ENVIRONMENTAL EFFECTS OF MULTI-STAGE FLASH (MSF) DESALINATION PLANT AT AL-JUBAIL SAUDI ARABIA

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By

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Dedicated to My Parents

Muhammad Hussain Khan and Amtul Hafeez

For Their Love, Encouragement, and Invaluable Sacrifice,

Throughout My Life

Abstract

This study presents and compares the marine and atmospheric discharges, with an attempt to assess the environmental effects resulting from Al-Jubail MSF desalination plant, the largest in the world, producing 253.5 million gallons of desalinated water per day. For the analyses of air pollution, AERMOD, an air dispersion model, is used to simulate the ambient concentrations of sulfur dioxide, oxide of nitrogen, and fine particulate matter. The emission results/pollutant levels were compared with the Meteorological and Environmental Protection Agency (MEPA) standards.

Similarly, for brine discharge, CORMIX a hydrodynamic mixing model is used for the prediction of plume dilution. Thermal effects and elevated total dissolved solids concentration in brine discharge were also simulated and the results were compared with the U.S. EPA approved Surface Water Quality Standards. It has been found in this study that the plume elevated temperature drops to ambient temperature within five minutes, traveling a distance of 101.4 meters along the downstream, and the TDS concentrations in the brine plume drops to 4700 ppm above the ambient concentration, while traveling a distance of 217 meters, downstream, which is 10 percent above the ambient concentration, which shows that both the pollutants (elevated temperature and elevated TDS) were within the limits as specified by the Surface Water Quality Standards. However, a detailed information regarding the site specific meteorological data, fuel and brine characteristics, and plant specific information should be carried out.

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Table of Contents

Abstract iii

Acknowledgments iv

Table of Contents v

List of Tables x

List of Figures xi

Nomenclature xiv

I. INTRODUCTION 1

- 1.1 Background History 1
- 1.2 Desalination 10
- 1.3 Objectives 19
- 1.4 Thesis Layout 20

II. LITERATURE REVIEW 21

- 2.1 Desalination Process 21
  - 2.1.1 Thermal Processes 22
    - 2.1.1.1 Multistage Flash Desalination (MSF) Process 26
    - 2.1.1.1.1 Multi-Stage Flash (MSF) Distillation Process with Brine Circulation 26
    - 2.1.1.1.2 Multiple Effect Distillation/Evaporation 30
    - 2.1.1.1.3 Vapor Compression Method 32

2.1.2 Membrane Processes 34

2.1.2.1 Reverse Osmosis 34

2.1.2.2 Electro-dialysis 36

2.1.3 Freezing Process 38

III. AIR POLLUTION – AN OVERVIEW AND BRIEF HISTORY 40

3.1 Introduction 40

3.1.1 Sulfur Dioxide (SO_2) 41

3.1.1.1 Health and Environmental Impacts of SO_2 42

3.1.2 Nitrogen Oxide (NO_x) 42

3.1.2.1 Health and Environmental Impacts of NO_x 43

3.1.3 Carbon Monoxide (CO) 43

3.1.3.1 Health and Environmental Impacts of CO 44

3.1.4 Particulate Matter (PM) 44

3.1.4.1 Health and Environmental Impacts of PM 45

3.1.5 Ozone (O_3) 45

3.2 Relevance to Society 46

3.3 Boundary Layer Meteorological Concepts for Plume Dispersion 49

3.4 Plume Dispersion Modeling Concept 53

3.5 Meteorology and Dispersion 55

3.6 Model Selection Criteria 58

3.7 Model Selection & Comparison 63

IV. AERMOD MODEL FORMULATION ---- 71
4.1 Model Overview ---- 71
4.1.1 Model Description ---- 71
4.1.2 Technical Description ---- 75
4.1.2.1 Convective Boundary Layer (CBL) Concentration Equation ---- 79
4.1.2.2 Concentration in Stable Boundary Layer (SBL) By AERMOD ---- 81
4.1.3 Data Acquisition ---- 82
4.1.4 Development of Meteorological Data for AERMOD ---- 82
4.2 Run-Stream File for the AERMOD Model ---- 88
4.2.1 Emission Inventory ---- 89
4.2.2 Source input data ---- 94
4.2.3 Receptor Information ---- 94
4.2.4 Selected Output Options ---- 95
V. STUDY AREA ---- 97
5.1. Al-Jubail Desalination Plant ---- 97
VI. DATA ANALYSIS AND RESULTS ---- 101
6.1 Air Quality Standards ---- 101
6.2 Data Analysis and Processing ---- 104
6.3 Sulfur Dioxide Results ---- 106
6.3.1 1 - Hour Average Concentration Level ---- 106

6.3.2 Daily Average Concentration Level 107

6.3.3 Annual Average Concentration Level 109

6.4 Nitrogen Oxide Results 111

6.4.1 Hourly Average Concentration Level 111

6.4.2 Annual Average Concentration Level 112

6.5 Particulate Matter Results 113

6.5.1 Daily Average Concentration Level 113

6.5.2 Annual Average Concentration Level 115

6.6 Analysis of the Results 116

VII. RESULTS AND ANALYSIS OF BRINE DISCHARGE USING CORMIX1 118

7.1 CORMIX System 118

7.2 CORMIX Technical Description 121

7.3 CORMIX Data Input 123

7.3.1 Site Identification Data 124

7.3.2 Ambient Data 124

7.3.3 CORMIX Discharge Data 127

7.3.4 Pollutant Data 129

7.4 Geographical Description of the Site 130

7.5 Data Acquisition for CORMIX 132

7.6 Results and Analysis of Elevated Thermal Discharge From Al-Jubail Plant 134

7.7 Results and Analysis of Elevated Total Dissolved Solids (TDS) From Al-Jubail Plant 138

VIII. CONCLUSION AND RECOMMENDATIONS 141

8.1 Conclusions 141

8.2 Recommendations 143

References 144

Appendix-A A-1

Appendix-B B-1

Appendix-C C-1

Appendix-D D-1

Appendix-E E-1

Appendix-F F-1

Appendix-G G-1

LIST OF TABLES

	Title	Page
Table 1.1.	Desalination Plants in Operation	7
Table 1.2.	Desalination Plants Under Construction	8
Table 1.3.	Summary of Worldwide Desalination Capacity Split by Plant Type and Process Capacity Range	12
Table 1.4.	Summary of Worldwide Desalination Capacity (1998), Showing Contribution Made by Arab Nations	13
Table 1.5.	Rating of Various Desalination Processes	14
Table 3.1	Air Pollution Models Used for Air Quality Studies During Kuwaiti Oil Fires	60
Table 3.2.	Comparison of Dispersion Model (AERMET Vs ISCST3)	67
Table 4.1.	Albedo of Ground Covers by Land-Use and Season	84
Table 4.2.	Daytime Bowen Ratio by Land Use and Season Dry Conditions	85
Table 4.3	Fossil Fuel Properties	89
Table 5.1.	Coordinates and Locations of Receptor Points	100
Table 6.1.	MEPA Air Quality Standards	103
Table 7.1	Characteristics of Outfall	132

LIST OF FIGURES

	Title	Page
Figure 1.1	Map of Saudi Arabia	4
Figure 1.2	SWCC Desalination Plants Across the Kingdom	9
Figure 2.1	Phase Diagram for Saline and Pure Water	23
Figure 2.2	Schematic Presentation of a Multi-Stage Flash Desalination Plant	28
Figure 2.3	Schematic of Multi-Effect Distillation Plant	31
Figure 2.4	A Conventional Vapor Compression (VC) System	33
Figure 2.5	Principle of Water Movement in Reverse Osmosis	35
Figure 2.6	Schematic Presentation of a Reverse Osmosis Desalination Plant	36
Figure 2.7	Principle of Water Movement in Electro-Dialysis Units	37
Figure 2.8	Conventional Electro-Dialysis; A, Anion-Permeable Membrane; C, Cation-Permeable Membrane	38
Figure 3.1.	The Pathway of Pollutants in the Air on a Local Scale	48
Figure 3.2.	Qualitative Presentation of Atmospheric Turbulence Intensity, Temperature Profile, and Radiation During Unstable, Neutral and Stable Atmosphere	52
Figure 3.3.	The Gaussian Plume Concept	54
Figure 3.4.	Temperature Profile in Atmospheric Layer	56
Figure 3.5.	Model Selection Process	63
Figure 4.1.	Schematic Showing the AERMOD Air Dispersion Model with Pre-Processors	72
Figure 4.2.	AERMOD Two State Approach. Total Concentration Predicted by AERMOD	76
Figure 4.3	Construction of Weighting Factor and Calculating Total Concentration	78

Figure 4.4 AERMOD Dispersion in CBL Using Two Gaussian Distribution 79
Figure 4.5 Receptor Grid for AERMOD Model Runs 95
Figure 5.1 Schematic Diagram of Al-Jubail MSF Desalination Plant 99
Figure 5.2 Jubayl Desalination Plant and Surrounding Cities 100
Figure 6.1 Flow Diagram of Data Analysis and Processing System 105
Figure 6.2 1-Hour Average Concentration Plot of SO_2 for the Year 1995 106
Figure 6.3 Plot of 50 Highest Concentrations of SO_2 on 24-Hour (Daily) Average Basis for the Year 1995 108
Figure 6.4 Daily Average Concentration Plot of SO_2 for the Year 1995 109
Figure 6.5. Annual Average SO_2 Concentration Plot ($\mu g/m^3$) Al-Jubail MSF Desalination Plant for the Year 1995 110
Figure 6.6. 1-Hour Average Concentration Plot ($\mu g/m^3$) of NO_x for Al-Jubail Desalination Plant 111
Figure 6.7. Plot of 20 Highest Concentration Levels of NO_x on 1-Hour Average Basis for the Year 1995 112
Figure 6.8. Annual Average Concentration ($\mu g/m^3$) Plot of NO_x for Al-Jubail Desalination Plant 113
Figure 6.9. Daily Average Concentration ($\mu g/m^3$) Plot of Particulate Matters for the Year 1995 114
Figure 6.10. Plot of 20 Highest Concentration ($\mu g/m^3$) Levels of Particulate Matters on Daily Average Basis for the Year 1995 115
Figure 6.11. Annual Average Concentration Plot of Particulate Matters for the Year 1995 116

Figure 7.1. General Three-Dimensional Trajectory of Submerged Buoyant Jet in Ambient Stratified Cross flow 122
Figure 7.2. The Geometry and Flow Characteristics for a Submerge Single Port Discharge 128
Figure 7.3. Persian Gulf between Lat. 26° 52' & 26° 55' N and between Long. 49° 45' & 49° 52' E. Study Site and Depth Contours 131
Figure 7.4. Distribution of Elevated Thermal Discharge in The Persian Gulf 136
Figure 7.5. Concentration Versus Downstream Distance 137
Figure 7.6. Total Dissolved Solid Versus Downstream Distance 139
Figure 7.7. Distribution of Increased Total Dissolved Solids Concentration in the Persian Gulf as a Result of Brine Discharge from Al-Jubail Desalination Plant 140

NOMENCLATURE

AGCC	Arabian Gulf Co-Operation Council
ABL	Atmospheric Boundary Layer
AERMIC	American Society/Environmental Protection Agency Regulatory Model Improvement Committee
BTG	Boiler Turbo Generator
CAA	Clean Air Act
CTDMPLUS	Complex Terrain Dispersion Model Plus Algorithms for Unstable Situations
CO	Control
CORMIX	Cornell Mixing Expert System
CBL	Convective Boundary Layer
CO_2	Carbon Dioxide
DOS	Disk Operating System
DEM	Digital Elevation Model
DC	Direct Current
ED	Electro-Dialysis
GRAMP	Gulf Regional Air Monitoring Program
HPDM	Hybrid Plume Dispersion Model
IDA	International Desalination Association
ISCST	Industrial Source Complex Short Term
ISC	Industrial Source Complex
JDP	Jubayl Desalination Plant
JIC	Jubayl Industrial City
KSA	Kingdom of Saudi Arabia
m	Meters
MSF	Multi Stage Flash
MSF-OT	Multi Stage Flash – Once Through
MSF-M	Multi Stage Flash – Brine Mixing

MED	Multiple Effect Distillation
ME	Meteorology
mb	Milli-bar
MEPA	Meteorological Environmental Protection Agency
MDCA	ministry of Defense and Civil Aviation
NWS	National Weather Services
NO_x	Oxides of Nitrogen
NAAQS	National Ambient Air Quality Standards
OAQPS	Office of Air Quality Planning and Standards
OU	Out Put
pdf	Probability Distribution Function
PBL	Planetary Boundary Layer
PM	Particulate Matter
ppm	Parts Per Million
QA	Quality Assessment
RO	Reverse Osmosis
RE	Receptor
RED	Reverse Electro – Dialysis
RTD	Rough Terrain Diffusion Model
SO_2	Sulfur Dioxide
SO	Source
SPM	Suspended Particulate Matter
SBL	Stable Boundary Layer
SWCC	Saline Water Conversion Cooperation
TDS	Total Dissolved Solids
U.S. EPA	United States Environmental Protection Agency
VC	Vapor Compression
VOC	Volatile Organic Compounds

Chapter I

INTRODUCTION

1.1 Background History

In March 2002, the United Nations Secretary General Kofi Annan stated that more than six billion people live on this planet earth, out of which approximately 1.1 billion people lack access to safe drinking water, and by the end of 2025, two thirds of the world's population is likely to live with moderate or severe water shortage (Annan, 2002). Water scarcity is considered to be a sleeping tiger for most of the environmental problems, and this tiger is waking up (Sandra, 1999).

Gelick in 1996 mentioned that each person consumed a minimum of 50 liters of water per day, excluding the water required for irrigation. The distribution of this 50 liters daily water consumption is as follows: 5 liters are used for drinking, 20 liters for sanitation, 15 liters for bathing, and 10 liters for food preparation.

Considering the above facts and the scarcity of renewable fresh water resources on per capita basis, Falkenmark in1989, has distributed the water scarce countries under one of the five water competition categories:

1. ***Limited water problem countries*** - Countries having more than 10,000 m^3 per person per year renewable water resources.
2. ***General water problem countries*** - Countries having water availability between 1670 to 10,000 m^3 per person per year renewable water resources.
3. ***Water Stressed Countries*** - Countries having water availability between 1000 to 1670 m^3 per person per year renewable water resources.
4. ***Chronic Water Scarcity Countries*** - Countries having water availability between 500 and 1000 m^3 per person per year renewable water resources.
5. ***Beyond "water barrier" countries*** - Countries having less than 500 m^3 per person per year renewable water resources.

All of the above classification is based on the net stream flow measurement within each country in consideration, after adjusting for evaporation and other losses.

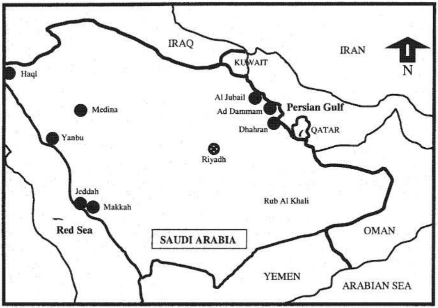
Water scarcity is a major political, economical and environmental problem in the world and in the Middle East. The shortage of natural fresh water supply for domestic purposes is very acute for the Arabian Peninsula (Saudi Arabia, Kuwait, Bahrain, Qatar, the United Arab Emirates, Oman, and Yemen). In these countries the demand for domestic water increases at the rate of 3% or more annually. These countries consume about 60% of the total world desalting water; therefore they are mostly dependent on brackish and seawater desalination to meet their water demands (Al-Mumtaz & Wagialla. 1988, Al-Sahlawi M.A. 1999). The limitation of fresh ground water supply has led the Middle East countries to become increasingly dependent on desalination.

The Middle East countries are facing acute water shortage because of hot and arid climatic conditions, increase in per capita water demand due to high standard of living, and rapid population growth. Despite the shortage, countries in the region have initiated ambitious agricultural development plan with the concept of self-sufficiency in food. As a result, a significant amount of non-renewable deep groundwater resources has been mined causing water quality deterioration and significant depletion of non-renewable water resources in aquifers. To meet this increasing demand of high quality potable water, oil rich Gulf countries have heavily invested in seawater desalination. More than 40% of the world's desalination capacity is concentrated in the Gulf region of which Saudi Arabia shares more than two-third capacity. Saudi Arabia has become the world's major producer of desalinated water (Al-Sahlawi, 1999).

Saudi Arabia, with an area of about 865,000 square miles, occupies the major portion of the Arabian Peninsula. It is roughly one-third the size of the United States, and the same size as all of Western Europe. Saudi Arabia lies at the crossroads of three continents: Europe, Asia, and Africa. It extends from the Red Sea on the west to the Arabian Gulf in the east. To the north it borders on Jordan, Iraq, and Kuwait, and to the south, on Yemen and the Sultanate of Oman. Towards the east lie the United Arab Emirates, Qatar, and the island state of Bahrain as shown in Figure 1.1.

Figure 1.1

Map of Saudi Arabia



(Modified from Source: Saudi Arabia Map)

Saudi Arabia's terrain is varied but on the whole fairly barren and harsh, with salt flats, gravel plains, and sand dunes but few lakes or permanent streams. In the south is the Rub Al-Khali (Empty Quarter), the largest sand desert in the world. In the southwest, the mountain range of Asir Province rises to over 9,000 feet. Saudi Arabia is one of the arid countries in the world, with an average rainfall of less than 5 inches per year. The climate is principally determined by the southerly shift in wind patterns during the winter months, which brings rain and cool weather.

Summer in Saudi Arabia is hot with temperatures in some areas reaching 49°C (120°F). Winter is mild with an average temperature of 23°C (74°F) in Jeddah and 14°C (58°F) in Riyadh. From June through August, midday temperatures in the desert can reach/soar to 50°C (122°F). In contrast to this weather in other parts of the country like in the northern and central regions the temperature may drop to below freezing.

The *shamal*, sand-laden winds from the northern deserts, is most frequent in early summer and can blow for days at 25-30 miles an hour. Rainfall ranges from none at all for up to 10 inches a years in the Rub Al-Khali, to 20 inches a year in the mountains of Asir Province. Temperature between October and May is generally pleasant with cool nights and sunny days. Night temperatures in the coastal areas may dip into the 4.4°C (40°F). From April to November, on the other hand, temperatures are considerably higher and life without air-conditioning would be very unpleasant indeed.

Due to extreme climatic and geographical conditions, there is a dearth of water resources in the kingdom. Because of the harsh climatic situations there exist a rapid increase in demand for the water in the Arabian Gulf countries. Saudi Arabia' Kuwait, the United Arab Emirates, Qatar, Bahrain, and Oman where conventional water resources such as fresh surface water and renewable groundwater are extremely limited, other alternatives such as wastewater reclamation and desalination have been adopted since 1960s. Countries such as Saudi Arabia, Kuwait, Qatar, and Bahrain all use nonrenewable groundwater resources in large quantity, causing depletion of these valuable resources and deterioration in the quality of water. In some of the more arid parts of the Middle East, in particular the Gulf states, where good quality water is not available or is extremely limited, desalination of seawater has been commonly used to solve the problems of water supply for municipal and industrial uses (Al-Quarashi and Husain, 2001).

Saudi Arabia entered the desalinated water field in 1970. Since then it has constructed desalination plants on both the Red Sea and the Gulf coasts as shown in Figure 1.2. Realizing the need of water for the continuous growth of the country, the Saudi government constituted the Saline Water Conversion Corporation (SWCC) to meet its water needs. The SWCC has so far 23 plants, distributed at fifteen locations along the Eastern and Western Coast of Saudi Arabia. 19 of these are on the Red Sea Coast and the remaining 4 on the Persian Gulf Coast. Table 1.1 will describe the 23 plants, which are in operation in the Kingdom. The total production of desalinated water is estimated to be 2.16 million m^3 (572 million [US] gal.) per day including a facility at Al-Jubail producing 1 million m^3 per day, which is currently the world's largest distillation plant. The Al-Jubail desalination plant supplies water to the capital city Riyadh, while the Makkah and other Holy places are supplied by Al-Shoaibah plant, which has the daily production capacity of 48 million gallons of water.

Table 1.1

Desalination Plants in Operation

PLANT		**CAPACITY**			**BENIFICIARY CITIES**
		Daily Water		Electricity	
Name	Phase	Cubic Meter	Gallons	Megawatt	
Haql	II	3,785	1,000,000	----	Haql and Adjacent Villages
Duba	III	3,785	1,000,000	----	Duba and Adjacent Villages
Alwajh	II	473	125,000	----	Al Wajh
	Exp.1	825	218,000	----	
	Exp.2	1,032	273,000	----	
Umlujj	II	3785	1000,000	----	Um Lujj
Rabigh	I	1204	318000	----	Rabigh and Surrounding Villages
Aziziah	I	3870	1000000	----	Aziziah Island
Albirk	I	1952	500,000	----	Al Birk & Adjacent Villages
Farasan	I	430	114000	----	Farasan Island and Adjacent Villages
	Exp.1	1075	284000	----	
Jeddah	II	37850	10,000,000	71	Jeddah
	III	75700	20,000,000	200	
	IV	189250	50,000,000	500	
	R.O.1	48825	13,000,000	----	
	R.O.2	48827	13,000,000	----	
Madinah/ Yanbu	I	95000	25000,000	300	Madinah/Yanbu and Adjacent Villages
Shouibah	I	181,860	48,000,000	220	Makkah/ Taif
Assir	I	75,700	20,000,000	45	Abha/Khamis Mushat/ Ahad Refida and Adjacent villages
Western Coast Total		775,230	204,832,000	1336	
Khafji	II	18624	4919902	-----	Khafji
Alkhobar	II	193536	51126405	500	Khobar, Dammam, Dharan, Khatf, Sahhat, Safwa, Rahima, Coast Guard and Airbase
Jubail	I	116035	30,653000	238	Riyadh, Jubah Marine Base & Al-Jubail Royal Commission
	II	798864	211,036,000	812	
Eastern Coast Total		1,127,059	297,735,307	1550	
TOTAL		**1,902,289**	**502,567,307**	**2,886**	

(Adopted From SWCC, 1995)

Figure 1.2, shows the location of main desalination plants in the kingdom of Saudi Arabia. Four new desalination and power production plants are now under construction, two of these are on Red Sea Coast, the Al-Medinah Yanbu Plant (Phase-II) and the Al-Shoaibah plant (Phase-II). The other two projects are on the Arabian Gulf Coast; these are Al-Jubail Plant (Reverse Osmosis), and the Al-Khobar Plant (Phase-III). Complete information about these four plants is provided in Table 1.2. In response to its need and care about the future consumption of sweet water, the SWCC is now studying fifteen more desalination plants in Saudi Arabia.

Table 1.2

Desalination Plants Under Construction

PROJECT		**CAPACITY**			**BENIFICIARY CITIES**
		Daily Water		Electricity	
S.No	Name	Cubic Meter	Gallons	Megawatt	
1.	Madinah/ Yanbu PhaseII	60,000,000	227,272	35	Madinah, Yanbu, Al-Bahr, Badr, Al-Rayes, Mufrohat, Al-Hamra, Al-Frish, Mulailaih, Khief, Al-Khuzami, Al-Musaijeed
2.	Al-Jubail R.O Desalinated Plant	24,015,000	90,909	-----	Interior Locations, Qassim, Sudair, Washem.
3.	Al-Khobar Phase III	60,000,000	227,272	370	Al-Khobar, Dammam, Dhahran, Qatif, Saihat, Rahima, Al-Ahsa, Buqaiq
4.	Al-Shoabah Phase II	100,000,000	378,787	340	Jeddah, Makkah, Taif

Adopted From SWCC, 1995

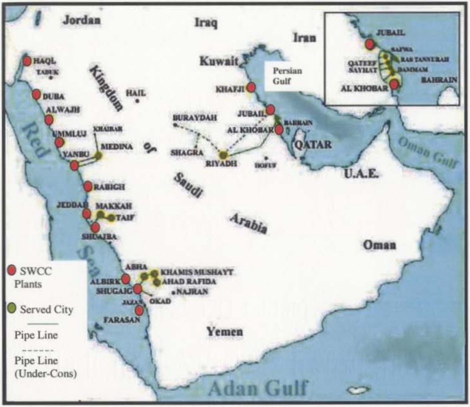


Figure 1.2 SWCC Desalination Plants Across the Kingdom (Adopted from SWCC, 1995)

Most of the above desalination plants are multistage flash (MSF) types, which use a significant amount of energy to produce high quality drinking water from seawater. Although these desalination plants are equipped with the latest technology and due consideration is given to protect the environment and coastal ecosystems, but despite all these measures and control technologies employed, the potential coastal zone impact from these plants cannot be completely avoided (Husain, $2001^{a,b}$).

1.2 Desalination

Desalting/desalination/desalinization refers to the method or water treatment process in which salt is removed from water. This process can be used in different ways but the end result will always be the same, fresh water.

The process of desalination has been practiced for more than 50 years (Wagnick, 1996, 1998) and is a well-established means of water supply in many countries. In nature, the water evaporates from the seas, giving rise to the clouds and then subsequently condenses back in as rainwater. Rainwater is almost pure and all this process of rainmaking is a true physical liquid and solid phase separation in seawater.

Desalination is also an ongoing process in the polar region of the earth where the seawater freezes; the ice crystals produced are pure water and contain none of the salt present in seawater. The basis of all desalination processes is conversion of part of the seawater into fresh water. While looking at the above natural processes one can understand that the process of distillation/desalination technique is based on evaporation and condensation (Al-Mumtaz & Wagialla, 1988; Al-Sahlawi, 1999).

Membrane separation techniques of electrodialysis and reverse osmosis also occur in nature, and its development into commercially viable processes is a recent success of understanding of physical chemistry of phase separation by membranes.

The economical production of fresh water from seawater became possible in 1957 with the advent of multistage flash process (MSF) (IDA, 1998). The MSF process brings a dramatic change in the cost of desalination water. Table 1.3 shows the statistics for the global production of desalinated water, by process and plant capacity (IDA, 1998). It shows that MSF plants have a higher total production capacity than any other process, despite the larger number of reverse osmosis plants. Table 1.3 shows that, of the larger desalination plants (>4000 $m^3 d^{-1}$), MSF plants make up 64 per cent of the total capacity. About 67.6% of the total capacity installed in the gulf countries are of the multi-stage flash type. The capacity of the large plants installed during the eighties were as follows:

▪ Al-Jubail Plant, Saudi Arabia	253.5 million gallons per day
▪ Jeddah IV, Saudi Arabia	58.0 million gallons per day
▪ Al-Khobar II, Saudi Arabia	51.0 million gallons per day
▪ Um El-Nar Plant, Abu Dhabi	95.0 million gallons per day

Table 1.3
Summary of Worldwide Desalination capacity Split by Plant Type and Process Capacity Range

Desalting process	**Percentage of Using Technologies**	**Capacity (10^6 m^3 d^{-1})**	**Capacity (10^6 gal d^{-1})**	**No. of plants**
Unit Capacity 100-60,000 m^3d^{-1}				
Multistage flash	44.4	10.02	2204	1244
Reverse osmosis	39.1	8.83	1943	7851
Multiple effect	4.1	0.92	202	682
Electrodialysis	5.6	1.27	279	1470
Vapor compression	4.3	0.97	213	903
Membrane softening	2.0	0.45	99	101
Hybrid	0.2	0.05	11	62
Others	0.3	0.06	13	120
Total	100.0	22.57	4965	12433
Unit Capacity 500-60,000 m^3d^{-1}				
Multistage flash	46.8	10.00	2200	1033
Reverse osmosis	37.9	8.10	1782	3835
Multiple effect	3.8	0.81	178	653
Electrodialysis	4.7	1.00	220	230
Vapor compression	4.2	0.90	198	486
Membrane softening	2.1	0.45	99	64
Hybrid	0.2	0.04	9	27
Others	0.28	0.06	13	108
Total	100.0	21.36	4699	6436
Unit Capacity 4000-60,000 m^3d^{-1}				
Multistage flash	64.0	9.27	2039	496
Reverse osmosis	25.7	3.72	818	613
Multiple effect	3.6	0.52	114	48
Electrodialysis	2.1	0.31	68	60
Vapor compression	1.9	0.28	62	42
Membrane softening	2	0.36	79	50
Hybrid	0	0.02	4	2
Others	0	0.00	0	0
Total	100.0	14.48	3186	1311

Source: International Desalination Association, Topsfield, MA, 1998. Worldwide Desalting Plants Inventory Report No. 15

Table 1.4, as shown below, gives more information regarding the large share of the world's desalination capacity, which is in the Arab states, and particularly in the Persian Gulf.

Table 1.4

Summary of Worldwide Desalination Capacity (1998), Showing Contribution Made by Arab Nations

Desalting process	% of using Technology	Capacity (10^6 m^3 d^{-1})	Capacity (10^6 gal d^{-1})
Global			
Multistage Flash	44.4	10.02	2204
Reverse Osmosis	39.1	8.83	1943
Multiple Effect	4.1	0.92	202
Electrodialysis	5.6	1.27	279
Vapor Compression	4.3	0.97	213
Membrane Softening	2.0	0.45	99
Hybrid	0.2	0.05	11
Others	0.3	0.07	15
Total	100.0	22.58	4968
Arab States including AGCC States			
Multistage Flash	37.6	8.50	1870
Reverse Osmosis	12.0	2.70	594
Multiple Effect	0.5	0.12	26
Electrodialysis	1.6	0.35	77
Vapor Compression	1.6	0.36	79
Membrane Softening	0.0	0.00	0
Hybrid	0.0	0.01	2
Others	0.0	0.00	0
Total	52.3	12.04	2649
AGCC States Only			
Multistage Flash	35.0	7.90	1738
Reverse Osmosis	9.1	2.05	451
Multiple Effect	0.2	0.05	11
Electrodialysis	0.5	0.12	26
Vapor Compression	1.0	0.22	48
Membrane Softening	0.0	0.0	0.0
Hybrid	0.0	0.0	0.0
Others	0.0	0.0	0.0
Total	45.8	10.34	2275

AGCC = Arabian Gulf Co-Operation Council

Adopted from: International Desalination Association, Topsfield, MA, 1998. Worldwide Desalting Plants. Inventory Report No. 15

Therefore, it is clear from the literature search that in the arid Arabian Peninsula region the seawater desalination process is becoming increasingly important to satisfy the growing needs of domestic, agricultural, and industrial sectors (El-Nashar and Ali, 1989).

Table 1.3 and 1.4, depicts that the three main types of desalination plants are reverse osmosis (RO), electro-dialysis (ED) and multi stage flash (MSF) desalination. All of the above three desalination processes use fossil fuel as an energy driver. Burning fossil fuel produces the usual gaseous effluents along with particulate matter, because of these environmental issues the three desalination processes are evaluated and rated, as shown in Table 1.5, using the pseudo–quantitative scale where high (H=3), medium (M=2), and low (L=1). On this scale the RO seems to be close to ED and both are preferred to MSF from safety, health, and environmental point of view. However these factors are considered to be not exclusive (Sabri et al., 1980).

Table 1.5

Rating of Various Desalination Processes

EFFECTS	RO	MSF	ED
Noise	H	M	L
Water Effluent	M	H	M
Product Water Impurities			
1. Microelements	L	H	L
2. Toxic materials	M	H	M
Air Pollution	L	H	M
Industrial Risk	M	H	M
Total	8	17	10

Source: Sabri et al., 1980

From Tables 1.3 to 1.5, it has become obvious that the multistage flash (MSF) desalination plants are among the major source of potable water in the Arab Gulf countries and also in the world and is of major concern relating the environment.

The MSF are large, complex and expensive plants, which will be explained in more detailed in chapter 2. The MSF process consists of a series of stages, in which "flash" evaporation takes place from brine flowing through the bottom of the stage, with the vapour condensing to produce water on heat transfer tubes at the top of the stage. The transfer of latent heat heats seawater or brine flowing through the tubes. The heat to operate the process is supplied by steam condensing in the brine heater (or heat input section). MSF desalination process consumes large amount of seawater, with that a large amount of concentrated brine are disposed of into the ocean. This brine discharge from the MSF desalination plants is known to impact upon the marine organism in a number of ways. For instance, elevated temperatures and increased salinity reduce the overall concentration of dissolved oxygen in water, which restricts the life forms to those, which exist at low oxygen levels. Furthermore, at the level of individual organism, extreme temperatures may result in death; at the species level, excessive temperatures may lead to changes in individual abundance and population diversity (Morton et al., 1996).

Desalination plants are usually located on or near to the ocean. The most common and least expensive brine disposal method is ocean discharge. Just like other environmental regulatory guidelines, the U.S EPA Clean Water Act in 1977, classified the brine discharge (saline water) as conventional and non-conventional (and non toxic), and it sets the numeric limits or guidelines for conventional and non-conventional type of effluents, except for salinity. The U.S EPA Clean Water Act does not specifically identify brine total dissolved solids (TDS) as a pollutant. However, extremely low salinities (near zero) or extremely high salinities (twice the ocean ambient) can impact ocean biota if the biota is exposed for an extended period of time (Del Bene et al., 1994).

To study the concentration of TDS/salinity and temperature pattern/profile of the brine discharge from Al-Jubail desalination plant an EPA computer code will be used. Several hydrodynamic mixing models are in use for the evaluation of brine discharge in the surrounding body of water. The most popular of these are the PLUMES code from the EPA Pacific Ecosystems Branch in Newport, Oregon, and the CORMIX code from the EPA Environmental Research Laboratory in Athens, Georgia (Del Bene et al., 1994).

In this thesis in addition to detailed air pollution study, an effort will also be made while using the EPA CORMIX computer code to enable the modeling of submerge brine discharge, to suggest the mixing zone and dilution criteria in the Persian gulf.

Another feature characteristics of MSF desalination process is that it requires a large amount of energy input in order to achieve separation of fresh water from saline or seawater, this energy is mostly in the form of steam, condensing in the brine heater. In almost all instances, the energy required to run these plants is ultimately derived from the combustion of fossil fuels. Air pollutants are emitted from the stacks while burning fossil fuel to attain the energy required for desalination plants. The principal atmospheric pollutants generated by burning the fossil fuel are:

- Sulfur dioxide (SO_2)
- Oxides of nitrogen (NO_x)
- Suspended particulate matter (SPM)
- Carbon dioxide (CO_2), and
- Carbon Monoxide (CO)

All these pollutants are responsible for changing our atmosphere and affecting all forms of life and the environment. Studies have shown that air pollutants adversely affect human health. Mild irritation, severe asthmatic sickness and sometimes-chronic carcinogenic effects are all because of air pollutants. Children, elderly people and people with respiratory problems such as asthma, bronchitis, and people involved in vigorous outdoor activities are more susceptible to the adverse effects of air pollution. Thousands of people die prematurely each year because of air pollution (Husain, 2001[b]).

Besides affecting the human health the air pollution affects the environment by acidifying the water bodies creating photochemical smog, depletion of stratospheric ozone, and global warming.

Air pollutants are transported hundreds and thousands of miles away from the source by wind. These pollutants go through various physical and chemical processes before they finally are deposited. Meteorological and topographical conditions greatly influence the transportation, dispersion and deposition of air pollutants. The main factors effecting the deposition and dispersion of air pollutants are wind speed and direction, turbulence, temperature, topography, meteorological parameters, atmospheric moisture content and stability condition of the air.

In 1990, Zannetti characterized air pollution transport as:

- ***Near Field Transport***: Where building aerodynamics causes effects of the plume
- ***Short Range Transport***: Within 10 km from the source and in this region the primary pollutants are known to have maximum ground level impact.
- ***Intermediate Transport***: Between 10 km and 100 km from the source, where the chemical reactions plays and important role in the transformation of pollutants
- ***Long Range Transport***: Range more than 100 Km from the source, in this case large-scale meteorological effects and deposition and transformation rates play a significant role.

To study the detrimental affects caused by these air pollutants from an existing or proposed facility, the monitoring and controlling agencies propose two basic techniques, which are monitoring and modeling of the site. As the cost of monitoring is very high, therefore modeling is considered to be the most viable effective and economical tool, which is also widely used and highly recommended by the USEPA for such purposes. In this thesis work an EPA air dispersion model AERMOD will be used to simulate the current physical and chemical processes and predict the future concentrations of pollutants in the atmosphere. An effort will be made to control and reduce further deterioration of the atmosphere.

1.3 Objectives

Al-Mutaz and Wagialla, in 1988, stated that the desalination capacity in the Arabian Peninsula has increased from 0.5×10^6 m^3/d in 1973 to 5.8×10^6 m^3/d in 1984 almost a ten fold increase. Al-Sahlawi, in 1999, reported that in Arabian Peninsula which comprises of Saudi Arabia, Kuwait, Bahrain, Qatar, the United Arab Emirates, Oman, and Yemen, there is a 3% or more annual increase of water demand, which clearly shows the increasing demand for desalination plants in that area, comparing to the world desalination capacity, about 70% of large MSF plants are installed in Saudi Arabia.

A great deal of expansion is taking place in Saudi Arabia in the area of desalination. All of these desalination plants require an input of thermal or mechanical energy in order to achieve separation of fresh water from the seawater. The main consequences of such input of energy are an increase in the temperature of the brine discharge and the atmospheric emission. Therefore, this research will attempt to assess the environmental effects by MSF desalination process. Appropriate modeling techniques will be used to estimate the air emission and water pollutants from these plants, which will help in future expansion and reduction in the emission from these plants.

1.4 Thesis Layout

There are eight chapters altogether in this thesis, covering the methods, formulation and analysis of work. Chapter 1 briefly discusses the world and Middle East water shortage/crises, desalination, air and brine discharge problems from desalination plants and objectives of the study. Chapter 2 covers an extensive literature search related to desalination methods and processes. Chapter 3 represents an overview of air pollution and their effects on human health. Air pollution model selection and comparison criteria are also discussed in this chapter. Brief description of AERMOD model, formulation, data acquisition, emission inventory of Al-Jubail desalination plant, and receptor grid information about the site is discussed in chapter 4. Chapter 5 presents the background information about the study area. The results generated by AERMOD, their analysis with scientific and technical interpretation and discussions are presented in chapter 6.

Chapter 7 briefly explains the CORMIX system, the geographical description of the site, and the results and analysis of the brine discharge from Al-Jubail desalination plant.

Finally, in chapter 8, the findings and limitations were presented, and recommendations for the future work are make.

Chapter II

LITERATURE REVIEW

2.1 Desalination Process

In August 1999, the world population reached to six billion. As a result of rapid population growth, the need for water is rapidly increasing, and current freshwater resources will not be able to meet all the requirements. Water cannot be considered now as a low cost resource and easily accessible to all. Many years of drought at various locations, followed by desertification and movement of the population towards this essential resource calls for different considerations in terms of economic, environmental, and social effects (Semiat, 2000). The hydrological cycle provides the earth with a continuous supply of fresh water. Basically, the sun creates the cycle by providing the energy to evaporate water from ocean and from water bodies on land. This water vapor, which accumulates as clouds, condenses in the cooler upper atmosphere and falls to the

Earth's surface in the form of rain or snow. Man has distilled freshwater from seawater for many centuries. Egyptian, Persian, Hebrew, and Greek civilization all used various forms of desalination processes.

Worldwide supplies of saline water, and critical needs for fresh water have led to a substantial growth in the desalination technologies. By desalination we mean primarily the production, from saline water, of product water, which is suitable for human consumption. Even though desalted water represents only a small portion of water used, the impacts of these plants are expected to be considerable. This is especially true when it is coupled with the growth of industries and human population in the arid regions of the world.

2.1.1 Thermal Process

Over 60% of the world's desalted water is produced with heat to distill fresh water from seawater. In laboratory or in industrial plants, the water is heated to a boiling point to produce maximum quantity of water vapors.

Economically in the desalination plants adjusting the atmospheric pressure of the water controls the boiling point. The temperature required to boil water decreases as one moves from sea level to a higher elevation because of the reduced atmospheric pressure on the water. Thus water at a height of 6200 meters from sea level can be boiled at 16 C° less than boiling at sea level. The reduction in boiling point is important factor in desalination process for two major reasons:

1. Multiple boiling
2. Scale control

The important condition to boiled water is the proper temperature relative to its ambient pressure and enough energy for vaporization. For example, if the water is heated to its boiling point, and then the heat is turned off the water will continue to boil for a short time, but will need additional energy (the heat of vaporization) to continue boiling, which can achieved by either providing more heat or by reducing the ambient pressure above the water. By reducing the ambient pressure above the water one can reduce the temperature at which the water boils, as shown in Figure 2.1.

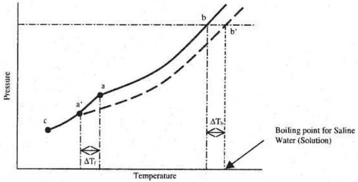


Figure 2.1 Phase Diagram for Saline Water and Pure Water
(Adopted from Spiegler and Laird, 1980)

The phase diagram (Figure 2.1) shows that by reducing the pressure the boiling point of water can be reduced. The point ‘a’ in Figure 2.1 is called the triple point, at this point pure water under equilibrium state can exist in three phases (solid, liquid, and gases) at an absolute pressure of 4.58 mm Hg (millimeter of mercury) and a temperature of 0.01°C. Where for saline or seawater the triple point is shifted from ‘a’ to ‘a`’, the degree of shift depends upon the salinity of water. Point ‘b’ represents the boiling point of pure water, while ‘b`’ boiling point for saline water, at a pressure if 1 atmospheric or 760 mm Hg. In Figure 2.1, the points ‘b’ & ‘b`’ represents the boiling point elevation ΔT_b.

To significantly reduce the amount of energy or heat needed for vaporization, the desalting process usually uses multiple boiling in successive stages, each operating at a lower temperature and pressure.

Scale formation is encountered in most of the desalination plants, and is basically formed from water, which contains ions (like calcium, magnesium, sulfate, and carbonate). These ions in water are capable of creating supersaturated molecules of materials, which are slightly soluble in water. These supersaturated materials tend to precipitate and produces a hard and adherent layer of the chemical, which drops out of the solution in the desalination process. This layer is referred to as “scale”. In all desalination plants the scales can be formed on any heat transfer surface, and can interfere with the heat flow between the surface and the liquid, and also with the movement of liquid through these surfaces (Howe, 1974).

The major types of scale forming salts in seawater desalination are $CaCO_3$, $Mg(OH)_2$, and Ca SO_4. The solubility of $CaCO_3$, and $Mg(OH)_2$, vary widely with the alkalinity of the solution as measured by the pH value, but the solubility of the three forms of $CaSO_4$ are nearly independent of the pH value. Therefore, in each case the scale formation control in desalination plants are treated in two parts, the first one is treating alkaline components and the other one is the control of sulfate scale components.

Sulfuric acid is the cheapest source/method of removing alkaline hardness (the bicarbonate ions), followed by aeration to remove the carbon dioxide. The action of hydrogen ion on the bicarbonate ion can be well understood from the following reaction:

$$H^+ + HCO_3^- \longrightarrow H_2O + CO_2 \qquad (2.1)$$

In the same way the $CaSO_4$ hardness is removed by introducing some vegetable extract, or the use of ion exchange method to replace either the calcium ions with sodium ions or sulfate ions with chloride ions. In scale control technologies the operational temperature in desalination plants are kept below the point where $CaSO_4$ and its hydrates become soluble.

The concept of reducing pressure and temperature has made distillation a successful process around the world. The process, which accounts for most of the desalting capacity is the multi-stage flash distillation/desalination, commonly referred to as MSF process.

2.1.1.1 MULTISTAGE FLASH DESALINATION (MSF) PROCESSES

In MSF desalination process the water is heated and vapors are condensed to collect fresh water. There are four main types of MSF processes namely:

1. Multistage flash desalination process with brine circulation (MSF) system
2. Multistage flash desalination process with once through (MSF-OT) system
3. Multistage flash desalination process with brine mixing (MSF-M) system
4. Multistage flash desalination process with brine circulation and vapor compression system.

2.1.1.1.1 Multistage Flash (MSF) Desalination Process with Brine Circulation

In flash desalination process the vapors are produced by sudden release of pressure on hot water, which is at its boiling temperature. The moment when the maximum boiling temperature has reached/achieved in the system, the pressure on the liquid in different stages is reduced, and at each stage/step with the reduction of pressure the vapours are formed by flashing, which are then collected as a distillate (Howe, 1974).

Figure 2.1, shows the essential features of MSF desalination with brine circulation process. If consists of five main streams including the intake stream, the distillate product, the concentrate out, the brine recycle, and the heating system. As a whole, the system includes the flashing chambers/stages, the brine heater, the pumping units, the venting system, the pretreatment compartment, and the primary steam source.

In the system the flashing chambers are divided into two sections, the heat recovery and the heat rejection. The heat rejection section is basically limited to 3-stages, while in the heat recovery section the flashing stages vary between 21 and 40. The intake seawater is treated first at the pre-treatment compartment with water treatment chemicals (like anti-scaling etc.), after treatment the water is then introduced inside into the preheated/condenser tubes in the last flashing stage of the heat rejection section as shown in the Figure 2.1. At the same time the brine recycle stream is introduced inside into the preheater/condensor tubes of the last flashing stage of the heat rejection section (Al-Wazzan, and Al-Modaf, 2001; Semiat, 2000).

The pre-treated seawater enters into the condenser tubes at stage 'n' and is heated by condensation of the vapors rising from the flash chamber of this stage. Each stage consists of flash chambers below the condenser tube. The seawater from this stage is

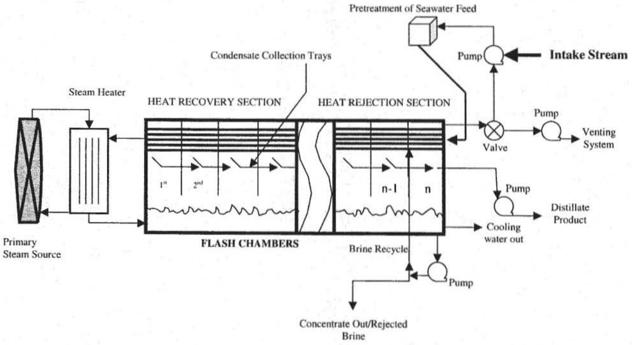


Figure: 2.2 Schematic Presentation of a Multi-Stage Flash Desalination Plant
(Adopted from: Semiat, 2000)

mixed with warm brine by the re-circulating pump to conserve heat, and pass successively through the other stages. In the heat recovery section, the heat is transferred from steam condensing on outside of the tubes while the water is flowing inside the tubes. The brine-seawater mix then enters the brine heater from the first stage of flash chambers. The brine heater is heated with the saturated steam at a temperature from 97 to 117C° (from a primary steam source). The heated steam flows outside of the brine heater tubes while the brine stream flows inside the tubes. As the heated steam condenses, the brine stream absorbs the latent heat of condensation and its temperature reaches the desired top brine temperature. The hot brine then enters the first flashing stage, where a small product of vapor is formed. The flashing process reduces the temperature of the un-evaporated brine. This temperature reduction across the stages is due to the drop in the atmospheric pressure, for pure water this pressure drop ranges from 760 mm Hg to 4.58 mm Hg, while in saline water it depends upon the percentage of salinity present in the water.

The highest pressure is found in the first stage after the brine heater and the lowest pressure is at the last stage 'n'. In each stage the flashed off vapors are condensed on the outer surface of the pre-heater/condenser tubes. The condensation process releases the latent heat of vaporization, which is used to preheat the brine recycle stream in the heat recovery section. After leaving the heat recovery section the water enters into the heat rejection section and splits into two streams. The first into the cooling seawater stream, which is rejected back to the sea, and the second to the feed seawater stream, which is mixed back into the seawater at the last flashing stage in the heat rejection section, and part of it is rejected as a concentrate out to the ocean. The distillate is collected in the collection trays, which are provided in each stage of the desalination plant. Additional units can be introduced into the desalination plants for the pretreatment of feed and intake seawater streams. Mostly, the treatment of intake seawater is limited to simple screening and filtration.

The three most important steps involved in producing distilled water in MSF desalination systems are:

1. Vapor formation by the addition of heat to a body of saline water
2. Removal of this vapor by contacting with the liquid from which it came, and
3. Condensation of vapors by removal of heat, usually it is done by contacting these vapors with cooled surface.

2.1.1.1.2 Multiple-Effect Distillation/Evaporation

From literature, it is clear that one can easily multiply the amount of vapors produced by placing several evaporators in series, while keeping the evaporating sides at low pressure values to ensure proper heat flow (Howe, 1974). The MED process has been used for a long time in the industrial sector. The MED process takes place in a series of vessels (effects), just like MSF. Similarly to MSF, in MED the ambient pressure is reduced in these vessels (effects), which basically provides the seawater intake to undergo a multiple boiling without supplying the additional heat after the first stage/effect.

As shown in Figure 2.3, the seawater enters into the condenser sector first, to gain temperature and produce vapors. Seawater from the condenser enters into the first effect of the MED system. At this section/stage the temperature of seawater is raised to its boiling point, all this heat is provided by an external steam source, as shown in Figure 2.3. The seawater is then either sprayed or distributed on the surface of evaporator tubes to achieve rapid boiling or evaporation. The condensate from the boiler steam is recycled back to the boiler for reuse. In the first effect when the seawater is heated to its boiling point, only a portion of it is evaporated and the rest of the seawater is fed to the second effect as brine (as shown in Figure 2.3). At the second stage/effect the ambient pressure is reduced, to reduce the boiling point, the seawater is again sprayed on a bundle of evaporators, which is then condensate to fresh water (distillate). In the same fashion this process can be continued for several effects, usually 8 to 16 stages/effects are used in the typical large plants.

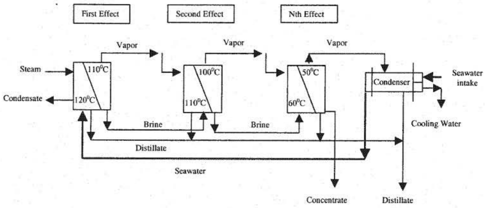


Figure 2.3 Schematic of Multi-Effect Distillation Plant
(Source: University of Waterloo, 2000)

The main differences between the MSF and MED distillation plants are:

1. The amount of water flowing in through a MSF plant is several times greater than the distillate formed in the MED process.
2. The gain output ratio (GOR), which is equal to the amount of distillate produced, divided by the amount of heating steam used in the high-pressure evaporator, is higher in MSF system than in MED system (Howe, 1974).

2.1.1.1.3 Vapor Compression Method

The vapor compression (VC) distillation process is generally used for small-and medium-scale seawater desalting units. The heat for evaporating the water in this system is generated from the compression of vapor rather than the direct exchange of heat from steam, produced in the boiler. The plants using this process are generally designed to take advantage of the principle of reducing the boiling point temperature by reducing the pressure.

In vapor compression system, the driving force is established by creating a higher saturated pressure through compression process. Figure 2.4 represents a conventional vapor compression system operating above the ambient temperature. In this, a mechanical compressor is used to generate the heat for evaporation. The compressor creates a vacuum in the vessel and then compresses the vapor taken from the vessel and condenses it inside of a tube bundle also in the same vessel. Seawater is sprayed on outside of the heated tube bundle where it boils and partially evaporates, producing more water (Spielgler and Laird, 1980).

In vapor compression system, generally two primary methods are used to condense vapor to produce enough heat to evaporate incoming seawater, these are mechanical compressor or a steam jet. The mechanical compressor is usually electrically driven, allowing the sole use of electrical power to produce water by distillation. VC units have been built in a variety of configurations to promote the exchange of heat to evaporate the seawater.

VC units are usually built in the range of 20- 2000 m^3/d (0.005- to 0.5-mgd). They are often used for resorts, industries, and drilling sites where fresh water is not readily available.

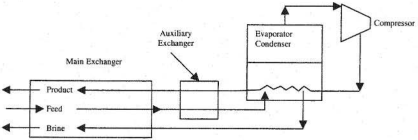


Fig. 2.4 A Conventional Vapor Compression (VC) System
(Source: Spielgler & Laird, 1980)

2.1.2 MEMBRANE PROCESSES

Membrane processes are currently the fastest growing techniques in water desalination. The two main membrane desalination processes are:

1. Reverse osmosis (RO), and
2. Electordialysis (ED)

Both these processes have been in use for many years. There has been faster development in the area of ED than RO, but still RO has been considered to be more sound and simple water distillation process as compared to ED (Dukhin et al., 1991).

In the early 60s, the only process that was used in the industries was ED. There were no RO units at all in that era (Pilat, 2001), but with the invention/technology of organic synthesis the RO system has become dominated in the membrane processes.

Both of the above processes (i.e. reverse osmosis and electrodialysis) will be discussed briefly in the next sections.

2.1.2.1 Reverse Osmosis (RO)

If a solution, for example salt water, is placed on one side of semi-permeable membrane and water is placed on the other side, then there develop a natural tendency, termed "osmosis", in which the water has to diffuse through the membrane to the solute side until an equilibrium osmotic pressure is achieved. Now if pressure is applied to the solute side, substantially greater than the osmotic pressure, then water will diffuse from the solution through the membrane to the freshwater side. This is called reverse osmosis (RO). In this process as shown in Figure 2.5, the water flow passes through the membrane under pressure

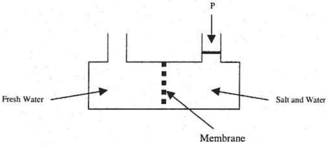


Fig. 2.5 Principle of Water Movement in Reverse Osmosis
(Adopted from Pilat, 2001)

The process is continuous and the membrane separates the feed fluid into two streams: a concentrated one containing impurities, and pure water called permeate (Faller, 1999). The RO membrane technique is considered to be very effective for brackish and seawater desalination (Furukawa, 1997).

Figure 2.6, shows the schematic presentation of RO desalination plant. The process takes place in ambient temperature. The only electrical energy required is for pumping the water to a relatively high operating pressure. Some times special energy recovery turbines are used to reclaim part of the energy. Operating pressure varies between 10-25 bars for brackish water and 50-80 bars for seawater.

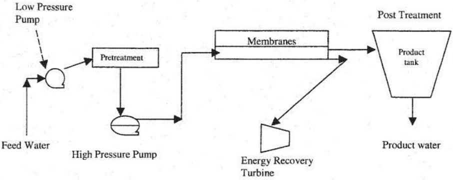


Fig. 2.6 Schematic Presentation of a Reverse Osmosis Desalination Plant (Semiat, 2000)

2.1.2.2 Electrodialysis (ED)

Electrodialysis (ED) or more widespread Reversible Electrodialysis (RED) system is the system in which ions are forced to pass by means of DC electrical power through semi-permeable membranes into the concentrated streams leaving behind diluted salt solutions. The main principle of water flow movement towards membranes in electro-dialysis unit is presented in Figure 2.7 (Pilat, 2001, Semiat, 2000).

Basically, the anions and cations migrate through a membrane the main water flow moves parallel with the membrane (tangentially in relation to migration ions). This system has a nominal initial brackish water recovery, in the range of 80% to 90% (Pilat, 2001).

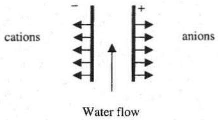


Fig. 2.7 Principle of Water Movement in Electro-Dialysis Units
(Pilat, 2001)

In recent years, large variety of processes have been developed in which different types and combinations of membranes have been uniquely arranged, in an attempt to enhance the performance of, or to simplify the equipments needs for the practical application and use of electro-dialysis (Shaffer and Mintz, 1980). All of these processes use the same principle as described in Figure 2.7.

Figure 2.8, shows the conventional electro-dialysis system, in which, both the cation-permeable and anion-permeable membranes are used, these are arranged in an alternating pattern. Arrangements are made in such a way that two salts depleted boundary layers and two salt concentrated boundary layers are formed in alternate compartments. The water flows across these compartments or membranes and the salt is removed in this process. The end result is water with an acceptable concentration of total dissolved solids/salts.

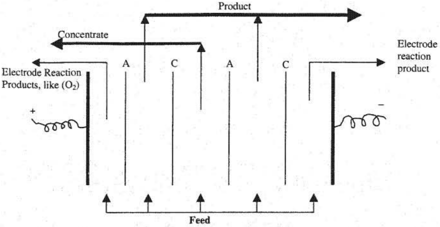


Fig. 2.8 Conventional Electro-dialysis; A, Anion-Permeable Membrane; C, Cation-Permeable Membrane (Sahffer and Mintz, 1980)

2.1.3 FREEZING PROCESS

Extensive work has been done in the late 50s and 60s to invent a freezing desalination process. During this process the dissolved salts are naturally excluded in the formation of ice crystals. Desalination can be achieved by cooling the water to form crystals under controlled conditions. Before the entire mass of water has been frozen, the mixture is usually washed and rinsed to remove the salts in the remaining water, or adhering to the ice crystals. The ice is then melted to produce fresh water.

Theoretically, freezing has some advantages over distillation. These advantages include a lower theoretical energy requirement, minimal potential for corrosion, and little scaling or precipitation. The disadvantage is that it involves handling ice and water mixtures that are mechanically complex to move and process.

A small number of plants have been built over the past 40 years, but the process has not been a commercial success in the production of fresh water for municipal purposes. The most recent significant example of freezing desalting was an experimental solar-powered unit constructed in Saudi Arabia in the late 1980s. The experimental work has been concluded, and the plant disassembled. At this stage, freezing desalting technology probably has a better application in the treatment of industrial wastes rather than the production of municipal drinking water.

Chapter III

AIR POLLUTION - AN OVERVIEW

3.1 Introduction

Air pollution is a problem for all of us. It has been reported that an average adult breathes 20 m^3 of air every day. Children breathe even more air per pound of body weight and are more susceptible to air pollution. Many air pollutants, like urban smog and toxic compounds will remain in the environment for a longer period of time and are carried by the winds hundreds of miles from their origin.

Millions of people live in areas where urban smog, particulate matters and toxic pollutants pose serious health concerns. People exposed to high levels of air pollutants may experience burning eyes, irritated throat, or breathing difficulties. Long-term exposure to air pollution can cause cancer, and long-term damage to the immune, neurological, reproductive, and respiratory systems. In extreme cases, it can even cause death.

The U.S Environmental Protection Agency (EPA) has set National Ambient Air Quality Standards (NAAQS) for the following five common pollutants:

1. Sulfur Dioxide (SO_2)
2. Nitrogen Dioxide (NO_x)
3. Carbon Monoxide (CO)
4. Particulate Matter (PM)
5. Ozone (O_3)

3.1.1 Sulfur Dioxide (SO_2)

SO_2 is a colorless gas with pungent suffocating smell, which, belongs to the family of sulfur oxide gases (SO_x). It can easily be dissolved in water vapor to form acid. When fuel-containing sulfur is burned, it will generate SO_2 gas. Sulfur is basically present in raw materials like gas, crude oil, coal, and ore (containing metal like aluminum, copper, zinc, lead, and iron).

Pollutants, such as sulfate particles are formed from SO_2. These pollutants can be transported and deposited over a long distances from the point of origin. This means that pollutants created by SO_2 is not confined only to the place of origin from where it is emitted. Studies show that about 65% of SO_2 is released into the air (i.e. more than 13 million tons per year), has been produced by the electric generating utilities, and especially those that burn coal and crude oil as fuel (Heinsohn and Kabel, 1999).

3.1.1.1. Health and Environmental Impacts of SO_2

SO_2 causes a wide variety of health and environmental impacts, particularly with asthma among children, the elderly, and people with heart and lung diseases. Sulfur dioxide can cause temporary breathing difficulty for people with asthma who are active outdoors. Long-term exposure to high levels of SO_2 gas aggravates existing heart diseases. Sulfate particles, which are produced from sulfur dioxide when inhaled, deposited in the lungs causes difficulty in breathing and premature death (Amin and Husain, 1994). Sulfate particle are responsible for reducing the visibility. SO_2 react with other substances in the air to form acids which, falls down on the earth as acid rain, damaging forests and crops, changes the makeup of soil, and make lakes and streams acidic and unsuitable for fish. It also accelerates the decay of building materials and paints.

3.1.2 Nitrogen Oxide (NO_x)

Nitrogen oxide belongs to a family of highly reactive gases, which contains oxygen and nitrogen in different proportion. NO_x are basically colorless and odorless in nature, but NO_2 along with particles in the air can be seen as a reddish-brown layer over many urban areas.

The nitrogen oxides (NO and NO_2) are the principal species in tropospheric chemistry generated entirely by combustion processes. Thus the main source of nitrogen oxides is stationary and mobile combustion sources (Butler, 1979).

3.1.2.1 Health and Environmental Impacts of Nitrogen Oxide (NO_x)

Studies have shown that high levels of nitrogen oxides can cause lung damage and other respiratory illnesses, particularly in children and people suffering from asthma (American Lung Association, 1993). NO_x is considered to be one of the main ingredients involved in the formation of ground level ozone. Nitrogen oxides are also a contributing agent in forming acid rain and deposition, which affects the plant and aquatic life and material. Also it is considered that nitric oxide and nitrogen dioxide can have an adverse human health effects (Amin and Husain, 1994). Nitric oxide (NO) and nitrogen dioxide (NO_2) react in air to produce ozone and other pollutants that lead to the production of smog, affecting plants and causing adverse human health effects like eye irritation, shortness of breath, increased respiratory illness and decreased lung function, also reduced the resistance to infections (Gardner, D.E., 1984 and Pennington, 1988).

3.1.3. Carbon Monoxide (CO)

Carbon monoxide is a colorless, odorless gas that formed when carbon in fuel is not burned completely. About 56% of all CO emission is contributed by motor vehicle exhaust. Other sources emissions are residential wood burning, gas stoves, and cigarette smoke. The highest levels of CO in the outside air typically occur in colder months of the year when inversion conditions are more frequent. The air pollution is trapped near the ground beneath a layer of warm air. CO is considered to be a poisonous gas even to healthy people if in high levels in the air. It can also affect the heart disease and can damage the central nervous system (Butler, 1979).

3.1.3.1 Health and Environmental Impacts of Carbon Monoxide (CO)

Carbon dioxide (CO) can cause harmful health effects to the heart, brain, and tissues by reducing the supply of oxygen to these organs. CO is considered to be a toxic gas because of the fact that hemoglobin absorbs CO more readily then oxygen and as a result the brain does not receive enough oxygen. It can produce adverse effects such as reduced visual acuity, psychomotor skill, and pulmonary function, and can also cause death. CO can also aggravate angina problem, a pain in the chest and left arm due to the sudden decrease in blood supply to the heart muscle (McCartney, 1990).

3.1.4. Particulate Matter (PM)

Particulate matter can be described as anything that is airborne, and are microscopic in size. PM include dust, dirt, soot, and smoke. Particles might be suspended in air for long periods of time; they might be dark enough to be seen as soot or smoke, or sometimes microscopic in size. Most of these particles are directly emitted from factories, cars, and burning of fuel. Most of particles may be formed in air from the chemical change of gases, when they react with sunlight and water vapor. PM can be differentiated into Coarse and fine particulates, anything less than 10 microns and greater than 2.5 microns in size are considered as coarse PM or PM_{10}. PM less than 2.5 microns in size are considered as fine PM or $PM_{2.5}$. Both PM_{10} and $PM_{2.5}$ are of great concern to human health, and visibility. PM's can cause a serious health problem to people with sensitivity if exposed to high levels of PM for several days in a row.

3.1.4.1 Health & Environmental Impacts of Particulate Matter (PM)

Particulate matter is considered to be creating a lot of environmental and health impacts. Scientific studies and researches have shown that inhaling PM can cause a series of health problems like aggravating asthma, increase in respiratory symptoms like coughing and pain breathing, chronic bronchitis, decrease lung function, and premature death.

Particulate matter is one of the major causes of reduced visibility (haze). Particles are also carried over to a longer distances by wind which then settle down on ground and water effecting the pH of lakes and stream, changing the nutrient balance of coastal waters, large rivers basins and soil, and also affecting the diversity of ecosystems. Fine particulate in the form of soot, stains and damages the aesthetic view of the monuments and materials (Environment Canada, 1998: U.S EPA, 2001).

3.1.5 Ozone (O_3)

Ozone is a colorless, odorless gas basically composed of three oxygen atoms. Ozone can be found at two different altitudes in the atmosphere, stratospheric ozone occurs naturally in the stratosphere approximately 10 to 30 miles above the earth's surface and forms a layer that protects the life on earth from harmful ultraviolet radiation from the sun. While the ground level ozone, which is basically generated by a chemical reaction between oxides of nitrogen (NO_x) and volatile organic compounds (VOC) in the presence of heat and sunlight, are considered to be harmful to human health.

Ozone is a photochemical oxidant and is a major constituent of smog. The ground level ozone causes a variety of health problems, even at very low levels can cause permanent lung damage after a long-term exposure (Tilton, 1989 & Lipmann, 1991). Ozone is also responsible for damaging plants and the ecosystem.

3.2 Relevance to Society

In all decision-making processes, great importance has been given to the environmental issues. Environmental Impacts due to human activities on air, water, and soil are the factors that have been quantified in many ways to identify, regulate, and control all these kinds of activities. In all these, air has been documented to have a considerable impact on the quality of human life. As mentioned before, people who are sensitive to irritation of bronchial tubes may suffer more because of air pollution. Also compounds like ozone, sulfur dioxide and nitrogen oxides in air may reduce the growth of plants and trees. Sulfur dioxide and nitrogen oxides are the major constituents of acid deposition, the sulfur dioxide emission is considered to be a factor that is too high in Europe and in the Middle East.

Mostly, on a local scale, individual sources have occasionally proven to cause large problems. The pathway of pollutants in the air on a local scale is presented in Figure 3.1 (Erbrink, 1995).

Various government organizations in the world have issued a lot of measures for the reduction of air pollution and to monitor air quality. In doing so, air quality standards have been introduced to check the hourly or daily mean maximum concentration during a year. All these standards are evaluated by means of measurements or by applying dispersion models (for future emissions). It has been considered necessary that for all rationale the dispersion model for stack emissions is an important factor. All these models are implemented on computers in which the transport and dispersion of air pollutants is described. Therefore, for these kinds of models the meteorological sciences are of importance and are frequently applied to air pollution studies.

All the processes in the atmosphere are basically started by the incoming radiation from the sun. The sun continuously disturbs the tendency of the atmosphere to keep things in balance by restoring equilibrium or at least achieving a stationary situation. Usually due to unequal heating of the earth surface, pressure gradients are developed, which force the air to move from one place to another.

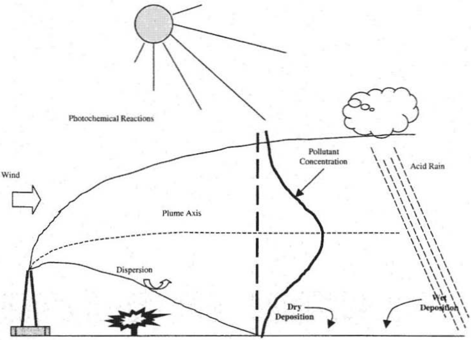


Figure 3.1 The Pathway of Pollutants in the Air on a Local Scale
(Source: Erbrink, 1995)

The pollutants emitted from the source, into the atmosphere, experience the influence of molecular diffusion, turbulent dispersion and transport with the mean wind field (speed and direction). In describing the plume/pollutants dispersion two basic subject-fields have to be considered:

1. The meteorological processes that act on a local scale, and
2. The boundary layer meteorology and the concentration distribution of plumes on a local scale

The term "local" means to include distances up to several tens of kilometers. In many instances the chemical reactions determine the local concentrations, creating a third field of research to be considered: atmospheric chemistry, which describe a chain of reactions in both gas-phase and liquid phase (Erbrink, 1995).

3.3 Boundary Layer Meteorological Concept for Plume Dispersion

In all air pollution studies, the basic parameters of concerned are the wind profile (wind speed and direction, determining the transport process), the degree of turbulence near the surface (responsible for the spreading and dilution of the plume) and the height of the boundary layer. The later parameter determines the extent or the height the pollutants may be carried up into the atmosphere. Turbulence and boundary layer parameters are not measured on a routine basis; therefore, indirect methods are applied to determine these parameters from heat, moisture, and fluxes at the surface of the earth.

To describe the structure of boundary layer, it is important to know the routine measurements carried out at the surface of the earth. Monin and Obukhov in 1954 presented a theory in this area, which is considered to be the most widely accepted theories in the field of plume dispersion modeling. Their theory basically claims that fluxes of heat, momentum and moisture are the functions of two scaling parameters, which are roughness length of the surface, and the length scale for instability. As their theory predicts parameter values at various heights with similar parameters measured at the surface, this theory is also sometimes called similarity theory (Erbrink, 1995).

Monin-Obukhov theory made it possible to calculate the profiles of wind speed and turbulence, which are the crucial parameters in the area of air pollution modeling. Although the Monin-Obukhov theory strictly applies to the surface layer (roughly 10% of height of the atmospheric boundary layer), it is also frequently applied to greater heights with considerable success (Barad, 1958; Businger et al., 1971; Kaimal et al., 1972 and 1976).

Deardorff in 1974 suggested that heat flux and height of the boundary layer are the only two parameters that can determine the properties of the mixed layer. He introduces the convective velocity scale, which is considered to be the most important parameter. His theory applies not only to the surface layer but also to the whole convective boundary layer.

A simple procedure is to account for the various degrees of turbulence, which consists of the use of stability classes. The concept of stability classes has played a major role in the dispersion modeling for many years. Classification of meteorological parameters in general was necessary in the early phase of dispersion modeling because of the fact that computation were not always carried out on computers but by means of nomograms (Erbrink, 1995).

The degree and nature of atmospheric turbulence is the most important parameter. Pasquill in 1961 gave a simple method for the stability classification, modified by Turner in 1967 and Gifford in 1976, and is known as Pasquill-Turner-Gifford method. The method is principally based on observations of the standard deviation of the wind direction on paper recorders, and was widely used in the form of a scheme derived from observations of cloud cover and wind speed.

Figure 3.2, shows the different aspects of atmospheric stability. It shows that during the day when the sky conditions are clear and the net radiation is more towards the earth surface and less reflection back to the sky (i.e. small radiation is reflected back from the earth surface), turbulence and the boundary layer will be at the maximum as shown in the Figure 3.2, and the stability class will be "unstable". While at night when the sky is clear, the net radiation of emission from the earth to the atmosphere is more, under these conditions the boundary layer height is small, the turbulence intensity is at a minimum, and the stability class is "stable". The "neutral" stability class is the time when the sky condition is overcast (day or night), and the turbulence, radiation and boundary layer is at the average.

Many methods are reported to estimate the atmospheric stability. Atmospheric stability is characterized by several physical parameters (Kretzschmar and Mertens, 1980). Most of these parameters are temperature profile near the surface, some indicators for the net radiation (cloud cover) or standard deviation of wind direction. Another and better way of stability class determination is the use of Obukhov length scale, which is considered to be the more appropriate one (Golder, 1972) or the convective velocity scale (Weil and Brower, 1984).

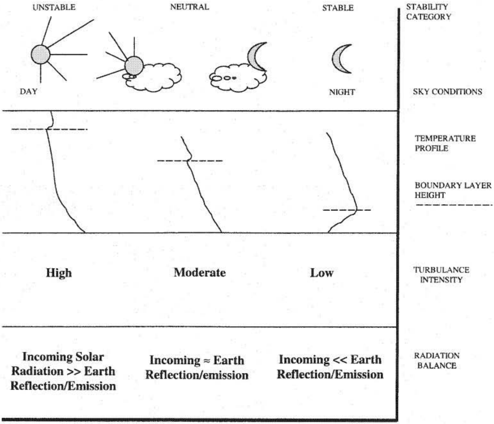


Figure 3.2 Qualitative Presentation of Atmospheric Turbulence Intensity, Temperature Profile, and Radiation during Unstable, Neutral & Stable Atmosphere
(Adopted from Erbrink, 1995)

3.4 Plume Dispersion Modeling Concept

In 1921, G.I Taylor's analysis started the dispersion theory that described the behavior of particles in homogeneous turbulence state. His analysis is considered to be very important and was taken as the basis for many recommendations. Pasquill in 1976 came out with some realistic formulations, which appear to be more reliable for the value of lateral dispersion parameter σ_y (Irwin, 1983). The horizontal standard deviation σ_y and the vertical standard deviation σ_z of the plume shape were developed somewhat later, but most of the work was done while providing the dispersion models with stability classes.

In the eighties a more physical approach was applied to the models. At that time, classification and simple schemes were not used, but they coupled dispersion directly to physically meaningful parameters, which led to a next generation of dispersion models. Principally, most of the dispersion models use the gaussian plume concept as a starting point, considering height of the plume as axis and determining the parameters σ_y and σ_z as shown in Figure 3.3. The gaussian plume model approach is relatively simple and is frequently used in the prediction of atmospheric pollutant dispersion (Husain, 1990). In this research the air emission model selected work on the same principle as the gaussian plume concept/approach. The other non-gaussian models also became applicable because of a growing computational capacity of non-mainframe computers and later the more user-friendly workstations. The Monte Carlo models (or Lagrangian Particle Models) are one of the non-gaussian models, which are capable of handling non-homogeneous turbulence. These models are based on the idea of describing the single motions of many particles in terms of mean and turbulent behavior.

The gaussian models can be applied to flat terrain, while Monte Carlo model is best applied to non-uniform terrain. Zannetti (1990) gives a detailed overview of all these models. It is clear from the literature search that all these different models reflect the reality that atmospheric processes are very complicated. Each model can only handle a restricted subset of processes, depending on the purpose of the model and the available input parameters, which determines the models applicability and usefulness.

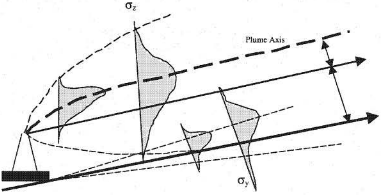


Fig. 3.3 The Gaussian Plume Concept (Adopted from Erbrink, 1995)

3.5 Meteorology and Dispersion

The earth's atmosphere can be divided into different horizontal layers, depending on the dominancy of physical processes, and these are mainly determined by the vertical temperature gradient. The troposphere is the lower part of the atmosphere, where the temperature decreases with increasing height (up to 10-15 km), all weather processes like evaporation, condensation, turbulence generation and dissipation take place in this layer. From height > 15 km within the troposphere the temperature is constant for several kilometers, but then starts increasing significantly, this stage/layer is the stratosphere, which reaches up to 50 km.

The next layer of atmosphere is the mesosphere, the temperature drops until it reaches to the minimum of 180 to 200 K, but then starts increasing in the thermosphere to high values of over 1200 K. Figure 3.4 presents the detailed over view of the atmospheric layers.

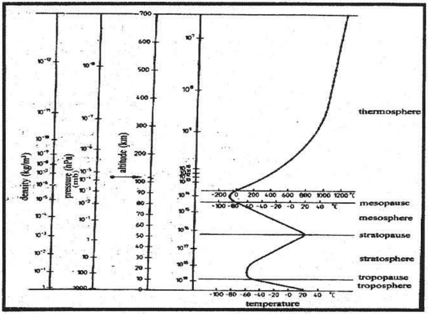


Figure 3.4 Temperature Profile in Atmospheric Layers (Williamson, 1973)

For dispersion problems the troposphere is the most important layer, since it is there that almost all air pollution processes take place like dispersion, chemical reactions, uptake in clouds and removal mechanism such as deposition.

When pollutants, able to make their way into the stratosphere (e.g. through volcanoes, or in the case of very resistant compounds by slow diffusion processes), they usually become part of a system with very low degrees of deposition and remain there for a longer time (sometimes many years), as one can see in the case with the stratospheric ozone problem.

The troposphere layer is very different than stratosphere. In troposphere the turbulence and the clouds influence are important factors, causing pollutants mixing much faster in this layer. The troposphere layer can be divided into two parts the lower and the upper. The lower part is called *the* ***atmospheric boundary layer*** (ABL), and the upper part *the* ***free atmosphere***. Within the atmospheric boundary layer the influence of the surface is large, that is heating and cooling of the air by the surface and friction are dominant factors. While in free atmosphere these influence are no longer important. The physical processes in the free atmosphere are determined by pressure gradients (causing the wind), density differences (causing cloud formation, convective turbulence and subsidence), and temperature effects (Erbrink, 1995). As one can observe that in most of the air emissions, air pollutants occur near the surface (except those from aircrafts and rockets), therefore the processes in the ABL are important to be understood from the viewpoint of environmental problems. In the ABL the influence of the free atmosphere and the influence of the surface interacts with each other, resulting in a large variety of wind, temperature and turbulence profiles.

To describe the pollutant pathways through air, it is important to consider two important factors. First, the description of the meteorological processes in the ABL, which is necessary in predicting the location of depositions, the concentrations occurring in the air and the rate of changes in these concentration and deposition. Secondly, the concentration gradient, which should be described mathematically.

In the ABL, the important parameters to be considered related to meteorology are:

- mean wind field, (horizontal & vertical gradient being of greatest interest)
- turbulent components in the wind field, and
- height of the ABL

While the elements which are relevant to dispersion are:

- emission data from stack (e.g. SO_2, NO_x, PM etc., and the heat emission)
- pollutant concentration patterns in horizontal and vertical direction: the shape (gaussian – non-gaussian), the height of the plume axis, and
- chemical reactions and deposition in the production and removal process of pollutants.

3.6 Model selection Criteria

An air pollution dispersion model is a mathematical expression for predicting the air pollutants emissions. This includes mainly the effects of transport, dispersion, plume rise, and chemical and physical transformation. After the Iraq's invasion of Kuwait, more than 700 oil wells were left on fire, emitting hundreds of tons of air pollutant in the atmosphere every day after the war was over. This prompted an environmental crisis in the Gulf region, which brought in the Gulf Regional Air Monitoring Program (GRAMP) in 1991. With the development of this program numerous models were tested and used to study the local and regional scale environmental impacts of the plumes emitted from those burning oil wells (Husain, 1995).

Many air pollution models were used in the Kuwaiti oil fire fields, to simulate the plume originated from those wells. The applications and limitations of those models used were summarized in Table 3.1 (WMO, 1992; Husain, 1995).

In this research the input is the meteorological data and total emissions from a source of pollution, while the output consists of estimated pollutant concentrations. These concentration results may be for various time periods and may be point estimates or a spatial average. Air dispersion model are usually classified in to three categories:

1. Gaussian Model,
2. Box Model, and
3. Mass conservation Model

Gaussian and box models are used for chemically non-reactive pollutants, while mass conservation models are used for chemically reactive pollutants. The above-cited models have their own limitation and assumptions. The simplest of all is the box model, which is used for area sources. The most widely used method for estimating air pollution dispersion is the use of gaussian plume model. This model is used for point sources, area sources, and volume sources

Table 3.1

Air Pollution Models Used for Air Quality Studies During Kuwaiti Oil Fires

Group/Model	Application	Domain (km)	Meteorology Used	Species	Diffusion Techniques Used
KNMI/RIVM (Verver, 1992)	Regional Real-Time	3500×3500 3-D	ECMWF Global Model	Soot	Multiple Puff
LLNL/ARAC (Sullivan, 1992)	Regional Real-Time Global	3000×3000 3-D	USAF Global + RWM (MATHEW)	Soot, Optical Depth	Particle in Cell
NOAA HYSPLIT (Draxler, 1992, McQueen et al., 1992, Heffter, 1991)	Regional Real-Time	2000×2000 3-D	NWS MRF	Soot, SO_2	Semi-Langrangian PIC
U.K. Met Office	Regional	3-D	ECMWF	Soot, SO_2	Monte Carlo
Max Planck Inst. STEM II	Regional	4000×4000 3-D	Hydro-Mesoscale	CO_2, VOC, NO_2, Ozone	-----
EURAD (Hass et al., 1991)	Regional	3-D	Regional	Soot, SO_2, NO_x	Eulerian
CANARM (Pudykiewicz, 1991)	Regional Global	10000×10000	Regional	Soot, SO_2	Semi-Langrangian PIC
TASC (Janota and Chase, 1991)	Regional Global	Hemi-Spheric 2-d	Regional	Soot, SO_2	Semi-Langrangian PIC
Meteorological Nat. Frnace MEDIA (Bompay, 1991)	Regional Global	Hemi-Spheric 3-d	Emeraude and Periodot	Soot	Eulerian
Sandia National Laboratory (Angi, 1991)	Regional	1000×1000 3-D	Climatology	Soot, SO_2 CO, H_2S	Gaussian Plume

LNLL/ARAC (Lawrence Livermore National Laboratory/Atmospheric Release Advisory Capability
TASC (The Analytic Sciences Corporation
NOAA (National Oceanic and Atmospheric Administration
HYSPLIT (Hybrid Single Particle Langrangian Integrated Trajectories Model)
EURAD (European acid Deposition Model)
ECMWF (European Centre for Medium Range Weather Forecasts
NWS (National Weather Services

(Source: WMO, 1992; Husain, 1995)

To characterize the variations of pollutant in space and time, one has to perform either monitoring/modeling, or the combination of these two methods. Air monitoring is an expensive and time-consuming process, which requires skilled manpower and sophisticated equipment (Dop and Steyn 1991).

Pollutants emitted from the source into the atmosphere are very complex and dynamic in nature and it varies mostly with time and space and mostly depends upon meteorological and topographical conditions.

Due to these limitations and constrains in air monitoring, air quality simulation models are used with the latest and highly sophisticated and reliable techniques. These models are classified by source, pollutant, transformations and removal, distance of pollutant transport, averaging time and many other parameters. Model selection for a particular scenario, and for particular situation should be the most accurate representative of atmospheric transport, dispersion, and chemical transformation for the required study area. The extent to which a specific air quality model is suitable for evaluation of source impact depends upon several factors:

1. The availability of meteorological and topographical conditions of the area
2. The level of detail and accuracy needed for the analysis
3. The detail and accuracy of the database, i.e., emission inventory, meteorological data, air quality data

4. The type of sources the model can handle (point, line, area, combination or multiple sources)
5. The output options of the model, such as more than one averaging time period, the highest concentration tables, and
6. The validation of model under a given situation and condition.

All of the above relies heavily on experience, self-judgment and literature search. Zannetti (1990) suggested a process for selecting an air pollution model. His process of selecting a model is shown in Figure 3.5. Hunt et al. (1991), suggested some basic important points for improving the air quality modeling system, these points are:

1. That the model should be capable of optimal utilization of detailed meteorological information.
2. It should be well versed in dealing with complex effects such as buoyant gas emission or dense gas emission and dispersion from arbitrary heights in the atmosphere over irregular terrain, buildings and coastlines. It should also be able to calculate the vertical distribution of concentration, including ground level concentrations.
3. It must accommodate the complex dispersion processes associated with short time releases, deposition, and concentration fluctuations.
4. The model output should be in a form that is compatible with other calculation methodologies for various purposes such as health effect and risk assessment.

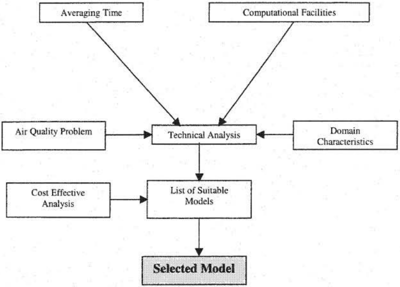


Fig. 3.5 Model Selection Process (Source: Zannetti, 1990)

3.7 Model Selection and Comparison

Three US EPA air pollution models were examined in view of the selection criteria discussed in section 3.6. These three models ISCST3, AERMOD, and CALPUFF are compared in detail. The comparison between AERMOD and ISCST3 is given in Table 3.2. Most of the features of AERMOD and ISCST3 models are same and some of them are notably different.

After defining the study objectives and detailed analysis of the problem, the above three models were reviewed as per guidelines and criteria discussed in the previous section, to select one model. The model selected for this research is AERMOD, which is a state-of-the-art model in all the EPA's air quality models, as by superior technical formulation of AERMOD and its better evaluation performance relative to ISCST3, the American Society/Environmental Protection Agency Regulatory Model Improvement Committee (AERMIC) concluded that AERMOD could justify as a replacement for ISCST3 for Regulatory Modeling application.

In the model selection and comparison, the CALPUFF was screened out. The CALPUFF model can be defined as a multi-layer, multi-species non-steady-state puff dispersion model that simulates the effects of time- and space-varying meteorological conditions on pollutant transport, transformation and removal. The CALPUFF was not selected in this study because of the following facts:

1. It is basically a long range transport model (applicable beyond 50-100 km distances)
2. Requires large modeling domains
3. Complex winds: non-uniform wind field is a controlling feature of the analysis in CALPUFF.
4. In simplest mode, it requires the control file, and file of hourly, gridded meteorological data (which is a multi-step process with CALMET)

5. Also the land use and terrain heights are derived from programs and data provided with the CALPUFF Modeling system compact disc, or self generated software or data. Whatever method is chosen, this stage required several steps to obtain the final file of geophysical parameters. This kind of information in the present research work and for the required study area is difficult to obtain.

Because of the above facts it has been deduced that the CALPUFF is not viable for the current study area and for the available meteorological data.

The other two air dispersion models (ISCST3 and AERMOD) were compared as shown in Table 3.2. As compared to ISCST3, AERMOD contains new and improved algorithms for

1. Dispersion in both convective and stable boundary layer
2. Plume rise and buoyancy
3. Plume penetration into elevated inversion
4. Computation of vertical profiles of wind, turbulence, and temperature
5. The urban boundary layer, and
6. The treatment of receptors on all types of terrain from the surface up to and above the plume height.

AERMOD is the updated/newer version of EPA air dispersion model. Also, AERMOD duplicates most of the features available in ISCST3 model. Therefore, the AERMOD model, which is sufficiently flexible and comprehensive in nature, was selected for the Al-Jubail desalination plant emissions study.

Table 3.2 Comparison of Dispersion Model (AERMOD Vs ISCST3)

FEATURE	ISCST3	AERMOD	COMMENTS
Sources types that can be modeled	Point, area, and volume sources	Point, area, and volume sources	Both models are capable of modeling the same types of sources.
Plume Rise	In any condition the ISCST3 model for plume rise use the Briggs equation with stack-top wind speed and vertical temperature gradient.	The AERMOD in stable conditions for plume rise use the Briggs equations with winds and temperature gradient at stack top, while in convective conditions, plume rise is superimposed on the displacements caused by random convective velocities.	AERMOD is better because in stable conditions it factors in wind and temperature changes above stack top, while in unstable condition it uses the convective updraft and downdrafts
Meteorological Data Input	One level of data is accepted in this case	Large number of data levels can be utilized.	AERMOD can adapt multiple levels of data to various stack and plume heights
Profiling Meteorological Data	Only wind speed profiled	AERMOD creates profile of wind, temperature, and turbulence, using all available measurement levels	AERMOD is much improved over ISCST3

FEATURE	ISCST3	AERMOD	COMMENTS
Use of Meteorological Data in Plume Dispersion	Stack-top variables for all downwind distances	Variables measured throughout the plume depth (averaged from plume centerline to 2.15 sigma-z below centerline; changes with downwind distances	AERMOD is more advance than the ISCST3. It accounts for meteorological data throughout the plume depth.
Plume Dispersion General Treatment	For plume dispersion ISCST3 use Gaussian treatment in horizontal and vertical direction.	AERMOD in stable conditions uses Gaussian treatment in horizontal and vertical direction, while in unstable conditions it considered the non-Gaussian probability density function in vertical direction.	AERMOD in unstable conditions, gives more accurate concentration of dispersion than ISCST3
Urban Treatment	ISCST3 has only two options to model rural or urban	AERMOD can model all the sources individually as rural or urban, considering the city size and population.	AERMOD give variable urban treatment as a function of city population, and have the option of rural or urban
Characterization of the Modeling Domain Surface characteristics	Choice of rural or urban	Selection by direction and month of roughness length, albedo, and Bowen ratio, gives more flexibility	AERMODE is more comprehensive and detailed in the selection of surface characteristics.

(Adopted from U.S. EPA, 1999)

FEATURE	ISCST3	AERMOD	COMMENTS
Boundary Layer Parameters	Wind speed, mixing height, and stability class	Friction velocity, Monin-Obukhov length, Convective Velocity Scale, Mechanical and Convective mixing height, Sensible heat flux	AERMOD provides parameters, which are used with up-to-date planetary boundary layer (PBL). ISCST3 does not
Mixed Layer Height	ISCST3 uses interpolation based upon maximum afternoon mixing height	AERMOD has convective and mechanical mixing layer height, where convective height is mainly based upon hourly sensible heat flux	AERMOD uses hourly input data, which gives more realistic sequence of the diurnal mixing height changes.
Terrain Depiction	Elevation at each receptor point	Special terrain preprocessor is used to obtain hill and elevation points, by using the digital elevation model (DEM) data	AERMOD terrain processor is more advance and can use digital data to obtain receptor elevations
Plume Dispersion: Plume Growth Rates	It depends on the six discrete Pasquill-Gifford stability classes	Instead of Pasquill stability it uses the vertical and horizontal turbulence from measurements, or the PBL theory to calculate the plume growth rates.	Use of turbulence based plume growth with height dependence rather than based on stability class give AERMOD a substantial advancements over ISCST3

FEATURE	ISCST3	AERMOD	COMMENTS
Plum Interaction with Mixing Lid: Convective Conditions	If plume center line is above lid, zero ground level concentration is assumed	In this case three condition are considered: a direct plume that is directed to the ground in a downdraft, an indirect plume that is caught in an updraft that reaches the lid and eventually is brought to the ground, and a plume that penetrates the mixing lid and disperses more slowly in the stable layer aloft (can re-enter the mixed layer and disperse to the ground)	The AERMOD treatments avoid any under predictions suffered by ISCST3 due to its all or nothing treatment of the plume. AERMOD's use of convective updrafts and downdrafts in a probability density function approach is a significant advancement over ISCST3
Plume interaction with Mixing Lid, Stable Conditions	The mixing Lid id ignored in this it is assumed that its infinitely high	A mechanical mixed layer near the ground is considered. Plume reflection from an elevated lid is used to account for the effects of sharply reduced turbulence aloft	AERMOD's use of mechanically mixed layer is an advancement over the very simplistic ISCST3 approach

(Source: Adopted from U.S. EPA, 1999)

Chapter IV

AERMOD MODEL FORMULATION

4.1 MODEL OVERVIEW

The following sections will briefly describe the AERMOD air dispersion model, based on its fundamental principles, necessary inputs and outputs, and its limitations.

4.1.1 Model Description

AERMOD is a steady state, plume, AMS/EPA Regulatory Model in a stable boundary layer (SBL). This model can be used to compute impact of various pollutants in both flat and complex terrain. AERMOD uses the Gaussian form for the distributions in both the vertical and horizontal dimensions for stable conditions, and in the horizontal for convective conditions. To calculate the vertical distribution of concentrations for convective conditions, AERMOD uses a Bi-Gaussian probability density function (pdf) this behavior of distributions in the CBL was demonstrated by Briggs in 1993.

As shown in Figure 4.1, AERMOD is designed to work in coordination with two pre-processors, AERMET and AERMAP. AERMET processes meteorological data, while the AERMAP processes the terrain elevation data and produces receptor information, both the output files from AERMET and from AERMAP are then fed into AERMOD for further processing.

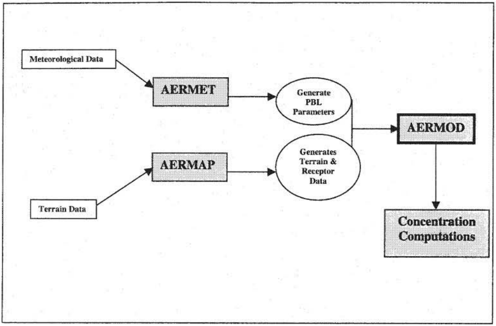


Fig. 4.1 Schematic Showing the AERMOD Air Dispersion Model with Pre-Processors

The schematic of AERMOD (Figure 4.1) consists of two pre-processors and the dispersion model. The AERMET (Meteorological Pre-Processor) provides AERMOD with the Meteorological information needed to characterize the Planetary Boundary Layer (PBL). PBL is the turbulent air layer next to the earth's surface that is controlled by the surface heating and friction and the overlaying stratification. The PBL typically ranges from a few hundreds meters in depth at night to 1–2 km during day. Major development in understanding of the PBL began in the 1970's through numerical modeling, field observations, and laboratory simulations (Wyngaard, 1988).

Basically, the AERMET uses the meteorological data and the surface characteristics to calculate boundary layer parameters like mixing height, friction velocity, etc., which is needed by the AERMOD. This data, which is either measured off-site or on-site, must be representative of meteorology in the modeling domain. Surface characteristics like surface roughness, Bowen ratio, and albedo, plus standard meteorological observations like wind speed, wind direction, temperature, and cloud cover are inputted into AERMET. The AERMET then calculates the PBL parameters/profiles which are friction velocity (U_*), Monin-Obukhov Length (L), convective velocity scale (W_*), temperature scale (θ_*), mixing height (Z_i), and surface heat flux (H). These parameters are then passed to the interface (within AERMOD) where similarity expressions (in conjunction with measurements) are used to calculate the vertical profiles of wind speed (U), lateral and vertical turbulent fluctuations, potential temperature gradient, and potential temperature.

The AERMAP characterizes the terrain and generates receptor grids and elevations for the dispersion model. AERMOD also uses a new and simple approach about flow and dispersion in complex terrain; the plume is modeled as either impacting and/or following the terrain. This approach has been designed to be physically realistic and simple to implement, avoiding the need to distinguish among simple, intermediate and complex terrains, as is required by the other presently available air regulatory models. (Synder et al., 1985).

AERMOD has the option to construct vertical profiles of wind speed, wind direction, turbulence, and temperature. Temperature gradient is estimated using all available meteorological observations. AERMOD is designed to run with minimum observed meteorological parameters.

In 1987, Pain and Egan compared the performance of AERMOD with Rough Terrain Diffusion Model (RTDM). Hanna and Pain (1989) and Hanna and Chang (1993) compared the AERMOD with Hybrid Plume Dispersion Model (HPDM). Perry (1992) compared the Complex Terrain Dispersion Model Plus Algorithms for Unstable Situations (CTDMPLUS). All these models were compared with AERMOD using the procedures in EPA's "Protocol for Determining the Best Performing Model". It was concluded in the 1999, at the seventh modeling conference that AERMOD is more effective, and better in performance as compare to the models listed in this section (Code of Federal Regulations, 1997).

AERMOD like most of the other air dispersion models requires an input run-stream file and meteorological data files. The run-stream file, which contains the options how to run the model, the meteorological data files, and the met data information, are explained in Appendix-A.

4.1.2 Technical Description

This section will describe the basic formulation of the AERMOD dispersion model, which includes the general form of concentration equation for terrain, and the dispersion algorithms considering the convective and stable boundary layer.

As mentioned in the previous section that AERMOD (like ISC) is a steady state plume model, this means that it is applicable to source releases and meteorological conditions that are assumed to be in steady state. AERMOD uses a simple two-layer (upper and lower layer) concept about flow and dispersion over the terrain. In very stable conditions the AERMOD assume that the lower layer of the plume remains horizontal while the upper layer tends to rise over the terrain. While in neutral and unstable conditions, the lower layer disappears and the entire flow with the plume tends to rise up and over the terrain. Basically the AERMOD assumes that the plume exists in two states and that the concentration at a receptor, located at a position (x,y,z) is the weighted sum of the two concentration estimates:

1. where the plume is horizontal (horizontal plume state)
2. where the plume travels over the terrain (terrain response plume state)

Mostly, in stable conditions, the horizontal plume dominates and is given greater weight while in neutral and unstable conditions the plume traveling over the terrain is more important or is heavily weighted, as shown in Figure 4.2 (Cimorelli et al., 1998).

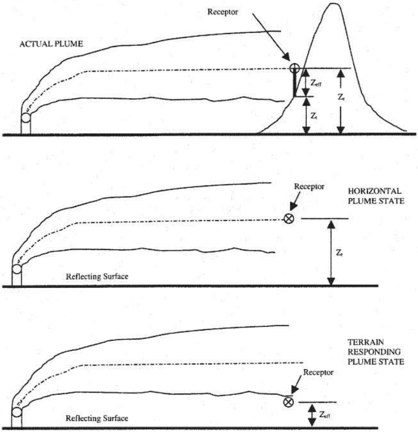


Figure 4.2 AERMOD Two State Approach. Total Concentration Predicted by AERMOD

The general form of equation applied in AERMOD for calculating the total concentration at any terrain elevation is:

$$C_T(x_r,y_r,z_r) = f \times C_{c,s}(x_r,y_r,z_r) + (1 - f) \times C_{c,s}(x_r,y_r,z_{eff}) \qquad (4.1)$$

Where:

$C_T(x_r,y_r,z_r)$ = Total concentration (g/m^3) or ($\mu g/m^3$)

$C_{c,s}(x_r,y_r,z_r)$ = Concentration from the horizontal plume state (g/m^3) or ($\mu g/m^3$)

$C_{c,s}(x_r,y_r,z_{eff})$ = Concentration from the terrain following plume state (g/m^3)($\mu g/m^3$)

f = Weighting factor related to the fraction of plume material that is below the height (H_c), of the dividing streamline.

Z_r = height of receptor from the stack base elevation (meter or feet)

Z_{eff} = effective receptor height (which is equal to 'z' in flat terrain) (meter or feet)

H_c = is a function of wind speed, vertical potential temperature gradient and the height of the terrain influencing the flow

In equation (4.1) the subscripts (c,s) represent the total concentration during convective conditions 'c' and stable conditions 's'. The first term on the right hand side of equation (4.1), represents the contribution from the horizontal plume and is evaluated at a receptor height 'Z_r'. The second equation on the right hand side represents the contribution from the plume adjusted by the terrain and is evaluated at an effective receptor height 'Z_{eff}'.

Also in equation (4.1) the weighting factor 'f' is a function of the fraction (ϕ) of plume mass that is below 'H_c' at the downwind distance of the receptor. The fraction 'ϕ' of a mass below H_c is calculated by the AERMOD as:

$$\phi = \frac{\int_0^{Hc} C_T(x_r, y_r, z_r)dz}{\int_0^{\infty} C_T(x_r, y_r, z_r)dz} \tag{4.2}$$

In neutral to unstable conditions (or in flat terrain for all conditions), $H_c = 0$, and thus $\phi = 0$. Figure 4.3, will show the construction of the weighting factor and its relationship in calculating the total concentration.

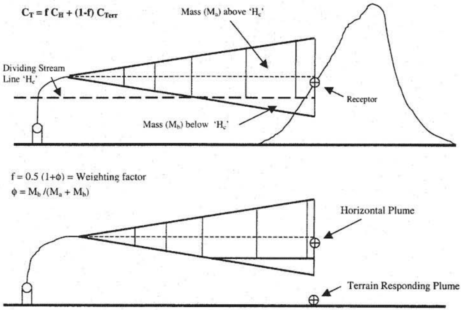


Figure 4.3 Construction of Weighting Factor and Calculating Total Concentration

In the equation (4.1), the $C_{c,s}$ (x_r, y_r, z_r) can be defined for convective and stable conditions, which are explained in the next sections.

4.1.2.1 Convective Boundary Layer (CBL) Concentration Equation

In 1959, Gifford proposed a concept for the dispersion algorithms in the convective boundary layer (CBL). In this, the plume, which is randomly varying, is assumed to have Gaussian distribution about its centerline in convective conditions. The mean or average concentration in CBL is found by summing the concentrations of all the random centerline displacements. This averaging process results in a skewed distribution, which AERMOD represents as a bi-Gaussian p.d.f (i.e., one for updrafts and the other for downdrafts). Figure 4.4 shows the superposition of updraft and downdraft plumes (Cimorelli et al., 1998).

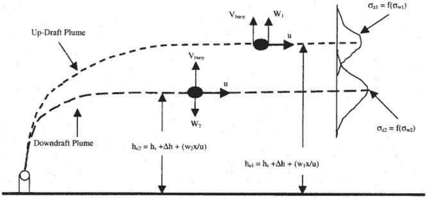


Figure 4.4 AERMOD Dispersion in CBL Using Two Gaussian distribution

In AERMOD the average concentration in the convective condition is due to three plume contributions:

- A 'direct' plume, which emanates from stacks and are sufficiently large that the downdrafts bring them down to the surface.
- An 'indirect' plume which rises to the CBL top, delayed due to buoyancy and then dispersed downwards.
- A 'penetrated' plume, which represent the plume material with sufficient buoyancy to escape the mixed layer (Venkatram, 1983).

In convective conditions when Monin-Obukhov length (L) is less than zero ($L < 0$), the general expression for the total concentration in the CBL for the horizontal plume is

$$C_c\,(x_r,y_r,z_r) = C_d\,(x_r,y_r,z_r) + C_r\,(x_r,y_r,z_r) + C_p\,(x_r,y_r,z_r)\ \ (g/m^3) \text{ or } (\mu g/m^3) \qquad (4.3)$$

Where:

$C_c\,(x_r,y_r,z_r)$ = Total Concentration in CBL

$C_d\,(x_r,y_r,z_r)$ = Direct Source Concentration Contribution

$C_r\,(x_r,y_r,z_r)$ = Indirect Source Concentration Contribution

$C_p\,(x_r,y_r,z_r)$ = Penetrated Source Concentration Contribution

The total concentration for the terrain responding state is almost the same as that of equation (4.3), only 'Z_r' is replaced by 'Z_p'. For more detail about equation (4.3), read AERMOD description of formulation, draft document by Cimorelli et al (1998).

4.1.2.2 Concentration in Stable Boundary Layer (SBL) by AERMOD

The concentration expression for stable condition (L>0) in AERMOD is almost the same as in ISC3. The ISCST model uses the following equation to calculate the hourly ground level concentration at the downwind distance 'x' and crosswind distance 'y' from the source.

$$C_s\,(x_r,y_r,z_r) = \frac{K\,.\,Q}{\pi.u.(h).\sigma_y.\sigma_z} \exp\{-1/2\,[y/\sigma_y]^2\}.D \qquad (4.4)$$

Where:

Q = Pollutant emission rate (mass per unit time)

K = Conversion factor to calculate concentration in desired units

σ_y = Standard deviation of lateral concentration distribution (m)

σ_z = Standard deviation of vertical concentration distribution (m)

u = mean wind speed (m/sec)

h = stack height (m)

D = Decay term

AERMOD uses the same equation (4.4), as used by ISCST for calculating the emission concentration in stable condition with little modification and alteration, again for more detailed information on this the author suggest to study the draft document by Cimorelli et al. (1998).

4.1.3 Data Acquisition

Surface meteorological data for the year 1995, of the study site area were obtained from MEPA. The data was supplied in raw form on diskettes. The raw surface data were formatted and entered into the system. The format of data was already discussed in the previous section.

Surface meteorological data like wind speed & direction, ambient temperature, and surface heat flux for the year 1995 were obtained from the raw data provided. The rest of the upper air and surface meteorological parameters were calculated, the details of which are listed in the next section

4.1.4 Development of Meteorological Data for AERMOD

The minimum meteorological input data files (Surface File with PBL Parameters & Profile File) required to perform the dispersion analysis by the AERMOD are described below:

(1) Hourly Surface Observation/Surface File with PBL Parameters

  (i) Wind speed & direction
  (ii) Ambient temperature
  (iii) Surface heat flux

The above parameters for the year 1995 were extracted from the on-site raw data collected for the study area. The rest of the parameters were calculated and are discussed below:

(iv) Surface Roughness Height (Z_o)

The surface roughness height (Z_o), which is the height above the ground at which horizontal wind velocity is typically zero, is taken as 0.01 m (Rehman et al., 1990 & 1994).

(v) Instrument Height (Z_{ref}) for Wind Speed

The Saudi Arabian Wind Energy Atlas (1986), has reported that all the wind sensors are located at a height of 10 m above the ground surface at most of the meteorological data acquisition stations. This height for the sensor has been recommended by the World meteorological Organization (WMO). At some stations, the sensors were installed at 7, 8, and 9 m above the ground surface. In this study the instrument height (Z_{ref}) for wind speed were taken as 10 m above the surface (Rehman et al., 1994).

(vi) Albedo (γ)

Albedo can be defined as the fraction of total incident solar radiation reflected by the surface back to space without absorption. The values are given in Table 4.1.

Table 4.1

Albedo of Ground Covers by Land-Use and Season

Land Use	Spring	Summer	Autumn	Winter
Water (Fresh and Sea)	0.12	0.10	0.14	0.20
Deciduous Forest	0.12	0.12	0.12	0.50
Coniferous Forest	0.12	0.12	0.12	0.35
Swamp	0.12	0.14	0.16	0.30
Cultivated Land	0.14	0.20	0.18	0.60
Grass Land	0.18	0.18	0.20	0.60
Urban	0.14	0.16	0.18	0.35
Desert Shrubland	0.30	0.28	0.28	0.45

Source: User's Guide for the AERMOD Meteorological Preprocessor (AERMET)

(vii) Bowen Ration (β_0)

Bowen Ratio is an indicator for surface moisture, and can be defined as the ratio of the sensible heat flux to the latent heat flux, mainly used for determining the planetary boundary layer parameters for convective conditions.

The values used are listed in Table 4.2, adopted from the user's guide for the AERMOD meteorological pre-processor (AERMET).

Table 4.2

Daytime Bowen Ratio by Land Use and Season Dry Conditions

Land Use	Spring	Summer	Autumn	Winter
Water (Fresh and Sea)	0.1	0.1	0.1	2.0
Deciduous Forest	1.5	0.6	2.0	2.0
Coniferous Forest	1.5	0.6	1.5	2.0
Swamp	0.2	0.2	0.2	2.0
Cultivated Land	1.0	1.5	2.0	2.0
Grass Land	1.0	2.0	2.0	2.0
Urban	2.0	4.0	4.0	2.0
Desert Shrubland	5.0	6.0	10.0	10.0

Source: User's Guide for the AERMOD Meteorological Preprocessor (AERMET)

(viii) Friction Velocity (U_*)

Friction velocity is a measure of the vertical transport of horizontal moment. It is calculated via dimensional analysis that defines the velocity scale for the flow near the surface (Kagan, 1995). In this study the friction velocity parameters are calculated by using the equation (4.5), which was modified by Mackay and Yeun in 1983 (Hicks, B.B., 1973: Mackay and Yeun, 1983).

$$[U_*/U_{10}]^2 = [0.65 + 0.07\ U_{10}] \times 10^{-3} \tag{4.5}$$

Where

U_{10} is the wind velocity at 10 m height above the Earth's surface.

Therefore, $$[U_*]^2 = [U_{10}]^2\ [0.65 + 0.07\ U_{10}] \times 10^{-3}$$

$$U_* = \{U_{10}\,[0.65 + 0.07\,U_{10}]^{0.5}\}/31.6227 \qquad (4.6)$$

The final values were multiplied by the factor 3 to make the data accountable to the real data as recommended by the U.S EPA AERMOD air dispersion Model.

(ix) Turbulent Velocity Scale (W_*)

The turbulent Velocity Scale (W_*) parameter is calculated using the equation given in the User's Guide for the AERMOD Meteorological Preprocessor (AERMET) as shown below:

$$W_* = (g\,H\,Z_{ic} / \rho\,C_p\,T)^{1/3} \qquad (4.7)$$

Where:

$g = 9.81$ m/sec^2

H = Sensible heat flux (watts/m^2)

Z_{ic} = Convective Mixing Height (m)

C_p = Specific heat Constant of air = 1004.67 J/Kg-K

T = Temperature in (K)

ρ = Dry air density = 1.275 kg/m^3

(x) Monin-Obukhov Length (L)

The Obukhov length is parameter, which gives a relation between parameters characterizing dynamic, thermal and buoyancy processes. This parameter was first described by Obukhov in 1946, and later on in 1954 was modified by Monin and is then was called as Monin-Obukhov length. The value of L has often been used to make diagnosis of the atmospheric conditions like stable, neutral, or unstable. Many researchers use a partition such as:

- Stable if $0 < L < 1000$ (meters)
- Neutral if $|L| > 1000$, and
- Unstable condition if $-1000 < L < 0$

Basically, the quantity L is a (vertical) length scale (Erbrink, 1995). 'L' reflects the height to which the friction forces are dominant over buoyant forces. In stable conditions L is positive, because of the downward (negative) sensible heat flux to the soil, where heat is converted into radiation and is sent into space in situations without clouds. In neutral conditions the L is close to zero and in unstable conditions L is negative because of a positive heat flux.

The Monin-Obukhov parameter for this research is calculated using the equation given in the User's Guide for the AERMOD Meteorological Preprocessor (AERMET), is shown below

$$L = -[\rho\ C_p\ T\ U_*^3] / [k\ g\ H] \qquad (4.8)$$

Where

ρ = Dry air density = 1.275 kg/m^3

C_p = Specific heat Constant of air = 1004.67 J/Kg-K

$g = 9.81$ m/sec^2

k = Von Kerman constant = 0.4

H = Sensible heat flux (W/m^2)

U_* = Friction velocity (m/sec)

Placing the constant values in equation (i), it is modified to

$$L = -326.44094 \times [(T \times U_*^3) / H] \tag{4.9}$$

Equation (4.9) has been used to find the Monin-Obukhov length for the AERMOD model in this study.

4.2 Run-stream File for the AERMOD Model

The AERMOD model was used to simulate the ambient concentration of different pollutants for various averaging periods, from Al-Jubail Desalination Plant (JDP) emissions. JDP is located at 100 km north of Dammam, and to the eastern coast of Saudi Arabia. The JDP is one of the biggest water desalination plant in the world, producing approximately 253 million gallons per-day (mgd). Studies are underway to expand the desalination water capacity of JDP, which is considered to supply another 817300 m^3/day (S.W.C.C., 1995).

The run-stream files/data available for AERMOD model is discussed in the following sections.

4.2.1 Emission Inventory

The complete emission inventory of the primary pollutants from the Jubayl desalination plant, considering the production capacity of 253 mgd (Al Mutaz, I.S., & Wagialia, K.M, 1990), is described in detail in this section. Table 4.3 summarizes the properties of fossil fuel oil, which is mainly used in most of the MSF desalination plants in Saudi Arabia. The properties of fossil fuel used in other plants are same as used in Al-Jubail desalination plant (Abrams, et. al., 1989).

Table 4.3

Fossil Fuel Properties

Physical Properties	
Specific Gravity	0.875 (source: Husain, T. 1995)
Viscosity at 50°C	184.4 (centistokes)
Appearance	Normal
Flashpoint (°C)	92
Heating Value (Btu/Ib)	18492
Composition	
Sulfur	3.5 wt. %
Nitrogen	0.24 wt.%
Ash	0.00985 wt.%
Moisture	0.0622 wt.%
Vanadium	40 ppm
Nickle	16.05 wt.%
Sodium	9.65 wt.%
Ash	0.00985 wt.%
Hydrocarbon	30.5 %

Source: Abrams, et al., 1989.

It has been clear from the literature search that a typical MSF desalination plant will consume about 16.62 kWh, of energy to produce 1 m^3 of desalinated water (Al-Marafie and Darwish, 1989). In addition to that 15% of energy will be added for using evacuating ejectors, therefore the total energy consumed by the MSF plant with a boiler efficiency of 85% to produce 1 m^3 of fresh water will be 19.78 kilowatts-hours (Al-Marafie and Darwish, 1989).

The total production of desalinated water from Al-Jubail MSF desalination plant in Saudi Arabia is 253 mgd. Therefore, to calculate the total amount of pollutant emission from JDP while producing 253mgd of desalinated water will be:

As we know that

$0.003785 \text{ m}^3 = 1 \text{ gallon}$

Therefore, $1 \text{ m}^3 = 264.2 \text{ gallon}$

also $1 \text{ kWh} = 3413 \text{ Btu}$

$19.784 \text{ kWh} = 3413 \times 19.78 = 67509 \text{ Btu}$

or $19.784 \text{ kW} = 67509 \text{ Btu/hr}$

Therefore, producing 253×10^6 gallons will required 64647×10^6 Btu/hr. The boiler is working with an efficiency of 85 %, and the oil used in burning have a heating value of 18492 Btu/Ib:

$= 6.4 \times 10^{10} \text{ (Btu/hr)} / (0.85 \times 18492) \text{ (Btu/Ib)}$

$= 34{,}95944 \text{ Ib/hr}$

The total fuel consumption by Jubayl MSF desalination plant to produce 253mgd of water is 1,585,749 kg/hr.

We know that Sulfur in fossil fuel is converted into SO_2, which is shown as below

$$S_{(32)} + O_{2\,(32)} \longrightarrow SO_{2\,(64)} \tag{4.10}$$

Equation (4.10) shows that, about 32 kg of sulfur produces 64 kg of SO_2, or
1 kg of sulfur produces 2 kg of SO_2.

From Table 4.3, it has been clear that the sulfur content in fuel is 3.5 % by wt. Therefore, the total sulfur content from the total fuel consumed in JDP will be:

$= 0.035 \times 1585749$ kg/hr

$= 55501$ kg/hr

The SO_2 generated from the plant while burning 1585749 kg/hr of fuel is

$= 55501 \times 2$

$= 111002$ kg/hr

Therefore, the SO_2 produced is **30,833 g/sec**.

The other important pollutant is NO_x, the formation of NO_x (more precisely in this study NO_2) can be attributed to two distinct chemical kinetic process. One is called the "thermal NO_x" and another is "fuel NO_x". Thermal NO_x/NO_2 are mainly generated by the oxidation of atmospheric nitrogen present in the combustion air, while the fuel NO_x/NO_2 are formed by the oxidation of nitrogen present in the fuel.

It has been reported that the total NO_x (i.e. Thermal and Fuel) emissions from an industrial boiler while burning residual oil is 60 Ibs/1000 gallons (U.S. EPA, 2001). To calculate the fuel NO_x emissions, it has been shown previously in Table 4.3, that the percentage of nitrogen present in the fossil fuel is 0.24 % by wt. Therefore the total Fuel NO_2 emitted will be:

$$\text{Fuel } (NO_2) = 22 + 400\,(N)^2 \text{ (Ibs/1000gallons)} \tag{4.11}$$

Where: N is the percentage, by weight, of the nitrogen present in oil

$$= 22 + 400\,(0.24)^2$$

$$= 45.04 \text{ Ibs of } NO_2/1000 \text{ gallons}$$

Similarly, the thermal NO_2 emitted from the plant is 14.96 Ibs of NO_2/ 1000 gallons. Form equation (4.11) the amount of fuel NO_2 generated is 45.04 Ibs/1000 gal. Also it is calculated that by burning 1000 gallons of fossil fuel in industrial or commercial boiler will generate a total of 60 Ibs (27.2 kg) of NO_2 (U.S EPA, 2001). The residual fuel used in the Al-Jubail desalination plant has a heating value of 18492 Btu/Ib, and specific density of 0.875.

Therefore,

$$\text{Density(R. Oil)} = (0.875)(1000\ \text{kg/m}^3) = 875\ \text{kg/m}^3$$

Or $$\text{Density(R. Oil)} = 1929.375\ \text{Ibs/m}^3$$

From the above density calculations we can conclude that 1 Ib of residual oil is equal to 5.1×10^{-4} m^3 by volume. The heating value of residual oil is 18492 Btu/Ib, so the total volume of oil burned to produced 64647×10^6 Btu/hr of energy, will be 1811.95 m^3/hr. Now we know that:

$$1\ \text{m}^3 = 264.2\ \text{gallons}$$

Therefore, $$1811.95\ \text{m}^3/\text{hr} = 4{,}78{,}718.9\ \text{gallons/hr}$$

As it has been stated earlier that by burning 1000 gallons of residual oil in the boiler will generate a total (thermal and fuel) of 27.2 kg of NO_2. Therefore, by burning 4,78,718.9 gal/hr will generate total NO_2 of 13021.15kg/ hr, or the total NO_2 emission from Al-Jubail desalination plant is **3616.98 g/sec**.

The third important pollutant is the Particulate matter (PM), again based on previously given Table 4.3, the ash contents by wt.% is 0.00985.

Therefore, the total PM emitted from the JDP while burning 1585749 Kg/hr of fossil fuel will be:

PM in fuel = 1585749 × 0.0000985

PM in emission = 156 Kg/hr, or

PM in emission = **43.3 g/sec** of fine particulate

4.2.2 Source Input Data

As all the stacks in JDP are placed together therefore, in this study it has been considered as a single point source and will be assumed as one single stack emission. The coordinates for the stack were entered as (0.0, 0.0). The other source parameters and their respective values, which were entered into the AERMOD model, are:

- Pollutant emission rates as been calculated in previous section
- A stack height of 65 meters (typical height)
- Stack gas exit temperature were assumed to be 440 K
- Stack gas exit velocity of 12 m/sec was assumed (Memon, 2000), and
- Stack inside diameter was taken as 1.5 meters

4.2.3 Receptor Information

An option of Cartesian grid receptor network was selected to estimate the short term and annual averages concentrations at various receptor grids. The receptor grid network is extended 50 km in each direction from 27° 02′ N & 49° 38′ E, covering the King Abdul Aziz Naval base, Al-Ajam city, Najma, Jhaab (gas oil seperator plant), Jazirat Al Batinah, Abu Ali, and Al Qatif city. The receptor network developed for this study is shown in

Figure 4.5. The vertical axis in Figure 4.5 and in all other figures (in chapter 6), which shows the AERMOD emission result are in North South direction.

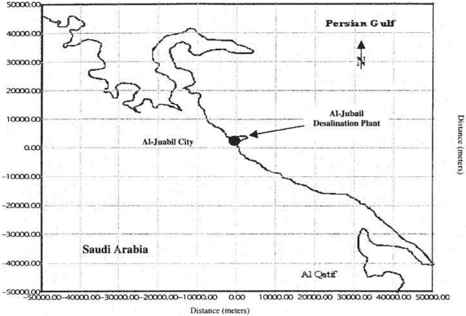


Figure 4.5 Receptor Grid for AERMOD Model Runs

4.2.4 Selected Output Options

The AERMOD model provide user with an option to select various output options for viewing and studying the generated results. In this study the following output options were selected:

- High value summary table for different averaging times for separate receptors
- Overall maximum value summary tables
- Average annual values, and
- Daily and hourly average values table.

A sample run-stream file for AERMOD model is presented in Appendix-B

Chapter V

STUDY AREA

5.1 Al - Jubail Desalination Plant (JDP)

JDP is located on the shores of the Arabia/Persian Gulf and in center of Saudi Arabia's major oil producing region. Al-Jubail, the largest of the Kingdom's new cities, is a major cornerstone of the Kingdom's economic development program. The infrastructure of the industrial city of Al-Jubail is established on a site covering 1,030 km^2 and its population is estimated to be that by the year 2010 the city will accommodate 290,000 inhabitants.

Al-Jubail Industrial City (JIC) is considered to be one of the leading industrial cities of Saudi Arabia with a total investment of $46 billion. This accounts for almost 60 per cent of the Kingdom's non-oil exports and has registered sustained annual production growth of 4%. JIC is also the largest converter of natural gas resources to added value petrochemicals with 6 to 7 per cent market share of world's petrochemicals.

The city of Jubail receives most of it fresh water from Al-Jubail desalination plant. The Al-Jubail power and desalination plant is one of the largest in the world. It consists of ten Boiler-Turbo-Generator (BTG) sets of about 130 MW output each. Each one of the ten-backpressure turbines feeds low-grade steam to four MSF distillers (i.e. forty distillers in total are installed). Thirty distillers have 19 stages in the recovery section and 3 stages in the rejection section each. The remaining ten distillers have 17 stages in the heat recovery and 2 stages in the heat rejection section.

The evaporators are designed for operation at a brine top temperature of 90.6°C with a production of 5.2 MGD and a top temperature of 112.8°C with a production of 6.29 MGD (Al-Sofi, et al., 1987: Al-Mudaiheem, 1991). Figure 5.1, shows the complete detail of the Al-Jubail MSF desalination plant.

Due to the projected increase in population and industries in the city of Al-Jubail an environmental assessment on air and water quality is required. This study has been conducted to observe if there is any drastic impacts/affects from Al-Jubail desalination plant on the surrounding environment.

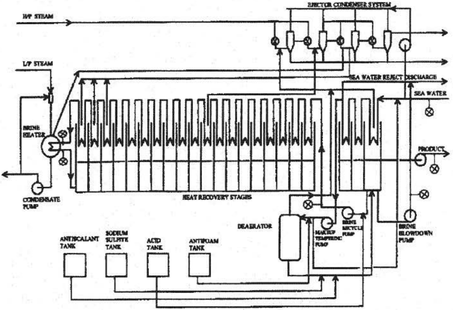


Figure 5.1 Schematic diagram of Al-Jubail MSF Desalination Plant
(Source: Al-Sofi et al., 2001)

In this research an EPA air dispersion model was used to simulate the plume and to estimate the concerned pollutants from the JDP. Also the available meteorological data for the said region was examined. Emission concentrations were predicted while using air dispersion model, and in the end the computed results were analyzed and compared with the local regulating agency's standards. This study will basically provide an estimate of different air pollutants emitted from the Al-Jubail desalination plant and its deposition at various receptor points and city. Figure 5.2 shows the Al-Jubail plant and some of the cities surrounding the plant. The coordinates and location of these cities/places in the study area are shown in Table 5.1.

Table 5.1

Coordinates and Locations of Receptor Points

Site Number	Coordinate X (m)	Coordinate Y (m)	Location
1	0.00	0.00	Al-Jubail City
2	5000	-5000	King Abdul Aziz Naval Base
3	-45000	45,000	Cemetry Jinnah
4	-50,000	5000	Gas Oil Separator Plant
5	30,000	-50,000	Al-Ajam City
6	40,000	-35,000	Najmah
7	30,000	-20,000	Jhaab (Gas Oil seperator)
8	-15,000	25,000	Jazirat Al Batimah
9	-10,000	35,000	Abu Ali (Sub Stations and Buildings)
10	35,000	-50,000	Al-Qatif City

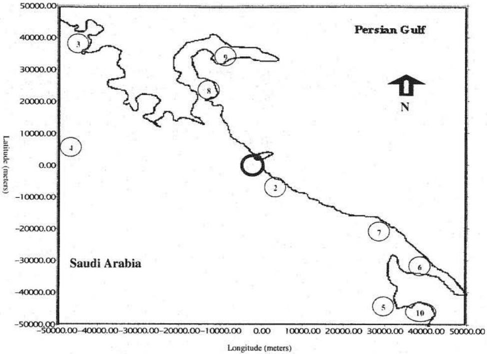


Figure 5.2 Al-Jubail Desalination Plant and Surrounding Cities

Chapter VI

DATA ANALYSIS AND RESULTS

6.1 Air Quality Standards

Air quality has been a major environmental issue for a long time. This is because of the threat of possible global climate change and the "greenhouse effect" that are caused by anthropogenic emissions.

All types of emissions into the atmosphere must be controlled in order to maintain a clean environment for man and nature. Therefore, it is important to control all these emissions from the industries and any other sources, also it is important to determine the quality and concentration of the emissions. Environmental regulatory agencies have established ambient air quality standards, to set legal limits for all kind of emissions to protect the environment and public health.

Rapid technology advancement and industrialization has greatly increased the productivity in Saudi Arabia, but at the same time it has poses many serious environmental degradation problems (Rehman et al., 1990). In the initial period of industrialization, more importance was given to productivity than to the quality of environment. However, in the last two decades more attention has been focused on the impact of industrial pollutants. In Saudi Arabia, the Meteorological and Environmental Protection Administration (MEPA), a branch of the Ministry of Defense and Civil Aviation, is responsible since 1970s for the preparation of environmental standards for different types of environmental pollutants (Rehman et al., 1990).

The Clean Air Act (CAA), which was last amended in 1990, requires Environmental Protection Agency (EPA) to sets National Ambient Air Quality Standards (NAAQs) for pollutants considered harmful to public health and to the environment. The criteria pollutants for various averaging periods, as set by MEPA are almost the same as develop by the NAAQs. These standards are presented in Table 6.1.

The Clean Air Act (CAA) established two types of national air quality standards. *Primary Standards* are implemented to protect public health, including the health of sensitive populations such as asthmatics, children, and elderly peoples. *Secondary Standards* set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings. These standards are set by the regulatory agencies using the best scientific evidence available relating the levels of emissions to adverse effects to human health and to the environment (Office of Air Quality Planning and Standards, 2001)

Table 6.1

MEPA Air Quality Standards

Pollutants & Averaging Time	Standard/Maximum Concentration	Standard Type	Exceedences
Sulfur Dioxide (SO_2)			
1 – Hour	730 μgm^{-3} (0.28 ppm)	Secondary	Twice a Month
24 – Hour	365 μgm^{-3} (0.14 ppm)	Primary	Once a Year
Annual	80 μgm^{-3} (0.03 ppm)	Primary	
Particulate Matter (PM)			
24 – Hour	340 μgm^{-3}	Primary & Secondary	Once a Year
Annual	80 μgm^{-3}	Primary & Secondary	
Nitrogen Oxide (Define as Nitrogen Dioxide, NO_2)			
1 – Hour	660 μgm^{-3} (0.35 ppm)	Primary & Secondary	Twice a Month
Annual	100 μgm^{-3} (0.05 ppm)	Primary & Secondary	
Photochemical Oxidants (Define as Ozone, O_3)			
1 – Hour	295 μgm^{-3} (0.15 ppm)	Primary & Secondary	Twice a Month
Carbon Monoxide (CO)			
1 – Hour	40.0 mgm^{-3} (35.0 ppm)	Primary	Twice a Month
8 – Hour	10 mgm^{-3} (9.0 ppm)	Primary	Twice a Month
Hydrogen Sulfide (H_2S)			
1 – Hour	195 μgm^{-3} (0.14 ppm)		Twice a Month
24 – Hour	40 μgm^{-3} (0.03 ppm)		Once a Month
Fluorides (F^-)			
30 – Day	1 μgm^{-3} (0.001 ppm)		
Lead (Pb)			
Quarterly Average	1.5 μgm^{-3}	Primary & Secondary	

(Modified from Amin, 1994)

6.2 Data Analysis and Processing

The main steps, involved in this research for data analysis and processing, are shown in Figure 6.2. One year (1995) of upper air and surface meteorological data were used and processed to obtain daily maximum and minimum mixing height values.

As described previously in section 4.1, AERMOD requires two types of meteorological data files, which are provided by the AERMET meteorological preprocessor or formatting the data files manually. One file consists of surface scalar parameters, and the other consists of vertical profiles of meteorological data. These meteorological data files are described briefly in section 4.2 and 4.3, for applications involving the elevated terrain effects. The receptor and terrain data will need to be processed by the AERMAP terrain preprocessor program or can be generated manually, as done in this case. The output files generated by the preprocessors (AERMET & AERMAP) are in such a format that it is directly acceptable to the AERMOD model. The other information, like source emissions data and model control parameters, were prepared and stored in separate files.

The AERMOD model was used to print the highest concentrations, and 20 maximum concentration tables. Hourly and daily concentration values were calculated, as well as the annual average concentration values and were compared and checked against the maximum concentration allowed in the MEPA Air Quality Standards as shown in Table 6.1.

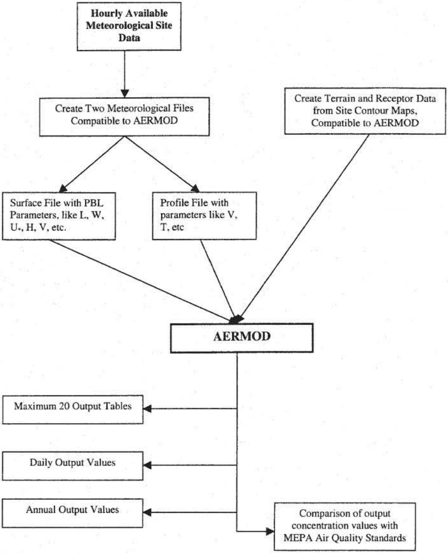


Figure 6.1 Flow Diagram of Data Analysis and Processing System

6.3 Sulfur Dioxide Results

6.3.1. 1–Hour Average Concentration Level

Concentration values for 1-hour average were calculated using the air emission AERMOD model. The results were then compared against the MEPA's maximum concentration standard of 730 μgm^{-3}. The concentration values obtained for the Al-Jubail MSF desalination plants were shown in Appendix-C. A total of 441 average concentration points were calculated, out of which twenty values exceeded the standard maximum concentration. Figure 6.2 shows the concentration plot for the MSF desalination plant at Al-Jubail, Saudi Arabia.

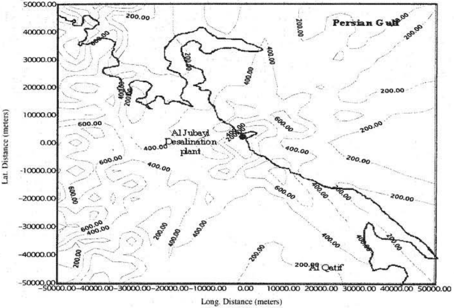


Figure. 6.2 1-Hour Average Concentration (μg/m^3) Plot of SO_2 for the Year 1995

The areas where the MEPA standards have been violated are the South East part at (Figure 6.2) – 40000 meter (Long), 50000 meter (Lat) from the point of emission, the other highest concentration was calculated at –5000 meter (Long), 25000 meter (Lat) (mainly open sandy area).

It has been observed that the frequency of exceedence based on hourly average varies from a minimum of 2 in August to 3 in January, to 10 times in the month of July.

6.3.2 Daily Average Concentration Level

SO_2 concentration values were simulated to calculate the daily average concentration levels at each grid and discrete receptor points for the year 1995. The estimated average daily concentrations were also compared against the MEPA average daily standard concentration value of $365 \mu g m^{-3}$.

The emission result shows that only 5.2% of the total value exceeded the daily average emission concentration values. The highest concentration values based on average daily estimates for the year 1995 are given in Appendix-B. The maximum 50 daily highest concentration values for the year 1995 are shown in Figure 6.3.

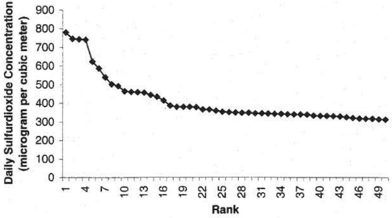


Figure. 6.3 Plot of 50 Highest Concentrations of SO_2 on 24-Hour (Daily) Average Basis for the Year 1995

A total of 23 values exceeded the MEPA standard value of 365μgm^{-3}. Analysis of SO_2 concentrations based on daily average data (Appendix-C) shows that values greater than the standard 365μgm^{-3} were estimated at the King Abdul Aziz Naval Complex and towards the Persian Gulf as shown in Figure 6.4.

Values at other locations were insignificant, because of the fact that they were within the limits of maximum concentration of 365μgm^{-3}.

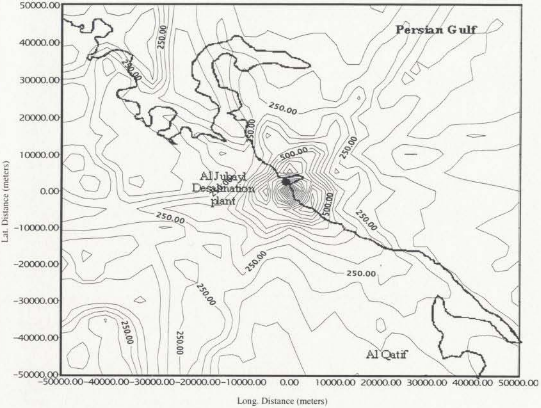


Figure. 6.4 Daily Average Concentration ($\mu g/m^3$) Plot of SO_2 for the Year 1995

6.3.3 Annual Average Concentration Level

Annual average SO_2 concentration results for the year 1995 are presented in Appendix-C. The six highest annual concentrations result, along with their respective locations are also shown in Appendix-B. The annual average SO_2 emissions result is plotted as shown in Figure 6.5. It has been observed from the AERMOD emission results that only 14 values exceeded the MEPA standard of 80μgm^{-3} for the year 1995, and the exceedance is only by 10μgm^{-3}. AERMOD results show that over ninety percent of the annual average concentration emission from the Al-Jubail desalination plant is within the MEPA standard. Therefore we can say that the estimated annual average concentrations of SO_2 are within the safe limits of specified MEPA standards.

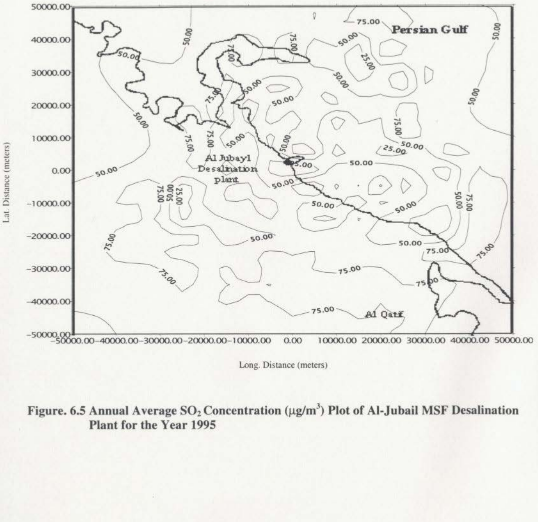


Figure. 6.5 Annual Average SO_2 Concentration (μg/m^3) Plot of Al-Jubail MSF Desalination Plant for the Year 1995

6.4 Nitrogen Oxides Results

6.4.1 Hourly Average Concentration Level

Hourly average ambient air concentration of NO_x contributed by Al-Jubail desalination plant for the year 1995 is shown in Appendix-D. These emission concentration results were compared against the MEPA maximum concentration standard of 660 μgm^{-3}. It was estimated from the emission result that only eight values exceeded the specified allowable limit of MEPA. Figure 6.6 shows the concentration plot for 1-hour average concentration levels of NO_x. Maximum 20-concentration level was generated for the year 1995, and is shown in Figure 6.7.

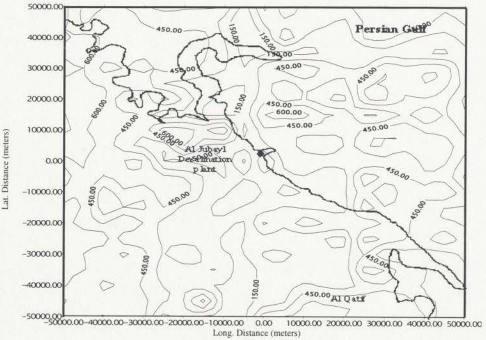


Figure 6.6 1-Hour Average Concentration ($\mu g/m^3$) Plot of NO_x for Al-Jubail Desalination Plant

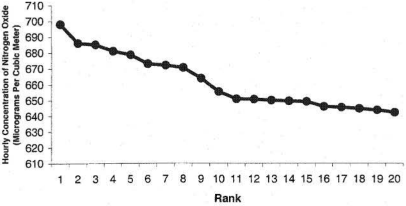


Figure 6.7 Plot of 20 Highest Concentration levels of NO_x on 1-Hour Average Basis for the Year 1995

6.4.2 Annual Average Concentration Level

Annual average emission concentration results of NO_x from Al-Jubail desalination plants are shown in Appendix-D, all these concentration results from AERMOD were compared against the MEPA maximum standard 1 year NO_x concentration of 100 μgm^{-3}, and it was found that most of the concentration result were within the standards. The six highest concentration values were shown in Appendix-D.

The annual average concentration results for NO_x were found to be more than ninety nine percent within the MEPA regulatory limits. The Annual Average concentration plot for NO_x is drawn and is shown in Figure 6.8.

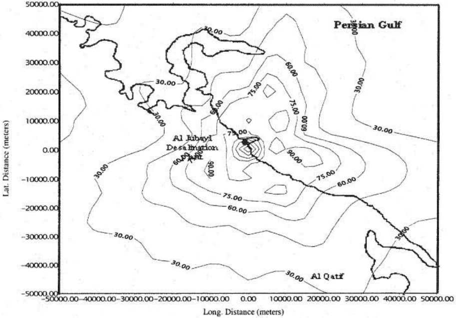


Figure 6.8 Annual Average Concentration (μg/m^3) Plot of NO$_x$ for Al-Jubail Desalination Plant

6.5 Particulate Matter Results

6.5.1 Daily Average Concentration Level

Particulate concentration values were estimated to determine the daily average concentration levels at each grid and discrete receptor point for the year 1995. Estimated average daily particulate concentrations were compared against the average daily standard value of 340 μgm^{-3} as specified by MEPA. The emission results at each grid point are shown in Appendix-E. The concentration plot, as shown in Figure 6.9, and the

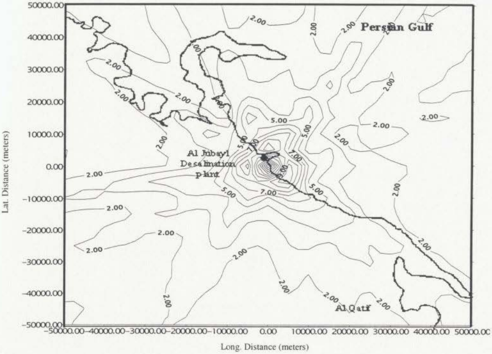


Figure 6.9 Daily Average Concentration (μg/m^3) Plot of Particulate Matters for the Year 1995

AERMOD emission result shows that all the values for PM are with in the standard limit and that the particulate concentration levels at all the grids are much lower than the specified MEPA standards.

The maximum 20 particulate matter concentrations were plotted as shown in Figure 6.10, the result also satisfied the MEPA standards for highest PM concentration.

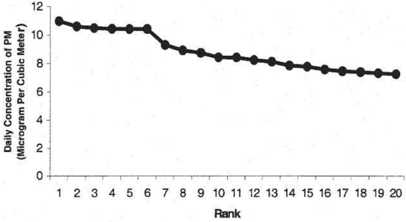


Figure 6.10 Plot of 20 Highest Concentration (μg/m^3) Levels of Particulate Matters On Daily Average Basis for the Year 1995

6.5.2 Annual Average Concentration Level

Annual average particulate concentration for the year 1995 are presented in Appendix-E, the result generated by AERMOD is compared with the MEPA standard of 80 μgm^{-3}, it was observed that all the values were far below the MEPA standard. Figure 6.11, shows the concentration plot for PM on an annual average concentration base, which satisfied the MEPA standards for PM.

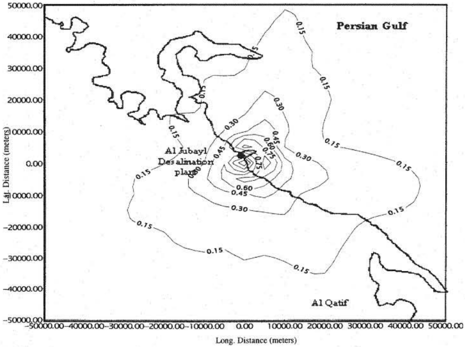


Figure 6.11 Annual Average Concentration ($\mu g/m^3$) Plot of Particulate Matters for the Year 1995

6.6 Analysis of the Results

The analysis of the results indicates that the pollutants of concern from Al-Jubail desalination plant were SO_2 and NO_x. The Sulfur dioxide results showed that some of the emission results (3 to 5%) for all the averaging period were above the standard limits.

However, the NO_x limits were within the range for annual average, and only 1.81% of the concentration level is exceeded in 24-hour averaging period. In case of particulate matter the estimated concentrations were well within the MEPA standard limits.

From the concentration plots and AERMOD results it was found that the higher concentrations were found to be towards the North East (Persian Gulf) side of Al-Jubail desalination plant.

Chapter VII

RESULTS AND ANALYSIS OF BRINE DISCHARGE USING CORMIX-1

7.1 CORMIX System

Brine discharge with high concentrations of total dissolved solids (TDS) and elevated temperatures to the ocean from desalination plants can cause a potential problem and may threaten the benthic environment. To deal with this the EPA CORMIX computer code model will be used to investigate the brine discharge from Al-Jubail MSF desalination plant. Suggestions will be made, regarding the high TDS (salinity) and elevated temperature in the discharge water to the ocean.

The Cornell Mixing Expert System (CORMIX) represents a robust and versatile computerized methodology for predicting both the qualitative features (e.g. flow classification) and the quantitative features (e.g. dilution ratio, plume trajectory) of the hydrodynamic mixing processes resulting from different discharge configurations in all types of ambient water bodies, including small streams, large rivers, lakes, reservoirs, estuaries, and coastal waters (Mukhtasor et al., 2001).

The CORMIX consists of a series of software systems for analysis, prediction, and design of toxic or conventional pollutant discharges into diverse water bodies, with emphasis on the geometry and dilution characteristics of the initial mixing zone, including the evaluation of regulatory requirements. CORMIX a U.S EPA approved system, which emphasizes on the prediction of plume boundary interaction and provides extensive documentation of input data verification, hydrodynamic model selection, and documentation of simulation results (Doneker and Jirka, 2001).

CORMIX is approved and used for environmental impact assessment of mixing zones resulting from point source discharges (Akar and Jirka, 1991; Donekar, and Jirka, 1990). The methodology contains systems to model submerged single-port (CORMIX-1), which predicts the geometry and dilution characteristics of the effluent. It has been proved that CORMIX-1 works better than 95% on submerged single-port designs, while CORMIX2 is developed for multi-port diffuser configurations. Three commonly used types of submerged multi-port diffuser discharges are accumulated in CORMIX2 under the same general effluent and ambient conditions as CORMIX1. It has been shown that CORMIX2 applies better than 80% of the multi-port designs. CORMIX3 analyzes the buoyant surface discharges, which are originated when an effluent enters a larger water body laterally, through a canal, channel, or near-surface pipe. Also the CORMIX3, in contrast to CORMIX1 and CORMIX2, is limited to positively or neutrally buoyant effluents. In CORMIX3, different discharge geometries and orientations can be analyzed including flush or protruding channel mouths, and orientations normal, oblique, or parallel to the bank (Akar and Jirka, 1991; Donekar, and Jirka, 1990; Jones et al., 1996). The other major assumptions in CORMIX models are as follows:

- All subsystems require that, the actual cross-section of the water body be described as a rectangular straight uniform channel that may be bounded laterally or unbounded. The ambient velocity is assumed to be uniform within that cross-section.
- In addition to a uniform ambient density, CORMIX allows for three generic types of ambient stratification profiles to be used for the approximation of the actual vertical density distribution.
- All CORMIX subsystems in principle are **steady-state models**, however recent developments and with the new version of CORMIX the analysis of **unsteady mixing** in tidal environments can be performed.
- All CORMIX systems can predict mixing for both conservative and first-order decay processes, and can simulate heat transfer from thermal plumes.

As it has been observed that the Al-Jubail desalination plant is discharging the brine in a submerge fashion, the brine discharge pipe is releasing effluent from the plant into the Persian Gulf at a depth of 4 meter (Abdul Azis et al., 2000). Therefore, in this research CORMIX1 system will be used to simulate the TDS and elevated temperature results.

7.2 CORMIX Technical Description

This section will describe the formulation and technical description of the CORMIX computer code system. All the CORMIX sub-models assume steady-state ambient discharge conditions. All these sub-models within the CORMIX system can be used to predict the geometry and dilution characteristics of effluent flow from different discharging systems.

CORMIX system with submerge discharge/plume, the concentration profile can be calculated by using the following formula

$$C(n) = C_c\, e^{-(n/b)2} \qquad (7.1)$$

Where C(n) is the lateral concentration (any units), 'n' is the coordinate position measured transversely away from the centerline (meters), C_c is the centerline concentration (any units), 'e' is the natural logarithm base, and 'b' is the local plume half width (meters) (Jirka et al., 1996).

The CORMIX system is enhanced in performance by the CORJET, which contribute as a part of the CORMIX system. The model basically works on the assumption of Gaussian profile for jet velocity u, buoyancy 'g', and concentration 'c', as shown in Figure 7.1.

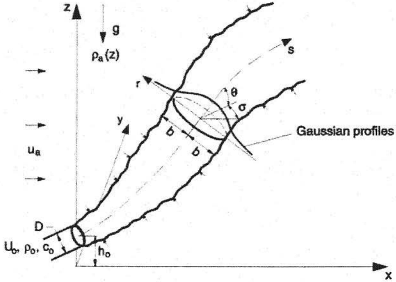


Figure 7.1 General Three-Dimensional Trajectory of Submerged Buoyant Jet in Ambient Stratified Cross flow (Adopted from Jirka et al., 1996)

Where, 'D' is the diameter of the brine discharge jet (meter), 'h_o' is the height of the jet from the surface bed (meter), 'U_o' is the discharge velocity (m/sec), 'ρ_o' is the brine density (kg/m^3), 'C_o' is the concentration of discharge (ppb, mg/l or degrees), 'b' is the half plume width (meter), 's' is the center of the plume, 'g' is the gravitational force (m/sec^2), 'U_a, and 'ρ_a' are the ambient velocity and density. From Figure 7.1, it is clear that there are three main fluid forces acting on the jet plume; the entrainment force in the x-direction, the buoyant force in the z- direction, and the drag force normal to the jet. Where the jet velocity 'u', the Buoyancy 'g', and the concentration 'c' is calculated by the system, using the equation as shown below:

$$u = u_c\, e^{-r^2/b^2} + u_a \cos\sigma \cos\theta\,, \quad g' = g'_c\, e^{-r^2/(\lambda b)^2}\,, \quad c = c_c\, e^{-r^2/(\lambda b)^2} \tag{7.2}$$

In equation (7.2) the subscript 'c' denotes the centerline values, while the 'b' represent the jet width, and 'λ' describe the dispersion ratio which is always greater than 1 for the scalar quantities. For more information on these equations (entrainment, buoyant, and drag), the author would suggest to read Jirka (1999).

7.3 CORMIX Data Input

The main input data required by the CORMIX systems are the discharge configurations and discharge site information, the ambient conditions and pollutant characteristics. In all these the most important factors that can influence the mixing or dilution of the plume are the ambient depth, ambient velocity and effluent discharge velocity, all these will be discussed in detailed in the next sections.

All the CORMIX systems have the same data input features. All data is entered interactively in response to the CORMIX system prompts and is totally guided by the system. The user is asked for a complete specification about the site/case descriptions, ambient conditions, discharge characteristics, and regulatory definitions, which will be discussed in the proceeding sections. The whole input data can be entered in an open format that is not concern for letter case or decimal placement (Jirka et al., 1996).

7.3.1 Site Identification Data

The first basic input data and the information needed for the program (system) to operate/run is a two-part identifier for labeling the output and the computer file name. Site identifier data is necessary to specify the site/case labels, which help in the identification of printed output records and also aid in good record keeping. The CORMIX provide one label for SITE NAME, and another for DESIGN CASE.

7.3.2 Ambient Data

All CORMIX analyses are usually carried out under the assumption of **steady-state** ambient conditions. Even though the actual water environment is never in a true steady state, this assumption is usually adequate since mixing processes are quite rapid relative to the time scale of hydrographic variations. In highly unsteady tidal reversing flows the assumption is no longer valid and significant concentration build-up can occur. CORMIX will assess this situation and compute some re-entrainment effects on plume behavior.

As this research is concerned with the desalination plant in the Persian Gulf, in the CORMIX system the water body will be taken as unbounded. Therefore, the focus of study will be on unbounded discharge, and the ambient input data requirements for the CORMIX will be as follows:

(1) Hydrographic Data

If the detailed hydrographic data from field surveys or from hydraulic numerical model calculations are available, then the "***cumulative ambient discharge***" from the shore to the discharge location for the discharge cross-section is calculated. Values for the ***ambient/average depth (HA)*** and ***ambient velocity (UA)*** are calculated for input specifications. The ***distance from the shore (DISTB)*** for the outfall location is typically specified as the cumulative ambient discharge divided by the product UA times HA.

When detailed hydrographic data are unavailable, data or estimates of the vertically averaged velocity at the discharge location can be used to specify HA, UA, and DISTB.

(2) **Water Depth (HD)**

The actual water depth at the submerge discharge location (HD), for CORMIX1 & 2, must be specified. In CORMIX a check is used so that the HD depth should not differ more than +/- 30% of that of average depth HA. This restriction is included to prevent CORMIX misuse in several discharge/ambient combinations involving strongly non-uniform channels. In highly non-uniform conditions, HD is the variable that usually influences the near field mixing, while HA is important for far field transport and never influence the near field.

(3) Manning (n)/ Darcy-Weisbach Friction Factor (f)

Manning's "n" or the Darcy-Weisbach Friction Factor "f" is specified for the ambient roughness characteristics. If the unbounded case represents a large lake or coastal area, it is often preferable to use the friction factor 'f'. Typical 'f' values for such open water bodies' range from 0.020 to 0.030, with larger values for rougher conditions.

(4) Ambient Density

Ambient density specification in the water body is an important parameter for the correct prediction of effluent discharge plume behavior. In CORMIX the option is provided to describe whether the ambient water is ***fresh or non-fresh*** (i.e. brackish or saline). If the ambient water is fresh and above 4 °C, the system provides the option of entering ambient temperature data so that the ambient density values can be computed internally. In saline water conditions the density of water is usually specified. The CORMIX also specifies the user to input whether the ambient density (or temperature) is ***uniform or non-uniform*** within the water body, and most importantly within the expected plume regions. In case of uniform conditions the average ambient density or average temperature must be specified.

(5) Wind Speed (UW)

The next important input parameter for CORMIX system is the ***wind speed (UW)***. Wind speed is not an important factor in case of near-field mixing, but may critically affect the plume behavior in the far field. This is especially important for heated discharges in the buoyant spreading region. Wind speed data from an adjacent meteorological station is usually sufficient for that purpose. Basically the wind speed categories which are measured at 10 m level are:

- Breeze (0 –3 m/s)
- Light wind (3 – 15 m/s)
- Strong wind (15 – 30 m/s)

If the data for the wind is not available then it is recommended that a value of 2 m/s should be considered for a conservative design condition.

7.3.3 CORMIX Discharge Data

In the discharge data, CORMIX-1 requires different parameters. Figure 7.2 defines the geometry and flow characteristics for submerge single port discharge. For the discharge geometry, CORMIX-1 requires the specification of 6 data entries, such as:

1. Location to the nearest bank (i.e. left or right), as seen by the observer looking downstream in the direction of flow
2. Distance to the nearest bank
3. Port radius (or cross sectional area for non circular shape ports)
4. Height of the port (H_o) center above the bottom
5. Vertical angle of discharge (theta) between the port centerline and a horizontal plane. Angle theta range between – 45° and 90°. As an example the vertical angle

is 90° for a discharge pointing vertically upward, and it is 0° for a horizontal discharge.

6. Horizontal angle of discharge (sigma), which is measured counterclockwise from the ambient current direction. Angle sigma ranges from 0° and 360°. as an example the horizontal angle is 0° (or 360°) when the port points downstream in the ambient flow direction, and it is 90°, when the port points to the left of the ambient flow direction.

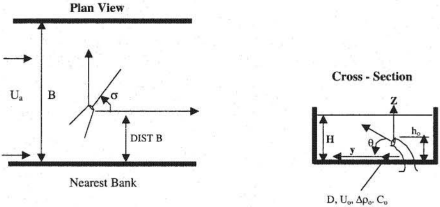


Figure 7.2 The Geometry and Flow Characteristics for a Submerge Single Port Discharge

In order to prevent any misuse or inappropriate system application, CORMIX-1 checks the specified geometry with the three important criteria, which are:

1. The port height (h_o) value must not exceed one third of the local water depth (HD) value
2. The port diameter value must not exceed HD's value for near-vertical designs and one third of the HD's value for near-horizontal designs, and
3. The pycnocline (a zone or level of strong density change that separates the upper and lower levels of the water column) value must be within the 40 to 90 percent range of HD's value.

The port height restriction implies that CORMIX-1 may only be applied to submerged discharge applications. For port discharge characteristics, CORMIX-1 requires the specification of 3 parameters. These specifications include:

- The discharge flow rate (Q_o) or discharge velocity (U_o)
- The discharge density or discharge temperature for an essentially freshwater discharge, and
- The discharge concentration of the material of interest.

The specification of the pollutants in the effluent is described in the next section.

7.3.4 Pollutant Data

CORMIX can handle three types of pollutants discharges, and these are:

1. **Conservative Pollutant:**

   In this case the pollutants does not undergo any type of decay or growth process

2. **Non-Conservative Pollutant**

   In this case the pollutants are considered to undergo a first order decay or growth process. The coefficient of decay (positive number) or growth (negative number) should be specified in units per day.

3. **Heated Discharge**

   In this case the discharge will experience a heat loss to the atmosphere at a point where the plume contacts the water surface. It is therefore important to specify the discharge condition in terms of excess temperature above the ambient temperature in ^{o}C, and the surface heat exchange coefficient in $W/(m^2\ ^{o}C)$.

7.4 Geographical Description of the Site

The study was carried out for Al-Jubail desalination plant, situated at the Persian Gulf. The sea region adjacent to the Al-Jubail desalination plant, where the brine is discharged is shallow and the seabed is mainly consists of Seaweeds (Abdul Azis et al., 2000).

Figure 7.3 shows that the marine basin in the area of study is very shallow, the sea depth ranging from 3 to 8 meter over a long distance from the shore (Abdul Azis et al., 2000).

In figure 7.3, the 2-meter contour is approximately 1-2 km, 5-meter contour 2-4 km, and 10-meter contour is 4-6 km away from the shore. In the southeast of desalination plant is the Naval Base, the commercial port, and the biggest petro-chemical complex in the world.

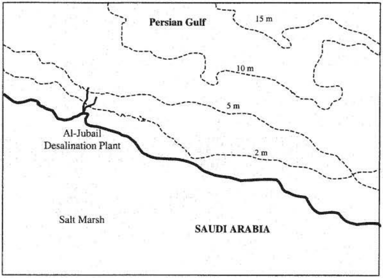


Figure 7.3 Persian Gulf between Lat. 26° 52' & 26° 55' N and between Long. 49° 45' & 49° 52' E. Study Site and Depth Contours
(Adopted from Abdul Azis et al., 2000)

The brine discharge pipe from Al-Jubail desalination plant is about 2000 meter away from the shore, and at a depth of 4 meter. While the seawater intake is at the depth of 2.5

meter, making it a typically coastal subsurface intake. The characteristics of brine discharge pipe are shown in Table 7.1.

Table 7.1 Characteristics of Outfall

OUTFALL	
Length (meter)	2000 m
Diameter (meter)	0.9 m (Adopted from Salibi, 2001)
Depth of Discharge (meter)	4 m

(Adopted from Abdul Azis et al., 2000)

7.5 Data Acquisition for CORMIX

The complete input data, which will be required to run CORMIX1, are as follows. The ***Average Depth*** of seawater is taken as 5 meter, while the Brine ***Discharge Depth*** is taken as 4 meter, both these numbers are adopted from Abdul Azis et al., (2000).

In this case the study region is the Persian Gulf, therefore the ***Unbounded*** option has been selected to run the CORMIX-1. Usually, in unbounded case the Darcy-Weisbach friction factor 'f' is adopted and these values ranges from 0.02 to 0.03, with larger values for rougher conditions (Jirka et al., 1996). Therefore, a value of 0.025 is selected.

Morton et al., in 1996, studied the MSF desalination plants situated at the Persian Gulf. They reported that the ***Average density*** of the Persian Gulf seawater is 1027.5 kg/m^3, while the brine from the MSF desalination plant has the ***discharge density*** of 1046.5 kg/m^3.

Similarly, the ***port diameter*** of 0.9 meter was selected as reported by Salibi in 2001. The Discharge flow rate for the Al-Jubail MSF desalination plant was reported by Al-Mumtaz & Wagialla in 1988, according to them MSF desalination plant with a production capacity of 253.5 million gallons per day has a net discharge of (Brine) about 371 million gallons per day, which is about 16.25 m^3/sec. Therefore the ***effluent flow rate*** entered into CORMIX-1, is 16.25 m^3/sec.

An ***Ambient velocity*** of 0.5 m/sec was selected based on Abdul Azis et al., (2001), who indicated that the Persian Gulf currents are generally of moderate nature. The average annual ***wind speed*** is taken as 5.0 m/sec, from the data used previously for running the AERMOD.

In the discharge analysis the first pollutant of interest is the ***Temperature.*** It was found by Abdul Azis et al., (2000), that the annual average ambient seawater (Persian Gulf) temperature is 26.06 °C. While Khawaji & Wie (2001), reported that for the MSF desalination plant, working with the top brine temperature (TBT) of 90 - 100 °C, has a brine discharge temperature of 33.0 °C. Therefore, a temperature rise of 6.94 degrees was simulated through CORMIX-1 to find its affects on the surrounding environment.

Elevated seawater temperature related to brine discharge of thermal effluent from MSF desalination plants has shown drastic impacts upon the marine organisms (Morton et al., 1996). From different researches it has been found that the elevated temperature and increased salinity minimizes the overall concentration of dissolved oxygen in the seawater, which might restrict the life forms of the marine organisms.

The other pollutant of interest was total dissolved solids (TDS). The average Persian Gulf seawater TDS (ambient TDS) was reported by Mumtaz and Wagialla (1988), to be 45000 ppm, while the brine discharge from Al-Jubail desalination plant have a concentration of TDS of 70,000 ppm.

All of the above parameters were plugged into the CORMIX-1 to predict the concentration profile for the brine discharge from Al-Jubail desalination plant. The results from these simulations are discussed in the next sections.

7.6 Results and Analysis of Elevated Thermal Discharge from Al-Jubail Plant

The results from CORMIX-1 for the elevated thermal discharge is shown in Appendix-F, which depicts that the thermal plume first rises and then slowly falls back towards the bottom of the sea while spreading sideways in the near field mixing region (NFR). The results also show that the temperature drop in the beginning of the discharge is very sharp till the plume touches the bottom of the sea at 2.77 meters from the point of discharge.

Within this distance the plume has significant mixing, and the centerline dilution is 30 times than at the point of attachment.

As the plume (effluent stream) travels farther along the downstream, the temperature drops gradually, the plume temperature drops almost equal to the ambient seawater temperature at a distance of 101.41 meters from the point of discharge.

The thermal results from CORMIX-1 were compared with the surface water quality standards proposed by U.S. EPA, which stated that there should be no direct heat additions within 1500 feet of the shoreline and no thermal alteration, which would cause temperature to deviate from ambient temperature by more than 2.2 °C (Surface Water Quality Standards, 2002). Also the elevated temperature should not retain in the ambient atmosphere for more than 4 months. The results from CORMIX-1 showed that the brine thermal discharge is within the standards limits. The results shows that in approximately 5 minutes the plume elevated temperature drop down almost equal to the ambient temperature while covering a distance of 101.41 meters along the downstream.

In Figure 7.4, we can assume that the thermal dilution is same for the surface and the bottom of the sea, because of the fact that the discharge area is very shallow. The contour in Figure 7.4 also showed that within a radial distance of 50 meter from the point of discharge the mixing and thermal drop is very fast.

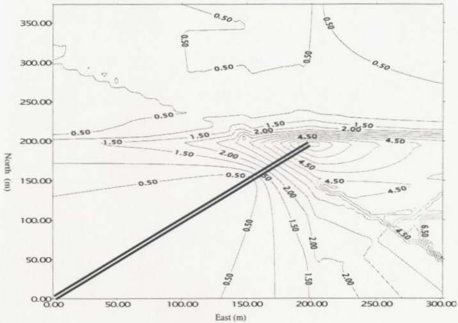


Figure 7.4 Distribution of Elevated Thermal Discharge (°C) in The Persian Gulf

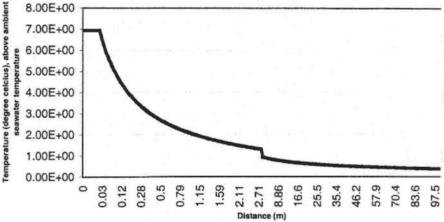


Figure 7.5 Temperature Drop (°C) Versus Downstream Distance

Figure 7.5 depicts that dilution is the function of distance from the point of discharge. The Concentration plot (Figure 7.5) also showed that the effluent plume attached to the bottom of the sea at approximately 4.91 meter from the point of discharge. Within this distance, as shown in Figure 7.5, the plume has significant mixing and the dilution is rapid. While as the effluent plume travels downstream, it continues with more gradual drop in temperature and in mixing.

From the results of CORMIX-1 and from the above figures, it has been clear that the thermally elevated brine discharge from Al-Jubail desalination plant has got no drastic impacts on the marine environment in the Persian Gulf, as compared to the criteria given by the U.S EPA surface water quality standards.

7.7 Results and Analysis of Elevated Total Dissolved Solids (TDS) Discharge from Al-Jubail Plant

The CORMIX-1 results as shown in Appendix-G, were generated for the elevated TDS effluent discharges from AL-Jubail desalination plant. These results were then compared with the U.S. EPA surface water quality standards. According to U.S EPA ocean discharge regulations, lower concentration (i.e. near to zero) of TDS (Salinity) in the seawater or higher concentration (i.e. twice the ocean ambient concentration) of TDS can impact the ocean biota/marine life if exposed to these extreme concentrations for longer time (Del Bene et al., 1994).

The CORMIX-1 results proved that after discharging the concentrated brine, the plume travels a distance of 3 meters downstream and 31 meters in lateral direction within 3 to 4 seconds, and dilute the higher concentration of TDS to 4700 ppm above the ambient concentration. The CORMIX-1 simulation further shows that the TDS concentration gradually decreases to a concentration of 1370 ppm as the effluent stream travels along the downstream.

Figure 7.6 shows that in the beginning of the brine discharge the mixing and dilution of TDS is fast, till the distance of 217 meter, downstream. After this, the plume travel slowly in the downstream direction and has gradual dilution/mixing in that region. Similarly Figure 7.7 shows TDS concentration distribution in the form of contour lines, it has been concluded from the result and from Figure 7.6 and 7.7, that the TDS concentration distribution from Al-Jubail desalination plant into the Persian Gulf has got no drastic impact on the benthic/marine environment. The concentrated brine discharge from Al-Jubail desalination plant takes only 5 to 6 minutes to dilute the concentration from 25000 ppm to 1300 ppm above the ambient level. Therefore we can say that the concentrated TDS brine discharge from the Al-Jubail desalination plant is with in the limits as specified by the U.S. EPA surface water standards.

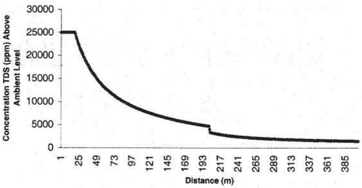


Figure 7.6 Total Dissolved Solid Versus Downstream Distance

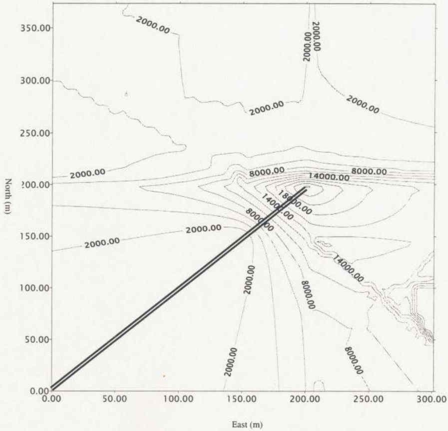


Figure 7.7 Distribution of Increased Total Dissolved Solids Concentration in the Persian Gulf as a Result of Brine Discharge from Al-Jubail Desalination Plant

Chapter VIII

Conclusions and Recommendations

8.1 Conclusions

The following conclusion are drawn from this study:

1. AERMOD model was found to be one of the most suitable and reliable for this research to study the short range/near source dispersion behavior of air born pollutants emitted from Al-Jubail Desalination plant.
2. In view of the nature of the fossil fuel used in generating steam for Al-Jubail desalination plant, the most important type of pollutants examined were sulfur dioxide (SO_2), nitrogen oxide (NO_x), and particulate matter (PM).
3. The estimated annual average concentration of SO_2 was found mostly within the MEPA specified standard of 80 $\mu g/m^3$. However, there were some points where the concentration exceeded only by 10 $\mu g/m^3$ above the MEPA standards.

4. The NO_x annual average concentrations were mostly within the limits. However, the 1-hour average NO_x concentration was exceeded by less than 1 percent of the total.
5. The daily (maximum 340 μgm^{-3}) and annual (maximum 80 μgm^{-3}) average estimates for PM were well within the safe limits of MEPA standards.
6. Among all available hydrodynamic mixing models, CORMIX was found to be the most suitable and user friendly for this study.
7. The results generated by CORMIX1 for the elevated thermal discharge from Al-Jubail desalination plant, shows no exceedence whatsoever as compared to the surface water quality standards specified by the U.S EPA, which states that there should be no direct heat addition within 1500 feet of the shoreline, and no thermal deviation which would cause temperature to deviate from ambient temperature by more than 2.2 °C.
8. The results for the elevated TDS concentration in the brine shows that the dilution in the NFR was reduced to 1300 ppm from 25000 ppm above the ambient level, which is within the criteria standards sets by the U.S. EPA for the surface water, according to which TDS (salinity) concentration in the NFR should not be twice the ocean ambient concentration.

8.2 Recommendations

Based on this study the following recommendations are made

1. Emission rates used in the simulation should be validated with actual measurements from Al-Jubail desalination plant.
2. Meteorological and ambient air monitoring stations at the site should be installed and operated.
3. Instead of generating the geographical file manually, DEM files should be created for the site and should be used in the AERMOD model, to get more precise readings at the grid points
4. A detailed physical oceanographic study of the region should be conducted, for effective use of any hydrodynamic mixing model. Daily measurement of brine discharge should be recorded. Also detailed characteristics of brine should be done on periodical basis.
5. Monitoring of seawater quality in the near field region (NFR) of outfall should be done on a regular basis. Such information will help in validating hydrodynamic models results.

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APPENDIX – A

AERMOD Model Inputs

The AERMOD model basically requires the run-stream setup file, the meteorological data file, and receptor & terrain data file. The run-stream setup file consists of a variety of data, like modeling options, source location and parameter data, receptor locations, meteorological data file specifications, and output options. The meteorological data is another basic input data file required by the AERMOD. AERMOD requires two types of these meteorological data files, one includes the surface scalar parameters and the other contains the vertical profiles of meteorological data, both these data files can be develop manually or by the AERMET pre-processor. When there is an elevated terrain effects involved, the receptor and terrain data are processed by AERMAP and inputted into the AERMOD model.

Basically, AERMOD provides several modeling options, which includes dispersion options, source options, receptor options, meteorological options, and output options. Within dispersion options, we have the choice of using stack-tip downwash and can use a routine for processing averages when calm winds or missing meteorological data occur. Furthermore, we have the option of either specifying short-term averages, which can be calculated in a single run of the model or selecting overall period averages.

Source option makes the model capable of handling multiple sources, including point, volume, line, and area source types.

In the Receptor Options, we can specify multiple receptor networks in a single run. Elevated receptor heights can be inputted so that the effects of terrain above (or below) the stack base may be modeled. Elevations may also be specified in order to model flagpole receptors.

For Meteorological Options, AERMOD uses a file of Surface Boundary Layer (.sfc) parameters and a file of Profile (.pfl) variables. The profile variables include wind speed, wind direction, and turbulence parameters. AERMET, the meteorological-preprocessor, generates these files.

Several options are available for the output that is produced by AERMOD. The three basic types of printed output available in AERMOD are:

(1) Summaries of high values by receptor averaging period and source group combination,

(2) Summaries of overall maximum values for each averaging period and source group combination, and

(3) Tables of concurrent values summarized by receptor for each averaging period and source group combination (EPA 1998a).

AERMOD requires a specific run-stream file, which is defined from a keyword/parameter approach. This run-stream has five functional pathways. A two-character ID that is placed at the beginning of each run-stream file defines each pathway.

These pathways are listed below in the order in which they are inputted to the model (EPA 1998a):

CO – Specifies the job COntrol options

SO – Specifies the SOurce information

RE – Specifies the REceptor information

ME – Specifies the MEteorological information

OU – Specifies the OUtput Options

Each line in the input run-stream file consists of a pathway ID and a parameter list. Many rules should be followed while structuring the run-stream files for AERMOD. For instance, the **CO** pathway should always comes first and is followed by the inputs for the **SO** pathway. Next, the beginning of each pathway is identified with a **STARTING** keyword and the end of each pathway is identified with a **FINISHED** keyword. All numeric input data are assumed to be in metric units otherwise has to be specified in the model.

If one does not specify keyword options, the AERMOD model will resort to default options. Such default options are listed below (EPA 1998a):

- Use elevated terrain algorithms requiring input of terrain height data
- Use stack-tip downwash
- Use the calms processing routines
- Use the missing data processing routines

- Use upper-bound concentration estimates for sources influenced by building downwash from super-squat buildings
- Use of a 4 hour half life for exponential decay of SO_2 for urban sources

The first run-stream input file for the AERMOD is the **CO** Pathway, which contains keywords that provide the overall control of the model run. The mandatory keywords for the **CO** Pathway are **STARTING**, **TITLEONE**, **MODELOPT**, **AVERTIME**, **POLLUTID**, **RUNORNOT**, and **FINISHED**. The **STARTING** keyword simply indicates the beginning of an input pathway. **TITLEONE** is a user-specified title line. **MODELOPT** keyword controls the modeling options that are selected for a model run via a series of secondary words.

In the model the secondary keyword **DFAULT** specifies that the regulatory default options will be used. **CONC** specifies that concentration values will be calculated. **FLAT** indicates the use of non-default option of assuming flat terrain. **NOSTD** indicates that the non-default option of no stack-tip downwash is used. **NOCHKD** indicates that the non-default option of suspending data checking will be used for non-sequential meteorological data files. **NOWARN** indicates that the option of suppressing the detailed list of warning messages in the main output file. Finally, the secondary keyword **SCREEN** indicates that the non-default option for running AERMOD in a screening mode will be used.

AVERTIME identifies the averaging periods to be calculated. **POLLUTID** identifies the type of pollutant that is to be modeled. **RUNORNOT** is a very useful keyword that instructs the model to either run the model executions or not. If the user chooses not, the run-stream setup file will be processed and the input errors are reported, but the dispersion calculations will not be carried out. **FINISHED**, the final mandatory keyword for the CO Pathway indicates that the user is finished with these inputs.

The second pathway in the input run-stream file is the **SO** Pathway, which contains keywords that define the source information for a particular model run. The **STARTING** and **FINISHED** keywords are mandatory for all five pathways. The other mandatory keywords for this pathway include **LOCATION**, **SCRPARAM**, and **SRCGROUP**. The **LOCATION** keyword identifies a particular source ID. Each individual source requires its own ID. It specifies the source type (one of the three source types point, volume, or area) and the location of that source. **SRCPARAM** specifies the source parameters for the source ID selected in the previous **LOCATION** command. **SRCGROUP** simply specifies the way in which the sources are grouped for calculation purposes. The **SO** Pathway offers some optional keywords. When a source is influenced by nearby buildings, it would be beneficial to include the optional keywords **BUILDHGT** and **BUILDWID**, as building dimensions will affect downwash effects.

The third pathway in the input run-stream file, the **RE** Pathway, contains keywords that define the receptor information. Within the RE Pathway, the user can specify either a polar receptor network or a Cartesian grid receptor network. After selecting one of these we can then identify the receptor locations within the network, and the boundary around a particular source. All of the receptor data are preprocessed by AERMAP in order to obtain receptor elevations and terrain height scales. This data is included in the AERMAP.OUT file or can be entered manually by taking the elevation points of the site from the site contour maps.

For AERMOD one has to define a modeling domain, which is the area that contains the receptors that are being modeled. It is also the geographic area in which the effect of terrain is considered. The user can specify this area in either the UTM or the longitude/latitude coordinate system. The receptors are specified in AERMAP in the same way that they are specified in AERMOD. Users can identify discrete receptors and either Cartesian or polar grid networks.

The fourth pathway in the input run-stream file, the **ME** Pathway, contains the keywords that define the input meteorological data for a particular model run. The ME Pathway has several mandatory keywords including **SURFILE**, **PROFILE**, **SURFDATA**, **UAIRDATA**, and **PROFBASE**. Of course, the **STARTING** and **FINISHED** keywords are used as well.

The **SURFFILE** specifies the filename and the format for the input surface meteorological data file. This surface data file is generated by the AERMET preprocessor. This file contains an abundance of data that is necessary for the efficient prediction of the dispersion of pollutants. The data included in the **SURFILE** are: year, month, day, Julian day, hour, sensible heat flux, surface friction velocity, convective velocity scale, vertical potential gradient, height of the convectively-generated boundary layer, height of the mechanically-generated boundary layer, Monin-Obukhov length, surface roughness length, Bowen ratio, albedo, wind speed, wind direction, height at which wind was measured, temperature used in computations, and height at which the temperature was measured.

The **PROFILE** specifies the filename and format for the meteorological data file. Like the surface file, the profile file data are generated by the AERMET preprocessor. This file consists of one or more records for each hour of data. Contents include year, month, day, hour, measurement height, top flag (=1 or =0), wind direction, wind speed, temperature at current level, standard deviation of the wind direction, and standard deviation of the vertical wind speed.

AERMET, which generates the profile and surface files, is designed to run as a 3-stage process and operate on three types of data. These three types of data are National Weather Service (NWS) hourly surface observations, NWS twice-daily upper air soundings, and data collected from an on-site measurement program (EPA 1998b). The three stages are apparent in Figure-A.

In the first stage of AERMET, the data is extracted and quality assessment (QA) of the data has been performed. The second stage merges all these data into 24-hour period and writes it to an intermediate file. The third and final stage reads the merged data file and develops the necessary boundary layer parameters for dispersion calculations by AERMOD. The last two output files from stage-3 will contain all the necessary meteorological data required by the AERMOD to perform dispersion analysis.

There will be no processing header records in these files, but there will be a single record at the beginning of the file with the boundary layer parameters that will identify the site, which is used in the processing.

The surface parameters provided by AERMET are the Monin-Obukhov Length (L), surface friction velocity (u_*), surface roughness length (z_0), surface heat flux (H), and the convective scaling velocity (w_*). AERMET also provides estimates for the convective and mechanical mixing layer heights, z_{ic} and z_{im}. Although AERMOD is capable of estimating meteorological profiles with data from as little as one measurement height, it will use as much data as the user can provide for defining the vertical structure of the boundary layer. In addition to PBL parameters, AERMET passes all measurements of wind, temperature, and turbulence in a form compatible to AERMOD.

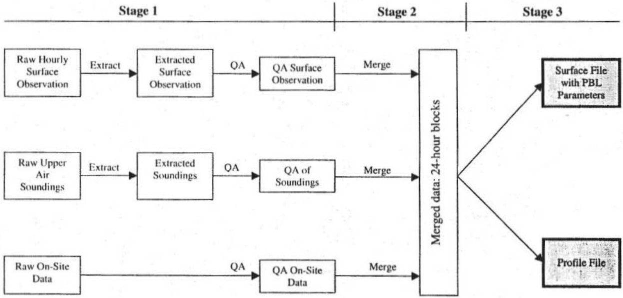

Figure-A1 Schematics Showing AERMET Three Stage Processing (EPA 1998b)

APPENDIX – B

Sample AERMOD run-stream file

```
** AERMOD Model is Run to Estimate The Ambient Concentrations
** of SO2 as a Result of Al-Jubail Desalination Plant Emissions
** Located at Al-Jubail City in The Kingdom of Saudi Arabia

CO STARTING
   TITLEONE
   MODELOPT DFAULT CONC
   AVERTIME 1  24  PERIOD
   POLLUTID SO2
   RUNORNOT RUN
CO FINISHED

SO STARTING
** As Default option is selected therefore effects of elevated terrain are
** included, so it is important to specify the source base elevation above
** mean sea level on the LOCATION card. Here in this example it is 24.0m (MSL)
   LOCATION STACK1 POINT 0.0 0.0 24.0
** POINT SOURCE    QS(g/s)  HS(m)  TS(K)   VS(m/s)  DS(m)
** Parameters       --       --     --       --      --
   SRCPARAM STACK1 30833.0 65.0 440.0 12.0 1.5
   BUILDHGT STACK1 36*24
```

```
  BUILDWID STACK1 35.0 36.2 33.2 35.4 32.6 38.3 34.2 33.0
           STACK1 25.6 26.3 24.3 28.9 33.5 23.6 33.9 35.6
           STACK1 22.3 23.4 26.3 24.9 29.8 31.8 33.3 34.9
           STACK1 15.3 16.4 18.9 16.8 29.4 28.6 33.5 34.6
           STACK1 36.5 35.2 23.9 35.9
  SRCGROUP ALL
SO FINISHED

RE STARTING
RE ELEVUNIT FEET
RE GRIDCART CG1 STA
        XYINC -50000. 21 5000. -50000. 21 5000.
RE GRIDCART CG1 ELEV  1 276. 276. 318. 318. 220. 220. 220. 171. 171. 145. 112. 112. 108. 112. 112. 112. 115. 115. 115.  00.  00.
RE GRIDCART CG1 ELEV  2 276. 276. 318. 318. 220. 220. 220. 171. 145. 108. 112. 112. 106. 112. 112. 115. 115.  00.  00.  00. 315.
RE GRIDCART CG1 ELEV  3 338. 276. 220. 220. 210. 171. 171. 145. 145. 145. 145. 145. 108. 112. 108. 115. 108.  00.  00.  00. 325.
RE GRIDCART CG1 ELEV  4 276. 220. 220. 220. 218. 171. 171. 145. 108. 145. 145. 118. 142. 108. 108.  69. 108.  00. 235. 235.  00.
RE GRIDCART CG1 ELEV  5 250. 220. 220. 220. 201. 171. 171. 142. 142. 118. 145. 108. 125. 380. 115.  69. 115. 115.  00.  00.  00.
RE GRIDCART CG1 ELEV  6 220. 220. 203. 203. 203. 171. 165. 142. 142. 125. 125. 108. 118. 118. 115.  75. 230.  00.  00.  00.  00.
RE GRIDCART CG1 ELEV  7 220. 220. 215. 203. 203. 164. 164. 164. 142. 142. 118. 118. 125. 118.  69. 225. 225.  00.  00.  00.  00.
RE GRIDCART CG1 ELEV  8 220. 203. 203. 203. 203. 174. 164. 164. 164. 164. 110. 118. 125. 300. 220.  00.  00.  00.  00.  00.  00.
RE GRIDCART CG1 ELEV  9 190. 203. 203. 203. 203. 164. 164. 164. 164. 164. 306. 120.  69.  00.  00.  00.  00.  00.  00.  00.  00.
RE GRIDCART CG1 ELEV 10 190. 190. 135. 135. 135. 210. 164. 118.  76.  76.  76.  76.  00.  00.  00.  00.  00.  00.  00.  00.  00.
RE GRIDCART CG1 ELEV 11 190. 190. 135. 135. 135. 135. 135. 210.  76.  76.  76.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.
RE GRIDCART CG1 ELEV 12 190. 190. 135. 135. 135. 135. 135. 118.  76.  76.  76.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.
RE GRIDCART CG1 ELEV 13 200. 170. 135.  76.  76.  66.  60.  79. 225.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.
RE GRIDCART CG1 ELEV 14 200. 112. 118. 120.  66.  66.  66.  79.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.
RE GRIDCART CG1 ELEV 15 200. 112. 112. 110. 110.  66.  00.  79.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.
```

```
RE GRIDCART CG1 ELEV 16 177. 177.  70.  70.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.
RE GRIDCART CG1 ELEV 17 177. 177.  70.  79.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.
RE GRIDCART CG1 ELEV 18 177. 125.  79.  00.  00.  00.  79.  00.  79.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.
RE GRIDCART CG1 ELEV 19 125. 125.  79.  00.  00.  00.  79.  79.  79.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.
RE GRIDCART CG1 ELEV 20 125. 125. 125.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.
RE GRIDCART CG1 ELEV 21  79.  39.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.  00.
RE GRIDCART CG1 HILL  1 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL  2 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL  3 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL  4 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL  5 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL  6 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL  7 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL  8 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL  9 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL 10 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL 11 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL 12 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL 13 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL 14 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL 15 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL 16 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL 17 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL 18 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL 19 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL 20 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 HILL 21 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00. 00.
RE GRIDCART CG1 END
RE FINISHED
```

```
ME STARTING
   SURFFILE  ann1.SFC
   PROFFILE  ann1.PFL
   SURFDATA  12345  1995 Jubail,KSA
   UAIRDATA  12345  1995 Jubail,KSA
   DAYRANGE  1-366
**PROFBASE is used to specify the base elev. (AMSL) for potential temp.
** profile generated by AERMOD for use in plume rise calculation.
** this should correspond to the base elev. for main met. tower, which in this
** example is 24 m and is same as the source base elevation.
   PROFBASE 24 METERS
ME FINISHED

OU STARTING
OU RECTABLE  ALLAVE FIRST SECOND
OU MAXTABLE  ALLAVE 20
OU FINISHED
```

APPENDIX – C

1–Hour Average Concentration Values of SO_2 for the Year 1995

```
                            *** MODELING OPTIONS USED:  CONC ELEV      DFAULT
           *** THE    1ST HIGHEST 1-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL ***
                                   INCLUDING SOURCE(S): STACK1   ,
                           *** NETWORK ID: CG1; NETWORK TYPE: GRIDCART ***
                               ** CONC OF SO2  IN MICROGRAMS/M**3 **

 Y-COORD  |                                    X-COORD (METERS)
 (METERS) |   -50000.00              -45000.00             -40000.00              -35000.00              -30000.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  50000.0 |  329.83690 (95060301)  503.43950 (95060301)  942.56840 (95102823)  749.70410 (95081522)  168.28130 (95080322)
  45000.0 |  352.73730 (95032115)  194.64260 (95060301)  728.99800 (95060301)  728.35550 (95102823)  730.76560 (95030903)
  40000.0 |   20.32810 (95011705)  181.30270 (95032115)  646.36620 (95060301)  439.42770 (95060301)  376.46090 (95081522)
  35000.0 |  851.12890 (95011705)  216.26170 (95011705)  159.84470 (95032115)  216.32810 (95060301)  723.00980 (95060301)
  30000.0 |  726.19530 (95072723)  835.50000 (95011705)  612.22270 (95011705)  369.55470 (95011705)  221.25780 (95060301)
  25000.0 |  942.31250 (95072723)  561.14450 (95072723)  876.55860 (95011705)  480.24610 (95011705)  385.49220 (95011705)
  20000.0 |   72.01560 (95072924)  673.24610 (95070421)  255.50590 (95072723)  656.79100 (95072723)  163.89060 (95011705)
  15000.0 |  250.68360 (95072521)  722.19530 (95013023)  703.02730 (95013023)  468.68750 (95072924)  726.94730 (95072723)
  10000.0 |  726.64060 (95072521)  200.09380 (95072521)  620.95700 (95072521)  177.11910 (95072521)  291.25780 (95013023)
   5000.0 |  411.55470 (95072521)  744.64450 (95072521)  629.34380 (95072521)  781.17970 (95072521)  444.46090 (95072521)
      0.0 |  707.61720 (95081706)  274.94920 (95081706)  727.60350 (95072521)  736.46090 (95072521)  426.00200 (95072521)
  -5000.0 |  650.76950 (95111922)  759.91020 (95111922)  869.95700 (95111922)  619.69140 (95111922)  292.90630 (95032524)
 -10000.0 |  197.93360 (95032524)  229.57420 (95032524)  200.54690 (95032524)  510.09960 (95032524)   57.83980 (95032524)
 -15000.0 |  639.66800 (95032524)  650.78910 (95032524)  483.26760 (95112219)  651.98050 (95112219)   38.63090 (95041418)
 -20000.0 |  642.48440 (95112219)  293.89450 (95112219)  344.91410 (95041418)  503.79300 (95090520)  172.25980 (95090520)
 -25000.0 |  659.67770 (95041418)  644.88670 (95090520)  637.77730 (95090520)  368.41210 (95092520)  464.73240 (95072519)
 -30000.0 |  625.80860 (95090520)  198.68160 (95090520)  660.37500 (95092520)  269.80270 (95072519)   28.10160 (95072519)
 -35000.0 |  313.57420 (95092520)   46.83010 (95092520)  788.89450 (95072519)  640.96290 (95032422)   52.19340 (95073020)
 -40000.0 |  505.18550 (95090520)  310.37700 (95072519)  273.25390 (95032422)  707.92190 (95073020)   22.22360 (95120223)
 -45000.0 |   98.57030 (95072519)  134.63870 (95032422)  724.40630 (95073020)  100.61520 (95073020)  139.75000 (95051719)
 -50000.0 |  223.82230 (95032422)  906.88180 (95073020)  470.65920 (95073020)  864.69531 (95051719)  857.12890 (95080319)
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                        *** THE   1ST HIGHEST 1-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL ***
                                                 INCLUDING SOURCE(S): STACK1  ,

                                          *** NETWORK ID: CG1; NETWORK TYPE: GRIDCART ***

                                               ** CONC OF SO2 IN MICROGRAMS/M**3 *

 Y-COORD  |                                             X-COORD (METERS)
 (METERS) |  -25000.00                -20000.00                -15000.00                -10000.00                -5000.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  50000.0 |  347.86720 (95080322)  284.76560 (95080322)  225.80080 (95060624)  217.72270 (95052324)  216.19920 (95062623)
  45000.0 |  328.20310 (95080322)  362.89840 (95080322)  213.33590 (95101919)  249.06840 (95052324)  226.96480 (95062623)
  40000.0 |  253.66410 (95080322)  406.18750 (95080322)  300.94140 (95080322)  264.63280 (95052324)  236.93750 (95062623)
  35000.0 |  172.80080 (95081522)  375.60160 (95080322)  418.91410 (95080322)  293.36520 (95060624)  242.76950 (95062623)
  30000.0 |  150.03030 (95102823)  256.71880 (95080322)  495.08590 (95080322)  300.92580 (95080322)  265.36330 (95052324)
  25000.0 |  218.81250 (95060301)  177.86720 (95102823)  437.49220 (95080322)  496.23050 (95080322)  361.29690 (95052324)
  20000.0 |  302.53710 (95011705)  256.34380 (95060301)  241.92580 (95081522)  654.13280 (95080322)  432.38670 (95052324)
  15000.0 |  312.47460 (95011705)  425.68750 (95011705)  314.73630 (95060301)  509.41020 (95080322)  581.41410 (95080322)
  10000.0 |  296.14060 (95013023)  383.17190 (95072723)  549.67580 (95011705)  410.27340 (95060301)  104.93800 (95080322)
   5000.0 |  519.82030 (95072521)  553.20310 (95072521)  500.39450 (95072521)  619.79690 (95072723)  682.26560 (95060301)
      0.0 |  275.18550 (95072521)  348.01560 (95072521)  520.60940 (95072521)  654.76170 (95072521)  119.57800 (95072521)
  -5000.0 |  325.91800 (95032524)  409.65630 (95032524)  468.71090 (95032524)  531.61330 (95112219)  708.29690 (95092520)
 -10000.0 |  339.34380 (95112219)  287.19140 (95112219)  465.29690 (95092520)  461.19530 (95072519)  468.55470 (95080319)
 -15000.0 |  275.99800 (95090520)  416.10940 (95092520)  323.40630 (95072519)  279.81840 (95120223)  611.10940 (95032301)
 -20000.0 |  336.53910 (95092520)  249.81450 (95072519)  244.19140 (95120223)  259.85350 (95080319)  413.05470 (95032301)
 -25000.0 |  204.58200 (95072519)  198.29300 (95120223)  201.42190 (95051719)  337.73440 (95032301)  297.23830 (95091219)
 -30000.0 |  160.40430 (95120223)  165.14260 (95051719)  195.62890 (95080319)  377.21880 (95032301)  267.34770 (95091219)
 -35000.0 |  162.09570 (95120223)  176.29880 (95080319)  218.49800 (95032302)  319.20310 (95032301)  229.07230 (95091219)
 -40000.0 |  147.06640 (95051719)  185.45900 (95080319)  268.74610 (95032301)  228.35940 (95032301)  191.23830 (95091219)
 -45000.0 |  204.22460 (95080319)  183.17970 (95080319)  285.28130 (95032301)  178.32420 (95091219)  170.43750 (95042903)
 -50000.0 |  218.93360 (95080319)  187.88090 (95032302)  258.96680 (95032301)  183.56050 (95091219)  165.50590 (95042903)
```

```
                   * THE   1ST HIGHEST 1-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL ***
                                        INCLUDING SOURCE(S):STACK1    ,
                                   *** NETWORK ID: CG1; NETWORK TYPE: GRIDCART ***
                                      ** CONC OF SO2       IN MICROGRAMS/M**3  **

Y-COORD  |                                               X-COORD (METERS)
(METERS) |      0.00                    5000.00                 10000.00                15000.00                20000.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 50000.0 |   185.85550 (95062623)    149.10160 (95040402)    179.82030 (95081921)    157.35640 (95052901)    173.96880 (95020205)
 45000.0 |   202.76560 (95062623)    164.69340 (95040402)    193.35940 (95081921)    192.01560 (95020205)    190.43360 (95082823)
 40000.0 |   222.05860 (95062623)    179.47460 (95040402)    202.94140 (95081921)    215.76950 (95020205)    228.33200 (95040421)
 35000.0 |   247.52340 (95062623)    207.95700 (95081921)    201.50590 (95081921)    221.99020 (95082823)    292.61330 (95070722)
 30000.0 |   279.96880 (95062623)    247.36910 (95081921)    258.88670 (95020205)    281.66210 (95040421)    476.13670 (95070722)
 25000.0 |   321.30080 (95062623)    292.70120 (95081921)    287.65820 (95020205)    458.89840 (95070722)    592.94530 (95070722)
 20000.0 |   381.27730 (95062623)    332.62500 (95081921)    376.83200 (95040421)    700.92190 (95070722)    472.60940 (95070722)
 15000.0 |   474.84380 (95062623)    424.06250 (95020205)    809.28130 (95070722)    607.36330 (95070722)    304.92970 (95043005)
 10000.0 |   640.94920 (95062623)    765.52340 (95070722)    854.07030 (95070722)    266.25000 (95043005)    313.06840 (95041303)
  5000.0 |   105.11700 (95062623)    488.96900 (95070722)    564.92580 (95041303)    535.05080 (95041303)    354.56250 (95041303)
     0.0 |     0.00000 (00000000)    578.23440 (95121006)    351.56250 (95121006)    262.75980 (95121006)    212.89840 (95121006)
 -5000.0 |   119.29700 (95070621)    108.04700 (95050601)    546.54690 (95081722)    716.30470 (95081722)    322.76170 (95081722)
-10000.0 |   750.09380 (95042903)    553.88280 (95061422)    682.48440 (95050601)    286.90040 (95060422)    254.98440 (95081722)
-15000.0 |   493.44530 (95042903)    435.16410 (95081822)    405.73440 (95090720)    507.35160 (95050601)    228.72660 (95020206)
-20000.0 |   404.63280 (95042903)    552.06250 (95081822)    323.37890 (95101721)    317.77340 (95082020)    424.61720 (95050601)
-25000.0 |   346.85550 (95042903)    548.26560 (95081822)    239.29100 (95051323)    319.21480 (95061422)    239.35350 (95082020)
-30000.0 |   305.11330 (95042903)    493.97270 (95081822)    211.31640 (95050524)    273.45510 (95081104)    248.81050 (95090720)
-35000.0 |   274.32230 (95042903)    424.39450 (95081822)    272.87890 (95081822)    214.44530 (95101721)    259.85550 (95061422)
-40000.0 |   250.83980 (95042903)    379.47660 (95070621)    318.51560 (95081822)    173.03320 (95050524)    195.71090 (95101721)
-45000.0 |   230.58200 (95042903)    329.00000 (95070621)    337.96880 (95081822)    158.11910 (95050524)    192.27930 (95101721)
-50000.0 |   214.55470 (95042903)    292.96480 (95070621)    337.28520 (95081822)    169.56050 (95013112)    143.62010 (95050524)
```

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*** THE   1ST HIGHEST  1-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL        ***
                            INCLUDING SOURCE(S):        STACK1   ,
                       *** NETWORK ID: CG1;  NETWORK TYPE: GRIDCART ***
                             ** CONC OF SO2 IN MICROGRAMS/M**3 **

 Y-COORD  |                                        X-COORD (METERS)
 (METERS) |  25000.00              30000.00              35000.00              40000.00              45000.00
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  50000.0 |  194.17190 (95040421)  236.80270 (95070722)  343.09380 (95070722)  362.07420 (95070722)  295.95120 (95070722)
  45000.0 |  211.36330 (95040421)  343.11720 (95070722)  395.10940 (95070722)  332.62110 (95070722)  217.23440 (95070722)
  40000.0 |  329.21090 (95070722)  429.59380 (95070722)  378.28130 (95070722)  244.63670 (95070722)  161.51370 (95040904)
  35000.0 |  459.46090 (95070722)  434.42580 (95070722)  279.43950 (95070722)  175.55860 (95040904)  181.86330 (95043005)
  30000.0 |  504.08980 (95070722)  324.15630 (95070722)  203.26950 (95043005)  180.80470 (95043005)  103.82810 (95043006)
  25000.0 |  385.42970 (95070722)  240.44530 (95043005)  166.69140 (95043005)   98.89648 (95040822)  135.22070 (95040205)
  20000.0 |  279.28130 (95043005)  144.79980 (95043006)  150.33400 (95040205)  186.49610 (95040205)  205.84380 (95041303)
  15000.0 |  164.09180 (95040205)  228.76950 (95040205)  266.93950 (95041303)  271.24220 (95041303)  246.63670 (95041303)
  10000.0 |  365.85940 (95041303)  328.53910 (95041303)  259.59770 (95041303)  192.78910 (95041303)  138.88870 (95041303)
   5000.0 |  216.77340 (95041303)  161.21000 (95090903)  126.58980 (95090903)  102.19730 (95100905)   95.96191 (95100905)
      0.0 |  180.61720 (95121006)  157.72070 (95121006)  140.31840 (95121006)  127.34770 (95121006)  116.88280 (95121006)
  -5000.0 |  261.16800 (95051121)  216.45120 (95051121)  175.08400 (95051121)  147.00980 (95101723)  129.28420 (95101723)
 -10000.0 |  480.42970 (95081722)  435.64840 (95081722)  273.23440 (95081722)  178.35160 (95051121)  172.65630 (95051121)
 -15000.0 |  200.43750 (95060422)  152.25390 (95081722)  309.37700 (95081722)  371.30470 (95081722)  323.00590 (95081722)
 -20000.0 |  213.84380 (95123120)  187.59380 (95060422)  151.10940 (95060422)  106.70800 (95060422)  208.68750 (95081722)
 -25000.0 |  364.81640 (95050601)  194.69140 (95081721)  149.52340 (95020206)  147.49800 (95060422)  120.42870 (95060422)
 -30000.0 |  180.63870 (95082020)  315.63670 (95050601)  194.38870 (95081721)  141.53320 (95020206)  134.41990 (95060422)
 -35000.0 |  226.44920 (95090720)  166.00000 (95050601)  288.47460 (95050601)  189.73050 (95081721)  132.00980 (95123120)
 -40000.0 |  218.45700 (95112122)  194.51950 (95082020)  173.88480 (95050601)  263.91800 (95050601)  185.45900 (95081721)
 -45000.0 |  213.79100 (95061422)  186.07810 (95090720)  167.56250 (95082020)  171.38090 (95050601)  242.10550 (95050601)
 -50000.0 |  165.56640 (95101721)  197.26950 (95112122)  176.72270 (95090720)  138.76950 (95082020)  168.61910 (95050601)
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                *** THE   1ST HIGHEST  1-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL***
                                       INCLUDING SOURCE(S):   STACK1   ,
                                 *** NETWORK ID: CG1; NETWORK TYPE: GRIDCART ***
                                    ** CONC OF SO2        IN MICROGRAMS/M**3 **

 Y-COORD  |                                        X-COORD (METERS)
 (METERS) |      50000.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  50000.0 |   194.52730 (95070722)
  45000.0 |   149.17580 (95040904)
  40000.0 |   173.80470 (95043005)
  35000.0 |   107.20310 (95043006)
  30000.0 |    88.00391 (95040822)
  25000.0 |   159.26460 (95040205)
  20000.0 |   222.91990 (95041303)
  15000.0 |   207.74020 (95041303)
  10000.0 |   121.75980 (95090903)
   5000.0 |    89.43945 (95100905)
      0.0 |   107.87500 (95121006)
  -5000.0 |   113.73240 (95101723)
 -10000.0 |   160.34180 (95051121)
 -15000.0 |   229.47850 (95081722)
 -20000.0 |   287.87890 (95081722)
 -25000.0 |    86.42578 (95060422)
 -30000.0 |   122.81840 (95060422)
 -35000.0 |   119.46970 (95060422)
 -40000.0 |   133.64360 (95123120)
 -45000.0 |   174.00200 (95081721)
 -50000.0 |   225.30470 (95050601)
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Daily Average Concentration Values of SO_2 for the Year 1995

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                                   *** MODELING OPTIONS USED:  CONC   ELEV      DFAULT
                 *** THE   1ST HIGHEST 24-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL ***
                                        INCLUDING SOURCE(S):        STACK1  ,
                                  *** NETWORK ID: CG1      ;  NETWORK TYPE: GRIDCART ***
                                           ** CONC OF SO2       IN MICROGRAMS/M**3 **

 Y COORD  |                                            X COORD  (METERS)
 (METERS) |      -50000.00            -45000.00            -40000.00            -35000.00            -30000.00
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  50000.0 |    259.51367 (95040424)   273.37256 (95040424)   304.77692 (95040424)   341.87708 (95020124)   115.07642 (95020124)
  45000.0 |    278.35345 (95020124)   210.54144 (95040424)   342.83203 (95040424)   269.14520 (95040424)   125.71204 (95020124)
  40000.0 |    290.13458 (95020124)   265.75555 (95020124)   306.97021 (95040424)   271.47821 (95040424)   105.27087 (95020124)
  35000.0 |    107.79089m(95011724)   265.91205m(95011724)   354.00293 (95020124)   210.87042 (95040424)   111.17065 (95040424)
  30000.0 |    133.44604 (95072724)   111.30103m(95011724)   119.04834m(95011724)   103.39539 (95020124)   104.70020 (95040424)
  25000.0 |    126.92883 (95072724)   154.68103 (95072724)   147.23547 (95072724)   140.01404m(95011724)   122.42810 (95020124)
  20000.0 |    266.22534m(95013024)   101.58539 (95070424)   151.46338 (95072724)   183.09375 (95072724)   151.42664 (95072724)
  15000.0 |    134.66589 (95072524)   106.33984m(95013024)   113.46106m(95013024)   119.53137 (95070424)   193.46985 (95072724)
  10000.0 |    216.66431 (95072524)   220.46411 (95072524)   206.85962 (95072524)   187.16028 (95072524)   157.63953 (95072524)
   5000.0 |    156.34436 (95072524)   183.71680 (95072524)   199.73572 (95072524)   235.96509 (95072524)   278.80762 (95072524)
      0.0 |    229.74811 (95081224)   298.37909 (95081224)   282.15411 (95081224)   108.13464 (95081224)   121.93701 (95081224)
  -5000.0 |    295.57446 (95111924)   298.14532 (95111924)   263.57184m(95032524)   104.55920m(95032524)   127.91565m(95032524)
 -10000.0 |    283.55975 (95111924)   298.12030m(95032524)   111.51941m(95032524)   121.24536m(95032524)   122.13623m(95032524)
 -15000.0 |    214.60590m(95032524)   200.46631m(95032524)   197.69708 (95112224)   107.62573 (95112224)   137.30957m(95041424)
 -20000.0 |    268.49097 (95112224)   245.76678 (95112224)   106.41675m(95041424)   135.52649m(95041424)   182.45740 (95092524)
 -25000.0 |    278.80530m(95041424)   286.86621m(95041424)   121.62671 (95092524)   177.06458 (95092524)   161.09314 (95092524)
 -30000.0 |    244.80548m(95041424)   235.35364 (95092524)   161.23535 (95092524)   134.74011 (95072524)   351.06641 (95072524)
 -35000.0 |    386.76270 (95092524)   318.90491 (95092524)   119.02490 (95072524)   308.43488 (95072524)   350.60150m(95042724)
 -40000.0 |    333.92773 (95092524)   348.75159 (95072524)   302.38086 (95072524)   366.81366m(95042724)   330.79602 (95120224)
 -45000.0 |    340.84424 (95072524)   329.03870 (95072524)   317.47223 (95073024)   332.66498m(95042724)   380.12506 (95091624)
 -50000.0 |    360.03760 (95072524)   379.94199 (95073024)   281.51434m(95042724)   273.04715m(95042724)   340.72479 (95091624)
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          *** THE   1ST HIGHEST 24-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL       ***
                                      INCLUDING SOURCE(S):       STACK1   ,
                                 *** NETWORK ID: CG1      ;  NETWORK TYPE: GRIDCART ***
                                    ** CONC OF SO2       IN MICROGRAMS/M**3   **

 Y-COORD  |                                          X-COORD (METERS)
 (METERS) |   -25000.00            -20000.00            -15000.00            -10000.00             -5000.00
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  50000.0 |   246.56934 (95080324)   227.06262 (95080324)    93.21307 (95060624)    90.11346 (95052324)    90.19366 (95062624)
  45000.0 |   237.87512 (95080324)   256.00098 (95080324)    96.95599 (95080324)   104.29456 (95052324)    94.85181 (95062624)
  40000.0 |   243.79309 (95020124)   271.28210 (95080324)   239.02148 (95080324)   110.40137 (95052324)    98.08942 (95062624)
  35000.0 |   236.41309 (95020124)   257.35059 (95080324)   284.21619 (95080324)   122.70532 (95060624)   101.41162 (95062624)
  30000.0 |   228.60095 (95040424)   275.47131 (95020124)   210.46509 (95080324)   146.69922 (95080324)   110.51514 (95052324)
  25000.0 |   223.24573 (95040424)   250.09387 (95040424)   206.47925 (95020124)   223.67798 (95080324)   150.30408 (95052324)
  20000.0 |   252.52515m(95011724)   251.13428 (95040424)   206.23901 (95020124)   279.38599 (95080324)   180.01648 (95052324)
  15000.0 |   226.22314 (95072724)   205.52197m(95011724)   196.97656 (95040424)   312.51563 (95020124)   276.18848 (95080324)
  10000.0 |   151.23425m(95013024)   266.91870 (95072724)   275.64087 (95072724)   273.50781 (95040424)   456.31982 (95020124)
   5000.0 |   320.95288 (95072524)   346.36108 (95072524)   309.19019 (95072524)   460.49170 (95072724)   538.87061 (95020124)
      0.0 |   142.56628m(95032524)   182.23059m(95032524)   252.02515 (95072524)   379.80786m(95032524)   743.10303m(95032524)
  -5000.0 |   155.55432m(95032524)   188.71143m(95032524)   209.80664m(95032524)   280.93726m(95041424)   444.10205 (95092524)
 -10000.0 |   141.78430 (95112224)   190.78333m(95041424)   309.11548 (95092524)   267.35278 (95072524)   366.71484 (95080324)
 -15000.0 |   177.02295m(95041424)   263.56274 (95092524)   184.88147 (95072524)   136.65662 (95091624)   464.35107 (95032324)
 -20000.0 |   207.81421 (95092524)   141.00085 (95072524)   107.41589m(95042724)   201.14539 (95080324)   317.20337 (95032324)
 -25000.0 |   114.80872 (95072524)    89.43811m(95042724)   107.86279 (95080324)   272.53467 (95032324)   227.37085m(95042924)
 -30000.0 |    75.43695m(95042724)    82.89056 (95091624)   146.74023 (95080324)   277.52661 (95032324)   197.25696m(95042924)
 -35000.0 |    69.35358 (95120224)   101.51782 (95080324)   173.92639 (95032324)   226.45630 (95032324)   176.91650m(95042924)
 -40000.0 |    81.47882 (95091624)   128.96155 (95080324)   209.28589 (95032324)   162.91467 (95032324)   159.15674m(95042924)
 -45000.0 |   107.41711 (95080324)   156.46582 (95080324)   207.00220 (95032324)   130.47998m(95042924)   145.42578m(95042924)
 -50000.0 |   134.96130 (95080324)   155.44287 (95032324)   179.10876 (95032324)   120.04773m(95042924)   135.33606m(95042924)
```

```
*** THE   1ST HIGHEST 24-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL ***
                    INCLUDING SOURCE(S):       STACK1  ,
               *** NETWORK ID: CG1       ;  NETWORK TYPE: GRIDCART ***
                    ** CONC OF SO2       IN MICROGRAMS/M**3 **

Y-COORD  |                                         X-COORD (METERS)
(METERS) |      0.00                 5000.00                10000.00                15000.00                20000.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 50000.0 |    78.72510 (95030824)   108.17590 (95081924)   118.36853 (95081924)    97.92578 (95081924)   128.36023m(95011024)
 45000.0 |    85.13055 (95103024)   124.20398 (95081924)   123.69263 (95081924)   116.76074m(95011024)   146.04309m(95011024)
 40000.0 |    96.95752 (95103024)   142.45410 (95081924)   129.51270 (95081924)   147.43738m(95011024)   155.31982m(95011024)
 35000.0 |   109.92285 (95103024)   163.22559 (95081924)   138.89905 (95081924)   178.60889m(95011024)   143.95459m(95011024)
 30000.0 |   126.32202 (95103024)   185.05164 (95081924)   168.89929m(95011024)   195.95654m(95011024)   200.49426 (95070724)
 25000.0 |   150.49512 (95103024)   209.42993 (95081924)   227.05444m(95011024)   191.06946 (95070724)   254.83203 (95070724)
 20000.0 |   185.08362 (95103024)   238.50317 (95081924)   269.44312m(95011024)   299.12769 (95070724)   249.79004 (95102924)
 15000.0 |   241.69043 (95103024)   310.30786m(95011024)   342.47266 (95070724)   314.37817 (95102924)   325.65234m(95043024)
 10000.0 |   348.87524 (95103024)   458.60986m(95011024)   434.98535 (95102924)   345.44922m(95043024)   204.51257 (95101824)
  5000.0 |   623.94678 (95103024)   746.37891 (95102924)   344.35669 (95101824)   244.93896m(95041324)   185.93750 (95121024)
     0.0 |     0.00000 (00000000)   741.30908 (95121024)   413.57764 (95121024)   291.51367 (95121024)   226.19922 (95121024)
 -5000.0 |   780.66895m(95042924)   491.59375 (95050624)   242.47241 (95081724)   300.34790 (95081724)   145.48840m(95013024)
-10000.0 |   502.94678m(95042924)   586.95703 (95061424)   305.91431 (95050624)   159.40515 (95060424)   113.65173 (95060424)
-15000.0 |   331.57129m(95042924)   292.92554 (95120824)   377.97437 (95061424)   231.14551 (95050624)   170.84216 (95123124)
-20000.0 |   264.15161m(95042924)   259.75903 (95050524)   339.30493 (95061424)   192.80603 (95061424)   192.97070 (95050624)
-25000.0 |   221.58325m(95042924)   235.45801 (95081824)   167.95764 (95120824)   308.89722 (95061424)   106.82507 (95082024)
-30000.0 |   192.11682m(95042924)   213.96948 (95081824)   171.28381 (95050524)   208.04395 (95061424)   214.40259 (95061424)
-35000.0 |   169.72351m(95042924)   185.10876 (95081824)   163.23132 (95050524)   139.58142 (95061424)   248.10474 (95061424)
-40000.0 |   152.37744m(95042924)   161.83936 (95081824)   148.16248 (95050524)   118.70764 (95050524)   194.52002 (95061424)
-45000.0 |   138.69019m(95042924)   138.90808 (95081824)   146.27014 (95081824)   122.95129 (95050524)   122.90759 (95061424)
-50000.0 |   128.02075m(95042924)   123.53076 (95070624)   147.32214 (95081824)   119.43213 (95050524)    88.18164 (95120824)
```

```
                    *** THE   1ST HIGHEST 24-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL ***
                                            INCLUDING SOURCE(S):       STACK1   ,
                                       *** NETWORK ID: CG1       ;  NETWORK TYPE: GRIDCART ***
                                            ** CONC OF SO2 IN MICROGRAMS/M**3 **

 Y COORD  |                                                    X-COORD (METERS)
 (METERS) |         25000.00              30000.00              35000.00              40000.00              45000.00
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  50000.0 |   129.06995m(95011024)   98.13007 (95070724)  144.56482 (95070724)  155.28625 (95070724)  129.95032 (95070724)
  45000.0 |   123.48389m(95011024)  144.04895 (95070724)  168.91699 (95070724)  145.58777 (95070724)  133.64307 (95102924)
  40000.0 |   137.39075 (95070724)  182.20984 (95070724)  165.35803 (95070724)  148.26563 (95102924)  143.90771m(95043024)
  35000.0 |   194.97229 (95070724)  188.49304 (95070724)  167.78748 (95102924)  167.29834m(95043024)  179.10901m(95043024)
  30000.0 |   218.16187 (95070724)  187.84583 (95102924)  198.03369m(95043024)  190.37903m(95043024)  129.82227m(95043024)
  25000.0 |   211.81348 (95102924)  235.20923m(95043024)  195.90552m(95043024)  116.91455m(95043024)  110.62585 (95101824)
  20000.0 |   280.15649m(95043024)  188.98645m(95043024)  130.37817 (95101824)  120.59827 (95101824)   96.28772m(95041324)
  15000.0 |   163.62000m(95043024)  149.74792 (95101824)  123.89429m(95041324)  123.80042m(95041324)  110.14075m(95041324)
  10000.0 |   168.01782m(95041324)  148.30115m(95041324)  116.26001m(95041324)  101.50098 (95121024)   91.54010 (95121024)
   5000.0 |   157.08728 (95090924)  147.81458 (95090924)  133.94617 (95090924)  119.69434 (95090924)  107.66284 (95090924)
      0.0 |   185.71765 (95121024)  158.29297 (95121024)  137.72839 (95121024)  122.08398 (95121024)  110.00964 (95121024)
  -5000.0 |   140.84912m(95013024)  117.64954m(95013024)   94.13159m(95013024)   80.53595 (95100324)   76.81342 (95100324)
 -10000.0 |   200.65735 (95081724)  185.75452 (95081724)  133.04700 (95081724)   84.11615m(95013024)   87.07672m(95013024)
 -15000.0 |   104.11072 (95060424)   80.57281 (95060424)  128.80859 (95081724)  155.61096 (95081724)  139.23669 (95081724)
 -20000.0 |   160.71875 (95123124)   91.93842 (95060424)   79.08881 (95060424)   63.11279 (95060424)   86.13751 (95081724)
 -25000.0 |   163.19641 (95050624)  136.92981 (95123124)   89.50604 (95123124)   71.98712 (95060424)   63.74689 (95060424)
 -30000.0 |    80.60529 (95082024)  141.98230 (95050624)  116.82178 (95123124)   99.29034 (95123124)   63.10364 (95060424)
 -35000.0 |   143.72546 (95061424)   76.05249 (95050624)  128.87402 (95050624)   93.47168 (95123124)   97.56622 (95123124)
 -40000.0 |   203.49646 (95061424)   91.09204 (95061424)   79.15283 (95050624)  117.89343 (95050624)   82.40039 (95123124)
 -45000.0 |   205.98169 (95061424)  150.97913 (95061424)   73.34344 (95082024)   77.12817 (95050624)  107.09399 (95050624)
 -50000.0 |   161.44104 (95061424)  184.33838 (95061424)  108.42798 (95061424)   60.01508 (95082024)   75.79639 (95050624)
```

```
                    *** THE   1ST HIGHEST 24-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL  ***
                                            INCLUDING SOURCE(S):   STACK1    ,
                                      *** NETWORK ID: CG1 ;  NETWORK TYPE: GRIDCART ***
                                           ** CONC OF SO2 IN MICROGRAMS/M**3  **

 Y COORD  |                                       X-COORD (METERS)
 (METERS) |       50000.00
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  50000.0 |   120.74292 (95102924)
  45000.0 |   123.26550m(95043024)
  40000.0 |   165.43372m(95043024)
  35000.0 |   137.98730m(95043024)
  30000.0 |    89.91064 (95101824)
  25000.0 |   101.97614 (95101824)
  20000.0 |   101.97717m(95041324)
  15000.0 |    92.46057m(95041324)
  10000.0 |    87.09723 (95090924)
   5000.0 |    96.77863 (95090924)
      0.0 |   100.10297 (95121024)
  -5000.0 |    73.83466 (95121024)
 -10000.0 |    83.84436m(95013024)
 -15000.0 |   112.78076 (95081724)
 -20000.0 |   119.57654 (95081724)
 -25000.0 |    51.00018 (95060424)
 -30000.0 |    60.86395 (95060424)
 -35000.0 |    56.25964 (95060424)
 -40000.0 |    95.97198 (95123124)
 -45000.0 |    72.41675 (95081724)
 -50000.0 |    99.49805 (95050624)
```

Annual Average Concentration Values of SO$_2$ for the Year 1995

```
                                   *** AERMOD - VERSION 99351 ***
                            *** MODELING OPTIONS USED:  CONC  ELEV  DFAULT
          *** THE PERIOD (8760 HRS) AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP: ALL ***
                                 INCLUDING SOURCE(S):        STACK1   ,
                          *** NETWORK ID: CG1       NETWORK TYPE: GRIDCART ***
                                  ** CONC OF SO2 IN MICROGRAMS/M**3 **

 Y COORD  |                                           X COORD  (METERS)
 (METERS) |   -50000.00   -45000.00   -40000.00   -35000.00   -30000.00   -25000.00   -20000.00   -15000.00   -10000.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 50000.00 |    45.12792    47.15191    49.95341    54.76144    57.70130    57.23923    60.91344    60.71569    57.81684
 45000.00 |    47.89684    49.47809    51.92350    56.56661    62.47505    63.81617    65.41388    68.38557    64.54062
 40000.00 |    53.31001    53.85639    56.50929    59.67120    65.30811    71.57571    71.84876    76.50395    73.52071
 35000.00 |    59.23924    60.68187    62.46180    64.60056    68.87627    77.11064    72.06732    74.80705    75.60175
 30000.00 |    62.89670    67.26202    71.16849    72.55738    75.26750    80.56846    73.01653    76.01847    71.06775
 25000.00 |    62.05075    69.94174    78.36403    79.64257    76.36994    70.13772    70.33576    63.83300    69.06913
 20000.00 |    57.10790    65.99619    77.05255    79.18588    79.33556    76.47668    72.64595    30.23439    43.44797
 15000.00 |    57.12338    63.32512    71.28693    73.90363    73.07330    23.34437    38.50095    50.34601    61.62074
 10000.00 |    62.00176    68.03318    75.01473    75.17023    77.64315    18.24545    52.92404    74.25809    72.73085
  5000.00 |    52.95993    60.25415    68.44437    80.29718    76.02088    17.25028    46.60655    73.78673    78.80518
     0.00 |    40.42075    45.09927    50.37045    57.84251    67.82447    71.82774    72.86441    38.89732    59.85721
 -5000.00 |    35.08266    38.80783    42.28630    47.96119    55.39879    67.23706    81.14172    58.82689    72.03387
-10000.00 |    34.21916    37.84647    41.93837    46.96885    53.59411    65.38397    90.65437    33.69188    64.04018
-15000.00 |    32.85141    35.61816    39.62873    46.72217    60.08935    79.87811    74.02626    71.16832    17.49834
-20000.00 |    31.44316    36.39905    44.64261    56.12891    70.29078    74.02657    74.46931    72.78489    11.06684
-25000.00 |    35.38332    42.71987    51.74224    61.70401    70.02074    68.07069    64.71356    77.78093    58.34330
-30000.00 |    40.63170    47.57861    54.64503    59.58032    56.64474    53.43996    60.63898    74.45787    70.81824
-35000.00 |    43.81429    48.71942    51.55669    48.43764    45.34657    49.82001    58.07550    74.11448    78.77422
-40000.00 |    40.81956    45.45808    42.30762    39.57183    42.07979    48.36021    56.01003    73.36726    77.13660
-45000.00 |    40.44157    37.37260    34.37698    36.15835    41.02396    46.21393    56.71255    69.81345    67.26668
-50000.00 |    33.55852    31.37913    32.05841    34.98003    39.64577    44.94399    57.20294    63.83154    59.37615
```

```
              *** THE PERIOD (8760 HRS) AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP: ALL ***
                                  INCLUDING SOURCE(S): STACK1   ,
                             *** NETWORK ID: CG1 ;  NETWORK TYPE: GRIDCART ***
                                 ** CONC OF SO2 IN MICROGRAMS/M^3  **

 Y COORD  |                                          X-COORD (METERS)
  (METERS) |   -5000.00     0.00      5000.00    10000.00    15000.00    20000.00    25000.00    30000.00    35000.00
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

   50000.00 |   62.05075   67.50315   64.75513   61.78976   66.12984   72.98638   76.79931   74.86773   67.70510
   45000.00 |   67.97551   74.58832   71.31062   69.17136   75.83963   73.53037   74.70248   77.78226   70.01768
   40000.00 |   75.36505   78.39425   79.48978   79.05751   78.65103   75.33951   80.95087   80.50912   74.03449
   35000.00 |   74.92683   77.64564   80.06382   78.82421   78.39412   79.09762   74.83754   75.24290   77.65056
   30000.00 |   77.93397   79.52672   74.39414   72.84695   75.42446   75.31070   70.45089   70.22105   71.10968
   25000.00 |   76.84972   73.11067   75.23524   63.02614   65.37334   62.84192   67.59159   75.47674   75.88026
   20000.00 |   46.58591   60.42636   59.12814   74.75964   58.93033   33.69749   35.94854   22.47768   34.03328
   15000.00 |   75.73624   59.67238   23.73764   25.07990   76.80737   47.22791   28.76089   19.10631   12.47711
   10000.00 |   81.97833   54.99405   51.11365   61.16360   33.93851   77.94328   61.07155   44.32396   28.52335
    5000.00 |   46.52408   76.33936   98.64301   46.52563   76.01660   21.44727   81.65332   52.81534   31.52013
       0.00 |   20.82733    0.00000   12.56049   69.27100   55.58826   66.73045   59.93254   34.66237   16.31267
   -5000.00 |   29.70151   74.20886   78.21286   13.81929   46.07368   17.99580   22.18903   40.95721   82.17657
  -10000.00 |   16.78706   63.83240   52.05563   37.88004   44.78278   42.34315   82.61369   70.98296   63.37997
  -15000.00 |   59.99525   35.14226   66.92328   11.82036   51.86864   48.62583   83.40723   67.29540   57.88743
  -20000.00 |   49.01016   60.06120   68.77583   76.10019   59.53354   55.72688   78.29303   70.08114   59.03516
  -25000.00 |   18.11235   27.18401   73.55753   63.11243   35.19829   44.52679   12.53607   74.36787   62.44936
  -30000.00 |   67.28884   65.11153   58.37050   48.77335   10.60876   33.50574   25.48225   76.32833   65.09727
  -35000.00 |   72.63406   79.59291   31.35492   37.46312   11.85414   79.30131   73.91484   71.13159   66.51672
  -40000.00 |   72.07493   77.95191   50.62781   66.05465   34.82043   71.00655   72.74236   68.68639   62.32856
  -45000.00 |   64.14777   69.24140   74.85531   74.48383   76.00889   74.77551   78.17570   69.51360   59.54048
  -50000.00 |   57.65431   62.08446   72.57088   63.42431   75.79710   80.47784   72.43270   68.50096   59.75109
```

```
*** THE PERIOD (8760 HRS) AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP: ALL***
                      INCLUDING SOURCE(S):  STACK1   ,
                *** NETWORK ID: CG1; NETWORK TYPE: GRIDCART ***
                      ** CONC OF SO2 IN MICROGRAMS/M³ **

 Y COORD  |                                        X-COORD (METERS)
 (METERS) |    40000.00     45000.00     50000.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 50000.00 |    62.03587     58.56940     54.43989
 45000.00 |    65.40485     60.49204     55.63824
 40000.00 |    68.03739     62.18462     58.08739
 35000.00 |    70.43061     65.16817     60.37124
 30000.00 |    74.11207     68.06602     63.80822
 25000.00 |    78.54660     74.05426     71.38285
 20000.00 |    79.28954     76.14613     72.88829
 15000.00 |    75.56063     78.06093     70.67078
 10000.00 |    74.57037     79.67061     72.72487
  5000.00 |    75.32146     79.63680     72.45000
     0.00 |    72.41019     71.51459     72.74921
 -5000.00 |    75.04956     69.11713     64.08850
-10000.00 |    57.90261     53.53999     50.06414
-15000.00 |    51.72979     46.93089     43.33445
-20000.00 |    50.13962     44.51919     40.80312
-25000.00 |    53.11521     45.61050     39.86174
-30000.00 |    55.42752     48.10581     42.24741
-35000.00 |    56.66788     48.90330     43.85947
-40000.00 |    58.43346     52.05066     43.92408
-45000.00 |    55.03852     52.14072     44.87943
-50000.00 |    51.63321     49.31878     47.08415

     GROUP ID                   AVERAGE CONC         RECEPTOR      (XR, YR, ZELEV, ZFLAG)        OF TYPE  GRID-ID
--------------------------------------------------------------------------------------------------------------------

1ST HIGHEST VALUE IS      98.64301 AT (  5000.00,    5000.00,      0.00,    0.00)  GC    CG1
2ND HIGHEST VALUE IS      90.65437 AT (-20000.00,  -10000.00,     23.16,    0.00)  GC    CG1
3RD HIGHEST VALUE IS      83.40723 AT ( 25000.00,  -15000.00,     23.16,    0.00)  GC    CG1
4TH HIGHEST VALUE IS      82.61369 AT ( 25000.00,  -10000.00,     23.16,    0.00)  GC    CG1
5TH HIGHEST VALUE IS      82.17657 AT ( 35000.00,   -5000.00,      0.00,    0.00)  GC    CG1
6TH HIGHEST VALUE IS      81.97833 AT ( -5000.00,   10000.00,     23.16,    0.00)  GC    CG1
```

APPENDIX – D

Hourly Average Concentration Values of NO$_x$ for the Year 1995

```
                                   MODELING OPTIONS USED:  CONC    ELEV     DFAULT
               *** THE   1ST HIGHEST  1-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL ***
                                           INCLUDING SOURCE(S): STACK1   ,
                                   *** NETWORK ID: CG1 ;  NETWORK TYPE: GRIDCART ***
                                           CONC OF NO2 IN MICROGRAMS/M**3

 Y-COORD  |                                              X-COORD (METERS)
 (METERS) |      50000.00               -45000.00               -40000.00               -35000.00               -30000.00
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  50000.0 |    540.91113 (95060301)    509.82813 (95060301)    443.93359 (95102823)    557.15625 (95081522)    499.62500 (95080322)
  45000.0 |    419.77246 (95032115)    575.56738 (95060301)    516.34082 (95060301)    484.70020 (95102823)    489.32422 (95030903)
  40000.0 |    649.83643 (95011705)    453.73438 (95032115)    634.20410 (95060301)    544.34717 (95060301)    429.29004 (95081522)
  35000.0 |    671.02832 (95011705)    617.18164 (95011705)    493.50879 (95032115)    498.78418 (95060301)    476.49707 (95060301)
  30000.0 |    606.37695 (95072723)    600.16500 (95011705)    485.10640 (95011705)    623.96484 (95011705)    493.73242 (95060301)
  25000.0 |    686.10254 (95072723)    642.49609 (95072723)    681.33789 (95011705)    358.96680 (95011705)    371.27539 (95011705)
  20000.0 |    622.26953 (95072924)    566.05371 (95070421)    429.51758 (95072723)    597.70313 (95072723)    447.11720 (95011705)
  15000.0 |    622.08789 (95072521)    588.89453 (95013023)    205.50195 (95013023)    299.53320 (95072924)    272.37700 (95072723)
  10000.0 |    514.62990 (95072521)    578.21880 (95072521)    226.97070 (95072521)    430.58110 (95072521)    376.86230 (95013023)
   5000.0 |    331.11330 (95072521)    588.07230 (95072521)    446.79690 (95072521)    535.73440 (95072521)    532.05080 (95072521)
      0.0 |    561.08496 (95081706)    615.50244 (95081706)    462.29443 (95072521)    597.16016 (95072521)    593.17383 (95072521)
  -5000.0 |    640.51514 (95111922)    655.71826 (95111922)    545.81396 (95111922)    360.76172 (95111922)    255.63090 (95032524)
 -10000.0 |    584.27539 (95032524)    613.52832 (95032524)    518.18260 (95032524)    454.64750 (95032524)    376.74220 (95032524)
 -15000.0 |    590.50488 (95032524)    673.37109 (95032524)    521.86914 (95112219)    482.32230 (95112219)    425.15674 (95041418)
 -20000.0 |    651.09766 (95112219)    628.65918 (95112219)    627.44824 (95041418)    313.76758 (95090520)    328.61130 (95090520)
 -25000.0 |    650.29492 (95041418)    619.22510 (95090520)    579.04492 (95090520)    597.19730 (95092520)    547.20120 (95072519)
 -30000.0 |    546.81836 (95090520)    601.00195 (95090520)    404.63180 (95092520)    457.21290 (95072519)    404.46338 (95072519)
 -35000.0 |    642.11328 (95092520)    644.90527 (95092520)    551.26760 (95072519)    536.53906 (95032422)    497.80859 (95073020)
 -40000.0 |    570.53564 (95090520)    646.29199 (95072519)    581.96777 (95032422)    593.28711 (95073020)    591.13086 (95120223)
 -45000.0 |    649.45996 (95072519)    420.28857 (95032422)    574.22266 (95073020)    560.87598 (95073020)    422.36133 (95051719)
 -50000.0 |    650.97510 (95032422)    422.46387 (95073020)    445.58691 (95073020)    444.40918 (95051719)    413.23975 (95080319)
```

```
              *** THE   1ST HIGHEST  1-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL  ***
                                             INCLUDING SOURCE(S): STACK1   ,
                                   *** NETWORK ID: CG1 ;  NETWORK TYPE: GRIDCART ***
                                            CONC OF NO2 IN MICROGRAMS/M**3

 Y-COORD  |                                               X-COORD (METERS)
 (METERS) |      -25000.00               -20000.00                -15000.00               -10000.00                -5000.00
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  50000.0 |  109.65430 (95080322)   240.11820 (95080322)   129.99219 (95060624)   117.74414 (95052324)    86.71680 (95062623)
  45000.0 |  319.92480 (95080322)   292.73830 (95080322)   641.20605 (95101919)   123.51370 (95052324)    98.17773 (95062623)
  40000.0 |  292.02730 (95080322)   268.83400 (95080322)   168.26950 (95080322)   137.62990 (95052324)    70.39258 (95062623)
  35000.0 |  214.22461 (95081522)   219.32810 (95080322)   288.94730 (95080322)   281.77150 (95060624)    39.96582 (95062623)
  30000.0 |  290.24121 (95102823)   417.33980 (95080322)   280.35550 (95080322)   167.45310 (95080322)   148.46880 (95052324)
  25000.0 |  275.76367 (95060301)   211.71777 (95102823)   255.93360 (95080322)   127.44920 (95080322)   148.70210 (95052324)
  20000.0 |  252.44530 (95011705)   202.59180 (95060301)   292.18164 (95081522)   222.14840 (95080322)   136.12500 (95052324)
  15000.0 |  452.21680 (95011705)   246.73440 (95011705)   257.74710 (95060301)   363.15230 (95080322)   279.32810 (95080322)
  10000.0 |  532.11130 (95013023)   532.18160 (95072723)   277.45700 (95011705)   256.19920 (95060301)   425.34380 (95080322)
   5000.0 |  470.41410 (95072521)   433.77730 (95072521)   288.08200 (95072521)   138.53520 (95072723)   281.45310 (95060301)
      0.0 |  150.62700 (95072521)   150.26070 (95072521)   104.39060 (95072521)   151.19340 (95072521)   477.41410 (95072521)
  -5000.0 |  203.43750 (95032524)   606.88670 (95032524)   293.93550 (95032524)   260.95700 (95112219)   231.64840 (95092520)
 -10000.0 |  672.49020 (95112219)   645.71480 (95112219)   574.15430 (95092520)   698.13670 (95072519)   113.74220 (95080319)
 -15000.0 |  178.93460 (95090520)   269.00590 (95092520)   132.67680 (95072519)   130.91500 (95120223)   200.89840 (95032301)
 -20000.0 |  639.98050 (95092520)   408.81250 (95072519)   206.63379 (95120223)   107.81540 (95080319)   152.61330 (95032301)
 -25000.0 |  298.67969 (95072519)   258.11621 (95120223)   187.51465 (95051719)   191.55470 (95032301)   150.39750 (95091219)
 -30000.0 |  505.59863 (95120223)   501.33691 (95051719)   414.30859 (95080319)   312.43160 (95032301)   154.69730 (95091219)
 -35000.0 |  568.72803 (95120223)   569.31836 (95080319)   460.63379 (95032302)   339.18360 (95032301)    90.26367 (95091219)
 -40000.0 |  563.74756 (95051719)   541.60938 (95080319)   486.48440 (95032301)   284.29785 (95032301)    54.39307 (95091219)
 -45000.0 |  310.29395 (95080319)   338.50488 (95080319)   394.66210 (95032301)   230.95996 (95091219)    10.27637 (95042903)
 -50000.0 |  542.15820 (95080319)   486.38232 (95032302)   462.85450 (95032301)   434.60449 (95091219)    93.37500 (95042903)
```

```
                  ** THE   1ST HIGHEST  1-HR AVERAGE CONCENTRATION    VALUES FOR SOURCE GROUP:  ALL  ***
                                             INCLUDING SOURCE(S): STACK1   ,
                                       *** NETWORK ID: CG1 ;  NETWORK TYPE: GRIDCART ***
                                             CONC OF NO2 IN MICROGRAMS/M**3

 Y COORD  |                                          X-COORD (METERS)
 (METERS) |        0.00                 5000.00              10000.00              15000.00              20000.00
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  50000.0 |   529.20020 (95062623)   607.48438 (95040402)   629.01074 (95081921)   640.42725 (95052901)   601.13135 (95020205)
  45000.0 |   200.22461 (95062623)   266.63477 (95040402)   584.24121 (95081921)   581.96240 (95020205)   571.73584 (95082823)
  40000.0 |   213.31934 (95062623)   226.54199 (95040402)   320.70117 (95081921)   275.48242 (95020205)   227.79883 (95040421)
  35000.0 |   222.32810 (95062623)   240.49805 (95081921)   218.46680 (95081921)   299.17969 (95082823)   184.35160 (95070722)
  30000.0 |   313.54100 (95062623)   333.89060 (95081921)   247.04000 (95020205)   241.43460 (95040421)   230.35160 (95070722)
  25000.0 |   235.32130 (95062623)   186.82320 (95081921)   164.22660 (95020205)   157.10160 (95070722)   103.10940 (95070722)
  20000.0 |   468.56450 (95062623)   348.09570 (95081921)   526.67380 (95040421)   442.89840 (95070722)   414.54300 (95070722)
  15000.0 |   225.11330 (95062623)   320.91020 (95020205)   284.93750 (95070722)   262.48830 (95070722)   236.29880 (95043005)
  10000.0 |   277.11720 (95062623)   104.18950 (95070722)   164.40630 (95070722)   180.75590 (95043005)   272.79490 (95041303)
   5000.0 |   208.99610 (95062623)   235.45310 (95070722)   289.04100 (95041303)   172.32420 (95041303)   238.25200 (95041303)
      0.0 |     0.00000 (00000000)   344.25980 (95121006)   427.31250 (95121006)   364.36820 (95121006)   362.40430 (95121006)
  -5000.0 |   264.17190 (95070621)   411.87500 (95050601)   215.89450 (95081722)   206.00590 (95081722)   305.40230 (95081722)
 -10000.0 |   413.87890 (95042903)   343.80860 (95061422)   368.76170 (95050601)   360.18360 (95060422)   331.91800 (95081722)
 -15000.0 |   595.75780 (95042903)   664.24020 (95081822)   643.94140 (95090720)   459.01170 (95050601)   426.63379 (95020206)
 -20000.0 |   392.78520 (95042903)   239.82420 (95081822)   311.88090 (95101721)   188.43160 (95082020)   122.43360 (95050601)
 -25000.0 |   348.01560 (95042903)   222.22660 (95081822)   372.39941 (95051323)   295.02930 (95061422)   270.71875 (95082020)
 -30000.0 |   382.83590 (95042903)   499.75390 (95081822)   556.75391 (95050524)   408.83400 (95081104)   307.61720 (95090720)
 -35000.0 |   127.97660 (95042903)   122.99220 (95081822)   106.54300 (95081822)   169.58398 (95101721)   153.38870 (95061422)
 -40000.0 |   143.69430 (95042903)   539.09380 (95070621)   290.62890 (95081822)   203.62012 (95050524)   192.75000 (95101721)
 -45000.0 |   346.42773 (95042903)   336.79490 (95070621)   369.43160 (95081822)   342.03809 (95050524)   278.68652 (95101721)
 -50000.0 |   487.11328 (95042903)   187.58200 (95070621)   368.66800 (95081822)   387.58984 (95013112)   383.40967 (95050524)
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```
                   *** THE   1ST HIGHEST  1-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL ***
                                              INCLUDING SOURCE(S): STACK1   ,
                                      *** NETWORK ID: CG1 ;  NETWORK TYPE: GRIDCART ***
                                              CONC OF NO2 IN MICROGRAMS/M**3

 Y-COORD  |                                           X-COORD (METERS)
 (METERS) |     25000.00                 30000.00                 35000.00                 40000.00                 45000.00
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  50000.0 |   590.20020 (95040421)    580.47461 (95070722)    528.09180 (95070722)    471.46090 (95070722)    197.91800 (95070722)
  45000.0 |   563.36719 (95040421)    544.72560 (95070722)    555.62300 (95070722)    348.74320 (95070722)    280.13867 (95070722)
  40000.0 |   363.31250 (95070722)    423.08010 (95070722)    327.05470 (95070722)    293.14355 (95070722)    155.70605 (95040904)
  35000.0 |   639.85550 (95070722)    603.44920 (95070722)    347.38570 (95070722)    311.06250 (95040904)    234.65723 (95043005)
  30000.0 |   452.98830 (95070722)    176.77340 (95070722)    242.19141 (95043005)    233.71338 (95043005)    218.59033 (95043006)
  25000.0 |   636.89840 (95070722)    561.98242 (95043005)    451.43359 (95043005)    399.63940 (95040822)    548.18896 (95040205)
  20000.0 |   348.53710 (95043005)    475.65186 (95043006)    482.66016 (95040205)    356.16895 (95040205)    333.52246 (95041303)
  15000.0 |   679.01563 (95040205)    469.46289 (95040205)    507.90230 (95041303)    399.78710 (95041303)    297.58398 (95041303)
  10000.0 |   528.15040 (95041303)    315.59960 (95041303)    535.69040 (95041303)    482.11523 (95041303)    562.88867 (95041303)
   5000.0 |   685.32813 (95041303)    539.98535 (95090903)    447.73926 (95090903)    417.38623 (95100905)    388.21484 (95100905)
      0.0 |   319.06738 (95121006)    395.03223 (95121006)    301.50781 (95121006)    515.99512 (95121006)    472.29883 (95121006)
  -5000.0 |   587.01070 (95051121)    592.90039 (95051121)    535.57715 (95051121)    596.99609 (95101723)    523.76563 (95101723)
 -10000.0 |   481.20310 (95081722)    538.81450 (95081722)    586.58200 (95081722)    421.59082 (95051121)    400.83984 (95051121)
 -15000.0 |   139.27051 (95060422)    190.48438 (95081722)    330.12990 (95081722)    205.80180 (95081722)    311.53910 (95081722)
 -20000.0 |   572.22852 (95123120)    613.02637 (95060422)    434.06494 (95060422)    430.56201 (95060422)    345.26367 (95081722)
 -25000.0 |   570.55570 (95050601)    586.35596 (95081721)    478.27637 (95020206)    596.73438 (95060422)    486.89648 (95060422)
 -30000.0 |   329.61865 (95082020)    586.90040 (95050601)    495.15430 (95081721)    572.92383 (95020206)    545.18164 (95060422)
 -35000.0 |   174.04688 (95090720)    234.12207 (95050601)    205.02930 (95050601)    166.44336 (95081721)    138.32910 (95123120)
 -40000.0 |   470.75391 (95112122)    495.20703 (95082020)    355.21191 (95050601)    267.84280 (95050601)    250.49414 (95081721)
 -45000.0 |   476.26172 (95061422)    549.15869 (95090720)    579.35938 (95082020)    496.37012 (95050601)    383.01953 (95050601)
 -50000.0 |   592.58789 (95101721)    517.15332 (95112122)    571.51758 (95090720)    561.94629 (95082020)    481.84668 (95050601)
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          *** THE   1ST HIGHEST  1-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL ***
                                    INCLUDING SOURCE(S):STACK1
                         *** NETWORK ID: CG1       ;  NETWORK TYPE: GRIDCART ***
                                   CONC OF NO2      IN MICROGRAMS/M**

 Y-COORD   |                                        X-COORD (METERS)
 (METERS)  |       50000.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  50000.0  |    278.42480 (95070722)
  45000.0  |    260.62061 (95040904)
  40000.0  |    170.30859 (95043005)
  35000.0  |    243.14844 (95043006)
  30000.0  |    335.45239 (95040822)
  25000.0  |    364.99512 (95040205)
  20000.0  |    290.21094 (95041303)
  15000.0  |    284.03613 (95041303)
  10000.0  |    349.98633 (95090903)
   5000.0  |    136.33545 (95100905)
      0.0  |    243.61230 (95121006)
  -5000.0  |    345.21533 (95101723)
 -10000.0  |    265.41211 (95051121)
 -15000.0  |    193.21680 (95081722)
 -20000.0  |    116.93850 (95081722)
 -25000.0  |    234.55322 (95060422)
 -30000.0  |    149.15479 (95060422)
 -35000.0  |    248.17676 (95060422)
 -40000.0  |    354.48438 (95123120)
 -45000.0  |    470.77734 (95081721)
 -50000.0  |    591.73828 (95050601)
```

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                                 *** AERMOD - VERSION 99351 ***
                             MODELING OPTIONS USED:  CONC  ELEV  DFAULT
  *** THE MAXIMUM   20   1-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL ***
                                   INCLUDING SOURCE(S):STACK1
                                 CONC OF NO2 IN MICROGRAMS/M**3

RANK        CONC     (YYMMDDHH) AT        RECEPTOR (XR,YR) OF TYPE    RANK        CONC     (YYMMDDHH) AT        RECEPTOR (XR,YR) OF TYPE
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   1.    698.13670 (95072519) AT (  -10000.00,   -10000.00)  GC       11.    651.09766 (95112219) AT (  -50000.00,   -20000.00)  GC
   2.    686.10254 (95072723) AT (  -50000.00,    25000.00)  GC       12.    650.97510 (95032422) AT (  -50000.00,   -50000.00)  GC
   3.    685.32813 (95041303) AT (   25000.00,     5000.00)  GC       13.    650.29492 (95041418) AT (  -50000.00,   -25000.00)  GC
   4.    681.33789 (95011705) AT (  -40000.00,    25000.00)  GC       14.    649.83643 (95011705) AT (  -50000.00,    40000.00)  GC
   5.    679.01563 (95040205) AT (   25000.00,    15000.00)  GC       15.    649.45996 (95072519) AT (  -50000.00,   -45000.00)  GC
   6.    673.37109 (95032524) AT (  -15000.00,   -45000.00)  GC       16.    646.29199 (95072519) AT (  -45000.00,   -40000.00)  GC
   7.    672.49020 (95112219) AT (  -25000.00,   -10000.00)  GC       17.    645.71480 (95112219) AT (  -20000.00,   -10000.00)  GC
   8.    671.02832 (95011705) AT (   35000.00,   -50000.00)  GC       18.    644.90527 (95092520) AT (  -45000.00,   -35000.00)  GC
   9.    664.24020 (95081822) AT (    5000.00,   -15000.00)  GC       19.    643.94140 (95090720) AT (   10000.00,   -15000.00)  GC
  10.    655.71826 (95111922) AT (  -45000.00,    -5000.00)  GC       20.    642.49609 (95072723) AT (  -45000.00,    25000.00)  GC
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Annual Average Concentration Values of NO$_x$ for the Year 1995

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                              MODELING OPTIONS USED:   CONC  ELEV  DFAULT
      *** THE PERIOD (8760 HRS) AVERAGE CONCENTRATION    VALUES FOR SOURCE GROUP: ALL ***
                              INCLUDING SOURCE(S):  STACK1    ,
                        *** NETWORK ID: CG1;  NETWORK TYPE: GRIDCART ***
                              CONC OF NO2  IN MICROGRAMS/M**3

 Y-COORD  |                                            X-COORD  (METERS)
 (METERS) |   -50000.00    -45000.00    -40000.00    -35000.00    -30000.00    -25000.00    -20000.00    -15000.00    -10000.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 50000.00 |    18.29823     19.11889     20.25482     22.20436     23.39641     23.20906     24.69886     24.61869     23.44326
 45000.00 |    19.42096     20.06210     21.05367     22.93631     25.33205     25.87583     26.52366     27.72863     26.16958
 40000.00 |    21.61587     21.83740     22.91310     24.19514     26.48077     29.02216     29.13287     31.02041     29.81082
 35000.00 |    24.02003     24.60495     25.32665     26.19390     27.92756     31.26640     33.27620     34.38709     34.70935
 30000.00 |    25.50301     27.27305     28.85701     29.42018     30.51910     33.07393     37.71584     38.93303     40.98042
 25000.00 |    25.16000     28.35961     31.77464     33.91489     35.02082     36.54856     40.68359     46.15640     48.27954
 20000.00 |    23.15582     26.75980     31.24287     36.16261     40.27807     43.17361     45.67511     52.80677     58.16451
 15000.00 |    23.16210     25.67671     28.90504     34.02079     41.79360     50.01303     56.15866     60.96148     73.64257
 10000.00 |    25.14016     27.58570     30.41657     34.53439     39.59181     47.94554     62.00674     78.76676     90.31169
  5000.00 |    21.47392     24.43153     27.75244     32.55847     38.93407     47.54200     59.44522     78.57554     91.15800
     0.00 |    16.38958     18.28662     20.42393     23.45367     27.50109     33.17907     41.70892     56.31940     85.09176
 -5000.00 |    14.22513     15.73560     17.14602     19.44704     22.46280     27.26292     32.90093     44.12659     73.81017
-10000.00 |    13.87499     15.34579     17.00496     19.04467     21.73105     26.51154     36.75802     54.20868     66.51411
-15000.00 |    13.32041     14.44226     16.06844     18.94464     24.36469     32.38854     42.18002     45.07593     47.64260
-20000.00 |    12.74940     14.75889     18.10145     22.75884     28.50111     34.07066     34.25017     33.56715     45.03473
-25000.00 |    14.34704     17.32185     20.98018     25.01940     28.39166     27.60093     26.23973     31.53818     43.93044
-30000.00 |    16.47513     19.29192     22.15718     24.15830     22.96800     21.66855     24.58757     30.19075     40.87926
-35000.00 |    17.76558     19.75448     20.90494     19.64025     18.38688     20.20075     23.54815     30.05152     35.99567
-40000.00 |    16.55130     18.43210     17.15467     16.04539     17.06228     19.60884     22.71064     29.74857     31.27692
-45000.00 |    16.39802     15.15366     13.93900     14.66131     16.63418     18.73857     22.99551     28.30757     27.27493
-50000.00 |    13.60713     12.72343     12.99888     14.18351     16.07536     18.22364     23.19433     25.88207     24.07553
```

```
                              MODELING OPTIONS USED:  CONC ELEV  DFAULT
          *** THE PERIOD (8760 HRS) AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP: ALL ***
                                   INCLUDING SOURCE(S):  STACK1   ,
                               *** NETWORK ID: CG1;  NETWORK TYPE: GRIDCART ***
                                  CONC OF NO2 IN MICROGRAMS/M**3

 Y COORD  |                                    X-COORD  (METERS)
 (METERS) |   -5000.00       0.00     5000.00    10000.00    15000.00    20000.00    25000.00    30000.00    35000.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 50000.00 |   25.15999    27.37085    26.25657    25.05420    26.81401    29.59415    31.14017    30.35696    27.45271
 45000.00 |   27.56234    30.24366    28.91466    28.04724    30.75104    33.86946    34.34472    31.53875    28.39042
 40000.00 |   30.55863    33.81422    32.23108    32.05583    35.94577    38.65778    36.87826    32.64443    30.01913
 35000.00 |   34.43568    38.37642    36.51855    37.63786    42.73460    43.42540    38.45417    34.56384    31.48534
 30000.00 |   39.70974    44.41032    42.32918    45.75656    50.85647    46.75560    40.73032    36.58237    32.88793
 25000.00 |   47.37963    52.75659    50.77975    57.99347    58.94513    49.80933    43.62569    38.71338    34.82225
 20000.00 |   59.43691    65.04881    64.52244    74.91530    64.44221    54.21096    47.01415    41.55208    38.12808
 15000.00 |   79.36615    85.01679    90.71996    91.26411    71.69089    59.69715    52.20925    48.29459    45.60664
 10000.00 |   74.33501    73.66731    82.36775    85.89520    82.69193    72.15147    65.31045    58.51974    52.11298
  5000.00 |   71.05409    73.69147    82.18726    80.50754    91.91776    89.79122    73.65569    61.96278    53.32803
     0.00 |   70.63484     0.00000    88.92490    89.72987    93.63466    79.76917    64.84859    54.60214    47.16183
 -5000.00 |   73.68558    73.37463    86.06787    86.69831    59.22930    47.84422    41.43507    36.88084    33.32051
-10000.00 |   87.90161    73.19641    88.96851    96.45428    58.70572    41.49757    33.49781    28.78180    25.69893
-15000.00 |   77.03827    87.23467    80.39492    85.88778    61.57893    44.04494    33.81957    27.28660    23.47190
-20000.00 |   60.41992    64.90092    96.81753    75.45906    56.57736    46.92437    35.80060    28.41612    23.93724
-25000.00 |   47.89155    51.56989    78.48259    66.13795    54.81957    42.38303    37.52104    30.15430    25.32161
-30000.00 |   39.44817    42.62007    64.21525    60.32385    44.84890    41.96895    34.66088    30.94922    26.39532
-35000.00 |   33.50601    36.32770    53.26102    55.73789    45.35408    40.26414    34.02535    28.84211    26.97080
-40000.00 |   29.22456    31.60751    44.85683    51.11192    42.50205    36.90086    33.55002    27.85057    25.27265
-45000.00 |   26.01031    28.07567    38.46135    46.42030    40.55101    34.37434    31.69823    28.18601    24.14216
-50000.00 |   23.37737    25.17364    33.48043    41.93594    38.84327    32.63179    29.36960    27.77542    24.22759
```

```
                                          MODELING OPTIONS USED:  CONC   ELEV     DFAULT
                              *** THE PERIOD (8760 HRS) AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP: ALL
                                                  INCLUDING SOURCE(S):   STACK1  ,
                                            *** NETWORK ID: CG1;  NETWORK TYPE: GRIDCART ***
                                                  CONC OF NO2   IN MICROGRAMS/M**3

   Y-COORD  |                                          X-COORD (METERS)
  (METERS)  |     40000.00     45000.00     50000.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  50000.00  |     25.15397     23.74841     22.07400
  45000.00  |     26.52000     24.52799     22.55988
  40000.00  |     27.58744     25.21425     23.55297
  35000.00  |     28.55783     26.42405     24.47901
  30000.00  |     30.05058     27.59908     25.87260
  25000.00  |     31.84866     30.02714     28.94395
  20000.00  |     36.20461     34.93007     33.60909
  15000.00  |     42.80215     39.76126     36.76469
  10000.00  |     46.45538     41.63033     37.59757
   5000.00  |     46.75996     41.61664     37.48613
      0.00  |     41.52470     37.10682     33.55274
  -5000.00  |     30.43071     28.02522     25.98628
 -10000.00  |     23.47801     21.70909     20.29974
 -15000.00  |     20.97510     19.02927     17.57101
 -20000.00  |     20.33037     18.05138     16.54461
 -25000.00  |     21.53688     18.49389     16.16295
 -30000.00  |     22.47442     19.50570     17.13024
 -35000.00  |     22.97738     19.82903     17.78387
 -40000.00  |     23.69328     21.10520     17.81008
 -45000.00  |     22.31674     21.14176     18.19750
 -50000.00  |     20.93595     19.99751     19.09146

GROUP ID                      AVERAGE CONC   RECEPTOR  (XR, YR, ZELEV, ZFLAG)   OF TYPE  GRID-ID
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
ALL       1ST HIGHEST VALUE IS    96.81753 AT (  5000.00,   -20000.00,      35.97,       0.00)  GC    CG1
          2ND HIGHEST VALUE IS    96.45428 AT (-10000.00,   -10000.00,      49.99,       0.00)  GC    CG1
          3RD HIGHEST VALUE IS    93.63466 AT ( 15000.00,        0.00,       0.00,       0.00)  GC    CG1
          4TH HIGHEST VALUE IS    91.91776 AT ( 15000.00,     5000.00,       0.00,       0.00)  GC    CG1
          5TH HIGHEST VALUE IS    91.26411 AT ( 10000.00,    15000.00,       0.00,       0.00)  GC    CG1
          6TH HIGHEST VALUE IS    91.15800 AT (-10000.00,     5000.00,      36.58,       0.00)  GC    CG1
```

APPENDIX – E

Daily Average Concentration Values of PM for the Year 1995

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                                  MODELING OPTIONS USED:  CONC ELEV  DFAULT
                *** THE   1ST HIGHEST 24-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL ***
                                       INCLUDING SOURCE(S):   STACK1   ,
                                  NETWORK ID: CG1  ;  NETWORK TYPE: GRIDCART
                                       CONC OF PM IN MICROGRAMS/M**3

 Y COORD  |                                         X-COORD (METERS)
 (METERS) |    -50000.00            -45000.00            -40000.00            -35000.00            -30000.00
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  50000.0 |  0.92618 (95040424)   1.08608 (95040424)   1.13018 (95040424)   1.46315 (95020124)   1.62633 (95020124)
  45000.0 |  0.95264 (95020124)   0.99784 (95040424)   1.18362 (95040424)   1.22057 (95040424)   1.76906 (95020124)
  40000.0 |  1.10962 (95020124)   1.07538 (95020124)   1.13326 (95040424)   1.36429 (95040424)   1.47634 (95020124)
  35000.0 |  1.51358m(95011724)   1.35647m(95011724)   1.25548 (95020124)   1.27917 (95040424)   1.55906 (95040424)
  30000.0 |  1.87963 (95072724)   1.56486m(95011724)   1.68247m(95011724)   1.45826 (95020124)   1.47133 (95040424)
  25000.0 |  1.77499 (95072724)   2.16364 (95072724)   2.07454 (95072724)   1.96750m(95011724)   1.72373 (95020124)
  20000.0 |  1.21647m(95013024)   1.42904 (95070424)   2.12542 (95072724)   2.57148 (95072724)   2.12115 (95072724)
  15000.0 |  1.88275 (95072524)   1.49891m(95013024)   1.59176m(95013024)   1.67612 (95070424)   2.71384 (95072724)
  10000.0 |  3.03571 (95072524)   3.10284 (95072524)   2.89696 (95072524)   2.63196 (95072524)   2.20852 (95072524)
   5000.0 |  2.19406 (95072524)   2.57797 (95072524)   2.79848 (95072524)   3.31419 (95072524)   3.90801 (95072524)
      0.0 |  1.16525 (95081224)   1.26163 (95081224)   1.37928 (95081224)   1.52530 (95081224)   1.71321 (95081224)
  -5000.0 |  0.97682 (95111924)   1.12087 (95111924)   1.21275m(95032524)   1.46130m(95032524)   1.78480m(95032524)
 -10000.0 |  1.24082 (95111924)   1.40170m(95032524)   1.57219m(95032524)   1.70240m(95032524)   1.72612m(95032524)
 -15000.0 |  1.28442m(95032524)   1.26456m(95032524)   1.37442 (95112224)   1.51335 (95112224)   1.92438m(95041424)
 -20000.0 |  1.21966 (95112224)   1.18774 (95112224)   1.49902m(95041424)   1.90222m(95041424)   2.56918 (95092524)
 -25000.0 |  1.23414m(95041424)   1.52633m(95041424)   1.70996 (95092524)   2.49420 (95092524)   2.27095 (95092524)
 -30000.0 |  1.32683m(95041424)   1.87529 (95092524)   2.26693 (95092524)   1.88566 (95072524)   1.33562 (95072524)
 -35000.0 |  1.94749 (95092524)   1.99262 (95092524)   1.67962 (95072524)   1.13532 (95072524)   0.91367m(95042724)
 -40000.0 |  1.17112 (95092524)   1.47280 (95072524)   0.98638 (95072524)   0.79600m(95042724)   0.88585 (95120224)
 -45000.0 |  1.32126 (95072524)   0.88338 (95072524)   0.72671 (95073024)   0.74804m(95042724)   0.95513 (95091624)
 -50000.0 |  0.78648 (95072524)   0.67400 (95073024)   0.67621m(95042724)   0.66432m(95042724)   1.04023 (95091624)
```

```
                                   MODELING OPTIONS USED:  CONC ELEV      DFAULT
              *** THE   1ST HIGHEST 24-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL ***
                                          INCLUDING SOURCE(S):       STACK1   ,
                                     *** NETWORK ID: CG1  NETWORK TYPE: GRIDCART ***
                                              CONC OF PM IN MICROGRAMS/M**3

 Y COORD  |                                          X-COORD (METERS)
 (METERS) |     -25000.00             -20000.00             -15000.00             -10000.00              -5000.00
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  50000.0 |     2.05956 (95080324)    1.79483 (95080324)    1.31897 (95060624)    1.27249 (95052324)    1.26839 (95062624)
  45000.0 |     1.92939 (95080324)    2.20060 (95080324)    1.35934 (95080324)    1.46093 (95052324)    1.32830 (95062624)
  40000.0 |     2.00932 (95020124)    2.41165 (95080324)    1.95206 (95080324)    1.54955 (95052324)    1.38340 (95062624)
  35000.0 |     1.91891 (95020124)    2.20531 (95080324)    2.58429 (95080324)    1.71850 (95060624)    1.42598 (95062624)
  30000.0 |     1.80682 (95040424)    2.46107 (95020124)    2.95398 (95080324)    2.05272 (95080324)    1.55111 (95052324)
  25000.0 |     1.73611 (95040424)    2.11788 (95040424)    2.90063 (95020124)    3.14527 (95080324)    2.11396 (95052324)
  20000.0 |     2.14516m(95011724)    2.12495 (95040424)    2.90030 (95020124)    3.92848 (95080324)    2.53064 (95052324)
  15000.0 |     3.17693 (95072724)    2.87963m(95011724)    2.75388 (95040424)    4.38507 (95020124)    3.88888 (95080324)
  10000.0 |     2.13352m(95013024)    3.74385 (95072724)    3.86283 (95072724)    3.84018 (95040424)    6.41407 (95020124)
   5000.0 |     4.50786 (95072524)    4.86935 (95072524)    4.33968 (95072524)    6.47329 (95072724)    7.56640 (95020124)
      0.0 |     2.00619m(95032524)    2.55622m(95032524)    3.54740 (95072524)    5.33201m(95032524)   10.44422m(95032524)
  -5000.0 |     2.18172m(95032524)    2.64677m(95032524)    2.94322m(95032524)    3.93908m(95041424)    6.23541 (95092524)
 -10000.0 |     1.98965 (95112224)    2.67215m(95041424)    4.34940 (95092524)    3.75710 (95072524)    5.15353 (95080324)
 -15000.0 |     2.49133m(95041424)    3.70263 (95092524)    2.59646 (95072524)    1.91504 (95091624)    6.51803 (95032324)
 -20000.0 |     2.91796 (95092524)    1.98012 (95072524)    1.51306m(95042724)    2.82995 (95080324)    4.46187 (95032324)
 -25000.0 |     1.61051 (95072524)    1.26171m(95042724)    1.50526 (95080324)    3.82055 (95032324)    3.19118m(95042924)
 -30000.0 |     1.06651m(95042724)    1.15843 (95091624)    2.05840 (95080324)    3.90199 (95032324)    2.77955m(95042924)
 -35000.0 |     0.97230 (95120224)    1.42192 (95080324)    2.43643 (95032324)    3.18709 (95032324)    2.48135m(95042924)
 -40000.0 |     1.13819 (95091624)    1.80312 (95080324)    2.94390 (95032324)    2.28614 (95032324)    2.24155m(95042924)
 -45000.0 |     1.50463 (95080324)    2.19704 (95080324)    2.90979 (95032324)    1.83193m(95042924)    2.03970m(95042924)
 -50000.0 |     1.88738 (95080324)    2.18999 (95032324)    2.51673 (95032324)    1.69791m(95042924)    1.90757m(95042924)
```

```
                                   MODELING OPTIONS USED:  CONC ELEV      DFAULT
                  *** THE   1ST HIGHEST 24-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL ***
                                        INCLUDING SOURCE(S):         STACK1   ,
                                     *** NETWORK ID: CG1 ;  NETWORK TYPE: GRIDCART ***
                                              CONC OF PM IN MICROGRAMS/M**3

 Y-COORD  |                                          X-COORD (METERS)
 (METERS) |         0.00                 5000.00                10000.00               15000.00               20000.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  50000.0 |    1.09781 (95030824)    1.52396 (95081924)    1.66045 (95081924)    1.37194 (95081924)    1.80649m(95011024)
  45000.0 |    1.20651 (95103024)    1.75009 (95081924)    1.73112 (95081924)    1.63712m(95011024)    2.05320m(95011024)
  40000.0 |    1.35232 (95103024)    2.00744 (95081924)    1.82074 (95081924)    2.07342m(95011024)    2.17998m(95011024)
  35000.0 |    1.53764 (95103024)    2.29360 (95081924)    1.93925 (95081924)    2.50198m(95011024)    2.01797m(95011024)
  30000.0 |    1.78115 (95103024)    2.60372 (95081924)    2.36196m(95011024)    2.74542m(95011024)    2.81218 (95070724)
  25000.0 |    2.11563 (95103024)    2.94129 (95081924)    3.20057m(95011024)    2.69222 (95070724)    3.58083 (95070724)
  20000.0 |    2.60517 (95103024)    3.34444 (95081924)    3.77970m(95011024)    4.20056 (95070724)    3.50634 (95102924)
  15000.0 |    3.39807 (95103024)    4.36512m(95011024)    4.80351 (95070724)    4.41297 (95102924)    4.57625m(95043024)
  10000.0 |    4.89957 (95103024)    6.44537m(95011024)    6.09903 (95102924)    4.85262m(95043024)    2.86838 (95101824)
   5000.0 |    8.75739 (95103024)   10.48252 (95102924)    4.83985 (95101824)    3.43914m(95041324)    2.60777 (95121024)
      0.0 |    0.00000 (00000000)   10.41923 (95121024)    5.80495 (95121024)    4.08875 (95121024)    3.17830 (95121024)
  -5000.0 |   10.95479m(95042924)    6.89895 (95050624)    3.40338 (95081724)    4.22615 (95081724)    2.04540m(95013024)
 -10000.0 |    7.05533m(95042924)    8.23358 (95061424)    4.28452 (95050624)    2.23347 (95060424)    1.59624 (95060424)
 -15000.0 |    4.66180m(95042924)    4.11461 (95120824)    5.30837 (95061424)    3.24563 (95050624)    2.39558 (95123124)
 -20000.0 |    3.71610m(95042924)    3.64673 (95050524)    4.76957 (95061424)    2.70027 (95061424)    2.70331 (95050624)
 -25000.0 |    3.11564m(95042924)    3.31067 (95081824)    2.35080 (95120824)    4.33084 (95061424)    1.50099 (95082024)
 -30000.0 |    2.69930m(95042924)    2.99401 (95081824)    2.40182 (95050524)    2.92811 (95061424)    3.01568 (95061424)
 -35000.0 |    2.38699m(95042924)    2.60520 (95081824)    2.29080 (95050524)    1.96549 (95061424)    3.49414 (95061424)
 -40000.0 |    2.14777m(95042924)    2.26497 (95081824)    2.08005 (95050524)    1.66935 (95050524)    2.73638 (95061424)
 -45000.0 |    1.95019m(95042924)    1.94909 (95081824)    2.05774 (95081824)    1.71744 (95050524)    1.72159 (95061424)
 -50000.0 |    1.80882m(95042924)    1.72808 (95070624)    2.06904 (95081824)    1.67598 (95050524)    1.24450 (95120824)
```

```
                          MODELING OPTIONS USED:  CONC ELEV      DFAULT
      *** THE   1ST HIGHEST 24-HR AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP:  ALL ***
                               INCLUDING SOURCE(S): STACK1    ,
                          *** NETWORK ID: CG1 ;  NETWORK TYPE: GRIDCART ***
                                 CONC OF PM IN MICROGRAMS/M**3

 Y-COORD  |                                             X-COORD (METERS)
 (METERS) |      25000.00             30000.00             35000.00             40000.00             45000.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  50000.0 |   1.81872m(95011024)   1.38486 (95070724)   2.02866 (95070724)   2.18415 (95070724)   1.82557 (95070724)
  45000.0 |   1.72802m(95011024)   2.02513 (95070724)   2.37322 (95070724)   2.04835 (95070724)   1.87008 (95102924)
  40000.0 |   1.93573 (95070724)   2.56321 (95070724)   2.31907 (95070724)   2.08863 (95102924)   2.01088m(95043024)
  35000.0 |   2.72859 (95070724)   2.65209 (95070724)   2.34635 (95102924)   2.35409m(95043024)   2.52094m(95043024)
  30000.0 |   3.06590 (95070724)   2.63152 (95102924)   2.78064m(95043024)   2.67720m(95043024)   1.81977m(95043024)
  25000.0 |   2.96992 (95102924)   3.30751m(95043024)   2.74254m(95043024)   1.63313m(95043024)   1.55829 (95101824)
  20000.0 |   3.93377m(95043024)   2.64154m(95043024)   1.83600 (95101824)   1.68886 (95101824)   1.35278m(95041324)
  15000.0 |   2.29275m(95043024)   2.10615 (95101824)   1.74123m(95041324)   1.73267m(95041324)   1.55199m(95041324)
  10000.0 |   2.37055m(95041324)   2.08587m(95041324)   1.63221m(95041324)   1.42470 (95121024)   1.28292 (95121024)
   5000.0 |   2.21757 (95090924)   2.06693 (95090924)   1.86910 (95090924)   1.67635 (95090924)   1.50498 (95090924)
      0.0 |   2.61027 (95121024)   2.22067 (95121024)   1.93620 (95121024)   1.71903 (95121024)   1.54760 (95121024)
  -5000.0 |   1.96867m(95013024)   1.65663m(95013024)   1.32729m(95013024)   1.12563 (95100324)   1.07546 (95100324)
 -10000.0 |   2.81382 (95081724)   2.60611 (95081724)   1.87486 (95081724)   1.18543m(95013024)   1.22890m(95013024)
 -15000.0 |   1.46769 (95060424)   1.13692 (95060424)   1.80852 (95081724)   2.18039 (95081724)   1.95798 (95081724)
 -20000.0 |   2.25217 (95123124)   1.28769 (95060424)   1.10955 (95060424)   0.88770 (95060424)   1.22056 (95081724)
 -25000.0 |   2.29778 (95050624)   1.92385 (95123124)   1.26040 (95123124)   1.00689 (95060424)   0.89280 (95060424)
 -30000.0 |   1.13696 (95082024)   1.98150 (95050624)   1.63159 (95123124)   1.39913 (95123124)   0.89331 (95060424)
 -35000.0 |   2.00922 (95061424)   1.07861 (95050624)   1.80721 (95050624)   1.31512 (95123124)   1.37564 (95123124)
 -40000.0 |   2.85432 (95061424)   1.27948 (95061424)   1.11105 (95050624)   1.64433 (95050624)   1.15914 (95123124)
 -45000.0 |   2.89151 (95061424)   2.11912 (95061424)   1.02986 (95082024)   1.08714 (95050624)   1.51261 (95050624)
 -50000.0 |   2.27003 (95061424)   2.59008 (95061424)   1.51869 (95061424)   0.85526 (95082024)   1.05718 (95050624)
```

```
                                   MODELING OPTIONS USED:  CONC ELEV DFAULT
                *** THE   1ST HIGHEST 24-HR AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP:  ALL ***
                                        INCLUDING SOURCE(S): STACK1   ,
                                  *** NETWORK ID: CG1 ;  NETWORK TYPE: GRIDCART ***
                                         CONC OF PM IN MICROGRAMS/M**3

 Y-COORD  |                                        X-COORD (METERS)
 (METERS) |      50000.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  50000.0 |     1.69187 (95102924)
  45000.0 |     1.73333m(95043024)
  40000.0 |     2.32479m(95043024)
  35000.0 |     1.92674m(95043024)
  30000.0 |     1.25957 (95101824)
  25000.0 |     1.42116 (95101824)
  20000.0 |     1.42959m(95041324)
  15000.0 |     1.29966m(95041324)
  10000.0 |     1.22753 (95090924)
   5000.0 |     1.35769 (95090924)
      0.0 |     1.40870 (95121024)
  -5000.0 |     1.03617 (95121024)
 -10000.0 |     1.17943m(95013024)
 -15000.0 |     1.58519 (95081724)
 -20000.0 |     1.68040 (95081724)
 -25000.0 |     0.72885 (95060424)
 -30000.0 |     0.84522 (95060424)
 -35000.0 |     0.78820 (95060424)
 -40000.0 |     1.34251 (95123124)
 -45000.0 |     1.02154 (95081724)
 -50000.0 |     1.40363 (95050624)
```

```
                                        MODELING OPTIONS USED:  CONC ELEV        DFAULT
                        *** THE MAXIMUM   20, 24-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL ***
                                                 INCLUDING SOURCE(S):   STACK1   ,
                                                  CONC OF PM IN MICROGRAMS/M**3

RANK        CONC     (YYMMDDHH) AT        RECEPTOR (XR,YR) OF TYPE     RANK        CONC     (YYMMDDHH) AT         RECEPTOR (XR,YR) OF TYPE
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  1.      10.95479m(95042924) AT (      0.00,    -5000.00)  GC       11.        8.42960 (95091724) AT (       0.00,     5000.00)  GC
  2.      10.60131 (95032324) AT (      0.00,    -5000.00)  GC       12.        8.23358 (95061424) AT (    5000.00,   -10000.00)  GC
  3.      10.48252 (95102924) AT (   5000.00,     5000.00)  GC       13.        8.11813 (95090924) AT (    5000.00,        0.00)  GC
  4.      10.44422m(95032524) AT (  -5000.00,        0.00)  GC       14.        7.85853m(95040924) AT (    5000.00,     5000.00)  GC
  5.      10.42024m(95043024) AT (   5000.00,     5000.00)  GC       15.        7.77900 (95120824) AT (       0.00,    -5000.00)  GC
  6.      10.41923 (95121024) AT (   5000.00,        0.00)  GC       16.        7.56640 (95020124) AT (   -5000.00,     5000.00)  GC
  7.       9.30374 (95072524) AT (  -5000.00,        0.00)  GC       17.        7.44890 (95120224) AT (       0.00,    -5000.00)  GC
  8.       8.91219 (95070724) AT (   5000.00,     5000.00)  GC       18.        7.39400 (95070624) AT (       0.00,    -5000.00)  GC
  9.       8.75739 (95103024) AT (      0.00,     5000.00)  GC       19.        7.31524m(95021624) AT (   -5000.00,        0.00)  GC
 10.       8.43232 (95081824) AT (      0.00,    -5000.00)  GC       20.        7.23951 (95040424) AT (   -5000.00,     5000.00)  GC

 RECEPTOR TYPES:  GC = GRIDCART
                  GP = GRIDPOLR
                  DC = DISCCART
                  DP = DISCPOLR
```

Annual Average Concentration Values of PM for the Year 1995

```
                              MODELING OPTIONS USED:  CONC ELEV   DFAULT
         *** THE PERIOD (8760 HRS) AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP: ALL ***
                               INCLUDING SOURCE(S):       STACK1  ,
                            *** NETWORK ID: CG1 ;  NETWORK TYPE: GRIDCART ***
                                   CONC OF PM IN MICROGRAMS/M**3


 Y COORD  |                                        X COORD  (METERS)
 (METERS) |   50000.00   -45000.00   -40000.00    35000.00   -30000.00   -25000.00   -20000.00   -15000.00   -10000.00
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 50000.00 |    0.06337     0.06622     0.07015     0.07690     0.08103     0.08038     0.08554     0.08527     0.08119
 45000.00 |    0.06726     0.06948     0.07292     0.07944     0.08774     0.08962     0.09186     0.09604     0.09064
 40000.00 |    0.07487     0.07563     0.07936     0.08380     0.09171     0.10052     0.10090     0.10744     0.10325
 35000.00 |    0.08319     0.08522     0.08772     0.09072     0.09673     0.10829     0.11525     0.11910     0.12021
 30000.00 |    0.08833     0.09446     0.09994     0.10190     0.10570     0.11455     0.13063     0.13484     0.14193
 25000.00 |    0.08714     0.09822     0.11005     0.11746     0.12129     0.12658     0.14091     0.15986     0.16721
 20000.00 |    0.08020     0.09268     0.10821     0.12525     0.13950     0.14953     0.15819     0.18289     0.20145
 15000.00 |    0.08022     0.08893     0.10011     0.11783     0.14475     0.17322     0.19450     0.21114     0.25506
 10000.00 |    0.08707     0.09554     0.10535     0.11961     0.13712     0.16606     0.21476     0.27280     0.31279
  5000.00 |    0.07437     0.08462     0.09612     0.11276     0.13485     0.16466     0.20589     0.27214     0.41962
     0.00 |    0.05676     0.06333     0.07074     0.08123     0.09525     0.11491     0.14446     0.19506     0.29471
 -5000.00 |    0.04927     0.05450     0.05938     0.06735     0.07780     0.09442     0.11395     0.15283     0.25564
-10000.00 |    0.04806     0.05315     0.05890     0.06596     0.07526     0.09182     0.12731     0.18775     0.23037
-15000.00 |    0.04613     0.05002     0.05565     0.06561     0.08439     0.11218     0.14609     0.15612     0.16501
-20000.00 |    0.04416     0.05112     0.06269     0.07882     0.09871     0.11800     0.11862     0.11626     0.15598
-25000.00 |    0.04969     0.05999     0.07266     0.08665     0.09833     0.09559     0.09088     0.10923     0.15215
-30000.00 |    0.05706     0.06682     0.07674     0.08367     0.07955     0.07505     0.08516     0.10456     0.14158
-35000.00 |    0.06153     0.06842     0.07240     0.06802     0.06368     0.06996     0.08156     0.10408     0.12467
 40000.00 |    0.05732     0.06384     0.05941     0.05557     0.05909     0.06791     0.07866     0.10303     0.10833
-45000.00 |    0.05679     0.05248     0.04828     0.05078     0.05761     0.06490     0.07964     0.09804     0.09447
-50000.00 |    0.04713     0.04407     0.04502     0.04912     0.05568     0.06312     0.08033     0.08964     0.08338
```

```
                              MODELING OPTIONS USED:   CONC ELEV      DFAULT
              *** THE PERIOD (8760 HRS) AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP: ALL ***
                                   INCLUDING SOURCE (S): STACK 1
                             *** NETWORK ID: CG1; NETWORK TYPE: GRIDCART ***
                                    CONC OF PM IN MICROGRAMS/M**3

 Y-COORD  |                                        X-COORD (METERS)
 (METERS) |   -5000.00     0.00      5000.00    10000.00    15000.00    20000.00    25000.00    30000.00    35000.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 50000.00 |    0.08714    0.09480    0.09094    0.08677    0.09287    0.10250    0.10785    0.10514    0.09508
 45000.00 |    0.09546    0.10475    0.10014    0.09714    0.10650    0.11731    0.11895    0.10923    0.09833
 40000.00 |    0.10584    0.11711    0.11163    0.11102    0.12450    0.13389    0.12773    0.11306    0.10397
 35000.00 |    0.11927    0.13291    0.12648    0.13036    0.14801    0.15040    0.13318    0.11971    0.10905
 30000.00 |    0.13753    0.15381    0.14660    0.15848    0.17614    0.16194    0.14107    0.12670    0.11391
 25000.00 |    0.16410    0.18272    0.17587    0.20086    0.20415    0.17251    0.15110    0.13408    0.12060
 20000.00 |    0.20586    0.22529    0.22347    0.25947    0.22319    0.18776    0.16283    0.14391    0.13205
 15000.00 |    0.27488    0.29445    0.31420    0.31609    0.24830    0.20676    0.18082    0.16727    0.15796
 10000.00 |    0.39599    0.42831    0.49308    0.36676    0.28640    0.24989    0.22620    0.20268    0.18049
  5000.00 |    0.62707    0.80938    0.70026    0.48664    0.38762    0.31099    0.25510    0.21460    0.18470
     0.00 |    0.59098    0.00000    1.00068    0.51858    0.35893    0.27628    0.22460    0.18911    0.16334
 -5000.00 |    0.46301    0.94682    0.71370    0.30027    0.20514    0.16571    0.14351    0.12773    0.11540
-10000.00 |    0.30444    0.42668    0.55058    0.33406    0.20332    0.14372    0.11602    0.09968    0.08901
-15000.00 |    0.26682    0.30213    0.41698    0.29747    0.21328    0.15255    0.11713    0.09451    0.08129
-20000.00 |    0.20926    0.22478    0.33532    0.26135    0.19595    0.16252    0.12399    0.09842    0.08291
-25000.00 |    0.16587    0.17861    0.27182    0.22907    0.18986    0.14679    0.12995    0.10444    0.08770
-30000.00 |    0.13663    0.14761    0.22241    0.20893    0.15533    0.14536    0.12005    0.10719    0.09142
-35000.00 |    0.11605    0.12582    0.18447    0.19305    0.15708    0.13945    0.11785    0.09989    0.09341
-40000.00 |    0.10122    0.10947    0.15536    0.17702    0.14720    0.12780    0.11620    0.09646    0.08753
-45000.00 |    0.09009    0.09724    0.13321    0.16077    0.14045    0.11905    0.10979    0.09762    0.08362
-50000.00 |    0.08097    0.08719    0.11596    0.14524    0.13453    0.11302    0.10172    0.09620    0.08391
```

```
                                    MODELING OPTIONS USED:  CONC ELEV     DFAULT
                     THE PERIOD (8760 HRS) AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP: ALL
                                    INCLUDING SOURCE (S): STACK 1
                                 *** NETWORK ID: CG1; NETWORK TYPE: GRIDCART ***
                                    CONC OF PM IN MICROGRAMS/M**3


 Y COORD  |                                              X-COORD (METERS)
 (METERS) |     40000.00     45000.00     50000.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 50000.00 |      0.08712      0.08225      0.07645
 45000.00 |      0.09185      0.08495      0.07813
 40000.00 |      0.09555      0.08733      0.08157
 35000.00 |      0.09891      0.09152      0.08478
 30000.00 |      0.10408      0.09559      0.08961
 25000.00 |      0.11031      0.10400      0.10025
 20000.00 |      0.12539      0.12098      0.11640
 15000.00 |      0.14824      0.13771      0.12733
 10000.00 |      0.16090      0.14418      0.13022
  5000.00 |      0.16195      0.14414      0.12983
     0.00 |      0.14382      0.12852      0.11621
 -5000.00 |      0.10540      0.09706      0.09000
-10000.00 |      0.08131      0.07519      0.07031
-15000.00 |      0.07265      0.06591      0.06086
-20000.00 |      0.07041      0.06252      0.05730
-25000.00 |      0.07459      0.06405      0.05598
-30000.00 |      0.07784      0.06756      0.05933
-35000.00 |      0.07958      0.06868      0.06159
-40000.00 |      0.08206      0.07310      0.06168
-45000.00 |      0.07729      0.07322      0.06303
-50000.00 |      0.07251      0.06926      0.06612
```

```
                              MODELING OPTIONS USED:  CONC ELEV      DFAULT
                         *** THE SUMMARY OF MAXIMUM PERIOD (8760 HRS) RESULTS ***
                                      CONC OF PM IN MICROGRAMS/M**3

                                                                                                   NETWORK
GROUP ID                      AVERAGE CONC                 RECEPTOR  (XR, YR, ZELEV, ZFLAG)    OF TYPE  GRID-ID
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

ALL      1ST HIGHEST VALUE IS       1.00068 AT (   5000.00,       0.00,       0.00,       0.00)  GC    CG1
         2ND HIGHEST VALUE IS       0.94682 AT (      0.00,   -5000.00,      23.16,       0.00)  GC    CG1
         3RD HIGHEST VALUE IS       0.80938 AT (      0.00,    5000.00,      23.16,       0.00)  GC    CG1
         4TH HIGHEST VALUE IS       0.71370 AT (   5000.00,   -5000.00,      23.16,       0.00)  GC    CG1
         5TH HIGHEST VALUE IS       0.70026 AT (   5000.00,    5000.00,       0.00,       0.00)  GC    CG1
         6TH HIGHEST VALUE IS       0.62707 AT (  -5000.00,    5000.00,      23.16,       0.00)  GC    CG1

 *** RECEPTOR TYPES:  GC = GRIDCART
                      GP = GRIDPOLR
                      DC = DISCCART
                      DP = DISCPOLR
 *** AERMOD - VERSION 99351 ***
```

APPENDIX – F

CORMIX SESSION REPORT FOR ELEVATED TEMPERATURE:

CORMIX: CORNELL MIXING ZONE EXPERT SYSTEM
CORMIX-GI Version 4.1GT
SITE NAME/LABEL: Al-Jubail Saudi Arabia
DESIGN CASE: MSF Desalination Plant
FILE NAME: E:\cormix\Mansoor.prd
Using subsystem CORMIX1: Submerged Single Port Discharges
Start of session: 07/16/2002--14:27:14

****

SUMMARY OF INPUT DATA:

AMBIENT PARAMETERS:

Cross-section = unbounded
Average depth HA = 5 m
Depth at discharge HD = 4 m
Ambient velocity UA = 0.5 m/s
Darcy-Weisbach friction factor F = 0.025
Wind velocity UW = 5 m/s
Stratification Type STRCND = U
Surface density RHOAS = 1027.5 kg/m^3
Bottom density RHOAB = 1027.5 kg/m^3

DISCHARGE PARAMETERS: Submerged Single Port Discharge

Nearest bank = left
Distance to bank DISTB = 2000 m
Port diameter D0 = 0.9 m
Port cross-sectional area A0 = 0.6362 m^2
Discharge velocity U0 = 25.54 m/s
Discharge flowrate Q0 = 16.25 m^3/s
Discharge port height H0 = 0.2 m
Vertical discharge angle THETA = 45 deg
Horizontal discharge angle SIGMA = 90 deg
Discharge density RHO0 = 1046.5 kg/m^3
Density difference DRHO = -19 kg/m^3
Buoyant acceleration GP0 = -0.1813 m/s^2
Discharge concentration C0 = 6.94 deg. C
Surface heat exchange coeff. KS = 0.000007 m/s
Coefficient of decay KD = 0 /s

DISCHARGE/ENVIRONMENT LENGTH SCALES:

LQ = 0.80 m Lm = 40.75 m Lb = 23.57 m
LM = 53.57 m Lm' = 99999 m Lb' = 99999 m

NON-DIMENSIONAL PARAMETERS:

Port densimetric Froude number FR0 = 63.23
Velocity ratio R = 51.09

```
-----------------------------------------------------------------------------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST
PARAMETERS:
Toxic discharge              = no
Water quality standard specified     = no
Regulatory mixing zone           = no
Region of interest            = 2000 m downstream
*************************************************************************
HYDRODYNAMIC CLASSIFICATION:
  *-----------------------*
  | FLOW CLASS  = NH5 |
  *-----------------------*
This flow configuration applies to a layer corresponding to the full water
depth at the discharge site.
Applicable layer depth = water depth = 4 m
*************************************************************************
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):
-----------------------------------------------------------------------------
X-Y-Z Coordinate system:
Origin is located at the bottom below the port center:
2000 m from the left bank/shore.
Number of display steps NSTEP = 200 per module.
-----------------------------------------------------------------------------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no regulatory
implication.  However, this information may be useful for the discharge
designer because the mixing in the NFR is usually sensitive to the
discharge design conditions.
Pollutant concentration at edge of NFR = 0.38 deg. C
Dilution at edge of NFR          = 18.3
NFR Location:              x = 101.41 m
(centerline coordinates)       y = 173.25 m
z = 0 m
NFR plume dimensions:     half-width = 14.91 m
thickness = 4 m
-----------------------------------------------------------------------------
Buoyancy assessment:
The effluent density is greater than the surrounding ambient water
density at the discharge level.
Therefore, the effluent is NEGATIVELY BUOYANT and will tend to sink towards
the bottom.
-----------------------------------------------------------------------------
Near-field instability behavior:
The discharge flow will experience instabilities with full vertical mixing
in the near-field.
There may be benthic impact of high pollutant concentrations.
-----------------------------------------------------------------------
FAR-FIELD MIXING SUMMARY:
Plume becomes vertically fully mixed ALREADY IN NEAR-FIELD at 0 m
```

downstream and continues as vertically mixed into the far-field.

PLUME BANK CONTACT SUMMARY:

Plume in unbounded section does not contact bank in this simulation.

****

TOXIC DILUTION ZONE SUMMARY

No TDZ was specified for this simulation.

****

REGULATORY MIXING ZONE SUMMARY

No RMZ and no ambient water quality standard have been specified.

****

FINAL DESIGN ADVICE AND COMMENTS

The discharge port or nozzle points towards the nearest bank.
Since this is an UNUSUAL DESIGN, check whether you have specified
correctly the port horizontal angle (SIGMA).

REMINDER: The user must take note that HYDRODYNAMIC MODELING by any known technique is
NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
CORMIX predictions on dilutions and concentrations (with associated
plume geometries) are reliable for the majority of cases and are accurate
to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it judges
the design configuration as highly complex and uncertain for prediction.

CORMIX1 PREDICTION FILE FOR ELEVATED TEMPERATURE:

```
CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX1:  Submerged Single Port Discharges
CORMIX-GI Version 4.1GT
------------------------------------------------------------------------------
```

CASE DESCRIPTION

```
Site name/label:  Al-Jubail Saudi Arabia
Design case:      MSF Desalination Plant
FILE NAME:          E:\cormix\Mansoor.prd
Time stamp:       Tue Jul 16 14:27:15 2002
```

ENVIRONMENT PARAMETERS (metric units)

```
Unbounded section
HA  =    5.00 HD  =    4.00
UA  =    0.500 F  =    0.025 USTAR =0.2795E-01
UW  =    5.000 UWSTAR=0.5890E-02
Uniform density environment
STRCND= U      RHOAM = 1027.5000
```

DISCHARGE PARAMETERS (metric units)

```
BANK = LEFT     DISTB =  2000.00
D0  =    0.900 A0  =    0.636 H0  =    0.20
THETA =    45.00 SIGMA =    90.00
U0  =  25.543 Q0  =    16.250      =0.1625E+02
RHO0 = 1046.5000 DRHO0 =-.1900E+02 GP0  =-.1813E+00
C0  = 0.6940E+01 CUNITS= deg. C
IPOLL = 3      KS  =0.7165E-05 KD  =0.0000E+00
```

FLUX VARIABLES (metric units)

```
Q0  =0.1625E+02 M0  =0.4151E+03 J0  =-.2947E+01 SIGNJ0=   -1.0
Associated length scales (meters)
LQ  =    0.80 LM  =    53.57 Lm  =    40.75 Lb  =    23.57
Lmp  = 99999.00 Lbp  = 99999.00
```

NON-DIMENSIONAL PARAMETERS

```
FR0  =    63.23 R   =    51.09
```

FLOW CLASSIFICATION

```
1  Flow class (CORMIX1)      =   NH5    1
1  Applicable layer depth HS =    4.00    1
```

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS

```
C0   = 0.6940E+01 CUNITS=  deg. C
NTOX  = 0
NSTD  = 0
REGMZ = 0
XINT  =  2000.00 XMAX  =  2000.00
```

```
X-Y-Z COORDINATE SYSTEM:
ORIGIN is located at the bottom and below the center of the port:
2000.00 m  from the LEFT  bank/shore.
X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP =200 display intervals per module
-----------------------------------------------------------------------------
NOTE on dilution/concentration values for this HEATED DISCHARGE (IPOLL=3):
S  = hydrodynamic dilutions, include buoyancy (heat) loss effects, but
provided plume has surface contact
C  = corresponding temperature values (always in "degC"!),
include heat loss, if any
-----------------------------------------------------------------------------
BEGIN MOD101: DISCHARGE MODULE
COANDA ATTACHMENT immediately following the discharge.

  X      Y      Z      S        C            B
0.00   0.00   0.00   1.0  0.694E+01      0.64

END OF MOD101: DISCHARGE MODULE
-----------------------------------------------------------------------------
BEGIN CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION
Bottom-attached jet motion.
Profile definitions:
B = Gaussian 1/e (37%) half-width, normal to trajectory
Half wall jet, attached to bottom.
S = hydrodynamic centerline dilution
C = centerline concentration (includes reaction effects, if any)

X        Y      Z      S     C          B
0.00   0.00   0.00   1.0  0.694E+01  0.45
0.00   0.12   0.00   1.0  0.694E+01  0.47
0.00   0.28   0.00   1.0  0.694E+01  0.49
0.00   0.44   0.00   1.0  0.694E+01  0.50
0.00   0.60   0.00   1.0  0.694E+01  0.52
0.00   0.76   0.00   1.0  0.694E+01  0.54
0.00   0.92   0.00   1.0  0.694E+01  0.56
0.00   1.08   0.00   1.0  0.694E+01  0.57
0.00   1.24   0.00   1.0  0.694E+01  0.59
0.00   1.36   0.00   1.0  0.694E+01  0.60
0.01   1.52   0.00   1.0  0.694E+01  0.62
0.01   1.68   0.00   1.0  0.694E+01  0.64
0.01   1.84   0.00   1.0  0.694E+01  0.66
0.01   2.00   0.00   1.0  0.694E+01  0.67
0.01   2.16   0.00   1.0  0.694E+01  0.69
0.01   2.32   0.00   1.0  0.694E+01  0.71
0.02   2.48   0.00   1.0  0.694E+01  0.73
0.02   2.64   0.00   1.0  0.694E+01  0.75
0.02   2.76   0.00   1.0  0.694E+01  0.76
0.02   2.92   0.00   1.0  0.682E+01  0.78
0.02   3.08   0.00   1.0  0.667E+01  0.79
0.03   3.24   0.00   1.1  0.652E+01  0.81
0.03   3.40   0.00   1.1  0.638E+01  0.83
```

0.03	3.56	0.00	1.1	0.625E+01	0.85
0.04	3.72	0.00	1.1	0.612E+01	0.86
0.04	3.88	0.00	1.2	0.600E+01	0.88
0.04	4.04	0.00	1.2	0.588E+01	0.90
0.04	4.16	0.00	1.2	0.580E+01	0.91
0.05	4.32	0.00	1.2	0.569E+01	0.93
0.05	4.48	0.00	1.2	0.558E+01	0.95
0.06	4.64	0.00	1.3	0.548E+01	0.97
0.06	4.80	0.00	1.3	0.538E+01	0.98
0.06	4.96	0.00	1.3	0.528E+01	1.00
0.07	5.12	0.00	1.3	0.519E+01	1.02
0.07	5.28	0.00	1.4	0.510E+01	1.04
0.08	5.44	0.00	1.4	0.502E+01	1.05
0.08	5.56	0.00	1.4	0.496E+01	1.07
0.08	5.72	0.00	1.4	0.488E+01	1.08
0.09	5.88	0.00	1.4	0.480E+01	1.10
0.09	6.04	0.00	1.5	0.465E+01	1.14
0.10	6.36	0.00	1.5	0.458E+01	1.16
0.11	6.52	0.00	1.5	0.451E+01	1.17
0.12	6.68	0.00	1.6	0.444E+01	1.19
0.12	6.84	0.00	1.6	0.437E+01	1.21
0.13	6.96	0.00	1.6	0.433E+01	1.22
0.13	7.12	0.00	1.6	0.426E+01	1.24
0.14	7.28	0.00	1.7	0.420E+01	1.26
0.14	7.44	0.00	1.7	0.415E+01	1.28
0.15	7.60	0.00	1.7	0.409E+01	1.29
0.16	7.76	0.00	1.7	0.403E+01	1.31
0.16	7.92	0.00	1.7	0.398E+01	1.33
0.17	8.08	0.00	1.8	0.393E+01	1.35
0.18	8.24	0.00	1.8	0.388E+01	1.36
0.18	8.36	0.00	1.8	0.384E+01	1.38
0.19	8.52	0.00	1.8	0.379E+01	1.40
0.20	8.68	0.00	1.9	0.374E+01	1.41
0.20	8.84	0.00	1.9	0.369E+01	1.43
0.21	9.00	0.00	1.9	0.365E+01	1.45
0.22	9.16	0.00	1.9	0.360E+01	1.47
0.23	9.32	0.00	1.9	0.356E+01	1.48
0.24	9.48	0.00	2.0	0.352E+01	1.50
0.24	9.64	0.00	2.0	0.348E+01	1.52
0.25	9.76	0.00	2.0	0.345E+01	1.53
0.26	9.92	0.00	2.0	0.341E+01	1.55
0.27	10.08	0.00	2.1	0.337E+01	1.57
0.28	10.24	0.00	2.1	0.333E+01	1.59
0.28	10.39	0.00	2.1	0.329E+01	1.60
0.29	10.55	0.00	2.1	0.326E+01	1.62
0.30	10.71	0.00	2.2	0.322E+01	1.64
0.31	10.87	0.00	2.2	0.319E+01	1.66
0.32	11.03	0.00	2.2	0.315E+01	1.68
0.33	11.15	0.00	2.2	0.313E+01	1.69
0.34	11.31	0.00	2.2	0.309E+01	1.71
0.35	11.47	0.00	2.3	0.306E+01	1.72
0.36	11.63	0.00	2.3	0.303E+01	1.74
0.37	11.79	0.00	2.3	0.300E+01	1.76

0.38	11.95	0.00	2.3	0.297E+01	1.78
0.39	12.11	0.00	2.4	0.294E+01	1.80
0.40	12.27	0.00	2.4	0.291E+01	1.81
0.41	12.43	0.00	2.4	0.288E+01	1.83
0.42	12.55	0.00	2.4	0.286E+01	1.85
0.43	12.71	0.00	2.4	0.283E+01	1.86
0.44	12.87	0.00	2.5	0.281E+01	1.88
0.45	13.03	0.00	2.5	0.278E+01	1.90
0.46	13.19	0.00	2.5	0.275E+01	1.92
0.48	13.35	0.00	2.5	0.273E+01	1.94
0.49	13.51	0.00	2.6	0.270E+01	1.95
0.50	13.67	0.00	2.6	0.268E+01	1.97
0.51	13.83	0.00	2.6	0.265E+01	1.99
0.52	13.95	0.00	2.6	0.263E+01	2.00
0.53	14.11	0.00	2.7	0.261E+01	2.02
0.54	14.27	0.00	2.7	0.259E+01	2.04
0.56	14.43	0.00	2.7	0.256E+01	2.06
0.57	14.58	0.00	2.7	0.254E+01	2.08
0.58	14.74	0.00	2.8	0.252E+01	2.09
0.60	14.90	0.00	2.8	0.250E+01	2.11
0.61	15.06	0.00	2.8	0.248E+01	2.13
0.62	15.22	0.00	2.8	0.246E+01	2.15
0.63	15.34	0.00	2.8	0.244E+01	2.16
0.65	15.50	0.00	2.9	0.242E+01	2.18
0.66	15.66	0.00	2.9	0.240E+01	2.20
0.67	15.82	0.00	2.9	0.238E+01	2.22
0.69	15.98	0.00	2.9	0.236E+01	2.23
0.70	16.14	0.00	3.0	0.234E+01	2.25
0.72	16.30	0.00	3.0	0.232E+01	2.27
0.73	16.46	0.00	3.0	0.230E+01	2.29
0.75	16.62	0.00	3.0	0.229E+01	2.31
0.76	16.74	0.00	3.1	0.227E+01	2.32
0.77	16.90	0.00	3.1	0.225E+01	2.34
0.79	17.06	0.00	3.1	0.224E+01	2.36
0.80	17.21	0.00	3.1	0.222E+01	2.37
0.82	17.37	0.00	3.2	0.220E+01	2.39
0.84	17.53	0.00	3.2	0.219E+01	2.41
0.85	17.69	0.00	3.2	0.217E+01	2.43
0.87	17.85	0.00	3.2	0.215E+01	2.45
0.88	18.01	0.00	3.2	0.214E+01	2.47
0.90	18.13	0.00	3.3	0.212E+01	2.48
0.91	18.29	0.00	3.3	0.211E+01	2.50
0.93	18.45	0.00	3.3	0.209E+01	2.52
0.95	18.61	0.00	3.3	0.208E+01	2.53
0.96	18.77	0.00	3.4	0.206E+01	2.55
0.98	18.93	0.00	3.4	0.205E+01	2.57
1.00	19.08	0.00	3.4	0.203E+01	2.59
1.01	19.24	0.00	3.4	0.202E+01	2.61
1.03	19.40	0.00	3.5	0.200E+01	2.63
1.05	19.52	0.00	3.5	0.199E+01	2.64
1.06	19.68	0.00	3.5	0.198E+01	2.66
1.08	19.84	0.00	3.5	0.197E+01	2.68
1.10	20.00	0.00	3.6	0.195E+01	2.69

1.12	20.16	0.00	3.6	0.194E+01	2.71
1.14	20.32	0.00	3.6	0.193E+01	2.73
1.15	20.48	0.00	3.6	0.191E+01	2.75
1.17	20.63	0.00	3.7	0.190E+01	2.77
1.19	20.79	0.00	3.7	0.189E+01	2.79
1.21	20.91	0.00	3.7	0.188E+01	2.80
1.23	21.07	0.00	3.7	0.187E+01	2.82
1.25	21.23	0.00	3.7	0.185E+01	2.84
1.27	21.39	0.00	3.8	0.184E+01	2.86
1.29	21.55	0.00	3.8	0.183E+01	2.87
1.31	21.71	0.00	3.8	0.182E+01	2.89
1.33	21.87	0.00	3.8	0.180E+01	2.91
1.35	22.02	0.00	3.9	0.179E+01	2.93
1.37	22.18	0.00	3.9	0.178E+01	2.95
1.38	22.30	0.00	3.9	0.177E+01	2.96
1.40	22.46	0.00	3.9	0.176E+01	2.98
1.42	22.62	0.00	4.0	0.175E+01	3.00
1.44	22.78	0.00	4.0	0.174E+01	3.02
1.47	22.94	0.00	4.0	0.173E+01	3.04
1.49	23.09	0.00	4.0	0.172E+01	3.06
1.51	23.25	0.00	4.1	0.171E+01	3.08
1.53	23.41	0.00	4.1	0.170E+01	3.09
1.55	23.57	0.00	4.1	0.169E+01	3.11
1.57	23.69	0.00	4.1	0.168E+01	3.13
1.59	23.85	0.00	4.2	0.167E+01	3.15
1.61	24.01	0.00	4.2	0.166E+01	3.16
1.64	24.16	0.00	4.2	0.165E+01	3.18
1.66	24.32	0.00	4.2	0.164E+01	3.20
1.68	24.48	0.00	4.3	0.163E+01	3.22
1.71	24.64	0.00	4.3	0.162E+01	3.24
1.73	24.80	0.00	4.3	0.161E+01	3.26
1.75	24.96	0.00	4.3	0.160E+01	3.28
1.77	25.07	0.00	4.4	0.159E+01	3.29
1.79	25.23	0.00	4.4	0.158E+01	3.31
1.82	25.39	0.00	4.4	0.157E+01	3.33
1.84	25.55	0.00	4.4	0.157E+01	3.35
1.87	25.71	0.00	4.5	0.156E+01	3.37
1.89	25.87	0.00	4.5	0.155E+01	3.39
1.92	26.02	0.00	4.5	0.154E+01	3.40
1.94	26.18	0.00	4.5	0.153E+01	3.42
1.97	26.34	0.00	4.6	0.152E+01	3.44
1.98	26.46	0.00	4.6	0.152E+01	3.46
2.01	26.62	0.00	4.6	0.151E+01	3.48
2.04	26.77	0.00	4.6	0.150E+01	3.49
2.06	26.93	0.00	4.7	0.149E+01	3.51
2.09	27.09	0.00	4.7	0.148E+01	3.53
2.11	27.25	0.00	4.7	0.147E+01	3.55
2.14	27.41	0.00	4.7	0.147E+01	3.57
2.17	27.56	0.00	4.8	0.146E+01	3.59
2.19	27.72	0.00	4.8	0.145E+01	3.61
2.21	27.84	0.00	4.8	0.144E+01	3.62
2.24	28.00	0.00	4.8	0.144E+01	3.64
2.27	28.15	0.00	4.9	0.143E+01	3.66

APPENDIX – G

CORMIX SESSION REPORT FOR TOTAL DISSOLVED SOLIDS:

```
CORMIX: CORNELL MIXING ZONE EXPERT SYSTEM
CORMIX-GI Version 4.1GT
SITE NAME/LABEL:              Al-Jubail Saudi Arabia
DESIGN CASE:               MSF Desalination Plant
FILE NAME:                E:\cormix\MansoorTDS.prd
Using subsystem CORMIX1:    Submerged Single Port Discharges
Start of session:        07/16/2002--14:55:32
*****************************************************
SUMMARY OF INPUT DATA:
----------------------------------------------------------------------------
AMBIENT PARAMETERS:
Cross-section                  = unbounded
Average depth            HA   = 5 m
Depth at discharge        HD   = 4 m
Ambient velocity          UA   = 0.5 m/s
Darcy-Weisbach friction factor F   = 0.025
Wind velocity            UW   = 5 m/s
Stratification Type       STRCND = U
Surface density          RHOAS = 1027.5 kg/m^3
Bottom density           RHOAB = 1027.5 kg/m^3
----------------------------------------------------------------------------
DISCHARGE PARAMETERS:         Submerged Single Port Discharge
Nearest bank                  = left
Distance to bank          DISTB = 2000 m
Port diameter          D0    = 0.9 m
Port cross-sectional area    A0    = 0.6362 m^2
Discharge velocity        U0    = 25.54 m/s
Discharge flowrate        Q0    = 16.25 m^3/s
Discharge port height       H0    = 0.2 m
Vertical discharge angle      THETA = 45 deg
Horizontal discharge angle     SIGMA = 90 deg
Discharge density         RHO0  = 1046.5 kg/m^3
Density difference        DRHO  = -19 kg/m^3
Buoyant acceleration        GP0   = -0.1813 m/s^2
Discharge concentration      C0    = 25000 ppm
Surface heat exchange coeff.  KS    = 0 m/s
Coefficient of decay       KD    = 0 /s
----------------------------------------------------------------------------
DISCHARGE/ENVIRONMENT LENGTH SCALES:
LQ  = 0.80 m      Lm  = 40.75 m      Lb  = 23.57 m
LM  = 53.57 m     Lm' = 99999 m      Lb' = 99999 m
----------------------------------------------------------------------------
NON-DIMENSIONAL PARAMETERS:
Port densimetric Froude number  FR0  = 63.23
Velocity ratio            R    = 51.09
----------------------------------------------------------------------------
```

```
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST
PARAMETERS:
Toxic discharge                = no
Water quality standard specified     = no
Regulatory mixing zone              = no
Region of interest              = 2000 m downstream
*****************************************************
HYDRODYNAMIC CLASSIFICATION:
*------------------------*
| FLOW CLASS  = NH5 |
*------------------------*
This flow configuration applies to a layer corresponding to the full water
depth at the discharge site.
Applicable layer depth = water depth = 4 m
*****************************************************
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):
-----------------------------------------------------------------------------
X-Y-Z Coordinate system:
Origin is located at the bottom below the port center:
2000 m from the left bank/shore.
Number of display steps NSTEP = 200 per module.
-----------------------------------------------------------------------------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no regulatory
implication.  However, this information may be useful for the discharge
designer because the mixing in the NFR is usually sensitive to the
discharge design conditions.
Pollutant concentration at edge of NFR = 1368.7229 ppm
Dilution at edge of NFR            = 18.3
NFR Location:                  x = 101.41 m
(centerline coordinates)         y = 173.25 m
z = 0 m
NFR plume dimensions:     half-width = 14.91 m
thickness = 4 m
-----------------------------------------------------------------------------
Buoyancy assessment:
The effluent density is greater than the surrounding ambient water
density at the discharge level.
Therefore, the effluent is NEGATIVELY BUOYANT and will tend to sink towards
the bottom.
-----------------------------------------------------------------------------
Near-field instability behavior:
The discharge flow will experience instabilities with full vertical mixing
in the near-field.
There may be benthic impact of high pollutant concentrations.
-----------------------------------------------------------------------------
FAR-FIELD MIXING SUMMARY:
Plume becomes vertically fully mixed ALREADY IN NEAR-FIELD at 0 m
downstream and continues as vertically mixed into the far-field.
```

PLUME BANK CONTACT SUMMARY:

Plume in unbounded section does not contact bank in this simulation.
****

TOXIC DILUTION ZONE SUMMARY

No TDZ was specified for this simulation.
****

REGULATORY MIXING ZONE SUMMARY

No RMZ and no ambient water quality standard have been specified.
****

FINAL DESIGN ADVICE AND COMMENTS

The discharge port or nozzle points towards the nearest bank.
Since this is an UNUSUAL DESIGN, check whether you have specified
correctly the port horizontal angle (SIGMA).

REMINDER: The user must take note that HYDRODYNAMIC MODELING by any known technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
CORMIX predictions on dilutions and concentrations (with associated
plume geometries) are reliable for the majority of cases and are accurate
to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it judges
the design configuration as highly complex and uncertain for prediction.

CORMIX1 PREDICTION FILE FOR TOTAL DISSOLVED SOLIDS:

```
CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX1:  Submerged Single Port Discharges
CORMIX-GI Version 4.1GT
-----------------------------------------------------------------------------
```

CASE DESCRIPTION

```
Site name/label:  Al-Jubail Saudi Arabia
Design case:      MSF Desalination Plant
FILE NAME:        E:\cormix\MansoorTDS.prd
Time stamp:       Tue Jul 16 14:55:33 2002
```

ENVIRONMENT PARAMETERS (metric units)

```
Unbounded section
HA  =    5.00 HD  =    4.00
UA  =   0.500 F   =   0.025 USTAR =0.2795E-01
UW  =   5.000 UWSTAR=0.5890E-02
Uniform density environment
STRCND= U      RHOAM = 1027.5000
```

DISCHARGE PARAMETERS (metric units)

```
BANK  = LEFT    DISTB =  2000.00
D0  =   0.900 A0  =   0.636 H0  =    0.20
THETA =   45.00 SIGMA =   90.00
U0  =  25.543 Q0  =  16.250     =0.1625E+02
RHO0 = 1046.5000 DRHO0 =-.1900E+02  GP0  =-.1813E+00
C0   = 0.2500E+05 CUNITS= ppm
IPOLL =  1      KS   =0.0000E+00  KD   =0.0000E+00
```

FLUX VARIABLES (metric units)

```
Q0   =0.1625E+02  M0   =0.4151E+03  J0   =-.2947E+01  SIGNJ0=   -1.0
Associated length scales (meters)
LQ  =    0.80  LM  =   53.57  Lm  =   40.75  Lb  =   23.57
Lmp  =  99999.00  Lbp  =  99999.00
```

NON-DIMENSIONAL PARAMETERS

```
FR0  =   63.23  R   =   51.09
```

FLOW CLASSIFICATION

```
1  Flow class (CORMIX1)      =   NH5    1
1  Applicable layer depth HS =    4.00  1
```

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS

```
C0   = 0.2500E+05 CUNITS= ppm
NTOX  =  0
NSTD  =  0
REGMZ =  0
XINT  =  2000.00  XMAX  =  2000.00
```

```
X-Y-Z COORDINATE SYSTEM:
ORIGIN is located at the bottom and below the center of the port:
2000.00 m  from the LEFT  bank/shore.
X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP =200 display intervals per module
BEGIN MOD101: DISCHARGE MODULE
COANDA ATTACHMENT immediately following the discharge.

  X     Y     Z     S      C         B
0.00  0.00  0.00   1.0  0.250E+05  0.64

END OF MOD101: DISCHARGE MODULE
-----------------------------------------------------------------------------
BEGIN CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION

Bottom-attached jet motion.
Profile definitions:
B = Gaussian 1/e (37%) half-width, normal to trajectory
Half wall jet, attached to bottom.
S = hydrodynamic centerline dilution
C = centerline concentration (includes reaction effects, if any)

  X     Y     Z     S      C         B
0.00  0.00  0.00   1.0  0.250E+05  0.45
0.00  0.12  0.00   1.0  0.250E+05  0.47
0.00  0.28  0.00   1.0  0.250E+05  0.49
0.00  0.44  0.00   1.0  0.250E+05  0.50
0.00  0.60  0.00   1.0  0.250E+05  0.52
0.00  0.76  0.00   1.0  0.250E+05  0.54
0.00  0.92  0.00   1.0  0.250E+05  0.56
0.00  1.08  0.00   1.0  0.250E+05  0.57
0.00  1.24  0.00   1.0  0.250E+05  0.59
0.00  1.36  0.00   1.0  0.250E+05  0.60
0.01  1.52  0.00   1.0  0.250E+05  0.62
0.01  1.68  0.00   1.0  0.250E+05  0.64
0.01  1.84  0.00   1.0  0.250E+05  0.66
0.01  2.00  0.00   1.0  0.250E+05  0.67
0.01  2.16  0.00   1.0  0.250E+05  0.69
0.01  2.32  0.00   1.0  0.250E+05  0.71
0.02  2.48  0.00   1.0  0.250E+05  0.73
0.02  2.64  0.00   1.0  0.250E+05  0.75
0.02  2.76  0.00   1.0  0.250E+05  0.76
0.02  2.92  0.00   1.0  0.246E+05  0.78
0.02  3.08  0.00   1.0  0.240E+05  0.79
0.03  3.24  0.00   1.1  0.235E+05  0.81
0.03  3.40  0.00   1.1  0.230E+05  0.83
0.03  3.56  0.00   1.1  0.225E+05  0.85
0.04  3.72  0.00   1.1  0.221E+05  0.86
0.04  3.88  0.00   1.2  0.216E+05  0.88
0.04  4.04  0.00   1.2  0.212E+05  0.90
```

0.04	4.16	0.00	1.2	0.209E+05	0.91
0.05	4.32	0.00	1.2	0.205E+05	0.93
0.05	4.48	0.00	1.2	0.201E+05	0.95
0.06	4.64	0.00	1.3	0.197E+05	0.97
0.06	4.80	0.00	1.3	0.194E+05	0.98
0.06	4.96	0.00	1.3	0.190E+05	1.00
0.07	5.12	0.00	1.3	0.187E+05	1.02
0.07	5.28	0.00	1.4	0.184E+05	1.04
0.08	5.44	0.00	1.4	0.181E+05	1.05
0.08	5.56	0.00	1.4	0.179E+05	1.07
0.08	5.72	0.00	1.4	0.176E+05	1.08
0.09	5.88	0.00	1.4	0.173E+05	1.10
0.09	6.04	0.00	1.5	0.170E+05	1.12
0.10	6.20	0.00	1.5	0.167E+05	1.14
0.10	6.36	0.00	1.5	0.165E+05	1.16
0.11	6.52	0.00	1.5	0.162E+05	1.17
0.12	6.68	0.00	1.6	0.160E+05	1.19
0.12	6.84	0.00	1.6	0.158E+05	1.21
0.13	6.96	0.00	1.6	0.156E+05	1.22
0.13	7.12	0.00	1.6	0.154E+05	1.24
0.14	7.28	0.00	1.7	0.151E+05	1.26
0.14	7.44	0.00	1.7	0.149E+05	1.28
0.15	7.60	0.00	1.7	0.147E+05	1.29
0.16	7.76	0.00	1.7	0.145E+05	1.31
0.16	7.92	0.00	1.7	0.143E+05	1.33
0.17	8.08	0.00	1.8	0.141E+05	1.35
0.18	8.24	0.00	1.8	0.140E+05	1.36
0.18	8.36	0.00	1.8	0.138E+05	1.38
0.19	8.52	0.00	1.8	0.136E+05	1.40
0.20	8.68	0.00	1.9	0.135E+05	1.41
0.20	8.84	0.00	1.9	0.133E+05	1.43
0.21	9.00	0.00	1.9	0.131E+05	1.45
0.22	9.16	0.00	1.9	0.130E+05	1.47
0.23	9.32	0.00	1.9	0.128E+05	1.48
0.24	9.48	0.00	2.0	0.127E+05	1.50
0.24	9.64	0.00	2.0	0.125E+05	1.52
0.25	9.76	0.00	2.0	0.124E+05	1.53
0.26	9.92	0.00	2.0	0.123E+05	1.55
0.27	10.08	0.00	2.1	0.121E+05	1.57
0.28	10.24	0.00	2.1	0.120E+05	1.59
0.28	10.39	0.00	2.1	0.119E+05	1.60
0.29	10.55	0.00	2.1	0.117E+05	1.62
0.30	10.71	0.00	2.2	0.116E+05	1.64
0.31	10.87	0.00	2.2	0.115E+05	1.66
0.32	11.03	0.00	2.2	0.114E+05	1.68
0.33	11.15	0.00	2.2	0.113E+05	1.69
0.34	11.31	0.00	2.2	0.111E+05	1.71
0.35	11.47	0.00	2.3	0.110E+05	1.72
0.36	11.63	0.00	2.3	0.109E+05	1.74
0.37	11.79	0.00	2.3	0.108E+05	1.76
0.38	11.95	0.00	2.3	0.107E+05	1.78
0.39	12.11	0.00	2.4	0.106E+05	1.80
0.40	12.27	0.00	2.4	0.105E+05	1.81

0.41	12.43	0.00	2.4	0.104E+05	1.83
0.42	12.55	0.00	2.4	0.103E+05	1.85
0.43	12.71	0.00	2.4	0.102E+05	1.86
0.44	12.87	0.00	2.5	0.101E+05	1.88
0.45	13.03	0.00	2.5	0.100E+05	1.90
0.46	13.19	0.00	2.5	0.992E+04	1.92
0.48	13.35	0.00	2.5	0.982E+04	1.94
0.49	13.51	0.00	2.6	0.973E+04	1.95
0.50	13.67	0.00	2.6	0.964E+04	1.97
0.51	13.83	0.00	2.6	0.956E+04	1.99
0.52	13.95	0.00	2.6	0.949E+04	2.00
0.53	14.11	0.00	2.7	0.941E+04	2.02
0.54	14.27	0.00	2.7	0.932E+04	2.04
0.56	14.43	0.00	2.7	0.924E+04	2.06
0.57	14.58	0.00	2.7	0.916E+04	2.08
0.58	14.74	0.00	2.8	0.908E+04	2.09
0.60	14.90	0.00	2.8	0.900E+04	2.11
0.61	15.06	0.00	2.8	0.892E+04	2.13
0.62	15.22	0.00	2.8	0.885E+04	2.15
0.63	15.34	0.00	2.8	0.879E+04	2.16
0.65	15.50	0.00	2.9	0.872E+04	2.18
0.66	15.66	0.00	2.9	0.865E+04	2.20
0.67	15.82	0.00	2.9	0.857E+04	2.22
0.69	15.98	0.00	2.9	0.850E+04	2.23
0.70	16.14	0.00	3.0	0.844E+04	2.25
0.72	16.30	0.00	3.0	0.837E+04	2.27
0.73	16.46	0.00	3.0	0.830E+04	2.29
0.75	16.62	0.00	3.0	0.823E+04	2.31
0.76	16.74	0.00	3.1	0.819E+04	2.32
0.77	16.90	0.00	3.1	0.812E+04	2.34
0.79	17.06	0.00	3.1	0.806E+04	2.36
0.80	17.21	0.00	3.1	0.800E+04	2.37
0.82	17.37	0.00	3.2	0.793E+04	2.39
0.84	17.53	0.00	3.2	0.787E+04	2.41
0.85	17.69	0.00	3.2	0.781E+04	2.43
0.87	17.85	0.00	3.2	0.775E+04	2.45
0.88	18.01	0.00	3.2	0.770E+04	2.47
0.90	18.13	0.00	3.3	0.765E+04	2.48
0.91	18.29	0.00	3.3	0.760E+04	2.50
0.93	18.45	0.00	3.3	0.754E+04	2.52
0.95	18.61	0.00	3.3	0.749E+04	2.53
0.96	18.77	0.00	3.4	0.743E+04	2.55
0.98	18.93	0.00	3.4	0.738E+04	2.57
1.00	19.08	0.00	3.4	0.732E+04	2.59
1.01	19.24	0.00	3.4	0.727E+04	2.61
1.03	19.40	0.00	3.5	0.722E+04	2.63
1.05	19.52	0.00	3.5	0.718E+04	2.64
1.06	19.68	0.00	3.5	0.713E+04	2.66
1.08	19.84	0.00	3.5	0.708E+04	2.68
1.10	20.00	0.00	3.6	0.703E+04	2.69
1.12	20.16	0.00	3.6	0.699E+04	2.71
1.14	20.32	0.00	3.6	0.694E+04	2.73
1.15	20.48	0.00	3.6	0.689E+04	2.75

1.17	20.63	0.00	3.7	0.684E+04	2.77
1.19	20.79	0.00	3.7	0.680E+04	2.79
1.21	20.91	0.00	3.7	0.676E+04	2.80
1.23	21.07	0.00	3.7	0.672E+04	2.82
1.25	21.23	0.00	3.7	0.667E+04	2.84
1.27	21.39	0.00	3.8	0.663E+04	2.86
1.29	21.55	0.00	3.8	0.659E+04	2.87
1.31	21.71	0.00	3.8	0.654E+04	2.89
1.33	21.87	0.00	3.8	0.650E+04	2.91
1.35	22.02	0.00	3.9	0.646E+04	2.93
1.37	22.18	0.00	3.9	0.642E+04	2.95
1.38	22.30	0.00	3.9	0.639E+04	2.96
1.40	22.46	0.00	3.9	0.635E+04	2.98
1.42	22.62	0.00	4.0	0.631E+04	3.00
1.44	22.78	0.00	4.0	0.627E+04	3.02
1.47	22.94	0.00	4.0	0.623E+04	3.04
1.49	23.09	0.00	4.0	0.619E+04	3.06
1.51	23.25	0.00	4.1	0.615E+04	3.08
1.53	23.41	0.00	4.1	0.611E+04	3.09
1.55	23.57	0.00	4.1	0.608E+04	3.11
1.57	23.69	0.00	4.1	0.605E+04	3.13
1.59	23.85	0.00	4.2	0.601E+04	3.15
1.61	24.01	0.00	4.2	0.598E+04	3.16
1.64	24.16	0.00	4.2	0.594E+04	3.18
1.66	24.32	0.00	4.2	0.590E+04	3.20
1.68	24.48	0.00	4.3	0.587E+04	3.22
1.71	24.64	0.00	4.3	0.583E+04	3.24
1.73	24.80	0.00	4.3	0.580E+04	3.26
1.75	24.96	0.00	4.3	0.577E+04	3.28
1.77	25.07	0.00	4.4	0.574E+04	3.29
1.79	25.23	0.00	4.4	0.571E+04	3.31
1.82	25.39	0.00	4.4	0.567E+04	3.33
1.84	25.55	0.00	4.4	0.564E+04	3.35
1.87	25.71	0.00	4.5	0.561E+04	3.37
1.89	25.87	0.00	4.5	0.558E+04	3.39
1.92	26.02	0.00	4.5	0.554E+04	3.40
1.94	26.18	0.00	4.5	0.551E+04	3.42
1.97	26.34	0.00	4.6	0.548E+04	3.44
1.98	26.46	0.00	4.6	0.546E+04	3.46
2.01	26.62	0.00	4.6	0.543E+04	3.48
2.04	26.77	0.00	4.6	0.540E+04	3.49
2.06	26.93	0.00	4.7	0.537E+04	3.51
2.09	27.09	0.00	4.7	0.534E+04	3.53
2.11	27.25	0.00	4.7	0.531E+04	3.55
2.14	27.41	0.00	4.7	0.528E+04	3.57
2.17	27.56	0.00	4.8	0.525E+04	3.59
2.19	27.72	0.00	4.8	0.522E+04	3.61
2.21	27.84	0.00	4.8	0.520E+04	3.62
2.24	28.00	0.00	4.8	0.517E+04	3.64
2.27	28.15	0.00	4.9	0.514E+04	3.66
2.29	28.31	0.00	4.9	0.512E+04	3.68
2.32	28.47	0.00	4.9	0.509E+04	3.70
2.35	28.63	0.00	4.9	0.506E+04	3.72

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2.38  28.79  0.00   5.0  0.504E+04  3.74
2.40  28.94  0.00   5.0  0.501E+04  3.76
2.43  29.10  0.00   5.0  0.498E+04  3.78
2.45  29.22  0.00   5.0  0.496E+04  3.79
2.48  29.38  0.00   5.1  0.494E+04  3.81
2.51  29.53  0.00   5.1  0.491E+04  3.83
2.54  29.69  0.00   5.1  0.489E+04  3.85
2.57  29.85  0.00   5.1  0.486E+04  3.87
2.60  30.01  0.00   5.2  0.484E+04  3.89
2.63  30.16  0.00   5.2  0.481E+04  3.91
2.66  30.32  0.00   5.2  0.479E+04  3.93
2.69  30.48  0.00   5.2  0.476E+04  3.95
2.71  30.59  0.00   5.3  0.474E+04  3.96
2.74  30.75  0.00   5.3  0.472E+04  3.98
2.77  30.91  0.00   5.3  0.470E+04  4.00
Cumulative travel time =        3. sec

END OF CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION

-----------------------------------------------------------------------------
BEGIN MOD133: LAYER BOUNDARY IMPINGEMENT/FULL VERTICAL MIXING

Control volume inflow:
X      Y       Z        S           C            B
2.77  30.91  0.00    5.3    0.470E+04    4.00

Profile definitions:
BV = layer depth (vertically mixed)
BH = top-hat half-width, in horizontal plane normal to trajectory
ZU = upper plume boundary (Z-coordinate)
ZL = lower plume boundary (Z-coordinate)
S  = hydrodynamic average (bulk) dilution
C  = average (bulk) concentration (includes reaction effects, if any)

     X       Y       Z       S          C          BV     BH     ZU     ZL
   -1.23  34.84  0.00   5.3     0.470E+04  0.00   0.00   0.00   0.00
   -0.76  34.84  0.00   5.3     0.470E+04  4.00   1.08   4.00   0.00
   -0.28  34.84  0.00   5.3     0.470E+04  4.00   1.52   4.00   0.00
    0.20  34.84  0.00   5.3     0.470E+04  4.00   2.15   4.00   0.00
    1.15  34.84  0.00   5.3     0.470E+04  4.00   2.41   4.00   0.00
    1.62  34.84  0.00   5.3     0.470E+04  4.00   2.64   4.00   0.00
    2.10  34.84  0.00   5.3     0.470E+04  4.00   2.85   4.00   0.00
    2.58  34.84  0.00   5.3     0.470E+04  4.00   3.04   4.00   0.00
    3.05  34.84  0.00   6.2     0.401E+04  4.00   3.23   4.00   0.00
    3.53  34.84  0.00   7.4     0.336E+04  4.00   3.40   4.00   0.00
Cumulative travel time =        5. sec

END OF MOD133: LAYER BOUNDARY IMPINGEMENT/FULL VERTICAL MIXING
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Phase 1: The plume is VERTICALLY FULLY MIXED over the entire layer depth.

```
Profile definitions:
BV = layer depth (vertically mixed)
BH = Gaussian 1/e (37%) half-width in horizontal plane normal to trajectory
ZU = upper plume boundary (Z-coordinate)
ZL = lower plume boundary (Z-coordinate)
S  = hydrodynamic centerline dilution
C  = centerline concentration (includes reaction effects, if any)

  X     Y     Z     S     C          BV    BH    ZU    ZL
 3.53  34.84  0.00  7.4  0.336E+04  4.00  2.77  4.00  0.00
 3.80  35.53  0.00  7.5  0.331E+04  4.00  2.84  4.00  0.00
 4.07  36.22  0.00  7.6  0.327E+04  4.00  2.90  4.00  0.00
 4.35  36.91  0.00  7.7  0.324E+04  4.00  2.97  4.00  0.00
 4.62  37.60  0.00  7.8  0.320E+04  4.00  3.04  4.00  0.00
 4.91  38.30  0.00  7.9  0.316E+04  4.00  3.10  4.00  0.00
 5.19  38.99  0.00  8.0  0.313E+04  4.00  3.17  4.00  0.00
 5.48  39.68  0.00  8.1  0.310E+04  4.00  3.24  4.00  0.00
 5.77  40.37  0.00  8.2  0.306E+04  4.00  3.30  4.00  0.00
 6.07  41.07  0.00  8.2  0.303E+04  4.00  3.37  4.00  0.00
 6.37  41.76  0.00  8.3  0.300E+04  4.00  3.43  4.00  0.00
 6.67  42.45  0.00  8.4  0.297E+04  4.00  3.50  4.00  0.00
 6.97  43.14  0.00  8.5  0.294E+04  4.00  3.56  4.00  0.00
 7.28  43.83  0.00  8.6  0.291E+04  4.00  3.63  4.00  0.00
 7.59  44.53  0.00  8.7  0.289E+04  4.00  3.70  4.00  0.00
 7.90  45.22  0.00  8.7  0.286E+04  4.00  3.76  4.00  0.00
 8.22  45.91  0.00  8.8  0.284E+04  4.00  3.83  4.00  0.00
 8.53  46.60  0.00  8.9  0.281E+04  4.00  3.89  4.00  0.00
 8.86  47.29  0.00  9.0  0.279E+04  4.00  3.96  4.00  0.00
 9.18  47.99  0.00  9.1  0.276E+04  4.00  4.02  4.00  0.00
 9.51  48.68  0.00  9.1  0.274E+04  4.00  4.09  4.00  0.00
 9.84  49.37  0.00  9.2  0.272E+04  4.00  4.15  4.00  0.00
10.17  50.06  0.00  9.3  0.269E+04  4.00  4.22  4.00  0.00
10.50  50.75  0.00  9.4  0.267E+04  4.00  4.28  4.00  0.00
10.84  51.45  0.00  9.4  0.265E+04  4.00  4.35  4.00  0.00
11.18  52.14  0.00  9.5  0.263E+04  4.00  4.41  4.00  0.00
11.52  52.83  0.00  9.6  0.261E+04  4.00  4.47  4.00  0.00
11.87  53.52  0.00  9.6  0.259E+04  4.00  4.54  4.00  0.00
12.22  54.21  0.00  9.7  0.257E+04  4.00  4.60  4.00  0.00
12.57  54.91  0.00  9.8  0.255E+04  4.00  4.67  4.00  0.00
12.92  55.60  0.00  9.9  0.254E+04  4.00  4.73  4.00  0.00
13.28  56.29  0.00  9.9  0.252E+04  4.00  4.80  4.00  0.00
13.63  56.98  0.00 10.0  0.250E+04  4.00  4.86  4.00  0.00
13.99  57.67  0.00 10.1  0.248E+04  4.00  4.92  4.00  0.00
14.36  58.37  0.00 10.1  0.247E+04  4.00  4.99  4.00  0.00
14.72  59.06  0.00 10.2  0.245E+04  4.00  5.05  4.00  0.00
15.09  59.75  0.00 10.3  0.243E+04  4.00  5.11  4.00  0.00
15.46  60.44  0.00 10.3  0.242E+04  4.00  5.18  4.00  0.00
15.84  61.14  0.00 10.4  0.240E+04  4.00  5.24  4.00  0.00
16.21  61.83  0.00 10.5  0.239E+04  4.00  5.31  4.00  0.00
16.59  62.52  0.00 10.5  0.237E+04  4.00  5.37  4.00  0.00
16.97  63.21  0.00 10.6  0.236E+04  4.00  5.43  4.00  0.00
17.35  63.90  0.00 10.7  0.234E+04  4.00  5.50  4.00  0.00
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17.74	64.60	0.00	10.7	0.233E+04	4.00	5.56	4.00	0.00
18.12	65.29	0.00	10.8	0.231E+04	4.00	5.62	4.00	0.00
18.51	65.98	0.00	10.9	0.230E+04	4.00	5.69	4.00	0.00
18.90	66.67	0.00	10.9	0.229E+04	4.00	5.75	4.00	0.00
19.30	67.36	0.00	11.0	0.227E+04	4.00	5.81	4.00	0.00
19.69	68.06	0.00	11.1	0.226E+04	4.00	5.87	4.00	0.00
20.09	68.75	0.00	11.1	0.225E+04	4.00	5.94	4.00	0.00
20.49	69.44	0.00	11.2	0.224E+04	4.00	6.00	4.00	0.00
20.90	70.13	0.00	11.2	0.222E+04	4.00	6.06	4.00	0.00
21.30	70.82	0.00	11.3	0.221E+04	4.00	6.13	4.00	0.00
21.71	71.52	0.00	11.4	0.220E+04	4.00	6.19	4.00	0.00
22.12	72.21	0.00	11.4	0.219E+04	4.00	6.25	4.00	0.00
22.53	72.90	0.00	11.5	0.218E+04	4.00	6.31	4.00	0.00
22.94	73.59	0.00	11.5	0.216E+04	4.00	6.38	4.00	0.00
23.36	74.28	0.00	11.6	0.215E+04	4.00	6.44	4.00	0.00
23.78	74.98	0.00	11.7	0.214E+04	4.00	6.50	4.00	0.00
24.20	75.67	0.00	11.7	0.213E+04	4.00	6.56	4.00	0.00
24.62	76.36	0.00	11.8	0.212E+04	4.00	6.63	4.00	0.00
25.05	77.05	0.00	11.8	0.211E+04	4.00	6.69	4.00	0.00
25.47	77.74	0.00	11.9	0.210E+04	4.00	6.75	4.00	0.00
25.90	78.44	0.00	12.0	0.209E+04	4.00	6.81	4.00	0.00
26.33	79.13	0.00	12.0	0.208E+04	4.00	6.87	4.00	0.00
26.77	79.82	0.00	12.1	0.207E+04	4.00	6.94	4.00	0.00
27.20	80.51	0.00	12.1	0.206E+04	4.00	7.00	4.00	0.00
27.64	81.21	0.00	12.2	0.205E+04	4.00	7.06	4.00	0.00
28.08	81.90	0.00	12.2	0.204E+04	4.00	7.12	4.00	0.00
28.52	82.59	0.00	12.3	0.203E+04	4.00	7.18	4.00	0.00
28.96	83.28	0.00	12.4	0.202E+04	4.00	7.25	4.00	0.00
29.41	83.97	0.00	12.4	0.201E+04	4.00	7.31	4.00	0.00
29.86	84.67	0.00	12.5	0.200E+04	4.00	7.37	4.00	0.00
30.31	85.36	0.00	12.5	0.200E+04	4.00	7.43	4.00	0.00
30.76	86.05	0.00	12.6	0.199E+04	4.00	7.49	4.00	0.00
31.21	86.74	0.00	12.6	0.198E+04	4.00	7.55	4.00	0.00
31.67	87.43	0.00	12.7	0.197E+04	4.00	7.62	4.00	0.00
32.12	88.13	0.00	12.8	0.196E+04	4.00	7.68	4.00	0.00
32.58	88.82	0.00	12.8	0.195E+04	4.00	7.74	4.00	0.00
33.04	89.51	0.00	12.9	0.194E+04	4.00	7.80	4.00	0.00
33.51	90.20	0.00	12.9	0.194E+04	4.00	7.86	4.00	0.00
33.97	90.89	0.00	13.0	0.193E+04	4.00	7.92	4.00	0.00
34.44	91.59	0.00	13.0	0.192E+04	4.00	7.98	4.00	0.00
34.91	92.28	0.00	13.1	0.191E+04	4.00	8.04	4.00	0.00
35.38	92.97	0.00	13.1	0.190E+04	4.00	8.10	4.00	0.00
35.85	93.66	0.00	13.2	0.190E+04	4.00	8.17	4.00	0.00
36.33	94.35	0.00	13.2	0.189E+04	4.00	8.23	4.00	0.00
36.80	95.05	0.00	13.3	0.188E+04	4.00	8.29	4.00	0.00
37.28	95.74	0.00	13.3	0.187E+04	4.00	8.35	4.00	0.00
37.76	96.43	0.00	13.4	0.187E+04	4.00	8.41	4.00	0.00
38.24	97.12	0.00	13.4	0.186E+04	4.00	8.47	4.00	0.00
38.73	97.81	0.00	13.5	0.185E+04	4.00	8.53	4.00	0.00
39.21	98.51	0.00	13.5	0.185E+04	4.00	8.59	4.00	0.00
39.70	99.20	0.00	13.6	0.184E+04	4.00	8.65	4.00	0.00
40.19	99.89	0.00	13.6	0.183E+04	4.00	8.71	4.00	0.00
40.68	100.58	0.00	13.7	0.183E+04	4.00	8.77	4.00	0.00

41.18	101.27	0.00	13.7	0.182E+04	4.00	8.83	4.00	0.00
41.67	101.97	0.00	13.8	0.181E+04	4.00	8.89	4.00	0.00
42.17	102.66	0.00	13.8	0.181E+04	4.00	8.95	4.00	0.00
42.67	103.35	0.00	13.9	0.180E+04	4.00	9.01	4.00	0.00
43.17	104.04	0.00	13.9	0.179E+04	4.00	9.07	4.00	0.00
43.67	104.74	0.00	14.0	0.179E+04	4.00	9.14	4.00	0.00
44.17	105.43	0.00	14.0	0.178E+04	4.00	9.20	4.00	0.00
44.68	106.12	0.00	14.1	0.177E+04	4.00	9.26	4.00	0.00
45.19	106.81	0.00	14.1	0.177E+04	4.00	9.32	4.00	0.00
45.70	107.50	0.00	14.2	0.176E+04	4.00	9.38	4.00	0.00
46.21	108.20	0.00	14.2	0.176E+04	4.00	9.44	4.00	0.00
46.72	108.89	0.00	14.3	0.175E+04	4.00	9.50	4.00	0.00
47.24	109.58	0.00	14.3	0.174E+04	4.00	9.56	4.00	0.00
47.75	110.27	0.00	14.4	0.174E+04	4.00	9.62	4.00	0.00
48.27	110.96	0.00	14.4	0.173E+04	4.00	9.68	4.00	0.00
48.79	111.66	0.00	14.5	0.173E+04	4.00	9.74	4.00	0.00
49.31	112.35	0.00	14.5	0.172E+04	4.00	9.79	4.00	0.00
49.83	113.04	0.00	14.6	0.171E+04	4.00	9.85	4.00	0.00
50.36	113.73	0.00	14.6	0.171E+04	4.00	9.91	4.00	0.00
50.89	114.42	0.00	14.7	0.170E+04	4.00	9.97	4.00	0.00
51.41	115.12	0.00	14.7	0.170E+04	4.00	10.03	4.00	0.00
51.94	115.81	0.00	14.8	0.169E+04	4.00	10.09	4.00	0.00
52.48	116.50	0.00	14.8	0.169E+04	4.00	10.15	4.00	0.00
53.01	117.19	0.00	14.9	0.168E+04	4.00	10.21	4.00	0.00
53.55	117.88	0.00	14.9	0.168E+04	4.00	10.27	4.00	0.00
54.08	118.58	0.00	15.0	0.167E+04	4.00	10.33	4.00	0.00
54.62	119.27	0.00	15.0	0.167E+04	4.00	10.39	4.00	0.00
55.16	119.96	0.00	15.1	0.166E+04	4.00	10.45	4.00	0.00
55.70	120.65	0.00	15.1	0.166E+04	4.00	10.51	4.00	0.00
56.25	121.34	0.00	15.1	0.165E+04	4.00	10.57	4.00	0.00
56.79	122.04	0.00	15.2	0.165E+04	4.00	10.63	4.00	0.00
57.34	122.73	0.00	15.2	0.164E+04	4.00	10.69	4.00	0.00
57.89	123.42	0.00	15.3	0.164E+04	4.00	10.75	4.00	0.00
58.44	124.11	0.00	15.3	0.163E+04	4.00	10.80	4.00	0.00
58.99	124.81	0.00	15.4	0.163E+04	4.00	10.86	4.00	0.00
59.54	125.50	0.00	15.4	0.162E+04	4.00	10.92	4.00	0.00
60.10	126.19	0.00	15.5	0.162E+04	4.00	10.98	4.00	0.00
60.65	126.88	0.00	15.5	0.161E+04	4.00	11.04	4.00	0.00
61.21	127.57	0.00	15.6	0.161E+04	4.00	11.10	4.00	0.00
61.77	128.27	0.00	15.6	0.160E+04	4.00	11.16	4.00	0.00
62.33	128.96	0.00	15.6	0.160E+04	4.00	11.22	4.00	0.00
62.90	129.65	0.00	15.7	0.159E+04	4.00	11.28	4.00	0.00
63.46	130.34	0.00	15.7	0.159E+04	4.00	11.33	4.00	0.00
64.03	131.03	0.00	15.8	0.158E+04	4.00	11.39	4.00	0.00
64.59	131.73	0.00	15.8	0.158E+04	4.00	11.45	4.00	0.00
65.16	132.42	0.00	15.9	0.158E+04	4.00	11.51	4.00	0.00
65.73	133.11	0.00	15.9	0.157E+04	4.00	11.57	4.00	0.00
66.31	133.80	0.00	15.9	0.157E+04	4.00	11.63	4.00	0.00
66.88	134.49	0.00	16.0	0.156E+04	4.00	11.69	4.00	0.00
67.46	135.19	0.00	16.0	0.156E+04	4.00	11.74	4.00	0.00
68.03	135.88	0.00	16.1	0.155E+04	4.00	11.80	4.00	0.00
68.61	136.57	0.00	16.1	0.155E+04	4.00	11.86	4.00	0.00
69.19	137.26	0.00	16.2	0.155E+04	4.00	11.92	4.00	0.00

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69.77  137.95  0.00  16.2  0.154E+04  4.00  11.98  4.00  0.00
70.36  138.65  0.00  16.3  0.154E+04  4.00  12.04  4.00  0.00
70.94  139.34  0.00  16.3  0.153E+04  4.00  12.09  4.00  0.00
71.53  140.03  0.00  16.3  0.153E+04  4.00  12.15  4.00  0.00
72.12  140.72  0.00  16.4  0.153E+04  4.00  12.21  4.00  0.00
72.71  141.41  0.00  16.4  0.152E+04  4.00  12.27  4.00  0.00
73.30  142.11  0.00  16.5  0.152E+04  4.00  12.33  4.00  0.00
73.89  142.80  0.00  16.5  0.151E+04  4.00  12.39  4.00  0.00
74.48  143.49  0.00  16.5  0.151E+04  4.00  12.44  4.00  0.00
75.08  144.18  0.00  16.6  0.151E+04  4.00  12.50  4.00  0.00
75.68  144.87  0.00  16.6  0.150E+04  4.00  12.56  4.00  0.00
76.28  145.57  0.00  16.7  0.150E+04  4.00  12.62  4.00  0.00
76.88  146.26  0.00  16.7  0.150E+04  4.00  12.67  4.00  0.00
77.48  146.95  0.00  16.8  0.149E+04  4.00  12.73  4.00  0.00
78.08  147.64  0.00  16.8  0.149E+04  4.00  12.79  4.00  0.00
78.68  148.34  0.00  16.8  0.148E+04  4.00  12.85  4.00  0.00
79.29  149.03  0.00  16.9  0.148E+04  4.00  12.91  4.00  0.00
79.90  149.72  0.00  16.9  0.148E+04  4.00  12.96  4.00  0.00
80.51  150.41  0.00  17.0  0.147E+04  4.00  13.02  4.00  0.00
81.12  151.10  0.00  17.0  0.147E+04  4.00  13.08  4.00  0.00
81.73  151.80  0.00  17.0  0.147E+04  4.00  13.14  4.00  0.00
82.34  152.49  0.00  17.1  0.146E+04  4.00  13.19  4.00  0.00
82.96  153.18  0.00  17.1  0.146E+04  4.00  13.25  4.00  0.00
83.57  153.87  0.00  17.2  0.146E+04  4.00  13.31  4.00  0.00
84.19  154.56  0.00  17.2  0.145E+04  4.00  13.37  4.00  0.00
84.81  155.26  0.00  17.2  0.145E+04  4.00  13.42  4.00  0.00
85.43  155.95  0.00  17.3  0.145E+04  4.00  13.48  4.00  0.00
86.05  156.64  0.00  17.3  0.144E+04  4.00  13.54  4.00  0.00
86.68  157.33  0.00  17.4  0.144E+04  4.00  13.60  4.00  0.00
87.30  158.02  0.00  17.4  0.144E+04  4.00  13.65  4.00  0.00
87.93  158.72  0.00  17.4  0.143E+04  4.00  13.71  4.00  0.00
88.56  159.41  0.00  17.5  0.143E+04  4.00  13.77  4.00  0.00
89.19  160.10  0.00  17.5  0.143E+04  4.00  13.83  4.00  0.00
89.82  160.79  0.00  17.6  0.142E+04  4.00  13.88  4.00  0.00
90.45  161.48  0.00  17.6  0.142E+04  4.00  13.94  4.00  0.00
91.08  162.18  0.00  17.6  0.142E+04  4.00  14.00  4.00  0.00
91.72  162.87  0.00  17.7  0.141E+04  4.00  14.05  4.00  0.00
92.35  163.56  0.00  17.7  0.141E+04  4.00  14.11  4.00  0.00
92.99  164.25  0.00  17.8  0.141E+04  4.00  14.17  4.00  0.00
93.63  164.94  0.00  17.8  0.140E+04  4.00  14.23  4.00  0.00
94.27  165.64  0.00  17.8  0.140E+04  4.00  14.28  4.00  0.00
94.91  166.33  0.00  17.9  0.140E+04  4.00  14.34  4.00  0.00
95.56  167.02  0.00  17.9  0.140E+04  4.00  14.40  4.00  0.00
96.20  167.71  0.00  18.0  0.139E+04  4.00  14.45  4.00  0.00
96.85  168.40  0.00  18.0  0.139E+04  4.00  14.51  4.00  0.00
97.50  169.10  0.00  18.0  0.139E+04  4.00  14.57  4.00  0.00
98.14  169.79  0.00  18.1  0.138E+04  4.00  14.62  4.00  0.00
98.79  170.48  0.00  18.1  0.138E+04  4.00  14.68  4.00  0.00
99.45  171.17  0.00  18.2  0.138E+04  4.00  14.74  4.00  0.00
100.10  171.87  0.00  18.2  0.137E+04  4.00  14.79  4.00  0.00
100.75  172.56  0.00  18.2  0.137E+04  4.00  14.85  4.00  0.00
101.41  173.25  0.00  18.3  0.137E+04  4.00  14.91  4.00  0.00
Cumulative travel time =        240. sec
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Entire region is occupied by Phase 1.
Plume does not re-stratify in this flow region.

END OF MOD154: VERTICALLY MIXED PLUME IN WEAK CROSS-FLOW
-----------------------------------------------------------------------------
** End of NEAR-FIELD REGION (NFR) **

CORMIX1: Submerged Single Port Discharges          End of Prediction File
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