2003

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

Juma Bin Khalfan Bin Khamis Al-Handhaly

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

By

Juma Bin Khalfan Bin Khamis Al-Handhaly
BSc. (Honour), University of Wales, Bangor, U.K, 1996

THESIS SUBMITTED TO THE UNITED ARAB EMIRATES UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENVIRONMENTAL SCIENCE

2003
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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 Osmosis (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 m³/d) and 61,000 G/d (230.91 m³/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/Co = 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 (α) 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.
ACKNOWLEDGMENTS

In retrospect, it seems impossible to acknowledge all individuals contributing to the completion of this study. To those not mentioned here, I convey my heart-felt thanks. My first debt of appreciation goes to the members of my supervisory committee Dr. A.M.O Mohammed, Associate Professor of Geotechnical and Geoenvironmental Engineering, Dr. Munjed Maraqa, Associate Professor and Dr. Mushtaque Ahmed, Associate Professor for their continuous guidance, encouragement, support, and understanding throughout the research process. Thanks to all of you for being my mentor and for going out of your way and looking out for my best interests. Yours enthusiasm and insight have been an inspiration for me.

Special thanks to Dr. Salim Al-Rawahi, Dr. Hyder AbdallRahman, and Professor Mathous Goshon of College of Agricultural and Marian Sciences, Sultan Qaboos University, for encouragements and support.

My deepest gratitude is also extended to Engineer Mahmoud Fahmy, manager of the Soil Mechanics laboratory, and Engineer Salem, manager of Environmental Engineering laboratory, Department of Civil and Environmental Engineering, UAE University. Further indebtedness and great appreciations extended to Dr. Waleed Hamza, Chairman, Biology Department, and Chairman of Master of Environmental Science Program, UAE University, Mr. Ezat and Engineer Bakheet Al-Katheri.
Thanks to my family, who has been an incredible source of love and support through all my life. Their encouragement has been invaluable in helping me through the most difficult parts of my study. Without those people, neither the desire nor the opportunity to pursue advanced degrees would have been possible.

My deep gratitude is also extended to the Central Laboratory Unit (CLU) Staff, UAE University for analyzing the water and soil samples, and without their cooperation I will not be able to complete this manuscript. Another source of support comes from my classmates, colleagues and friends who have supported me emotionally in the last two years and who have helped me through the various iterations of this research, especially Soil and Water Department Staff, College of Agriculture and Marian Science, Sultan Qaboos University. Oman. Also I would like to thank the National Drilling Company, Al-Ain Water Distribution Company, Sultan Qaboos University, and Middles Desalination Research Center for their cooperation.

Above All I give praise to God the most merciful, the most gracious who makes this work, these dear human relationships and everything else good possible.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>iii</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>V</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>viii</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td>x</td>
</tr>
<tr>
<td>CHAPTER 1: INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Background</td>
<td>1</td>
</tr>
<tr>
<td>1.2 Research Objectives</td>
<td>3</td>
</tr>
<tr>
<td>1.3 Scope and Boundaries of the Study</td>
<td>3</td>
</tr>
<tr>
<td>1.4 Thesis Organization</td>
<td>4</td>
</tr>
<tr>
<td>CHAPTER 2: LITERATURE REVIEW</td>
<td>6</td>
</tr>
<tr>
<td>2.1 Introduction</td>
<td>6</td>
</tr>
<tr>
<td>2.2 The Role of Desalination</td>
<td>10</td>
</tr>
<tr>
<td>2.3 Reject Brine</td>
<td>12</td>
</tr>
<tr>
<td>2.3.1 Concentrate chemical composition</td>
<td>12</td>
</tr>
<tr>
<td>2.3.2 Reverse osmoses concentrate disposal</td>
<td>15</td>
</tr>
<tr>
<td>2.3.3 Impact of reject brine on soil and groundwater</td>
<td>16</td>
</tr>
<tr>
<td>2.4 Environmental Fate and Modeling</td>
<td>18</td>
</tr>
<tr>
<td>2.4.1 The mobility of pollutants and their leaching through soil profile</td>
<td>18</td>
</tr>
<tr>
<td>CHAPTER 3: ASSESSMENT OF STUDY AREA</td>
<td>19</td>
</tr>
<tr>
<td>3.1 Study Area</td>
<td>19</td>
</tr>
<tr>
<td>3.2 Plant Visited</td>
<td>19</td>
</tr>
<tr>
<td>3.2.1 Feed, product and reject brine water production</td>
<td>22</td>
</tr>
<tr>
<td>3.2.2 Method of brine disposal</td>
<td>25</td>
</tr>
<tr>
<td>3.3 Sample Collection, Preparation and Analysis</td>
<td>27</td>
</tr>
<tr>
<td>3.3.1 Water samples</td>
<td>27</td>
</tr>
<tr>
<td>3.3.2 Soil samples</td>
<td>27</td>
</tr>
<tr>
<td>3.3.2.1 Physical analysis</td>
<td>27</td>
</tr>
<tr>
<td>3.3.2.2 Chemical analysis</td>
<td>28</td>
</tr>
<tr>
<td>3.4 Mineralogical Analysis</td>
<td>29</td>
</tr>
<tr>
<td>3.5 Sampling and Analysis of In-place and Sand Dune Soil Samples</td>
<td>29</td>
</tr>
<tr>
<td>3.6 Batch Isotherm Experiment</td>
<td>30</td>
</tr>
<tr>
<td>3.7 Miscible displacement experiment</td>
<td>33</td>
</tr>
</tbody>
</table>
3.8 Reject Brine Transport Modeling .......................................................... 36

CHAPTER 4: EVALUATION OF INLAND BWRO DESALINATION PLANTS..... 37

4.1 Variation of pH, EC, and Major Cations ............................................. 37
4.2 Variation of Major Anions ................................................................. 37
4.3 Variation of Heavy Metals ............................................................... 39
4.4 Variation of Total Petroleum Hydrocarbon (TPH) ............................... 40
4.5 Performance of Reject Brine Pits ..................................................... 40
4.3 Heavy Metal Analysis ........................................................................ 43
4.4 Total Petroleum Hydrocarbon (TPH) Analysis ..................................... 44
4.5 Performance of Reject Brine Pits ..................................................... 45

CHAPTER 5: EVALUATION OF SUBSURFACE POLLUTANT DISTRIBUTION AT AL-QUA’A DISPOSAL SITE ........................................................................................................... 43

5.1 Soil Characterization ......................................................................... 43
  5.1.1 Grain size and silt analysis ............................................................ 43
  5.1.2 Cation exchange capacity ............................................................. 45
  5.1.3 Mineralogical analysis ................................................................. 45
5.2 Pore Fluid Analysis ........................................................................... 46
  5.2.1 Anion distribution ....................................................................... 46
  5.2.2 Cation distribution ...................................................................... 50
  5.2.3 Heavy metals Distribution ........................................................... 52

CHAPTER 6: REJECT BRINE TRANSPORT ............................................. 54

6.1 Adsorption Isotherm .......................................................................... 54
6.2 Leaching Column Test ....................................................................... 57
6.3 Calculation of Transport Parameters .................................................. 60
  6.3.1 Time-Lag method ....................................................................... 60
  6.3.2 CXTFIT model ........................................................................... 61
6.4 Sensitivity Analysis Via CXTFIT Model ............................................. 65
6.5 Prediction for Field Condition ............................................................ 66

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS ..................... 68

7.1 Conclusion ......................................................................................... 68
7.2 Recommendation ............................................................................... 71

REFERENCES ......................................................................................... 75

APPENDIXES ......................................................................................... 79

Appendix A: Questionnaire .................................................................... 79
Appendix B: Photographs of Desalination Plants, Disposal Sit. ........................................ 83
Appendix C: Photographs of CLU Equipments, UAE University ........................................ 86
Appendix D: Experimental Data ..................................................................................... 88
Appendix E: GCC Drinking Water Standard .................................................................... 96
Appendix F: Regulations for Wastewater Re-use and Discharge ................................. 97
LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 2.1</td>
<td>Renewable Water Resources (Mm3/yr.) in the UAE and GCC</td>
<td>7</td>
</tr>
<tr>
<td>Table 2.2</td>
<td>Desalination Units in the Six GCC Countries</td>
<td>10</td>
</tr>
<tr>
<td>Table 2.3</td>
<td>Chemical Composition of Reject Brine from Inland (BWRO) Desalination plants in the GCC Countries (after Ahmed, Alabdul’aly)</td>
<td>14</td>
</tr>
<tr>
<td>Table 2.4</td>
<td>Methods of Concentrate Disposal</td>
<td>16</td>
</tr>
<tr>
<td>Table 2.5</td>
<td>Lists of the most Important Environmental Impacts of Desalination</td>
<td>17</td>
</tr>
<tr>
<td>Table 3.1</td>
<td>Basic Information on the Inland BWRO Desalination Plants</td>
<td>21</td>
</tr>
<tr>
<td>Table 3.2</td>
<td>Reject Brine Water Production (MG/Y), 1999 and 2002</td>
<td>22</td>
</tr>
<tr>
<td>Table 3.3</td>
<td>Concentration of the Target Elements in the Stock Solution</td>
<td>30</td>
</tr>
<tr>
<td>Table 3.4</td>
<td>Packed Column Properties</td>
<td>34</td>
</tr>
<tr>
<td>Table 4.1</td>
<td>pH, EC and Major Cations of Water Samples from the Desalination Plants</td>
<td>38</td>
</tr>
<tr>
<td>Table 4.2</td>
<td>Major Anions of Water Samples from the Desalination Plants</td>
<td>38</td>
</tr>
<tr>
<td>Table 4.3</td>
<td>Heavy Metals in Water Samples</td>
<td>39</td>
</tr>
<tr>
<td>Table 4.4</td>
<td>Characteristics of Reject Brine from Desalination Plants</td>
<td>41</td>
</tr>
<tr>
<td>Table 4.4</td>
<td>Ration of Major Ions of Feed water and Reject Brine of the plants</td>
<td>42</td>
</tr>
<tr>
<td>Table 4.6</td>
<td>Concentration Factor in Evaporation Ponds</td>
<td>42</td>
</tr>
<tr>
<td>Table 5.1</td>
<td>Calculated Coefficient of Uniformity ($C_u$), Coefficient of Curvature ($C_c$) and Approximate Hydraulic Conductivity</td>
<td>44</td>
</tr>
<tr>
<td>Table 5.2</td>
<td>Soil Minerals</td>
<td>46</td>
</tr>
<tr>
<td>Table 6.1</td>
<td>Retardation Factor ($R$) from Batch Isotherm</td>
<td>57</td>
</tr>
<tr>
<td>Table 6.2</td>
<td>Retardation Measure ($A_R$) from Miscible Displacement Experiment</td>
<td>58</td>
</tr>
<tr>
<td>Table 6.3</td>
<td>Dispersion Coefficient ($D_d$), Retardation Coefficient, R$^2$quare, and Diffusion Coefficient ($D_d/R$), obtained by fitting the data from Miscible Displacement Experiment for Sand Dune and In-place Soil.</td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Table 6.4</td>
<td>Comparison between the two Methods for Calculating the Diffusion Coefficient</td>
<td></td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td>------</td>
</tr>
<tr>
<td>Figure 2.1</td>
<td>Map of UAE</td>
<td>6</td>
</tr>
<tr>
<td>Figure 2.2</td>
<td>Renewable Water Resources (Mm³ yr.) in the UAE and GCC Countries.</td>
<td>7</td>
</tr>
<tr>
<td>Figure 2.3</td>
<td>Contribution of the Different Water Resources in the UAE for year 2000</td>
<td>8</td>
</tr>
<tr>
<td>Figure 2.4</td>
<td>Distribution of Water uses by Sector in the UAE</td>
<td>8</td>
</tr>
<tr>
<td>Figure 2.5</td>
<td>Percentage Water Consumption by Different Sectors</td>
<td>9</td>
</tr>
<tr>
<td>Figure 2.6</td>
<td>Total Production of Desalinated Water (MCM) in UAE in 2000</td>
<td>11</td>
</tr>
<tr>
<td>Figure 2.7</td>
<td>Percentage of Desalinated Water Production in UAE Emirates for Year 2000</td>
<td>12</td>
</tr>
<tr>
<td>Figure 3.1a</td>
<td>Map of the Study Area</td>
<td>20</td>
</tr>
<tr>
<td>Figure 3.1b</td>
<td>Sketch of the Study Area</td>
<td>20</td>
</tr>
<tr>
<td>Figure 3.1</td>
<td>Total Desalinated and Reject Water Produced in year 2002 (Mm³)</td>
<td>23</td>
</tr>
<tr>
<td>Figure 3.2</td>
<td>Rate of Change of Water Production, Al Qua’a, a Desalinated Plant</td>
<td>23</td>
</tr>
<tr>
<td>Figure 3.3</td>
<td>Yearly Feed, Product, and Brine Production, Al Qua’a Desalination Plant</td>
<td>24</td>
</tr>
<tr>
<td>Figure 3.4</td>
<td>Monthly Desalinated Water and Rejects Brine form Al Wagan Desalination plants.</td>
<td>24</td>
</tr>
<tr>
<td>Figure 3.5</td>
<td>Monthly Desalinated Water and Rejects Brine form Um Al Zumool Desalination plants.</td>
<td>25</td>
</tr>
<tr>
<td>Figure 3.6</td>
<td>Brine Disposal Site, Al-Wagan</td>
<td>26</td>
</tr>
<tr>
<td>Figure 3.7</td>
<td>Brine Disposal Site, Al-Qua’a</td>
<td>27</td>
</tr>
<tr>
<td>Figure 3.8</td>
<td>Soil Sampling Locations (Al Qua’a Disposal Site)</td>
<td>28</td>
</tr>
<tr>
<td>Figure 3.9</td>
<td>Schematic Diagram Showing Batch Equilibrium Procedures</td>
<td>33</td>
</tr>
</tbody>
</table>
Figure 3.10  Leaching Column Systems with a Fraction Collector  
Figure 4.1  The Level of TPH in Water Samples  
Figure 5.1  Grain Size Distributions of the in-place and Sand Dune Soil, Al Qua’a Disposal Site  
Figure 5.2  Variation in silt Content between Sampling Points  
Figure 5.3  Variations in Soil CEC between Sampling Points  
Figure 5.4  Anion Distributions in Subsurface Soil below the Disposal Site at an Average Depth of 1.0 m (a) Chloride; (b) Nitrate (c) Sulfate and (d) Bicarbonate  
Figure 5.5  Cation Distributions in Subsurface Soil below the Disposal Site at an Average Depth of 1.0 m (a) Potassium; (b) Sodium (c) Magnesium; and (d) Calcium  
Figure 5.6  Strontium Distributions in Subsurface Soil below the Disposal Site at an Average Depth of 1.0 m  
Figure 6.1  Equilibrium Distributions of Sr  
Figure 6.2  Equilibrium Distributions of K  
Figure 6.3  Equilibrium Distributions of SO₄²⁻  
Figure 6.4  Breakthrough curves for Electrical Conductivity (EC) and Strontium (Sr) For (a) In-place soil and (b) Sand Dune Soil  
Figure 6.5  Determination of Diffusion using Time-Lag Method for Sand Dune Soil, Al Qua’a  
Figure 6.6  Determination of Diffusion using Time-Lag Method for In-place Soil, Al Qua’a  
Figure 6.7  Experimental and Fitted Breakthrough Curves for Strontium in the case of Sand Dune Soil  
Figure 6.8  Experimental and Fitted Breakthrough Curves for Electrical Conductivity in the case of Sand Dune Soil  
Figure 6.9  Experimental and Fitted Breakthrough Curves for Strontium in the case of In-place Soil
Figure 6.10  Experimental and Fitted Breakthrough Curves for Electrical Conductivity in the case of In-place Soil  

Figure 6.11  Effects of the Variability in the Dispersion Coefficient $9D$), using Fixed $(D)$ and $(v)$ values of 2.5 and 2.5, respectively  

Figure 6.12  Effects of the Variability in the Retardation Coefficient $(R)$, using Fixed $(R)$ and $(v)$ values of 1.5 and 0.4, respectively  

Figure 6.13  Predicted Sr Concentration Profile versus Depth with the Time (Sand Dune Soil)  

Figure 6.14  Predicted Sr Concentration Profile versus Depth with the Time (In-place Soil)
LIST OF ABBREVIATIONS

BRINE  Brine TDS >5000 mg/l
BW  Brackish Water (TDS 3,000 mg/l - 15,000 mg/l)
M$^3$/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 Qu'a'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 m³/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 antiscale 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.


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.
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$^3$/yr while the total water demand was 2180 Mm$^3$ in the year 2000. The forecasted demand for the year of 2025 is 3200 Mm$^3$/yr (Sommarive and Syambabu, 2001).

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

Table 2.1: Renewable Water Resources (Mm$^3$/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.
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).
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$^3$/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$^3$/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$^3$/yr, as shown in Table 2.2.

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

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 byproduct 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 (Mickle, 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.

\[ CF = \frac{1}{1-SR} \]  

[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).
<table>
<thead>
<tr>
<th>Parameter</th>
<th>AlWadnarat, Oman</th>
<th>Umm Al Quwain, UAE</th>
<th>Hamriyah, Sharjah, UAE</th>
<th>Saja'a, Sharjah, UAE</th>
<th>Buwailb, Saudi Arabia</th>
<th>Salbough, Saudi Arabia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca²⁺ mg/l</td>
<td>923</td>
<td>202</td>
<td>173</td>
<td>188</td>
<td>573</td>
<td>404</td>
</tr>
<tr>
<td>Mg²⁺, mg/l</td>
<td>413</td>
<td>510</td>
<td>311</td>
<td>207</td>
<td>373</td>
<td>257</td>
</tr>
<tr>
<td>Na⁺, mg/l</td>
<td>2780</td>
<td>3190</td>
<td>1930</td>
<td>4,800</td>
<td>2327</td>
<td>1433</td>
</tr>
<tr>
<td>K⁺, mg/l</td>
<td>81.5</td>
<td>84.5</td>
<td>50.7</td>
<td>60</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Sr²⁺, mg/l</td>
<td>28.2</td>
<td>21.10</td>
<td>14.20</td>
<td>40</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>ΣCation meq/l</td>
<td>203.06</td>
<td>192.98</td>
<td>119.48</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>pH</td>
<td>7.21</td>
<td>7.54</td>
<td>7.66</td>
<td>7.95</td>
<td>4.1</td>
<td>4.5</td>
</tr>
<tr>
<td>Electrical conductivity</td>
<td>16.8</td>
<td>14.96</td>
<td>127.41</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>(mS/cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDS, mg/l</td>
<td>10553</td>
<td>10923</td>
<td>7350</td>
<td>12,239</td>
<td>10800</td>
<td>6920</td>
</tr>
<tr>
<td>NO₃, mg/l</td>
<td>7.2</td>
<td>27.4</td>
<td>15.9</td>
<td>NR</td>
<td>143</td>
<td>142</td>
</tr>
<tr>
<td>F, mg/l</td>
<td>-1</td>
<td>1.6</td>
<td>1.3</td>
<td>8.0</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Cl, mg/l</td>
<td>4532</td>
<td>4108</td>
<td>2933</td>
<td>4,860</td>
<td>2798</td>
<td>1457</td>
</tr>
<tr>
<td>SO₄, mg/l</td>
<td>1552</td>
<td>2444</td>
<td>1537</td>
<td>2,400</td>
<td>4101</td>
<td>2840</td>
</tr>
<tr>
<td>SO₂, mg/l</td>
<td>NR</td>
<td>164.09</td>
<td>133.71</td>
<td>120</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Carbonate, CO₃⁻</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Bicarbonate, HCO₃⁻</td>
<td>466</td>
<td>656</td>
<td>753</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>N</td>
<td>1.6</td>
<td>6.2</td>
<td>3.6</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Sanions, meq/l</td>
<td>167.88</td>
<td>198.05</td>
<td>127.41</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Ion Balance</td>
<td>9.48</td>
<td>4.02</td>
<td>-3.21</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>SAR</td>
<td>19.12</td>
<td>27.20</td>
<td>20.30</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>SER</td>
<td>59.55</td>
<td>71.91</td>
<td>70.27</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>L₁</td>
<td>1.24</td>
<td>1.04</td>
<td>1.26</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>R₁</td>
<td>4.73</td>
<td>5.46</td>
<td>5.14</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Total ion, mg/l</td>
<td>10781</td>
<td>11245</td>
<td>7719</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Total alkalinity</td>
<td>380</td>
<td>538</td>
<td>617</td>
<td>945</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Total Hardness₄</td>
<td>4041</td>
<td>2630</td>
<td>1730</td>
<td>NR</td>
<td>2968</td>
<td>2066</td>
</tr>
<tr>
<td>Fe, mg/l</td>
<td>0.06</td>
<td>0.08</td>
<td>0.05</td>
<td>NR</td>
<td>65.5</td>
<td>NR</td>
</tr>
<tr>
<td>Mn, mg/l</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>NR</td>
<td>22.6</td>
<td>NR</td>
</tr>
<tr>
<td>Cu, mg/l</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>NR</td>
<td>10.8</td>
<td>NR</td>
</tr>
<tr>
<td>Zn, mg/l</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Cr, mg/l</td>
<td>0.02</td>
<td>0.12</td>
<td>0.05</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Al, mg/l</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>182</td>
<td>NR</td>
</tr>
<tr>
<td>Ba, mg/l</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>68</td>
<td>NR</td>
</tr>
<tr>
<td>As, mg/l</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>23.2</td>
<td>NR</td>
</tr>
<tr>
<td>Pb, mg/l</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>5.2</td>
<td>NR</td>
</tr>
<tr>
<td>Sc, mg/l</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>7.7</td>
<td>NR</td>
</tr>
</tbody>
</table>

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
m³/day (Squire, 2000). About 73% of the plants were brackish water RO, 11% were
nonofiltration (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.

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

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.

### Environmental Impacts

#### 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.

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 interbeded 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
<table>
<thead>
<tr>
<th>Item</th>
<th>AlWagan</th>
<th>Al Quaa</th>
<th>Um Al Zumool</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Plants</td>
<td>11 plants (4 mobile and 7 Stationary)</td>
<td>12 plants (6 mobile and 6 stationary)</td>
<td>2 Stationary</td>
</tr>
<tr>
<td>Purposes</td>
<td>Domestic and livestock supply</td>
<td>Domestic and livestock supply</td>
<td>Domestic</td>
</tr>
<tr>
<td>Feed Method</td>
<td>Brackish Groundwater</td>
<td>Brackish Groundwater</td>
<td>Brackish</td>
</tr>
<tr>
<td>Total Capacity (G/d)</td>
<td>25,000 – 50,000</td>
<td>25,000 – 60,000</td>
<td>25,000</td>
</tr>
<tr>
<td>Recovery Rate (%)</td>
<td>70%</td>
<td>70%</td>
<td>60%</td>
</tr>
<tr>
<td>Disposal Methods</td>
<td>Unlined pit</td>
<td>Unlined pit</td>
<td>Unlined pit</td>
</tr>
<tr>
<td>No. of Feeding Well</td>
<td>13</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>Feed Salinity &amp; Pre-treatment</td>
<td>6500 mS/cm</td>
<td>6000 mS/cm</td>
<td>17000 mS/cm</td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>Sand filtration</td>
<td>Sand filtration Carbon filtration Cartridges filtration</td>
<td>Sand filtration Carbon &amp; Cartridge filt.</td>
</tr>
<tr>
<td>Chemical treatment</td>
<td>Anti-scale, Sulphuric Acid</td>
<td>Anti-scale, H2SO4</td>
<td>Anti-scale, Sulphuric Acid</td>
</tr>
<tr>
<td>Post Treatment</td>
<td>1u-5u filters</td>
<td>UV System</td>
<td>-</td>
</tr>
<tr>
<td>RO membrane cleaning frequency</td>
<td>every 2000 hrs 22 working hrs/d</td>
<td>every 2000 hrs 20 working hrs/d</td>
<td>every 2000 hrs 16 hrs/d</td>
</tr>
<tr>
<td>Chemical used for cleaning</td>
<td>Citric acid, Bioclean L607, RO clean L607 Bioclean 511</td>
<td>Citric acid, and Fouling (115,807)</td>
<td>-</td>
</tr>
<tr>
<td>Membrane manufactures &amp; Type</td>
<td>Fluid System, Filmtech Hydro matrix, Spiral Wound &amp; Seawater membranes are used</td>
<td>Fluid System, Dupont spiral wound, Seawater Membrane 4(SW-4040), 8 inch</td>
<td>Filmtech</td>
</tr>
<tr>
<td>Membrane life time</td>
<td>9 yr. for Fluid System 5-6 yr for Filmtech 3 yrs. for Hydro matrix</td>
<td></td>
<td>8 inch, SW8040</td>
</tr>
</tbody>
</table>

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%.

<table>
<thead>
<tr>
<th>Plants (BWRO)</th>
<th>Year</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1999</td>
<td>2002</td>
<td></td>
</tr>
<tr>
<td>Al Wagan</td>
<td>25,425,605</td>
<td>49,627,511</td>
<td></td>
</tr>
<tr>
<td>Al Qua’a</td>
<td>33,129,547</td>
<td>49,749,263</td>
<td></td>
</tr>
<tr>
<td>Um Al Zumool</td>
<td>9,675,080</td>
<td>10,584,469</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.2 Reject Brine Water Production (MG/Y), year 1999 and 2002
Fig. 3.1: Total Desalinated and Reject water Produced in year 2002 (Mm$^3$)

Fig. 3.2: Rate of Change of Water Production, Al Qua'a 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 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 (HCO₃, SO₄, Cl, NO₃), 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.
**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 (HNO₃ : HCL). Heavy metals and some anions have been analyzed using ICP-OES-VISTA-MPX CCD Simultaneous.

Fig. 3.8: Soil Sampling Location (Al Qua’a Disposal Site)
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 μm) 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-Kα radiation (λ= 1.542 Å) at 40 kV, 30 mA and scanning speed of 0.02°/S was used. The diffraction peaks between 2θ =2° and 2θ =60° were recorded. The corresponding spacing (d in Å) and the relative intensities (I/1°) 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.

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 (SO₄, 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, N₂O₆Sr and Na₂SO₄ 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.
<table>
<thead>
<tr>
<th>Chemical</th>
<th>M.Wt.</th>
<th>M.Wt. of target element</th>
<th>Amount g / L</th>
<th>Concentration of target substance (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KBr</td>
<td>119</td>
<td>39</td>
<td>0.149</td>
<td>48.8</td>
</tr>
<tr>
<td>N₂O₆Sr</td>
<td>211.6</td>
<td>87.6</td>
<td>0.241</td>
<td>100</td>
</tr>
<tr>
<td>Na₂SO₄</td>
<td>142</td>
<td>96</td>
<td>0.148</td>
<td>100</td>
</tr>
</tbody>
</table>

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

Initial concentrations of Sr and SO₄ 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):

$$q = \frac{(C_0-C) \times V}{M}$$  \[3.1\]

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:

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

$$\frac{dq}{dc} = k_d$$  \[3.3\]

$k_d$ 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:

$$R = 1 + (\rho_d \times k_d) / \eta$$  \[3.4\]

Where $\rho_d$ is the dry density, $k_d$ is the distribution coefficient, and $\eta$ is the porosity.
3.7 MISCELLANEOUS 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$^2$) | 19.6 | 19.6
- The volume of the column (cm$^3$) | 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$^3$) (assuming the density of water 1g/cm$^3$) | 391 | 295.5
- Porosity | 0.38 | 0.30
- The moisture content (%) | 38 | 30
- Bulk density (g/cm$^3$) | 1.689 | 1.75
- Hydraulic conductivity, k (cm/sec) | 6.50x10$^{-5}$ | 9.0x10$^{-5}$
- 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$_2$ 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, $C_e/Co$, versus time or pore volumes of flow (PV).

![Leaching Column System with a Fraction Collector](image)

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

### 3.8 REJECT BRINE TRANSPORT MODELING

The movement of containments through soil profile is an active area of research. Models have been developed to stimulate 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-Zumool, 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 Na\(^+\), Ca\(^{2+}\) and 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 (NO\(_3^-\)) and Phosphorus (P), whereas the concentrations of Sulfate (SO\(_4^{2-}\)) and Chloride (Cl\(^-\)) were exceeding the allowable limits. The higher SO\(_4^{2-}\) 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.
### Table 1: pH, EC and Major Cations of Water Samples from the Desalination Plants

<table>
<thead>
<tr>
<th>Plant &amp; Water Sample Name</th>
<th>pH (EC)</th>
<th>Na (mg/l)</th>
<th>Ca (mg/l)</th>
<th>Mg (mg/l)</th>
<th>K (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Al Wagan</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed</td>
<td>7.02</td>
<td>14.7</td>
<td>741.59</td>
<td>146.31</td>
<td>112.846</td>
</tr>
<tr>
<td>Product</td>
<td>7.02</td>
<td>0.82</td>
<td>55.25</td>
<td>140.00</td>
<td>0.941.30</td>
</tr>
<tr>
<td>Reject</td>
<td>5.64</td>
<td>30.3</td>
<td>2248</td>
<td>367.96</td>
<td>282.6849</td>
</tr>
<tr>
<td>Pond</td>
<td>6.76</td>
<td>26.6</td>
<td>1985</td>
<td>393.25</td>
<td>300.5660</td>
</tr>
<tr>
<td><strong>Al Qu’a’a</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed</td>
<td>6.67</td>
<td>4.61</td>
<td>451.13</td>
<td>162.36</td>
<td>104.2724</td>
</tr>
<tr>
<td>Product</td>
<td>7.46</td>
<td>0.22</td>
<td>39.20</td>
<td>1.80</td>
<td>1.160.90</td>
</tr>
<tr>
<td>Reject</td>
<td>6.67</td>
<td>16.9</td>
<td>2880</td>
<td>518.86</td>
<td>337.9464</td>
</tr>
<tr>
<td>Pond</td>
<td>7.14</td>
<td>14.6</td>
<td>1994</td>
<td>366.86</td>
<td>252.6167</td>
</tr>
<tr>
<td><strong>Um Al-Zumool</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed</td>
<td>7.57</td>
<td>5.05</td>
<td>2482</td>
<td>456.40</td>
<td>194.1101</td>
</tr>
<tr>
<td>Product</td>
<td>7.40</td>
<td>0.34</td>
<td>151.0</td>
<td>18.23</td>
<td>7.754.64</td>
</tr>
<tr>
<td>Reject</td>
<td>7.03</td>
<td>12.9</td>
<td>6206</td>
<td>846.78</td>
<td>361.2640</td>
</tr>
<tr>
<td>Pond</td>
<td>8.41</td>
<td>14.0</td>
<td>5517</td>
<td>782.75</td>
<td>336.2450</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Plant &amp; Sample Name</th>
<th>Anions (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cl⁻</td>
</tr>
<tr>
<td><strong>Al Wagan</strong></td>
<td></td>
</tr>
<tr>
<td>Feed</td>
<td>3.827</td>
</tr>
<tr>
<td>Product</td>
<td>398.0</td>
</tr>
<tr>
<td>Reject</td>
<td>8.946</td>
</tr>
<tr>
<td>Pond</td>
<td>9.943</td>
</tr>
<tr>
<td><strong>Al Qu’a’a</strong></td>
<td></td>
</tr>
<tr>
<td>Feed</td>
<td>6.213</td>
</tr>
<tr>
<td>Product</td>
<td>1.143</td>
</tr>
<tr>
<td>Reject</td>
<td>7.212</td>
</tr>
<tr>
<td>Pond</td>
<td>10.437</td>
</tr>
<tr>
<td><strong>Um Al-Zumool</strong></td>
<td></td>
</tr>
<tr>
<td>Feed</td>
<td>9.443</td>
</tr>
<tr>
<td>Product</td>
<td>1.243</td>
</tr>
<tr>
<td>Reject</td>
<td>23.856</td>
</tr>
<tr>
<td>Pond</td>
<td>19.880</td>
</tr>
</tbody>
</table>

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

38
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.

<table>
<thead>
<tr>
<th>Plant &amp; Water Sample Name</th>
<th>Heavy metals Concentration (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Al</td>
</tr>
<tr>
<td>AlWagan</td>
<td></td>
</tr>
<tr>
<td>Feed</td>
<td>0.10</td>
</tr>
<tr>
<td>Product</td>
<td>ND</td>
</tr>
<tr>
<td>Reject</td>
<td>0.02</td>
</tr>
<tr>
<td>Pond</td>
<td>0.02</td>
</tr>
<tr>
<td>AlQua'a</td>
<td></td>
</tr>
<tr>
<td>Feed</td>
<td>0.01</td>
</tr>
<tr>
<td>Product</td>
<td>ND</td>
</tr>
<tr>
<td>Reject</td>
<td>0.03</td>
</tr>
<tr>
<td>Pond</td>
<td>0.02</td>
</tr>
<tr>
<td>Um Al Zumool</td>
<td></td>
</tr>
<tr>
<td>Feed</td>
<td>0.02</td>
</tr>
<tr>
<td>Product</td>
<td>ND</td>
</tr>
<tr>
<td>Reject</td>
<td>ND</td>
</tr>
<tr>
<td>Pond</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Table 4.3: Heavy metals in water samples
4.4 VARIATION OF TOTAL PETROLEUM 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.

![Graph showing the level of TPH in water samples](image)

**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 rations (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.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>ALWAGAN</th>
<th>ALQUAA</th>
<th>UMZOMOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>pH</td>
<td>7.03</td>
<td>6.67</td>
<td>5.62</td>
</tr>
<tr>
<td>Electrical Conductivity (mS/cm)</td>
<td>12.9</td>
<td>16.9</td>
<td>30.3</td>
</tr>
<tr>
<td>TDS</td>
<td>7.77</td>
<td>10.2</td>
<td>18.3</td>
</tr>
<tr>
<td>Ca, mg/l</td>
<td>367.96</td>
<td>518.86</td>
<td>846.78</td>
</tr>
<tr>
<td>Mg,</td>
<td>282.02</td>
<td>337.26</td>
<td>361.68</td>
</tr>
<tr>
<td>Na,</td>
<td>2.248</td>
<td>2.880</td>
<td>6.206</td>
</tr>
<tr>
<td>K,</td>
<td>68.44</td>
<td>94.64</td>
<td>264.05</td>
</tr>
<tr>
<td>SO₄</td>
<td>1.540</td>
<td>1.979</td>
<td>4.179</td>
</tr>
<tr>
<td>Cl,</td>
<td>8.946</td>
<td>7.212</td>
<td>2.385</td>
</tr>
<tr>
<td>NO₃</td>
<td>7.11</td>
<td>5.30</td>
<td>17.1</td>
</tr>
<tr>
<td>F</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Al</td>
<td>0.02</td>
<td>0.03</td>
<td>ND</td>
</tr>
<tr>
<td>Mn</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>P</td>
<td>0.40</td>
<td>0.42</td>
<td>0.28</td>
</tr>
<tr>
<td>Cu</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Zn</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Ni</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Cr</td>
<td>0.70</td>
<td>0.63</td>
<td>0.09</td>
</tr>
<tr>
<td>Cd</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Ba</td>
<td>0.10</td>
<td>0.01</td>
<td>0.32</td>
</tr>
<tr>
<td>B</td>
<td>1.40</td>
<td>1.92</td>
<td>3.40</td>
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<td>V</td>
<td>0.11</td>
<td>0.11</td>
<td>0.04</td>
</tr>
<tr>
<td>Se</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
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<td>Pb</td>
<td>ND</td>
<td>ND</td>
<td>0.01</td>
</tr>
<tr>
<td>Sr</td>
<td>21.63</td>
<td>30.10</td>
<td>30.10</td>
</tr>
</tbody>
</table>

Table 4.4: Characteristics of Reject Brine from Desalination plants
<table>
<thead>
<tr>
<th>Location</th>
<th>Constituents (mg/l)</th>
<th>Na</th>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
<th>EC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Al Wagan</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed water</td>
<td>741.59</td>
<td>146.31</td>
<td>112.41</td>
<td>28.46</td>
<td>5.05</td>
<td></td>
</tr>
<tr>
<td>Reject water</td>
<td>2,248</td>
<td>367.96</td>
<td>282.02</td>
<td>66.49</td>
<td>12.90</td>
<td></td>
</tr>
<tr>
<td>Ratio</td>
<td>3.03</td>
<td>2.51</td>
<td>2.50</td>
<td>2.34</td>
<td>2.55</td>
<td></td>
</tr>
<tr>
<td><strong>Al Qu'a'a</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed water</td>
<td>451.13</td>
<td>162.36</td>
<td>103.64</td>
<td>27.24</td>
<td>4.61</td>
<td></td>
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<tr>
<td>Reject water</td>
<td>2,880</td>
<td>518.86</td>
<td>337.26</td>
<td>94.64</td>
<td>16.90</td>
<td></td>
</tr>
<tr>
<td>Ratio</td>
<td>6.83</td>
<td>3.19</td>
<td>3.25</td>
<td>3.47</td>
<td>3.66</td>
<td></td>
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<tr>
<td><strong>Um Al Zumool</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed water</td>
<td>2,481</td>
<td>456.40</td>
<td>194.50</td>
<td>110.29</td>
<td>14.70</td>
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</tr>
<tr>
<td>Reject water</td>
<td>6,206</td>
<td>846.78</td>
<td>361.68</td>
<td>264.05</td>
<td>30.30</td>
<td></td>
</tr>
<tr>
<td>Ratio</td>
<td>2.50</td>
<td>1.85</td>
<td>1.86</td>
<td>2.40</td>
<td>2.06</td>
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</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Location</th>
<th>Constituents (mg/l)</th>
<th>Na</th>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
<th>EC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Al Wagan</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2,248</td>
<td>367.96</td>
<td>282.02</td>
<td>68.49</td>
<td>12.90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1,985</td>
<td>393.25</td>
<td>300.95</td>
<td>56.60</td>
<td>14.00</td>
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<tr>
<td></td>
<td>0.88</td>
<td>1.07</td>
<td>1.07</td>
<td>0.82</td>
<td>1.85</td>
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</tr>
<tr>
<td><strong>Al Qu'a'a</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2,880</td>
<td>518.86</td>
<td>337.26</td>
<td>94.64</td>
<td>16.90</td>
<td></td>
</tr>
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<td></td>
<td>1,994</td>
<td>366.86</td>
<td>252.75</td>
<td>61.60</td>
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<tr>
<td></td>
<td>0.70</td>
<td>0.70</td>
<td>0.75</td>
<td>0.65</td>
<td>0.86</td>
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</tr>
<tr>
<td><strong>Um Al Zumool</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6,206</td>
<td>846.78</td>
<td>361.68</td>
<td>264.05</td>
<td>30.30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5,516</td>
<td>782.75</td>
<td>336.42</td>
<td>245.42</td>
<td>26.60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.88</td>
<td>0.92</td>
<td>0.93</td>
<td>0.93</td>
<td>0.87</td>
<td></td>
</tr>
</tbody>
</table>

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.

![Grain Size Distribution Graph](image)

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

<table>
<thead>
<tr>
<th>Soil ID</th>
<th>$C_u$</th>
<th>$C_c$</th>
<th>$K$</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-Place Soil</td>
<td>0.363</td>
<td>0.817</td>
<td>3.6 E-07</td>
</tr>
<tr>
<td>Sand Dune Soil</td>
<td>2.5</td>
<td>0.9</td>
<td>3.36 E-07</td>
</tr>
</tbody>
</table>

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.
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.
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, Cu-Kα 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 downstream contains high amount of gypsum. This finding corresponds to the geological formation and the soil classification of the area (Gypsiferous soil) (UAE Atlas, 2000). Appendix D summarizes the physical and chemical properties of the tested soil.

Table 5.1: Soil Minerals

<table>
<thead>
<tr>
<th>Sample I.D</th>
<th>Major minerals</th>
<th>Subordinate minerals</th>
<th>Minor minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Quartz, Plagioclase</td>
<td>Plagioclase, calcite</td>
<td>Calcite</td>
</tr>
<tr>
<td>A2</td>
<td>Quartz</td>
<td>Plagioclase, calcite</td>
<td>Calcite</td>
</tr>
<tr>
<td>A3</td>
<td>Quartz, Calcite</td>
<td>Plagioclase</td>
<td>Gypsum</td>
</tr>
<tr>
<td>B1</td>
<td>Plagioclase</td>
<td>Plagioclase, calcite</td>
<td>Plagioclase, calcite</td>
</tr>
<tr>
<td>B2</td>
<td>Quartz,</td>
<td>Plagioclase</td>
<td>Plagioclase, calcite</td>
</tr>
<tr>
<td>B3</td>
<td>Quartz,</td>
<td>Calcite</td>
<td>Plagioclase, calcite</td>
</tr>
<tr>
<td>Sand Dune Soil</td>
<td>Plagioclase, calcite</td>
<td>Calcite</td>
<td>Gypsum</td>
</tr>
<tr>
<td>In-place Soil</td>
<td>Quartz, Calcite, Gypsum</td>
<td>Calcite</td>
<td>Plagioclase, calcite</td>
</tr>
</tbody>
</table>

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 mainly in the vertical direction. Nitrate concentration was lower than the maximum allowable limits set 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).
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.

![Potassium (K) Contour Map](image)
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/displacement 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.

![Equilibrium Distribution of Sr](image)

**Fig. 6.1: Equilibrium Distribution of Sr.**
Fig. 6.2: Equilibrium Distribution of $K_0$

![Graph showing equilibrium distribution of $K_0$](image)

Fig. 6.3: Equilibrium Distribution of $SO_4$

![Graph showing equilibrium distribution of $SO_4$](image)
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.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Sr</th>
<th>EC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sand Dune</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- $A_R$ (area under the curve)</td>
<td>1.35</td>
<td>0.92</td>
</tr>
<tr>
<td>- $A_R$ (PV at C/Co = 0.5)</td>
<td>1.3</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>In-place Soil</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- $A_R$ (area under the curve)</td>
<td>2.94</td>
<td>1.28</td>
</tr>
<tr>
<td>- $A_R$ (PV at C/Co = 0.5)</td>
<td>3.20</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Table 6.2: Retardation Measure ($A_R$) from Miscible Displacement Experiment
Fig. 6.4: Breakthrough Curves for Electrical Conductivity and Strontium for In-place soil, and Sand Dune soil.

A. In-place Soil

B. Sand Dune
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, $Q_t$, 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 $Q_t$ 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:

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

The diffusion coefficient $D$ can be calculated using the above Eq. [6.1] by plotting $Q_t$ 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.
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 Qu'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.

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

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, $D_d/R = 1.378 \times 10^{-7}$ m$^2$/sec and for in-place soil, $D_d/R$ is $6.58 \times 10^{-8}$ m$^2$/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.
<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Diffusion Coefficient (m²/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time Lag</td>
</tr>
<tr>
<td>Sand Dune</td>
<td>1.653x10⁻⁶</td>
</tr>
<tr>
<td>In-place Soil</td>
<td>1.446x10⁻⁵</td>
</tr>
</tbody>
</table>

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 (v) Values of 1.5 and 0.4, respectively.](image)

---

65
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.

4. 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.

5. The percentages of reject brine from the three investigated plants varied between 30 to 40%.

6. 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, whereas 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 SO₄⁻, 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 K > Sr > SO₄. 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 SO₄ 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://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 Na₂CO₃, NaHCO₃ and NH₄Cl 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 waste disposal and reduce the stress in environment (Al-Mutaz, I.S., and Wagialla, K.M., 1988).
REFERENCES


ADWEA and FEWA Report, 2000. Water Demand Forecast and Management of UAE. UAE


http://jperrt.tripod.com/research_johan/spirulina.html

http://www.brineshrimpdirect.com


Appendix A

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

**QUESTIONNAIRE SURVEY**
Distributed to Inland Desalination Plants, UAE

---

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

**STUDENT NAME:** JUMA KHALFAN K. AL-HANDHALY
Tel: 050-7634667 Fax: 03-7623154,
Att. Dr. A.M.O. Mohamed

**MAJOR SUPERVISOR:** Dr. ABDEL MOHSEN O. MOHAMED
COLLEGE OF ENGINEERING
CIVIL & ENVIRONMENTAL ENGINEERING DEPT.
UAEU, Al-Ain

A. Primary Data:

1. Name of the desalination plant:

2. Type of the desalination plant:

3. Capacity (m³/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 (m³):
### Average quality of feed, product and brine water:

#### A. Electrical conductivity (mS/cm)

<table>
<thead>
<tr>
<th>Year</th>
<th>Feed</th>
<th>Product</th>
<th>Brine</th>
</tr>
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<tbody>
<tr>
<td>90</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>02</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 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.
<table>
<thead>
<tr>
<th>Year</th>
<th>Water type</th>
</tr>
</thead>
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<tr>
<td></td>
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<tr>
<td>2001</td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td></td>
</tr>
</tbody>
</table>

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 a monitoring system (monitoring wells) for the quality of the underlying groundwater?
☐ Yes     ☐ No

B. Chemicals used at your Desalination Plant

<table>
<thead>
<tr>
<th>Treatment Process</th>
<th>Chemicals used</th>
<th>Purpose of using this chemical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment of feed water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment of product water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemicals used in cleaning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-cleaning treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment of brine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Thank you for your kind cooperation.
APPENDIX B

PHOTOGRAPHS OF INLAND DESALINATION PLANTS AND DISPOSAL SITES

Figure B.1: 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
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*         | 124          | 36.2| 92.3|
| Dist. Water    | 0            | 0   | 0   |

\[ K = \text{Soil mass (g)} \times \text{Solution volume (ml)} \times \text{Co} \]

<table>
<thead>
<tr>
<th>Bottle</th>
<th>Soil I.D</th>
<th>Soil mass (g)</th>
<th>Solution volume (ml)</th>
<th>Co</th>
<th>Ceq (mg/l)</th>
<th>Ssoil</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(100ppm)</td>
<td>S. Dune 10</td>
<td>10</td>
<td>100</td>
<td>36.2</td>
<td>33</td>
<td>32</td>
</tr>
<tr>
<td>2(50 ppm)</td>
<td>S. Dune 10</td>
<td>10</td>
<td>100</td>
<td>18.1</td>
<td>16.8</td>
<td>13</td>
</tr>
<tr>
<td>3(25 ppm)</td>
<td>S. Dune 10</td>
<td>10</td>
<td>100</td>
<td>9.05</td>
<td>7.7</td>
<td>13.5</td>
</tr>
<tr>
<td>4(10 ppm)</td>
<td>S. Dune 10</td>
<td>10</td>
<td>100</td>
<td>3.62</td>
<td>4.1</td>
<td>-4.8</td>
</tr>
<tr>
<td>5 (5 ppm)</td>
<td>S. Dune 10</td>
<td>10</td>
<td>100</td>
<td>1.81</td>
<td>2.4</td>
<td>-5.9</td>
</tr>
<tr>
<td>6(100ppm)</td>
<td>In-place 10</td>
<td>10</td>
<td>100</td>
<td>36.2</td>
<td>31.6</td>
<td>46</td>
</tr>
<tr>
<td>7 (50ppm)</td>
<td>In-place 10</td>
<td>10</td>
<td>100</td>
<td>18.1</td>
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<td>12</td>
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<td>8 (25ppm)</td>
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<td>10</td>
<td>100</td>
<td>9.05</td>
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<td>100</td>
<td>3.62</td>
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<td>-38.9</td>
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<tr>
<td>11 Control</td>
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<td></td>
<td>36.2</td>
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</tr>
</tbody>
</table>

\[ *Ssoil = (mg/kg Soil) \]
### Sr

<table>
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<tr>
<th>Bottle</th>
<th>Soil I.D</th>
<th>soil mass</th>
<th>solution volume</th>
<th>Co</th>
<th>Ceq</th>
<th>Ssoil</th>
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<tbody>
<tr>
<td>1(100ppm)</td>
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<td>243</td>
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<tr>
<td>3(25 ppm)</td>
<td>S. Dune</td>
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<td>100</td>
<td>31</td>
<td>17.5</td>
<td>135</td>
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<tr>
<td>4(10 ppm)</td>
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<td>50</td>
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<td>100</td>
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<tr>
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### SO4

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<th>solution volume</th>
<th>Co</th>
<th>Ceq</th>
<th>Ssoil</th>
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<tbody>
<tr>
<td>1(100ppm)</td>
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<td>100</td>
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<td>95.8</td>
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<td>10</td>
<td>100</td>
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<td>57.9</td>
<td>-348.25</td>
</tr>
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<td>100</td>
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<td>S. Dune</td>
<td>10</td>
<td>100</td>
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<td>-544.85</td>
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<td>100</td>
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<td>-577</td>
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The initial concentrations of Sr, K, and SO4 in the two soils are summarized below:

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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:

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### Miscible Displacement Experiment

**Column #1: Sand Dune**

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## Miscible Displacement Experiment

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<th>rho (g/cm³)</th>
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**Sample #**

- For each sample, the values are presented in the format of (PV, Sr, C/Co(Sr), Area under).

**Note:** The table above lists the measured values for a miscible displacement experiment involving in-place soil. The columns represent various parameters such as time, actual time, flow rate (Q), length (L), cross-sectional area (A), theta angle, velocity (v), density (rho), sample number, Sr concentration, C/Co(Sr) ratio, and the area under the curve for Sr analysis.
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D3: CXTFIT MODEL DATA
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)

ERSE MODE NREDU
1 2

LOCK B: INVERSE PROBLEM

ILMT MASS
0 0 0

BLOCK C: TRANSPORT PARAMETERS

D R Mu
1.698 1.0 1.0 0.0
1 1 1 0

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

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

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

DI

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

IODP

BLOCK G: DATA FOR INVERSE PROBLEM

*UTM =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.)

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</tr>
<tr>
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<tr>
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<td>0.379580</td>
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<td>0.470610</td>
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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 (Sh Shoizawa, unpublished, f0)

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

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

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

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

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

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

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

0.356597  0.010356  
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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  

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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-Handaly, 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

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<td>D</td>
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<td>Y</td>
</tr>
<tr>
<td>R</td>
<td>0.1000E+01</td>
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<tr>
<td>mu</td>
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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
NO FURTHER DECREASE IN SSQ OBTAINED FROM 12 TO 15 ITERATIONS

COVARIANCE MATRIX FOR FITTED PARAMETERS

\[
\begin{align*}
D & \quad R \\
D & \quad 1.000 \\
R & \quad 0.687 \quad 1.000
\end{align*}
\]

RSQUARE FOR REGRESSION OF OBSERVED VS PREDICTED = 0.56266463
(COEFFICIENT OF DETERMINATION)

NON-LINEAR LEAST SQUARES ANALYSIS, FINAL RESULTS

95% CONFIDENCE LIMITS

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

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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

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<td>mu...</td>
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### BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS

**STEP INPUT OF CONC. = 1.0000**

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### DATA INPUT FILE: srsand.in
SOLUTE FREE INITIAL CONDITION
NO PRODUCTION TERM

PARAMETER ESTIMATION MODE

MAXIMUM NUMBER OF ITERATIONS = 150

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COVARIANCE MATRIX FOR FITTED PARAMETERS

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D_{....} & R_{....} \\
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R_{....} & 0.031 & 1.000
\end{pmatrix}
\]

RSQUARE FOR REGRESSION OF OBSERVED VS PREDICTED = 0.95225796
(COEFFICIENT OF DETERMINATION)

NON-LINEAR LEAST SQUARES ANALYSIS, FINAL RESULTS

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95% CONFIDENCE LIMITS

ORDERED BY COMPUTER INPUT

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Equilibrium one-site CDE
Effect of Changing D

\[ \text{Inverse Mode NREDU} \]
\[ 0 \quad 1 \quad 2 \]

\[ \text{MODC ZL} \]
\[ 1 \quad 50 \]

** BLOCK C: TRANSPORT PARAMETERS

\[ V \quad D \quad R \quad \text{Mu1} \]
\[ 0.4 \quad 0.1 \quad 1.5 \quad 0.0 \]

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

\[ \text{MODB} \]
\[ 4 \quad \text{MULTIPLE} \]
\[ 5 \quad \text{EXPONENTIAL} \]
\[ 6 \quad \text{ARBITRARY} \]

2
1.0

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

\[ \text{MODI} \]

0

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

\[ \text{MODP} \]

0

** BLOCK H: POSITION AND TIME FOR DIRECT PROBLEM

\[ \text{NZ \quad DZ \quad ZI \quad NT \quad DT \quad TI \quad MPRINT} \]
\[ 1 \quad 1.0 \quad 1.0 \quad 101 \quad 0.05 \quad 0.0 \quad 0 \]

** BLOCK A: MODEL DESCRIPTION

---

** 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 ***************

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

Page 3
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

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BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS

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

= 1.0000  (FLUX CONC. VS. TIME)
\( \mu m(C\cdot dT) = 3.5000 \)

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ANALYTICAL SOLUTIONS FOR ONE-DIMENSIONAL CDE
DIRECT PROBLRM

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

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CXTFIT VERSION 2.0 (1/2/95)
ANALYTICAL SOLUTIONS FOR ONE-DIMENSIONAL CDE
DIRECT PROBLEM
direct21

* 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

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BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS

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

\[ \mu m(C^2dT) = 3.5710 \]

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### Analytical Solutions for One-Dimensional CDE Direct Problrm

**Fig 4-15. Equilibrium one-site CDE**

Effect of Changing D

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CXTFIT VERSION 2.0 (1/2/95)
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

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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
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

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

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

\[ J_m(C*dT) = 0.6161 \]

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---|---
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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
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0.9500 | 0.35445E-08
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| 0.1500 | 0.31390E-06 |
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| 0.2500 | 0.16971E-05 |
| 0.3000 | 0.35657E-05 |
| 0.3500 | 0.70731E-05 |
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| 0.4500 | 0.23991E-04 |
| 0.5000 | 0.41413E-04 |
| 0.5500 | 0.68858E-04 |
| 0.6000 | 0.11067E-03 |
| 0.6500 | 0.17247E-03 |
| 0.7000 | 0.26131E-03 |
| 0.7500 | 0.38587E-03 |
| 0.8000 | 0.55655E-03 |
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| 2.2500 | 0.10839E+00 |
| 2.3000 | 0.11798E+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

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

INITIAL VALUES OF COEFFICIENTS

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BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS

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

1.0000 (FLUX CONC. VS. TIME)
\( \frac{\partial C}{\partial t} = 0.0000 \)

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

** BLOCK C: TRANSPORT PARAMETERS

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

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

** MODI

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

** MODP

** BLOCK H: POSITION AND TIME FOR DIRECT PROBLEM

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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 ZEF; =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
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

<table>
<thead>
<tr>
<th>ME</th>
<th>INITIAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1698E+01</td>
</tr>
<tr>
<td></td>
<td>0.6220E+01</td>
</tr>
<tr>
<td></td>
<td>0.1250E+01</td>
</tr>
<tr>
<td></td>
<td>0.0000E+00</td>
</tr>
</tbody>
</table>

BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS

- STEP INPUT OF CONC. = 20.0000
- DILUTE FREE INITIAL CONDITION
- PRODUCTION TERM

\( (C*\text{d}Z) = 10.00000 \quad \text{Sum}(Cl*\text{d}Z) = 12.50000 \) (TOTAL MASS)

\( C = Cl (=R*C) \)

<table>
<thead>
<tr>
<th>0.81500</th>
<th>(RESIDENT AND TOTAL RESIDENT CONC. VS. DEPTH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>0.200000E+02 0.250000E+02</td>
</tr>
<tr>
<td>0000</td>
<td>0.000000E+00 0.000000E+00</td>
</tr>
<tr>
<td>0000</td>
<td>0.000000E+00 0.000000E+00</td>
</tr>
<tr>
<td>0000</td>
<td>0.000000E+00 0.000000E+00</td>
</tr>
<tr>
<td>0000</td>
<td>0.000000E+00 0.000000E+00</td>
</tr>
</tbody>
</table>
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 (M\(\mu\)=0)

DATA INPUT FILE: Direct.in

DEL DESCRIPTION

DETERMINISTIC EQUILIBRIUM CDE (MODE=1)
RESIDENT CONCENTRATION (THIRD-TYPE INPUT)
REDUCED TIME (T), POSITION(Z)

(HALL PARAMETERS EXCEPT D AND V ARE DIMENSIONLESS)

CHARACTERISTIC LENGTH = ********

FOR DIMENSIONLESS PARAMETERS

INITIAL VALUES OF COEFFICIENTS

<table>
<thead>
<tr>
<th>ME</th>
<th>INITIAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1698E+01</td>
</tr>
<tr>
<td></td>
<td>0.6220E+01</td>
</tr>
<tr>
<td></td>
<td>0.125C:C::</td>
</tr>
<tr>
<td></td>
<td>0.0000E+00</td>
</tr>
</tbody>
</table>

BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS

STEP INPUT OF CONC. = 20.0000

OLUTE FREE INITIAL CONDITION

RODUCTION TERM

3.63000 (RESIDENT AND TOTAL RESIDENT CONC. VS. DEPTH)
C*C*dZ) = 30.00000 Sum(Ct*dZ) = 37.50000 (TOTAL MASS)
C Ct (=R*C)
000 0.20000E+02 0.25000E+02
000 0.20000E+02 0.25000E+02
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 IN.UT 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

<table>
<thead>
<tr>
<th>NAME</th>
<th>INITIAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>(v)</td>
<td>0.1698E+01</td>
</tr>
<tr>
<td>(d)</td>
<td>0.6220E+01</td>
</tr>
<tr>
<td>(r)</td>
<td>0.1250E+01</td>
</tr>
<tr>
<td>(\mu)</td>
<td>0.0000E+00</td>
</tr>
</tbody>
</table>

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)
8.26000 (RESIDENT AND TOTAL RESIDENT CONC. VS. DEPTH)
{(C*t*dZ) = 50.00000 Sum(Ct*dZ) = 62.50000 (TOTAL MASS)}

Ct (=R*C)

<table>
<thead>
<tr>
<th>C</th>
<th>Ct (=R*C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.200000E+02 0.250000E+02</td>
</tr>
<tr>
<td>0</td>
<td>0.200000E+02 0.250000E+02</td>
</tr>
<tr>
<td>0</td>
<td>0.200000E+02 0.250000E+02</td>
</tr>
<tr>
<td>0</td>
<td>0.28662E-17 0.35827E-17</td>
</tr>
<tr>
<td>0</td>
<td>0.00000E+00 0.00000E+00</td>
</tr>
<tr>
<td>0</td>
<td>0.00000E+00 0.00000E+00</td>
</tr>
<tr>
<td>0</td>
<td>0.00000E+00 0.00000E+00</td>
</tr>
<tr>
<td>0</td>
<td>0.00000E+00 0.00000E+00</td>
</tr>
</tbody>
</table>
**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 (In-place Soil)

---

**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**

<table>
<thead>
<tr>
<th>NAME</th>
<th>INITIAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>( W )</td>
<td>( 0.1341E+01 )</td>
</tr>
<tr>
<td>( D )</td>
<td>( 0.7880E+01 )</td>
</tr>
<tr>
<td>( R )</td>
<td>( 0.3320E+01 )</td>
</tr>
<tr>
<td>( \mu )</td>
<td>( 0.0000E+00 )</td>
</tr>
</tbody>
</table>

---

**BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS**

<table>
<thead>
<tr>
<th>STEP INPUT OF CONC. = 20.0000</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOLUTE FREE INITIAL CONDITION</td>
</tr>
<tr>
<td>NO PRODUCTION TERM</td>
</tr>
</tbody>
</table>

\[
\sum (C*dZ) = 1000000 \quad \text{Sum}(C*t*dZ) = 3320000 \quad (\text{TOTAL MASS})
\]

\[
\begin{align*}
\sigma & = 0.0000 \quad \mu = 0.200000E+02 \\
\omega & = 0.000000E+00 \quad 0.000000E+00 \\
\nu & = 0.000000E+00 \quad 0.000000E+00 \\
\chi & = 0.000000E+00 \quad 0.000000E+00 \\
\end{align*}
\]
CXTFIT VERSION 2.0 (1/2/95)
ANALYTICAL SOLUTIONS FOR ONE-DIMENSIONAL CDE
DIRECT PROBLEM

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

<table>
<thead>
<tr>
<th>NAME</th>
<th>INITIAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>u</td>
<td>0.1698E+01</td>
</tr>
<tr>
<td>v</td>
<td>0.6220E+01</td>
</tr>
<tr>
<td>w</td>
<td>0.1250E+01</td>
</tr>
<tr>
<td>D</td>
<td>0.0000E+00</td>
</tr>
</tbody>
</table>

BOUNDARY, INITIAL AND PRODUCTION CONDITIONS

STEP INPUT OF CONC = 20.0000
ABSO FREE INITIAL CONDITION
PRODUCTION TERM

\[
(C*dZ) = 27.05917 \quad \text{Sum}(Ct*dZ) = 33.82396 \text{ (TOTAL MASS)}
\]

(0.000 0.20000E+02 0.25000E+02)
(0.000 0.17059E+02 0.21324E+02)
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

<table>
<thead>
<tr>
<th>NAME</th>
<th>INITIAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>0.1698E+01</td>
</tr>
<tr>
<td>Cd</td>
<td>0.6220E+01</td>
</tr>
<tr>
<td>Fr</td>
<td>0.1250E+01</td>
</tr>
<tr>
<td>tmu</td>
<td>0.0000E+00</td>
</tr>
</tbody>
</table>

BOUNDARY, INITIAL, AND PRODUCTION CONDITIONS

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

= 1.92960 (RESIDENT AND TOTAL RESIDENT CONC. VS. DEPTH)
PRODUCTION TERM

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

\[(C^*dZ) = 48.66594 \text{ Sum}(Ct^*dZ) = 60.83243 \text{ (TOTAL MASS)}\]

\[C \quad Ct (= R^*C)\]

00 0.20000E+02 0.25000E+02
00 0.20000E+02 0.25000E+02
00 0.18666E+02 0.23333E+02
00 0.00000E+00 0.00000E+00
00 0.00000E+00 0.00000E+00
00 0.00000E+00 0.00000E+00
00 0.00000E+00 0.00000E+00
00 0.00000E+00 0.00000E+00
00 0.00000E+00 0.00000E+00
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 replaces 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, reservoirs 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

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

* Knowing that the natural levels of ammonia in ground and surface waters are usually below 0.5 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>
<thead>
<tr>
<th>Constituent</th>
<th>Maximum level (p.p.m.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>0.01</td>
</tr>
<tr>
<td>Barium</td>
<td>0.7</td>
</tr>
<tr>
<td>Boron</td>
<td>0.5</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.003</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.05</td>
</tr>
<tr>
<td>Copper</td>
<td>2</td>
</tr>
<tr>
<td>Cyanide</td>
<td>0.07</td>
</tr>
<tr>
<td>Cyanide (as NO3)</td>
<td>0.6 - 1.5</td>
</tr>
<tr>
<td>Lead</td>
<td>0.01</td>
</tr>
<tr>
<td>Silver</td>
<td>0.1</td>
</tr>
<tr>
<td>Tin</td>
<td>1 µg/l</td>
</tr>
<tr>
<td>Uranium</td>
<td>2 µg/l</td>
</tr>
<tr>
<td>Beryllium</td>
<td>1 µg/l</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.5</td>
</tr>
<tr>
<td>Mercury (total)</td>
<td>0.001</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>0.07</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.02</td>
</tr>
<tr>
<td>Nitrate (as NO3)</td>
<td>50</td>
</tr>
<tr>
<td>Nitrite (as NO2)</td>
<td>5</td>
</tr>
<tr>
<td>Selenium</td>
<td>0.01</td>
</tr>
<tr>
<td>Antimony</td>
<td>0.005</td>
</tr>
</tbody>
</table>

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

\[
\text{Fluoride concentrate} = \frac{0.34}{D}
\]

Where:

\[
D = 0.038 + [0.0062 \times (\text{daily atmospheric temperature in °C}) - 32] \]

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

\[
\frac{C_{\text{no}}}{20} + \frac{C_{\text{ Lowell}}}{3} \leq 1
\]

**TABLE NO. (5)**

Organic Constituents Contents

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Maximum level (µg/Litre)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>a- Chlorinated alkanes:</strong></td>
<td></td>
</tr>
<tr>
<td>Carbon tetrachloride</td>
<td>2</td>
</tr>
<tr>
<td>dichloromethane</td>
<td>20</td>
</tr>
<tr>
<td>1,2-dichloroethane</td>
<td>30</td>
</tr>
<tr>
<td>1,1,1-trichloroethane</td>
<td>2000</td>
</tr>
<tr>
<td><strong>b- Chlorinated ethenes:</strong></td>
<td></td>
</tr>
<tr>
<td>Vinyl chloride</td>
<td>3</td>
</tr>
<tr>
<td>1,1-dichloroethene</td>
<td>30</td>
</tr>
<tr>
<td>1,2-dichloroethene</td>
<td>50</td>
</tr>
<tr>
<td>trichloroethene</td>
<td>70</td>
</tr>
<tr>
<td>tetrachloroethene</td>
<td>40</td>
</tr>
<tr>
<td><strong>c- Aromatic hydrocarbons:</strong></td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Toluene</td>
<td>700</td>
</tr>
<tr>
<td>Xylenes</td>
<td>500</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>500</td>
</tr>
<tr>
<td>Styrene</td>
<td>20</td>
</tr>
<tr>
<td>Benzoylene</td>
<td>&gt;10</td>
</tr>
<tr>
<td><strong>d- Chlorinated benzenes:</strong></td>
<td></td>
</tr>
<tr>
<td>Monochlorobenzene</td>
<td>500</td>
</tr>
<tr>
<td>1,2-dichlorobenzene</td>
<td>1000</td>
</tr>
<tr>
<td>1,4-dichlorobenzene</td>
<td>500</td>
</tr>
<tr>
<td>trichlorobenzene (total)</td>
<td>20</td>
</tr>
<tr>
<td><strong>e- Miscellaneous organic chemicals</strong></td>
<td></td>
</tr>
<tr>
<td>Di ethylhexyl adipate</td>
<td>8</td>
</tr>
<tr>
<td>Di ethylhexyl phthalate</td>
<td>8</td>
</tr>
<tr>
<td>Acrylamide</td>
<td>0.5</td>
</tr>
<tr>
<td>Epichlorohydrin</td>
<td>0.8</td>
</tr>
<tr>
<td>Hexachlorobutadiene</td>
<td>0.5</td>
</tr>
<tr>
<td>Edecar acid E.D.T.A.</td>
<td>400</td>
</tr>
<tr>
<td>Nitrotriacene acid</td>
<td>200</td>
</tr>
<tr>
<td>Tributyrin oxide</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Nitrobenzin - RLU</td>
<td>&gt;10</td>
</tr>
</tbody>
</table>
## TABLE NO. (4)

**Pesticides Contents**

<table>
<thead>
<tr>
<th>Pesticide</th>
<th>Maximum level (µg/Litre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alachlor</td>
<td>20</td>
</tr>
<tr>
<td>Aldicarb</td>
<td>10</td>
</tr>
<tr>
<td>Aldrin/dieldrin</td>
<td>0.02</td>
</tr>
<tr>
<td>Atrazine</td>
<td>2</td>
</tr>
<tr>
<td>Bentazone</td>
<td>300</td>
</tr>
<tr>
<td>Carbofuran</td>
<td>7</td>
</tr>
<tr>
<td>Chlordane</td>
<td>0.2</td>
</tr>
<tr>
<td>Chlorotoluron</td>
<td>30</td>
</tr>
<tr>
<td>D.D.T.</td>
<td>2</td>
</tr>
<tr>
<td>1,2-dibromo-3-chloropropene</td>
<td>1</td>
</tr>
<tr>
<td>2,4-dichlorophenoxyacetic acid</td>
<td>30</td>
</tr>
<tr>
<td>1,2-dichloropropane</td>
<td>40</td>
</tr>
<tr>
<td>1,3-dichloropropene</td>
<td>20</td>
</tr>
<tr>
<td>Heptachlor and heptachlor epoxide</td>
<td>0.02</td>
</tr>
<tr>
<td>Hexachlorobenzene</td>
<td>1</td>
</tr>
<tr>
<td>Isoproturonate</td>
<td>8</td>
</tr>
<tr>
<td>Lindane</td>
<td>2</td>
</tr>
<tr>
<td>MCPA</td>
<td>2</td>
</tr>
<tr>
<td>Methoxychlor</td>
<td>20</td>
</tr>
<tr>
<td>Metolachlor</td>
<td>10</td>
</tr>
<tr>
<td>Molinate</td>
<td>6</td>
</tr>
<tr>
<td>Pendimethalin</td>
<td>20</td>
</tr>
<tr>
<td>Pentachlorophenol</td>
<td>9</td>
</tr>
<tr>
<td>Permethrin</td>
<td>20</td>
</tr>
<tr>
<td>Propanil</td>
<td>20</td>
</tr>
<tr>
<td>Pyridate</td>
<td>100</td>
</tr>
<tr>
<td>Simazine</td>
<td>9</td>
</tr>
<tr>
<td>Trifluralin</td>
<td>20</td>
</tr>
<tr>
<td>2,4-DB</td>
<td>90</td>
</tr>
<tr>
<td>Dichlorprop</td>
<td>100</td>
</tr>
<tr>
<td>Fenoprop</td>
<td>9</td>
</tr>
<tr>
<td>Metoprop</td>
<td>19</td>
</tr>
<tr>
<td>2,4,5-T</td>
<td>9</td>
</tr>
<tr>
<td>Cyanazine</td>
<td>0.5</td>
</tr>
<tr>
<td>1,2-dibromoethane</td>
<td>15</td>
</tr>
<tr>
<td>Disuath</td>
<td>10</td>
</tr>
<tr>
<td>Turbutylazine (TBA)</td>
<td>7</td>
</tr>
</tbody>
</table>
### TABLE NO. (5)

Disinfectants and Disinfectant By-Products Contents

<table>
<thead>
<tr>
<th>Disinfectants</th>
<th>Maximum level (µg/liter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monochloramine</td>
<td>3</td>
</tr>
<tr>
<td>Chlorine</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Disinfectants by-products</th>
<th>Maximum level (µg/liter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bromate</td>
<td>25</td>
</tr>
<tr>
<td>Chlorite</td>
<td>200</td>
</tr>
<tr>
<td>2,4,6-trichlorophenol</td>
<td>200</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>900</td>
</tr>
<tr>
<td>Bromoform</td>
<td>100</td>
</tr>
<tr>
<td>Dibromo chloromethane</td>
<td>100</td>
</tr>
<tr>
<td>Bromo dichloromethane</td>
<td>60</td>
</tr>
<tr>
<td>Chloroform</td>
<td>200</td>
</tr>
<tr>
<td>Dichloroacetic acid</td>
<td>50</td>
</tr>
<tr>
<td>Trichloroacetic acid</td>
<td>100</td>
</tr>
<tr>
<td>Chloraldehyde (trichloroacetaldehyde)</td>
<td>10</td>
</tr>
<tr>
<td>Dichloroacetitrile</td>
<td>90</td>
</tr>
<tr>
<td>Di bromoacetitrile</td>
<td>100</td>
</tr>
<tr>
<td>Trichloroacetitrile</td>
<td>1</td>
</tr>
<tr>
<td>Cyanogenchloride</td>
<td>70</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Radionuclide*</th>
<th>Dose conversion factor (Sv/Bq)*</th>
<th>Calculated rounded value (Bq/litre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^3$H</td>
<td>$1.8 \times 10^{-11}$</td>
<td>7800</td>
</tr>
<tr>
<td>$^{14}$C</td>
<td>$5.6 \times 10^{-10}$</td>
<td>250</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>$7.2 \times 10^{-9}$</td>
<td>20</td>
</tr>
<tr>
<td>$^{49}$Sr</td>
<td>$3.8 \times 10^{-9}$</td>
<td>37</td>
</tr>
<tr>
<td>$^{90}$Sr</td>
<td>$2.8 \times 10^{-8}$</td>
<td>5</td>
</tr>
<tr>
<td>$^{129}$I</td>
<td>$1.1 \times 10^{-7}$</td>
<td>1</td>
</tr>
<tr>
<td>$^{131}$I</td>
<td>$2.2 \times 10^{-8}$</td>
<td>6</td>
</tr>
<tr>
<td>$^{134}$Cs</td>
<td>$1.9 \times 10^{-8}$</td>
<td>7</td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>$1.3 \times 10^{-8}$</td>
<td>10</td>
</tr>
<tr>
<td>$^{210}$Pb</td>
<td>$1.3 \times 10^{-6}$</td>
<td>0.1</td>
</tr>
<tr>
<td>$^{210}$Po</td>
<td>$6.2 \times 10^{-7}$</td>
<td>0.2</td>
</tr>
<tr>
<td>$^{224}$Ra</td>
<td>$8.0 \times 10^{-8}$</td>
<td>2</td>
</tr>
<tr>
<td>$^{226}$Ra</td>
<td>$2.2 \times 10^{-7}$</td>
<td>1</td>
</tr>
<tr>
<td>$^{228}$Ra</td>
<td>$2.7 \times 10^{-7}$</td>
<td>1</td>
</tr>
<tr>
<td>$^{232}$Th</td>
<td>$1.3 \times 10^{-6}$</td>
<td>0.1</td>
</tr>
<tr>
<td>$^{234}$U</td>
<td>$3.9 \times 10^{-5}$</td>
<td>4</td>
</tr>
<tr>
<td>$^{238}$U</td>
<td>$3.6 \times 10^{-6}$</td>
<td>4</td>
</tr>
<tr>
<td>$^{239}$Pu</td>
<td>$5.6 \times 10^{-7}$</td>
<td>3</td>
</tr>
</tbody>
</table>
Environmental Protection and Occupational Health

ADNOC Group Policy and Guidelines
ADNOC LIMITS FOR EFFLUENTS DISCHARGED INTO THE DESERT

<table>
<thead>
<tr>
<th>COMPOUND</th>
<th>DESIRABLE LIMITS (mg/l)</th>
<th>MAXIMUM PER. LIMITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Nitrogen (As)</td>
<td>0.1</td>
<td>0.5 As</td>
</tr>
<tr>
<td>Chemical Oxygen Demand (BOD)</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>(Cd)</td>
<td>0.1</td>
<td>0.2 Cd</td>
</tr>
<tr>
<td>Cd (residual)</td>
<td>1.0</td>
<td>2.0 Cd</td>
</tr>
<tr>
<td>Am, total (Cr)</td>
<td>0.1</td>
<td>0.2 Cr</td>
</tr>
<tr>
<td>Cd (Cu)</td>
<td>1.3</td>
<td>3.0 Cu</td>
</tr>
<tr>
<td>Chemical Oxygen demand (CN)</td>
<td>150</td>
<td>290 CN</td>
</tr>
<tr>
<td>Total (Fe)</td>
<td>2.0</td>
<td>5.0 Fe</td>
</tr>
<tr>
<td>Zn (Pb)</td>
<td>0.1</td>
<td>0.3 Zn</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>2.0</td>
<td>3.0 Mn</td>
</tr>
<tr>
<td>(Ag)</td>
<td>0.001</td>
<td>0.05 Ag</td>
</tr>
<tr>
<td>(Hg)</td>
<td>0.2</td>
<td>1.0 Hg</td>
</tr>
<tr>
<td>6-9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na (total, as P)</td>
<td>30</td>
<td>40 Na</td>
</tr>
<tr>
<td>(Se)</td>
<td>0.05</td>
<td>0.09 Se</td>
</tr>
<tr>
<td>(As)</td>
<td>0.05</td>
<td>0.1 As</td>
</tr>
<tr>
<td>0.2</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX F

REGULATION FOR EFFLUENT DISPOSAL
HEALTH, SAFETY AND ENVIRONMENTAL MANAGEMENT POLICY GUIDELINES

ADNOC GROUP GUIDELINES FOR THE PROTECTION OF USABLE GROUND WATER

[Signature]

APPROVED BY: GENERAL MANAGER

DATE: 22 MAR 1998
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 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.
3.1. 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 Dammanm, Simsima and Umm El Redehuma 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 such that gradient is towards an area utilising ground water from the shallow aquifer for such purposes as agriculture, reforestation or any other purpose.
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 1).

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 (1000 ملغرام / لتر).

كما دلت الدراسة على إن حركة المواد الكيميائية أفقية أكثر منها رأسيا وأجريت تجارب أخرى على أعمدة تربة لدراسة حركة هذه المواد ووجد أن معدلات الإبطاء كانت للبوتاسيوم أكثر من الاسترونيوم والتي كانت أكثر من السلفات.

كما أظهرت هذه التجارب أن تعامل الإبطاء في المسامية الكلية وتركيز أولي / نهائي = 50 كانت أعلى في التربة المتواجدة في الموضوع طبيعي 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 إلى المياه الجوفية على أعمق 100 متر تتراوح بين 13 - 14 يوما في الكثبان الرملية، بينما تستغرق 17 يوما في التربة الطبيعية ، ولقد تمتد 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 المأخوذة من المحطات الداخلية على النتر في المناطق الشرقية من الإمارات العربية المتحدة خاصة الوجن والزمر. تم تجميع العينات من 20 محطة تستخدم مياه التحلية الخشكي (11 من الوجن و12 من القوع و2 من أم الزمور). تراوحت ثعة هذه المحطات من 26,000 جالون/اليوم (99.9 متر مكعب/اليوم) و61,000 جالون/اليوم (209.9 متر مكعب/اليوم) بينما تراوحت معدلات المياه المستخدمة من 30 و70% والمياه الراجحة بين 40 و70% تراوحت معدلات التوصيل الكهربائي لمياه التغذية والراجحة بين 41.7 و71.4 ملي سيمن/سم و12.9 - 13.3 ملي سيمن/سم على التوالي. ويتم التخلص من المياه الراجحة في برك غير مبطنة ذات تربة قليلة الطمي والمياه العضوية والتبادل الأيوني.

ويتم استخدام المياه الجوفية لأعمق تتراوح بين 100 - 150 متر، بينما تبعد البرك مسافة 5 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 والراجحة كيميائيا للعناصر الكبرى والنادرة. ودلت التحالف على وجود العناصر في هذه المياه بمعدلات تفوق تلك الموصى عليها في معايير مجلس التعاون الخليجي، وشركة النفط الوطنية أدنوك الوطنية (أدنوك) لمياه الشرب والمخلفات التي يتم التخلص منها في الصحراء.
التأثيرات البيئية الناتجة عن
مخلفات محطات التحلية الكيميائية
المالحة على التربة والمياه الجوفية

إعداد

جمعة بن خلفان بن خميس الحنظلي
رسالة مقدمة لعمادة الدراسات العليا
ضمن متطلبات الحصول على درجة
الماجستير في علم البيئة

أغسطس 2003