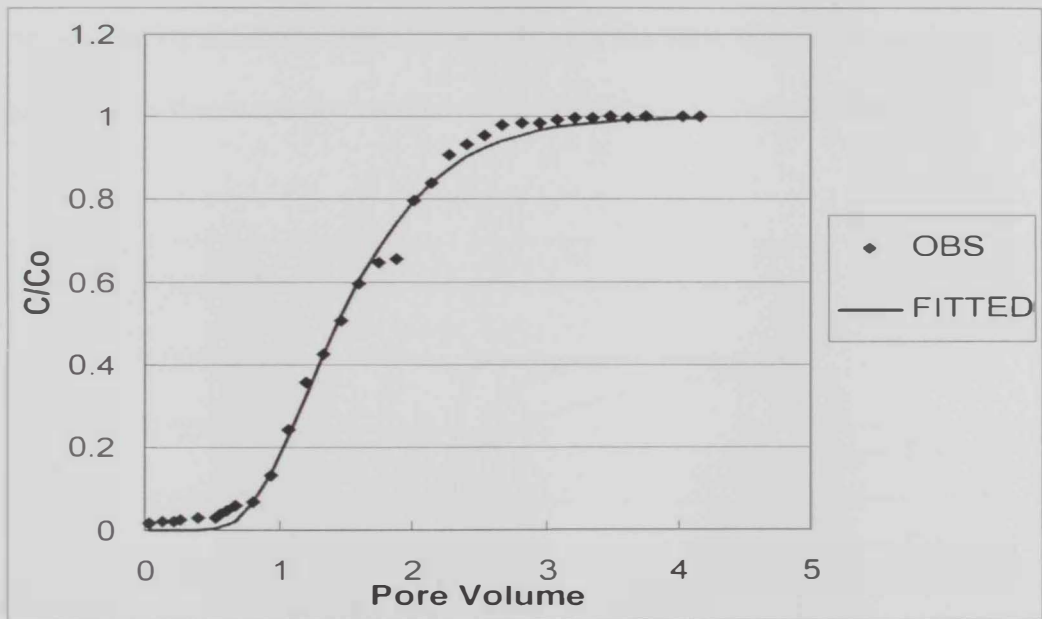


Fig. 6.10: Experimental and Fitted Breakthrough Curves for Electrical Conductivity for the case of In-place soil.

Table 6.4 shows a comparison between the two methods for calculating the diffusion coefficients.

Soil Type	Diffusion Coefficient (m <sup>2</sup> /sec)	
	Time Lag	CXTFIT
Sand Dune	1.653x10 <sup>-6</sup>	1.378x10 <sup>-7</sup>
In-place Soil	1.446x10 <sup>-6</sup>	6.58x10 <sup>-8</sup>

Table 6.4: Comparison between the two methods for calculating the diffusion coefficients.

#### 6.4 SENSITIVITY ANALYSIS VIA CXTFIT MODEL

A Sensitivity analysis has been conducted to illustrate the variability in the dispersion coefficient ( $D_d$ ) and Retardation coefficient ( $R$ ). Figs. 6.8 and 6.9 illustrate the effect of different  $D$  and  $R$  values, using CXTFIT (direct problem). The figures indicate that for the same retardation and dispersivity, as the dispersion coefficient increases, the breakthrough retards (Fig. 6.8). For the same dispersion coefficient and dispersivity, as the retardation coefficient increases the breakthrough retards.

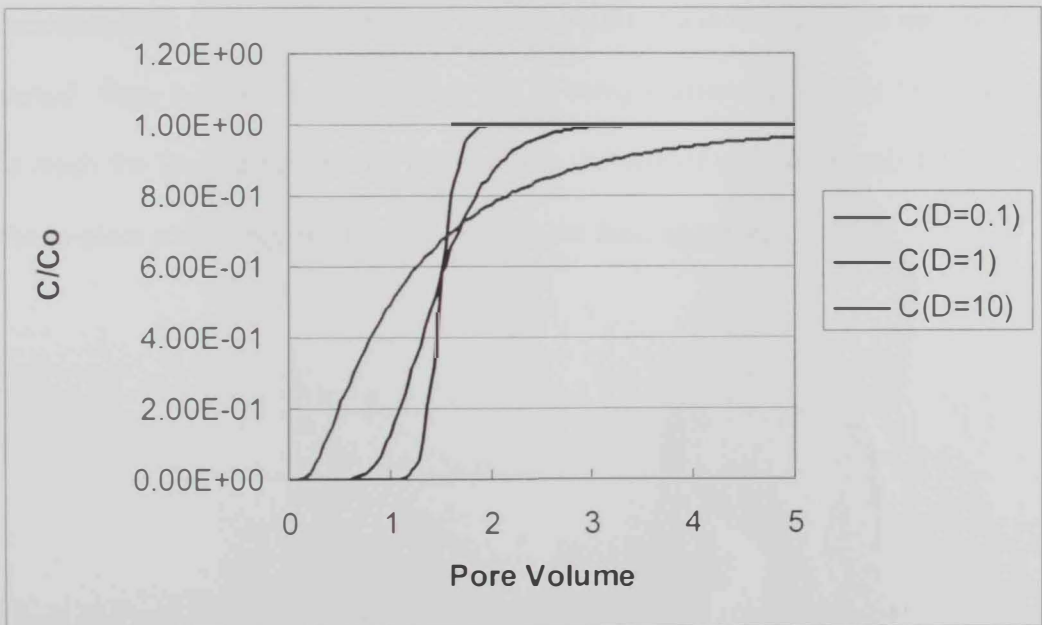


Fig.6.11: Effects of the Variability in the Dispersion Coefficient ( $D$ ), using Fixed ( $R$ ) and ( $\nu$ ) Values of 1.5 and 0.4, respectively.

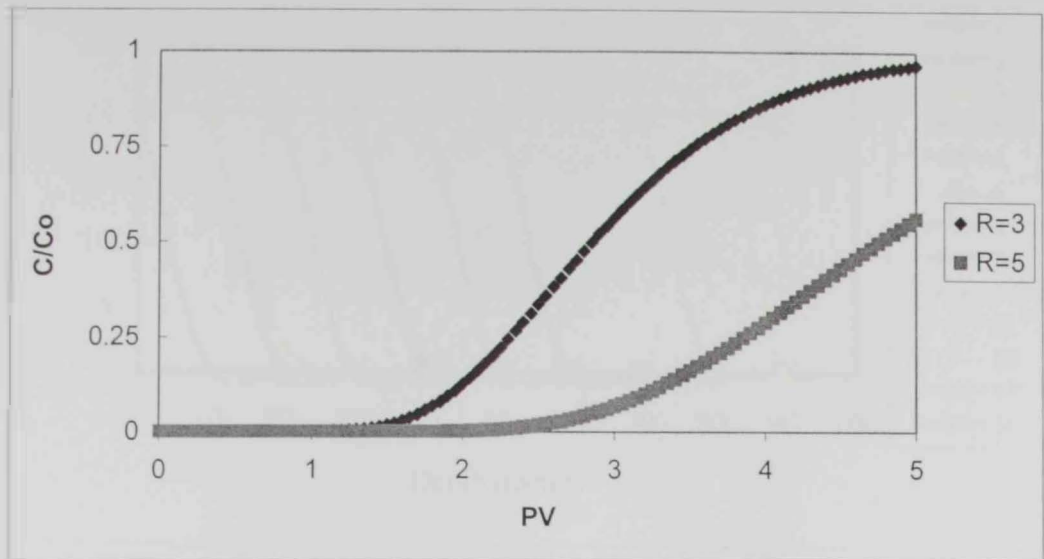


Fig.6.12: Effects of the Variability in the Retardation Coefficient ( $R$ ), using Fixed ( $D$ ) and ( $v$ ) Values of 2.5 and 2.5, respectively

### 6.5 PREDICTIONS FOR FIELD CONDITION

Contaminant transport models (CXTFIT) have been used to predict the movement of contaminants for field condition. This is vital for accurate assessment of the advance of contaminant plumes in the subsurface, and /or distribution of concentrations of target pollutants at various points of concern and after specific time period. Figs. 6.13 and 6.14 show that the Sr concentration will require 13 to 14 days to reach the feeding aquifers of 100 depth in the case of sand dune soil, whereas for the In-place soil it requires 16 days to reach the feeding aquifer.

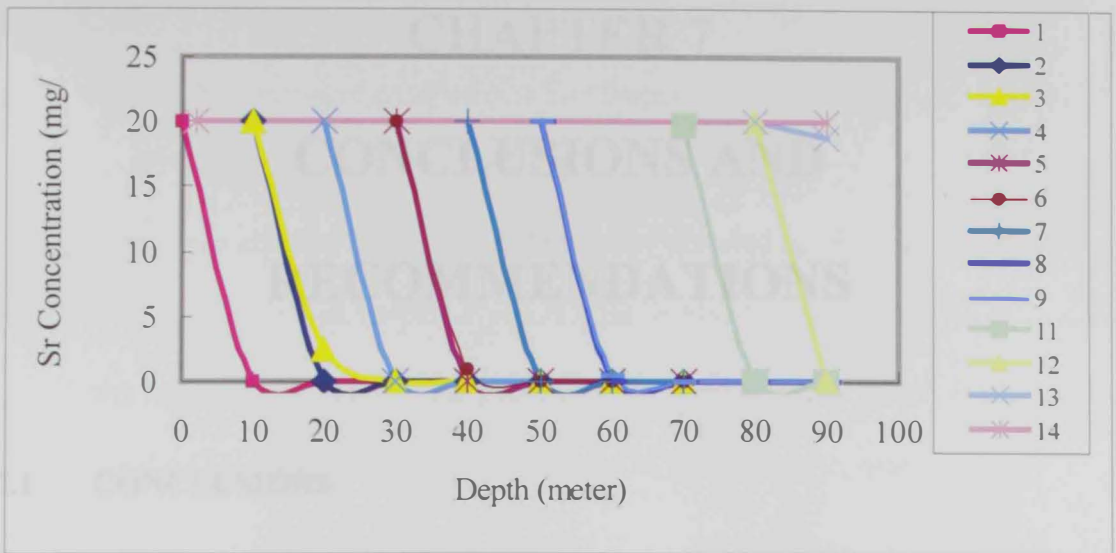


Fig. 6.13: Predicted Sr Concentration Profile versus Depth with the Time (Sand Dune Soil)

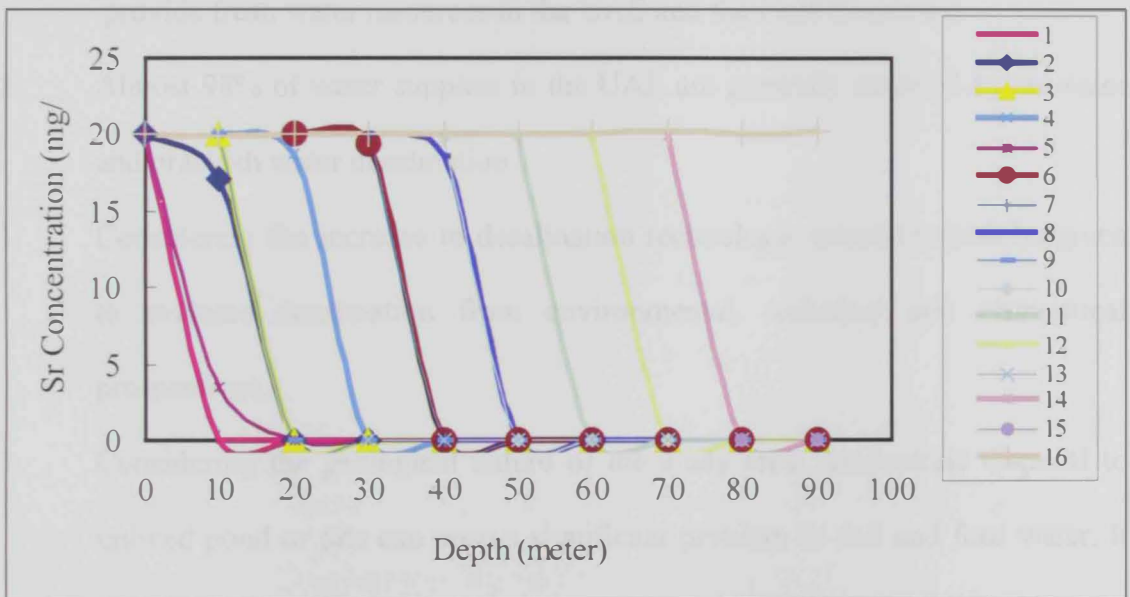


Fig. 6.14: Predicted Sr Concentration Profile versus Depth with the Time (In-place Soil)

# CHAPTER 7

## CONCLUSIONS AND RECOMMENDATIONS

### 7.1 CONCLUSIONS

#### Generally:

1. Seawater and brackish groundwater are considered as strategic alternatives to provide fresh water resources in the UAE and the Gulf Countries.
2. Almost 98% of water supplies in the UAE are currently satisfied by seawater and brackish water desalination.
3. Considering the increase in desalination technology, attention must be given to evaluate desalination from environmental, technical and economical perspectives.
3. Considering the geological nature of the study area, concentrate disposal to unlined pond or pits can pose a significant problem to soil and feed water. It can increase the risk of saline brackish water intrusion into fresh water.
4. The percentages of reject brine from the three investigated plants varied between 30 to 40 %.
5. The surveyed plants use unlined disposal pits for disposal of reject brine. Chemical analysis showed a slight increase in the concentration of various salts and EC level indicating that concentrate is easily reaching the groundwater.

### Specifically:

1. The TDS of reject brine showed a low degree of variability ranging from (7.77 – 18.3 mS/cm)
2. Heavy metals (Cr,P,Sr,V,B) and TPH were detected in all water samples.
3. Water samples collected from reject brine at Um Al Zumool RO plant showed the highest increase in TPH and electrical conductivity, where as the highest level of TPH in feed water was observed at the Al Qua'a plant.
4. Increase in TPH in desalinated water can pose a significant health risk. The origin of TPH, types of hydrocarbons should be investigated. A fingerprint study could be useful to define the source of such organic compound.
5. XRDA conclude that the dominants minerals near the disposal site A1, A2, A3, and B1, B2, and B3 are Quartz, Calcite and Plagioclase, whereas the sample collected, about 1.5 km (original soil) contain high amount of gypsum. This finding corresponds to the geological formation and the soil classification of the area, which is classified as Gyps- ferrous Soil. Feed water analysis confirms also, that the soil contains  $\text{SO}_4^-$ , Ca, Mg, and Na.
6. The krigging analysis illustrates that the concentration of reject brine decreases by distance suggesting a horizontal than laterally transport of contaminant. Core samples are required to solidate this findings.
7. The Adsorption Isotherm results reveal that the retardation takes the following order  $\text{K} > \text{Sr} > \text{SO}_4$ . The In-place soil showed a higher tendency to interact with the above elements as compared to sand dune soil.
8. The Miscible displacement results reveal that for strontium and EC breakthrough curves measured for In-place and sand dune soil, retardation

values are higher for In-place soil than sand dune soil, whereas for EC they are the same for both soils confirming that EC is acting as an ideal tracer.

9. The outcomes from the CXTFIT model reveal that original soil has higher dispersion and retardation coefficients than sand dune soil, suggesting a faster movement of contaminants in sand dune soil.
10. Predictions of field condition using CXTFIT model show that Sr require 13-14 days to reach the feeding aquifers of 100 m depth in the case of sand dune soil, whereas for the In-place soil it requires 16 days.

The overall study indicates that effluents discharge to the desert can have an adverse effect to the feed water or/ underground aquifers. The RO concentrate released has a TDS concentration about two fold higher than the feed water supply. The mechanism for this increase may be attributed to saline intrusion to the feeding aquifers, salts from the reject brine might precipitate out of solution as the discharge water infiltrate to the water table. The salt may be then taken into solution at a new concentration. The re-solution of salts during transport to the water table and enrichments of the soil in the area with gypsum as has been concluded from XRD results may explain the increase in water hardness and  $\text{SO}_4$  concentrations. With regards to the impacts on soil quality, the outcomes of this project can give a preliminary findings, further research is required to confirm conclusion.



## 7.2 RECOMMENDATIONS

The following recommendations can be considered to reduce the impact of concentrate disposal from inland desalination plants:

1. Proactive approaches must be considered to protect groundwater from further deterioration (i.e., lining systems, long term monitoring program, field research etc.)
2. Regulations and polices related to reject brine chemical composition and concentrate disposal must be used in place.
3. Enforcement of regulations of brine disposal on the concerned sectors.
4. Private companies have to be encouraged by government to play a role in research, education and training in the field of desalination. Options that can be adopted by the UAE and the Gulf Countries are highlighted below:

**(A) Zero-discharge of brines from desalination plants:** Industries should apply pollution reduction programs including, recycling and reusing water, and developing alternative technology. The zero discharged concepts deal with the reduction in waste volume.

**(B) Use of reject in solar pond for electricity:** Saline effluents from large desalination plants are increasing dramatically, especially in the Arabian Gulf region. Solar ponds can be used for the production of heat and electricity.

**(C) Enhanced evaporation mechanism:** The size of the evaporation pond affect the rate at which reject brine is evaporated from it. Different methods can be used to enhance evaporation include:

- Use low cost technology for enhance evaporation
- Spraying of brine
- Creating turbulence in the pond

- Creating airflow over the pond

**(D) Spirulina, Fish, and Shrimp Culture using reject brine from desalination**

**plants:** Treated reject brine water from desalination plants with high alkalinity and salinity, and the availability of solar radiation and high temperature can provide an ideal growth medium for Spirulina i.e., Arthospira Platensis and Tilapia which are of high commercial value. Adopting such project can contribute to the decrease of the cost of waste disposal, and reduce the impact on environment. ([http://jperret.tripod.com/research\\_johan/spirulina.html](http://jperret.tripod.com/research_johan/spirulina.html), (<http://www.brineshrimpdirect.com>), Suresh, A., and Lin, K., 1992).

**(E) Chemical conversions of salt concentrate from desalination plants:**

There is a possibility of producing some chemicals from the salt concentrate. The preliminary results indicate the chance of converting NaCl to producing Na<sub>2</sub>CO<sub>3</sub>, NaHCO<sub>3</sub> and NH<sub>4</sub>Cl using a series of batch gas bubbler (Baba El-Yakubu, J., and Ibrahim, A.A, 2001).

**(F) Mineral Extraction from desalination plants:**

Extraction of minerals from desalination reject brine can represent a potential important source of minerals, minimize east disposal and reduce the stress in environment (Al-Mutaz, I.S., and Wagialla, K.M., 1988).

## REFERENCES

- Addiscott , T.M., and R.J. Wagent, 1985. Concepts of solute leaching in soils: A review of modeling approaches, *Journal of Soil Science* 85, 411-424
- ADWEA and FEWA Report, 2000. Water Demand Forecast and Management of UAE. UAE
- Ahmed, M. 2000. Investigation on the use of evaporation ponds for brine disposal in inland desalination plants. MEDRC Project: 97-AS-007. Published Report.
- Ahmed, M., Arakel, A., Hoey, D. and Coleman, M. 2001. Integrated power, water and salt generation: a discussion paper. *Desalination* 134 (2001) 37-45.
- Ahmed, M., Shayya, W., Hoey, D., and Al-Handhaly, J.K., (2002). Brine Disposal from Inland Desalination Plants: Research Needs Assessments. *Water International*, Volume 27, Number 2, 194-201, June 2002.
- Alabdula'aly, A.I., and Khan M.A., 1997. Trace Metals in Groundwater RO Plants Brine Water. IDA World Congress on Desalination and Water Reuse. Vol. 15, pp 573-596
- Alabdula'aly, A.I., and Saati, A.J. 1995. *Disposal in Groundwater RO Plants in the Central Region of Saudi Arabia*. Proceeding of 1995 International Desalination Association Conference, Abu Dhabi, Nov 1995.
- Al-Hiti N.A. and Al-Hadithi,. (2001). The use of water in the GCC Countries. *Proceeding, WSTA5<sup>th</sup> Gulf Water Conference, March 24-28, 2001, Doha, Qatar*.
- Almulla, A., Mohamed E., Pierre C., and J. Coburn, *Desalination*, 153 (2002) 237-243
- Al-Mutaz, I.S and Wagialla. 1988. Techno-Economic Feasibility of Extracting Minerals from Desalination Brines. *Desalination*. 69 (1988) 297-307.

- Baba El-Yakubu, J** and **Ibrahim, A.A.** 2001. Chemical conversions of salt concentrates from desalination plants. *Desalination* 139 (2001) 287-295
- Burns, I. G.** (1974). A model for predicting the redistribution of salts applied to fallow soil after excess rainfall or evaporation. *Journal of Soil Science*. 74:165-178
- Campall, G. S.,** (1985). *Soil Physics with BASIC: Transport Models for Soil-Plant Systems*. Elsevier Science Publication. Netherlands. 149 pp
- Evangelous, V. P.,** (1998). *Environmental Soil and Water Chemistry: Principle and Application*. Publisher: A Wiley - Interscience.
- Global Water Intelligence (GWI).** October 2000. Publishing, London, UK.
- Glueckstern, P., Priel, M., Thoma, A. and Gelman, Y.** 2000. Desalination of brackish fish pond effluents-pilot testing and comparative economic evaluation of integrated UF-RO systems vs. conventional systems. *Desalination*. 132 (2000) 55-64.
- Hamoda, H.F.,** 2001. Desalination and water resource management in Kuwait *Desalination*. 138 (2001) 385-393
- Hoffman, D., J.D. Rhoades, J. Letey, and F. Sheng.** 1990. "Salinity Management."pp. 667-715. In *Management of Farm Irrigation Systems*, eds. G. J. Hoffman, T.A. Howell, and K. H. Soloman. New York: American Society of Agricultural Engineers.
- Hopner, T and Windelberg, J.,** (1996). Elements of environmental impact studies on costal desalination plants. *Desalination*. 108 (1996) 11-18.
- [http://jpertr.tripod.com/research\\_johan/spirulina.html](http://jpertr.tripod.com/research_johan/spirulina.html)
- <http://www.brineshrimpdirect.com>

- Khordagui H.**, 1997. Environmental Aspects of Brine Reject from Desalination Industry in the ESCWA Region. ESCWA, Beirut, Lebanon.
- Lu, M., Walton, J.C. and Swift, A.H.P.** 2001. Desalination coupled with salinity-gradient solar ponds. *Desalination*. 136 (2001) 13-23
- Maas, E. V.** 1990. "Crop Salt Tolerance." Pp. 262-303. In *Agricultural Salinity Assessment and Management*, ed. K. K. Tanji. New York, U.S: American Society of Civil Engineers.
- Mandil, A.M.** 1991. "Desalination and Environment". In *Proceedings of the Third International Symposia on Industry and Environment in the Developing World*. May, Alexandria. Egypt.
- Maraqqa, M.** 2002. Leachability of Heavy Metals From Fertilizers Applied to UAE Agricultural land: A Preliminary Study. *Proceedings, of the 4<sup>th</sup> Annual UAE University Research Conference, April 27<sup>th</sup> -29<sup>th</sup>, 2003, Al Ain, UAE.*
- Mickley M.** and Hamilton, B. 1993. Membrane Concentration Disposal. American Water Works Association Research Foundation, Denver, Colorado.
- Mickley, M.** 1995. *Environmental Considerations for the disposal of Desalination Concentrates*. Proceeding of the 1995 International Desalination Association Conference. Abu Dhabi, Nov.
- Mohamed, A.M.O., and Antia, H.E.** 1998. Geoenvironmental Engineering. First Edition. Publisher: Elsevier science.
- Muckley, C.A., Simpson, C.A. and Schutte, C.F.** 1987. The treatment and disposal of waste brine solutions. *Desalination*. 67 (1987) 431-438.
- National Drilling Company (NDC)**, 1993. Ground Water Resources of Al Ain Area, Abu Dhabi Emirate. U.S. Geological Survey Administration Report prepared in Cooperation with the National Drilling Company, Emirate of Abu Dhabi.

- Oldfield, J. W** and **Todd, B.** 1995. A review of materials and corrosion in desalination – Key factors for plant reliability. *Paper presented at the IDA World Congress on Desalination and Water Sciences held in Abu Dhabi, Nov. 18-24, 1995.*
- Rao N.S., Venkateswara R.T.N., Rao G. B., and Rao K.V.G.,** 1990. Impact of Reject Water from the Desalination Plants on Groundwater Quality. *Desalination*, 78:429-437.
- Rhoades, J.D.,** and **J. Loveday.** 1990. "Salinity in Irrigated Agriculture." pp. 1089-1142. In *Irrigation of Agricultural Crops*, eds. B.A. Stewart and D.R. Nielson. Wisconsin: American Society of Agronomy.
- Rosegrant, M.W.** 1997. *Water Resources in the Twenty-First Century: Challenges and Implications for Action.* Washington D.C.: International Food and Policy Research Institute.
- Selim, H. M., J.M. Davidson, and P. S. Rao,** 1977. Transport of reactive solutes through multi-layered soils, *Soil Science Society of America Journal*, **41**, 3-10.
- Semiati, R.** 2000. Desalination: Present and Future. *Water International*, Volume 25, Number 1: 54-65. March 2000.
- Sommariva, C., and Syambabu, V.S.N.** 2001. Increase in water production in UAE., *Desalination*, 138 (2001) 173-179
- Soyza, A, G.,** 2002. Towards Integrated Water Resources Management in the UAE. 2002 Symposium "Water Resources Management: Recent Developments in the UAE and the Netherlands. 19 October, 2002, Al-Ain, UAE.
- Squire D., Murrer J., Holden P., and Fitzpatrick C.,** 1996. Disposal of reverse osmosis membrane concentrate. *Desalination*, 108 (1996) 143-147.

- Squire, D.** 2000. Reverse osmosis concentrate disposal in the UK. *Desalination*, 132, (2000) 47-45
- Starr, J.R.** 1999. "Water Politics in the Middle East." *Business and Economics* 7 (2/3): 64-70.
- Suresh, A.V** and **Lin, C.K.** 1992. Tilapia culture in saline water: a review. *Aquaculture*, 106 (1992) 201-226
- Tsiourtis, N.T.** Desalination and Environment. *Desalination*, 138 (2001) 1.
- UN, ESCWA.** 2001. The Role of Desalinated Water in Augmentation of the Water Supply in Selected ESCWA Member Countries. E/ESCWA/ENR/2001/19, 28 December 2001
- United Arab Emirates University.** 1993. National Atlas of United Arab Emirates. UAEU, ISBN 0-86351-100-7
- Waston, I.C.** 1990. Characterization of Desalting Concentrates. *Desalination*. 78, (1990) 5-9.
- Yong, R.N., Mohamed, A.M.O. and Warkentin, B.P.** 1992. Principles of Contaminant Transport in Soils. Publisher: Elsevier science.

# Appendix A



**UNITED ARAB EMIRATES UNIVERSITY  
FACULTY OF GRADUATE STUDIES  
ENVIRONMENTAL SCIENCE MASTER PROGRAM**

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## QUESTIONNAIRE SURVEY

Distributed to Inland Desalination Plants, UAE

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**THESIS TITLE:**                    **IMPACT OF REJECT BRINE CHEMICAL COMPOSITION FROM DESALINATION PLANT ON SOIL AND GROUNDWATER**

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### A. Primary Data:

1. Name of the desalination plant: \_\_\_\_\_
2. Type of the desalination plant: \_\_\_\_\_
3. Capacity (m<sup>3</sup>/day): \_\_\_\_\_
4. Date of operation: \_\_\_\_\_
5. Location: \_\_\_\_\_
6. Purpose of the plant: Please mark the appropriate box(es)  
 Domestic supply       Industrial supply       Agricultural supply
7. Source of feed water:  
 Groundwater                       Sea water
8. Depth to groundwater table: \_\_\_\_\_
9. Total volume of feed, Product, and brine water produced (m<sup>3</sup>): \_\_\_\_\_



Year	Water type		
	Feed	Product	Brine
90			
91			
92			
93			
94			
95			
96			
97			
98			
99			
00			
01			
02			

10. Average quality of feed, product and brine water:

A. Electrical conductivity (mS/cm)

Water type	Year												
	90	91	92	93	94	95	96	97	98	99	00	01	02
Feed													
Product													
Brine													

B. Does your company conduct heavy metal analysis for the feed, brine or product?

Yes

Feed

Product

Brine

If yes, please fill the attached table (A) for the results of the analysis of the following metals: As, Ba, Cr, Cd, Pb, Hg, Se.

C. Does your company conduct total hydrocarbon analysis for the feed, brine or product water?

Yes

Feed

Product

Brine

If yes, please fill the following table for the results in the previous years.

Year	Water type		
	Feed	Product	Brine
1990			
1991			
1992			
1993			
1994			
1995			
1996			
1997			
1998			
1999			
2000			
2001			
2002			

11. Brine Disposal Method (Please mark the appropriate disposal method)

- Surface water discharge.
- Deep well injection.
- Evaporation ponds (lined or unlined).
- Distance of the disposal site from the intake source: \_\_\_\_\_

12. Is there are a monitoring system (monitoring wells) for the quality of the underlying groundwater?

- Yes                       No

B. Chemicals used at your Desalination Plant

Treatment Process	Chemicals used	Purpose of using this chemical
Treatment of feed water		
Treatment of product water		
Chemicals used in cleaning		
Post-cleaning treatment		
Treatment of brine		
Others		

**Thank you for your kind cooperation.**

## APPENDIX B

### PHOTOGRAPHS OF INLAND DESALINATION PLANTS AND DISPOSAL SITES



Figure B1: Al Wagan Desalination Plant



Figure B.2: Chemical used for various purposes in RO Desalination Plant, Al Wagan



Figure B3: Mobile Desalination Plant, Al Wagan



Figure B.4: Sand Filtration used for Pre-Treatment of Feed water, Mobile RO Plant



Figure B.5: Point Source of Reject Brine, Al Wagan



Figure B 6: Landscape Around a Disposal Site, Al Wagan

## APPENDIX C

### PHOPTGRAPHS OF CLU EQUIPLMENTS, UAE UNIVERSITY



Figure C.1: Inductively Coupled Plasma Mass Spectrometry (ICP-MS) ICP-OES (VISTA – MPX, CCD)



Figure C.2: MAGNA – IR (560), E.S., Spectrometer



Figure C.3: MAGNA – IR (560), E.S., Spectrometer Figure B.3: HACH DR 4000U Spectrophotometer

Conc. (mg/l)	Opt. Density	Conc. (mg/l)	Opt. Density	Conc. (mg/l)	Opt. Density
100	0.5	100	0.5	100	0.5
80	0.4	80	0.4	80	0.4
60	0.3	60	0.3	60	0.3
40	0.2	40	0.2	40	0.2
20	0.1	20	0.1	20	0.1
Blank	0	Blank	0	Blank	0

Conc. (mg/l)	Opt. Density	Conc. (mg/l)	Opt. Density	Conc. (mg/l)	Opt. Density
100	0.5	100	0.5	100	0.5
80	0.4	80	0.4	80	0.4
60	0.3	60	0.3	60	0.3
40	0.2	40	0.2	40	0.2
20	0.1	20	0.1	20	0.1
Blank	0	Blank	0	Blank	0

# APPENDIX D

## EXPERIMENTAL AND MODEL DATA

### D1. Adsorption Isotherm Experiment

#### Batch Equilibrium Test (Adsorption Isotherms)

Table Chemical analysis of Ce in the liquid phase using ICP

Sample I.D	Conc.(mg/l)	Sr	K	SO4
Sand Dune	100	105	2.4	147
Sand Dune	50	37.7	4.1	95.8
Sand Dune	25	17.5	7.7	57.9
Sand Dune	10	7.4	16.8	57.7
Sand Dune	5	4.4	33	59.1
Orig. Soil	100	42.5	31.6	150
Orig. Soil	50	24.2	16.9	103
Orig. Soil	25	14.9	10.3	93.2
Orig. Soil	10	11.3	5.7	68.2
Orig. Soil	5	9.2	5.7	78.8
Blank*		<b>124</b>	<b>36.2</b>	<b>92.3</b>
Dist. Water		0	0	0

#### K

Bottle	Soil I.D	Soil mass (g)	Solution volume (ml)	Co	Ceq (mg/l)	Ssoil
1(100ppm)	S. Dune	10	100	36.2	33	32
2(50 ppm)	S. Dune	10	100	18.1	16.8	13
3(25 ppm)	S. Dune	10	100	9.05	7.7	13.5
4(10 ppm)	S. Dune	10	100	3.62	4.1	-4.8
5 (5 ppm)	S. Dune	10	100	1.81	2.4	-5.9
6(100ppm)	In-place	10	100	36.2	31.6	46
7 (50ppm)	In-place	10	100	18.1	16.9	12
8 (25ppm)	In-place	10	100	9.05	10.3	-12.5
9(10 ppm)	In-place	10	100	3.62	5.7	-20.8
10(5 ppm)	In-place	10	100	1.81	5.7	-38.9
11	Control	0	100	36.2		

\*Ssoil = (mg/kg Soil)



**Sr**

Bottle	Soil I.D	soil mass (g)	solution volume	Co	Ceq	Ssoil
1(100ppm)	S. Dune	10	100	124	105	190
2(50 ppm)	S. Dune	10	100	62	37.7	243
3(25 ppm)	S. Dune	10	100	31	17.5	135
4(10 ppm)	S. Dune	10	100	12.4	7.4	50
5 (5 ppm)	S. Dune	10	100	6.2	4.4	18
6(100ppm)	In-place	10	100	124	42.5	815
7(50 ppm)	In-place	10	100	62	24.2	378
8(25 ppm)	In-place	10	100	31	14.9	161
9(10 ppm)	In-place	10	100	12.4	11.3	11
10(5 ppm)	In-place	10	100	6.2	9.2	-30
11	Control	0	100	124		

**SO4**

Bottle	Soil I.D	soil mass (g)	solution volume	Co	Ceq	Ssoil
1(100ppm)	S. Dune	10	100	92.3	147	-547
2(50 ppm)	S. Dune	10	100	46.15	95.8	-496.5
3(25 ppm)	S. Dune	10	100	23.08	57.9	-348.25
4(10 ppm)	S. Dune	10	100	9.23	57.7	-484.7
5 (5 ppm)	S. Dune	10	100	4.62	59.1	-544.85
6(100ppm)	In-place	10	100	92.3	150	-577
7(50 ppm)	In-place	10	100	46.15	103	-568.5
8(25 ppm)	In-place	10	100	23.08	93.2	-701.25
9(10 ppm)	In-place	10	100	9.23	68.2	-589.7
10(5 ppm)	In-place	10	100	4.62	78.8	-741.85
11	Control	0	100	92.3		

The initial concentrations of Sr, K, and SO4 in the two soils are summarized below:

	Sr	In-place Soil SO4	K
Acid Digestion (mg/kg soil)	1,292	24,513	1,589
1:2.5 Ratio (mg/l)	6.41	0	69.52
	Sr	Sand Dune SO4	K
Acid Digestion (mg/kg soil)	80.03	4,700	534.61
1:2.5 Ratio (mg/l)	4	897	18.591

N/B. Reject Brine Water were collected from Al-Wagan BWRO Plant and used to run the Column test. The Reject Brine Contains the following constituents:

Sr	SO4	K	EC (mS/cm)	Na	Cl	pH
21.63	1,540	68.49	12.9	2,248	8,946	7.03
TDS						
7.77						

## D2. Miscible Displacement Experiment

### Miscible Displacement Experiment

#### Column # 1: Sand Dune

<b>Q</b>	10	ml/hr
<b>L</b>	50	cm
<b>A</b>	19.63	cm <sup>2</sup>
<b>theta</b>	0.3	
<b>v</b>	1.698081	cm/hr
<b>rho</b>	1.7	g/cm <sup>3</sup>

Tube #	Time (hr)	Actual time	# PV	Sample #	Sr	EC
7	10.5	9.75	0.3566	3.9	0.6	0.1398
10	15	14.25	0.50942	5.7	0.65	0.1423
14	21	20.25	0.71319	8.1	0.66	0.1795
15	22.5	21.75	0.76414	8.7	1.33	1.795
16	24	23.25	0.81508	9.3	3.08	2.98
17	25.5	24.75	0.86602	9.9	9.89	3.98
18	27	26.25	0.91696	10.5	12.8	7.65
19	28.5	27.75	0.96791	11.1	15.69	11.6
20	30	29.25	1.01885	11.7	19.89	12.76
21	31.5	30.75	1.06979	12.3	24.66	13.08
22	33	32.25	1.12073	12.9	30.57	13.34
23	34.5	33.75	1.17168	13.5	34.2	13.35
28	42	41.25	1.42639	16.5	36.8	13.35
30	45	44.25	1.52827	17.7	38	13
38	57	56.25	1.93581	22.5	40.9	13.45
43	64.5	63.75	2.19052	25.5	42.7	13.38
48	72	71.25	2.44524	28.5	48.8	13.24
53	79.5	78.75	2.69995	31.5	51.3	13.45
58	87	86.25	2.95466	34.5	51.8	13.3
63	94.5	93.75	3.20937	37.5	51.9	13.4
69	103.5	102.75	3.51503	41.1	52.4	13.16
70	106.5	104.25	3.61691	41.7	52.4	13.18
73	111	108.75	3.76974	43.5	52.3	13.2
75	114	111.75	3.87163	44.7	52.4	13.46
80	121.5	119.25	4.12634	47.7	52.6	13.23
85	129	126.75	4.38105	50.7	52.6	13
90	135	134.25	4.58482	53.7	52	13.21
95	144	141.75	4.89047	56.7	52.4	13.39
99	150	147.75	5.09424	59.1	52	13.25
100	151.5	149.25	5.14519	59.7	52	13.23
101	153	150.75	5.19613	60.3	52	13.25
105	159	156.75	5.3999	62.7	52.4	13.55
110	168	164.25	5.70555	65.7	52.4	13.44
115	175.5	171.75	5.96026	68.7	52.5	13.48
120	183	179.25	6.21498	71.7	52	13.27
121	184.5	180.75	6.26592	72.3	52.2	13.26

C/Co(Sr)	C/Co(EC)	R for Sr Area under	R for EC Area under
0.01145	0.010356		
0.012405	0.010541	0.001822845	0.0016
0.012595	0.013296	0.002547122	0.00243
0.025382	0.132963	0.000967323	0.00373
0.058779	0.220741	0.002143665	0.00901
0.18874	0.294815	0.006304612	0.01313
0.244275	0.566667	0.011029426	0.02194
0.299427	0.859259	0.013848759	0.03632
0.37958	0.945185	0.017295151	0.04596
0.470611	0.968889	0.021655396	0.04875
0.583397	0.988148	0.026846858	0.04985
0.652672	0.988889	0.031484175	0.05036
<b>0.70229</b>	0.988889	0.172562638	0.25188
<b>0.725191</b>	0.962963	0.072719354	0.09943
<b>0.780534</b>	0.996296	0.306821231	0.39924
<b>0.814885</b>	0.991111	0.20318643	0.25311
0.931298	0.980741	0.222387061	0.25113
0.979008	0.996296	0.243289015	0.25179
0.98855	0.985185	0.250580394	0.25235
0.990458	0.992593	0.25203867	0.25188
1	0.974815	0.304196334	0.30067
1	0.976296	<b>2.163726459</b>	<b>2.59456</b>
0.998092	0.977778	<b>1.35130156</b>	<b>0.92047</b>
1	0.997037		
1.003817	0.98		
1.003817	0.962963		
0.992366	0.978519		
1	0.991852		
0.992366	0.981481		
0.992366	0.98		
0.992366	0.981481		
1	1.003704		
1	0.995556		
1.001908	0.998519		
0.992366	0.982963		
0.996183	0.982222		

Miscible Displacement Experiment

Column # 2: In-place Soil

Q	10	ml/hr
L	50	cm
A	19.63	cm <sup>2</sup>
theta	0.38	
v	1.34059	cm/hr
rho	1.7	g/cm <sup>3</sup>

							R for Sr
Tube #	Time (hr)	Actual time	# PV	Sample #	Sr	C/Co(Sr)	Area under
1	1	0.5	0.026812	0.2	0.119	0.00144593	
5	5	4.5	0.134059	1.8	0.135	0.00164034	0.000165497
8	8	7.5	0.214494	3	0.156	0.0018955	0.000142204
10	10	9.5	0.268118	3.8	0.169	0.00205346	0.000105879
15	15	14.5	0.402177	5.8	0.196	0.00238153	0.000297276
20	20	19.5	0.536236	7.8	2.66	0.03232078	0.002326079
21	21	20.5	0.563048	8.2	2.37	0.02879708	0.00081934
23	23	22.5	0.616672	9	3.83	0.04653706	0.002019845
25	25	24.5	0.670295	9.8	4.95	0.06014581	0.002860361
30	30	29.5	0.804354	11.8	5.7	0.06925881	0.008673929
35	35	34.5	0.938413	13.8	6.84	0.08311057	0.010213246
40	40	39.5	1.072472	15.8	9.81	0.11919806	0.01356065
45	45	44.5	1.206531	17.8	10.96	0.13317132	0.016916198
50	50	49.5	1.34059	19.8	12.67	0.15394897	0.019245535
55	55	54.5	1.474649	21.8	13.83	0.16804374	0.021583017
60	60	59.5	1.608708	23.8	15.2	0.18469016	0.023643584
65	65	64.5	1.742768	25.8	16.2	0.19684083	0.025573839
70	70	69.5	1.876827	27.8	16.7	0.20291616	0.026795519
75	75	74.5	2.010886	29.8	17.99	0.21859052	0.028253391
80	80	79.5	2.144945	31.8	19.88	0.24155529	0.030843353
85	85	84.5	2.279004	33.8	23.01	0.27958688	0.034931909
90	90	89.5	2.413063	35.8	25.87	0.31433779	0.039810485
95	95	94.5	2.547122	37.8	27.51	0.33426488	0.043475526
100	100	99.5	2.681181	39.8	30.73	0.37339004	0.04743377
105	105	104.5	2.81524	41.8	34.97	0.42490887	0.053509592
110	110	109.5	2.949299	43.8	38.63	0.46938032	0.059943775
115	115	114.5	3.083358	45.8	39.96	0.4855407	0.064007897
120	120	119.5	3.217417	47.8	41.11	0.49951397	0.066027742
125	125	124.5	3.351476	49.8	43.25	0.5255164	0.068707294
130	130	129.5	3.485535	51.8	45.6	0.55407047	0.07236419
135	135	134.5	3.619594	53.8	48.79	0.59283111	0.076876262
140	140	139.5	3.753653	55.8	51.23	0.62247874	0.081461635
145	145	144.5	3.887712	57.8	52.98	0.64374241	0.084874195
150	150	149.5	4.021771	59.8	55.87	0.67885784	0.088653259
155	155	154.5	4.15583	61.8	64.3	0.78128797	0.097872872
160	160	159.5	4.289889	63.8	66.71	0.81057108	0.106701548
165	165	164.5	4.423948	65.8	69.4	0.84325638	0.110855261
170	170	169.5	4.558007	67.8	69.77	0.84775213	0.113347488
175	175	174.5	4.692066	69.8	71.83	0.8727825	0.11532661
180	180	179.5	4.826125	71.8	73.7	0.89550425	0.118527412
185	185	184.5	4.960184	73.8	74.04	0.89963548	0.120327354
190	190	189.5	5.094244	75.8	80.76	0.98128797	0.126077396
195	195	194.5	5.228303	77.8	82.18	0.99854192	0.132707047
200	200	199.5	5.362362	79.8	82.28	0.99975699	0.133945016

205	205	204.5	5.496421	81.8	82.6	1.0036452	0.134287087
210	210	209.5	5.63048	83.8	82.63	1.00400972	<b>2.426091362</b>
215	215	214.5	5.764539	85.8	83.67	1.01664642	<b>2.936270222</b>
220	220	219.5	5.898598	87.8	82.69	1.00473876	

R for EC

Tube #	Time (hr)	Actual time	# PV	Sample #	EC	C/Co(EC)	Area under
1	1	0.5	0.026812	0.2	0.203	0.01514925	
5	5	4.5	0.134059	2	0.288	0.02149254	0.001964865
8	8	7.5	0.214494	3.2	0.295	0.02201493	0.001749771
10	10	9.5	0.268118	4	0.36	0.02686567	0.001310577
12	12	11.5	0.321742	4.8	0.377	0.02813433	0.001474649
14	14	13.5	0.375365	5.6	0.41	0.03059701	0.001574693
16	16	15.5	0.428989	6.4	0.521	0.0388806	0.00186282
18	18	17.5	0.482613	7.2	0.623	0.04649254	0.002289008
20	20	19.5	0.536236	8	0.826	0.06164179	0.002899277
23	23	22.5	0.616672	9.2	0.899	0.06708955	0.00517728
25	25	24.5	0.670295	10	1.766	0.13179104	0.005332348
30	30	29.5	0.804354	12	3.235	0.24141791	0.025016017
35	35	34.5	0.938413	14	4.766	0.35567164	0.040022626
40	40	39.5	1.072472	16	5.688	0.42447761	0.05229303
45	45	44.5	1.206531	18	6.79	0.50671642	0.062417489
50	50	49.5	1.34059	20	7.981	0.59559701	0.07388754
55	55	54.5	1.474649	22	8.65	0.64552239	0.083191638
60	60	59.5	1.608708	24	8.77	0.65447761	0.087138376
65	65	64.5	1.742768	26	10.661	0.79559701	0.097197806
70	70	69.5	1.876827	28	11.211	0.83664179	0.109408183
75	75	74.5	2.010886	30	12.12	0.90447761	0.116706397
80	80	79.5	2.144945	32	12.46	0.92985075	0.122954149
85	85	84.5	2.279004	34	12.76	0.95223881	0.126155559
90	90	89.5	2.413063	36	13.14	0.98059701	0.129557057
95	95	94.5	2.547122	38	13.17	0.98283582	0.13160796
100	100	99.5	2.681181	40	13.18	0.98358209	0.131808048
105	105	104.5	2.81524	42	13.26	0.98955224	0.132258247
110	110	109.5	2.949299	44	13.36	0.99701493	0.133158643
115	115	114.5	3.083358	46	13.36	0.99701493	0.133658863
120	120	119.5	3.217417	48	13.38	0.99850746	0.133758907
125	125	124.5	3.351476	50	13.37	0.99776119	0.133808929
130	130	129.5	3.485535	52	13.39	0.99925373	0.133858951
135	135	134.5	3.619594	54	13.38	0.99850746	0.133908974
140	140	139.5	3.753653	56	13.39	0.99925373	0.133908974
145	145	144.5	3.887712	58	13.39	0.99925373	0.133958996
150	150	149.5	4.021771	60	13.41	1.00074627	0.13405904
155	155	154.5	4.15583	62	13.25	0.98880597	0.133358731
160	160	159.5	4.289889	64	13.24	0.9880597	0.132508357
165	165	164.5	4.423948	66	13.29	0.99179104	0.132708445
170	170	169.5	4.558007	68	13.36	0.99701493	0.133308709
175	175	174.5	4.692066	70	13.37	0.99776119	0.133708885
180	180	179.5	4.826125	72	13.39	0.99925373	0.133858951
185	185	184.5	4.960184	74	13.38	0.99850746	0.133908974
190	190	189.5	5.094244	76	13.37	0.99776119	0.133808929
195	195	194.5	5.228303	78	13.36	0.99701493	0.133708885
200	200	199.5	5.362362	80	13.38	0.99850746	0.133758907

105	205	104.5	5.496421	82	13.39	0.99925373	0.133908974
210	210	209.5	5.63048	84	13.39	0.99925373	<b>4.219882436</b>
215	215	214.5	5.764539	86	13.39	0.99925373	<b>1.544656267</b>
220	220	219.5	5.898598	88	13.39	0.99925373	

DISCRETE MODEL DATA



srsand

BLOCK A: MODEL DESCRIPTION \*\*\*\*\*

Simulation #2: Steady saturated flow in a In-place Soil column

Co(Sr) vs. PV at 50 cm (Juma K. Al-Handhaly, UAEU)

INVERSE MODE NREDU

1 2

MODC ZL(BLANK IF MODE=NREDU=1)

50

BLOCK B: INVERSE PROBLEM \*\*\*\*\*

IT ILMT MASS

0 0 0

BLOCK C: TRANSPORT PARAMETERS \*\*\*\*\*

Y D R Mu

.698 1.0 1.0 0.0

1 1 0

BLOCK D: BVP; MODB=0 ZERO; =1 Dirac ; =2 STEP; =3 A PULSE \*\*\*\*\*

MODB =4 MULTIPLE; =5 EXPONENTIAL; =6 ARBITRARY

0

BLOCK E: IVP; MODI=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL \*\*

MODI

BLOCK F: PVP; MODP=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL

MODP

BLOCK G: DATA FOR INVERSE PROBLEM \*\*\*\*\*

PUTM =0; Z,T,C =1; T,C FOR SAME Z =2; Z,C FOR SAME T

V C/Co (Give "0 0 0" after last data set.)

.356597	0.011450
.59424	0.012404
.713194	0.012595
.764137	0.025381
.815079	0.058778
.866021	0.188740
.916964	0.244274
.967906	0.299427
.018849	0.379580
.069791	0.470610
.120734	0.583396
.171676	0.652671
.426388	0.702290
.528273	0.725190
.935813	0.780534
.2190525	0.814885
.2445237	0.931297
.2699949	0.979007
.2954661	0.988549



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3.209373 0.990458  
3.515028 1.000000  
3.616913 1.000000  
0.00 0.00

\*\*\* BLOCK A: MODEL DESCRIPTION \*\*\*\*\*

Fig.7-3a: Steady saturated flow in a sand column  
C/Co(EC) vs. PV at 50 cm (sho shiozawa, unpublished, f0)

INVERSE MODE NREDU  
1 1 2  
MODC ZL(BLANK IF MODE=NREDU=1)  
1 50

\*\*\* BLOCK B: INVERSE PROBLEM \*\*\*\*\*

MIT ILMT MASS  
150 0 0

\*\*\* BLOCK C: TRANSPORT PARAMETERS \*\*\*\*\*

V D R Mu  
1.698 1.0 1.0 0.0  
0 1 1 0

\*\*\* BLOCK D: BVP; MODB=0 ZERO; =1 Dirac; =2 STEP; =3 A PULSE \*\*\*\*\*

MODB =4 MULTIPLE; =5 EXPONENTIAL; =6 ARBITRARY  
2  
1.0

\*\*\* BLOCK E: IVP; MODI=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL \*\*

MODI  
0

\*\*\* BLOCK F: PVP; MODP=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL

\*\*  
MODP  
0

\*\*\* BLOCK G: DATA FOR INVERSE PROBLEM \*\*\*\*\*

INPUTM =0; Z,T,C =1; T,C FOR SAME Z =2; Z,C FOR SAME T

1  
1  
PV C/Co (Give "0.0.0" after last data set.)  
0.356597 0.010356  
0.59424 0.010541  
0.713194 0.013296  
0.764137 0.132963  
0.815079 0.220741  
0.866021 0.294815  
0.916964 0.566667  
0.967906 0.859259  
1.018849 0.945185  
1.069791 0.968889  
1.120734 0.988148  
1.171676 0.988889  
1.426388 0.988889  
1.528273 0.962963  
1.935813 0.996296  
2.190525 0.991111

srsand

2.445237 0.980741  
2.699949 0.996296  
2.954661 0.985185  
3.209373 0.992593  
3.515028 0.974815  
3.616913 0.976296  
0.00 0.00

srsand

```
*****
*
* CXTFIT VERSION 2.0 (1/2/95)
* ANALYTICAL SOLUTIONS FOR ONE-DIMENSIONAL CDE
* NON-LINEAR LEAST-SQUARES ANALYSIS
*
* Simulation #1: Steady saturated flow in a sand dune column
* C/Co(Sr) vs. PV at 50 cm (Juma K. Al-Handhaly, UAEU)
*
* DATA INPUT FILE: srsand.in
*
*****
```

MODEL DESCRIPTION

```
=====
DETERMINISTIC EQUILIBRIUM CDE (MODE=1)
FLUX-AVERAGED CONCENTRATION
REDUCED TIME (T), POSITION(Z)
(ALL PARAMETERS EXCEPT D AND V ARE DIMENSIONLESS)
CHARACTERISTIC LENGTH = 50.0000
FOR DIMENSIONLESS PARAMETERS
```

INITIAL VALUES OF COEFFICIENTS

```
=====
NAME      INITIAL VALUE  FITTING
V.....  0.1698E+01   N
D.....  0.1000E+01   Y
R.....  0.1000E+01   Y
mu.....  0.0000E+00   N
```

BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS

```
=====
STEP INPUT OF CONC. = 1.0000
SOLUTE FREE INITIAL CONDITION
NO PRODUCTION TERM
```

PARAMETER ESTIMATION MODE

```
=====
MAXIMUM NUMBER OF ITERATIONS = 150
```

ITER	SSQ	D....	R....
0	0.4564E+00	0.100E+01	0.100E+01
1	0.2090E+00	0.183E+01	0.108E+01

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2	0.1476E+00	0.285E+01	0.113E+01
3	0.1247E+00	0.391E+01	0.117E+01
4	0.1162E+00	0.478E+01	0.120E+01
5	0.1135E+00	0.537E+01	0.122E+01
6	0.1127E+00	0.571E+01	0.123E+01
7	0.1126E+00	0.588E+01	0.124E+01
8	0.1125E+00	0.596E+01	0.124E+01
9	0.1125E+00	0.600E+01	0.124E+01
10	0.1125E+00	0.601E+01	0.124E+01
11	0.1125E+00	0.602E+01	0.124E+01
12	0.1125E+00	0.602E+01	0.124E+01
13	0.1125E+00	0.603E+01	0.124E+01
14	0.1125E+00	0.603E+01	0.124E+01
15	0.1125E+00	0.603E+01	0.124E+01

NO FURTHER DECREASE IN SSQ OBTAINED FROM 12 TO 15 ITERATIONS

COVARIANCE MATRIX FOR FITTED PARAMETERS

=====

D.... R....

D.... 1.000

R.... 0.687 1.000

RSQUARE FOR REGRESSION OF OBSERVED VS PREDICTED =0.99266463  
(COEFFICIENT OF DETERMINATION)

NON-LINEAR LEAST SQUARES ANALYSIS, FINAL RESULTS

=====

95% CONFIDENCE LIMITS

NAME	VALUE	S.E.COEFF.	T-VALUE	LOWER	UPPER
D....	0.6026E+01	0.1032E+00	.5838E+02	0.5811E+01	0.6242E+01
R....	0.1243E+01	0.1032E+00	.1204E+02	0.1027E+01	0.1458E+01

-----ORDERED BY COMPUTER INPUT-----

\$	NO	DISTANCE	CONCENTRATION		RESI-	DUAL
			TIME	OBS	FITTED	
	1	1.0000	0.3566	0.0115	0.0003	0.0111
	2	1.0000	0.5942	0.0124	0.0318	-0.0194
	3	1.0000	0.7132	0.0126	0.0907	-0.0781
	4	1.0000	0.7641	0.0254	0.1264	-0.1010
	5	1.0000	0.8151	0.0588	0.1674	-0.1086
	6	1.0000	0.8660	0.1887	0.2126	-0.0238
	7	1.0000	0.9170	0.2443	0.2608	-0.0165
	8	1.0000	0.9679	0.2994	0.3108	-0.0114
	9	1.0000	1.0188	0.3796	0.3616	0.0179
	10	1.0000	1.0698	0.4706	0.4122	0.0584

				srsand	
11	1.0000	1.1207	0.5834	0.4618	0.1216
12	1.0000	1.1717	0.6527	0.5097	0.1430
13	1.0000	1.4264	0.7023	0.7107	-0.0084
14	1.0000	1.5283	0.7252	0.7710	-0.0458
15	1.0000	1.9358	0.7805	0.9173	-0.1368
16	1.0000	2.1905	0.8149	0.9582	-0.1433
17	1.0000	2.4452	0.9313	0.9793	-0.0480
18	1.0000	2.6999	0.9790	0.9899	-0.0109
19	1.0000	2.9547	0.9885	0.9951	-0.0066
20	1.0000	3.2094	0.9905	0.9977	-0.0072
21	1.0000	3.5150	1.0000	0.9990	0.0010
22	1.0000	3.6169	1.0000	0.9993	0.0007

```

*****
*
* CXTFIT VERSION 2.0 (1/2/95)
* ANALYTICAL SOLUTIONS FOR ONE-DIMENSIONAL CDE
* NON-LINEAR LEAST-SQUARES ANALYSIS
*
* Simulation #1: Steady saturated flow in a sand column
* C/Co(EC) vs. PV at 50 cm (sho shiozawa, unpublished, f0)
*
* DATA INPUT FILE: srsand.in
*
*****

```

MODEL DESCRIPTION  
=====

DETERMINISTIC EQUILIBRIUM CDE (MODE=1)  
 FLUX-AVERAGED CONCENTRATION  
 REDUCED TIME (T), POSITION(Z)  
 (ALL PARAMETERS EXCEPT D AND V ARE DIMENSIONLESS)  
 CHARACTERISTIC LENGTH = 50.0000  
 FOR DIMENSIONLESS PARAMETERS

INITIAL VALUES OF COEFFICIENTS  
=====

NAME	INITIAL VALUE	FITTING
V.....	0.1698E+01	N
D.....	0.1000E+01	Y
R.....	0.1000E+01	Y
mu.....	0.0000E+00	N

BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS  
=====

STEP INPUT OF CONC. = 1.0000

srsand

SOLUTE FREE INITIAL CONDITION  
NO PRODUCTION TERM

PARAMETER ESTIMATION MODE

=====

MAXIMUM NUMBER OF ITERATIONS = 150

ITER	SSQ	D...	R...
0	0.5314E+00	0.100E+01	0.100E+01
1	0.8811E-01	0.951E+00	0.880E+00
2	0.2868E-01	0.304E+00	0.897E+00
3	0.2562E-01	0.372E+00	0.899E+00
4	0.2542E-01	0.389E+00	0.898E+00
5	0.2541E-01	0.393E+00	0.898E+00
6	0.2541E-01	0.394E+00	0.896E+00
7	0.2541E-01	0.394E+00	0.898E+00

COVARIANCE MATRIX FOR FITTED PARAMETERS

=====

	D...	R...
D...	1.000	
R...	0.031	1.000

RSQUARE FOR REGRESSION OF OBSERVED VS PREDICTED =0.99225796  
(COEFFICIENT OF DETERMINATION)

NON-LINEAR LEAST SQUARES ANALYSIS, FINAL RESULTS

=====

NAME	VALUE	S.E.COEFF.	T-VALUE	95% CONFIDENCE LIMITS	
				LOWER	UPPER
D....	0.3943E+00	0.3566E-01	.1106E+02	0.3200E+00	0.4687E+00
R....	0.8978E+00	0.3566E-01	.2518E+02	0.8234E+00	0.9722E+00

-----ORDERED BY COMPUTER INPUT-----

\$	NO	DISTANCE	CONCENTRATION		RESI-	
			TIME	OBS	FITTED	DUAL
	1	1.0000	0.3566	0.0104	0.0000	0.0104
	2	1.0000	0.5942	0.0105	0.0000	0.0105
	3	1.0000	0.7132	0.0133	0.0094	0.0039
	4	1.0000	0.7641	0.1330	0.0518	0.0812
	5	1.0000	0.8151	0.2207	0.1695	0.0512
	6	1.0000	0.8660	0.2948	0.3722	-0.0774
	7	1.0000	0.9170	0.5667	0.6056	-0.0389
	8	1.0000	0.9679	0.8593	0.7966	0.0626

				srsand	
9	1.0000	1.0188	0.9452	0.9136	0.0316
10	1.0000	1.0698	0.9689	0.9693	-0.0005
11	1.0000	1.1207	0.9881	0.9908	-0.0026
12	1.0000	1.1717	0.9889	0.9976	-0.0087
13	1.0000	1.4264	0.9889	1.0000	-0.0111
14	1.0000	1.5283	0.9630	1.0000	-0.0370
15	1.0000	1.9358	0.9963	1.0000	-0.0037
16	1.0000	2.1905	0.9911	1.0000	-0.0089
17	1.0000	2.4452	0.9807	1.0000	-0.0193
18	1.0000	2.6999	0.9963	1.0000	-0.0037
19	1.0000	2.9547	0.9852	1.0000	-0.0148
20	1.0000	3.2094	0.9926	1.0000	-0.0074
21	1.0000	3.5150	0.9748	1.0000	-0.0252
22	1.0000	3.6169	0.9763	1.0000	-0.0237

6

\*\*\* BLOCK A: MODEL DESCRIPTION \*\*\*\*\*

Equilibrium one-site CDE

Effect of Changing D

INVERSE MODE NREDU

0 1 2

MODC ZL

1 50

\*\*\* BLOCK C: TRANSPORT PARAMETERS \*\*\*\*\*

V D R Mu1

0.4 0.1 1.5 0.0

\*\*\* BLOCK D: BVP; MODB=0 ZERO; =1 Delta; =2 STEP; =3 A PULSE \*\*\*\*\*

MODB =4 MULTIPLE; =5 EXPONENTIAL; =6 ARBITRARY

2

1.0

\*\*\* BLOCK E: IVP; MODI=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL \*\*

MODI

0

\*\*\* BLOCK F: PVP; MODP=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL

\*\*\*

MODP

0

\*\*\* BLOCK H: POSITION AND TIME FOR DIRECT PROBLEM \*\*\*\*\*

NZ DZ ZI NT DT TI MPRINT

1 1.0 1.0 101 0.05 0.0 0

\*\*\* BLOCK A: MODEL DESCRIPTION \*\*\*\*\*

Fig.4-15. Equilibrium one-site CDE

Effect of Changing D

INVERSE MODE NREDU

0 1 2

MODC ZL

1 50

\*\*\* BLOCK C: TRANSPORT PARAMETERS \*\*\*\*\*

V D R Mu1

0.4 1 1.5 0.0

\*\*\* BLOCK D: BVP; MODB=0 ZERO; =1 Delta; =2 STEP; =3 A PULSE \*\*\*\*\*

MODB =4 MULTIPLE; =5 EXPONENTIAL; =6 ARBITRARY

2

1.0

\*\*\* BLOCK E: IVP; MODI=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL \*\*

MODI

0

\*\*\* BLOCK F: PVP; MODP=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL

\*\*\*

MODP

0

\*\*\* BLOCK H: POSITION AND TIME FOR DIRECT PROBLEM \*\*\*\*\*

NZ DZ ZI NT DT TI MPRINT

1 1.0 1.0 101 0.05 0.0 0

\*\*\* BLOCK A: MODEL DESCRIPTION \*\*\*\*\*



Fig.4-15. Equilibrium one-site CDE  
Effect of Changing D

```

INVERSE  MODE  NREDU
  0      1      2
MODC     ZL
  1      50
*** BLOCK C: TRANSPORT PARAMETERS *****
  V  D  R  Mu1
  0.4 10 1.5 0.0
*** BLOCK D: BVP; MODB=0 ZERO; =1 Delta; =2 STEP; =3 A PULSE *****
MODB           =4 MULTIPLE; =5 EXPONENTIAL; =6 ARBITRARY
  2
  1.0
*** BLOCK E: IVP; MODI=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL **
MODI
  0
*** BLOCK F: PVP; MODP=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL
**
MODP
  0
*** BLOCK H: POSITION AND TIME FOR DIRECT PROBLEM *****
  NZ  DZ  ZI  NT  DT  TI  MPRINT
  1   1.0 1.0 101 0.05 0.0  0
*** BLOCK A: MODEL DESCRIPTION *****

```

Fig.4-15. Equilibrium one-site CDE  
Effect of Changing D

```

INVERSE  MODE  NREDU
  0      1      2
MODC     ZL
  1      50
*** BLOCK C: TRANSPORT PARAMETERS *****
  V  D  R  Mu1
  0.4 1  3 0.0
*** BLOCK D: BVP; MODB=0 ZERO; =1 Delta; =2 STEP; =3 A PULSE *****
MODB           =4 MULTIPLE; =5 EXPONENTIAL; =6 ARBITRARY
  2
  1.0
*** BLOCK E: IVP; MODI=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL **
MODI
  0
*** BLOCK F: PVP; MODP=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL
**
MODP
  0
*** BLOCK H: POSITION AND TIME FOR DIRECT PROBLEM *****
  NZ  DZ  ZI  NT  DT  TI  MPRINT
  1   1.0 1.0 101 0.05 0.0  0
*** BLOCK A: MODEL DESCRIPTION *****

```

Fig.4-15. Equilibrium one-site CDE  
Effect of Changing D

direct21

```
INVERSE  MODE  NREDU
  0      1      2
MODC     ZL
  1     50
*** BLOCK C: TRANSPORT PARAMETERS *****
  V  D  R  Mu1
  0.4 1  5  0.0
** BLOCK D: BVP; MODB=0 ZERO; =1 Delta; =2 STEP; =3 A PULSE *****
MODB           =4 MULTIPLE; =5 EXPONENTIAL; =6 ARBITRARY
  2
  1.0
*** BLOCK E: IVP; MODI=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL **
MODI
  0
*** BLOCK F: PVP; MODP=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL
**
MODP
  0
*** BLOCK H: POSITION AND TIME FOR DIRECT PROBLEM *****
  NZ  DZ  ZI  NT  DT  TI  MPRINT
  1   1.0 1.0 101 0.05 0.0  0
*** BLOCK A: MODEL DESCRIPTION *****
```

Fig.4-15. Equilibrium one-site CDE

Effect of Changing D

```
INVERSE  MODE  NREDU
  0      1      2
MODC     ZL
  1     50
*** BLOCK C: TRANSPORT PARAMETERS *****
  V  D  R  Mu1
  0.265 0.25 10 0.0
** BLOCK D: BVP; MODB=0 ZERO; =1 Delta; =2 STEP; =3 A PULSE *****
MODB           =4 MULTIPLE; =5 EXPONENTIAL; =6 ARBITRARY
  2
  1.0
*** BLOCK E: IVP; MODI=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL **
MODI
  0
*** BLOCK F: PVP; MODP=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL
**
MODP
  0
*** BLOCK H: POSITION AND TIME FOR DIRECT PROBLEM *****
  NZ  DZ  ZI  NT  DT  TI  MPRINT
  1   1.0 1.0 101 0.05 0.0  0
```

direct21

\*\*\*\*\*

```
*
*
* CXTFIT VERSION 2.0 (1/2/95)
* ANALYTICAL SOLUTIONS FOR ONE-DIMENSIONAL CDE
* DIRECT PROBLRM
*
* Fig.4-15. Equilibrium one-site CDE
* Effect of Changing D
*
* DATA INPUT FILE: Direct21.in
*
```

\*\*\*\*\*

MODEL DESCRIPTION

=====

DETERMINISTIC EQUILIBRIUM CDE (MODE=1)  
FLUX-AVERAGED CONCENTRATION  
REDUCED TIME (T), POSITION(Z)  
(ALL PARAMETERS EXCEPT D AND V ARE DIMENSIONLESS)  
CHARACTERISTIC LENGTH = 50.0000  
FOR DIMENSIONLESS PARAMETERS

INITIAL VALUES OF COEFFICIENTS

=====

NAME	INITIAL VALUE
V.....	0.4000E+00
D.....	0.1000E+00
R.....	0.1500E+01
mu.....	0.0000E+00

BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS

=====

STEP INPUT OF CONC. = 1.0000  
SOLUTE FREE INITIAL CONDITION  
NO PRODUCTION TERM

== 1.0000 (FLUX CONC. VS. TIME)

uum(C\*dT)= 3.5000

TIME	C
0.0000	0.00000E+00
0.0500	0.00000E+00
0.1000	0.00000E+00
0.1500	0.00000E+00

direct21

2500	0.00000E+00
3000	0.00000E+00
3500	0.00000E+00
4000	0.00000E+00
4500	0.00000E+00
5000	0.00000E+00
5500	0.97559E-25
6000	0.17056E-20
6500	0.51903E-17
7000	0.40013E-14
7500	0.10293E-11
8000	0.10865E-09
8500	0.55127E-08
9000	0.15209E-06
9500	0.25152E-05
10000	0.26977E-04
10500	0.19976E-03
11000	0.10771E-02
11500	0.44173E-02
12000	0.14297E-01
12500	0.37687E-01
13000	0.83156E-01
13500	0.15732E+00
14000	0.26075E+00
14500	0.38608E+00
15000	0.51990E+00
15500	0.64736E+00
16000	0.75684E+00
16500	0.84244E+00
17000	0.90386E+00
17500	0.94462E+00
18000	0.96980E+00
18500	0.98436E+00
19000	0.99228E+00
19500	0.99636E+00
20000	0.99836E+00
20500	0.99929E+00
21000	0.99970E+00
21500	0.99988E+00
22000	0.99995E+00
22500	0.99998E+00
23000	0.99999E+00
23500	0.10000E+01
24000	0.10000E+01
24500	0.10000E+01
25000	0.10000E+01
25500	0.10000E+01
26000	0.10000E+01
26500	0.10000E+01
27000	0.10000E+01
27500	0.10000E+01

direct21

2.7500 0.10000E+01  
2.8000 0.10000E+01  
2.8500 0.10000E+01  
2.9000 0.10000E+01  
2.9500 0.10000E+01  
3.0000 0.10000E+01  
3.0500 0.10000E+01  
3.1000 0.10000E+01  
3.1500 0.10000E+01  
3.2000 0.10000E+01  
3.2500 0.10000E+01  
3.3000 0.10000E+01  
3.3500 0.10000E+01  
3.4000 0.10000E+01  
3.4500 0.10000E+01  
3.5000 0.10000E+01  
3.5500 0.10000E+01  
3.6000 0.10000E+01  
3.6500 0.10000E+01  
3.7000 0.10000E+01  
3.7500 0.10000E+01  
3.8000 0.10000E+01  
3.8500 0.10000E+01  
3.9000 0.10000E+01  
3.9500 0.10000E+01  
4.0000 0.10000E+01  
4.0500 0.10000E+01  
4.1000 0.10000E+01  
4.1500 0.10000E+01  
4.2000 0.10000E+01  
4.2500 0.10000E+01  
4.3000 0.10000E+01  
4.3500 0.10000E+01  
4.4000 0.10000E+01  
4.4500 0.10000E+01  
4.5000 0.10000E+01  
4.5500 0.10000E+01  
4.6000 0.10000E+01  
4.6500 0.10000E+01  
4.7000 0.10000E+01  
4.7500 0.10000E+01  
4.8000 0.10000E+01  
4.8500 0.10000E+01  
4.9000 0.10000E+01  
4.9500 0.10000E+01  
5.0000 0.10000E+01

direct21

CXTFIT VERSION 2.0 (1/2/95) \*  
ANALYTICAL SOLUTIONS FOR ONE-DIMENSIONAL CDE \*  
DIRECT PROBLRM \*

Fig.4-15. Equilibrium one-site CDE \*  
Effect of Changing D \*

DATA INPUT FILE: Direct21.in \*

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MODEL DESCRIPTION

=====

DETERMINISTIC EQUILIBRIUM CDE (MODE=1)  
FLUX-AVERAGED CONCENTRATION  
REDUCED TIME (T), POSITION(Z)  
(ALL PARAMETERS EXCEPT D AND V ARE DIMENSIONLESS)  
CHARACTERISTIC LENGTH = 50.0000  
FOR DIMENSIONLESS PARAMETERS

INITIAL VALUES OF COEFFICIENTS

=====

NAME	INITIAL VALUE
.....	0.4000E+00
.....	0.1000E+01
.....	0.1500E+01
ju.....	0.0000E+00

BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS

=====

STEP INPUT OF CONC. = 1.0000  
DOLUTE FREE INITIAL CONDITION  
NO PRODUCTION TERM

1.0000 (FLUX CONC. VS. TIME)

n(C\*dT)= 3.5000

TIME	C
0.0000	0.00000E+00
0.5000	0.00000E+00
1.0000	0.27480E-29
2.5000	0.20556E-18
5.0000	0.54135E-13
7.5000	0.93196E-10
10.0000	0.12929E-07
12.5000	0.42464E-06

direct21

0.4500	0.41413E-04
0.5000	0.19868E-03
0.5500	0.70185E-03
0.6000	0.19709E-02
0.6500	0.46395E-02
0.7000	0.95098E-02
0.7500	0.17453E-01
0.8000	0.29288E-01
0.8500	0.45663E-01
0.9000	0.66981E-01
0.9500	0.93354E-01
1.0000	0.12461E+00
1.0500	0.16033E+00
1.1000	0.19988E+00
1.1500	0.24253E+00
1.2000	0.28745E+00
1.2500	0.33379E+00
1.3000	0.38077E+00
1.3500	0.42764E+00
1.4000	0.47375E+00
1.4500	0.51856E+00
1.5000	0.56161E+00
1.5500	0.60256E+00
1.6000	0.64118E+00
1.6500	0.67729E+00
1.7000	0.71082E+00
1.7500	0.74175E+00
1.8000	0.77009E+00
1.8500	0.79593E+00
1.9000	0.81937E+00
1.9500	0.84053E+00
2.0000	0.85956E+00
2.0500	0.87660E+00
2.1000	0.89180E+00
2.1500	0.90532E+00
2.2000	0.91731E+00
2.2500	0.92790E+00
2.3000	0.93725E+00
2.3500	0.94547E+00
2.4000	0.95268E+00
2.4500	0.95899E+00
2.5000	0.96451E+00
2.5500	0.96932E+00
2.6000	0.97352E+00
2.6500	0.97716E+00
2.7000	0.98032E+00
2.7500	0.98307E+00
2.8000	0.98544E+00
2.8500	0.98749E+00

direct21

9500	0.99079E+00
0000	0.99211E+00
0500	0.99324E+00
1000	0.99421E+00
1500	0.99505E+00
2000	0.99577E+00
2500	0.99639E+00
3000	0.99691E+00
3500	0.99737E+00
4000	0.99775E+00
4500	0.99808E+00
5000	0.99837E+00
5500	0.99861E+00
6000	0.99882E+00
6500	0.99899E+00
7000	0.99914E+00
7500	0.99927E+00
8000	0.99938E+00
8500	0.99947E+00
9000	0.99955E+00
9500	0.99962E+00
00000	0.99968E+00
00500	0.99973E+00
01000	0.99977E+00
01500	0.99980E+00
02000	0.99983E+00
02500	0.99986E+00
03000	0.99988E+00
03500	0.99990E+00
04000	0.99991E+00
04500	0.99993E+00
05000	0.99994E+00
05500	0.99995E+00
06000	0.99996E+00
06500	0.99996E+00
07000	0.99997E+00
07500	0.99997E+00
08000	0.99998E+00
08500	0.99998E+00
09000	0.99998E+00
09500	0.99999E+00
00000	0.99999E+00

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direct21

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* Fig.4-15. Equilibrium one-site CDE
* Effect of Changing D
*
* DATA INPUT FILE: Direct21.in
*

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\*\*\*\*\*

MODEL DESCRIPTION

=====

DETERMINISTIC EQUILIBRIUM CDE (MODE=1)  
 FLUX-AVERAGED CONCENTRATION  
 REDUCED TIME (T), POSITION(Z)  
 (ALL PARAMETERS EXCEPT D AND V ARE DIMENSIONLESS)  
 CHARACTERISTIC LENGTH = 50.0000  
 FOR DIMENSIONLESS PARAMETERS

INITIAL VALUES OF COEFFICIENTS

=====

NAME	INITIAL VALUE
V.....	0.4000E+00
D.....	0.1000E+02
R.....	0.1500E+01
mu.....	0.0000E+00

BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS

=====

STEP INPUT OF CONC. = 1.0000  
 SOLUTE FREE INITIAL CONDITION  
 NO PRODUCTION TERM

= 1.0000 (FLUX CONC. VS. TIME)

$\int_0^L \mu m(C \cdot dT) = 3.5710$

TIME	C
0.0000	0.00000E+00
0.0500	0.11561E-06
0.1000	0.28375E-03
0.1500	0.40765E-02
0.2000	0.15871E-01
0.2500	0.36377E-01
0.3000	0.63754E-01
0.3500	0.95669E-01
0.4000	0.13015E+00
0.4500	0.16573E+00
0.5000	0.20140E+00
0.5500	0.23650E+00

direct21

6500 0.30348E+00  
7000 0.33495E+00  
7500 0.36498E+00  
8000 0.39354E+00  
8500 0.42066E+00  
9000 0.44638E+00  
9500 0.47076E+00  
0000 0.49386E+00  
0500 0.51574E+00  
1000 0.53647E+00  
1500 0.55611E+00  
2000 0.57472E+00  
2500 0.59238E+00  
3000 0.60913E+00  
3500 0.62502E+00  
4000 0.64012E+00  
4500 0.65446E+00  
5000 0.66810E+00  
5500 0.68107E+00  
6000 0.69342E+00  
6500 0.70518E+00  
7000 0.71638E+00  
7500 0.72706E+00  
8000 0.73725E+00  
8500 0.74697E+00  
9000 0.75625E+00  
9500 0.76511E+00  
0000 0.77359E+00  
0500 0.78169E+00  
1000 0.78944E+00  
1500 0.79686E+00  
2000 0.80396E+00  
2500 0.81077E+00  
3000 0.81729E+00  
3500 0.82354E+00  
4000 0.82953E+00  
4500 0.83529E+00  
5000 0.84081E+00  
5500 0.84611E+00  
6000 0.85120E+00  
6500 0.85609E+00  
7000 0.86079E+00  
7500 0.86531E+00  
8000 0.86966E+00  
8500 0.87384E+00  
9000 0.87787E+00  
9500 0.88174E+00  
0000 0.88548E+00  
0500 0.88907E+00

direct21

3.1500	0.89587E+00
3.2000	0.89909E+00
3.2500	0.90219E+00
3.3000	0.90518E+00
3.3500	0.90806E+00
3.4000	0.91085E+00
3.4500	0.91354E+00
3.5000	0.91613E+00
3.5500	0.91864E+00
3.6000	0.92105E+00
3.6500	0.92339E+00
3.7000	0.92565E+00
3.7500	0.92783E+00
3.8000	0.92994E+00
3.8500	0.93198E+00
3.9000	0.93395E+00
3.9500	0.93586E+00
4.0000	0.93770E+00
4.0500	0.93949E+00
4.1000	0.94121E+00
4.1500	0.94288E+00
4.2000	0.94450E+00
4.2500	0.94607E+00
4.3000	0.94758E+00
4.3500	0.94905E+00
4.4000	0.95048E+00
4.4500	0.95185E+00
4.5000	0.95319E+00
4.5500	0.95448E+00
4.6000	0.95573E+00
4.6500	0.95695E+00
4.7000	0.95813E+00
4.7500	0.95927E+00
4.8000	0.96038E+00
4.8500	0.96145E+00
4.9000	0.96249E+00
4.9500	0.96350E+00
5.0000	0.96448E+00

\*\*\*\*\*

CXTFIT VERSION 2.0 (1/2/95)  
ANALYTICAL SOLUTIONS FOR ONE-DIMENSIONAL CDE  
DIRECT PROBLRM

Fig.4-15. Equilibrium one-site CDE  
Effect of Changing D

\*\*\*\*\*

MODEL DESCRIPTION

=====

DETERMINISTIC EQUILIBRIUM CDE (MODE=1)  
 FLUX-AVERAGED CONCENTRATION  
 REDUCED TIME (T), POSITION(Z)  
 (ALL PARAMETERS EXCEPT D AND V ARE DIMENSIONLESS)  
 CHARACTERISTIC LENGTH = 50.0000  
 FOR DIMENSIONLESS PARAMETERS

INITIAL VALUES OF COEFFICIENTS

=====

NAME	INITIAL VALUE
.....	0.4000E+00
.....	0.1000E+01
.....	0.3000E+01
U.....	0.0000E+00

BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS

=====

STEP INPUT OF CONC. = 1.0000  
 SOLUTE FREE INITIAL CONDITION  
 NO PRODUCTION TERM

1.0000 (FLUX CONC. VS. TIME)

(C\*dT)= 2.0235

TIME	C
0000	0.00000E+00
0500	0.00000E+00
1000	0.00000E+00
1500	0.00000E+00
2000	0.27480E-29
2500	0.92476E-23
3000	0.20556E-18
3500	0.25888E-15
4000	0.54135E-13
4500	0.34169E-11
5000	0.93196E-10
5500	0.13803E-08
6000	0.12929E-07
6500	0.85111E-07
7000	0.42464E-06
7500	0.16971E-05

direct21

0.8500	0.16289E-04
0.9000	0.41413E-04
0.9500	0.94818E-04
1.0000	0.19868E-03
1.0500	0.38587E-03
1.1000	0.70185E-03
1.1500	0.12058E-02
1.2000	0.19709E-02
1.2500	0.30831E-02
1.3000	0.46395E-02
1.3500	0.67452E-02
1.4000	0.95098E-02
1.4500	0.13044E-01
1.5000	0.17453E-01
1.5500	0.22838E-01
1.6000	0.29288E-01
1.6500	0.36876E-01
1.7000	0.45663E-01
1.7500	0.55690E-01
1.8000	0.66981E-01
1.8500	0.79540E-01
1.9000	0.93354E-01
1.9500	0.10839E+00
2.0000	0.12461E+00
2.0500	0.14195E+00
2.1000	0.16033E+00
2.1500	0.17967E+00
2.2000	0.19988E+00
2.2500	0.22087E+00
2.3000	0.24253E+00
2.3500	0.26476E+00
2.4000	0.28745E+00
2.4500	0.31049E+00
2.5000	0.33379E+00
2.5500	0.35725E+00
2.6000	0.38077E+00
2.6500	0.40426E+00
2.7000	0.42764E+00
2.7500	0.45083E+00
2.8000	0.47375E+00
2.8500	0.49635E+00
2.9000	0.51856E+00
2.9500	0.54032E+00
3.0000	0.56161E+00
3.0500	0.58236E+00
3.1000	0.60256E+00
3.1500	0.62218E+00
3.2000	0.64118E+00
3.2500	0.65956E+00

direct21

3500	0.69438E+00
4000	0.71082E+00
4500	0.72661E+00
5000	0.74175E+00
5500	0.75624E+00
6000	0.77009E+00
6500	0.78332E+00
7000	0.79593E+00
7500	0.80795E+00
8000	0.81937E+00
8500	0.83023E+00
9000	0.84053E+00
9500	0.85031E+00
10000	0.85956E+00
10500	0.86832E+00
11000	0.87660E+00
11500	0.88442E+00
12000	0.89180E+00
12500	0.89876E+00
13000	0.90532E+00
13500	0.91150E+00
14000	0.91731E+00
14500	0.92277E+00
15000	0.92790E+00
15500	0.93272E+00
16000	0.93725E+00
16500	0.94149E+00
17000	0.94547E+00
17500	0.94919E+00
18000	0.95268E+00
18500	0.95594E+00
19000	0.95899E+00
19500	0.96184E+00
20000	0.96451E+00

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\*  
CXTFIT VERSION 2.0 (1/2/95) \*  
ANALYTICAL SOLUTIONS FOR ONE-DIMENSIONAL CDE \*  
DIRECT PROBLRM \*

Fig.4-15. Equilibrium one-site CDE  
Effect of Changing D

DATA INPUT FILE: Direct21.in \*  
\*  
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direct21

MODEL DESCRIPTION

=====

DETERMINISTIC EQUILIBRIUM CDE (MODE=1)  
FLUX-AVERAGED CONCENTRATION  
REDUCED TIME (T), POSITION(Z)  
(ALL PARAMETERS EXCEPT D AND V ARE DIMENSIONLESS)  
CHARACTERISTIC LENGTH = 50.0000  
FOR DIMENSIONLESS PARAMETERS

INITIAL VALUES OF COEFFICIENTS

=====

NAME	INITIAL VALUE
V.....	0.4000E+00
D.....	0.1000E+01
R.....	0.5000E+01
mu.....	0.0000E+00

BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS

=====

STEP INPUT OF CONC. = 1.0000  
SOLUTE FREE INITIAL CONDITION  
NO PRODUCTION TERM

= 1.0000 (FLUX CONC. VS. TIME)

$\int_0^1 \mu(C \cdot dT) = 0.6161$

TIME	C
0.0000	0.00000E+00
0.0500	0.00000E+00
0.1000	0.00000E+00
0.1500	0.00000E+00
0.2000	0.00000E+00
0.2500	0.00000E+00
0.3000	0.00000E+00
0.3500	0.98508E-28
0.4000	0.75610E-24
0.4500	0.79188E-21
0.5000	0.20556E-18
0.5500	0.19338E-16
0.6000	0.84953E-15
0.6500	0.20769E-13
0.7000	0.32032E-12
0.7500	0.34169E-11
0.8000	0.27011E-10
0.8500	0.16682E-09
0.9000	0.83859E-09
0.9500	0.35446E-08

direct21

.0500	0.41559E-07
.1000	0.11977E-06
.1500	0.31390E-06
.2000	0.75706E-06
.2500	0.16971E-05
.3000	0.35657E-05
.3500	0.70731E-05
.4000	0.13327E-04
.4500	0.23991E-04
.5000	0.41413E-04
.5500	0.68858E-04
.6000	0.11067E-03
.6500	0.17247E-03
.7000	0.26131E-03
.7500	0.38587E-03
.8000	0.55653E-03
.8500	0.78547E-03
.9000	0.10867E-02
.9500	0.14760E-02
0000	0.19709E-02
00500	0.25906E-02
01000	0.33556E-02
01500	0.42877E-02
02000	0.54098E-02
02500	0.67452E-02
03000	0.83178E-02
03500	0.10152E-01
04000	0.12270E-01
04500	0.14697E-01
05000	0.17453E-01
05500	0.20561E-01
06000	0.24041E-01
06500	0.27909E-01
07000	0.32183E-01
07500	0.36876E-01
08000	0.42002E-01
08500	0.47569E-01
09000	0.53584E-01
09500	0.60054E-01
00000	0.66981E-01
00500	0.74365E-01
01000	0.82203E-01
01500	0.90492E-01
02000	0.99225E-01
02500	0.10839E+00
03000	0.11798E+00
03500	0.12799E+00
04000	0.13839E+00
04500	0.14918E+00



direct21

3.5500	0.17182E+00
3.6000	0.18365E+00
3.6500	0.19578E+00
3.7000	0.20819E+00
3.7500	0.22087E+00
3.8000	0.23379E+00
3.8500	0.24693E+00
3.9000	0.26027E+00
3.9500	0.27378E+00
4.0000	0.28745E+00
4.0500	0.30124E+00
4.1000	0.31514E+00
4.1500	0.32912E+00
4.2000	0.34316E+00
4.2500	0.35725E+00
4.3000	0.37136E+00
4.3500	0.38548E+00
4.4000	0.39957E+00
4.4500	0.41363E+00
4.5000	0.42764E+00
4.5500	0.44158E+00
4.6000	0.45544E+00
4.6500	0.46919E+00
4.7000	0.48283E+00
4.7500	0.49635E+00
4.8000	0.50972E+00
4.8500	0.52295E+00
4.9000	0.53601E+00
4.9500	0.54890E+00
5.0000	0.56161E+00

\*\*\*\*\*  
\*  
CXTFIT VERSION 2.0 (1/2/95) \*  
ANALYTICAL SOLUTIONS FOR ONE-DIMENSIONAL CDE \*  
DIRECT PROBLRM \*

Fig.4-15. Equilibrium one-site CDE  
Effect of Changing D

DATA INPUT FILE: Direct21.in \*  
\*

\*\*\*\*\*  
MODEL DESCRIPTION  
=====

1 DETERMINISTIC EQUILIBRIUM CDE (MODE=1)

direct21

REDUCED TIME (T), POSITION(Z)  
(ALL PARAMETERS EXCEPT D AND V ARE DIMENSIONLESS)  
CHARACTERISTIC LENGTH = 50.0000  
FOR DIMENSIONLESS PARAMETERS

INITIAL VALUES OF COEFFICIENTS

=====

NAME	INITIAL VALUE
.....	0.2650E+00
.....	0.2500E+00
.....	0.1000E+02
u.....	0.0000E+00

BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS

=====

STEP INPUT OF CONC. = 1.0000  
ABSOLUTE FREE INITIAL CONDITION  
NO PRODUCTION TERM

1.0000 (FLUX CONC. VS. TIME)

$\int (C \cdot dT) = 0.0000$

TIME	C
0000	0.00000E+00
0500	0.00000E+00
1000	0.00000E+00
1500	0.00000E+00
2000	0.00000E+00
2500	0.00000E+00
3000	0.00000E+00
3500	0.00000E+00
4000	0.00000E+00
4500	0.00000E+00
5000	0.00000E+00
5500	0.00000E+00
6000	0.00000E+00
6500	0.00000E+00
7000	0.00000E+00
7500	0.00000E+00
8000	0.00000E+00
8500	0.00000E+00
9000	0.00000E+00
9500	0.00000E+00
10000	0.00000E+00

direct21

1.2500	0.00000E+00
1.3000	0.00000E+00
1.3500	0.00000E+00
1.4000	0.00000E+00
1.4500	0.00000E+00
1.5000	0.11709E-28
1.5500	0.19272E-27
1.6000	0.26534E-26
1.6500	0.31058E-25
1.7000	0.31352E-24
1.7500	0.27642E-23
1.8000	0.21527E-22
1.8500	0.14958E-21
1.9000	0.93578E-21
1.9500	0.53132E-20
2.0000	0.27580E-19
2.0500	0.13174E-18
2.1000	0.58255E-18
2.1500	0.23975E-17
2.2000	0.92280E-17
2.2500	0.33369E-16
2.3000	0.11382E-15
2.3500	0.36758E-15
2.4000	0.11278E-14
2.4500	0.32978E-14
2.5000	0.92166E-14
2.5500	0.24685E-13
2.6000	0.63515E-13
2.6500	0.15736E-12
2.7000	0.37616E-12
2.7500	0.86932E-12
2.8000	0.19458E-11
2.8500	0.42254E-11
2.9000	0.89158E-11
2.9500	0.18307E-10
3.0000	0.36628E-10
3.0500	0.71501E-10
3.1000	0.13634E-09
3.1500	0.25425E-09
3.2000	0.46415E-09
3.2500	0.83031E-09
3.3000	0.14568E-08
3.3500	0.25093E-08
3.4000	0.42462E-08
3.4500	0.70650E-08
3.5000	0.11566E-07
3.5500	0.18644E-07
3.6000	0.29611E-07
3.6500	0.46363E-07

direct21

7500	0.10915E-06
8000	0.16431E-06
8500	0.24435E-06
9000	0.35919E-06
9500	0.52212E-06
0000	0.75082E-06
0500	0.10686E-05
1000	0.15057E-05
1500	0.21012E-05
2000	0.29053E-05
2500	0.39812E-05
3000	0.54086E-05
3500	0.72868E-05
4000	0.97385E-05
4500	0.12914E-04
5000	0.17006E-04
5500	0.22219E-04
6000	0.28828E-04
6500	0.37150E-04
7000	0.47560E-04
7500	0.60499E-04
8000	0.76487E-04
8500	0.96122E-04
9000	0.12010E-03
9500	0.14922E-03
0000	0.18440E-03

\*\*\*\*\*

Fig.7-1: The deterministic CDE (BVP+PVP)  
Effect of the first-decay constant (Mu=0)

INVERSE        MODE        NREDU  
0                1                2  
MODC            ZL(BLANK IF MODE=NREDU=1)  
3                10000

\*\*\* BLOCK C: TRANSPORT PARAMETERS

\*\*\*\*\*

V                D                R                Mu  
1.698            6.22            1.25            0.0

\*\*\* BLOCK D: BVP; MODB=0 ZERO; =1 Dirac ; =2 STEP; =3 A PULSE

\*\*\*\*\*

MODB                    =4 MULTIPLE; =5 EXPONENTIAL; =6 ARBITRARY  
2  
20.0

\*\*\* BLOCK E: IVP; MODI=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL

\*\*

MODI( 3 steps distribution)  
0

\*\*\* BLOCK F: PVP; MODP=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL

\*\*

MODP  
0

\*\*\* BLOCK H: POSITION AND TIME FOR DIRECT PROBLEM

\*\*\*\*\*

NZ            DZ            ZI            NT            DT            TI            MPRINT  
10            1            0.0            1.0            0.0            9.645            2

\*\*\* BLOCK A: MODEL DESCRIPTION

\*\*\*\*\*

Fig.7-1: The deterministic CDE (BVP+PVP)  
Effect of the first-decay constant (Mu=0.0)

INVERSE        MODE        NREDU  
0                1                2  
MODC            ZL(BLANK IF MODE=NREDU=1)  
3                10000

\*\*\* BLOCK C: TRANSPORT PARAMETERS

\*\*\*\*\*

V                D                R                Mu  
1.7              6.22            1.25            0.0

\*\*\* BLOCK D: BVP; MODB=0 ZERO; =1 Dirac ; =2 STEP; =3 A PULSE

\*\*\*\*\*

MODB                    =4 MULTIPLE; =5 EXPONENTIAL; =6 ARBITRARY  
2  
20.0

\*\*\* BLOCK E: IVP; MODI=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL

\*\*

MODI( 3 steps distribution)  
0

\*\*\* BLOCK F: PVP; MODP=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL

\*\*

MODP  
0

\*\*\* BLOCK H: POSITION AND TIME FOR DIRECT PROBLEM

\*\*\*\*\*

NZ            DZ            ZI            NT            DT            TI            MPRINT  
10            1            0.0            1            0.0            12.86            2

□

\*\*\* BLOCK A: MODEL DESCRIPTION

\*\*\*\*\*

The deterministic CDE (BVP+PVP)

Prediction for Sr Transport in a Field Condition (Sand Dune Soil,

INVERSE        MODE            NREDU

0                1                2

MODC            ZL(BLANK IF MODE=NREDU=1)

3                10000

\*\*\* BLOCK C: TRANSPORT PARAMETERS

\*\*\*\*\*

V                D                R                Mu

1.34059        7.88            3.32            0.0

\*\*\* BLOCK D: BVP; MODB=0 ZERO; =1 Dirac ; =2 STEP; =3 A PULSE

\*\*\*\*\*

MODB                            =4 MULTIPLE; =5 EXPONENTIAL; =6 ARBITRARY

2

20.0

\*\*\* BLOCK E: IVP; MODI=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL

\*\*

MODI( 3 steps distribution)

0

\*\*\* BLOCK F: PVP; MODP=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL

\*\*

MODP

0

\*\*\* BLOCK H: POSITION AND TIME FOR DIRECT PROBLEM

\*\*\*\*\*

NZ            DZ            ZI            NT            DT            TI            MPRINT

10            1            0.0            1            0.0            8.359            2

\*\*\* BLOCK A: MODEL DESCRIPTION

\*\*\*\*\*

Fig.7-1: The deterministic CDE (BVP+PVP)

Effect of the first-decay constant (Mu=0)

INVERSE        MODE            NREDU

0                1                2

MODC            ZL(BLANK IF MODE=NREDU=1)

3                10000

\*\*\* BLOCK C: TRANSPORT PARAMETERS

\*\*\*\*\*

V                D                R                Mu

1.698            6.22            1.25            0.0

\*\*\* BLOCK D: BVP; MODB=0 ZERO; =1 Dirac ; =2 STEP; =3 A PULSE

\*\*\*\*\*

MODB                            =4 MULTIPLE; =5 EXPONENTIAL; =6 ARBITRARY

2

20.0

\*\*\* BLOCK E: IVP; MODI=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL

\*\*

MODI( 3 steps distribution)

0

\*\*\* BLOCK F: PVP; MODP=0 ZERO; =1 CONSTANT; =2 STEPWISE; =3 EXPONENTIAL

\*\*

MODP

0

\*\*\* BLOCK H: POSITION AND TIME FOR DIRECT PROBLEM

\*\*\*\*\*

NZ            DZ            ZI            NT            DT            TI            MPRINT

10            1            0.0            1            0.0            9.002            2

\*\*\* BLOCK A: MODEL DESCRIPTION

\*\*\*\*\*  
 \*  
 CXTFIT VERSION 2.0 (1/2/95) \*  
 ANALYTICAL SOLUTIONS FOR ONE-DIMENSIONAL CDE \*  
 DIRECT PROBLRM \*

\*  
 The deterministic CDE (BVP+PVP) \*  
 Prediction for Sr Transport in a Field Condition (Sand Dune \*  
 \*

\*  
 DATA INPUT FILE: Direct.in \*

\*\*\*\*\*  
 \*\*\*\*\*  
 \*\*\*\*\*  
 MODEL DESCRIPTION  
 =====

DETERMINISTIC EQUILIBRIUM CDE (MODE=1)  
 RESIDENT CONCENTRATION (THIRD-TYPE INPUT)  
 REDUCED TIME (T), POSITION(Z)  
 (ALL PARAMETERS EXCEPT D AND V ARE DIMENSIONLESS)  
 CHARACTERISTIC LENGTH = \*\*\*\*\*  
 FOR DIMENSIONLESS PARAMETERS

INITIAL VALUES OF COEFFICIENTS  
 =====

NAME	INITIAL VALUE
.....	0.1698E+01
.....	0.6220E+01
.....	0.1250E+01
.....	0.0000E+00

BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS  
 =====

STEP INPUT OF CONC. = 20.0000  
 ABSOLUTE FREE INITIAL CONDITION  
 NO PRODUCTION TERM

0.81500 (RESIDENT AND TOTAL RESIDENT CONC. VS. DEPTH)

$\int_0^1 C \cdot dZ = 10.0000$   $\text{Sum}(Ct \cdot dZ) = 12.5000$  (TOTAL MASS)

C Ct (=R\*C)

0000	0.20000E+02	0.25000E+02
0000	0.00000E+00	0.00000E+00
0000	0.00000E+00	0.00000E+00
0000	0.00000E+00	0.00000E+00
0000	0.00000E+00	0.00000E+00
0000	0.00000E+00	0.00000E+00

0000 0.00000E+00 0.00000E+00  
0000 0.00000E+00 0.00000E+00  
0000 0.00000E+00 0.00000E+00  
0000 0.00000E+00 0.00000E+00

\*\*\*\*\*

CXTFIT VERSION 2.0 (1/2/95) \*  
ANALYTICAL SOLUTIONS FOR ONE-DIMENSIONAL CDE \*  
DIRECT PROBLRM \*

Fig.7-1: The deterministic CDE (BVP+PVP) \*  
Effect of the first-decay constant (Mu=0) \*

DATA INPUT FILE: Direct.in \*

\*\*\*\*\*

MODEL DESCRIPTION

=====

DETERMINISTIC EQUILIBRIUM CDE (MODE=1)  
RESIDENT CONCENTRATION (THIRD-TYPE INPUT)  
REDUCED TIME (T), POSITION(Z)  
(ALL PARAMETERS EXCEPT D AND V ARE DIMENSIONLESS)  
CHARACTERISTIC LENGTH = \*\*\*\*\*  
FOR DIMENSIONLESS PARAMETERS

INITIAL VALUES OF COEFFICIENTS

=====

NAME	INITIAL VALUE
.....	0.1698E+01
.....	0.6220E+01
.....	0.1250E+01
.....	0.0000E+00

BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS

=====

STEP INPUT OF CONC. = 20.0000  
ABSOLUTE FREE INITIAL CONDITION  
NO PRODUCTION TERM

0.63000 (RESIDENT AND TOTAL RESIDENT CONC. VS. DEPTH)  
 $C^*dZ = 30.00000$   $Sum(Ct*dZ) = 37.50000$  (TOTAL MASS)  
C Ct (=R\*C)

0000 0.20000E+02 0.25000E+02  
0000 0.20000E+02 0.25000E+02



0.0000 0.00000E+00 0.00000E+00  
0.0000 0.00000E+00 0.00000E+00  
0.0000 0.00000E+00 0.00000E+00  
0.0000 0.00000E+00 0.00000E+00  
0.0000 0.00000E+00 0.00000E+00  
0.0000 0.00000E+00 0.00000E+00  
0.0000 0.00000E+00 0.00000E+00  
0.0000 0.00000E+00 0.00000E+00

\*\*\*\*\*

CXTFIT VERSION 2.0 (1/2/95)  
ANALYTICAL SOLUTIONS FOR ONE-DIMENSIONAL CDE  
DIRECT PROBLRM

Fig.7-1: The deterministic CDE (BVP+PVP)  
Effect of the first decay constant ( $\mu=0$ )

DATA INPUT FILE: Direct in

\*\*\*\*\*

MODEL DESCRIPTION

DETERMINISTIC EQUILIBRIUM CDE (MODE=1)  
RESIDENT CONCENTRATION (THIRD-TYPE INPUT)  
REDUCED TIME (T), POSITION(Z)  
(ALL PARAMETERS EXCEPT D AND V ARE DIMENSIONLESS)  
CHARACTERISTIC LENGTH = \*\*\*\*\*  
FOR DIMENSIONLESS PARAMETERS

INITIAL VALUES OF COEFFICIENTS

NAME	INITIAL VALUE
Y.....	0.1698E+01
Q.....	0.6220E+01
R.....	0.1250E+01
mu.....	0.0000E+00

BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS

STEP INPUT OF CONC. = 20.0000  
SOLUTE FREE INITIAL CONDITION  
NO PRODUCTION TERM

2.44500 (RESIDENT AND TOTAL RESIDENT CONC. VS. DEPTH)





0000 0.00000E+00 0.00000E+00  
 0000 0.00000E+00 0.00000E+00  
 0000 0.00000E+00 0.00000E+00  
 0000 0.00000E+00 0.00000E+00

\*\*\*\*\*

CXTFIT VERSION 2.0 (1/2/95)  
 ANALYTICAL SOLUTIONS FOR ONE-DIMENSIONAL CDE  
 DIRECT PROBLRM

Fig.7-1: The deterministic CDE (BVP+PVP)  
 Effect of the first-decay constant (Mu=0)

DATA INPUT FILE: Direct.in

\*\*\*\*\*

MODEL DESCRIPTION

DETERMINISTIC EQUILIBRIUM CDE (MODE=1)  
 RESIDENT CONCENTRATION (THIRD-TYPE INPUT)  
 REDUCED TIME (T), POSITION(Z)  
 (ALL PARAMETERS EXCEPT D AND V ARE DIMENSIONLESS)  
 CHARACTERISTIC LENGTH = \*\*\*\*\*  
 FOR DIMENSIONLESS PARAMETERS

INITIAL VALUES OF COEFFICIENTS

NAME	INITIAL VALUE
.....	0.1698E+01
.....	0.6220E+01
.....	0.1250E+01
U.....	0.0000E+00

BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS

STEP INPUT OF CONC. = 20.0000  
 SOLUTE FREE INITIAL CONDITION  
 NO PRODUCTION TERM

0.28600 (RESIDENT AND TOTAL RESIDENT CONC. VS. DEPTH)  
 (C\*dZ) = 27.05917 Sum(Ct\*dZ) = 33.82396 (TOTAL MASS)  
 C Ct (=R\*C)  
 0000 0.20000E+02 0.25000E+02  
 0000 0.17059E+02 0.21324E+02



D PRODUCTION TERM

2.57280 (RESIDENT AND TOTAL RESIDENT CONC. VS. DEPTH)

(C\*dZ) = 48.66594 Sum(Ct\*dZ) = 60.83243 (TOTAL MASS)

	C	Ct (=R*C)
000	0.20000E+02	0.25000E+02
000	0.20000E+02	0.25000E+02
000	0.18666E+02	0.23332E+02
000	0.00000E+00	0.00000E+00
000	0.00000E+00	0.00000E+00
000	0.00000E+00	0.00000E+00
000	0.00000E+00	0.00000E+00
000	0.00000E+00	0.00000E+00
000	0.00000E+00	0.00000E+00
000	0.00000E+00	0.00000E+00
000	0.00000E+00	0.00000E+00

APPENDIX I  
DRINKING WATER STANDARD

**APPENDIX E**  
**DRINKING WATER STANDARD**

**STANDARDIZATION AND METROLOGY ORGANIZATION  
FOR G.C.C COUNTRIES**

**DRAFT  
GULF STANDARD**

**NO. ....**

**UNBOTTLED DRINKING WATER**

**PREPARED BY  
KINGDOM OF SAUDI ARABIA**

---



## FOREWORD

This standard cancels and replaced the Gulf Standard No. 149/1993 "Unbottled Drinking Water" which was published in 07/05/1993.

This standard has been revised and some amendments introduced.

# UNBOTTLED DRINKING WATER

## 1- SCOPE AND FIELD OF APPLICATION

This Gulf standard is concerned with unbottled drinking water.

## 2- COMPLEMENTARY REFERENCES

- 2.1 GS No. 111/1989 "Methods of Test for Drinking and Mineral Water - Part 1: Sampling".
- 2.2 GS No. 378/1994 "Methods of Test for Drinking and Mineral Water - Third Part: Routine Microbiological Tests".
- 2.3 GS No. 818/1997 "Methods of Test for Drinking and Mineral Water - Part 15: Non-Routine Microbiological".
- 2.4 Gulf Standards approved concerning "Methods of Test for Drinking and Mineral Water - Physical, Chemical".

## DEFINITIONS

### 1.1 Unbottled drinking water

Water fit for human consumption which is supplied to the public through the public distribution system, or the limited water supply system, or from wells, springs or any other water source from surface water sources, used for drinking and complying with all the specific properties mentioned in this standard.

### Public distribution system

A system for supplying the public with water suitable for human consumption, and includes collection, treatment, storage and distribution of drinking water from the source to the consumer.

3.3 Limited water system

A system for supplying the public with water suitable for human consumption and comprises less than 15 connections.

3.4 Well

A vertical hole cut into the earth for access to underground water.

3.5 Spring

A place where a natural outflow of water to the surface of the ground takes place.

3.6 Surface water

Collection rain water in valleys, dams, reservoir or open tanks which is collected for drinking purposes.

4- CHARACTERISTICS

The following shall be met in unbottled drinking water:

4.1 Characteristics aesthetic quality

Unbottled drinking water should not contain any substances which would effect its color, odour or appearance. It should be free from foreign bodies such as soil, sand, hair and other substances and impurities which are visible to the naked eye.

4.2 The substances and parameters aesthetic quality shall be according to the Table No. 1.

- 4.5 Total residual chlorine
- 4.5.1 Total residual chlorine concentration in treated unbottled drinking water shall be sufficient to kill all microbes therein, provided that the chlorine concentration shall range between 0.2 ppm and 0.5 ppm.
- 4.5.2 Concentration of chlorine shall be increased in case of epidemic or special circumstances according to instructions of the Ministries of Health or the concerned authorities.
- 4.6 When the water is treated with chlorine, ozone, ultraviolet rays or by other means, this treatment shall be sufficient to kill all microbes and the treated water shall conform to the microbiological characteristics of treated water mentioned in item 4.8.
- 4.7 Biological characteristics  
Unbottled drinking water shall be completely free from algae, moulds, parasites and insects, other eggs, larvae, vesicles and insect parts.
- 4.8 Microbiological characteristics
- 4.8.1 Unbottled drinking water shall be completely free from pathogenic and faecal microbes and viruses which may be hazardous to public health.
- 4.8.2 Treated water entering the distribution system:  
It shall be free from coliform bacteria and faecal coliform bacteria in any 100 ml examined sample.
- 4.8.3 Treated water in the distribution system:
- 4.8.3.1 It shall be free from faecal coliform bacteria in any 100 ml examined sample.
- 4.8.3.2 It shall be free from coliform bacteria in any 100 ml of examined sample, in 95% of the samples examined throughout the year, in the case of large supplies when sufficient samples are examined.

## 5- SAMPLING

Samples shall be taken according to Gulf standard in item (2.1).

## 6- METHODS OF EXAMINATION AND TEST

All necessary tests shall be carried out on the representative sample taken according to (5) determine its compliance with all item of this standard.

6.1 Tests of microbiological, routine and non-routine shall be carried out according to Gulf standard mentioned in item (2.2, 2.3).

6.2 Tests of physical, chemical shall be carried out according to Gulf standard mentioned in item (2.4).

**TABLE NO. (1)**  
**Substances and Parameters Related to Quality of**  
**Unbottled Drinking Water**

Substances and parameters	Quality levels and measurement units	Reasons for affecting in water quality
<b>a- <u>Physical parameters</u></b>		
Colour	15 true colour unit	appearance
Turbidity	5 nephelometric turbidity unit	appearance and disinfection
Taste and odour	acceptable	
Temperature	acceptable	
<b>b- <u>Inorganic constituents</u></b>		
Aluminium	0.2 ppm	depositions, discolouration
* Ammonia	1.5 ppm	odour and taste
Chloride	250 ppm	taste, corrosion
Copper	1 ppm	staining of laundry
Total hardness	500-600 ppm	high hardness: scale deposition and scum formation, low hardness: possible corrosion
Hydrogen sulfide	0.05 ppm	odour and taste
Iron	0.3 ppm	staining of laundry
Manganese	0.1 ppm	staining of laundry
pH	6.5 - 8.5	low pH: corrosion high pH: taste, soapy feel
Sodium	200 ppm	taste
Sulfate	250 ppm	taste, corrosion
T.D.S.	1000 ppm	taste
Zinc	3 ppm	appearance, taste

\* Knowing that the natural levels of ammonia in ground and surface waters are usually below 0.2 ppm or less and increase in this level is an indication of pollution with animal waste.

4.3 Chemical constituents of healthy significance in unbottled drinking water according to Tables No. 2, 3, 4, 5

TABLE NO. (2)  
Inorganic Constituents Contents

Constituent	Maximum level (p.p.m.)
Arsenic	0.01
Barium	0.7
Boron	0.5
Cadmium	0.003
Chromium	0.05
Copper	2
Cyanide	0.07
<sup>1</sup> Fluoride	0.6 - 1.5
Lead	0.01
Silver	0.1
Tin	1 $\mu\text{g}/\text{l}$
Uranium	2 $\mu\text{g}/\text{l}$
Beryllium	1 $\mu\text{g}/\text{l}$
Manganese	0.5
Mercury (total)	0.001
Molybdenum	0.07
Nickel	0.02
<sup>2</sup> Nitrate (as NO <sub>3</sub> )	50
<sup>2</sup> Nitrite (as NO <sub>2</sub> )	3
Selenium	0.01
Antimony	0.005

- 1- To determine the fluoride concentration in unbottled drinking water according to daily atmospheric temperature as follows:

$$\text{Fluoride concentration} = \frac{0.54}{D}$$

Where:

$$D = 0.038 + [0.0062 \times (\text{daily atmospheric temperature in } ^\circ\text{C} \times \frac{9}{5} - 32)]$$

2- Total concentrate nitrate and nitrite should not exceed 1, i.e.

$$\frac{C_{\text{nitrite}}}{50} + \frac{C_{\text{nitrate}}}{3} \leq 1$$

TABLE NO. (3)  
Organic Constituents Contents

Constituent	Maximum level (µg/Litre)
a- <u>Chlorinated alkanes</u> :	
Carbon tetrachloride	2
dichloromethane	20
1,2-dichloroethane	30
1,1,1-trichloroethane	2000
b- <u>Chlorinated ethenes</u> :	
Vinyl chloride	3
1,1-dichloroethene	30
1,2-dichloroethene	50
trichloroethene	70
tetrachloroethene	40
c- <u>Aromatic hydrocarbons</u> :	
Benzene	10
Toluene	700
Xylenes	500
Ethylbenzene	300
Styrene	20
Benzopyrene	0.7
d- <u>Chlorinated benzenes</u> :	
Monochlorobenzene	300
1,2-dichlorobenzene	1000
1,4-dichlorobenzene	300
trichlorobenzene (total)	20
e- <u>Miscellaneous organic chemicals</u>	
Di ethylhexyl adipate	80
Di ethyl hexyl phthalate	3
Acrylamide	0.5
Epichlorohydrin	0.1
Hexachlorobutadiene	0.5
Edenic acid E.D.T.A.	500
Nitrotriacetic acid	200
Tributyltin oxide	1
Nitroacetin - RI	1



TABLE NO. (4)  
Pesticides Contents

Pesticide	Maximum level (µg/Litre)
Alachlor	20
Aldicarb	10
Aldrin/dieldrin	0.05
Atrazin	2
Bentazone	300
Carbofuran	7
Chlordane	0.2
Chlorotoluron	30
D.D.T.	2
1,2-dibromo-3-chloropropane	1
2,4-dichlorophenoxyacetic acid	30
1,2-dichloropropane	40
1,3-dichloropropene	20
Heptachlor and heptachlor epoxide	0.05
Hexachlorobenzene	1
Isoprothiuron	9
Lindane	2
MCPA	2
Methoxychlor	20
Metolachlor	10
Molinate	6
Pendimethalin	20
Pentachlorophenol	9
Permethrin	20
Propenil	20
Pyridate	100
Simazine	2
Trifluralin	20
2,4-DB	90
Dichloroprop	100
Fenoprop	9
Mecoprop	10
2,4,5-T	9
Cyanazine	0.5
1,2-dibromoethane	15
Diquat	10
Turbutylazine (TBA)	7

TABLE NO. (5)


## Disinfectants and Disinfectant By-Products Contents

Disinfectants	Maximum level ( $\mu\text{g/liter}$ )
Monochloramine	3
Chlorine	5
Disinfectants by-products	Maximum level ( $\mu\text{g/liter}$ )
Bromate	25
Chlorite	200
2,4,6-trichlorophenol	200
Formaldehyde	900
Bromoform	100
Dibromo chloromethane	100
Bromo dichloromethane	60
Chloroform	200
Dichloroacetic acid	50
Trichloroacetic acid	100
Chloralhydrate (trichloroacetaldehyde)	10
Dichloro acetonitrile	90
Di bromoacetonitrile	100
Trichloro acetonitrile	1
Cyanogenchloride	70

4.4 Without prejudice to what is stated in the Gulf standards mentioned in item (2.2) activity concentration of various radionuclides in drinking water shall be carried out according to Table (6).

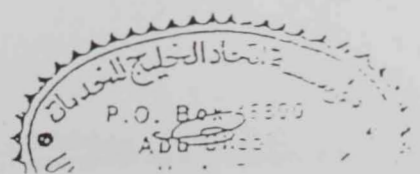
TABLE (6)  
Activity concentration of various radionuclides in drinking-water  
corresponding to a dose of 0.1 mSv from 1 year's intake


Radionuclide <sup>a</sup>	Dose conversion factor (Sv/Bq) <sup>b</sup>	Calculated rounded value (Bq/litre)
<sup>3</sup> H	$1.8 \times 10^{-11}$	7800
<sup>14</sup> C	$5.6 \times 10^{-10}$	250
<sup>60</sup> Co	$7.2 \times 10^{-9}$	20
<sup>89</sup> Sr	$3.8 \times 10^{-9}$	37
<sup>90</sup> Sr	$2.8 \times 10^{-8}$	5
<sup>129</sup> I	$1.1 \times 10^{-7}$	1
<sup>131</sup> I	$2.2 \times 10^{-8}$	6
<sup>134</sup> Cs	$1.9 \times 10^{-8}$	7
<sup>137</sup> Cs	$1.3 \times 10^{-5}$	10
<sup>210</sup> Pb	$1.3 \times 10^{-6}$	0.1
<sup>210</sup> Po	$6.2 \times 10^{-7}$	0.2
<sup>224</sup> Ra	$8.0 \times 10^{-8}$	1
<sup>226</sup> Ra	$2.2 \times 10^{-7}$	1
<sup>228</sup> Ra	$2.7 \times 10^{-7}$	1
<sup>232</sup> Th	$1.8 \times 10^{-6}$	0.1
<sup>234</sup> U	$3.9 \times 10^{-2}$	4
<sup>238</sup> U	$3.6 \times 10^{-8}$	4
<sup>239</sup> Pu	$5.6 \times 10^{-7}$	0.3

 <p>ADNOC</p>	Environmental Protection and Occupational Health Management	Page :      Of :
	Policy and Guidelines	Effective Date : August 01, 1992
		Approved by: General Manager
		Version : 1.0

# Environmental Protection and Occupational Health

ADNOC Group Policy and Guidelines

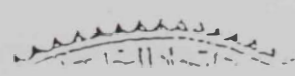


	Environmental Protection and Occupational Health Management	Page :            Of :
	Environmental emissions Guideline Limit Values	Effective Date : August 01, 1992
		Approved by: General Manager
		Version : 1.0

**ADNOC LIMITS FOR EFFLUENTS DISCHARGED INTO THE DESERT**


EFFLUENTS	DESIRABLE	MAXIMUM	
	LIMITS (mg/l)	PER. LIMITS	

Ammoniacal Nitrogen	05	10	
Ar (As)	0.1	0.5	ARSENIC
Biochemical Oxygen Demand (BOD)	30	50	Bio-chemical
Cadmium (Cd)	0.1	0.2	CADMIUM
Chloride (residual)	1.0	2.0	Chlorine
Chromium, total (Cr)	0.1	0.2	Cr
Copper (Cu)	1.5	3.0	Cu
Chemical Oxygen demand	150	200	CO <sub>2</sub>
Cyanide (CN)	0.1	0.2	CN
	15	25	Oil
Total Iron (Fe)	2.0	5.0	Total Iron
Lead (Pb)	0.1	0.3	Lead
Manganese (Mn)	2.0	3.0	Manganese
Mercury (Hg)	0.001	0.05	Hg
Nickel (Ni)	0.2	1.0	Ni
	6-9	6-9	P <sup>-</sup>
	0.2	0.5	
Phosphate (total, as P)	30	40	PO <sub>4</sub>
Selenium (Se)	0.05	0.09	
Silver (Ag)	0.05	0.1	Ag
Sulfide	0.2	0.5	S <sup>2-</sup>
Total Solids	30	50	Total Solids
Turbidity	90	120	fine solids (everything)
Zinc (Zn)	0.5	5.0	Zn



**APPENDIX F**

**REGULATION FOR EFFLUENT DISPOSAL**

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		Version: 3.0

HEALTH, SAFETY AND ENVIRONMENTAL  
MANAGEMENT POLICY GUIDELINES

ADNOC GROUP GUIDELINES FOR THE PROTECTION OF  
USABLE GROUND WATER.

APPROVED BY :



GENERAL MANAGER

DATE: \_\_\_\_\_

22 MAR 1998



Health, Safety and Environmental Management

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Effective Date: March 20, 1998

Guidelines for the Protection of Usable Ground Water - Definition

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## INTRODUCTION

These Guidelines are developed to promote good industrial practice and sustainable development in the concession areas with a duty of care to protect and manage the usable ground water resources. Compliance with the Guidelines will ensure performance aimed to eliminate / minimise Risks to the Environment, facilitating the beneficial uses of the ground water resources of the Emirate of Abu Dhabi.

## DEFINITIONS

- Aquifer means any geological unit capable of yielding usable quantities of ground water for drinking, irrigation or other purpose.
- Brackish water means the total dissolved solids concentration of the water ranges between 1,500-15,000mg/l.
- Contractor means any individual, partnership, firm, or corporation retained by the OPCO/Operation to perform work or provide supplies or equipment or services.

Discharge means any release of pollutant(s) into the environment, be it of a gaseous, liquid, or solid nature, or a combination thereof. This includes any Discharges (any waste water, salt concentrates, or sludge) from any operations.

Environment means all environmental media i.e. air, land and water.

Fresh water means the total dissolved solids concentration of the water is less than 1,500mg/l.


Monitoring means measurement of the properties of a material (such as a discharge) or [usually] the sampling of a material together with immediate or subsequent analysis or other form of measurement.

Monitoring well means a well identified by the OPCO/Operation to collect representative ground water samples for water quality monitoring.

Saline water means the total dissolved solids concentration of the water is more than 15,000mg/l.

Shallow aquifer means the upper water-bearing geological zone in any location, able of continuously yielding significant quantities of usable ground water.



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GUIDELINES

The concentrate of the reverse osmosis unit of Bu Hasa entered in the category of brackish water and not in the category of the saline water. Refer to page 1.

3.1. These guidelines apply to saline discharges such as produced water, injection water, waste water and/or effluents of salt concentrates of Reverse Osmosis (R.O) plants from ADNOC Group Operations, with high Total Dissolved Solids (TDS).

3.1.1. Surface Discharge

All saline discharges are prohibited. As a short term measure with the objective of eventually achieving zero discharges and, subject to ADNOC approval prior to implementation, saline discharges are permitted over saline aquifers, as delineated in Figure 1. Surface discharges are allowed after and only after due consideration has been given to all technically and economically feasible disposal/treatment and process modification options. Also, all saline surface discharges must conform to the requirements of ADNOC Limits for Effluents Discharged into the desert.


3.1.2. Sub Surface Discharge

All subsurface disposal/injection wells shall be completed in the Dammam, Simsima and Umm El Radhuma aquifers or deeper formation, or disposed in the reservoir concerned.

3.2. All discharges from ADNOC Group operations shall meet the above requirements. Each operating entity shall submit to ADNOC an action plan detailing how and when their existing discharges will comply with these requirements.

3.3. A minimum of one monitoring well shall be provided and maintained by the concerned OPCO/Operation, down gradient of any surface discharge area if that gradient is towards an area utilising ground water from the shallow aquifer for such purposes as agriculture, forestry or any other purpose.

ADNOC GROUP HEALTH, SAFETY AND ENVIRONMENT (HSE) COMMITTEE

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- 3.4. The OPCOs/Operations shall be responsible for the collection of sample(s) from each monitoring wells, estimations for the required ground water quality parameters of the samples and record keeping (Appendix I).
- 3.5. Sample collection for monitoring shall be throughout the shallow aquifer. ISO 5667-11 on 'Guidance on sampling of ground waters' may be consulted, if required. The determinations of the concentrations for the required parameters shall be consistent with the respective analytical methods specified by ISO in the laboratories of ADNOC, OPCOs or a laboratory approved for the purpose. These procedures are subject to audit by personnel designated by the ADNOC Group HSE Committee.
- 3.6. Drilling operations / activities bordering afforestation and/or agricultural areas shall be subject to the above provisions other than monitoring.
- 3.7. OPCO/Operation shall ensure that the Contractors engaged by the OPCC Operation are aware of the contents of these Guidelines and that the Contractors comply with the provisions of the Guidelines in terms of the Contractual Agreement.



كما تم اكتشاف كاربوهيدرات النفط الكلي حتى في المياه المستخلصة بمعدلات تفوق المعايير الموضوعة ( ٠,١ ملغرام / لتر ) .

كما دلت الدراسة على إن حركة المواد الكيميائية أفقيا أكثر منها رأسيا وأجريت تجارب أخرى على أعمدة تربة لدراسة حركة هذه المواد ووجد أن معامل الإبطاء كانت للبتواسيوم أكثر من الاسترونسيوم والتي كانت أكثر من السلفات .

كما أظهرت هذه التجارب أن معامل الإبطاء في المسامية الكلية وتركيز أولى / نهائي = ٠,٥ كانت أعلى في التربة المتواجدة في الموضوع طبيعيا عنها في الكثبان الرملية .

كما أن التوصيلة الكهربائية كانت متقاربة ، ولقد أظهرت النماذج الرياضية أن معدلات الانتشار ومعامل الإبطاء كانت أعلى في التربة الطبيعية، ما يدل على حركة أسرع للملوثات في الكثبان الرملية .

كما دلت النماذج الرياضية إن الوقت اللازم بوصول هذه الملوثات وإلى المياه الجوفية على أعماق ١٠٠ متر تتراوح بين ١٣ - ١٤ يوما في الكثبان الرملية، بينما تستغرق ١٦ يوما في التربة الطبيعية ، ولقد تمت في هذه الدراسة مناقشة بعض التوصيات للتقليل من التلوث الناتج .

بسم الله الرحمن الرحيم

## الخلاصة

في هذه الدراسة تم تقييم أثر المكونات الكيميائية في مياه التحلية الراجعة من المحطات الداخلية على التربة في المناطق الشرقية من الإمارات العربية المتحدة خاصة الوجن القوع وأم الزمول . تم تجميع العينات من ٢٥ محطة للتحلية تستخدم التناضح العكسي ( ١١ من الوجن و ١٢ من القوع و ٢ من أم الزمول ) . تراوحت سعة هذه المحطات من ٢٦,٤٠٠ جالون / اليوم ( ٩٩,٩٢ متر / اليوم ) و ٦١,٠٠٠ جالون / اليوم ( ٣٢٠,٩١ متر / اليوم ) بينما تراوحت معدلات المياه المستخدمة من ٦٠ و ٧٠ % والمياه الراجعة بين ٤٠ % و ٣٠ % تراوحت معدلات التوصيل الكهربائي لمياه التغذية والراجعة بين ٤,٦١ و ١٤,٧ ملي سيمن / سم و ١٢,٩ - ٣٠,٣ ملي سيمن / سم على التوالي ، ويتم التخلص من المياه الراجعة في برك غير مبطنه ذات تربة قليلة الطمي والمواد العضوية والتبادل الأيوني .

وتمتد مستويات المياه الجوفية لأعماق تتراوح بين ١٠٠ - ١٥٠ متر ، ريثما تبعد البرك مسافة ٥ كيلومترات من المحطات في المتوسط . في هذه الدراسة تم جمع المعلومات الأولية حول المواد الكيميائية المستخدمة .

وأن كانت هناك أي بيانات سابقة تم رصدها كما تم تحليل عينات مياه التغذية والراجعة كيميائيا للعناصر الكبرى والنادرة . ودلت التحاليل على وجود العناصر في هذه المياه بمعدلات تفوق تلك المنصوص عليها في معايير مجلس التعاون الخليجي ، وشركة النفط الوطنية أدنوك الوطنية ( أدنوك ) لمياه الشرب والمخلفات التي يتم التخلص منها في الصحراء .



جامعة الإمارات العربية  
عمادة الدراسات العليا  
برنامج ماجستير علوم البيئة

التأثيرات البيئية الناتجة عن  
مخلفات محطات التحلية الكيميائية  
المالحة على التربة والمياه الجوفية

إعداد

جمعه بن خلفان بن خميس الحنظلي

رسالة مقدمة لعمادة الدراسات العليا  
ضمن متطلبات الحصول على درجة  
الماجستير في علوم البيئة

أغسطس 2003