

AP - 75

**AMENDED  
STAGE 2  
WORKPLANS**

**DATE:**

**5-27-08**

---

RECEIVED May 27, 2008  
2008 MAY 30 PM 1 39

## **AMENDED STAGE 2 ABATEMENT PLAN**

### **BD JCT. J-26 SITE (AP-75)**

---

### **T21S, R37E, SECTION 26, UNIT LETTER J**

### **LEA COUNTY, NEW MEXICO**



Prepared by:



P. O. Box 7624  
Midland, Texas 79708

Prepared for:



122 West Taylor  
Hobbs, New Mexico 88240

RECEIVED

2008 MAY 30 PM 1 39



CERTIFIED MAIL

RETURN RECEIPT NO. 7099 3400 0017 1737 2022

May 27, 2008

Mr. Edward Hansen  
New Mexico Energy, Minerals, & Natural Resources  
Oil Conservation Division, Environmental Bureau  
1220 S. St. Francis Drive  
Santa Fe, New Mexico 87504

**RE: Amended Stage Abatement Plan (AP-75)**  
**BD Jct. J-26 Site**  
**T21S-R37E-Section 26, Unit Letter J**  
**Lea County, New Mexico**

Dear Mr. Hansen

On behalf of Rice Operating Company (ROC), enclosed is the *Amended Stage 2 Abatement Plan* for the above-referenced site in response to your February 13, 2008 email recommendations.

If you have any questions please call me at 432-638-8740 or Kristin Pope at 505-393-9174.

Sincerely,

A handwritten signature in black ink, appearing to read "Gilbert Van Deventer", is written over a horizontal line.

Gilbert Van Deventer, REM, PG  
Trident Environmental

cc: JSC, KFP, MB

Gil Van Deventer

---

From: "Gil Van Deventer" <gilbertvandeventer@suddenlink.net>  
To: "Hansen, Edward J., EMNRD" <edwardj.hansen@state.nm.us>  
Cc: "Larry Johnson" <larry.johnson@state.nm.us>; "Kristin Pope" <kpope@riceswd.com>; "Marvin Burrows" <mburrows@riceswd.com>  
Sent: Tuesday, May 27, 2008 7:08 PM  
Attach: J26\_AS2AP\_text.pdf  
Subject: Amended Stage 2 Abatement Plan for the BD Jct J-26 Site (AP-75)

Subject: Amended Stage 2 Abatement Plan

Site Name: BD Jct J-26 Site (AP-75)

Site Location: T21S - R37E - Section 26, Unit Letter J

Site Agent: RICE Operating Company

Hello Edward:

Trident Environmental is pleased to submit the attached *Amended Stage 2 Abatement Plan* (AP-75) for the above-referenced site. The attached version is abbreviated to include mostly text to keep the file size small enough for transmission by email. One complete hard copy and one complete copy on compact disk is also being sent today via USPS Certified Mail (# 7099 3400 0017 1737 2022). A copy will be hand delivered to the NMOCD District 1 office in Hobbs next week.

If you have any questions, please contact me at 432-638-8740, or Kristin Pope or Marvin Burrows at Rice Operating Company (505-393-9174).

Thanks -Gil

Gilbert J. Van Deventer, PG, REM  
Trident Environmental  
P. O. Box 7624, Midland TX 79708  
Work/Mobile: 432-638-8740  
Fax: 413-403-9968  
Home: 432-682-0727

**CONFIDENTIALITY NOTICE**

This message (including attachments) is subject as a confidential communication and is intended solely for the use of the addressee. It is not intended for transmission to, or receipt by, any unauthorized person. If you are not the intended recipient or received these documents by mistake, please contact the sender by return e-mail. If you are not the intended recipient, you are hereby notified that any disclosure, copying, distribution, action or reliance upon the contents of the documents is strictly prohibited.



## TABLE OF CONTENTS

1.0	EXECUTIVE SUMMARY.....	1
2.0	CHRONOLOGY OF EVENTS .....	2
3.0	BACKGROUND .....	4
3.1	SITE LOCATION AND LAND USE .....	4
3.2	SUMMARY OF PREVIOUS WORK AND INVESTIGATIONS .....	4
4.0	GEOLOGY AND HYDROGEOLOGY .....	7
4.1	REGIONAL AND LOCAL GEOLOGY .....	7
4.2	REGIONAL AND LOCAL HYDROGEOLOGY.....	7
5.0	GROUNDWATER QUALITY.....	8
5.1	MONITORING PROGRAM.....	8
6.0	FATE AND TRANSPORT MODELING RESULTS.....	14
7.0	AMENDED STAGE 2 ABATEMENT PLAN.....	15
7.1	PROPOSED MONITORING/RECOVERY WELL INSTALLATIONS.....	15
7.2	SOURCE REMOVAL TESTING AND PROPOSED ABATEMENT OPTIONS.....	15
7.3	SCHEDULE OF ACTIVITIES .....	17

## TABLES

TABLE 1.....SUMMARY OF WATER WELL DATA .....	8
TABLE 2.....REGIONAL GROUNDWATER SAMPLING RESULTS .....	9
TABLE 3.....HISTORICAL GROUNDWATER SAMPLING RESULTS.....	13

## FIGURES

FIGURE 1..... SITE TOPOGRAPHIC MAP .....	5
FIGURE 2..... SITE AERIAL PHOTO MAP .....	6
FIGURE 3..... REGIONAL GROUNDWATER GRADIENT AND CHLORIDE/TDS CONCENTRATION MAP .....	11
FIGURE 4..... LOCAL GROUNDWATER GRADIENT AND CHLORIDE/TDS CONCENTRATION MAP .....	12

## APPENDICES

APPENDIX A ....DESCRIPTION OF FATE & TRANSPORT MODELING PROCEDURES AND PARAMETER INPUTS	
APPENDIX B .....DOCUMENTATION OF WINTRAN (VERSION 1.03) FATE & TRANSPORT MODEL CAPABILITIES AND BENCHMARKING	
APPENDIX C ....AQUIFER TEST PROCEDURES AND OUTPUT	
APPENDIX D ....LABORATORY REPORTS & CHAINS OF CUSTODY	
APPENDIX E .....NMOCD CORRESPONDENCE	

## 1.0 EXECUTIVE SUMMARY

This Amended Stage 2 Abatement Plan presents the results of the characterization activities performed by Trident Environmental and the characterization and site closure activities performed by ROC at the Jct. J-26 site. This plan fulfills the obligations of ROC presented in the Stage 1 and 2 Abatement Plan of December 5, 2005, which was approved by NMOCD on June 26, 2006. It also includes amended groundwater abatement options for technical deficiencies set forth by the NMOCD in their email dated February 13, 2008 (Appendix E).

The following corrective actions were performed in accordance with the Stage 1 and 2 Abatement Plan:

- Quarterly groundwater monitoring activities of the three on site monitoring wells were continued to document the return of chloride and total dissolved solids (TDS) concentrations to background levels. The 2007 Annual Groundwater Monitoring Report was submitted to the NMOCD on March 18, 2008.
- Regional groundwater sampling was conducted to confirm that remediation of the constituents of concern is taking place, changes in the local and regional groundwater flow directions were noted, and ambient groundwater chemistry was confirmed.
- Data was input into a fate and transport model (WinTran - Version 1.3) to forecast the movement and attenuation of the chloride/TDS plume by dispersion and abatement by the water supply wells.

Since July 2004, chloride and TDS concentrations at the Jct. J-26 site have generally remained at or near background levels in each of the three on site monitoring wells. Background concentrations of chlorides and TDS at the site have been confirmed through recent laboratory analysis of several surrounding wells and research of local groundwater data. There is strong evidence that the continual withdrawal of groundwater by several supply wells for the operation of the Eunice Gas Plant has assisted in the redirection and recovery of residual chloride and TDS constituents from the Jct. J-26 site. In addition, WinTran fate and transport simulations show the effects of the water supply wells and natural dispersion in attenuating chloride and TDS constituents.

However, on February 13, 2008 (Appendix E) the NMOCD requested via email communication for ROC to install additional monitoring wells and a groundwater recovery system downgradient of the BD Jct. J-26 Site. ROC proposes a phased approach for abatement by converting one of the additional downgradient monitoring wells for groundwater recovery after first confirming that the groundwater resource in the area will achieve the highest environmental benefit via a groundwater extraction system. A more detailed scope of additional characterization and abatement options is included in section 7.0.

## 2.0 CHRONOLOGY OF EVENTS

April 23, 2002	Initial soil sampling activities were conducted to delineate the extent of chloride and hydrocarbon-impacted soils near the Jct. J-26.
September 2002	Excavation of chloride and TPH-impacted soil was completed to a depth of 42 feet bgs. 480 yd <sup>3</sup> of the impacted soils were removed and disposed. Imported backfill was placed in the deep excavation from 42 feet to 27 feet bgs. A 12-inch compacted clay layer was then installed prior to backfilling with the remediated soil in 3-foot lifts. A second 12-inch compacted clay layer was installed at 5 feet bgs. The remaining remediated soil was placed above the clay layer and contoured to drain rainwater away from the area. A new replacement junction box was installed about 60 feet north of the former location. The surface was then reseeded and monitored for growth which resulted in re-establishing the native vegetation.
October 10, 2002	One monitoring well (MW-1) was installed immediately adjacent to the southeast corner of the excavated area to further assess if groundwater was impacted with chlorides. Subsequent sampling of MW-1 confirmed that groundwater was impacted with chloride and TDS levels above WQCC standards; however there was no hydrocarbon impact based on BTEX concentrations below laboratory detection limit of 0.001 mg/L.
October 29, 2002	The disclosure report detailing all of the above-referenced work was completed and forwarded to the NMOCD in early 2003.
December 13, 2002	ROC notified the NMOCD Environmental Bureau Chief of groundwater impact in accordance with NM Rule 116.
June 20, 2003	A work plan addressing further actions was submitted by Trident Environmental to Wayne Price at the NMOCD office in Santa Fe.
June 27, 2003	The work plan was approved by Wayne Price of the NMOCD office in Santa Fe.
August 19, 2003	Monitoring wells MW-2 and MW-3 were installed approximately 220 feet down gradient (south-southeast) and approximately 150 feet upgradient (northwest) of MW-1, respectively. Subsequent sampling results indicated MW-2 and MW-3 delineated the downgradient and upgradient extent of chloride and TDS impact to groundwater.
December 16, 2004	Trident Environmental submitted a request to Wayne Price of the NMOCD office in Santa Fe for further actions regarding the chloride and TDS-impacted groundwater at the BD Jct. J-26 site.

January 28, 2005	Trident Environmental submitted an Update to the Site Plan which described the findings of assessment activities and proposed corrective actions for the Jct. J-26 site.
May 5, 2005	Mr. Daniel Sanchez of the NMOCD requested that ROC submit an abatement plan to the NMOCD pursuant to Rule 19.
December 5, 2005	A Stage 1 and 2 Abatement Plan was prepared by R. T. Hicks Consultants Ltd. and submitted to the NMOCD
April 17, 2006	ROC submitted proof of public notifications to the NMOCD
June 26, 2006	NMOCD approved the Stage 1 & 2 Abatement Plan
August 1, 2006	Depth to water measurements and samples for chloride and TDS analysis were obtained from several off site wells in the surrounding area to confirm changes in the local and regional groundwater flow directions and ambient groundwater chemistry.
October 4, 2006	Trident Environmental initiated fate and transport simulations for the site to forecast the movement and attenuation of the chloride/TDS plume by dispersion and abatement by the area water supply wells.
November 22, 2006	Trident Environmental performed an aquifer test at two nearby water supply wells to determine site-specific hydrological parameters.
February 5, 2007	Trident Environmental submitted the 2006 Annual Groundwater Monitoring Report to the NMOCD.
February 19, 2007	Trident completed fate and transport simulations for the site.
November 20, 2007	Trident Environmental submitted a Stage 2 Final Investigation and Abatement Completion Report to the NMOCD.
February 13, 2008	NMOCD requested ROC to submit an Amended Stage 2 Abatement Plan that included additional downgradient monitoring wells and a groundwater recovery system.
March 18, 2008	Trident Environmental submitted the 2007 Annual Groundwater Monitoring Report to the NMOCD.



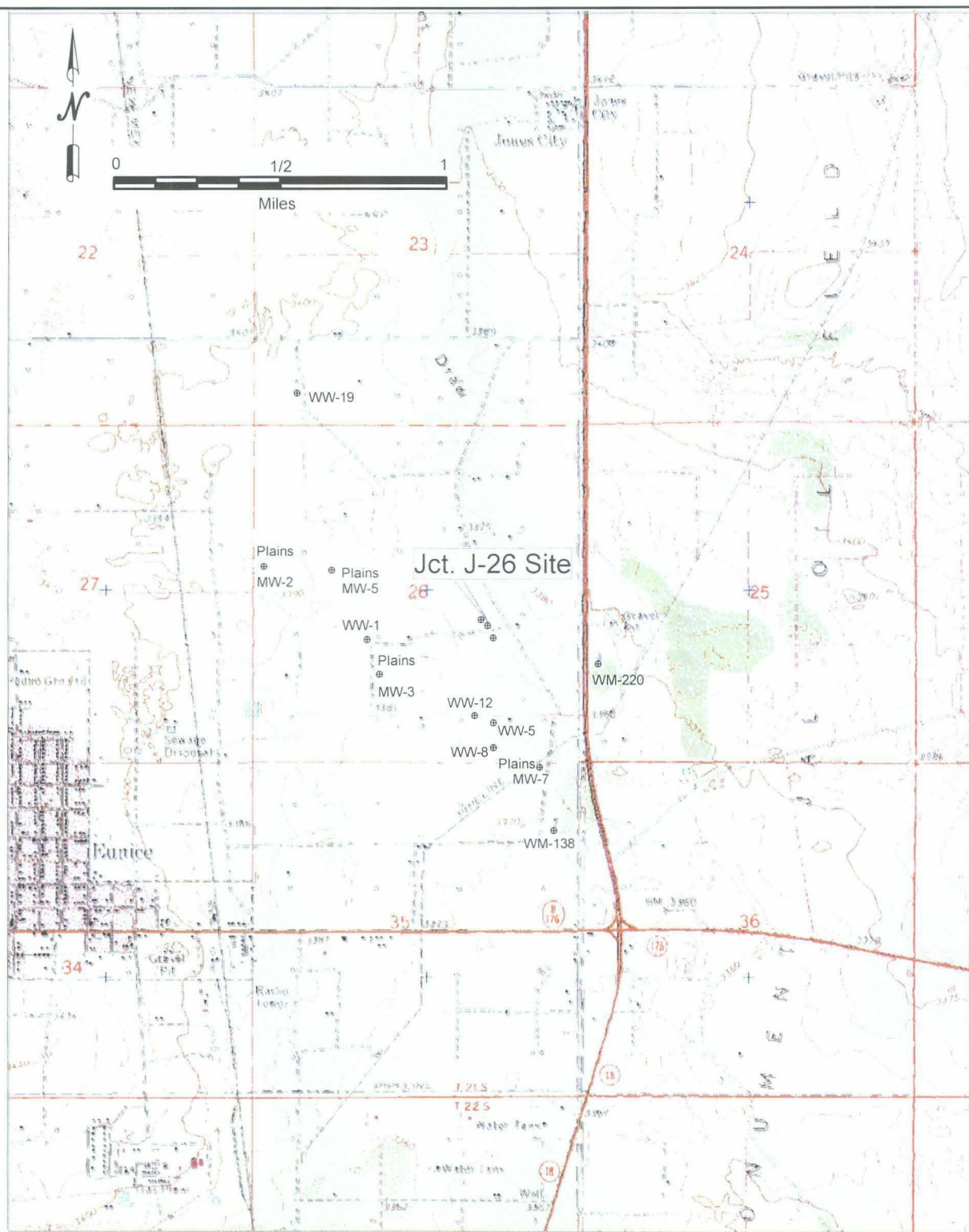
### **3.0 BACKGROUND**

#### **3.1 SITE LOCATION AND LAND USE**

The Jct. J-26 site is located in township 21 south, range 37 east, section 26, unit letter J approximately 1 mile north-northwest of the intersection of NM State Highway 18 and County Highway 176 near Eunice, NM as shown on the attached topographic map (Figure 1) and aerial photographic map (Figure 2). Land in the site area is primarily utilized for oil and gas production and cattle ranching.

#### **3.2 SUMMARY OF PREVIOUS WORK AND INVESTIGATIONS**

Brief descriptions of previous work and investigations are summarized in chronological order in section 2.0.



1-D TopoQuads Copyright © 1999 DeLorme, Vermont, ME 05490 Source Data: USGS

1:24,000 Scale 1:24,000 Date: 13-0 Datum: NAD83



BD J-26 Junction Box Site  
T21S - R37E - Section 26 - Unit J  
**RICE** Operating Company

FIGURE 1  
TOPOGRAPHIC MAP





BD J-26 Junction Box Site  
T21S - R37E - Section 26 - Unit J  
**RICE** *Operating Company*

FIGURE 2  
AERIAL PHOTO (2005)



## **GEOLOGY AND HYDROGEOLOGY**

### **4.1 REGIONAL AND LOCAL GEOLOGY**

The Jct. J-26 site is situated within the center of Monument Draw. According to published information (Nicholson and Clebsch, 1961, Barnes, 1976, and Anderson, Jones, and Green, 1997) the site is underlain by Quaternary Colluvial Deposits composed of sand, silt, and gravel deposited by slopewash, and talus from the Tertiary Ogallala Formation. These colluvial deposits are often calichified (indurated with cemented calcium carbonate) with caliche layers from 1 to 20 feet thick. The thickness of the colluvial deposits and Ogallala Formation is approximately 45 feet; however it varies locally as a result of significant paleo-topography at the top of the underlying Triassic Dockum Group. Since Cretaceous Age rocks in the region have been removed by pre-Tertiary erosion, the alluvium and Ogallala Formation rest unconformably on the Triassic Dockum Group. The uppermost unit of the Dockum Group is the Chinle Formation, which primarily consists of micaceous red clay and shale but also contains thin interbeds of fine-grained sandstone and siltstone. The red clays and shale of the Chinle Formation act as an aquitard beneath the water bearing colluvial deposits/Ogallala Formation and therefore limit the amount of recharge to the underlying Dockum Group.

Based on the lithologic log descriptions provided by Trident Environmental the subsurface soils are composed of caliche with varying amounts of very fine to fine-grained sand in matrix (0-40 ft), calcareous fine to medium-grained sand (40-50 ft), and fine to medium-grained sand (50-60 ft). More detailed descriptions of the subsurface lithology are provided on the lithologic logs in Appendix A of the Stage 1 and 2 Abatement Plan.

### **4.2 REGIONAL AND LOCAL HYDROGEOLOGY**

Potable groundwater used in southern Lea County is derived primarily from the Ogallala Formation and the Quaternary alluvium. Water from the Ogallala and alluvium aquifers in southern Lea County is used for irrigation, stock, domestic, industrial, and public supply purposes.

Based on the total depths of water wells in the area (85 feet) and the depth to groundwater (average of 40 feet bgs), the saturated thickness of the Ogallala Formation in the site area is estimated at approximately 45 feet.

Nicholsen and Clebsch (1961) found that the regional gradient of the Ogallala and interconnected colluvial aquifer in the site area generally flows toward the southeast and the hydraulic gradient varies from approximately 0.001 to 0.01 feet/feet.

Based on the recent depth to groundwater data from accessible wells located within a mile of the Jct. J-26 site the magnitude of the regional groundwater gradient is 0.003 feet/foot and the direction of flow is to the southeast (Figure 3). However, the local groundwater gradient

in the more immediate area of the site has indicated magnitudes of 0.005 feet/foot or greater with direction of flow towards the south (Figure 4). The difference between the localized and regional gradient is attributed to the effect of the continual groundwater withdrawal from several nearby water supply wells that provide water for the Eunice Gas Plant. Based on records from the New Mexico Office of the State Engineer (NMSEO) these wells have been pumping at a combined rate of approximately 82 gallons per minute between July 6, 2005 and January 8, 2007. The groundwater withdrawal induces groundwater to flow from the site towards the water supply wells, which are located south (WW-5, WW-8, and WW12) and west (WW-1) of the site, as evidenced by a local groundwater gradient trending to the south (Figure 4) which differs from the regional gradient to the southeast (Figure 3).

No water wells are located within 1,000 feet of the site. A summary of active water wells located in the vicinity of the Jct. J-26 site are listed in Table 1 below. These wells are also depicted in Figure 3.

**Table 1**  
**Summary of Water Well Data**

Well ID	Well Type/Use	Permit Holder (Site Name)	T21S-R37E		Distance from Jct. J-26 Site
			Sec	UL	
WM-220	Windmill/Livestock	Owens (L-0220)	25	I	1,610 ft East
WW-1	Industrial Supply	Targa (Eunice Gas Plant)	26	K	2,100 ft West
WW-5	Industrial Supply	Targa (Eunice Gas Plant)	26	P	1,450 ft South
WW-8	Industrial Supply	Targa (Eunice Gas Plant)	26	P	1,960 ft South
WW-12	Industrial Supply	Targa (Eunice Gas Plant)	26	O	1,410 ft SSW

There are no surface water bodies located within a mile of the site.



## 5.0 GROUNDWATER QUALITY

### 5.1 MONITORING PROGRAM

The on site monitoring wells at the Jct. J-26 site have been sampled on a quarterly basis for major ions, TDS, and benzene, toluene, ethylbenzene, and xylenes (BTEX). A complete summary of historical analytical results and groundwater elevations are provided in the 2007 Annual Groundwater Monitoring Report.

Each constituent of BTEX has been below the New Mexico Water Quality Control Commission (WQCC) standards at this site since the installation of monitoring well MW-1 in October 2002 (18 consecutive quarters).

Background concentrations of chlorides and TDS at the site have been confirmed through recent laboratory analysis of several surrounding wells and research of regional groundwater data. During the third quarter of 2006, access was granted for a one-time monitoring event (depth to water measurements and chloride and TDS analysis) for the following wells:

- Targa (Eunice Gas Plant) water supply wells (WW-1, WW-5, WW-8, WW-12, WW-19).
- One monitoring well at each of four nearby Plains Petroleum monitoring sites.
- One windmill (L-0220)

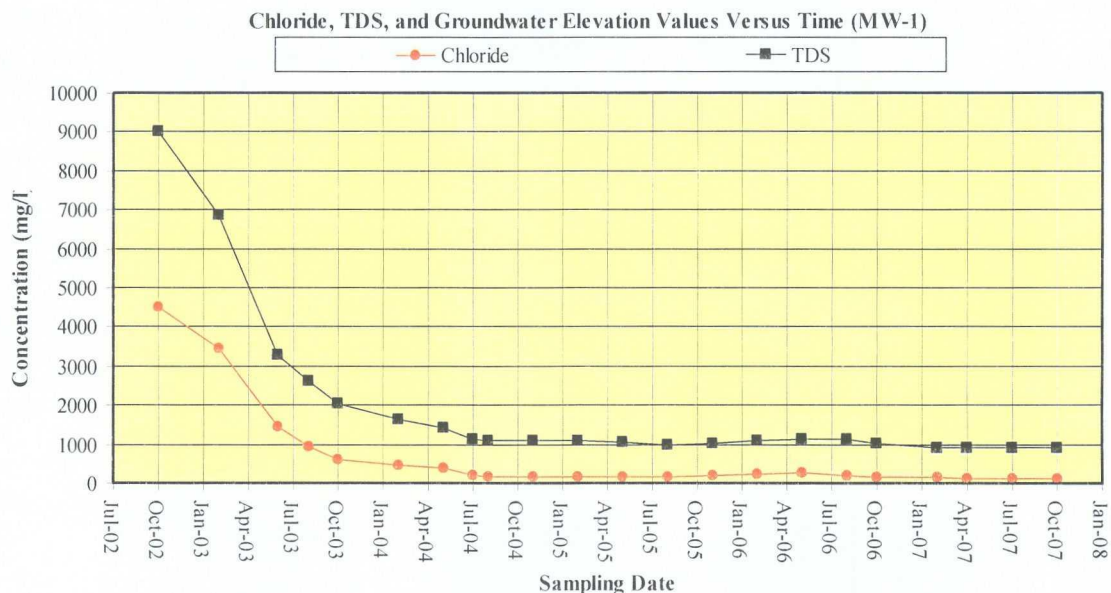
Results of this one time sampling event are summarized in Table 2 below and depicted in Figure 3. A copy of the laboratory analytical reports and chains of custody form are included in Appendix D.

**Table 2**  
**Regional Groundwater Sampling Results (August 1, 2006)**

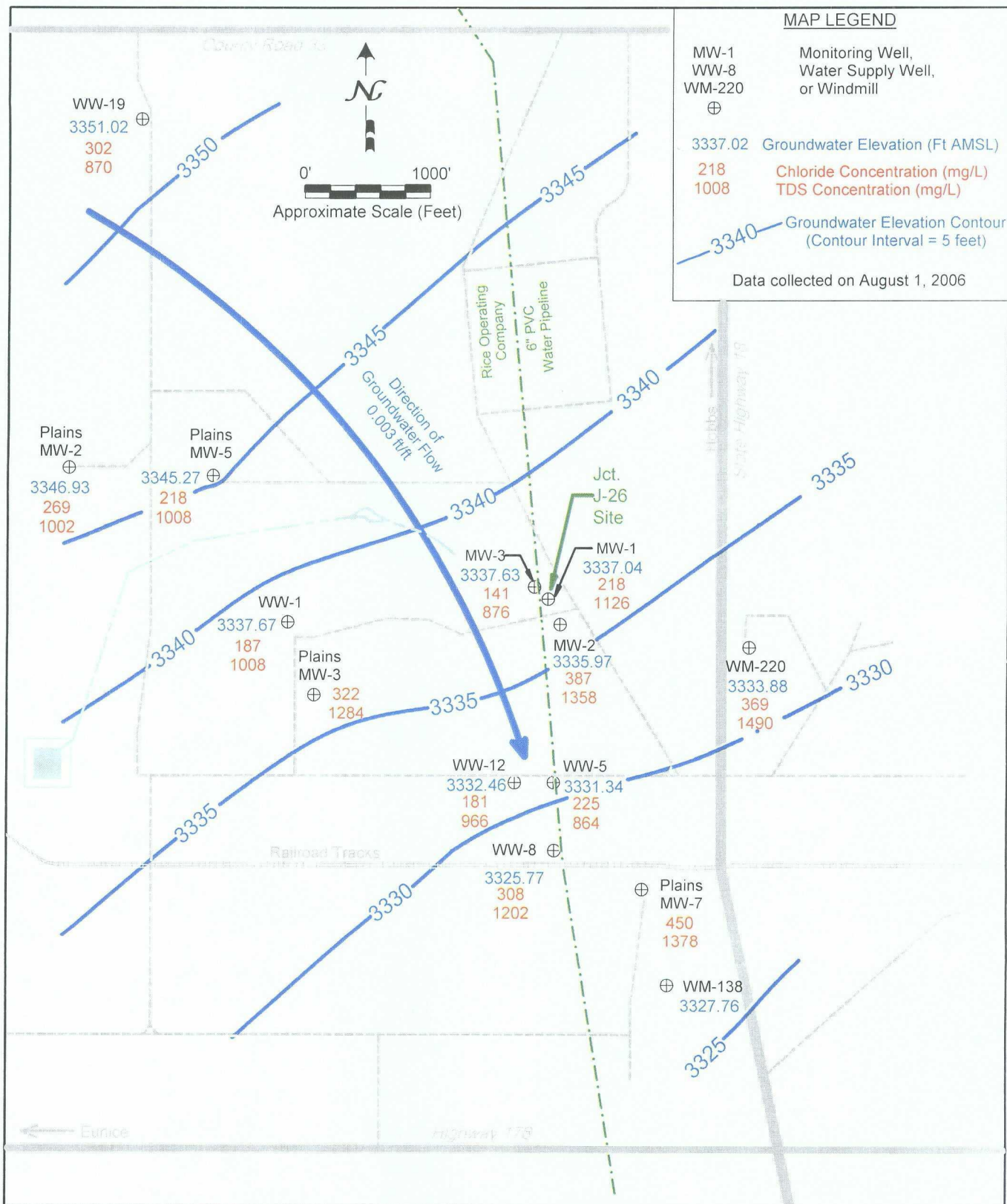
Well ID	Well Type/Use	Permit Holder	Site Name	Depth to Groundwater (feet BTOC)	Chloride (mg/L)	TDS (mg/L)
MW-1	Monitoring	ROC	Jct. J-26	38.80	218	1126
MW-2	Monitoring	ROC	Jct. J-26	39.35	387	1358
MW-3	Monitoring	ROC	Jct. J-26	38.22	141	876
WM-220	Windmill	Owens	L-0220	37.49	369	1490
MW-3	Monitoring	Plains	DH Gathering	45.52	322	1284
MW-7	Monitoring	Plains	Vacuum to Jal 14" Mainline#3	49.04	450	1378
MW-2	Monitoring	Plains	TNM 98-5B	47.82	269	1002
MW-5	Monitoring	Plains	TNM 98-5A	46.26	218	1008
WW-1	Industrial	Targa	Eunice Gas Plant	49.32	187	1008
WW-5	Industrial	Targa	Eunice Gas Plant	48.11	225	864
WW-8	Industrial	Targa	Eunice Gas Plant	51.00	308	1202
WW-12	Industrial	Targa	Eunice Gas Plant	49.28	181	966
WW-19	Abandoned	Targa	Eunice Gas Plant	47.28	302	870
Average (Background) Chloride and TDS Concentrations					275	1110

Based on the sampling results listed in the table above average (background) chloride and TDS concentrations in section 26 have ranged from 141 mg/L to 450 mg/L and 870 mg/L to 1,490 mg/L, respectively.

The highest chloride (4,520 mg/L) and TDS (9,020 mg/L) concentrations in MW-1 were observed during the first sampling event on October 29, 2002. The decreased chloride and TDS concentrations observed in MW-1, as shown in the graph below, can be attributed to the excavation activities (source removal) and the effect of groundwater withdrawal from the industrial water wells that supply process water for the Eunice Gas Plant. The groundwater withdrawal induces groundwater to flow from the site towards the water supply wells, which are located south (WW-5, WW-8, and WW-12) and west (WW-1) of the site and thus has assisted in the removal of any remnant chloride/TDS mass from the area of the Jct. J-26 site. Further evidence for this conclusion is supported by the fate and transport modeling simulations as explained in the following section.



There is no longer a threat of impact from the vadose zone at this site because of the excavation, source removal, and backfilling with an infiltration barrier over the former source area near MW-1 that was completed in 2002. The surrounding area was re-seeded with a mixture of native grasses and plants which has resulted in the re-establishment of native vegetation as depicted on the cover page photo of this report. ROC has been monitoring the site for continued healthy growth of native vegetation.



BD J-26 Junction Box Site

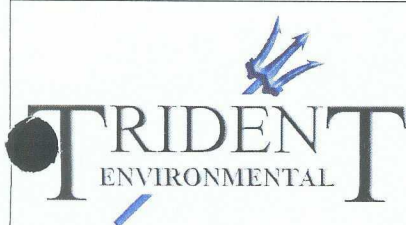
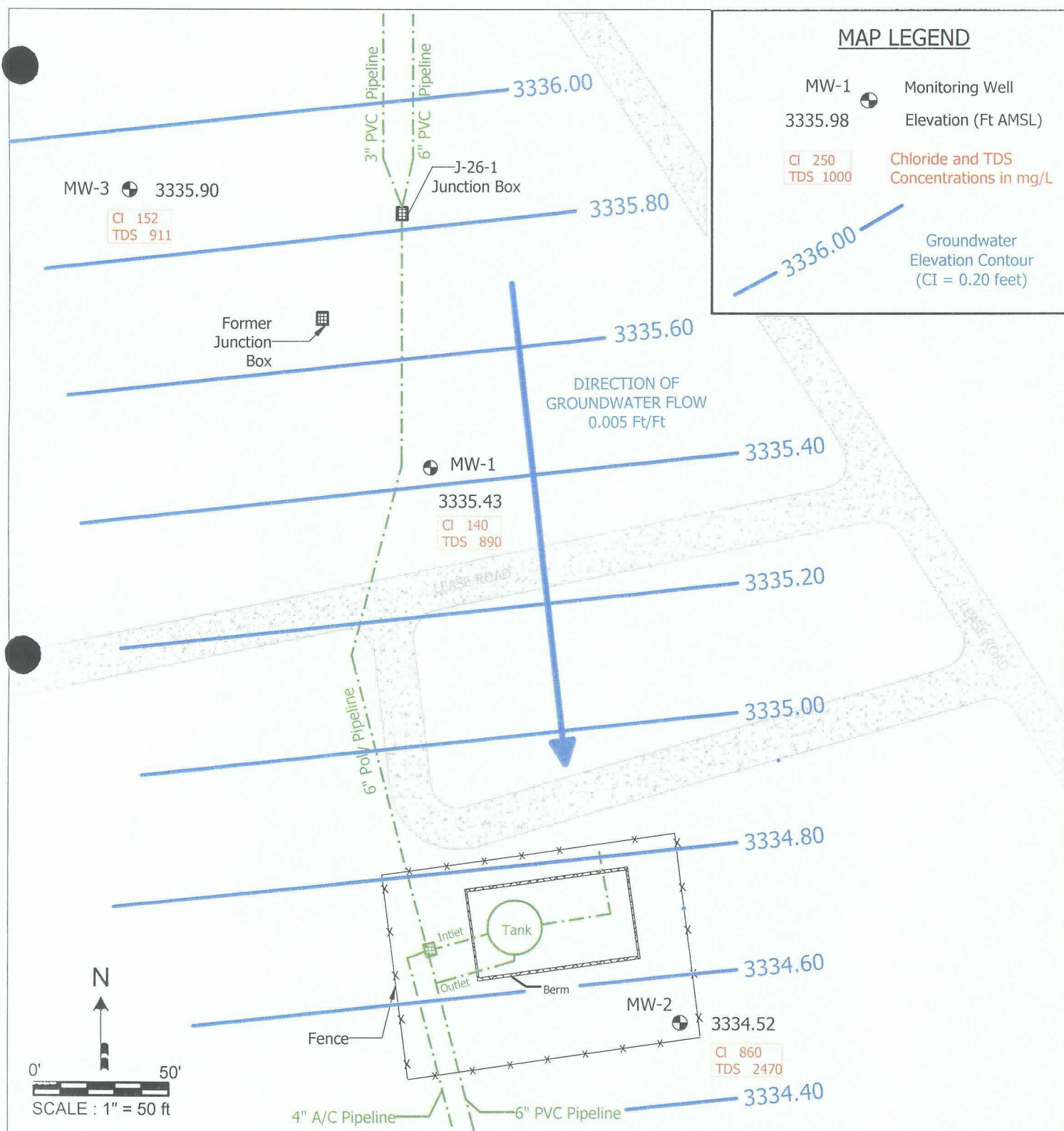
T21S - R37E - Section 26 - Unit J

**RICE** Operating Company

FIGURE 3

REGIONAL GROUNDWATER GRADIENT &  
CHLORIDE/TDS CONCENTRATION MAP





**BD Jct. J-26 Site**  
 T21S - R37E - Section 26 - Unit J  
**RICE Operating Company**

**FIGURE 4**  
**LOCAL GROUNDWATER GRADIENT MAP**  
 APRIL 4, 2008

**Table 3**  
**Historical Groundwater Sampling Results**

Monitoring Well	Sample Date	Depth to Groundwater (feet BTOC)	Groundwater Elevation (feet AMSL)	Chloride (mg/L)	TDS (mg/L)	Benzene (mg/L)	Toluene (mg/L)	Ethylbenzene (mg/L)	Xylene (mg/L)
MW-1	10/29/02	43.02	3332.82	4520	9020	< 0.001	< 0.001	< 0.001	< 0.001
	02/28/03	42.33	3333.51	3470	6870	< 0.001	< 0.001	< 0.001	< 0.001
	06/05/03	43.00	3332.84	1460	3280	< 0.001	< 0.001	< 0.001	< 0.001
	08/22/03	43.72	3332.12	957	2620	< 0.001	< 0.001	< 0.001	< 0.001
	10/30/03	43.91	3331.93	620	2040	< 0.001	< 0.001	< 0.001	< 0.001
	02/18/04	43.70	3332.14	478	1630	< 0.001	< 0.001	< 0.001	< 0.001
	05/05/04	40.80	3335.04	390	1440	< 0.001	< 0.001	< 0.001	< 0.001
	07/08/04	40.80	3335.04	230	1140	< 0.001	< 0.001	< 0.001	< 0.001
	08/10/04	37.02	3338.82	195	1080	< 0.001	< 0.001	< 0.001	< 0.001
	11/09/04	36.61	3339.23	177	1100	< 0.001	< 0.001	< 0.001	< 0.001
	02/09/05	36.62	3339.22	179	1090	< 0.001	< 0.001	< 0.001	< 0.001
	05/05/05	37.00	3338.84	179	1060	< 0.001	< 0.001	< 0.001	< 0.001
	08/13/05	37.56	3338.28	193	1000	< 0.001	< 0.001	< 0.001	< 0.001
	11/07/05	37.98	3337.86	233	1020	< 0.001	< 0.001	< 0.001	< 0.001
	02/06/06	38.39	3337.45	262	1080	< 0.001	< 0.001	< 0.001	< 0.001
	05/08/06	38.55	3337.29	282	1140	< 0.001	< 0.001	< 0.001	< 0.001
	08/01/06	38.80	3337.04	218	1126	< 0.001	< 0.001	< 0.001	< 0.001
	10/23/06	39.21	3336.63	193	1010	---	---	---	---
	02/08/07	39.52	3336.32	182	912	---	---	---	---
	04/18/07	39.66	3336.18	161	898	---	---	---	---
	07/18/07	39.86	3335.98	149	900	---	---	---	---
	10/10/07	40.07	3335.77	160	915	---	---	---	---
	01/14/08	40.35	3335.49	152	904	---	---	---	---
	04/04/08	40.41	3335.43	140	890	< 0.001	< 0.001	< 0.001	< 0.001
MW-2	08/22/03	43.99	3331.33	239	1180	< 0.001	< 0.001	< 0.001	< 0.001
	10/30/03	44.17	3331.15	239	1240	< 0.001	< 0.001	< 0.001	< 0.001
	02/18/04	43.91	3331.41	221	1150	< 0.001	0.001	< 0.001	< 0.001
	05/05/04	40.98	3334.34	204	1060	< 0.001	0.001	< 0.001	< 0.001
	08/10/04	37.14	3338.18	230	1120	< 0.001	< 0.001	< 0.001	< 0.001
	11/09/04	36.99	3338.33	230	1120	< 0.001	< 0.001	< 0.001	< 0.001
	02/09/05	37.03	3338.29	294	1220	< 0.001	< 0.001	< 0.001	< 0.001
	05/06/05	37.46	3337.86	257	1210	< 0.001	< 0.001	< 0.001	< 0.001
	08/13/05	38.02	3337.30	237	1180	< 0.001	< 0.001	< 0.001	< 0.001
	11/07/05	38.44	3336.88	206	1130	< 0.001	< 0.001	< 0.001	< 0.001
	02/06/06	38.83	3336.49	250	1090	< 0.001	< 0.001	< 0.001	< 0.001
	05/08/06	39.02	3336.30	257	1210	< 0.001	< 0.001	< 0.001	< 0.001
	08/01/06	39.35	3335.97	387	1358	< 0.001	< 0.001	< 0.001	< 0.001
	10/23/06	39.71	3335.61	395	1370	---	---	---	---
	02/08/07	40.03	3335.29	378	1220	---	---	---	---
	04/18/07	40.09	3335.23	446	1380	---	---	---	---
	07/18/07	40.30	3335.02	679	1720	---	---	---	---
	10/10/07	40.52	3334.80	730	1838	---	---	---	---
	01/14/08	40.74	3334.58	810	2061	---	---	---	---
	04/04/08	40.80	3334.52	860	2470	< 0.001	< 0.001	< 0.001	< 0.001
MW-3	08/22/03	43.06	3332.79	160	904	< 0.001	< 0.001	< 0.001	< 0.001
	10/30/03	43.28	3332.57	168	1070	< 0.001	< 0.001	< 0.001	< 0.001
	02/18/04	43.03	3332.82	160	862	< 0.001	< 0.001	< 0.001	< 0.001
	05/05/04	40.04	3335.81	160	891	< 0.001	< 0.001	< 0.001	< 0.001
	08/10/04	36.55	3339.30	164	941	< 0.001	< 0.001	< 0.001	< 0.001
	11/09/04	36.22	3339.63	142	1160	< 0.001	< 0.001	< 0.001	< 0.001
	02/09/05	36.17	3339.68	138	1010	< 0.001	< 0.001	< 0.001	< 0.001
	05/06/05	36.56	3339.29	141	870	< 0.001	< 0.001	< 0.001	< 0.001
	08/13/05	37.12	3338.73	125	842	< 0.001	< 0.001	< 0.001	< 0.001
	11/07/05	37.55	3338.30	125	826	< 0.001	< 0.001	< 0.001	< 0.001
	02/06/06	37.84	3338.01	119	748	< 0.001	< 0.001	< 0.001	< 0.001
	05/08/06	38.00	3337.85	142	806	< 0.001	< 0.001	< 0.001	< 0.001
	08/01/06	38.22	3337.63	141	876	< 0.001	< 0.001	< 0.001	< 0.001
	10/23/06	38.68	3337.17	147	834	---	---	---	---
	02/08/07	39.01	3336.84	147	788	---	---	---	---
	04/18/07	39.16	3336.69	150	818	---	---	---	---
	07/18/07	39.40	3336.45	139	848	---	---	---	---
	10/10/07	39.60	3336.25	164	857	---	---	---	---
	01/14/08	39.90	3335.95	160	886	---	---	---	---
	04/04/08	39.95	3335.90	152	911	< 0.001	< 0.001	< 0.001	< 0.001
WQCC Standards				250	1000	0.01	0.75	0.75	0.62



## 6.0 FATE AND TRANSPORT MODELING RESULTS

### 6.1 FATE AND TRANSPORT MODELING

As proposed in the NMOCD-approved Stage 1 and 2 Abatement Plan (November 27, 2007), fate and transport model simulations were performed to forecast the movement and attenuation of the chloride plume by dispersion and abatement by the water supply wells. Simulations were conducted with the two-dimensional groundwater flow and contaminant transport model WinTran, version 1.03 (1995) designed and distributed by Environmental Simulations, Inc. WinTran is built around a steady-state analytical element flow model, which is uniquely linked to a finite element contaminant transport model. A detailed description of the modeling procedure, parameter inputs, and the simulated results are provided in Appendix A. The features, equations, and benchmarking documentation are included in Appendix B.

The fate and transport model simulations demonstrate how chloride concentrations in the center of the plume will decrease to background levels by the year 2047 as the mass of the plume is captured by the water supply wells. The results of the fate and transport modeling simulations support the conclusion that the chloride plume is not likely to impact any drinking water, livestock, municipal, or irrigation water supplies, the closest of which is a windmill (NM File No. CP-220) located approximately 1,610 feet east of the Jct. J-26 site. This windmill, which is used for livestock watering, is cross-gradient from the junction box and, therefore not in the direct path of the simulated plume.

## **7.0 AMENDED STAGE 2 ABATEMENT PLAN**

Since July 2004, chloride and TDS concentrations at the Jct. J-26 site have generally remained at or near background levels in each of the three on site monitoring wells. Chloride and TDS concentrations in downgradient monitoring well MW-2 have exhibited a slight increase over background levels in the most recent quarter however, that is consistent with the modeling simulations as described in Appendix A. The fate and transport modeling simulates chloride concentrations in MW-2 peaking at 737 mg/L in year 2009 and then resume a decreasing trend.

Continued operation of the water supply wells is essential in maintaining the operation of the Eunice Gas Plant. The withdrawal of groundwater by several of these wells has resulted in redirecting and recovery of residual chloride and TDS constituents from the Jct. J-26 site. In addition, WinTran fate and transport modeling simulations show the capture effects of the water supply wells and natural dispersion in attenuating chloride and TDS constituents.

However, on February 13, 2008 (Appendix E) the NMOCD requested via email communication for ROC to install additional monitoring wells and a groundwater recovery system downgradient of the BD Jct. J-26 Site. ROC proposes a phased approach for abatement as proposed in the following sections.

### **7.1 PROPOSED MONITORING/RECOVERY WELL INSTALLATIONS**

ROC will install one downgradient monitoring well (MW-4) about 75 feet south of the bermed SWD collection facility. This location is directly downgradient from the former junction box based on historical groundwater flow directions. This well will be constructed of 2-in diameter well casing and screen to a depth of 55 ft bgs with a screened interval between 35 ft to 55 ft.

A second 4-in diameter monitoring well (MW-5) will be completed adjacent to MW-4 with a total depth reaching the base of the aquifer which is estimated at 85 ft to 90 ft bgs. The lower section of this well will be screened with a minimum of 15-ft of well screen for potential groundwater removal and testing. The wells will be installed and sampled after appropriate development using methods consistent with industry standards (ASTM, EPA).

### **7.2 SOURCE REMOVAL TESTING AND PROPOSED ABATEMENT OPTIONS**

If the characterization program shows that groundwater at this site exceeds 3,000 mg/L TDS, this plan proposes a 3-month source removal and test pumping program. The purpose of this pumping program is to determine if groundwater may be restored within a short time and to assist in the evaluation of groundwater abatement options. Water from the recovery well will

be stored on site for use in pipeline maintenance operations and/or discharged into the BD saltwater disposal system.

Experience suggests a pumping rate of 2 to 10 gallons per minute may be possible from a 4-inch diameter well completed at this site. The proposed testing program consists of:

1. Measurement of water levels in the recovery well and monitoring well(s):
  - a. On a daily/hourly basis for the first two days of pumping,
  - b. On a weekly basis for the first month of pumping, and
  - c. On a monthly basis for the next two months.
  - d. On a daily/hourly basis after cessation of pumping (after at least 2-days of pumping) to collect recovery data for calculation of hydrologic parameters.
2. Collection of groundwater samples for chloride and TDS analysis on a monthly basis from the recovery well,
3. Measurements of the flow rate and total flow from the recovery well at each site visit,
4. Collection of groundwater samples from all monitor wells before and after the 3-month pumping program.

Our evaluation of alternatives does not support a program that extracts groundwater and creates a waste (e.g. low concentration brine) that must be managed. Based on our analysis, the creation of a brine waste and the management of the waste and treatment system results in less benefit to the environment by creating more contamination (i.e. air pollution, dust, energy consumption) than it cures.

A strategy of pump-and-use without treatment provides the best abatement option if a bona fide use presently exists for the groundwater. In the absence of a bona fide use for this groundwater (e.g. pipeline maintenance, gas plant makeup water), a pump-and-use strategy is not the preferred abatement option.

If the groundwater at the site is suitable for mature livestock (i.e. less than 3,000 mg/L TDS, NMSU Guide M-112, 1995), then a pump-and-dispose groundwater restoration strategy results in the loss of a useful commodity and is not consistent with conservation and best management practices for the groundwater resource. A pump-and-dispose strategy may be reasonable where the migration of 3,000 mg/L or greater TDS groundwater threatens a well used for domestic purposes (drinking water), where groundwater should be less than 1,000 mg/L; however that scenario is not applicable to this site.

If a pump-and-use groundwater restoration program is not feasible and pump-and-dispose provides little benefit, the evaluation of alternatives suggests that natural restoration in conjunction with the existing groundwater extraction for use at the Eunice Gas Plant, and a groundwater monitoring program provides the best abatement option.

### 7.3 SCHEDULE OF ACTIVITIES

1. Install downgradient monitoring wells as proposed in section 7.1
2. Collect groundwater samples from all monitoring wells for chloride and TDS analysis to fully characterize extent of groundwater impact.
3. Commence ground water testing program as proposed in section 7.2
4. Submit notices of activities to NMOCD prior to implementing each phase and updates after the completion of each phase described herein.
5. Implement NMOCD-approved ground water remedy and begin long-term monitoring

## **APPENDIX A**

### **Description of Fate and Transport Modeling Procedures and Parameter Inputs**



## Description of Fate and Transport Modeling

### *Conceptual Model*

Produced water containing high concentrations of chloride, and resultant high levels of total dissolved solids (TDS), reportedly leaked from the J-26 junction box. Extrapolating from current conditions for decades into the future, taking account of both advective flow and attenuation by hydrodynamic dispersion, enables prediction of the probable distance that the residual plume will travel as well as the gradually declining concentrations in the plume.

### *Basic Site Data*

Information about site conditions was obtained from data collected by Rice Operating Company and Trident Environmental. This included lithologic records from well installations, water level data, and water quality analytical results.

### *Simulation Model*

Simulations were conducted with the two-dimensional groundwater flow and contaminant transport model WinTran, version 1.03 (1995) designed and distributed by Environmental Simulations, Inc. (ESI) of Herndon, Virginia. WinTran is built around a steady-state analytical element flow model, linked to a finite element contaminant transport model. The Windows interface allows for rapid data input, processing, parameter manipulation and optimization, and output in multiple formats. The fundamental mathematics of the model solutions, model verification (benchmarked against MODFLOW), and use of WinTran is documented in the "Guide to Using WinTran" published by ESI.

### *Base Map*

A simplified site base map, edited with TurboCAD (Version 12), was exported to a universal drawing exchange file (DXF) file format. The DXF base map was imported into WinTran, which preserves the original units of measurement.

### *Model Input Parameters*

The following table lists the various parameters input into the fate and transport model simulations.

Parameter	Value	Source of Data
Hydraulic Conductivity ( $K_x$ , $K_y$ , $K_z$ )	4.4 ft/day (1.2E-03 cm/sec)	Aquifer test (Appendix C)
Hydraulic Gradient	0.003 ft/ft	Observed and measured
Gradient Direction	56° south of due east (SE)	Observed and measured
Longitudinal Dispersivity	328 ft	Estimated plume length (2002)
Transverse Dispersivity	32.8 ft	One-tenth of longitudinal
Porosity	0.25	Professional judgement
Base elevation of aquifer	3250 ft AMSL	Observed and measured
Depth to groundwater	40 ft	Observed and measured
Saturated thickness	45 ft	Observed and measured
Model X Extent (100 nodes)	2.5 miles	Professional judgement
Model Y Extent (100 nodes)	2.5 miles	Professional judgement
Coefficient of molecular diffusion	0.34 ft <sup>2</sup> /yr (1.0E-07 cm <sup>2</sup> /sec)	Bear and Verruijt (1987)

### *Flow Parameters*

Input requirements for the steady-state groundwater flow simulation include: hydraulic gradient and direction of flow, hydraulic conductivity, aquifer top and bottom elevations, and reference head. The values used were based on the following sources:

- Hydraulic gradient – measured gradient of 0.003 feet/foot based on historical site measurements.
- Direction of flow – measured direction of approximately 56° south of due east (SE) based on past local and current regional measurements.
- Hydraulic conductivity – This is one of the most critical parameters used for any fate and transport modeling effort, and the various published values researched range widely from less than 2 ft/day to 200 ft/day. Therefore an aquifer test was performed at two nearby industrial water supply wells (WW-1 and WW-5) to determine the most accurate site-specific value. A hydraulic conductivity of 4.4 ft/day was determined by performing a Cooper-Jacob analysis of the recovery data, and a program from USGS Open-File 02-197 (Keith Halford, 2002). Documentation of the aquifer test procedures, results, and USGS program is included in Appendix C).
- Aquifer top and bottom elevations – bottom elevation of Ogallala Formation at 3250 feet based on published information (Nicholson & Clebsch, 1961). The top elevation for an unconfined aquifer must be greater than the reference head. An elevation of 3400 feet was assumed.
- Reference head – measured unconfined head of 3345 feet located upgradient of the site so as not to be influenced by pumping wells during modeling simulations.

### *Transport Parameters*

Input requirements for the contaminant transport numerical simulation include: longitudinal and transverse dispersivity, porosity, diffusion coefficient, contaminant half-life, and retardation coefficient. The values used were based on the following sources:

- Longitudinal and transverse dispersivity – Longitudinal dispersivity represents the spreading of the contaminant plume in the direction of groundwater flow. The transverse component represents spreading perpendicular to the flow direction. Dispersivity is a scale-dependent parameter which is generally larger as the scale of the contaminant plume increases. Fetter (1993, Section 2.11, pp. 71-77) notes the apparent scale-dependency of longitudinal dispersivity, which typically may be about 0.1 times the flow length. However, values of dispersivity reported in the literature generally range from 1 to 100 percent of the problem scale (Gelhar, 1986). For the current site scale, a conservative value of 328 feet (100 meters) was selected for longitudinal dispersivity. A value of 32.8 feet (i.e., 10 meters, or one-tenth of the longitudinal value) was selected for transverse dispersivity. These conservative values also minimized modeling transport errors.
- Porosity – no site measurements were available; therefore a literature value based on saturated zone lithology was selected. Typical lithology is described as silty sand and very fine sand. A range of 0.25 to 0.50 is typically given for unconsolidated “sand” (e.g., Freeze & Cherry, 1979, Table 2.4, p. 37); however, the Ogallala Formation is predominantly very fine grained, compacted and partly cemented, and may also fit within the range of 0.05 to 0.30 for sandstone. Fetter (1988, Table 4.3 and Figure 4.10, pp. 74-75) cites an average value of 0.20 for the specific yield of very fine sands. Specific retention of silty fine sand is approximately 0.05, for a total porosity of 0.25, which is the value selected for the transport modeling. WinTran uses the porosity term to estimate groundwater velocity, and actually requires an effective porosity value. Fetter (1988, Section 4.4, pp. 84-85) notes that pores of most sediments down to clay size are interconnected and that the effective porosity is virtually equal to the total porosity.
- Diffusion coefficient – occurs when a contaminant spreads in water due to concentration gradients. That is, dissolved contaminants will spread in water from areas of high concentration to areas of

lower concentration. This process is caused by random movement of molecules in a fluid. The coefficient of molecular diffusion (or simply the diffusion coefficient) is expressed in units of  $L^2/T$  (e.g.,  $cm^2/s$ ) and is often assumed to equal zero in advective-dominated transport. Only in very slow-moving groundwater is diffusion important. Bear and Verruijt (1987) estimate the diffusion coefficient to be approximately  $1 \times 10^{-5} \text{ cm}^2/s$  ( $0.34 \text{ ft}^2/\text{yr}$ ) in dilute systems.

- Contaminant half-life – this parameter accounts for chemical decay (e.g., radioisotopes, biological transformation of organic molecules); however, the species of interest in the present case are inorganic ions (chloride) and are not expected to decay to any appreciable extent. A conservative value of 1000 years was used, which produces a negligible decay coefficient of less than  $0.001 \text{ yr}^{-1}$ .
- Retardation coefficient – this parameter accounts for sorption processes that slow the movement of contaminants relative to the groundwater velocity. Inorganic ions such as chloride are commonly taken as conservative tracers in groundwater and are not considered to be retarded; therefore, a value of 1.0 was selected for the retardation coefficient.

### *Flow Model Calibration*

The vicinity of the site where water level measurements were recorded between October 2002 and August 2006 is simulated closely by the flow model.

### *Transport Model Calibration*

The objective of the transport modeling was to first obtain a plume configuration with concentration values that closely match current observed values. This was done by importing a grid file created from an isopleth map using Surfer (version 6.04) contouring program, producing the configuration and constituent concentration distribution observed in October 2002 at the completion of the upgrade of the junction box. The model again ran for 4 years (2002 to 2006) after entering in the known concentrations at each of the three monitoring wells and other area wells (Targa water recovery wells and two monitoring wells from nearby Plains Petroleum sites, and a windmill east-southeast of the site).

### *Simulation of Fate and Transport*

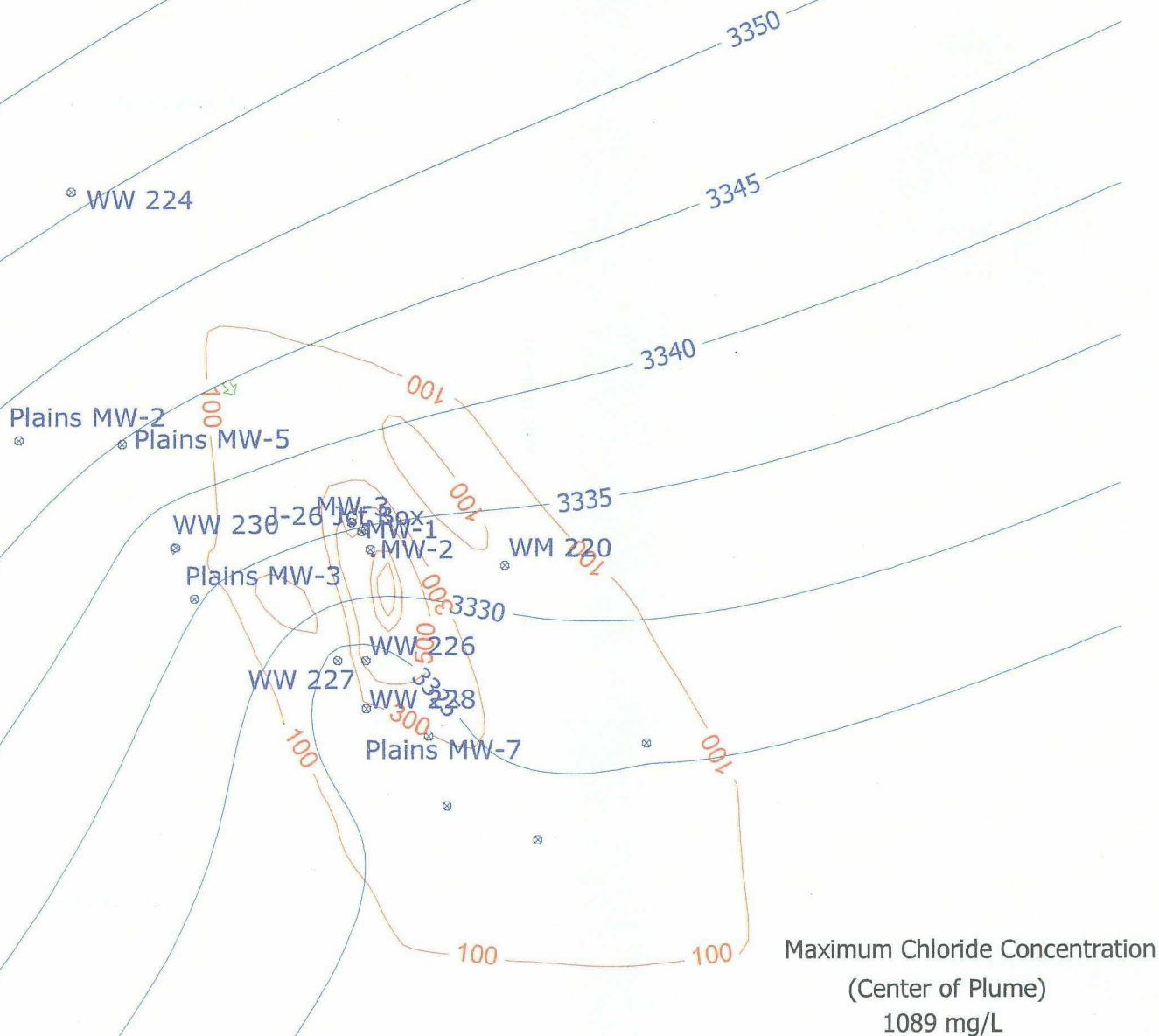
After model calibration, estimation of the fate and transport of chlorides was then achieved by restarting the transport model from the end of 2006 by retaining the distribution of contaminant mass and projecting into the future. Hydrodynamic dispersion serves to broaden the dimensions of the plume while reducing the concentrations in the middle of the plume. Advective flow moves the center of plume mass downgradient (southeast) while the groundwater withdrawal from the industrial supply wells directs the plume in a more southerly direction. Water supply wells WW-1 and WW-12 cause further dilution of the plume by directing the chloride mass transverse to the natural gradient direction. Similarly water supply wells WW-5 and WW-8 direct the chloride mass in a southerly direction. Various time increments were input to show the fate and transport of the chloride mass over a 41 year period (Years 2006 through 2047) after which the chloride plume center attenuated to a concentration of 276 mg/L (background conditions). Results of the fate and transport modeling output (Years 2010, 2015, 2020, 2025, 2030, 2035, 2040 and 2047) are depicted on site maps in the pages that follow.

For a hydraulic conductivity value of 4.4 ft/day the resultant average velocity is 14.9 ft/yr based on the darcy expression:  $v = (k \cdot i) / n$ , where  $k$  is the hydraulic conductivity (ft/yr),  $i$  is the hydraulic gradient (ft/ft), and  $n$  is the effective porosity (unitless). The center of the modeled plume moves at a greater rate (22.8 ft/yr) over successive time intervals than the average groundwater velocity based on Darcy's law, due to the added effect of dispersion and the capture effect from the water supply wells.

The fate and transport model simulations demonstrate how chloride concentrations in the center of the plume will decrease to background levels by the year 2047 as the mass of the plume is captured by the water supply wells and does not migrate beyond them. These results strongly support the evidence that the chloride plume is not likely to impact any existing sources of water supply, the closest of which is a windmill (NM File No. CP-220) located approximately 1,610 feet east of the Jct. J-26 site. This windmill, which is used for livestock watering, is cross-gradient from the junction box and, therefore not in the direct path of the simulated plume.

It is not necessary to simulate the fate and transport of TDS because those concentrations are closer to meeting background concentrations in comparison with chloride values. In other words, the standard for TDS concentrations will be met before those for chloride concentrations.

# BD J-26 Junction Box Site WinTran Fate & Transport Modeling Results

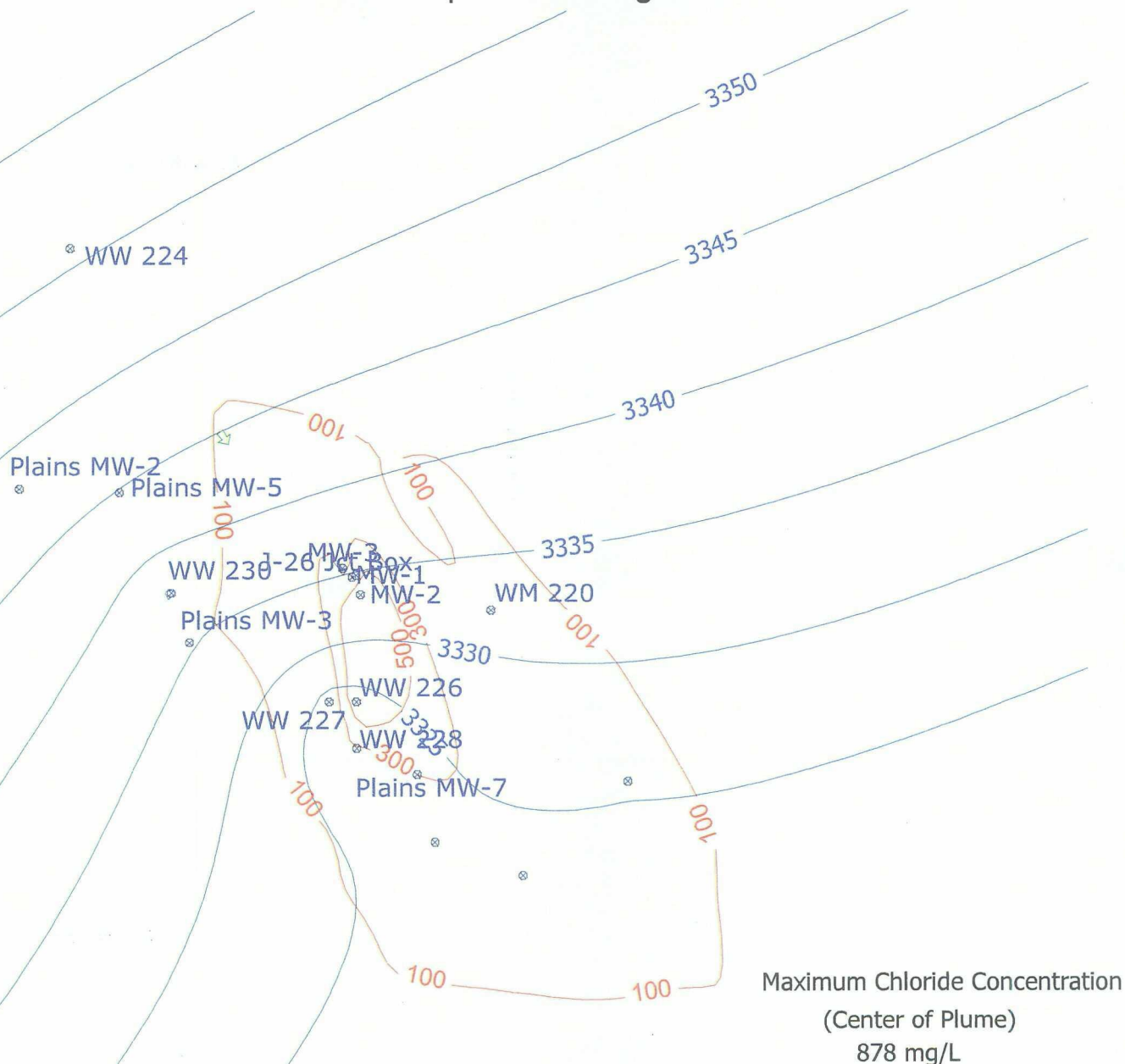


Estimated Conditions for Year 2010

## Modeling Assumptions

Hydraulic Conductivity = 1600 ft/yr (4.4 ft/day)  
 Hydraulic Gradient = 0.003 ft/ft (SE)  
 Longitudinal Dispersivity = 328 ft  
 Transverse Dispersivity = 32.8 ft  
 Diffusion Coefficient = 0.3349 ft<sup>2</sup>/day  
 Porosity = 0.25 percent  
 Aquifer Bottom at 3250 ft AMSL  
 Imported Surfer Initial WinTran 2002.grd

# BD J-26 Junction Box Site WinTran Fate & Transport Modeling Results



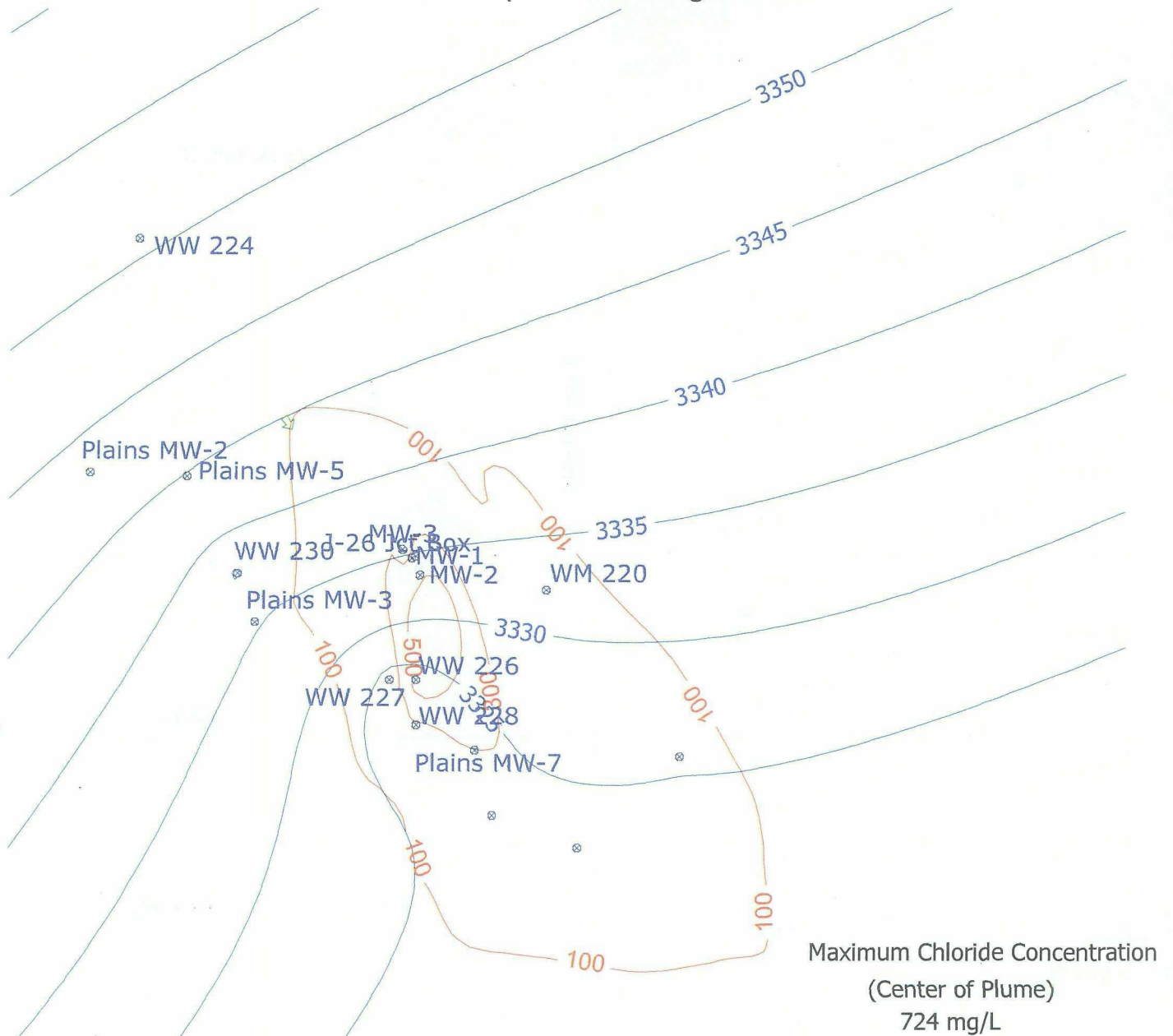
Estimated Conditions for Year 2015

## Modeling Assumptions

Hydraulic Conductivity = 1600 ft/yr (4.4 ft/day)  
 Hydraulic Gradient = 0.003 ft/ft (SE)  
 Longitudinal Dispersivity = 328 ft  
 Transverse Dispersivity = 32.8 ft  
 Diffusion Coefficient = 0.3349 ft<sup>2</sup>/day  
 Porosity = 0.25 percent  
 Aquifer Bottom at 3250 ft AMSL  
 Imported Surfer Initial WinTran 2002.grd



# BD J-26 Junction Box Site WinTran Fate & Transport Modeling Results



5280 feet

Estimated Conditions for Year 2020

## Modeling Assumptions

Hydraulic Conductivity = 1600 ft/yr (4.4 ft/day)

Hydraulic Gradient = 0.003 ft/ft (SE)

Longitudinal Dispersivity = 328 ft

Transverse Dispersivity = 32.8 ft

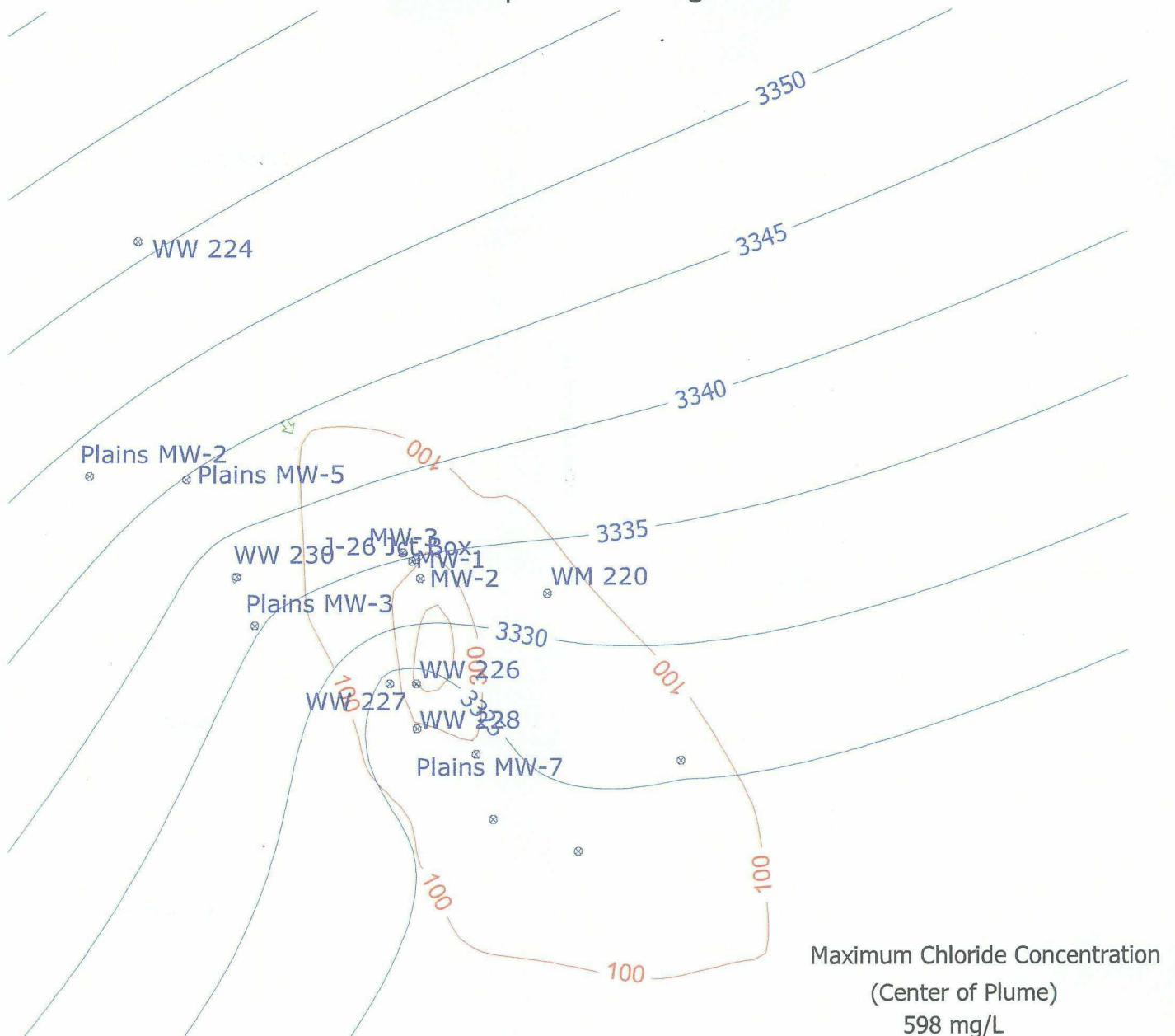
Diffusion Coefficient = 0.3349 ft<sup>2</sup>/day

Porosity = 0.25 percent

Aquifer Bottom at 3250 ft AMSL

Imported Surfer Initial WinTran 2002.grd

# BD J-26 Junction Box Site WinTran Fate & Transport Modeling Results



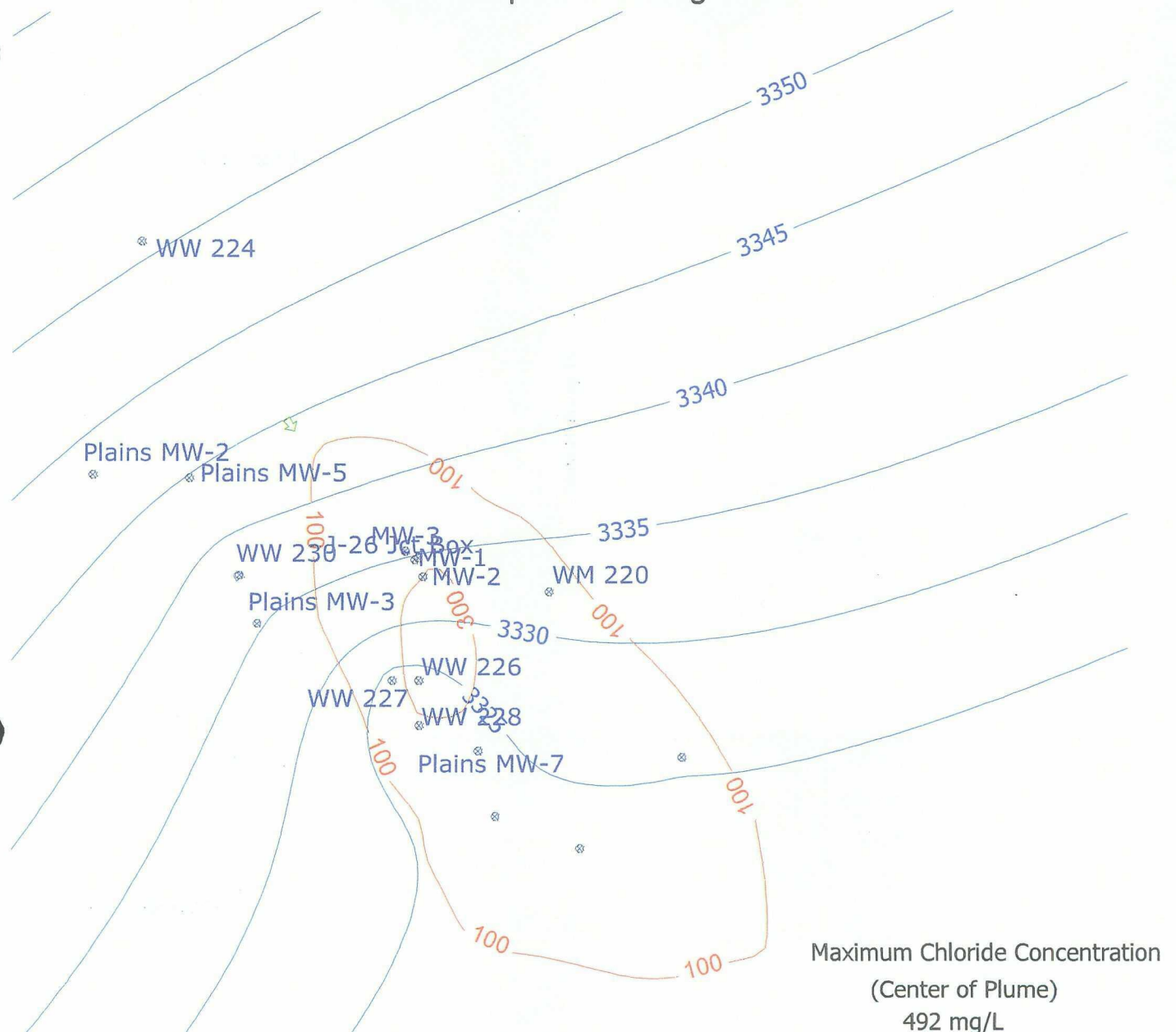
Estimated Conditions for Year 2025

## Modeling Assumptions

Hydraulic Conductivity = 1600 ft/yr (4.4 ft/day)  
 Hydraulic Gradient = 0.003 ft/ft (SE)  
 Longitudinal Dispersivity = 328 ft  
 Transverse Dispersivity = 32.8 ft  
 Diffusion Coefficient = 0.3349 ft<sup>2</sup>/day  
 Porosity = 0.25 percent  
 Aquifer Bottom at 3250 ft AMSL  
 Imported Surfer Initial WinTran 2002.grd



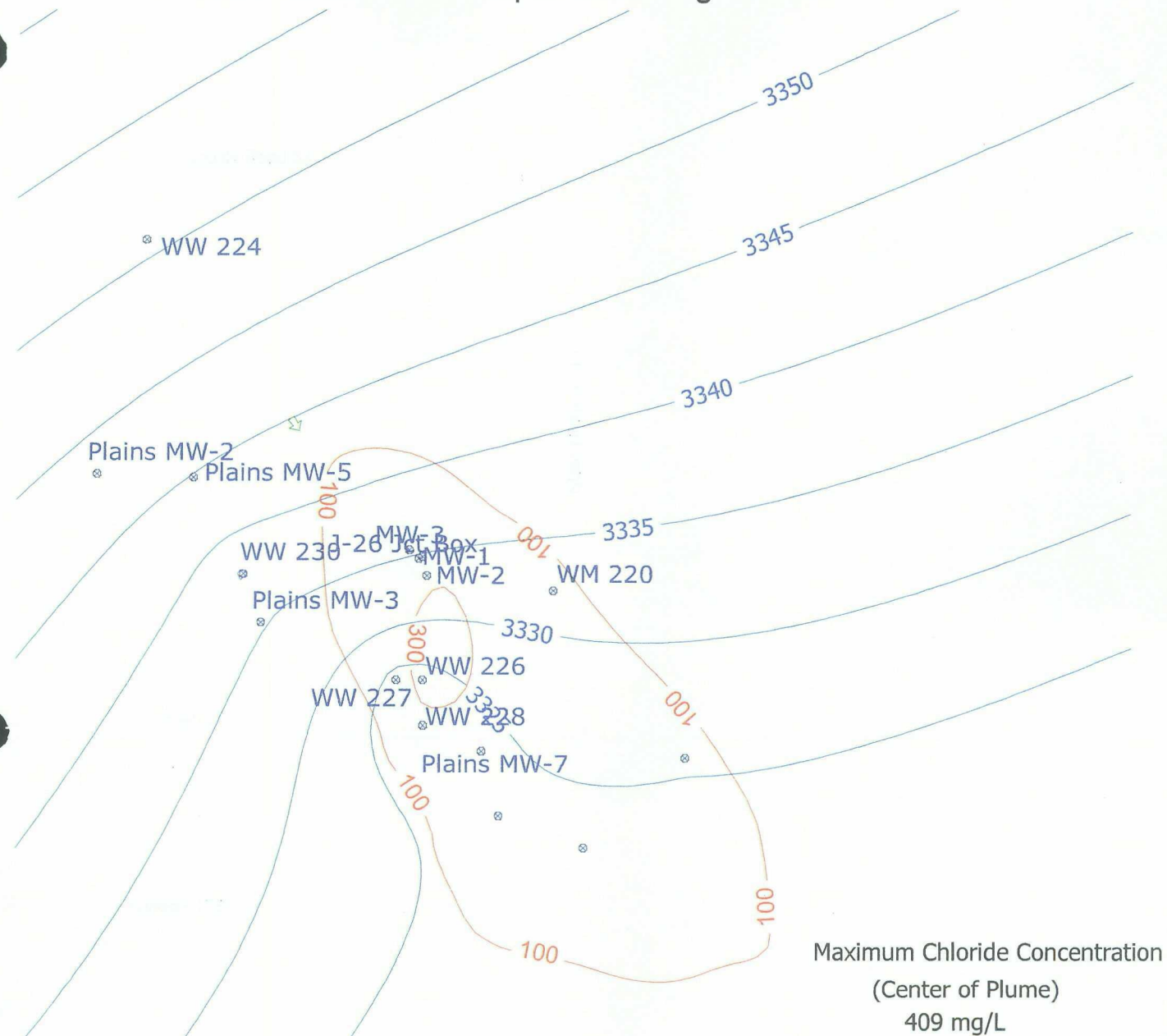
# BD J-26 Junction Box Site WinTran Fate & Transport Modeling Results



Estimated Conditions for Year 2030

**Modeling Assumptions**  
 Hydraulic Conductivity = 1600 ft/yr (4.4 ft/day)  
 Hydraulic Gradient = 0.003 ft/ft (SE)  
 Longitudinal Dispersivity = 328 ft  
 Transverse Dispersivity = 32.8 ft  
 Diffusion Coefficient = 0.3349 ft<sup>2</sup>/day  
 Porosity = 0.25 percent  
 Aquifer Bottom at 3250 ft AMSL  
 Imported Surfer Initial WinTran 2002.grd

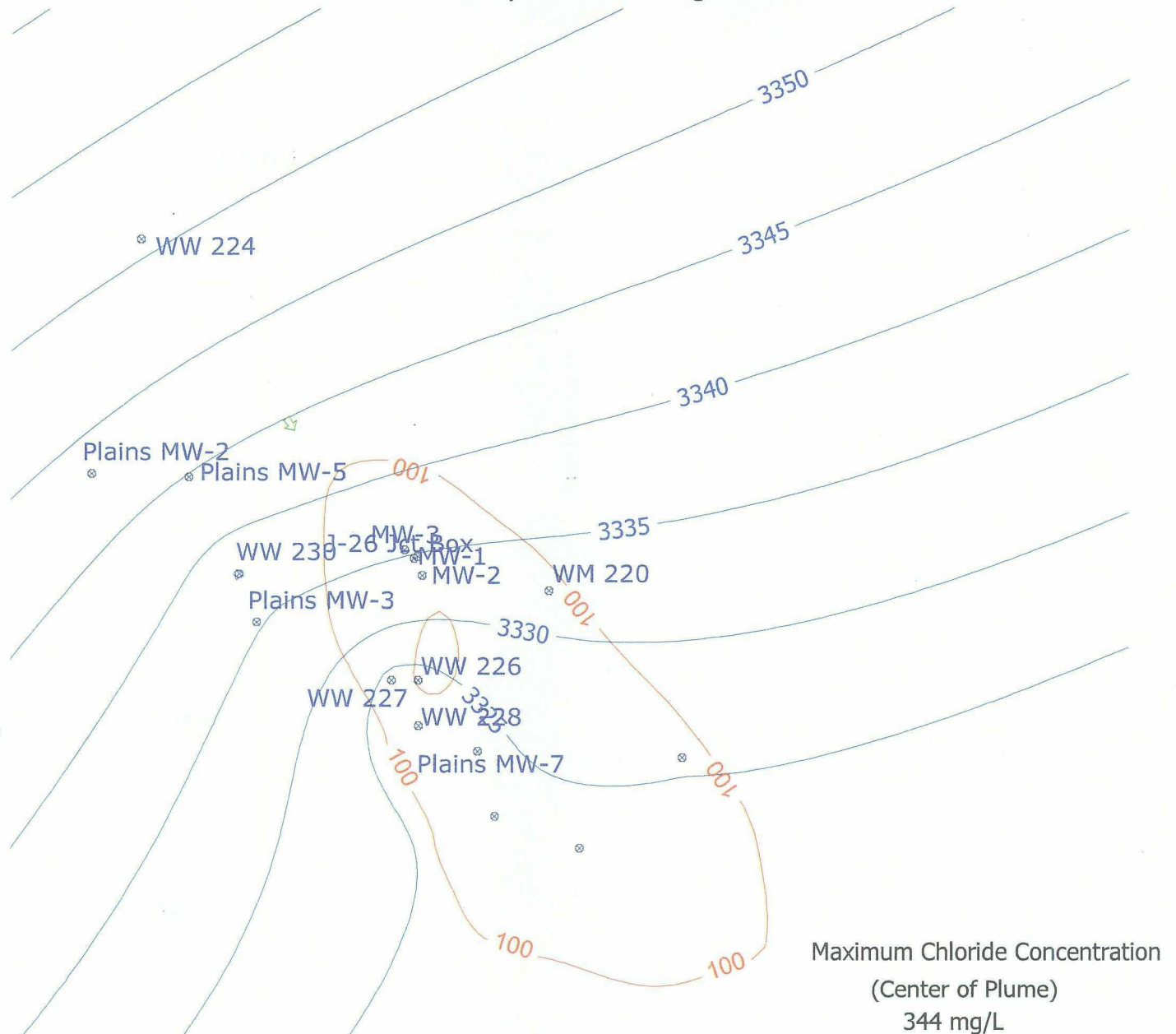
# BD J-26 Junction Box Site WinTran Fate & Transport Modeling Results



## Modeling Assumptions

Hydraulic Conductivity = 1600 ft/yr (4.4 ft/day)  
 Hydraulic Gradient = 0.003 ft/ft (SE)  
 Longitudinal Dispersivity = 328 ft  
 Transverse Dispersivity = 32.8 ft  
 Diffusion Coefficient = 0.3349 ft<sup>2</sup>/day  
 Porosity = 0.25 percent  
 Aquifer Bottom at 3250 ft AMSL  
 Imported Surfer Initial WinTran 2002.grd

# BD J-26 Junction Box Site WinTran Fate & Transport Modeling Results



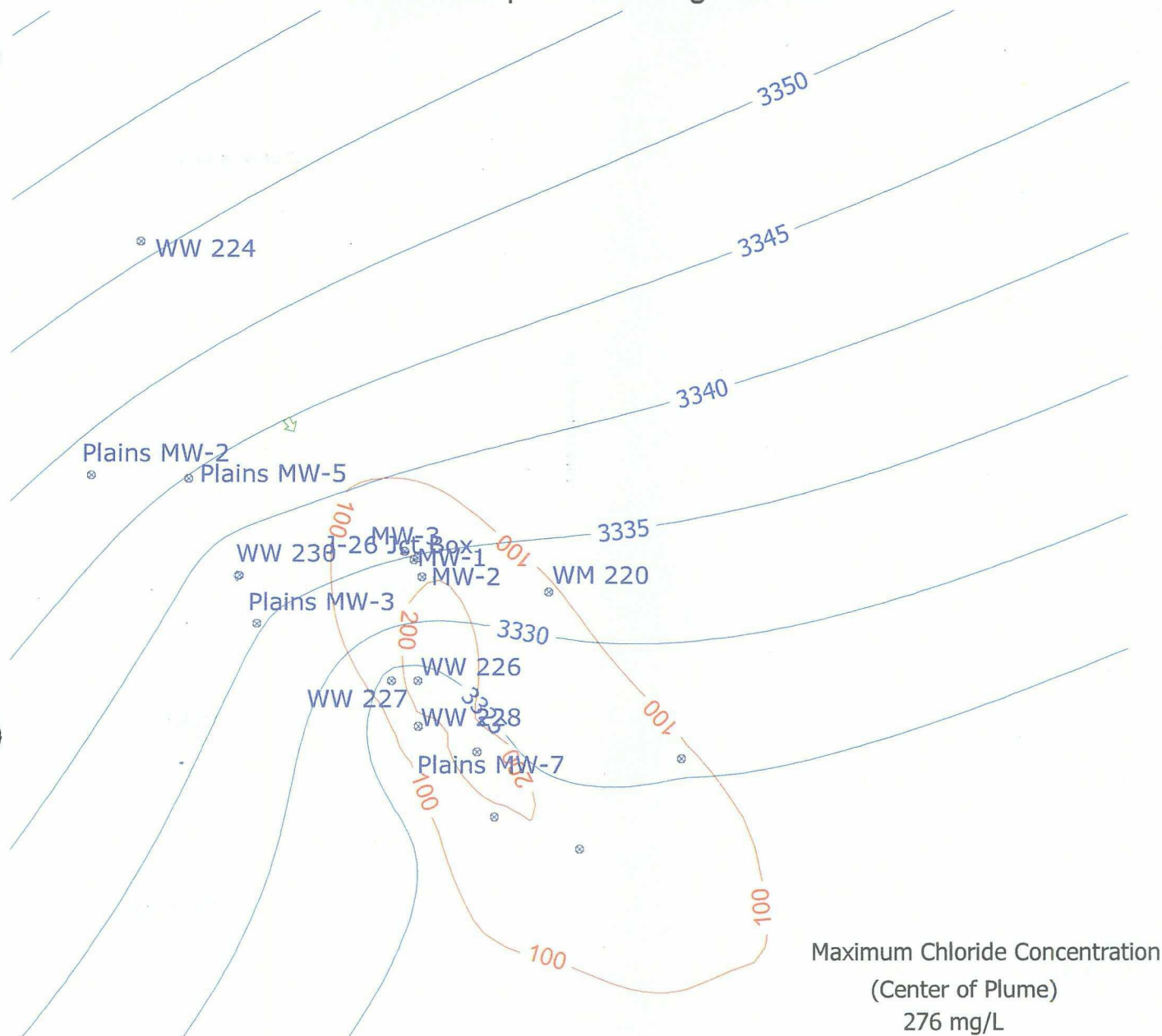
5280 feet

Estimated Conditions for Year 2040

## Modeling Assumptions

Hydraulic Conductivity = 1600 ft/yr (4.4 ft/day)  
 Hydraulic Gradient = 0.003 ft/ft (SE)  
 Longitudinal Dispersivity = 328 ft  
 Transverse Dispersivity = 32.8 ft  
 Diffusion Coefficient = 0.3349 ft<sup>2</sup>/day  
 Porosity = 0.25 percent  
 Aquifer Bottom at 3250 ft AMSL  
 Imported Surfer Initial WinTran 2002.grd

# BD J-26 Junction Box Site WinTran Fate & Transport Modeling Results



Estimated Conditions for Year 2047

## Modeling Assumptions

Hydraulic Conductivity = 1600 ft/yr (4.4 ft/day)  
 Hydraulic Gradient = 0.003 ft/ft (SE)  
 Longitudinal Dispersivity = 328 ft  
 Transverse Dispersivity = 32.8 ft  
 Diffusion Coefficient = 0.3349 ft<sup>2</sup>/day  
 Porosity = 0.25 percent  
 Aquifer Bottom at 3250 ft AMSL  
 Imported Surfer Initial WinTran 2002.grd



WinTran  
Analytical Model of 2D Ground-Water Flow and  
Finite-Element Contaminant Transport Model

Developed by

James O. Rumbaugh, III

Douglas B. Rumbaugh

(c) 1995 Environmental Simulations, Inc.

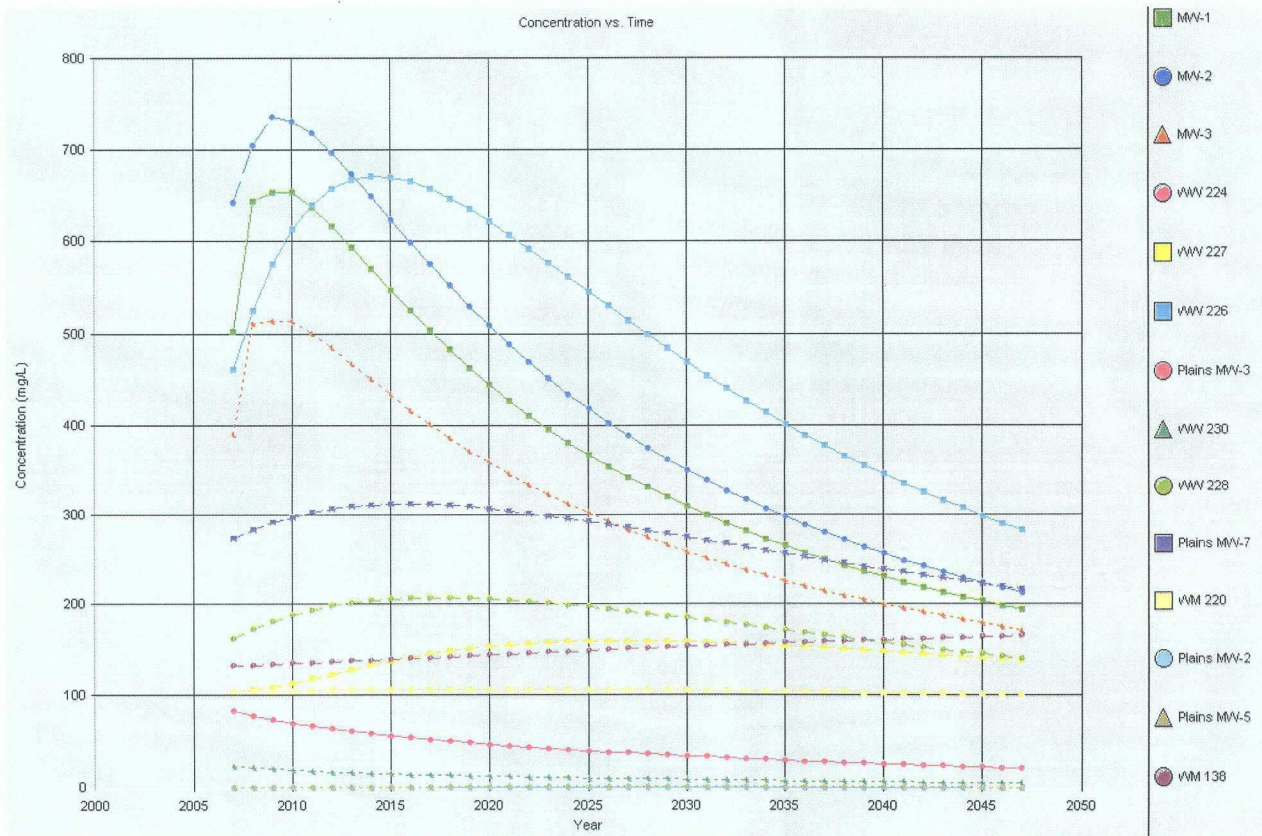
Model performed by: Trident Environmental (Gilbert Van Deventer)

Date: 03/02/07

Time: 13:19:54.00

Input File: 2006 CHLORIDE J26

Map File : D:\PROJECTS\RICE\BD\J-26\WINTRAN RESULTS\WINTRAN2002BASE.MAP



Model Entities

Number of Wells = 17

Well #1

Center of Well -- x: 3873.000000 y: 5443.000000  
Radius = 0.083330  
Pumping Rate = 0.000000  
Concentration of Injected Water = 218.000000  
Head at Well Radius = 3334.738437

Well #2

Center of Well -- x: 3969.000000 y: 5243.000000  
Radius = 0.083330  
Pumping Rate = 0.000000  
Concentration of Injected Water = 387.000000  
Head at Well Radius = 3333.495421

Well #3

Center of Well -- x: 3764.000000 y: 5540.000000  
Radius = 0.083330  
Pumping Rate = 0.000000  
Concentration of Injected Water = 141.000000  
Head at Well Radius = 3335.402430

Well #4

Center of Well -- x: 631.000000 y: 9185.000000  
Radius = 0.083330  
Pumping Rate = 0.000000  
Concentration of Injected Water = 302.000000  
Head at Well Radius = 3355.727045

Well #5

Center of Well -- x: 3611.000000 y: 4012.000000  
Radius = 0.375000  
Pumping Rate = 721412.000000  
Concentration of Injected Water = 181.000000  
Head at Well Radius = 3318.357873

Well #6

Center of Well -- x: 3921.000000 y: 4012.000000  
Radius = 0.375000  
Pumping Rate = 543819.000000  
Concentration of Injected Water = 225.000000  
Head at Well Radius = 3318.856940

Well #7

Center of Well -- x: 2012.000000 y: 4694.000000  
Radius = 0.083330  
Pumping Rate = 0.000000  
Concentration of Injected Water = 322.000000  
Head at Well Radius = 3335.282440

Well #8

Center of Well -- x: 1802.000000 y: 5262.000000  
Radius = 0.375000  
Pumping Rate = 1202639.000000  
Concentration of Injected Water = 187.000000  
Head at Well Radius = 3328.076355

Well #9

Center of Well -- x: 3927.000000 y: 3481.000000  
Radius = 0.375000  
Pumping Rate = 2748248.000000  
Concentration of Injected Water = 308.000000  
Head at Well Radius = 3289.944035

Well #10

Center of Well -- x: 4628.000000 y: 3178.000000  
Radius = 0.083330



Pumping Rate = 0.000000  
Concentration of Injected Water = 450.000000  
Head at Well Radius = 3323.670009

Well #11  
Center of Well -- x: 5472.000000 y: 5065.000000  
Radius = 0.250000  
Pumping Rate = 1000.000000  
Concentration of Injected Water = 620.000000  
Head at Well Radius = 3332.262314

Well #12  
Center of Well -- x: 60.000000 y: 6446.000000  
Radius = 0.083330  
Pumping Rate = 0.000000  
Concentration of Injected Water = 269.000000  
Head at Well Radius = 3348.295561

Well #13  
Center of Well -- x: 1205.000000 y: 6403.000000  
Radius = 0.083330  
Pumping Rate = 0.000000  
Concentration of Injected Water = 225.000000  
Head at Well Radius = 3344.810629

Well #14  
Center of Well -- x: 4829.000000 y: 2410.000000  
Radius = 0.250000  
Pumping Rate = 0.000000  
Concentration of Injected Water = 341.000000  
Head at Well Radius = 3324.074809

Well #15  
Center of Well -- x: 5838.000000 y: 2032.000000  
Radius = 0.250000  
Pumping Rate = 0.000000  
Concentration of Injected Water = 971.000000  
Head at Well Radius = 3323.649345

Well #16  
Center of Well -- x: 7050.000000 y: 3103.000000  
Radius = 0.375000  
Pumping Rate = 100000.000000  
Concentration of Injected Water = 405.000000  
Head at Well Radius = 3324.822825

Well #17  
Center of Well -- x: 3914.520000 y: 5464.310000  
Radius = 4.000000  
Pumping Rate = 0.000000  
Concentration of Injected Water = 60000.000000  
Head at Well Radius = 3334.824298

Reference Head = 3345.000000      Defined at -- x: 2360.290000      y: 7094.260000

---

## Aquifer Properties

### .... Steady-State Flow Model ....

Permeability.....= 1606.000000 [L/T]  
Porosity.....= 0.250000  
Elevation of Aquifer Top....= 3400.000000  
Elevation of Aquifer Bottom.= 3250.000000  
Uniform Regional Gradient...= 0.003000  
Angle of Uniform Gradient...= 304.000000  
Recharge.....= 0.000000

### .... Transient Transport Model ....

Longitudinal Dispersivity...= 328.000000 [L]  
Transverse Dispersivity.....= 32.800000 [L]  
Diffusion Coefficient.....= 0.000000 [L<sup>2</sup>/T]  
Contaminant half-life..... = 0.000000 [T]  
Retardation Coefficient.....= 1.000000  
Upstream Weighting in X.....= 0.000000  
Upstream Weighting in Y.....= 0.000000

### .... Time Stepping Information ....

Number of time steps.....= 41  
Starting time value.....= 2006.000000  
Initial time step size.....= 1.000000  
Time step multiplier..... = 1.000000  
Maximum time step size.....= 1.000000  
Time stepping scheme.....= Central Differencing

### .... Simulation Summary ....

Starting time.....= 2006.000000  
Ending time.....= 2047.000000  
Number of time steps.....= 41

(NOTE: following mass balance errors expressed as percent)  
Transport Mass Balance Error= 7.032368

Peclet Criterion.....= 0.516657  
Courant Number.....= 0.867743  
Flow Model Type.....= Analytic Element

## **APPENDIX B**

**Documentation of WinTran (Version 1.03)**

**Fate and Transport Model**

**Capabilities and Benchmarking**

# WinFlow/WinTran Verification

## Introduction

Verification is the process of demonstrating that the computer program performs as documented. In the case of a model, such as WinFlow, verification tests for proper implementation of the applicable equations. These equations are documented in Chapter 5 and are tested in this chapter.

The steady-state and transient models are tested separately, as described below. In each case, the model is first tested using a simple example that can be solved with a calculator. Next, WinFlow computations are compared against either another code solving the same problem or against published answers. The steady-state model is further tested by comparing WinFlow results against those of a popular numerical model, MODFLOW (McDonald and Harbaugh, 1988).

## Steady-state Model

Three sets of verification problems are presented for the steady-state analytical functions used in WinFlow. In the first problem, a simple uniform flow field with a single pumping well is solved using WinFlow and a calculator. This is one of the more common uses for WinFlow and illustrates that the basic code functions are programmed accurately. In the second case, a series of problems are benchmarked against the program SLWL (Strack, 1989). Finally, a simple test case of a single well in a uniform unconfined flow field is a benchmark against the numerical model, MODFLOW.

## Transient Model

Three sets of verification problems are presented for the transient analytical functions used in WinFlow. In the first problem, drawdown is computed for a single well. In the second case, a uniform regional gradient is added to the problem. In each of the first two test cases, WinFlow calculations are compared to those performed with a calculator. The final test presents tables of the Theis (1935) and Hantush and Jacob (1955) well functions for comparison with published tables.

## Transport Model

The finite-element transport model in WinTran is verified through comparison with an analytical solution from Wexler (1992) and with another finite-element transport model called SEFTRAN (Huyakorn et al., 1984). The Wexler analytical solution models transport of a dissolved contaminant from a point source in a two-dimensional uniform flow field. Six test cases were investigated with SEFTRAN for the three different source configurations (injection well, pond, and linesink) in both uniform flow and in non-uniform flow fields.

## Steady-state Model

Three sets of verification problems are presented for the steady-state analytical functions used in WinFlow. In the first problem, a simple uniform flow field with a single pumping well is solved using WinFlow and a calculator. This is one of the more common uses for WinFlow and illustrates that the basic code functions are programmed accurately. In the second case, a series of problems are benchmarked against the program SLWL (Strack, 1989). Finally, a simple test case of a single well in a uniform unconfined flow field is a benchmark against the numerical model, MODFLOW.



# Case 1: Uniform Flow with a Single Well

The steady-state analytic function for a single well in a uniform flow field is given by Strack (1989) as follows:

$$\Phi = -Q_0(x \cos \alpha + y \sin \alpha) + \frac{Q}{4\pi} \ln[r^2(x,y)] + C$$

where

- $\Phi$  = discharge potential [ $L^3/T$ ],
- $Q_0$  = uniform ground-water flow [ $L^2/T$ ],
- $x,y$  = coordinates of the calculation point,
- $\alpha$  = angle between uniform flow and x-axis,
- $r(x,y)$  = distance from the well to the calculation point (x,y),
- $Q$  = well discharge [ $L^3/T$ ],
- $C$  = constant.

In a confined aquifer system, the discharge potential,  $\Phi$ , is converted to head ( $\phi$ ) by the following equation.

$$\phi = \frac{\Phi + \frac{i}{2}KH^2}{KH}$$

where

- $\phi$  = head [ $L$ ],
- $K$  = hydraulic conductivity [ $L/T$ ],
- $H$  = aquifer thickness [ $L$ ].

The constant,  $C$ , is evaluated by specifying a reference head at a certain location within the flow system. The reference head remains constant during all subsequent calculations. The constant,  $C$ , is computed as follows:

$$C = \Phi_o + Q_o(x_o \cos \alpha + y_o \sin \alpha) - \frac{Q}{4\pi} \ln[r^2(x_o, y_o)]$$

where

$\Phi_o$  = reference discharge potential,

$(x_o, y_o)$  = coordinates of reference head.

In the first verification problem, the aquifer is confined with a uniform regional gradient parallel to the x-axis. The problem assumptions and parameters are listed below.

$K = 100$  ft/d

$H = 100$  ft

Gradient (i) = 0.01 ft/ft

$Q_o = KiH = 100$  ft<sup>2</sup>/d

reference head,  $\Phi_o = 200$  ft at  $(x_o=0, y_o=0)$

$\Phi_o = KH \Phi_o - \frac{1}{2}KH^2 = 1500000$  ft<sup>3</sup>/d

$Q = 100,000$  ft<sup>3</sup>/d at  $(x=1000, y=1000)$

Using these parameters and equation (3), the constant C equals 1,384,541. Table 1 lists the results of hand calculations and WinFlow results (using the Point Calculation option) for a series of coordinates. The two results are identical to five significant figures; the calculator results were rounded to five figures. Thus, WinFlow computes the correct answer for this test case.

Table 1 Comparison between WinFlow and calculator results for test case 1.

X	Y	$\Phi$	$\Phi$	$\Phi$ (WinFlow)
0	1000	1,494,480	199.45	199.448
250	1000	1,464,902	196.49	196.491
500	1000	1,433,449	193.34	193.345
750	1000	1,397,417	189.74	189.742
1000	1000	1,284,441	178.44	178.444
1250	1000	1,347,417	184.74	184.742
1500	1000	1,333,449	183.34	183.345
1750	1000	1,314,902	181.49	181.491
2000	1000	1,294,481	179.45	179.448

# Case 2: Benchmark with SLWL

The SLWL program is provided with the book, Groundwater Mechanics, (Strack, 1989). SLWL performs the same calculations as WinFlow. The primary difference between the two codes is that SLWL is written in FORTRAN, while WinFlow is written in the C programming language. SLWL has additional capabilities to those of WinFlow but is not as user-friendly nor does SLWL have good output capabilities.

A series of twelve test cases are developed to test each of the major components in WinFlow, including wells, ponds, linesinks, and recharge. Each feature added to the simulation is designed to produce a significant impact on the flow field, so that significant errors would be easily detected. Both confined and unconfined conditions are tested. These verification data sets are included on the WinFlow disk. The data file names are VER1.WFL, VER2.WFL, ....., and VER12.WFL.

SLWL was modified to export a SURFER contour matrix (grid file) in the same manner as WinFlow. The SURFER grid files were then subtracted from one another to create a matrix of differences. A simple program was created to compute the mean and maximum difference. The results are summarized in Table 2. The features tested in each simulation are summarized in Table 2, along with the mean and maximum differences between the two codes. The specific details of each test may be examined by retrieving the verification data files from within WinFlow.

The maximum difference for each simulation was a uniform value of 0.000198 feet. The maximum error was constant, probably due to a consistent difference in the computational algorithms used in the C and FORTRAN compilers used for the two codes (Microsoft FORTRAN and Microsoft Visual C++). The mean error for each run varied from a low of 0.00000186 (VER6.WFL) to a high of 0.0000139 (VER7.WFL). In all cases, the differences between the two codes are on the order of  $1.0 \times 10^{-6}$  percent.

Table 2 Mean and maximum differences between WinFlow and SLWL in 12 test cases.									
Data File	Uniform	Wells	Ponds	Line-sinks (head)	Line-sinks (flux)	Recharge	Aquifer Type (C/U)	Max. Error	Mean Error
ver1.wfl	✓	✓					C	0.000198	0.0000037
ver2.wfl	✓	✓					U	0.000198	0.0000019
ver3.wfl	✓	✓	✓				C	0.000198	0.0000038
ver4.wfl	✓	✓	✓				U	0.000198	0.0000020
ver5.wfl	✓	✓		✓			C	0.000198	0.0000051
ver6.wfl	✓	✓		✓			U	0.000198	0.0000019
ver7.wfl	✓	✓			✓		C	0.000198	0.0000014
ver8.wfl	✓	✓			✓		U	0.000198	0.0000066
ver9.wfl	✓	✓	✓	✓	✓		C	0.000198	0.0000048
ver10.wfl	✓	✓	✓	✓	✓		U	0.000198	0.0000030
ver11.wfl	✓	✓	✓	✓	✓	✓	C	0.000198	0.0000048
ver12.wfl	✓	✓	✓	✓	✓	✓	U	0.000198	0.0000030

# Case 3: Benchmark with Numerical Model

A final test of the steady-state analytic functions in WinFlow is a comparison with a numerical model. The model chosen for comparison is MODFLOW (McDonald and Harbaugh, 1988), which is a three-dimensional, finite-difference ground-water flow model developed by the United States Geological Survey. MODFLOW is one of the most widely used numerical ground-water flow models.

A simple problem involving a single pumping well in a uniform flow field is chosen as the test case. The aquifer is unconfined with homogeneous properties. The model parameters are summarized below for the WinFlow data set.

$$K = 100 \text{ ft/d};$$

$$\text{Aquifer bottom elevation} = 0.0 \text{ ft};$$

$$\text{Gradient (i)} = 0.001 \text{ ft/ft at an angle of } 0^\circ \text{ to the x-axis};$$

$$Q_o = KiH = 10 \text{ ft}^2/\text{d};$$

$$H_o = 100 \text{ ft at } (x_o=0, y_o=0).$$

A single well located at coordinates  $(x=5000, y=5000)$  pumps  $100,000 \text{ ft}^3/\text{d}$ . The WinFlow input data file for this problem is provided on the distribution disk. The file name is "modfl.wfl".

Additional information is required to simulate the same system with a numerical model, such as MODFLOW. A finite-difference grid was constructed measuring 10,000 feet in both the x- and y-directions. There are 125 rows and 125 columns in the grid, with a cell spacing of 80 ft. A constant head of 100 ft was placed along the first column and a constant head of 89.532 was placed along the last column. The odd number was used to maintain a constant regional flow of  $10 \text{ ft}^3/\text{d/ft}$  across the finite-difference grid under nonpumping conditions. The MODFLOW data set for this problem are contained on the WinFlow disk. Several files are required for input to the MODFLOW code. The files have a common root file name of "wflow" and a three-letter extension designating the MODFLOW package name. The MODFLOW files for this problem are as follows:

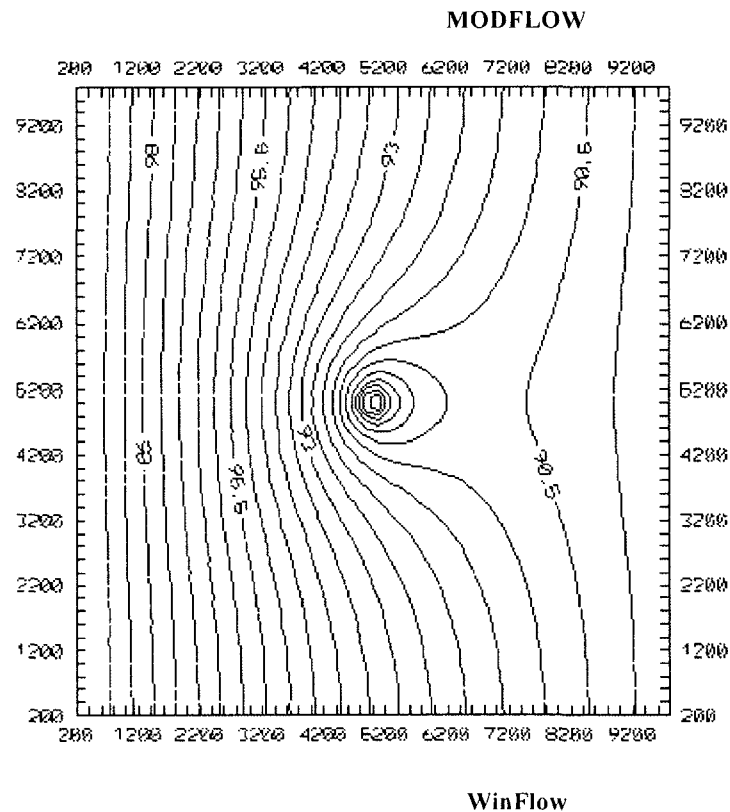
WFLOW.BAS	Basic Package Input
WFLOW.BCF	Block-Centered-Flow Package Input
WFLOW.SIP	Strongly Implicit Package Input
WFLOW.WEL	Well Package Input
WFLOW.OC	Output Control Input

The WinFlow and MODFLOW calculations were compared by producing a SURFER grid file with 50 rows and 50 columns. The grid corners are located at  $(x=200, y=200)$  and  $(x=9800, y=9800)$ . The two grid files were subtracted from each other to obtain a head difference file. A simple program was written to compute the maximum and mean differences. Contour maps produced for the WinFlow and MODFLOW results are also shown in Figure 1.

In the initial test case, MODFLOW and WinFlow compare favorably, with a maximum error of 0.84 feet and a mean error of 0.25 feet. The change in head across the model is 10.468 feet. Thus, there is a maximum difference of about 8 percent between the two codes. The contour maps shown in Figure 1 for the two codes are very similar. The primary difference is the behavior of the contours at the upper and lower (north and south) edge of the model. Contours from the MODFLOW run are perpendicular to the boundary, while WinFlow generated contours hit the boundary at an angle. This happens because MODFLOW treats the edge of the model as a no-flow or impermeable boundary forcing the contours to hit the boundary at right angles. WinFlow, on the other hand, assumes that the aquifer is infinite without any no-flow or impermeable boundaries.

A second test case was simulated by both WinFlow and MODFLOW in which no-flow boundaries were simulated with WinFlow. The northern and southern no-flow boundaries were reproduced in WinFlow using image wells. Two image wells were placed at coordinates  $(x=5000, y=15000)$  and  $(x=5000, y=-5000)$ . Each image well pumped  $100,000 \text{ ft}^3/\text{d}$ . Contour maps for the second test case are shown in Figure 2. Now the WinFlow contours also strike the boundary at close to right angles. The maximum difference between WinFlow and MODFLOW for the second case is 0.39 feet, with a mean difference of 0.11 feet. This represents a significant improvement over the first test case. The maximum difference is 3.7 percent in this case.

The two test cases presented for the benchmark between WinFlow and MODFLOW show that both codes calculate similar head fields for the same problem. Even though the method of solution is different (analytical vs. numerical), each software package gives similar results. These comparisons provide the user with confidence that WinFlow is solving the ground-water flow equations properly.





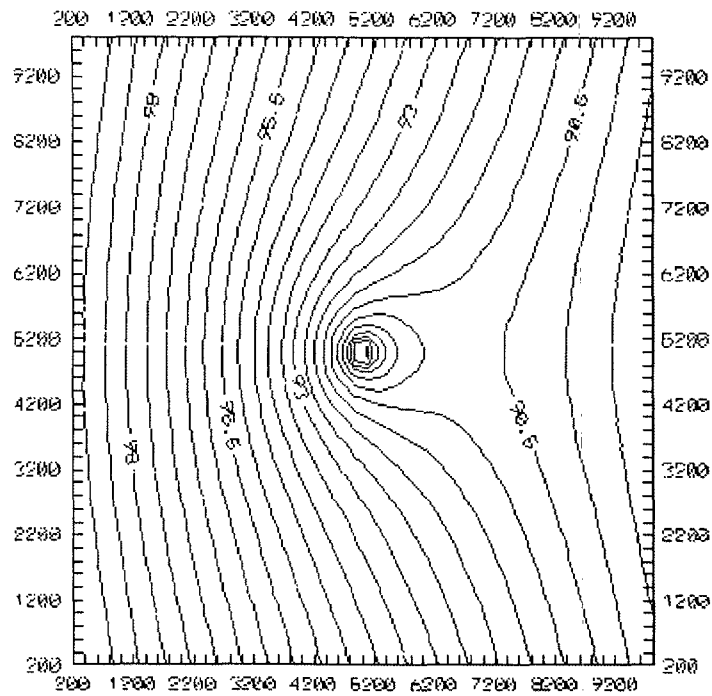
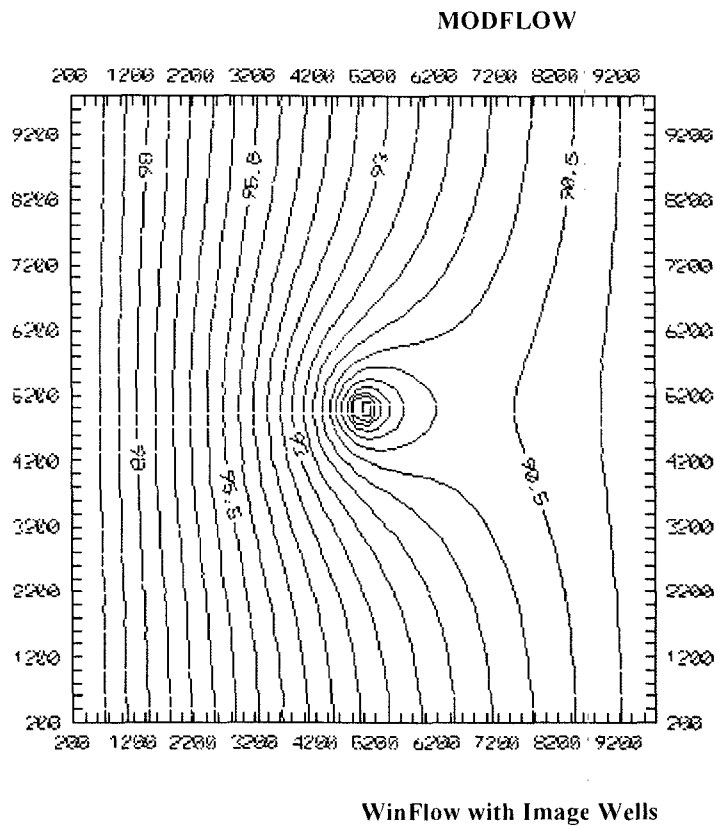


Figure 1. Comparison between WinFlow and MODFLOW for Test Case 1.



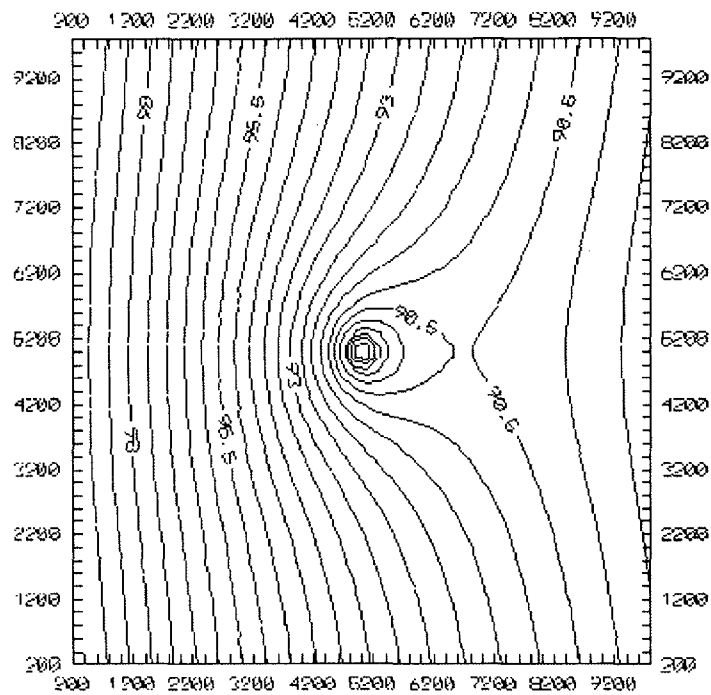


Figure 2. Comparison between WinFlow and MODFLOW for Test Case 2.

## Transient Model

Three sets of verification problems are presented for the transient analytical functions used in WinFlow. In the first problem, drawdown is computed for a single well. In the second case, a uniform regional gradient is added to the problem. In each of the first two test cases, WinFlow calculations are compared to those performed with a calculator. The final test presents tables of the Theis (1935) and Hantush and Jacob (1955) well functions for comparison with published tables.

# Case 1: Drawdown from a Single Well

The drawdown due to a single pumping well may be computed for any point in an aquifer using the following equation (Theis 1935):

$$s = \frac{Q}{4\pi T} W(u)$$

where

- $s$  = drawdown [L],
- $Q$  = well pumping rate [ $L^3/T$ ],
- $T$  = transmissivity [ $L^2/T$ ],
- $u$  =  $(r^2 S)/(4 T t)$ ,
- $r$  = distance between well and calculation point,
- $S$  = storage coefficient [dimensionless],
- $t$  = time after start of pumping [T],
- $W(u)$  = Theis well function.

In this example problem, we will choose the values of the parameters so that calculation is straightforward on a hand calculator and published tables of the Theis well function. The following parameters are used for Case 1:

- $T = 2500 \text{ ft}^2/\text{d}$
- $S = 0.01$
- $t = 1.0 \text{ d}$
- $Q = 10,000 \text{ ft}^3/\text{d}$

WinFlow computed the same values of drawdown ( $s$ ) as those computed using a calculator to four significant figures. The results of Case 1 are presented in Table 3.

Table 3 Comparison between WinFlow and calculator results for transient case 1.				
Radius (ft)	$u$	$W(u)$	$s$ (ft)	$s$ (WinFlow)
1.0	$10^{-6}$	13.24	4.214	4.214
10.0	$10^{-4}$	8.633	2.748	2.748
20.0	$4 \times 10^{-4}$	7.247	2.307	2.307
30.0	$9 \times 10^{-4}$	6.437	2.049	2.049
40.0		5.862	1.866	1.866

	$1.6 \times 10^{-3}$			
50.0	$2.5 \times 10^{-3}$	5.417	1.724	1.724
60.0	$3.6 \times 10^{-3}$	5.053	1.608	1.608
70.0	$4.9 \times 10^{-3}$	4.746	1.511	1.511
80.0	$6.4 \times 10^{-3}$	4.481	1.426	1.426
90.0	$8.1 \times 10^{-3}$	4.247	1.352	1.352
100.0	0.01	4.038	1.285	1.285

# Case 2: Drawdown from a Single Well in a Uniform Flow Field

The same parameters used in Case 1 above will be used in Case 2 and a uniform regional gradient will be added. Assume that the gradient is 0.001 ft/ft, with a reference head of 100 ft at the well. Because the transient model does not assume that the reference head is constant, the reference head may be specified anywhere (even at the well). We will also assume that the origin of the coordinate system ( $x=0$ ,  $y=0$ ) is at the well center.

The equation for a single well in a uniform flow field under transient conditions was given in the last chapter as

$$\phi(x,y,t) = C - G(x \cos \alpha + y \sin \alpha) - s$$

where

- $\phi$  = head [L],
- $G$  = regional gradient [L/L],
- $\alpha$  = angle between regional gradient and x-axis,
- $(x,y)$  = coordinates of calculation point,
- $t$  = time since start of pumping,
- $s$  = drawdown from well,
- $C$  = constant.

The constant,  $C$ , is equal to the reference head in this case.

The heads computed by WinFlow and using a hand calculator are presented in Table 4. Again, WinFlow results and the calculator results are identical to six significant figures.

Table 4 Comparison between WinFlow and hand calculations for transient case 2.			
X	Y	$\phi$	$\phi$ (WinFlow)
1.0	0.0	95.786	95.786
10.0	0.0	97.152	97.152
20.0	0.0	97.493	97.493
30.0	0.0	97.651	97.651
40.0	0.0	97.734	97.734
50.0	0.0	97.776	97.776
60.0	0.0	97.792	97.792
70.0	0.0	97.789	97.789
80.0	0.0	97.774	97.774
90.0	0.0	97.748	97.748
100.0	0.0	97.715	97.715



# Case 3: Calculation of Well Function Tables

The first two transient test cases tested the ability of WinFlow to compute drawdown with and without a regional gradient. These tests illustrated that WinFlow internal drawdown calculations are properly implemented. A further test of the software is calculation of well function tables, which tests WinFlow's ability to accurately compute drawdown over a wide range of conditions.

WinFlow uses two transient analytical functions: (1) the Theis (1935) equation for confined aquifers, and (2) the Hantush and Jacob (1955) equation for semi-confined (or leaky) aquifers. Values of the Theis well function,  $W(u)$ , were computed using the numerical routines in WinFlow for a wide range of values of  $u$ . These calculations are shown in Table 5. These values can be compared to any published values, although the format of the table is identical to that published by Kruseman and deRidder (1990) in Annex 3.1, page 294. Table 5 and Annex 3.1 (Kruseman and deRidder 1990) are identical, illustrating that WinFlow can calculate the Theis well function accurately over a wide range in  $u$ .

Similarly, the Hantush and Jacob (1955) well function,  $W(u, r/L)$ , was computed using the routines in WinFlow for a range of  $u$  and  $r/L$  values. These are shown in Tables 6, 7, and 8. Kruseman and deRidder (1990) have published similar tables in Annex 4.2 (pages 298 and 299). The Kruseman and deRidder (1990) tables and Tables 6, 7, and 8 are identical, confirming that WinFlow accurately computes values for the Hantush and Jacob leaky well function.

**Table 5 Theis well function,  $W(u)$ , computed using routines in WinFlow.**

$u$	$W(u)$	$W(u \cdot 10^{-1})$	$W(u \cdot 10^{-2})$	$W(u \cdot 10^{-3})$	$W(u \cdot 10^{-4})$	$W(u \cdot 10^{-5})$	$W(u \cdot 10^{-6})$	$W(u \cdot 10^{-7})$	$W(u \cdot 10^{-8})$	$W(u \cdot 10^{-9})$	$W(u \cdot 10^{-10})$
1.0	2.194e- 01			1.823e+004.038e+00		6.332e+00		8.633e+001.094e+01		1.324e+01	1.554e+01
1.784e+01	2.015e+01			2.245e+01							
1.2	1.584e- 01			1.660e+003.858e+00		6.149e+00		8.451e+001.075e+01		1.306e+01	1.536e+01
1.766e+01	1.996e+01			2.227e+01							
1.5	1.000e- 01			1.464e+003.637e+00		5.927e+00		8.228e+001.053e+01		1.283e+01	1.514e+01
1.744e+01	1.974e+01			2.204e+01							
2.0	4.890e- 02			1.223e+003.355e+00		5.639e+00		7.940e+001.024e+01		1.255e+01	1.485e+01
1.715e+01	1.945e+01			2.176e+01							
2.5	2.491e- 02			1.044e+003.137e+00		5.417e+00		7.717e+001.002e+01		1.232e+01	1.462e+01
1.693e+01	1.923e+01			2.153e+01							
3.0	1.305e- 02		9.057e- 01		2.959e+00	5.235e+00		7.535e+00		9.837e+00	1.214e+01
1.444e+01	1.674e+01		1.905e+01		2.135e+01						
3.5	6.970e- 03		7.942e- 01		2.810e+00	5.081e+00		7.381e+00		9.683e+00	1.199e+01
1.429e+01	1.659e+01		1.889e+01		2.120e+01						
4.0	3.779e- 03		7.024e- 01		2.681e+00	4.948e+00		7.247e+00		9.549e+00	1.185e+01
1.415e+01	1.646e+01		1.876e+01		2.106e+01						
4.5	2.073e- 03		6.253e- 01		2.568e+00	4.831e+00		7.129e+00		9.432e+00	1.173e+01
1.404e+01	1.634e+01		1.864e+01		2.094e+01						
5.0	1.148e- 03		5.598e- 01		2.468e+00	4.726e+00		7.024e+00		9.326e+00	1.163e+01
1.393e+01	1.623e+01		1.854e+01		2.084e+01						
6.0	3.601e- 04		4.544e- 01		2.295e+00	4.545e+00		6.842e+00		9.144e+00	1.145e+01
1.375e+01	1.605e+01		1.835e+01		2.066e+01						
7.0	1.155e- 04		3.738e- 01		2.151e+00	4.392e+00		6.688e+00		8.990e+00	1.129e+01
1.359e+01	1.590e+01		1.820e+01		2.050e+01						
8.0	3.767e- 05		3.106e- 01		2.027e+00	4.259e+00		6.554e+00		8.856e+00	1.116e+01

1.346e+01	1.576e+01	1.807e+01	2.037e+01				
9.0	1.245e-05	2.602e-01	1.919e+00	4.142e+00	6.437e+00	8.739e+00	1.104e+01
1.334e+01	1.565e+01	1.795e+01	2.025e+01				

**Table 6** Hantush well function,  $W(u, r/L)$ , computed using routines in WinFlow.

u	r/L = 0	0.005	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
1.0e-06	1.32e+01	1.08e+01	9.44e+00	8.06e+00	7.25e+00	6.67e+00	6.23e+00	5.87e+00	5.56e+00	5.29e+00	5.06e+00
2.0e-06	1.25e+01	1.08e+01	9.44e+00	8.06e+00	7.25e+00	6.67e+00	6.23e+00	5.87e+00	5.56e+00	5.29e+00	5.06e+00
4.0e-06	1.19e+01	1.07e+01	9.44e+00	8.06e+00	7.25e+00	6.67e+00	6.23e+00	5.87e+00	5.56e+00	5.29e+00	5.06e+00
6.0e-06	1.14e+01	1.06e+01	9.44e+00	8.06e+00	7.25e+00	6.67e+00	6.23e+00	5.87e+00	5.56e+00	5.29e+00	5.06e+00
8.0e-06	1.12e+01	1.05e+01	9.43e+00	8.06e+00	7.25e+00	6.67e+00	6.23e+00	5.87e+00	5.56e+00	5.29e+00	5.06e+00
1.0e-05	1.09e+01	1.04e+01	9.42e+00	8.06e+00	7.25e+00	6.67e+00	6.23e+00	5.87e+00	5.56e+00	5.29e+00	5.06e+00
2.0e-05	1.02e+01	9.95e+00	9.30e+00	8.06e+00	7.25e+00	6.67e+00	6.23e+00	5.87e+00	5.56e+00	5.29e+00	5.06e+00
4.0e-05	9.55e+00	9.40e+00	9.01e+00	8.03e+00	7.25e+00	6.67e+00	6.23e+00	5.87e+00	5.56e+00	5.29e+00	5.06e+00
6.0e-05	9.14e+00	9.04e+00	8.77e+00	7.98e+00	7.24e+00	6.67e+00	6.23e+00	5.87e+00	5.56e+00	5.29e+00	5.06e+00
8.0e-05	8.86e+00	8.78e+00	8.57e+00	7.91e+00	7.23e+00	6.67e+00	6.23e+00	5.87e+00	5.56e+00	5.29e+00	5.06e+00
1.0e-04	8.63e+00	8.57e+00	8.40e+00	7.84e+00	7.21e+00	6.67e+00	6.23e+00	5.87e+00	5.56e+00	5.29e+00	5.06e+00
2.0e-04	7.94e+00	7.91e+00	7.82e+00	7.50e+00	7.07e+00	6.62e+00	6.22e+00	5.86e+00	5.56e+00	5.29e+00	5.06e+00
4.0e-04	7.25e+00	7.23e+00	7.19e+00	7.01e+00	6.76e+00	6.45e+00	6.14e+00	5.83e+00	5.55e+00	5.29e+00	5.06e+00
6.0e-04	6.84e+00	6.83e+00	6.80e+00	6.68e+00	6.50e+00	6.27e+00	6.02e+00	5.77e+00	5.51e+00	5.27e+00	5.05e+00
8.0e-04	6.55e+00	6.55e+00	6.52e+00	6.43e+00	6.29e+00	6.11e+00	5.91e+00	5.69e+00	5.46e+00	5.25e+00	5.04e+00
1.0e-03	6.33e+00	6.33e+00	6.31e+00	6.23e+00	6.12e+00	5.97e+00	5.80e+00	5.61e+00	5.41e+00	5.21e+00	5.01e+00
2.0e-03	5.64e+00	5.64e+00	5.63e+00	5.59e+00	5.53e+00	5.45e+00	5.35e+00	5.24e+00	5.12e+00	4.98e+00	4.85e+00
4.0e-03	4.95e+00	4.95e+00	4.94e+00	4.92e+00	4.89e+00	4.85e+00	4.80e+00	4.74e+00	4.67e+00	4.59e+00	4.51e+00
6.0e-03	4.54e+00	4.54e+00	4.54e+00	4.53e+00	4.51e+00	4.48e+00	4.45e+00	4.41e+00	4.36e+00	4.30e+00	4.24e+00
8.0e-03	4.26e+00	4.26e+00	4.26e+00	4.25e+00	4.23e+00	4.21e+00	4.19e+00	4.15e+00	4.12e+00	4.08e+00	4.03e+00
1.0e-02	4.04e+00	4.04e+00	4.04e+00	4.03e+00	4.02e+00	4.00e+00	3.98e+00	3.95e+00	3.93e+00	3.89e+00	3.86e+00
2.0e-02	3.35e+00	3.35e+00	3.35e+00	3.35e+00	3.34e+00	3.34e+00	3.33e+00	3.31e+00	3.30e+00	3.28e+00	3.26e+00
4.0e-02	2.68e+00	2.68e+00	2.68e+00	2.68e+00	2.68e+00	2.67e+00	2.67e+00	2.66e+00	2.66e+00	2.65e+00	2.64e+00
6.0e-02	2.30e+00	2.30e+00	2.29e+00	2.29e+00	2.29e+00	2.29e+00	2.29e+00	2.28e+00	2.28e+00	2.27e+00	2.27e+00
8.0e-02	2.03e+00	2.03e+00	2.03e+00	2.03e+00	2.02e+00	2.02e+00	2.02e+00	2.02e+00	2.02e+00	2.01e+00	2.01e+00
1.0e-01	1.82e+00	1.82e+00	1.82e+00	1.82e+00	1.82e+00	1.82e+00	1.82e+00	1.82e+00	1.81e+00	1.81e+00	1.81e+00
2.0e-01	1.22e+00	1.22e+00	1.22e+00	1.22e+00	1.22e+00	1.22e+00	1.22e+00	1.22e+00	1.22e+00	1.22e+00	1.22e+00
4.0e-01	7.02e-01	7.02e-01	7.02e-01	7.02e-01	7.02e-01	7.02e-01	7.02e-01	7.02e-01	7.01e-01	7.01e-01	7.00e-01
6.0e-01	4.54e-01	4.54e-01	4.54e-01	4.54e-01	4.54e-01	4.54e-01	4.54e-01	4.54e-01	4.54e-01	4.54e-01	4.53e-01
8.0e-01	3.11e-01	3.11e-01	3.11e-01	3.11e-01	3.11e-01	3.10e-01	3.10e-01	3.10e-01	3.10e-01	3.10e-01	3.10e-01

**Table 7** Hantush well function,  $W(u, r/L)$ , computed using routines in WinFlow.

u	r/L = 0	0.1	0.2	0.3	0.4	0.6	0.8
1.0e-04	8.63e+00	4.85e+00	3.51e+00	2.74e+00	2.23e+00	1.56e+00	1.13e+00
2.0e-04	7.94e+00	4.85e+00	3.51e+00	2.74e+00	2.23e+00	1.56e+00	1.13e+00
4.0e-04	7.25e+00	4.85e+00	3.51e+00	2.74e+00	2.23e+00	1.56e+00	1.13e+00
6.0e-04	6.84e+00	4.85e+00	3.51e+00	2.74e+00	2.23e+00	1.56e+00	1.13e+00
8.0e-04	6.55e+00	4.84e+00	3.51e+00	2.74e+00	2.23e+00	1.56e+00	1.13e+00

1.0e-03	6.33e+00	4.83e+00	3.51e+00	2.74e+00	2.23e+00	1.56e+00	1.13e+00
2.0e-03	5.64e+00	4.71e+00	3.50e+00	2.74e+00	2.23e+00	1.56e+00	1.13e+00
4.0e-03	4.95e+00	4.42e+00	3.48e+00	2.74e+00	2.23e+00	1.56e+00	1.13e+00
6.0e-03	4.54e+00	4.18e+00	3.43e+00	2.74e+00	2.23e+00	1.56e+00	1.13e+00
8.0e-03	4.26e+00	3.98e+00	3.36e+00	2.73e+00	2.23e+00	1.56e+00	1.13e+00
1.0e-02	4.04e+00	3.82e+00	3.29e+00	2.71e+00	2.23e+00	1.56e+00	1.13e+00
2.0e-02	3.35e+00	3.24e+00	2.95e+00	2.57e+00	2.18e+00	1.55e+00	1.13e+00
4.0e-02	2.68e+00	2.63e+00	2.48e+00	2.27e+00	2.02e+00	1.52e+00	1.13e+00
6.0e-02	2.30e+00	2.26e+00	2.17e+00	2.02e+00	1.85e+00	1.46e+00	1.11e+00
8.0e-02	2.03e+00	2.00e+00	1.94e+00	1.83e+00	1.69e+00	1.39e+00	1.08e+00
1.0e-01	1.82e+00	1.80e+00	1.75e+00	1.67e+00	1.56e+00	1.31e+00	1.05e+00
2.0e-01	1.22e+00	1.22e+00	1.19e+00	1.16e+00	1.11e+00	9.96e-01	8.58e-01
4.0e-01	7.02e-01	7.00e-01	6.93e-01	6.81e-01	6.65e-01	6.21e-01	5.65e-01
6.0e-01	4.54e-01	4.53e-01	4.50e-01	4.44e-01	4.36e-01	4.15e-01	3.87e-01
8.0e-01	3.11e-01	3.10e-01	3.08e-01	3.05e-01	3.01e-01	2.89e-01	2.73e-01
1.0e+00	2.19e-01	2.19e-01	2.18e-01	2.16e-01	2.14e-01	2.06e-01	1.97e-01
2.0e+00	4.89e-02	4.89e-02	4.87e-02	4.85e-02	4.82e-02	4.72e-02	4.60e-02

Table 8 Hantush well function,  $W(u, r/L)$ , computed using routines in WinFlow.

u	r/L = 0	1.0	2.0	3.0	4.0	5.0	6.0
1.0e-02	4.04e+00	8.42e-01	2.28e-01	6.95e-02	2.23e-02	7.38e-03	2.49e-03
2.0e-02	3.35e+00	8.42e-01	2.28e-01	6.95e-02	2.23e-02	7.38e-03	2.49e-03
4.0e-02	2.68e+00	8.42e-01	2.28e-01	6.95e-02	2.23e-02	7.38e-03	2.49e-03
6.0e-02	2.30e+00	8.39e-01	2.28e-01	6.95e-02	2.23e-02	7.38e-03	2.49e-03
8.0e-02	2.03e+00	8.32e-01	2.28e-01	6.95e-02	2.23e-02	7.38e-03	2.49e-03
1.0e-01	1.82e+00	8.19e-01	2.28e-01	6.95e-02	2.23e-02	7.38e-03	2.49e-03
2.0e-01	1.22e+00	7.15e-01	2.27e-01	6.95e-02	2.23e-02	7.38e-03	2.49e-03
4.0e-01	7.02e-01	5.02e-01	2.10e-01	6.91e-02	2.23e-02	7.38e-03	2.49e-03
6.0e-01	4.54e-01	3.54e-01	1.77e-01	6.64e-02	2.22e-02	7.38e-03	2.49e-03
8.0e-01	3.11e-01	2.54e-01	1.44e-01	6.07e-02	2.17e-02	7.36e-03	2.49e-03
1.0e+00	2.19e-01	1.85e-01	1.14e-01	5.34e-02	2.07e-02	7.27e-03	2.49e-03
2.0e+00	4.89e-02	4.44e-02	3.34e-02	2.10e-02	1.12e-02	5.13e-03	2.10e-03
4.0e+00	3.78e-03	3.58e-03	3.06e-03	2.35e-03	1.63e-03	1.03e-03	5.86e-04

# WinFlow/WinTran Verification

## Transport Model

The finite-element transport model in WinTran is verified through comparison with an analytical solution from Wexler (1992) and with another finite-element transport model called SEFTRAN (Huyakorn et al., 1984). The Wexler analytical solution models transport of a dissolved contaminant from a point source in a two-dimensional uniform flow field. Six test cases were investigated with SEFTRAN for the three different source configurations (injection well, pond, and linesink) in both uniform flow and in non-uniform flow fields.

# Comparison to an Analytical Solution

Wexler (1992) presents a series of analytical solutions to the partial differential equations of dissolved contaminant transport in porous media. WinTran was compared to the solution for a continuous point source in an aquifer of infinite extent (see page 26 of Wexler, 1992). The analytical solution was implemented by Wexler in a FORTRAN program called POINT2.

The data for the test problem are presented in Table 1. Concentration is plotted versus time at two locations downgradient of the source for both WinTran and SEFTRAN (see Figure 1). These curves show that WinTran results are virtually identical to those of the analytical solution. Contours for both WinTran results and POINT2 results are shown in Figure 2. Again, these contours are almost identical for the two solutions. The largest difference is at the source, where WinTran slightly underpredicts the source concentration. This is probably caused by dilution of the source concentration in the finite-element cell. The majority of the plume, however, matches quite well between WinTran and POINT2.

Comparison of WinTran to an analytical solution confirms that the basic transport model has been coded properly. The analytical solution, however, assumes that the flow field is uniform and the source is a single point and continuous over time. The next section presents a series of tests that illustrate that WinTran performs properly for more complex scenarios.

Table 1. Model Parameters for the Analytical Solution Comparison

<u>Parameter</u>	<u>Value</u>
Hydraulic conductivity	100 ft/d
Top Elevation	-75 ft
Bottom Elevation	-100 ft
Porosity	0.2
Hydraulic Gradient	0.01 to the East
Groundwater Velocity	5 ft/d
Longitudinal Dispersivity	30 ft
Transverse Dispersivity	3 ft
Retardation Coefficient	1
X coordinate of source	212.32 ft
Y coordinate of source	230.87 ft
Source fluid flow rate	-1 ft <sup>3</sup> /d
Source concentration	100
Number of X nodes	70
Number of Y nodes	70
Minimum X coordinate	50.0 ft
Minimum Y coordinate	50.0 ft

Nodal Spacing in X	8.116 ft
Nodal Spacing in Y	5.652 ft
Number of time steps	50
Minimum time step size	0.5 day
Maximum time step size	10 days
Time step multiplier	1.1
Final time value	280.569 days

Figure 1. Time-series comparison between WinTran and an analytical solution at two downgradient nodes

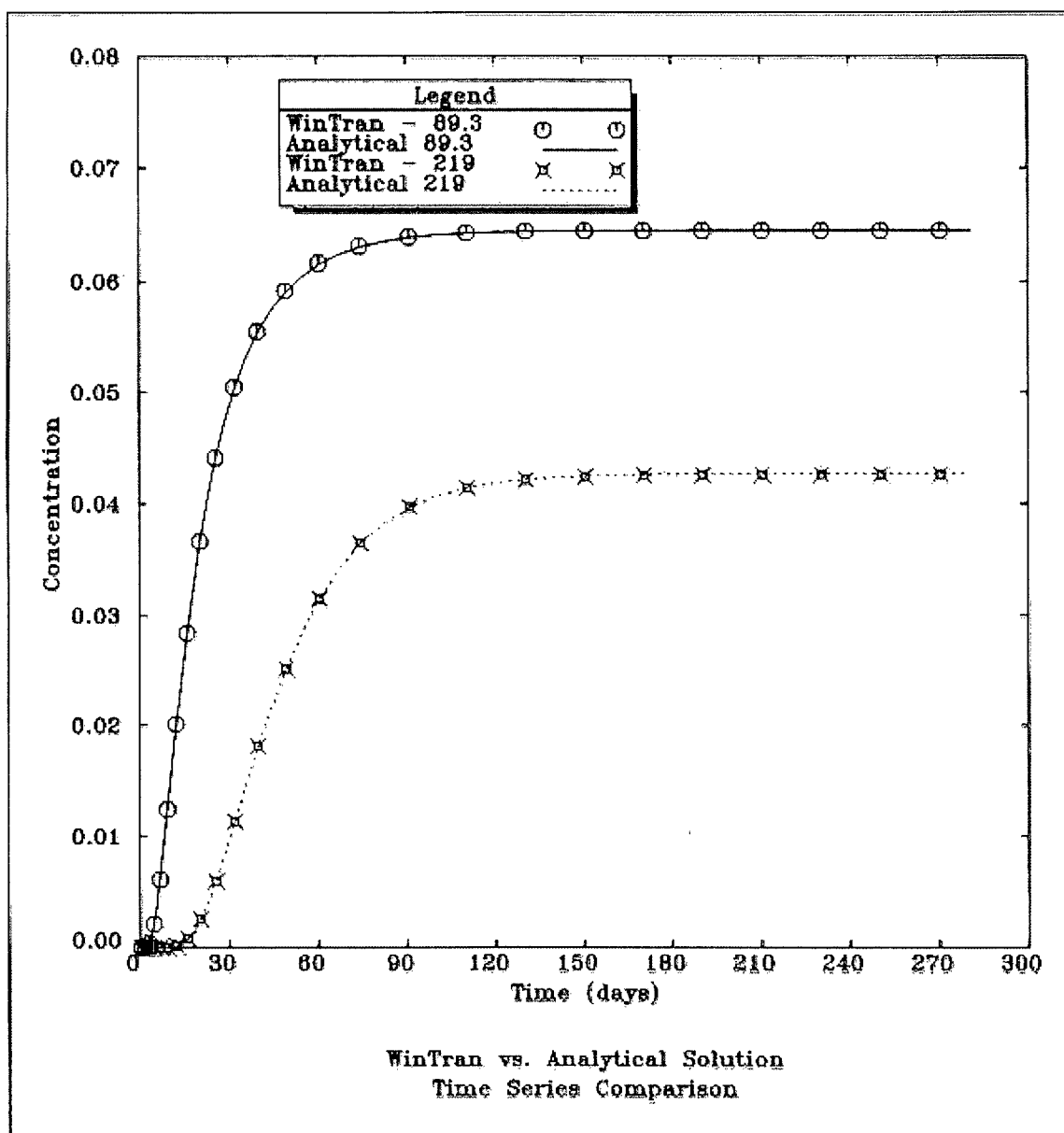
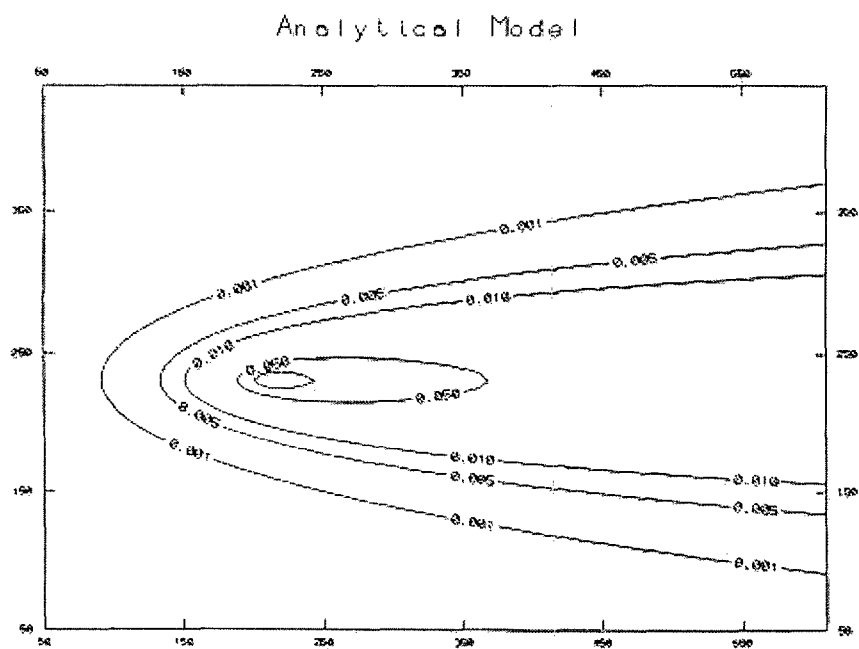
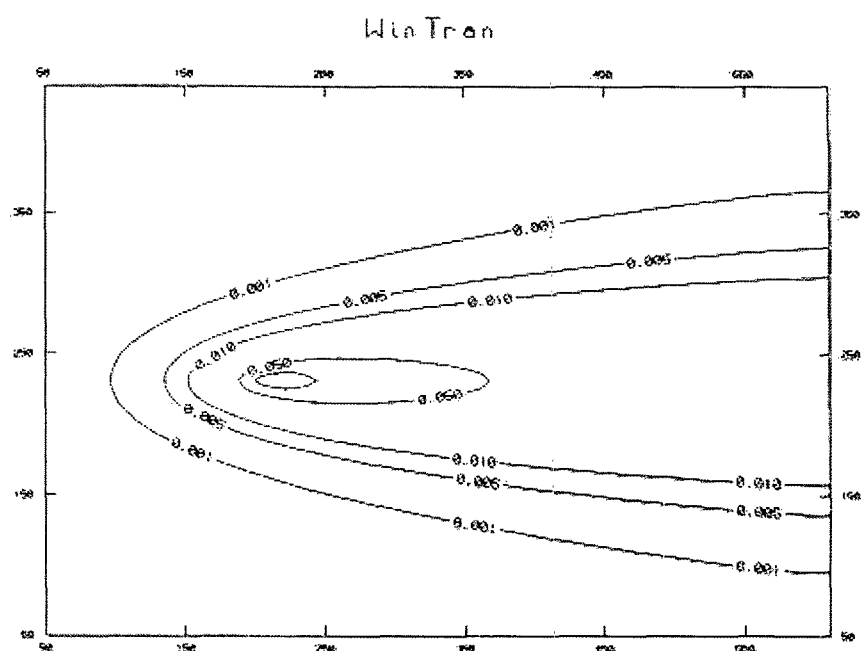


Figure 2. Concentration contours for WinTran and the analytical solution at time=260.569 days.





# Benchmarking with SEFTRAN

SEFTRAN (Huyakorn et al., 1984) was chosen for the majority of testing because it uses the same finite-element techniques that are employed by WinTran. SEFTRAN also makes a good choice for benchmark testing because it has undergone a significant amount of testing at the International Ground Water Modeling Center (Huyakorn et al., 1984).

To facilitate this testing, a special option has been added to the WinTran Export menu allowing WinTran to create SEFTRAN data input files. Three files are created, (1) a SEFTRAN flow data set (always called FLOW.IN), (2) a SEFTRAN transport data set (you specify the name in the dialog), and (3) a velocity file with analytically-computed velocities (always called FLOW.VEL).

A series of six simulations were performed to test the three different source configurations (point source using an injection well, pond infiltration, and linesink injection). Each of the three source terms was tested in both a uniform flow field and a non-uniform flow field. The non-uniform flow field was produced by adding a pumping well downgradient from the source. The results for the six simulations are summarized in Table 2 and Table 2b. Data for the simulations are shown in Table 3.

The benchmark simulations are evaluated by presenting the following in Table 2: (1) maximum source concentration computed by WinTran and SEFTRAN, (2) the mean and maximum differences (errors) when SEFTRAN uses WinTran-computed velocities, (3) the mean and maximum differences when SEFTRAN uses SEFTRAN-computed velocities, and (4) mass balance errors for the two models. The source concentrations were scaled to a value of 1.0 in WinTran. The mass balance errors are in percent.

The mean and maximum differences between the two codes are very low for the case when each code uses velocities computed by WinTran. This tests the WinTran transport model because both codes are using the same velocity field. The tests illustrate that the transport model in WinTran is functioning properly for all cases. The mass balance error for each code is comparable for all cases and the source concentrations are accurate to the fourth decimal place.

The second set of errors (differences) presented in Table 2 are for SEFTRAN results computed using velocities computed by the SEFTRAN flow model. In the first set of differences described in the previous paragraph, the SEFTRAN transport model read velocity data computed by WinTran. The second set of comparisons, therefore, are used to evaluate the hybrid modeling approach. The results show that for uniform flow conditions, WinTran and SEFTRAN velocities produce virtually the same results. In a non-uniform flow field, however, the differences are larger. This indicates that the analytically-computed velocities are slightly in error.

Table 2b presents the differences between SEFTRAN and WinTran when velocities in WinTran are computed using finite elements (rather than the analytical model). In this case, the differences are very minor. Thus, for complex flow fields, you may want to consider using the finite-element flow model to compute velocities. You may select this option using the **Model->Flow Model Type** menu.

Figures 3 through 8 present concentration contour maps created by WinTran and SEFTRAN. These figures further substantiate that the two models are producing the same results.

Table 2. Comparison Between WinTran and SEFTRAN for Six Simulations.

Description	Maximum	Maximum	WinTran Velocities		Sefran Velocities		Mass	Mass
	Conc.	Conc.					Balance	Balance
							Error	Error
	WinTran	Sefran	Mean	MaximumError	Mean	MaximumError	WinTran	Sefran
			Error		Error			

Test 1	1.0	1.000052	-1.1e-05	7.5e-05	3.8e-05	7.0e-05	0.0129	0.00082
Point Source								
Uniform Flow								
Test 2	1.0	1.00024	-4.2e-05	2.4e-04	4.9e-05	1.99e-04	0.00758	0.0069
Pond Source								
Uniform Flow								
Test 3	1.0	0.99992	1.66e-05	2.04e-04	1.47e-04	2.4e-03	0.00438	0.018
Line Source								
Uniform Flow								
Test 4	1.0	1.00005	-9.8e-06	7.3e-05	7.5e-06	5.8e-03	0.2057	0.195
Point Source								
Nonuniform Flow								
Test 5	1.0	0.99996	7.5e-06	7.23e-05	2.0e-05	0.045	0.147	0.136
Pond Source								
Nonuniform Flow								
Test 6	1.0	0.99991	1.06e-05	1.4e-04	4.2e-05	0.025	0.056	0.046
Line Source								
Nonuniform Flow								

Table 2b. Comparison Between WinTran (Using the Finite Element Flow Model) and SEFTRAN for the Nonuniform Flow Test Cases.

Description	Mean Error	Maximum Error	WinTran Mass Balance Error
Test 4	-6.33e-06	6.78e-05	0.145
Test 5	1.3e-06	1.4e-04	0.161
Test 6	2.6e-05	2.7e-04	0.20

Table 3. Model Parameters for the SEFTRAN Benchmarking

Parameter	Value
Hydraulic conductivity	100 ft/d
Top Elevation	100 ft
Bottom Elevation	0 ft
Reference Head	25 ft at (75,65)
Porosity	0.2
Hydraulic Gradient	0.01 to the East
Longitudinal Dispersivity	30 ft
Transverse Dispersivity	6 ft
Retardation Coefficient	1
Number of X nodes	35
Number of Y nodes	35
Minimum X coordinate	45.03 ft

Minimum Y coordinate	42.29 ft
Maximum X coordinate	678.81 ft
Maximum Y coordinate	413.66 ft

Number of time steps	30
Minimum time step size	1 day
Maximum time step size	100 days
Time step multiplier	1.2

Point Source Information (Simulation 1 and 4)

Fluid Injection Rate	-1.0 ft <sup>3</sup> /d
Concentration in fluid	100
Coordinates of Well (x,y)	(138.23,227.98)

Pumping Well Information (Simulations 4 through 6)

Pumping Rate	10,000 ft <sup>3</sup> /d
Coordinates of Well (x,y)	(604.25,315.36)

Table 3 (continued). Model Parameters for the SEFTRAN Benchmarking

Linesink Source Information (Simulations 3 and 6)

Linesink Injection Rate	-1 ft <sup>2</sup> /d
Concentration in fluid	100
Beginning Coordinates of line (x,y)	(145.27,275.11)
Ending Coordinates of line (x,y)	(143.65,167.59)

Pond Source Information (Simulations 2 and 5)

Pond Infiltration Rate	0.0015 ft/d
Concentration in fluid	100
Pond Radius	24.68 ft
Coordinates of pond center (x,y)	(137.99,227.41)

Figure 3. Concentration contours for WinTran and SEFTRAN at the final time step for Test Case 1.

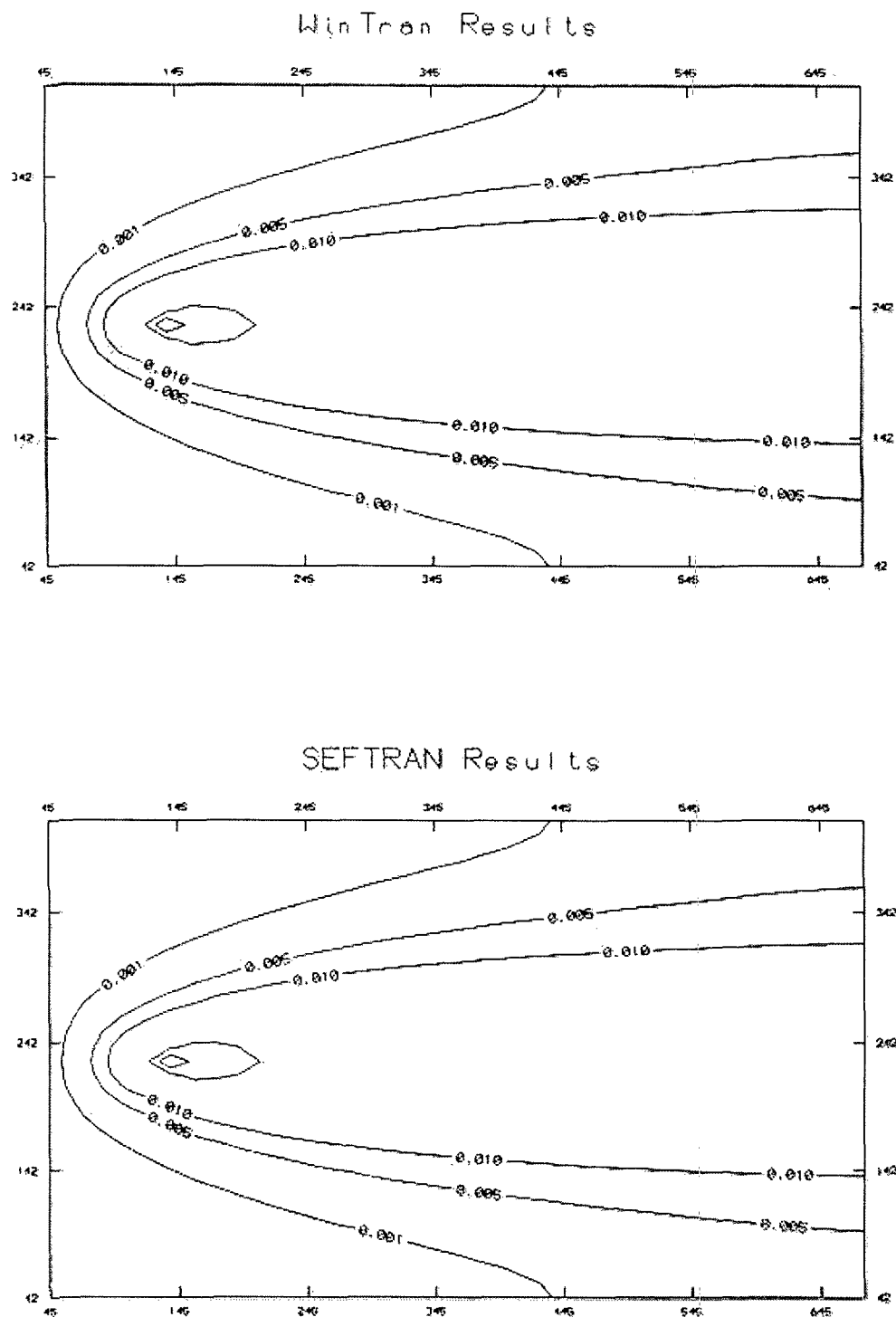
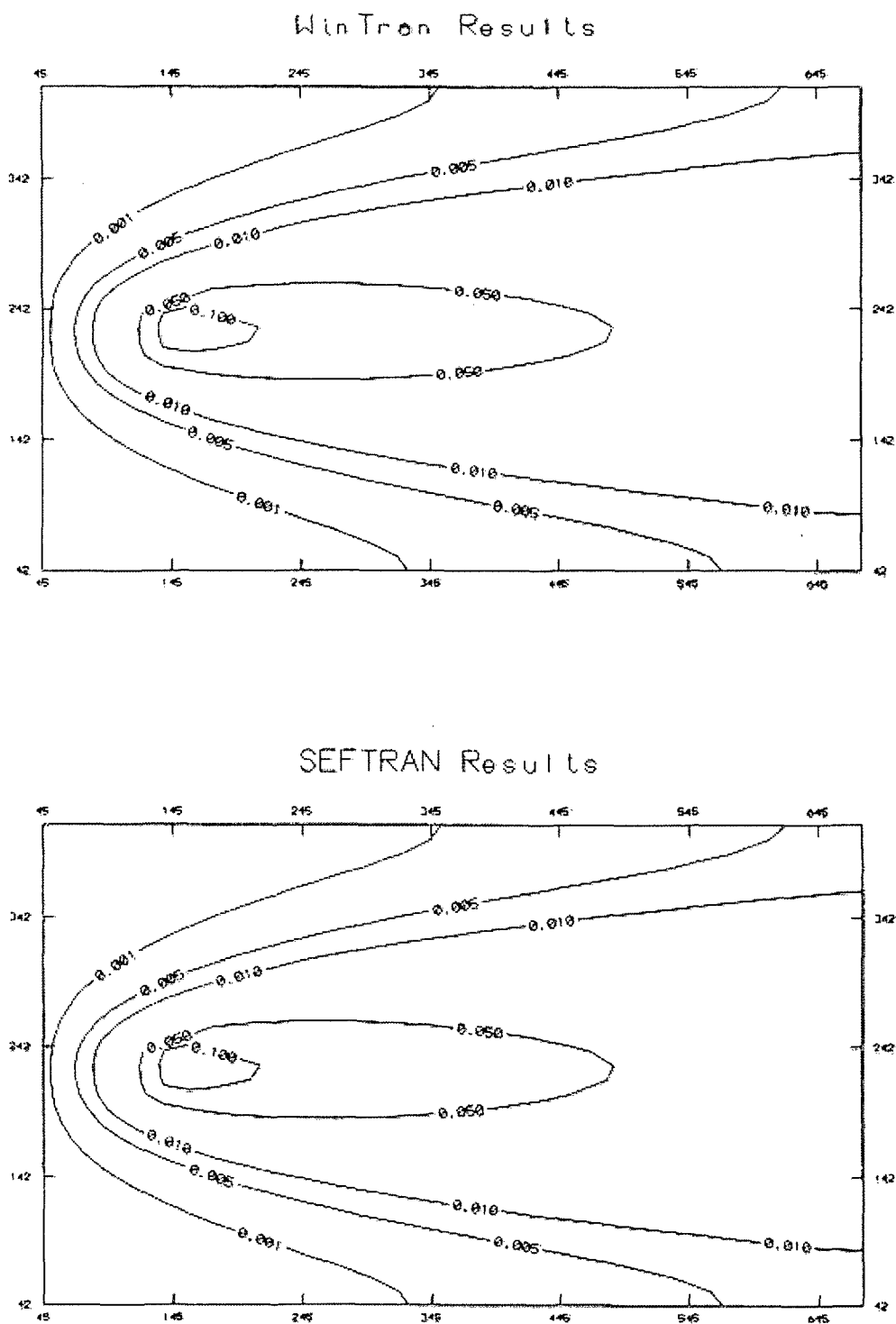


Figure 4. Concentration contours for WinTran and SEFTRAN at the final time step for Test Case 2.



**Figure 5. Concentration contours for WinTran and SEFTRAN at the final time step for Test Case 3.**



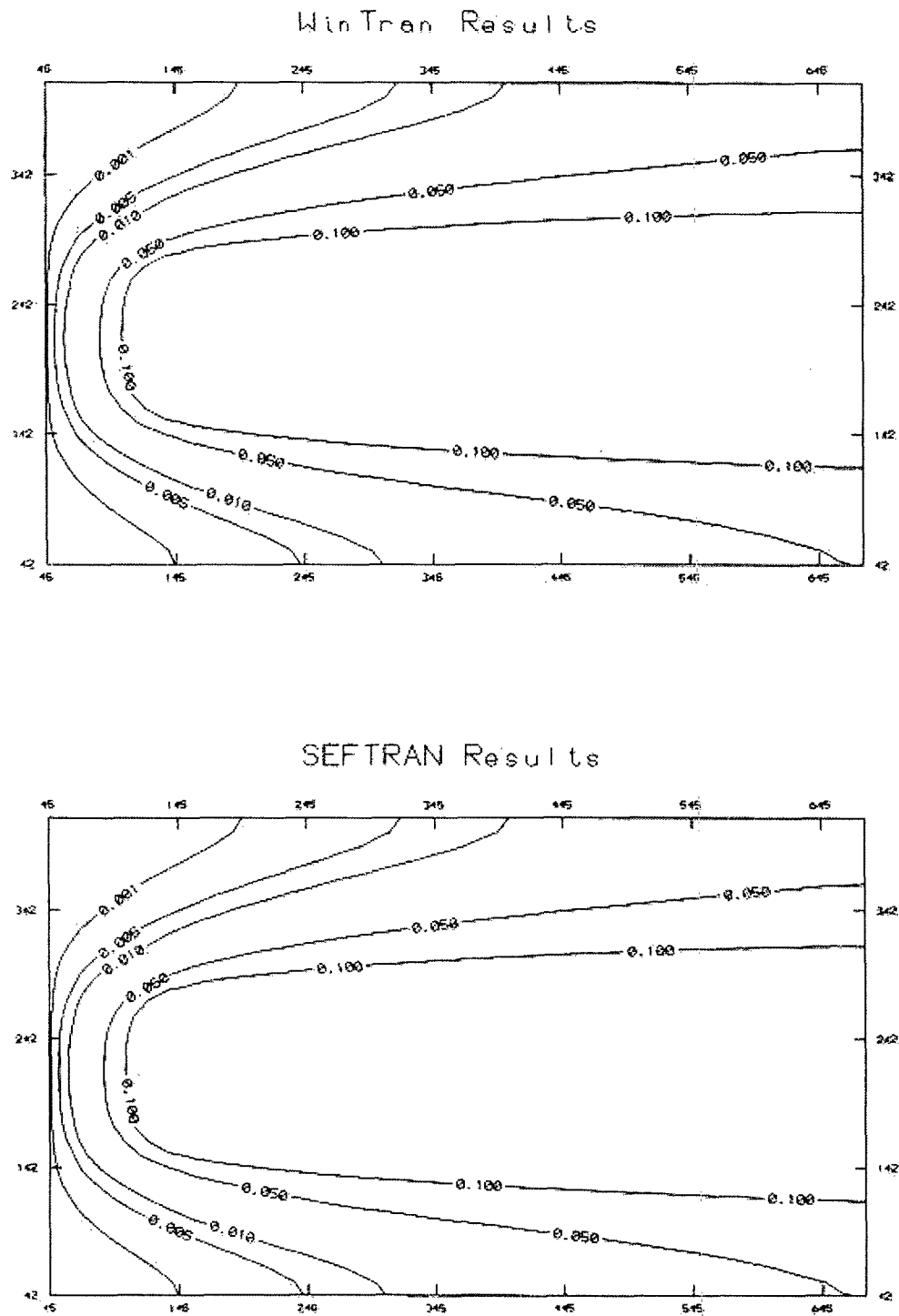


Figure 6. Concentration contours for WinTran and SEFTRAN at the final time step for Test Case 4.

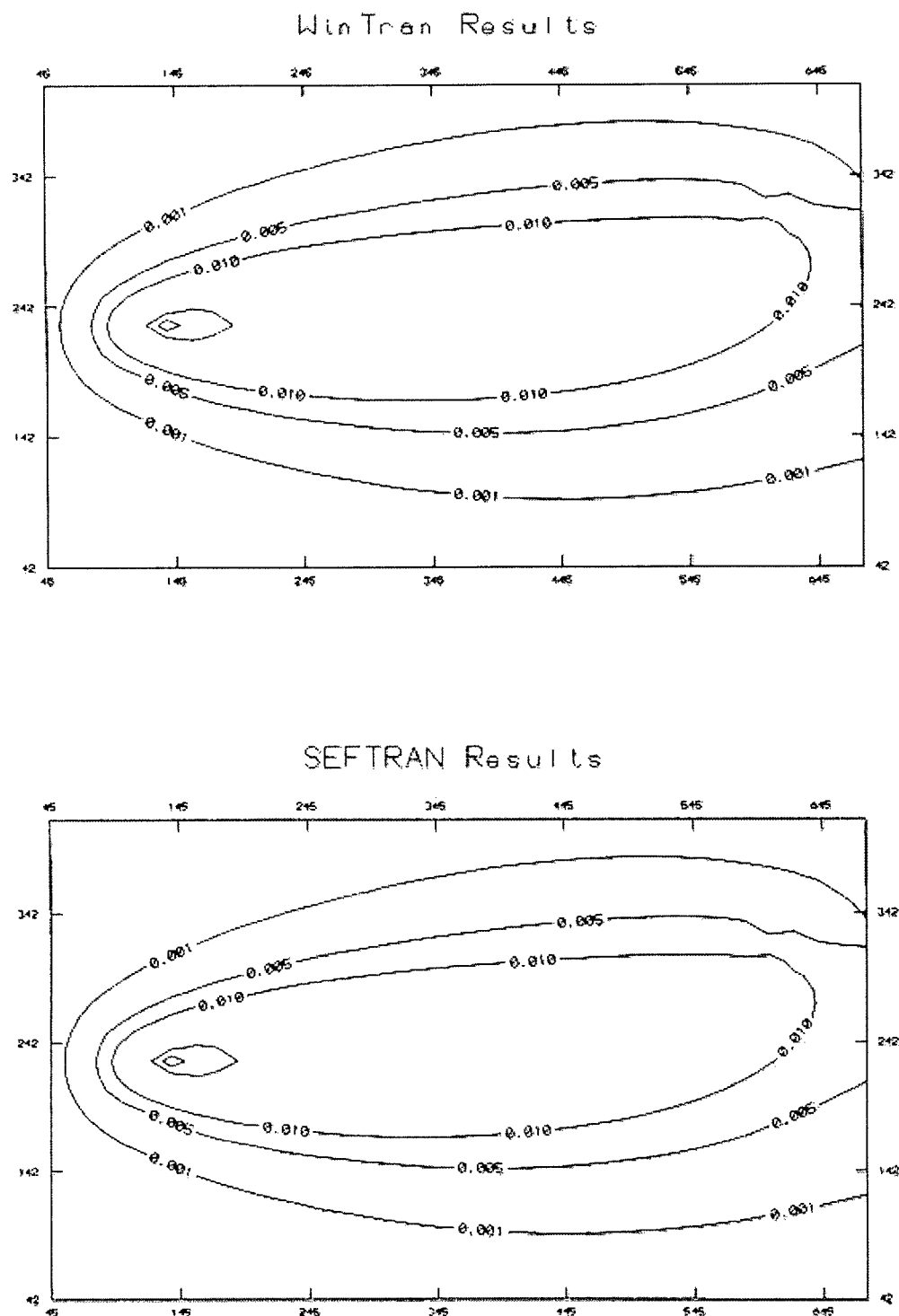


Figure 7. Concentration contours for WinTran and SEFTRAN at the final time step for Test Case 5.

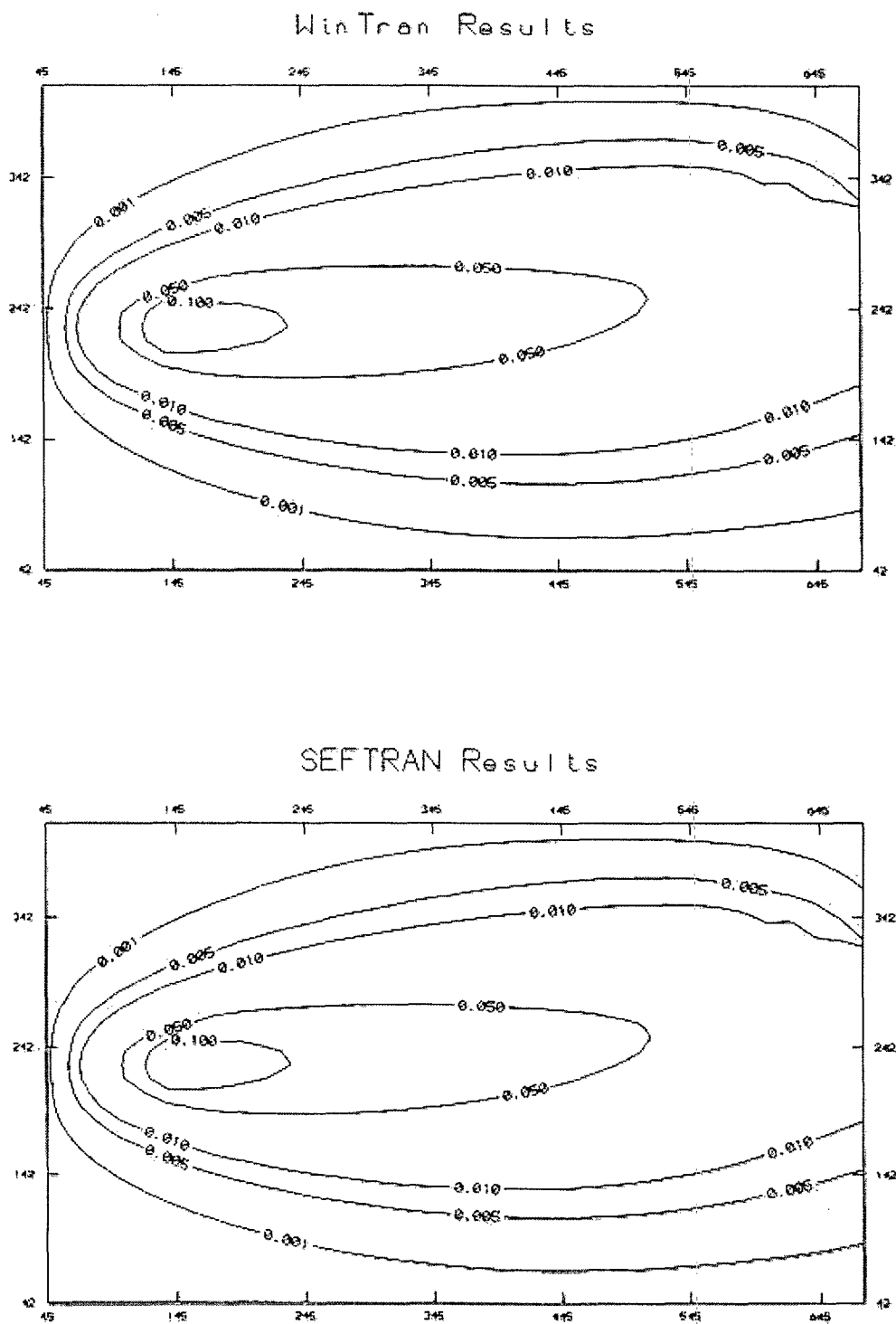
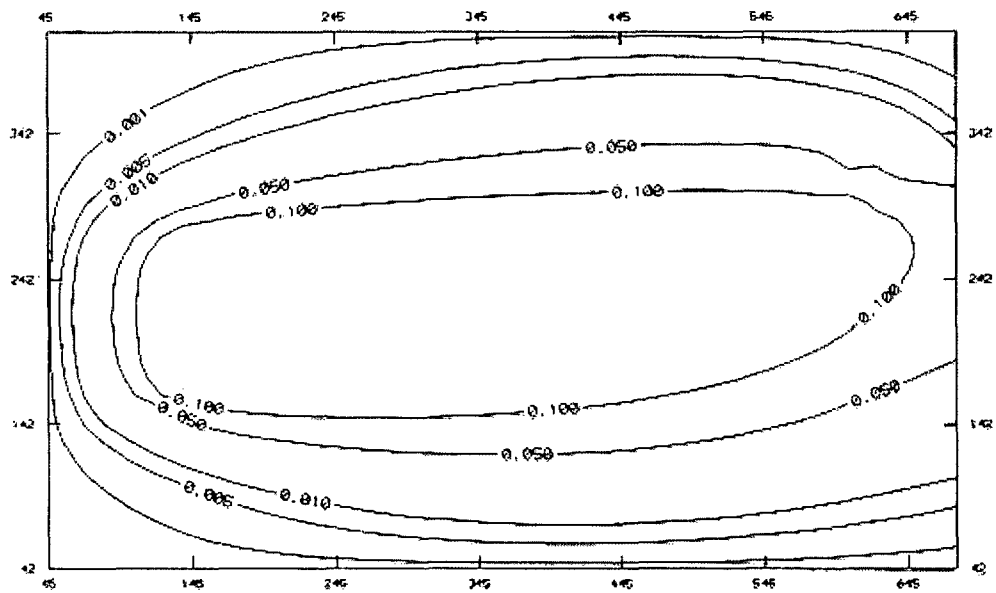
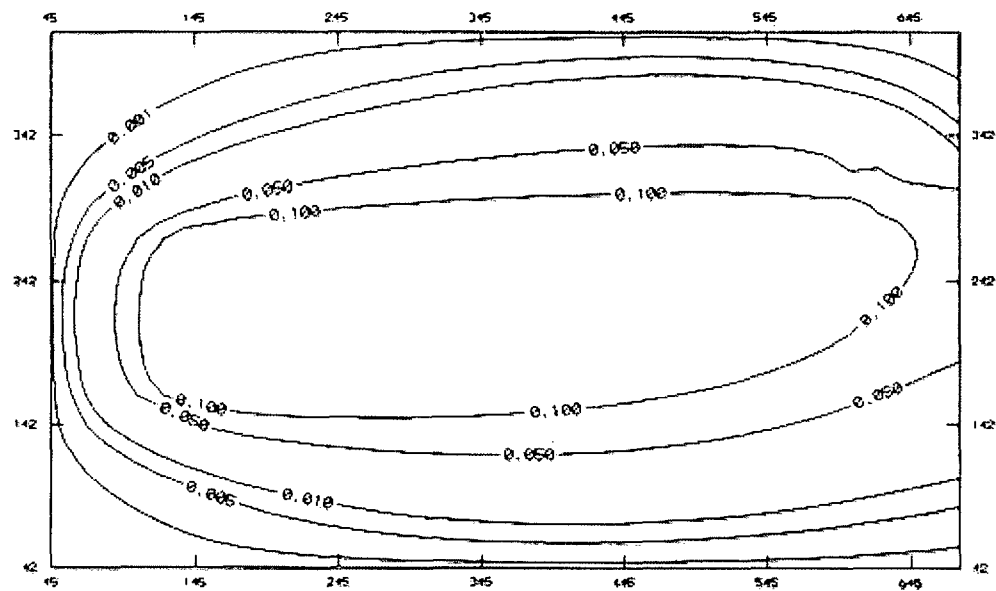


Figure 8. Concentration contours for WinTran and SEFTRAN at the final time step for Test Case 6.

### WinTron Results



### SEFTRAN Results



## WinFlow Assumptions

It is important to understand the many simplifying assumptions inherent in an analytical model before the model can be applied to a real-world problem. Chapter 5 described the equations that are solved in WinFlow. Chapter 6 verified that these equations are properly implemented in the WinFlow software. This chapter presents potential applications of WinFlow to the solution of ground-water problems. First, however, some important assumptions are discussed as they apply to the practical application of WinFlow. For easy identification, the primary assumptions are underlined.

WinFlow is designed to solve two-dimensional ground-water flow problems in a horizontal plane. It is not designed for two-dimensional cross-sections (2D vertical plane). The two primary assumptions are that ground-water flow is horizontal and occurs in an infinite aquifer. WinFlow should not be applied to aquifers exhibiting strong vertical gradients unless the scale of the problem is such that horizontal flow can still be considered dominant. WinFlow can be used even in cases where there are significant vertical gradients if the horizontal scale of the model is much larger than the vertical scale, such as in regional studies.

Another assumption is that the aquifer hydraulic conductivity is assumed to be isotropic and homogeneous. The base of the aquifer is horizontal and fixed at a given elevation. In the steady-state and transient models, the top of the aquifer is also horizontal and fixed at a given elevation. In the steady-state model, however, unconfined conditions are simulated when the hydraulic head is below the top of the aquifer. In the transient model, the aquifer is always confined, even when the head falls below the top of the aquifer.

The reference head in the steady-state model is constant throughout all calculations. The reference head is analogous to a constant head boundary condition in a numerical model. It is therefore very important to keep the reference head far from the area of interest so that model predictions are not impacted.

The reference head in the transient model is only used in combination with the uniform gradient to compute an initial planar potentiometric surface. Drawdowns computed by either the Theis (1935) or the Hantush and Jacob (1955) methods are then subtracted from the planar potentiometric surface to obtain the resulting flow field. Drawdowns are also subtracted from the reference head in the transient model; however, there is an option that allows the user to keep the reference head constant in the transient model. This option should only be used when trying to compare the transient model to the steady-state model.

All pumping rates, linesink fluxes, pond recharge, and elliptical recharge rates are constant through time. In the transient model, all wells start pumping or injecting water at time zero.

All wells are assumed to fully penetrate the aquifer. Wells are assumed to be perfectly efficient and linesinks are in perfect hydraulic communication with the aquifer. Both assumptions are rarely encountered in practice. There is often head loss around the well screen or stream bottom caused by clogging of the pore-space by fine-grained material (clay). There are two important consequences of imperfect hydraulic communication.

- (1) Pumping rates predicted by WinFlow to achieve a desired response may not be attainable because more drawdown will be encountered in the actual well. The increased drawdown encountered in the field is caused by inefficiency around the well screen. The same effect will happen using linesinks to simulate trenches or drains.
- (2) The amount of water produced or injected by a linesink to maintain a specified head in the linesink will be overestimated if the actual drain has less than 100 percent efficiency.

Particle traces and streamlines are two-dimensional. In cases where the aquifer receives recharge, the capture zone of a pumping well will be large enough to capture the amount of recharge equaling the pumping rate of the well (Larson et al., 1987). In two-dimensional analyses, such as in WinFlow, the capture zone extends upgradient until encountering a ground-water divide or infinity. This is an important consideration in designing a containment system.

## Analysis of Remedial Actions

WinFlow can provide valuable guidance in designing a ground-water remediation system. The most obvious remedial action that WinFlow can simulate is "pump & treat" where the goal is to contain a volume of contaminated aquifer. WinFlow can simulate the effects of both pumping and injection wells. To illustrate the capture zone of a well, use reverse particle-tracking and start the particles in a circle around the well.

WinFlow can simulate trenches and drains using linesinks. There are two options in simulating drains: (1) specify a head to be maintained in the drain and WinFlow will compute the discharge rate necessary to achieve the given head; or (2) specify the discharge rate and compute the resulting head in the drain. To illustrate the capture zone of the drain, use reverse particle-tracking and start the particles along two lines on either side of the linesink.

WinFlow can simulate a lagoon closure by using ponds. To do this, set up the initial analytical model with ponds that simulate the lagoon. Adjust the pond recharge rate to match field-measured heads. Finally, remove the pond (or set the pond recharge equal to zero) to simulate the effects of closure.

The effects of capping can be simulated with a combination of elliptical recharge and circular ponds. Set up the initial analytical model using recharge to match field-measured heads. A circular cap can then be simulated with a pond that has a recharge rate equivalent to the regional recharge rate but opposite in sign (e.g. negative).



## Pumping Test Analysis and Design

WinFlow's transient model can simulate the effects of a pumping test to facilitate interpreting test results or designing a future test. Pumping test results can be interpreted by contouring drawdown at a specified time after the start of the test. To contour drawdown, set the reference head equal to zero and the gradient equal to zero. Make sure that the top of the aquifer is less than zero if the steady-state model is used.

Drawdowns computed by WinFlow can be compared to drawdown contours from the pumping test. Hydraulic conductivity and storage can be adjusted until a reasonable match between observed and computed drawdown is achieved. Image wells can be added to the model to simulate boundary effects. Use calibration targets to provide a quantitative match between the results of your aquifer test and the model calculations.

When designing an aquifer test, WinFlow estimates the drawdown likely to occur at selected times and at various distances from the pumping well. Time and drawdown estimates can help select appropriate wells to monitor and determine the length of the test.

## Regional Modeling

Strack (1989) advocates the use of "analytic element models" (his term for the superposition of analytical functions) in regional flow system modeling. At a regional scale, most aquifers are very thin compared to the distance across the aquifer in the horizontal plane. Thus, the z-axis (vertical dimension) becomes quite small and vertical gradients are negligible compared to horizontal gradients. In this case, the problem becomes two-dimensional and can be easily simulated with analytical functions.

The regional model is constructed using linesinks to simulate rivers and streams. Recharge from precipitation is applied in a large ellipse covering the area of interest. Circular recharge areas (ponds) simulate lakes. Obviously, wells represent areas of ground-water extraction, such as wellfields.

Strack (1989) has developed many complex analytical functions or analytic elements to facilitate regional modeling. The Single-Layer Analytic Element Model (SLAEM) developed by Strack contains these advanced functions not available in WinFlow. SLAEM is available from Dr. Strack.

## Introduction

This chapter presents the major assumptions inherent in WinTran and guidelines for the use of the transport model. These guidelines include estimating memory requirements, dealing with model instabilities, and suggestions for simulating various transport scenarios.



## WinTran Assumptions

It is important to understand the many simplifying assumptions inherent in any model before the model can be applied to a real-world problem. This chapter presents potential applications of WinTran to the solution of contaminant fate and transport problems. First, however, some important assumptions are discussed as they apply to practical application of WinTran. For easy identification, the primary assumptions are underlined.

WinTran is designed to solve two-dimensional ground-water flow and transport problems in a horizontal plane. It is not designed for two-dimensional cross-sections (2D vertical plane). The two primary assumptions are that ground-water flow is horizontal and contaminant concentrations are the same throughout the entire aquifer thickness. WinTran should not be applied to aquifers exhibiting strong vertical gradients unless the scale of the problem is such that horizontal flow can still be considered dominant. WinTran can be used even in cases where there are significant vertical gradients if the horizontal scale of the model is much larger than the vertical scale, such as in regional studies.

Another assumption is that the aquifer hydraulic conductivity is assumed to be isotropic and homogeneous. The base of the aquifer is horizontal and fixed at a given elevation. The top of the aquifer is also horizontal and fixed at a given elevation. Unconfined conditions are simulated when the hydraulic head is below the top of the aquifer.

The reference head in the flow model is constant throughout all calculations. The reference head is analogous to a constant head boundary condition in a numerical model. It is therefore very important to keep the reference head far from the area of interest so that model predictions are not impacted.

All pumping rates, linesink fluxes, pond recharge, and elliptical recharge rates are constant through time. The transport model simulates transient movement of the contaminant in this steady-state velocity field.

All wells are assumed to fully penetrate the aquifer. Wells are assumed to be perfectly efficient and linesinks are in perfect hydraulic communication with the aquifer. Both assumptions are rarely encountered in practice. There is often head loss around the well screen or stream bottom caused by clogging of the pore-space by fine-grained material (clay). There are two important consequences of imperfect hydraulic communication.

- (1) Pumping rates predicted by WinTran to achieve a desired response may not be attainable because more drawdown will be encountered in the actual well. The increased drawdown encountered in the field is caused by inefficiency around the well screen. The same effect will happen using linesinks to simulate trenches or drains.
- (2) The amount of water produced or injected by a linesink to maintain a specified head in the linesink will be overestimated if the actual drain has less than 100 percent efficiency.

Particle traces and streamlines are two-dimensional. In cases where the aquifer receives recharge, the capture zone of a pumping well will be large enough to capture the amount of recharge equaling the pumping rate of the well (Larson et al. 1987). In two-dimensional analyses, such as in WinTran, the capture zone extends upgradient until encountering a ground-water divide or infinity. This is an important consideration in designing a containment system.

Chemical reactions are reduced to two types, (1) linear, fully-reversible sorption using a retardation coefficient, and (2) first-order decay. WinTran can be used to simulate biological decay of organic compounds only if the biological reactions can be reduced to a first-order decay reaction. That is, a contaminant half-life is estimated for the compound.

## Memory Requirements

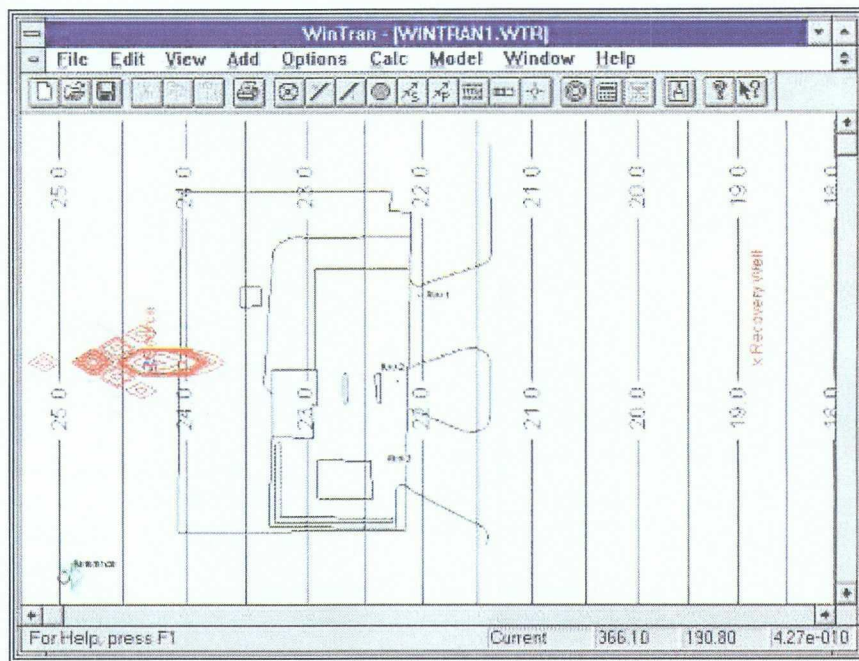
WinTran uses a substantial amount of computer memory to solve the finite-element transport model. The amount of memory required for each model is determined by the size of the contour matrix. The default size of the contour matrix is 35 x 35 (35 nodes in both the X- and Y-directions). In this case, the model requires about 1 megabyte of memory. The maximum matrix size allowed in WinTran is 100 x 100, requiring about 18 megabytes of memory. Other matrix sizes and memory requirements are shown below:

<u>Matrix Size</u>	<u>Memory Required</u>
35 x 35	1 megabyte
50 x 50	2.6 megabytes
75 x 75	8 megabytes
100 x 100	18 megabytes

## Problems with Model Stability

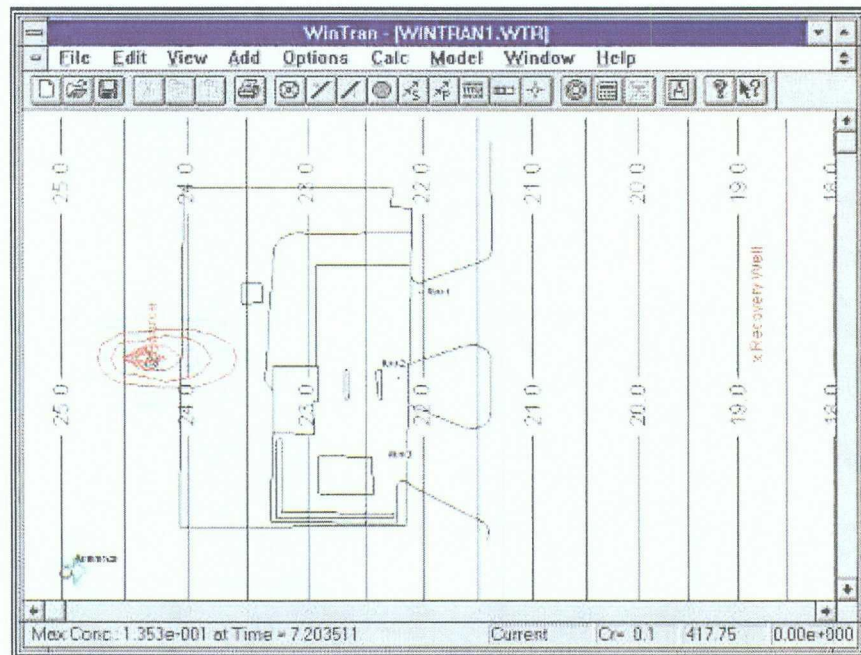
Numerical transport models require the user to carefully evaluate each simulation for potential errors. WinTran assists you in evaluating model error by displaying the mass balance error on the status bar when the transport model is running. The mass balance error is expressed as a percentage and should be less than 10 percent for a valid simulation. Usually, the mass balance error is less than 1 percent.

Even if the mass balance error is below 10 percent, there can be oscillations in the transport solution. Oscillations are indicated by negative concentrations computed by WinTran. In extreme cases, alternating nodes will have positive and negative concentrations producing diamond-shaped contours. The following screen shows a contour pattern that is typical of numerical oscillations:



Note the diamond shaped contours upgradient of the source. These contours are produced because alternating nodes are positive and negative. The contouring routine draws "bulls-eyes" around these high and low points producing the diamond-shaped contours. This is very typical of oscillating solutions and is probably the most common problem you will run into with WinTran.

The pattern above was produced in the tutorial model by lowering the time-step size to 0.1 days, using centered-in-time, and reducing the longitudinal dispersivity to 3 ft. This produces a Peclet number of 6.2, which is above the recommended limit of 2. In the screen shown below, the dispersivity value was increased to 30 ft, dropping the Peclet number to 0.62. This was enough to remove the oscillations.



When the transport solution oscillates, check the following:

(1) The Peclet number is displayed on the status bar as "Pe=" and is computed by dividing the nodal spacing (the distance between nodes in the contour matrix) by the longitudinal dispersivity. The Peclet number should generally be less than 2 for a stable solution. If you are experiencing mass balance problems or oscillations, increase dispersivity until the Peclet number is less than 2, as described above.

(2) The Courant number is another criterion used to judge the stability of a transport simulation. The Courant number is computed as the velocity times time-step size divided by nodal spacing. This criterion is displayed as "Cr=" on the status bar and should generally be less than 1. Again, if you are experiencing mass balance or oscillation problems, try decreasing the initial and maximum time-step sizes.

There are also times when the Courant number is too low. In cases where the Courant number is less than 0.1, there can be round-off errors in the matrix solver. In this case, you should increase the initial and maximum time-step sizes until the Courant number is close to 1.

There are two other WinTran options that can aid in model stability. These include the time discretization method (backward and centered in time) and upstream weighting. The time discretization methods are selected using the **Edit->Time Stepping** menu. Backward in time is unconditionally stable but is only first-order accurate, while centered in time is second-order accurate but may be subject to instability (Javandel et al., 1984). It is usually best to start with backward in time.

Upstream weighting factors in the X- and Y-directions are edited from the **Edit->Transport Parameters** menu. Upstream weighting factors of 1.0 indicate full upstream weighting, while a weighting factor of 0.0 turns off upstream weighting. Upstream weighting adds stability to the solution (helps eliminate oscillations) at the expense of added numerical dispersion. Numerical dispersion is artificial dispersion that produces similar results to an increase in the dispersivity coefficient.



# ● Setting Up the Flow Model

WinTran can provide valuable guidance in designing a ground-water remediation system. The most obvious remedial action that WinTran can simulate is "pump & treat" where the goal is to contain a volume of contaminated aquifer. WinTran can simulate the effects of both pumping and injection wells.

WinTran can simulate trenches and drains using linesinks. There are two options in simulating drains: (1) specify a head to be maintained in the drain and WinTran will compute the discharge rate necessary to achieve the given head; or (2) specify the discharge rate and compute the resulting head in the drain. To illustrate the capture zone of the drain, use reverse particle-tracking and start the particles along two lines on either side of the linesink.

WinTran can simulate a lagoon closure by using ponds. To do this, set up the initial analytical model with ponds that simulate the lagoon. Adjust the pond recharge rate to match field-measured heads. Finally, remove the pond (or set the pond recharge equal to zero) to simulate the effects of closure.

The effects of capping can be simulated with a combination of elliptical recharge and circular ponds. Set up the initial analytical model using recharge to match field-measured heads. A circular cap can then be simulated with a pond that has a recharge rate equivalent to the regional recharge rate but opposite in sign (e.g. negative).

# Setting Up the Transport Model


Remedial alternatives are usually simulated in several stages, as described below:

(1) Calibrate the transport model to the observed contaminant plume. This is accomplished by adding source terms to the model (injection wells, infiltrating ponds, or injecting linesinks) and adjusting the source concentration until the desired plume is simulated. The length of the simulation should be chosen to approximate the length of time that the source of contamination has been effecting the groundwater system.

An alternative approach to calibrating the plume configuration is to import a SURFER grid file (e.g. test.grd) containing the contaminant distribution data (use **File->Import** from the main menu). The contoured concentrations are then used as initial conditions for the remedial simulation.

(2) Save the calibrated concentrations as initial conditions using the **Calc->Restart** option on the main menu. Skip this step if you have imported a SURFER grid file for initial conditions.

(3) Add the remediation system (pumping wells or linesinks, etc.) and rerun the transport model. To simulate source removal, delete the source terms added in State 1 above. This is accomplished by moving the cursor over the source element (well, pond, or linesink) until the

four-arrow cursor () is displayed. Click the left mouse button to select the element and then press the delete key or select **Edit->Delete** from the main menu. Now, rerun the transport model to simulate source removal.

At any time during the simulations, you may save concentrations for later restart using the **File->Export** menu. Exporting concentration as a restart file (\*.rst) will allow you to **Import** these concentrations in later simulations.

## Simulating Biodegradation

Simulating the biodegradation of organic compounds is a popular modeling scenario, especially for dissolved hydrocarbons. WinTran does not simulate these complex degradation processes; however, the decay term in WinTran can be used to approximate biodecay. The biodegradation process is reduced to specifying a half-life for the compound. The half-life is the time required to remove half of the original mass. While the half-life is most often used for radioactive elements, such as uranium, it can also be used to express the decay of organic compounds through biodecay. The *Handbook of Environmental Degradation Rates* (Howard et al., 1991) is a good reference for contaminant half-life data.

## Performing Risk Assessments

WinTran is not a risk assessment model but can be useful in risk assessments by providing concentration data over time at receptor locations. To obtain the concentration over time at these receptor locations, you must add a well at the receptor. Specify the flow rate as zero (0.0) and check the "Observation well" option on the well dialog. These concentration-time data may then be saved to a file for use in other programs. To save these data, select **File->Export** and choose the file type **Conc-Time (\*.cvt)**. The file is a DOS text file delimited by commas. The first line contains the well names and subsequent lines list the time and concentration for each well.

## Digitized Map File Format

Digitized base maps increase the efficiency of site-specific modeling by placing the modeling results in context with the area to be modeled. As shown in the tutorial, WinFlow overlays the base map on head contours and streamlines, making it easier to interpret the results.

WinFlow uses a very simple file format for the digitized base map, as shown in Table 9. The file is made up of two sections. The first defines a series of line segments, while the second set of data defines a series of text strings. Each line segment requires the following data (1) the beginning and ending **X** and **Y** coordinates, (2) the line style, e.g., dashed or solid, and (3) the line color. The data for each line segment should appear on one line and be separated by at least one space between each data item. Commas may not be used to separate data items.

The following data items are required for each text item (1) **X** and **Y** coordinates of the lower left corner of the text, (2) angle of rotation of the text string, (3) height of the text, (4) color, and (5) a text string. The first four data items are entered on one line separated by at least one space between each data item. The text string is located on the following line and the height of the text string is in map coordinates (not in inches!).

Line and text colors are defined as integer numbers from 0 through 15. Each integer defines a unique color. The possible colors are shown in Table 10. These colors are all displayed on VGA color displays.

The digitized map file is a simple ASCII file that may be created in any text editor. You may also find it advantageous to write a simple program to convert files from your digitizing software to the WinFlow format. WinFlow also has the ability to convert DXF files directly. Simply choose **File** from the main menu and **Map** from the pull-down menu. Next select **DXF** from the menu. Specify the DXF file name and a conversion factor, which is explained below. The DXF file format is a relatively standard file format for CAD packages, such as AutoCad.

Table 9 File Format for WinFlow Digitized Maps.	
<b>Line 1</b> NLS, NTEXT	
NLS = Number of line segments in map	
NTEXT = Number of Text Strings in map	
<b>Lines 2 to NLS+1</b> (Enter one line for each line segment)	
X1, Y1, X2, Y2, NDASH, NCOLOR	
X1, Y1 = Beginning line coordinates	
X2, Y2 = Ending line coordinates	
NDASH = Positive integer for solid line, negative for dashed	
NCOLOR = Color index (integer)	
<b>Lines NLS+2 to end</b> (Enter one set per text item)	
X1, Y1, ANGLE, HEIGHT, NCOLOR	
TEXT	
X1, Y1 = Coordinates of left side of text string	
ANGLE = Angle of text string	
HEIGHT = Height of text string	
NCOLOR = Color index of text string	
TEXT = Text string	

Table 10 Definition of color indices.

Index	Color
0	BLACK
1	BLUE
2	GREEN
3	CYAN
4	RED
5	MAGENTA
6	BROWN
7	WHITE
8	GRAY
9	LIGHT BLUE
10	LIGHT GREEN
11	LIGHT CYAN
12	LIGHT RED
13	LIGHT MAGENTA
14	YELLOW
15	BRIGHT WHITE

## DXF Translator

The DXF (Drawing Interchange Format) file is a fairly standard format for exchanging data between CAD systems. In particular, the popular AutoCAD software uses DXF files extensively. A translator is provided with WinFlow to extract digitized information from DXF files and convert it to the WinFlow digitized map format.

The DXF file contains detailed data describing numerous CAD entities. An entity is a line or symbol placed on the drawing by the CAD system. The WinFlow DXF translator supports the following CAD entities:

- LINES
- POLYLINES
- POINTS
- ARCS
- CIRCLES
- TEXT

Certain aspects about these entities are ignored by the translator, such as elevation (for 3D CAD software such as AutoCAD Release 10), line style, and line thickness. In addition, the curve-fit and spline options applied to POLYLINES are ignored. The coordinates and color of the entity are preserved, however.

Many CAD drawings contain entities called BLOCKS, which are a collection of other entities (e.g., lines, circles, text, etc.). WinFlow will not interpret BLOCKS properly, so make sure that these are converted to other entities before creating the DXF file in your CAD package. In AutoCAD terminology, this is called "exploding" the blocks.

The DXF translator is activated from the File menu, as described above. Next, specify the DXF file name and a Map file name using standard Windows file dialogs. You only have to answer one additional prompt after starting the DXF translator - a conversion factor for the translation. Normally, a conversion factor of 1.0 will work; however, sometimes your CAD software will store coordinates in the DXF file in units of inches. If this happens, use a conversion factor of 0.0833333 (1.0/12.0). Each coordinate in the DXF file is multiplied by the conversion factor before being written to the WinFlow map file.

After all entities are processed in the DXF file, the digitized map file is created. A message to that effect is displayed at the bottom of the screen. After the translation is finished, the map file is imported into the model and displayed on your screen.

## ASTM Standards

D 4104 Test Method (Analytical Procedure) for Determining Transmissivity of Nonleaky Confined Aquifers by Overdamped Well Response to instantaneous Change in Head (Slug Tests), ASTM, 4 p.

D 4105 Test Method (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of Nonleaky Confined Aquifers by the Modified Theis Nonequilibrium Method, ASTM, 5 p.

D 4106 Test Method (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of Nonleaky Confined Aquifers by the Theis Nonequilibrium Method, ASTM, 5 p.

D5920-96. Test Method (Analytical Procedure) for Tests of Anisotropic Unconfined Aquifers by Neuman Method, ASTM, 8 p.



## Books

Bear, J. And A. Verruijt, 1987, *Modeling Groundwater Flow and Pollution*, D. Reidel Publishing Company, Boston, 414 p.

Butler, J. J., Jr., 1998, *The Design, Performance, and Analysis of Slug Tests*, Lewis Publishers, CRC Press, Boca Raton, Florida, 252 p.

Horne, R. N., 1995, *Modern Well Test Analysis*, Petroway, Inc., Palo Alto, California, 257 p.

Howard, P., R. Boethling, W. Jarvis, W. Meylan, and E. Michalenko, 1991, *Handbook of Environmental Degradation Rates*, Lewis Publishers, Inc., Chelsea, MI.

Huyakorn, P.S., A.G. Kretschek, R.W. Broome, B.H. Lester, J.W. Mercer, 1984, Testing and Validation of Models for Simulating Solute Transport in Groundwater: Development, Evaluation, and Comparison of Benchmark Techniques, International Groundwater Modeling Center Report GWMI 84-13, Golden, Colorado.

Javandel, I., C. Doughty, and C.F. Tsang, 1984, *Groundwater Transport: Handbook of Mathematical Models*, American Geophysical Union, Water Resources Monograph 10, Washington, D.C.

Kruseman, G.P. and N.A. de Ridder, 1990, *Analysis and Evaluation of Pumping Test Data*, Second Edition, ILRI publication 47, International Institute for Land Reclamation and Improvement, The Netherlands, 377 p.

Lohman, S.W., 1979, *Ground-Water Hydraulics*, U.S.G.S. Professional Paper 708, 70 p.

Reed, J.E., 1980, *Type Curves for Selected Problems of Flow to Wells in Confined Aquifers*, USGS TWRI Book 3, Chapter B3.

Strack, O.D.L., 1989, *Groundwater Mechanics*, Prentice Hall, Englewood Cliffs, New Jersey, 732 p.

Wexler, E.J., 1992, *Analytical Solutions for One-, Two-, and Three-Dimensional Solute Transport in Ground-Water Systems with Uniform Flow*, USGS Techniques of Water Resource Investigations (TWRI), Book 3, Chapter B7.

## Journal Papers

- Abramowitz, M., and I.A. Stegun, 1965, *Handbook of Mathematical Functions*, Dover Publications, New York.
- Case, C.M., D.L. Ghiglieri, and K. Fallon, 1979, *Tables of the Leaky Aquifer Well Function*, Desert Research Institute Publication No. 45016, Water Resources Center, Desert Research Institute, Reno, Nevada, 31 p.
- Birsoy Y.K. and Summers W.K., 1980, *Determination of aquifer parameters from step tests and intermittent pumping data*. *Ground Water*, 18, 137-146.
- Black, J.H., 1978, *The use of the slug test in groundwater investigations*, Water Services, March, p. 174-178.
- Bouwer, H. and R.C. Rice, 1976, *A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells*, *Water Resources Research*, v. 12, p. 423-428.
- Case, C.M., D.L. Ghiglieri, and K. Fallon, 1979, *Tables of the Leaky Aquifer Well Function*, Desert Research Institute Publication No. 45016, Water Resources Center, Desert Research Institute, Reno, Nevada, 31 p.
- Cooper, H.H., J.D. Bredehoeft, and I.S. Papadopoulos, 1967, *Response of a finite-diameter well to an instantaneous charge of water*, *Water Resources Research*, v.3, no. 1, p. 263-269.
- Eden, R.N. and Hazel C.P., 1973, *Computer and graphical analysis of variable discharge pumping tests of wells*. Inst. Engrs. Australia, Civil Eng. Trans., 5-10
- Hantush, M.S., 1956, *Analysis of data from pumping tests in leaky aquifers*, *Am. Geophys. Union Trans.*, v. 37, no. 6, p. 702-714.
- Hantush, M.S., 1960, *Modification of the theory of leaky aquifers*, *Journal of Geophysical Research*, v. 65, no. 11, p. 3713-3725.
- Hantush, M.S., 1964, *Hydraulics of Wells*, In *Advances in hydroscience* (V.T. Chow, editor), Vol. 1, pp. 281-432, Academic Press, New York.
- Hantush, M.S., 1967, *Growth and decay of groundwater-mounds in response to uniform percolation*, *Water Resources Research*, Vol. 3, No. 1, pp. 227-234.
- Hantush, M.S. and C.E. Jacob, 1955, *Non-steady radial flow in an infinite leaky aquifer*, *Am. Geophys. Union Trans.*, v. 36, no. 1, p. 95-100.
- Hvorslev, M.J., 1951, *Time lag and soil permeability in ground water observations*, U.S. Army Corps of Engineers Waterway Experimentation Station, Bulletin 36.
- Hyder, Z., Butler, J. J., Jr., McElwee, C. D., and Liu, W. Z., *Slug tests in partially penetrating wells*, *Water Resour. Res.*, 30(11), 2945, 1994.
- Jacob, C.E., 1944, *Notes on determining permeability by pumping tests under watertable conditions*, USGS Open File Report, In: USGS Water Supply Paper 1536-I, 1963, pp. 245-271.
- Jacob, C.E., 1963, *Determining the permeability of water-table aquifers*, in Bentall, Ray, compiler, *Methods of determining permeability, transmissibility, and drawdown*, U.S. Geol. Survey Water-Supply Paper 1536-I, p. 245-271.
- Kipp, K. L., Jr., 1985, *Type curve analysis of inertial effects in the response of a well to a slug test*, *Water Resources Research*, v.21, no. 9, p. 1397-1408.
- Larson, S.P., C.B. Andrews, M.D. Howland, and D.T. Feinstein, 1987, *Three-dimensional modeling analysis of ground water pumping schemes for containment of shallow ground water contamination*, *Proceedings of the Solving Ground-Water Problems with Models Conference*, National Ground Water Association, Denver, pp. 517-531.
- McDonald, M.G. and A.W. Harbaugh, 1988, *A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model*, USGS Techniques of Water Resource Investigations, Book 6, Chapter A1, 528 p.
- Moench, Allen F., 1997, *Flow to a well of finite diameter in a homogeneous, anisotropic water table aquifer*, *Water Resources Research*, vol. 33, no. 6, pp 1397-1407.
- Moench, A.F., 1996, *Flow to a well in a water-table aquifer: An improved Laplace Transform solution*, *Ground Water*, vol. 34, no. 4, pp. 593-596.

- Moench, A.F., 1985, *Transient Flow to a Large-Diameter Well in an Aquifer With Storative Semiconfining Layers*, Water Resources Research, vol. 21, no. 8, pp. 1121-1131.
- Moench, A.F., 1984, *Double-porosity models for a fissured groundwater reservoir with fracture skin*, Water Resources Research, vol. 20, no. 7, pp. 831-846.
- Neuman, S.P., 1972, *Theory of flow in unconfined aquifers considering delayed response of the watertable*, Water Resources Research, vol. 8, pp 1031-1045.
- Neuman, S.P., 1974, *Effect of partial penetration on flow in unconfined aquifers considering delayed gravity response*, Water Resources Research, vol. 10, pp 303-312.
- Papadopoulos, I.S. and H.H. Cooper, 1967, *Drawdown in a well of large diameter*, Water Resources Research, vol. 3, no. 1, pp. 157-168.
- Reilly, T.E., O.L. Franke, G.D. Bennett, 1987, *The Principle of Superposition and Its Application in Ground-Water Hydraulics*, USGS Techniques of Water Resource Investigations, Book 3, Chapter B6, 28 p.
- Rumbaugh, J.O., 1991, QuickFlow - Analytical 2D Ground-Water Flow Model, Version 1.0, Geraghty & Miller, Inc., Reston, Virginia.
- Shafer, J., 1987, GWPATh: Interactive Ground-Water Flow Path Analysis, Bulletin 69, Illinois State Water Survey, Champaign, Illinois.
- Spane, F.A. and S.K. Wurstner, *DERIV: A Computer Program for Calculating Pressure Derivatives for Use in Hydraulic Test Analysis*, Ground Water, vol. 31, no. 5, pp. 814-822.
- Theis, C.V., 1935, *The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage*, Trans. Amer. Geophys. Union, Vol. 16, pp. 519-524.

## **APPENDIX C**

### **Aquifer Test Procedures and Output**

## Description of Aquifer Test

Hydraulic conductivity is one of the most critical parameters used for any fate and transport modeling effort, and the various published values researched range widely over two orders of magnitude, from less than 2 ft/day to 200 ft/day. Therefore, an aquifer test at two nearby industrial water supply wells (WW-1 and WW-5) was performed on November 22, 2006, to determine site-specific hydraulic conductivity. There were several advantages in using these wells as follows:

- Each well is fully penetrating (screened across entire thickness of the aquifer)
- The wells had been reportedly running continuously for over 16-20 hours prior to recording the recovery drawdown data.
- The wells are located nearby the Jct. J-26 site thus available for site-specific testing.
- The wells were constructed efficiently as they are designed to provide maximum yields for supply to the Eunice Gas Plant.
- The wells play a useful role in abatement of chlorides and TDS in the area.

The wells had been running continuously for about 16-20 hrs according to the Eunice Gas Plant personnel who graciously allowed access to their wells for aquifer testing. Immediately prior to turning off the pump in each well, depth to groundwater was measured using an electronic water level indicator. A 10 psi pressure transducer and Hermit 2000 Data logger were then used to capture and record the recovery drawdown data. This instrumentation made it possible to obtain many data points early on in the test (first few minutes) which was essential for subsequent analysis and interpretation of the results. Data was recorded immediately after the water well pump was turned off to provide recovery drawdown data. Collection of data was terminated after the water table equilibrated to near static conditions; consequently the tests were of relatively short duration (less than 1 hour).

Hydraulic conductivity values were determined using a Cooper-Jacob analysis of the recovery data, and a program from USGS Open-File 02-197 (Keith Halford, 2002, documentation attached in Appendix C). The USGS program uses Thiem's equation and the Cooper-Jacob plotting methods for determining hydraulic conductivity. Results of the aquifer test analysis are shown on the following graphs and tables attached herein. The slope near the earlier time drawdown data (within the first few minutes of the test) provided the best estimation. Note that the time axis is plotted as  $t/t'$  so time increases from right to left. This is the preferred method to analyze recovery data from a pumping well.

Hydraulic conductivity values of 3.4 ft/day and 4.4 ft/day were calculated from water supply wells WW-1 and WW-5, respectively. Results from water supply well WW-1 probably provided better data because that well was pumping at a rate that stressed the aquifer, that is, the pumping water level was over 9 feet below the static level, whereas with WW-5 the pumping level was less than 2 feet from static. Either way the results from both tests are consistent with each other. The higher hydraulic conductivity value of 4.4 ft/day was used in the fate and transport modeling because it provided a more conservative value.

# WELL ID: WW-1

Local ID: T21S-R37E-Section 26-J

Date: 11/22/06

Time: 2:00 PM

## INPUT

Construction:	
Casing dia. ( $d_c$ )	8 Inch
Annulus dia. ( $d_w$ )	8 Inch
Screen Length (L)	40 Feet
Depths to:	
water level (DTW)	45 Feet
Top of Aquifer	45 Feet
Base of Aquifer	85 Feet
Annular Fill:	
across screen --	Gravel
above screen --	Cement
Aquifer Material --	Fine Sand
FLOW RATE	53 GPM

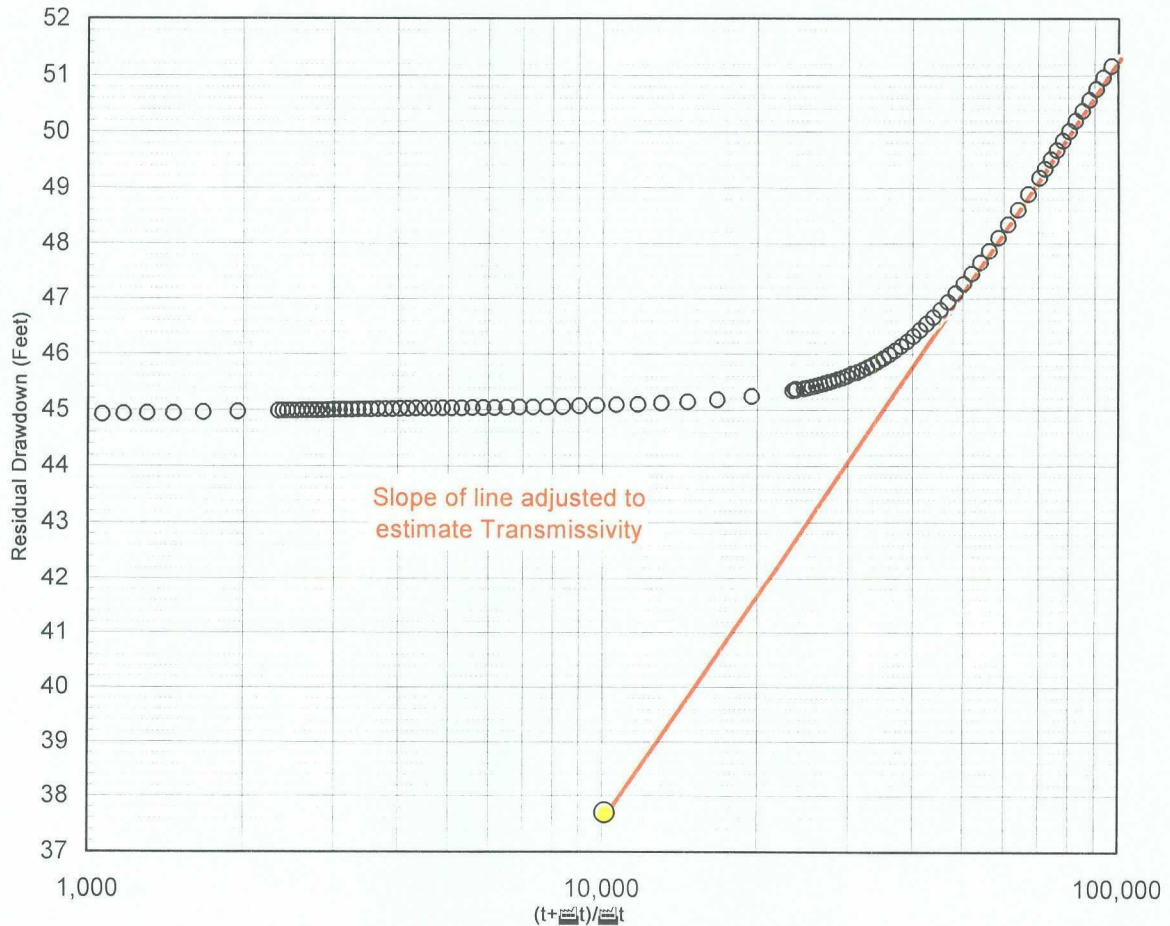
## COMPUTED

Aquifer thickness = 40 Feet

Slope = 13.708543 Feet/log10

Input is consistent.

K = 3.4 Feet/Day  
T = 140 Feet<sup>2</sup>/Day



REMARKS: Cooper-Jacob recovery analysis of single-well aquifer test

This recovery test was done on a water supply well (WW-1) that had been running continuously at ~53 gpm for 16-20 hours. A Hermit 2000 data logger was used to record the water level data for the length of the test (~50 minutes).

Depth to water before shutting off pump 54.09 ft ( $t = 0$  min).

Depth to water at end of recovery test 44.84 ft ( $t = 50$  min).

### Raw input recovery data for water supply well WW-1

Reduced Data								
Entry	Time, Date Hr:Min:Sec	Water Level Feet	Entry	Time, Date Hr:Min:Sec	Water Level Feet	Entry	Time, Date Hr:Min:Sec	Water Level Feet
1	1/0/00 0:00:00	0.00	51	11/22/06 14:00:44	45.71	101	11/22/06 14:07:48	45.00
2	11/22/06 14:00:00	54.09	52	11/22/06 14:00:45	45.67	102	11/22/06 14:08:00	45.00
3	11/22/06 14:00:08	54.09	53	11/22/06 14:00:46	45.65	103	11/22/06 14:08:12	44.99
4	11/22/06 14:00:08	53.99	54	11/22/06 14:00:47	45.61	104	11/22/06 14:08:24	44.99
5	11/22/06 14:00:09	53.74	55	11/22/06 14:00:48	45.57	105	11/22/06 14:08:36	44.99
6	11/22/06 14:00:09	53.47	56	11/22/06 14:00:49	45.55	106	11/22/06 14:08:48	44.99
7	11/22/06 14:00:10	53.22	57	11/22/06 14:00:50	45.52	107	11/22/06 14:09:00	44.99
8	11/22/06 14:00:11	52.96	58	11/22/06 14:00:51	45.50	108	11/22/06 14:09:12	44.99
9	11/22/06 14:00:11	52.72	59	11/22/06 14:00:52	45.47	109	11/22/06 14:09:24	44.99
10	11/22/06 14:00:11	52.48	60	11/22/06 14:00:53	45.45	110	11/22/06 14:09:36	44.99
11	11/22/06 14:00:12	52.25	61	11/22/06 14:00:54	45.43	111	11/22/06 14:09:48	44.99
12	11/22/06 14:00:12	52.02	62	11/22/06 14:00:55	45.42	112	11/22/06 14:10:00	44.98
13	11/22/06 14:00:13	51.80	63	11/22/06 14:00:56	45.40	113	11/22/06 14:12:00	44.96
14	11/22/06 14:00:14	51.59	64	11/22/06 14:00:57	45.38	114	11/22/06 14:14:00	44.96
15	11/22/06 14:00:14	51.37	65	11/22/06 14:00:59	45.36	115	11/22/06 14:16:00	44.94
16	11/22/06 14:00:14	51.16	66	11/22/06 14:00:59	45.37	116	11/22/06 14:18:00	44.94
17	11/22/06 14:00:15	50.96	67	11/22/06 14:01:00	45.34	117	11/22/06 14:20:00	44.93
18	11/22/06 14:00:15	50.76	68	11/22/06 14:01:12	45.24	118	11/22/06 14:22:00	44.92
19	11/22/06 14:00:16	50.56	69	11/22/06 14:01:24	45.18	119	11/22/06 14:24:00	44.91
20	11/22/06 14:00:17	50.37	70	11/22/06 14:01:36	45.14	120	11/22/06 14:26:00	44.90
21	11/22/06 14:00:17	50.19	71	11/22/06 14:01:48	45.12	121	11/22/06 14:28:00	44.89
22	11/22/06 14:00:17	50.01	72	11/22/06 14:02:00	45.10	122	11/22/06 14:30:00	44.89
23	11/22/06 14:00:18	49.84	73	11/22/06 14:02:12	45.09	123	11/22/06 14:34:00	44.88
24	11/22/06 14:00:18	49.67	74	11/22/06 14:02:24	45.08	124	11/22/06 14:36:00	44.87
25	11/22/06 14:00:19	49.50	75	11/22/06 14:02:36	45.07	125	11/22/06 14:38:00	44.86
26	11/22/06 14:00:20	49.34	76	11/22/06 14:02:48	45.06	126	11/22/06 14:40:00	44.86
27	11/22/06 14:00:20	49.18	77	11/22/06 14:03:00	45.05	127	11/22/06 14:42:00	44.86
28	11/22/06 14:00:21	48.89	78	11/22/06 14:03:12	45.05	128	11/22/06 14:44:00	44.85
29	11/22/06 14:00:22	48.61	79	11/22/06 14:03:24	45.05	129	11/22/06 14:46:00	44.84
30	11/22/06 14:00:23	48.34	80	11/22/06 14:03:36	45.04	130	11/22/06 14:48:00	44.84
31	11/22/06 14:00:24	48.10	81	11/22/06 14:03:48	45.04	131	11/22/06 14:50:00	44.84
32	11/22/06 14:00:25	47.87	82	11/22/06 14:04:00	45.04			
33	11/22/06 14:00:26	47.66	83	11/22/06 14:04:12	45.04			
34	11/22/06 14:00:27	47.46	84	11/22/06 14:04:24	45.03			
35	11/22/06 14:00:28	47.27	85	11/22/06 14:04:36	45.03			
36	11/22/06 14:00:29	47.10	86	11/22/06 14:04:48	45.03			
37	11/22/06 14:00:30	46.94	87	11/22/06 14:05:00	45.03			
38	11/22/06 14:00:31	46.80	88	11/22/06 14:05:12	45.02			
39	11/22/06 14:00:32	46.66	89	11/22/06 14:05:24	45.02			
40	11/22/06 14:00:33	46.55	90	11/22/06 14:05:36	45.02			
41	11/22/06 14:00:34	46.43	91	11/22/06 14:05:48	45.02			
42	11/22/06 14:00:35	46.32	92	11/22/06 14:06:00	45.02			
43	11/22/06 14:00:36	46.23	93	11/22/06 14:06:12	45.02			
44	11/22/06 14:00:37	46.14	94	11/22/06 14:06:24	45.01			
45	11/22/06 14:00:38	46.06	95	11/22/06 14:06:36	45.01			
46	11/22/06 14:00:39	45.99	96	11/22/06 14:06:48	45.01			
47	11/22/06 14:00:40	45.92	97	11/22/06 14:07:00	45.01			
48	11/22/06 14:00:41	45.86	98	11/22/06 14:07:12	45.00			
49	11/22/06 14:00:42	45.81	99	11/22/06 14:07:24	45.00			
50	11/22/06 14:00:43	45.76	100	11/22/06 14:07:36	45.00			

# WELL ID: WW-5

Local ID: T21S-R37E-Section 26-J

Date: 11/22/06

Time: 11:00 AM

## INPUT

Construction:	
Casing dia. ( $d_c$ )	8 Inch
Annulus dia. ( $d_w$ )	8 Inch
Screen Length (L)	34 Feet
Depths to:	
water level (DTW)	46 Feet
Top of Aquifer	46 Feet
Base of Aquifer	80 Feet
Annular Fill:	
across screen --	Gravel
above screen --	Cement
Aquifer Material -- Fine Sand	
FLOW RATE	20 GPM

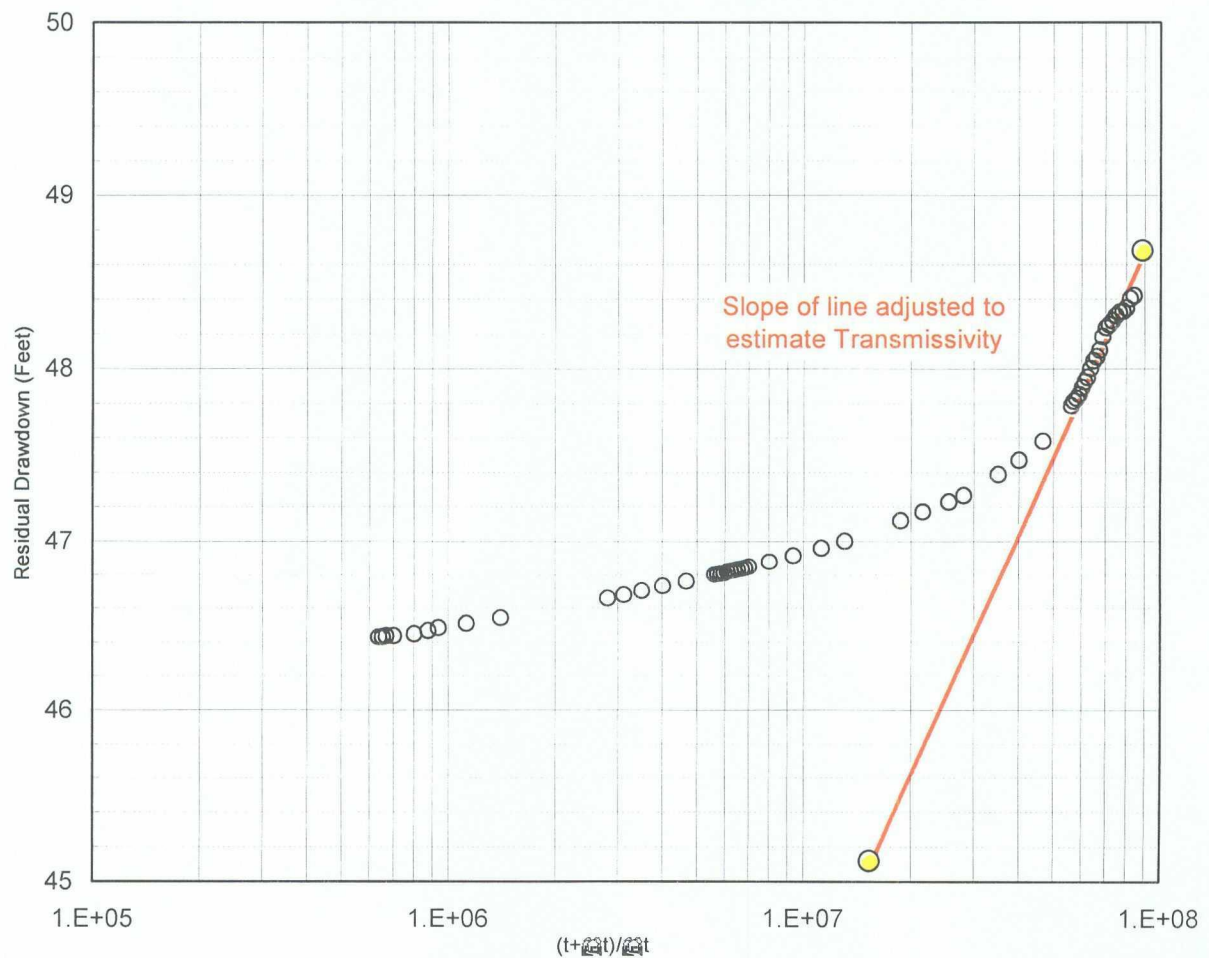
## COMPUTED

Aquifer thickness = 34 Feet

Slope = 4.6657929 Feet/log10

Input is consistent.

K = 4.4 Feet/Day  
T = 150 Feet<sup>2</sup>/Day



REMARKS: Cooper-Jacob recovery analysis of single-well aquifer test

This recovery test was done on a water supply well (WW-1) that had been running continuously at ~53 gpm for 16-20 hours. A Hermit 2000 data logger was used to record the water level data for the length of the test (~50 minutes).

Depth to water before shutting off pump 54.09 ft ( $t = 0$  min).

Depth to water at end of recovery test 44.84 ft ( $t = 50$  min).



**Raw input recovery data for water supply well WW-5**

Reduced Data					
	Time,	Water Level		Time,	Water Level
Entry	Date Hr:Min:Sec	Feet	Entry	Date Hr:Min:Sec	Feet
1	11/22/06 11:00:00	0.00	31	11/22/06 11:05:00	47.00
2	11/22/06 11:00:40	48.42	32	11/22/06 11:06:00	46.96
3	11/22/06 11:00:41	48.42	33	11/22/06 11:07:00	46.92
4	11/22/06 11:00:42	48.40	34	11/22/06 11:08:00	46.88
5	11/22/06 11:00:43	48.35	35	11/22/06 11:08:12	46.85
6	11/22/06 11:00:44	48.33	36	11/22/06 11:08:24	46.84
7	11/22/06 11:00:45	48.32	37	11/22/06 11:08:36	46.84
8	11/22/06 11:00:46	48.31	38	11/22/06 11:08:48	46.83
9	11/22/06 11:00:47	48.28	39	11/22/06 11:09:00	46.83
10	11/22/06 11:00:48	48.25	40	11/22/06 11:09:12	46.82
11	11/22/06 11:00:49	48.24	41	11/22/06 11:09:24	46.82
12	11/22/06 11:00:50	48.18	42	11/22/06 11:09:36	46.81
13	11/22/06 11:00:51	48.11	43	11/22/06 11:09:48	46.81
14	11/22/06 11:00:52	48.07	44	11/22/06 11:10:00	46.80
15	11/22/06 11:00:53	48.05	45	11/22/06 11:12:00	46.80
16	11/22/06 11:00:54	48.00	46	11/22/06 11:14:00	46.76
17	11/22/06 11:00:55	47.95	47	11/22/06 11:16:00	46.73
18	11/22/06 11:00:56	47.93	48	11/22/06 11:18:00	46.70
19	11/22/06 11:00:57	47.89	49	11/22/06 11:20:00	46.68
20	11/22/06 11:00:58	47.85	50	11/22/06 11:40:00	46.66
21	11/22/06 11:00:59	47.83	51	11/22/06 11:50:00	46.54
22	11/22/06 11:01:00	47.81	52	11/22/06 12:00:00	46.51
23	11/22/06 11:01:12	47.79	53	11/22/06 12:04:00	46.48
24	11/22/06 11:01:24	47.58	54	11/22/06 12:10:00	46.47
25	11/22/06 11:01:36	47.47	55	11/22/06 12:20:00	46.45
26	11/22/06 11:02:00	47.39	56	11/22/06 12:24:00	46.44
27	11/22/06 11:02:12	47.27	57	11/22/06 12:26:00	46.44
28	11/22/06 11:02:36	47.23	58	11/22/06 12:28:00	46.43
29	11/22/06 11:03:00	47.17			
30	11/22/06 11:04:18	47.12			

## **APPENDIX D**

### **Summary Laboratory Analytical Reports**

**And**

### **Chain of Custody Documentation**

**(Full length lab reports with all QA/QC information are  
included separately on compact disk in Adobe Reader format)**

## Summary Report

Kristen Farris-Pope  
Rice Operating Company  
122 W Taylor Street  
Hobbs, NM, 88240

Report Date: August 14, 2006

Work Order: 6080433



Project Location: Lea County, NM  
Project Name: BD Junction J-26

Sample	Description	Matrix	Date Taken	Time Taken	Date Received
98085	Monitor Well #1	water	2006-08-01	09:45	2006-08-04
98086	Monitor Well #2	water	2006-08-01	10:25	2006-08-04
98087	Monitor Well #3	water	2006-08-01	08:35	2006-08-04

### Sample: 98085 - Monitor Well #1

Param	Flag	Result	Units	RL
Hydroxide Alkalinity		<1.00	mg/L as CaCo3	1.00
Carbonate Alkalinity		<1.00	mg/L as CaCo3	1.00
Bicarbonate Alkalinity		226	mg/L as CaCo3	4.00
Total Alkalinity		226	mg/L as CaCo3	4.00
Dissolved Calcium		86.2	mg/L	0.500
Dissolved Potassium		41.6	mg/L	1.00
Dissolved Magnesium		23.9	mg/L	1.00
Dissolved Sodium		225	mg/L	1.00
Chloride		218	mg/L	0.500
Sulfate		248	mg/L	0.500
Total Dissolved Solids		1126	mg/L	10.00

### Sample: 98086 - Monitor Well #2

Param	Flag	Result	Units	RL
Hydroxide Alkalinity		<1.00	mg/L as CaCo3	1.00
Carbonate Alkalinity		<1.00	mg/L as CaCo3	1.00
Bicarbonate Alkalinity		216	mg/L as CaCo3	4.00
Total Alkalinity		216	mg/L as CaCo3	4.00
Dissolved Calcium		144	mg/L	0.500
Dissolved Potassium		18.3	mg/L	1.00
Dissolved Magnesium		42.4	mg/L	1.00
Dissolved Sodium		241	mg/L	1.00
Chloride		387	mg/L	0.500
Sulfate		247	mg/L	0.500

*continued ...*

*sample 98086 continued ...*

Param	Flag	Result	Units	RL
Total Dissolved Solids		1358	mg/L	10.00

**Sample: 98087 - Monitor Well #3**

Param	Flag	Result	Units	RL
Hydroxide Alkalinity		<1.00	mg/L as CaCo3	1.00
Carbonate Alkalinity		<1.00	mg/L as CaCo3	1.00
Bicarbonate Alkalinity		208	mg/L as CaCo3	4.00
Total Alkalinity		208	mg/L as CaCo3	4.00
Dissolved Calcium		91.8	mg/L	0.500
Dissolved Potassium		10.4	mg/L	1.00
Dissolved Magnesium		33.0	mg/L	1.00
Dissolved Sodium		140	mg/L	1.00
Chloride		141	mg/L	0.500
Sulfate		190	mg/L	0.500
Total Dissolved Solids		876.0	mg/L	10.00

Submittal of samples constitutes agreement to Terms and Conditions listed on reverse side of COC

# Cation-Anion Balance Sheet

DATE: 8/16/2006

Sample #	Calcium ppm	Magnesium ppm	Sodium ppm	Potassium ppm	Alkalinity ppm	Sulfate ppm	Chloride ppm	Nitrate ppm	Fluoride ppm	TDS ppm	EC µMHOs/cm
98085	86.2	23.9	225	41.6	226	248	217.755			1130	
98086	144	42.4	241	18.3	216	247	387			1360	
98087	91.8	33	140	10.4	208	190	140.922			876	
Total											Total

Sample #	Calcium in meq/L	Magnesium in meq/L	Sodium in meq/L	Potassium in meq/L	Alkalinity in meq/L	Sulfate in meq/L	Chloride in meq/L	Nitrate in meq/L	Fluoride in meq/L	Cations in meq/L	Anions in meq/L	Percentage Error
98085	4.30	1.97	9.79	1.06	4.52	5.16	6.14			17.12	15.83	7.85
98086	7.19	3.49	10.48	0.47	4.32	5.14	10.92			21.63	20.38	5.93
98087	4.58	2.72	6.09	0.27	4.16	3.96	3.98			13.65	12.09	12.13

EC/Cation	EC/Anion	range	0	10	0	TDS/EC	TDS/Cat	TDS/Anion	needs to be 0.55-0.77
98085		range	0	10	0		0.66	0.71	
98086		range	0	10	0		0.63	0.67	
98087		range	0	10	0		0.64	0.72	

## Summary Report

Kristin Farris-Pope  
Rice Operating Company  
122 W Taylor Street  
Hobbs, NM, 88240

Report Date: August 22, 2006

Work Order: 6080425



Project Location: Lea County,NM  
Project Name: Windmill 220

Sample	Description	Matrix	Date Taken	Time Taken	Date Received
98071	Windmill 220	water	2006-08-01	09:40	2006-08-04

### Sample: 98071 - Windmill 220

Param	Flag	Result	Units	RL
Hydroxide Alkalinity		<1.00	mg/L as CaCo3	1.00
Carbonate Alkalinity		<1.00	mg/L as CaCo3	1.00
Bicarbonate Alkalinity		248	mg/L as CaCo3	4.00
Total Alkalinity		248	mg/L as CaCo3	4.00
Dissolved Calcium		137	mg/L	0.500
Dissolved Potassium		15.3	mg/L	1.00
Dissolved Magnesium		47.8	mg/L	1.00
Dissolved Sodium		277	mg/L	1.00
Chloride		369	mg/L	0.500
Sulfate		292	mg/L	0.500
Total Dissolved Solids		1490	mg/L	10.00

## CHAIN-OF-CUSTODY AND ANALYSIS REQUEST

LAB Order ID #

## ANALYSIS REQUEST

(Circle or Specify Method No.)

55 McCutcheon Way, Suite H  
El Paso, Texas 79932  
Tel (915) 585-3443  
Fax (915) 585-4944

# TraceAnalysis, Inc.

Phone #:

(505) 393-9174

**Box #:**

(505) 397-1471

kpope@riceswd.com

Kristin Ferris - Data Object Scientist

**Invoice to:**

...If different from above)

**Project Name:**

Windmill ~ 220

**Sampler Signature:** Rozanne Johnson (505)631-9310

Lea County - New Mexico

[illegible]

REMARKS: Please email results to:

kpope@riceswd.com

mfranks@riceswd.com

rozanne@valornet.com

☐ check if special reporting limits needed

**LAB USE ONLY**

Contact Y/N

headspace	Y/N

Temp. \_\_\_\_\_

Log-in Review

Submittal of samples constitutes agreement to Terms and Conditions listed on reverse side of COC



# Cation-Anion Balance Sheet

DATE: 8/22/2006

Sample #	Calcium ppm	Magnesium ppm	Sodium ppm	Potassium ppm	Alkalinity ppm	Sulfate ppm	Chloride ppm	Nitrate ppm	Fluoride ppm	Bromide ppm	TDS ppm	EC µMHOs/cm
98071	137	47.8	277	15.3	248	292	369				1490	

Sample #	Calcium in meq/L	Magnesium in meq/L	Sodium in meq/L	Potassium in meq/L	Alkalinity in meq/L	Sulfate in meq/L	Chloride in meq/L	Nitrate in meq/L	Fluoride in meq/L	Bromide in meq/L	Cations in meq/L	Anions in meq/L	Percentage Error
98071	6.84	3.93	12.05	0.39	4.96	6.08	10.41	0	0	0	23.21	21.45	7.889490014

Sample #	EC/Cation	EC/Anion
98071	2321.0636	2144.893

TDS/EC #DIV/0!	TDS/Cat	TDS/Anion
	0.64	0.69

range 0 to 0 needs to be 0.55-0.77

## Summary Report

Kristin Farris-Pope  
Rice Operating Company  
122 W Taylor Street  
Hobbs, NM, 88240

Report Date: August 23, 2006

Work Order: 6080427



Project Location: Lea County,NM  
Project Name: Plains Pipeline-DS Hugh Gathering

Sample	Description	Matrix	Date Taken	Time Taken	Date Received
98073	Monitor Well #3	water	2006-08-01	11:35	2006-08-04

### Sample: 98073 - Monitor Well #3

Param	Flag	Result	Units	RL
Hydroxide Alkalinity		<1.00	mg/L as CaCo3	1.00
Carbonate Alkalinity		<1.00	mg/L as CaCo3	1.00
Bicarbonate Alkalinity		280	mg/L as CaCo3	4.00
Total Alkalinity		280	mg/L as CaCo3	4.00
Dissolved Calcium		124	mg/L	0.500
Dissolved Potassium		10.3	mg/L	1.00
Dissolved Magnesium		63.3	mg/L	1.00
Dissolved Sodium		195	mg/L	1.00
Chloride		322	mg/L	0.500
Sulfate		255	mg/L	0.500
Total Dissolved Solids		1284	mg/L	10.00

Page 1 of 1

<b>TraceAnalysis, Inc.</b> 155 McCutcheon Way, Suite H El Paso, Texas 79932 Tel (806) 794-1296 Fax (806) 794-1298 1 (800) 378-1296		<b>CHAIN-OF-CUSTODY AND ANALYSIS REQUEST</b> LAB Order ID # <u>6080427</u>																																																																													
Company Name: <u>RICE Operating Company</u> Address: <u>(Street, City, Zip)</u> <u>122 W Taylor Street - Hobbs, New Mexico 88240</u> Contact Person: <u>Kristin Faris - Pope, Project Scientist</u> Invoice to: <u>Kristin Faris - Pope, Project Scientist</u> (If different from above)		<b>ANALYSIS REQUEST</b> (Circle or Specify Method No.)																																																																													
Project Name: <u>Plains Pipeline-DS Hugh Gathering</u> Project Location: <u>Lea County - New Mexico</u> None Given Project #: <u>None</u> Sample Location: <u>None</u> Sampler Signature: <u>Rozanne Johnson</u> (505) 631-9310 Email: <u>rozanne@valornet.com</u>		ANALYSIS REQUEST (Circle or Specify Method No.)																																																																													
LAB # <u>98073</u>	FIELD CODE <u>Monitor Well #3</u>	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th rowspan="2">CONTAINERS</th> <th rowspan="2">VOLUME/AMOUNT</th> <th colspan="4">MATRIX</th> <th colspan="4">PRESERVATIVE METHOD</th> <th colspan="2">SAMPLING</th> </tr> <tr> <th>WATER</th> <th>SOIL</th> <th>AIR</th> <th>SLUDGE</th> <th>HCL</th> <th>HNO<sub>3</sub></th> <th>NaHSO<sub>4</sub></th> <th>H<sub>2</sub>SO<sub>4</sub></th> <th>ICE</th> <th>NONE</th> <th>DATE 2006</th> <th>TIME</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>1L</td> <td>X</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>X</td> <td></td> <td>8-1</td> <td>11:35</td> </tr> </tbody> </table>	CONTAINERS	VOLUME/AMOUNT	MATRIX				PRESERVATIVE METHOD				SAMPLING		WATER	SOIL	AIR	SLUDGE	HCL	HNO <sub>3</sub>	NaHSO <sub>4</sub>	H <sub>2</sub> SO <sub>4</sub>	ICE	NONE	DATE 2006	TIME	1	1L	X								X		8-1	11:35	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th colspan="2">LAB USE ONLY</th> </tr> </thead> <tbody> <tr> <td>TPH 418.1/TX1005 / TX1005 Extended (C35)</td> <td></td> </tr> <tr> <td>PAH 8270C</td> <td></td> </tr> <tr> <td>Total Metals Ag As Ba Cd Cr Pb Se Hg 6010B/200.7</td> <td></td> </tr> <tr> <td>TCLP Metals Ag As Ba Cd Cr Pb Se Hg</td> <td></td> </tr> <tr> <td>TCLP Volatiles</td> <td></td> </tr> <tr> <td>TCLP Semi Volatiles</td> <td></td> </tr> <tr> <td>TCLP Pesticides</td> <td></td> </tr> <tr> <td>RCI</td> <td></td> </tr> <tr> <td>GC/MS Vol. 8260B/624</td> <td></td> </tr> <tr> <td>GC/MS Semi. Vol. 8270C/625</td> <td></td> </tr> <tr> <td>PCBs 8082/608</td> <td></td> </tr> <tr> <td>Pesticides 8081A/608</td> <td></td> </tr> <tr> <td>BOD, TSS, pH</td> <td></td> </tr> <tr> <td>Moisture Content</td> <td></td> </tr> <tr> <td>Cations (Ca, Mg, Na, K)</td> <td>X</td> </tr> <tr> <td>Anions (Cl, SSSO<sub>4</sub>, CO<sub>3</sub>, HCO<sub>3</sub>)</td> <td>X</td> </tr> <tr> <td>Total Dissolved Solids</td> <td>X</td> </tr> <tr> <td>Turn Around Time if different from standard</td> <td></td> </tr> </tbody> </table>	LAB USE ONLY		TPH 418.1/TX1005 / TX1005 Extended (C35)		PAH 8270C		Total Metals Ag As Ba Cd Cr Pb Se Hg 6010B/200.7		TCLP Metals Ag As Ba Cd Cr Pb Se Hg		TCLP Volatiles		TCLP Semi Volatiles		TCLP Pesticides		RCI		GC/MS Vol. 8260B/624		GC/MS Semi. Vol. 8270C/625		PCBs 8082/608		Pesticides 8081A/608		BOD, TSS, pH		Moisture Content		Cations (Ca, Mg, Na, K)	X	Anions (Cl, SSSO <sub>4</sub> , CO <sub>3</sub> , HCO <sub>3</sub> )	X	Total Dissolved Solids	X	Turn Around Time if different from standard	
CONTAINERS	VOLUME/AMOUNT	MATRIX				PRESERVATIVE METHOD				SAMPLING																																																																					
		WATER	SOIL	AIR	SLUDGE	HCL	HNO <sub>3</sub>	NaHSO <sub>4</sub>	H <sub>2</sub> SO <sub>4</sub>	ICE	NONE	DATE 2006	TIME																																																																		
1	1L	X								X		8-1	11:35																																																																		
LAB USE ONLY																																																																															
TPH 418.1/TX1005 / TX1005 Extended (C35)																																																																															
PAH 8270C																																																																															
Total Metals Ag As Ba Cd Cr Pb Se Hg 6010B/200.7																																																																															
TCLP Metals Ag As Ba Cd Cr Pb Se Hg																																																																															
TCLP Volatiles																																																																															
TCLP Semi Volatiles																																																																															
TCLP Pesticides																																																																															
RCI																																																																															
GC/MS Vol. 8260B/624																																																																															
GC/MS Semi. Vol. 8270C/625																																																																															
PCBs 8082/608																																																																															
Pesticides 8081A/608																																																																															
BOD, TSS, pH																																																																															
Moisture Content																																																																															
Cations (Ca, Mg, Na, K)	X																																																																														
Anions (Cl, SSSO <sub>4</sub> , CO <sub>3</sub> , HCO <sub>3</sub> )	X																																																																														
Total Dissolved Solids	X																																																																														
Turn Around Time if different from standard																																																																															
Date: <u>8/30/06</u> Time: <u>2:30pm</u> Inquired by: <u>TraceAnalysis</u> Date: <u>8/30/06</u> Time: <u>2:30pm</u> Inquired by: <u>TraceAnalysis</u>		REMARKS: Please email results to: <u>kpope@riceswd.com</u> <u>mfranks@riceswd.com</u> <u>rozanne@valornet.com</u> <input type="checkbox"/> check if special reporting limits needed																																																																													
Date: <u>8/30/06</u> Time: <u>8:40p</u> Received by: <u>Jay Adams</u>		Date: <u>8/30/06</u> Time: <u>10AM</u> Received by: <u>Jay Adams</u>																																																																													
Date: <u>8/30/06</u> Time: <u>8:40p</u> Received by: <u>Jay Adams</u>		Date: <u>8/30/06</u> Time: <u>10AM</u> Received by: <u>Jay Adams</u>																																																																													

Initial of samples constitutes agreement to Terms and Conditions listed on reverse side of COC

# Cation-Anion Balance Sheet

DATE: 8/22/2006

Sample #	Calcium ppm	Magnesium ppm	Sodium ppm	Potassium ppm	Alkalinity ppm	Sulfate ppm	Chloride ppm	Nitrate ppm	Fluoride ppm	Bromide ppm	TDS ppm	EC µMHOs/cm	
98073	124	63.3	195	10.3	280	255	322				1284		
Sample #	Calcium in meq/L	Magnesium in meq/L	Sodium in meq/L	Potassium in meq/L	Alkalinity in meq/L	Sulfate in meq/L	Chloride in meq/L	Nitrate in meq/L	Fluoride in meq/L	Bromide in meq/L	Cations in meq/L	Anions in meq/L	Percentage Error
98073	6.19	5.21	8.48	0.26	5.60	5.31	9.08	0	0	0	20.14	19.99	0.746530774
98073	EC/Cation 2014.2531	EC/Anion 1999.272	range 0 to 0	TDS/EC #DIV/0!		TDS/Cat 0.64	TDS/Anion 0.64	needs to be 0.55-0.77					

## Summary Report

Kristin Farris-Pope  
Rice Operating Company  
122 W Taylor Street  
Hobbs, NM, 88240

Report Date: August 24, 2006

Work Order: 6080429



Project Location: Lea County,NM  
Project Name: Plains Pipeline-Vacuum to Jal 14 Inch Mainline #3

Sample	Description	Matrix	Date Taken	Time Taken	Date Received
98075	Monitor Well 7	water	2006-08-01	10:55	2006-08-04

### Sample: 98075 - Monitor Well 7

Param	Flag	Result	Units	RL
Hydroxide Alkalinity		<1.00	mg/L as CaCo3	1.00
Carbonate Alkalinity		<1.00	mg/L as CaCo3	1.00
Bicarbonate Alkalinity		190	mg/L as CaCo3	4.00
Total Alkalinity		190	mg/L as CaCo3	4.00
Dissolved Calcium		138	mg/L	0.500
Dissolved Potassium		13.8	mg/L	1.00
Dissolved Magnesium		75.8	mg/L	1.00
Dissolved Sodium		196	mg/L	1.00
Chloride		450	mg/L	0.500
Sulfate		216	mg/L	0.500
Total Dissolved Solids		1378	mg/L	10.00



# Cation-Anion Balance Sheet

DATE: 8/24/2006

Sample #	Calcium ppm	Magnesium ppm	Sodium ppm	Potassium ppm	Alkalinity ppm	Sulfate ppm	Chloride ppm	Nitrate ppm	Fluoride ppm	Bromide ppm	TDS ppm	EC µMHOS/cm
98075	138	75.8	196	13.8	190	215.661	450				1378	

Sample #	Calcium in meq/L	Magnesium in meq/L	Sodium in meq/L	Potassium in meq/L	Alkalinity in meq/L	Sulfate in meq/L	Chloride in meq/L	Nitrate in meq/L	Fluoride in meq/L	Bromide in meq/L	Cations in meq/L	Anions in meq/L	Percentage Error
98075	6.89	6.24	8.53	0.35	3.90	4.49	12.69	0	0	0	22.00	20.98	4.73731936

98075	EC/Cation	EC/Anion
	2200.2786	2098.4562

	TDS/EC	TDS/Cat	TDS/Anion
	#DIV/0!	0.63	0.66

range 0 to 0

## Summary Report

Kristin Farris-Pope  
Rice Operating Company  
122 W Taylor Street  
Hobbs, NM, 88240

Report Date: August 22, 2006

Work Order: 6080426



Project Location: Lea County,NM  
Project Name: Plains Pipeline-TNM 98-5B

Sample	Description	Matrix	Date Taken	Time Taken	Date Received
98072	Monitor Well #2	water	2006-08-01	12:50	2006-08-04

### Sample: 98072 - Monitor Well #2

Param	Flag	Result	Units	RL
Hydroxide Alkalinity		<1.00	mg/L as CaCo3	1.00
Carbonate Alkalinity		<1.00	mg/L as CaCo3	1.00
Bicarbonate Alkalinity		162	mg/L as CaCo3	4.00
Total Alkalinity		162	mg/L as CaCo3	4.00
Dissolved Calcium		95.1	mg/L	0.500
Dissolved Potassium		8.10	mg/L	1.00
Dissolved Magnesium		45.5	mg/L	1.00
Dissolved Sodium		146	mg/L	1.00
Chloride		269	mg/L	0.500
Sulfate		197	mg/L	0.500
Total Dissolved Solids		1002	mg/L	10.00



Submittal of samples constitutes agreement to Terms and Conditions listed on reverse side of COC

# Cation-Anion Balance Sheet

DATE: 8/22/2006

Sample #	Calcium ppm	Magnesium ppm	Sodium ppm	Potassium ppm	Alkalinity ppm	Sulfate ppm	Chloride ppm	Nitrate ppm	Fluoride ppm	Bromide ppm	TDS ppm	EC µMHOs/cm	
98072	95.1	45.5	146	8.1	162	196.943	268.96				1002		
Sample #	Calcium in meq/L	Magnesium in meq/L	Sodium in meq/L	Potassium in meq/L	Alkalinity in meq/L	Sulfate in meq/L	Chloride in meq/L	Nitrate in meq/L	Fluoride in meq/L	Bromide in meq/L	Cations in meq/L	Anions in meq/L	Percentage Error
98072	4.75	3.74	6.35	0.21	3.24	4.10	7.59	0	0	0	15.05	14.93	0.801773089
98072	EC/Cation 1504.7883	EC/Anion 1492.77149	range 0 to 0		TDS/EC #DIV/0!		TDS/Cat 0.67	TDS/Anion 0.67	needs to be 0.55-0.77				

## Summary Report

Kristin Farris-Pope  
Rice Operating Company  
122 W Taylor Street  
Hobbs, NM, 88240

Report Date: August 24, 2006

Work Order: 6080428



Project Location: Lea County, NM  
Project Name: Plains Pipeline- TNM 98-5A

Sample	Description	Matrix	Date Taken	Time Taken	Date Received
98074	Monitor Well #5	water	2006-08-01	12:15	2006-08-04

### Sample: 98074 - Monitor Well #5

Param	Flag	Result	Units	RL
Hydroxide Alkalinity		<1.00	mg/L as CaCo3	1.00
Carbonate Alkalinity		<1.00	mg/L as CaCo3	1.00
Bicarbonate Alkalinity		274	mg/L as CaCo3	4.00
Total Alkalinity		274	mg/L as CaCo3	4.00
Dissolved Calcium		96.3	mg/L	0.500
Dissolved Potassium		10.8	mg/L	1.00
Dissolved Magnesium		49.3	mg/L	1.00
Dissolved Sodium		167	mg/L	1.00
Chloride		218	mg/L	0.500
Sulfate		148	mg/L	0.500
Total Dissolved Solids		1008	ug/L	10.00



# Cation-Anion Balance Sheet

DATE: 8/24/2006

Sample #	Calcium ppm	Magnesium ppm	Sodium ppm	Potassium ppm	Alkalinity ppm	Sulfate ppm	Chloride ppm	Nitrate ppm	Fluoride ppm	Bromide ppm	TDS ppm	EC µMHOS/cm
98074	96.3	49.3	167	10.8	274	147.879	218.129				1008	

Sample #	Calcium in meq/L	Magnesium in meq/L	Sodium in meq/L	Potassium in meq/L	Alkalinity in meq/L	Sulfate in meq/L	Chloride in meq/L	Nitrate in meq/L	Fluoride in meq/L	Bromide in meq/L	Cations in meq/L	Anions in meq/L	Percentage Error
98074	4.81	4.06	7.26	0.28	5.48	3.08	6.15	0	0	0	16.40	14.71	10.8677829

EC/Cation	EC/Anion
1640.3031	1471.22599

TDS/EC #DIV/0!	TDS/Cat	TDS/Anion
	0.61	0.69

range 0 to 0

## Summary Report

Kristin Farris-Pope  
Rice Operating Company  
122 W Taylor Street  
Hobbs, NM, 88240

Report Date: August 29, 2006

Work Order: 6080422



Project Location: Lea County, NM  
Project Name: TARGA

Sample	Description	Matrix	Date Taken	Time Taken	Date Received
98065	Water Well #1	water	2006-08-01	15:40	2006-08-04
98066	Water Well #5	water	2006-08-01	14:50	2006-08-04
98067	Water Well #8	water	2006-08-01	15:03	2006-08-04
98068	Water Well #12	water	2006-08-01	15:12	2006-08-04

### Sample: 98065 - Water Well #1

Param	Flag	Result	Units	RL
Hydroxide Alkalinity		<1.00	mg/L as CaCo3	1.00
Carbonate Alkalinity		<1.00	mg/L as CaCo3	1.00
Bicarbonate Alkalinity		332	mg/L as CaCo3	4.00
Total Alkalinity		332	mg/L as CaCo3	4.00
Dissolved Calcium		101	mg/L	0.500
Dissolved Potassium		9.01	mg/L	1.00
Dissolved Magnesium		51.5	mg/L	1.00
Dissolved Sodium		143	mg/L	1.00
Chloride		187	mg/L	0.500
Sulfate		147	mg/L	0.500
Total Dissolved Solids		1008	mg/L	10.00

### Sample: 98066 - Water Well #5

Param	Flag	Result	Units	RL
Hydroxide Alkalinity		<1.00	mg/L as CaCo3	1.00
Carbonate Alkalinity		<1.00	mg/L as CaCo3	1.00
Bicarbonate Alkalinity		156	mg/L as CaCo3	4.00
Total Alkalinity		156	mg/L as CaCo3	4.00
Dissolved Calcium		83.1	mg/L	0.500
Dissolved Potassium		8.44	mg/L	1.00
Dissolved Magnesium		39.8	mg/L	1.00
Dissolved Sodium		126	mg/L	1.00
Chloride		225	mg/L	0.500

*continued ...*

*sample 98066 continued ...*

Param	Flag	Result	Units	RL
Sulfate		177	mg/L	0.500
Total Dissolved Solids		864.0	mg/L	10.00

**Sample: 98067 - Water Well #8**

Param	Flag	Result	Units	RL
Hydroxide Alkalinity		<1.00	mg/L as CaCo3	1.00
Carbonate Alkalinity		<1.00	mg/L as CaCo3	1.00
Bicarbonate Alkalinity		268	mg/L as CaCo3	4.00
Total Alkalinity		268	mg/L as CaCo3	4.00
Dissolved Calcium		90.5	mg/L	0.500
Dissolved Potassium		9.56	mg/L	1.00
Dissolved Magnesium		49.1	mg/L	1.00
Dissolved Sodium		206	mg/L	1.00
Chloride		308	mg/L	0.500
Sulfate		224	mg/L	0.500
Total Dissolved Solids		1202	mg/L	10.00

**Sample: 98068 - Water Well #12**

Param	Flag	Result	Units	RL
Hydroxide Alkalinity		<1.00	mg/L as CaCo3	1.00
Carbonate Alkalinity		<1.00	mg/L as CaCo3	1.00
Bicarbonate Alkalinity		296	mg/L as CaCo3	4.00
Total Alkalinity		296	mg/L as CaCo3	4.00
Dissolved Calcium		86.8	mg/L	0.500
Dissolved Potassium		9.66	mg/L	1.00
Dissolved Magnesium		42.7	mg/L	1.00
Dissolved Sodium		168	mg/L	1.00
Chloride		181	mg/L	0.500
Sulfate		160	mg/L	0.500
Total Dissolved Solids		966.0	mg/L	10.00

Report Date: August 29, 2006  
TARGA

Work Order: 6080422  
TARGA

Page Number: 13 of 14  
Lea County, NM

Page 1 of 1

# CHAIN-OF-CUSTODY AND ANALYSIS REQUEST

LAB Order ID # 6080422

## ANALYSIS REQUEST

(Circle or Specify Method No.)

MTBE 8021B/602	
BTEX 8021B/602	
TPH 418.1/TX1005 / TX1005 Extended (C35)	
PAH 8270C	
Total Metals Ag As Ba Cd Cr Pb Se Hg 6010B/200.7	
TCLP Metals Ag As Ba Cd Cr Pb Se Hg	
TCLP Volatiles	
TCLP Semi Volatiles	
TCLP Pesticides	
RCI	
GC/MS Vol. 8260B/624	
GC/MS Semi Vol. 8270C/625	
PCBs 8082/608	
Pesticides 8081A/608	
BOD, TSS, pH	
Moisture Content	
Cations (Ca, Mg, Na, K)	
Anions (Cl, SSSSO <sub>4</sub> , CO <sub>3</sub> , HCO <sub>3</sub> )	
Total Dissolved Solids	
Turn Around Time if different from standard	
Hold	

REMARKS: Please email results to:

[kpope@riceswd.com](mailto:kpope@riceswd.com)

[mfranks@riceswd.com](mailto:mfranks@riceswd.com)

[rozanne@valornet.com](mailto:rozanne@valornet.com)

☐ check if special reporting limits needed

## LAB USE ONLY

Intact Y/N

Headspace Y/N

Temp 40°C

Log-In Review

Carrier # 6080422

## TraceAnalysis, Inc.

155 McCutcheon Way, Suite H  
El Paso, Texas 79932  
Tel (915) 585-3443  
Fax (915) 585-4944

Phone #:

(505) 393-9174

Fax #:

(505) 397-1471

Contact Person: [kpope@riceswd.com](mailto:kpope@riceswd.com)

Invoice to:

Kristin Farris - Pope, Project Scientist

(If different from above)

Project #:

None Given

Project Location:

Lea County - New Mexico

Project Name:

TARGA

Sampler Signature: Gil Van Deventer

LAB # (LAB USE ONLY)	FIELD CODE	# CONTAINERS	Volume/Amount	MATRIX				PRESERVATIVE METHOD					SAMPLING	
				WATER	SOIL	AIR	SLUDGE	HCL	HNO <sub>3</sub>	NaHSO <sub>4</sub>	H <sub>2</sub> SO <sub>4</sub>	ICE	NONE	DATE 2006
98065	Water Well #1	1	1L	X								X	8-1	15:40
100	Water Well #5	1	1L	X								X	8-1	14:50
107	Water Well #8	1	1L	X								X	8-1	15:03
108	Water Well #12	1	1L	X								X	8-1	15:12

Requested by: Gil Van Deventer Date: 8/1/06 Time: 18:00

Received by: Rozanne Johnson Date: 8/1/06 Time: 18:00

Inquired by: Gil Van Deventer Date: 8/1/06 Time: 18:00

Received by: Rozanne Johnson Date: 8/1/06 Time: 18:00

Requested by: Gil Van Deventer Date: 8/1/06 Time: 18:00

Received by: Rozanne Johnson Date: 8/1/06 Time: 18:00

Inquired by: Gil Van Deventer Date: 8/1/06 Time: 18:00

Received by: Rozanne Johnson Date: 8/1/06 Time: 18:00

Requested by: Gil Van Deventer Date: 8/1/06 Time: 18:00

Received by: Rozanne Johnson Date: 8/1/06 Time: 18:00

Inquired by: Gil Van Deventer Date: 8/1/06 Time: 18:00

Received by: Rozanne Johnson Date: 8/1/06 Time: 18:00

Requested by: Gil Van Deventer Date: 8/1/06 Time: 18:00

Received by: Rozanne Johnson Date: 8/1/06 Time: 18:00

Initial of samples constitutes agreement to Terms and Conditions listed on (reverse side of COC)



# Cation-Anion Balance Sheet

DATE: 8/29/2006

Sample #	Calcium ppm	Magnesium ppm	Sodium ppm	Potassium ppm	Alkalinity ppm	Sulfate ppm	Chloride ppm	Nitrate ppm	Fluoride ppm	Bromide ppm	TDS ppm	EC µMHOs/cm
98065	101	51.5	143	9.01	332	147.08	187.376				1008	
98066	83.1	39.8	126	8.44	156	177.095	224.772				864	
98067	90.5	49.1	206	9.56	268	224.084	308				1202	
98068	86.8	42.7	168	9.66	296	160.337	180.704				966	

Sample #	Calcium in meq/L	Magnesium in meq/L	Sodium in meq/L	Potassium in meq/L	Alkalinity in meq/L	Sulfate in meq/L	Chloride in meq/L	Nitrate in meq/L	Fluoride in meq/L	Bromide in meq/L	Cations in meq/L	Anions in meq/L	Percentage Error
98065	5.04	4.24	6.22	0.23	6.64	3.06	5.29	0	0	0	15.73	14.99	4.822937211
98066	4.15	3.28	5.48	0.22	3.12	3.69	6.34	0	0	0	13.12	13.15	0.222402212
98067	4.52	4.04	8.96	0.24	5.36	4.67	8.69	0	0	0	17.76	18.71	5.220824465
98068	4.33	3.51	7.31	0.25	5.92	3.34	5.10	0	0	0	15.40	14.36	7.019268334

	EC/Cation	EC/Anion
98065	1572.88108	1498.80826
98066	1311.87272	1314.7936
98067	1776.19338	1871.41089
98068	1540.02058	1435.58762

	TDS/EC	TDS/Cat	TDS/Anion
98065	#DIV/0!	0.64	0.67
98066	#DIV/0!	0.66	0.66
98067	#DIV/0!	0.68	0.64
98068	#DIV/0!	0.63	0.67

needs to be 0.55-0.77  
needs to be 0.55-0.77  
needs to be 0.55-0.77  
needs to be 0.55-0.77

## Summary Report

Kristin Farris-Pope  
Rice Operating Company  
122 W Taylor Street  
Hobbs, NM, 88240

Report Date: August 22, 2006

Work Order: 6080423



Project Location: Lea County,NM  
Project Name: TARGA

Sample	Description	Matrix	Date Taken	Time Taken	Date Received
98069	Water Well #19	water	2006-08-01	17:55	2006-08-04

### Sample: 98069 - Water Well #19

Param	Flag	Result	Units	RL
Hydroxide Alkalinity		<1.00	mg/L as CaCo3	1.00
Carbonate Alkalinity		<1.00	mg/L as CaCo3	1.00
Bicarbonate Alkalinity		244	mg/L as CaCo3	4.00
Total Alkalinity		244	mg/L as CaCo3	4.00
Dissolved Calcium		92.7	mg/L	0.500
Dissolved Potassium		9.16	mg/L	1.00
Dissolved Magnesium		26.6	mg/L	1.00
Dissolved Sodium		156	mg/L	1.00
Chloride		302	mg/L	0.500
Sulfate		88.1	mg/L	0.500
Total Dissolved Solids		870.0	mg/L	10.00





PHONE (575) 393-2326 • 101 E. MARLAND • HOBBS, NM 88240

ANALYTICAL RESULTS FOR  
RICE OPERATING COMPANY  
ATTN: KRISTIN FARRIS-POPE  
122 W. TAYLOR STREET  
HOBBS, NM 88240  
FAX TO: (575) 397-1471

Receiving Date: 04/08/08  
Reporting Date: 04/11/08  
Project Number: NOT GIVEN  
Project Name: BD JUNCTION J-26  
Project Location: T21S R37E SEC26 J~LEA COUNTY, NM

Sampling Date: 04/04/08  
Sample Type: WATER  
Sample Condition: COOL & INTACT  
Sample Received By: ML  
Analyzed By: HM/KS

LAB NUMBER SAMPLE ID	Na (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	Conductivity ( $\mu$ S/cm)	T-Alkalinity (mgCaCO <sub>3</sub> /L)
ANALYSIS DATE:	04/11/08	04/10/08	04/10/08	04/11/08	04/09/08	04/09/08
H14598-1 MONITOR WELL #1	172	67.9	29.0	24.2	1,320	200
H14598-2 MONITOR WELL #2	357	240	78.6	19.3	3,460	208
H14598-3 MONITOR WELL #3	166	54.6	39.5	10.0	1,330	260
Quality Control	NR	49.2	50.0	3.53	1,429	NR
True Value QC	NR	50.0	50.0	3.00	1,413	NR
% Recovery	NR	98.5	100	118	101	NR
Relative Percent Difference	NR	2.8	1.6	2.9	0.4	NR

METHODS:	SM3500-Ca-D	3500-Mg E	8049	120.1	310.1
----------	-------------	-----------	------	-------	-------

	Cl <sup>-</sup> (mg/L)	SO <sub>4</sub> (mg/L)	CO <sub>3</sub> (mg/L)	HCO <sub>3</sub> (mg/L)	pH (s.u.)	TDS (mg/L)
ANALYSIS DATE:	04/09/08	04/09/08	04/09/08	04/09/08	04/09/08	04/08/08
H14598-1 MONITOR WELL #1	140	284	0	244	7.67	890
H14598-2 MONITOR WELL #2	860	292	0	254	7.38	2,470
H14598-3 MONITOR WELL #3	152	191	0	317	7.74	911
Quality Control	490	22.7	NR	1000	7.04	NR
True Value QC	500	25.0	NR	1000	7.00	NR
% Recovery	98.0	90.7	NR	100	100	NR
Relative Percent Difference	< 0.1	11.9	NR	1.2	< 0.1	NR

METHODS:	SM4500-Cl-B	375.4	310.1	310.1	150.1	160.1
----------	-------------	-------	-------	-------	-------	-------

*Kristin Supple*  
Chemist

04/14/08  
Date

PLEASE NOTE: Liability and Damages. Cardinal's liability and client's exclusive remedy for any claim arising, whether based in contract or tort, shall be limited to the amount paid by client for analyses. All claims, including those for negligence and any other cause whatsoever shall be deemed waived unless made in writing and received by Cardinal within thirty (30) days after completion of the applicable service. Cardinal shall not be liable for incidental or consequential damages, including, without limitation, business interruptions, loss of use, or loss of profits incurred by client, its subsidiaries, affiliates or successors arising out of or related to the performance of services hereunder by Cardinal, regardless of whether such claim is based upon any of the above-stated reasons or otherwise. Results relate only to the samples identified above. This report shall not be reproduced except in full with written approval of Cardinal Laboratories.

Page 1 of 1Page 1 of 1

## **APPENDIX E**

### **NMOCD Correspondence**

Gil Van Deventer

---

From: "Hansen, Edward J., EMNRD" <edwardj.hansen@state.nm.us>  
"Kristin Pope" <kpope@riceswd.com>  
Cc: "Price, Wayne, EMNRD" <wayne.price@state.nm.us>; "Gil Van Deventer" <gilbertvandeventer@suddenlink.net>  
Sent: Wednesday, February 13, 2008 12:32 PM  
Subject: Completion Report for AP-75 (1R0426-40) (Rice BD Jct. J-26 Site)

Dear Ms. Pope:

The NMOCD has reviewed the submitted Stage 2 Final Investigation and Abatement Completion Report (AP-75) (1R0426-40), dated November 20, 2007, for the above referenced site. The NMOCD cannot approve of the Report at this time. To expedite the approval process, the NMOCD recommends that the following amendments are made to the Abatement Plan:

1. The Corrective Action to the Groundwater must include that at least two additional groundwater monitoring wells will be installed downgradient of MW-2 at the Rice BD Jct. J-26 Site. In addition, one of the additional groundwater monitoring wells must be nested so that the well(s) is screened at the upper portion of the aquifer and at the lower portion of the aquifer. Two separate wells may be installed for this purpose for a total of three additional groundwater monitoring wells.
2. The Corrective Action to the Groundwater must include that a groundwater recovery well will be installed downgradient of the Rice BD Jct. J-26 Site (near MW-2). An existing groundwater monitoring well may be used for this purpose. Also, please propose a treatment and / or disposal method of the recovered groundwater.

If you have questions regarding this matter, please contact me at 505-476-3489.

Edward J. Hansen  
Hydrologist  
Environmental Bureau

P.S.: Please use the referenced OCD case # on future correspondence regarding the site listed above.

Confidentiality Notice: This e-mail, including all attachments is for the sole use of the intended recipient(s) and may contain confidential and privileged information. Any unauthorized review, use, disclosure or distribution is prohibited unless specifically provided under the New Mexico Inspection of Public Records Act. If you are not the intended recipient, please contact the sender and destroy all copies of this message. -- This email has been scanned by the Sybari - Antigen Email System.

**Gil Van Deventer**

---

From: "Hansen, Edward J., EMNRD" <edwardj.hansen@state.nm.us>  
 "Kristin Pope" <kpope@riceswd.com>  
 Cc: "Marvin Burrows" <mburrows@riceswd.com>; "Gil Van Deventer" <gilbertvandeventer@suddenlink.net>  
 Sent: Tuesday, April 29, 2008 2:19 PM  
 Subject: RE: Request for extension

Dear Ms. Pope:

The New Mexico Oil Conservation Division (NMOCD) has reviewed your request for the extension of the submittal date of the amended abatement plans for the below referenced sites. The NMOCD hereby approves the extension for the amended plan submittal date. The amended plans for the three EME sites must be submitted the NMOCD by Monday, June 16, 2008. However, the amended plan for the BD Jct J-26 (AP-75) must be submitted by Tuesday, May 27, 2008.

Please be advised that NMOCD approval of this extension does not relieve the owner/operator of responsibility should operations pose a threat to ground water, surface water, human health or the environment. In addition, NMOCD approval does not relieve the owner/operator of responsibility for compliance with any NMOCD, federal, state, or local laws and/or regulations.

If you have any questions regarding this matter, please contact me at 505-476-3489.

Edward J. Hansen  
 Hydrologist  
 Environmental Bureau

---

**From:** Gil Van Deventer [mailto:gilbertvandeventer@suddenlink.net]  
**Sent:** Monday, April 28, 2008 1:20 PM  
**To:** Hansen, Edward J., EMNRD  
**Cc:** Marvin Burrows; Kristin Pope  
**Subject:** Request for extension

Subject sites:

- o EME P-6 Release (AP-45)
- o EME Jct K-6 (AP-46)
- o EME Jct. N-5 (AP-66)
- o BD Jct J-26 (AP-75)

Hello Edward:

In reference to the subject sites listed above which have amended abatement plans coming due, and on behalf of Rice Operating Company (ROC), I would like to request an extension to June 16, 2008, for the following reasons:

- Ongoing review of draft reports still in progress
- Change of management at ROC (Kristin's departure end of May and Marvin's recent hiring)
- Gil's vacation (May 12-19 for son's wedding)
- Gil's scheduled fieldwork (May 2, 6,7,8, 27-30, and June 2-6)

We will likely submit amended plans one by one before this date in no particular order. Please accept my apologies if this is not convenient for NMOCD and let me know if you accept our request for extension.

Thank you!

Gilbert J. Van Deventer, PG, REM  
 Trident Environmental  
 P. O. Box 7624, Midland TX 79708  
 Work/Mobile: 432-638-8740

05/27/08



Fax: 413-403-9968  
Home: 432-682-0727

**CONFIDENTIALITY NOTICE**

This message (including attachments) is subject as a confidential communication and is intended solely for the use of the addressee. It is not intended for transmission to, or receipt by, any unauthorized person. If you are not the intended recipient received these documents by mistake, please contact the sender by return e-mail. If you are not the intended recipient, you are hereby notified that any disclosure, copying, distribution, action or reliance upon the contents of the documents is strictly prohibited.

---

This inbound email has been scanned by the MessageLabs Email Security System.

---

Confidentiality Notice: This e-mail, including all attachments is for the sole use of the intended recipient(s) and may contain confidential and privileged information. Any unauthorized review, use, disclosure or distribution is prohibited unless specifically provided under the New Mexico Inspection of Public Records Act. If you are not the intended recipient, please contact the sender and destroy all copies of this message. -- This email has been scanned by the Sybari - Antigen Email System.