National Aeronautics and Space Administration

2010 REGIONAL GROUNDWATER REMEDIATION PROGRAM PROGRESS REPORT

RESTORATION PROGRAM

NASA AMES RESEARCH CENTER
Moffett Field, California

NASA Ames Research Center
Moffett Field, CA

May 2011

This Page Intentionally Left Blank

National Aeronautics and Space Administration

2010 Regional Groundwater Remediation Program Progress Report

Restoration Program

NASA Ames Research Center
Moffett Field, California

May 2011

Prepared for:

NASA Ames Research Center
Environmental Management Division
Mail Stop 237-14
Moffett Field, California 94035-1000

Prepared by:

ISSI INTEGRATED Science Solutions, Inc
Mail Stop T20G-4
NASA Ames Research Center
Moffett Field, California 94035-1000

This Page Intentionally Left Blank

TABLE OF CONTENTS

1.0 INTRODUCTION 1

1.1. SITE BACKGROUND 1
1.2. REMEDY DESCRIPTION AND REMEDIAL ACTION SUMMARY 8
1.3. SITE HYDROGEOLOGY 9
1.4. 2010 SITE ACTIVITIES AND DELIVERABLES SUMMARY 11

2.0 2010 REMEDIAL ACTION PROGRESS 12

2.1. REMEDIAL ACTION OBJECTIVE 12
2.2. GROUNDWATER EXTRACTION AND TREATMENT SYSTEM DESCRIPTION AND PERFORMANCE 13
2.2.1. System Description 14
2.2.2. NASA Extraction Well Pump Rates 15
2.2.3 System Influent and Effluent Data 15
2.2.4. System Performance 17
2.2.5. System Operations and Maintenance 19
2.2.5.1. Suspension of Pumping at NASA-2A and NASA-4A 19
2.2.5.2. Carbon Replacement 19
2.3. HYDRAULIC CONTROL AND CAPTURE ZONE ANALYSES 19
2.3.1. Analysis Methodology 19
2.3.2. Estimated 2010 Capture Zones 20
2.3.2.1. Step 1 – Review Site Data, Conceptual Model, Remedial Objectives 20
2.3.2.2. Step 2 – Define Site-Specific Target Capture Zones 20
2.3.2.3. Step 3 – Interpret Water Levels 23
2.3.2.4. Step 4 – Perform Appropriate Calculations 30
2.3.2.5. Step 5 - Concentration Trends at monitoring wells 32
2.3.2.6. Step 6 – Interpret Actual Capture 32
2.4. SYSTEM ANALYTICAL RESULTS 41
2.4.1. Chemical Data Evaluation and Trend Analysis 41
2.4.1.1. Evaluation of TCE 42
2.4.1.2. Evaluation of *cis*-1,2-DCE 48
2.4.1.3. Evaluation of Vinyl Chloride 54

3.0 OPERATIONS AND MAINTENANCE PROBLEMS 58

4.0 TECHNICAL ASSESSMENT 58

4.1. REMEDY FUNCTIONALITY 58
4.1.1. Suspected Source Area, Area of Investigation 9 58
4.1.2. VTOL Pad/Navy Site 8 North Source Area, Area of Investigation 7 62
4.2. ARE CAPTURE ZONES ADEQUATE? 63
4.3. ARE CONCENTRATIONS DECREASING OVER TIME? 66

5.0 IMPACT OF UP-GRADIENT SOURCES 73

5.1. NORTHERN WATS AREA – MEW AND NAVY CAPTURE ZONES 73

6.0 OTHER 2010 ACTIVITIES 73

6.1. CENTER-WIDE GROUNDWATER SAMPLING PROGRAM 73
6.1.1. Orion Park Plume 73
6.1.2. N211 Aircraft Ramp 77
6.1.3. Area of Investigation 4 81
6.2. TREATED EFFLUENT REUSE 83

TABLE OF CONTENTS (cont.)

7.0 CONCLUSIONS AND RECOMMENDATIONS 84

7.1. SUSPECTED SOURCE AREA, AREA OF INVESTIGATION 9 84
7.2. VTOL PAD/NAVY SITE 8 NORTH SOURCE AREA, AREA OF INVESTIGATION 7 84
7.3. NORTHERN WATS AREA 85

8.0 FOLLOW-UP ACTIONS 87

9.0 UPCOMING 2011 WORK AND PLANNED FUTURE ACTIVITIES 87

10.0 REFERENCES 88

List of Figures

Figure 1 Site Location Map
Figure 2 Aerial View of NASA Ames Research Center
Figure 3 NASA Ames Areas of Investigation
Figure 4 NASA Ames Monitoring and Extraction Well Locations
Figure 5 Generalized Depositional Environment
Figure 6 NASA Ames GWTS Location and Layout
Figure 7 NASA Ames GWTS Treatment Process and Sample Points
Figure 8 2010 GWTS Monthly Influent VOC Concentrations
Figure 9 2010 GWTS Monthly Groundwater Extraction
Figure 10 2010 GWTS Monthly Mass Removed
Figure 11 Suspected Source Area, Former Navy Warehouse Area
Figure 12 Navy Site 8 North/VTOL Pad, Removed Source Area
Figure 13 Hydrograph of Well 14D12A
Figure 14 Hydrograph of Well 14D26A1
Figure 15 Groundwater Elevation Contours and Capture Zones, March 25, 2010
Figure 16 Geologic Cross Section near Extraction Well NASA-1A
Figure 17 Hydrograph of Wells 14D25A2 and 14D26A1
Figure 18 Groundwater Elevation Contours and Capture Zones, November 18, 2010
Figure 19 Distribution of Sand and Gravel Thickness, A/A1 Aquifer, Warehouse Area
Figure 20 NASA-1A Well Construction Detail and Lithology
Figure 21 Geologic Cross Section near Extraction Well NASA-1A
Figure 22 NASA-2A Well Construction Detail and Lithology
Figure 23 Distribution of Sand and Gravel Thickness, A/A1 Aquifer, VTOL Area
Figure 24 NASA-3A Well Construction Detail and Lithology
Figure 25 Geologic Cross Section near Extraction Well NASA-3A
Figure 26 TCE Concentration Contours, A1-Aquifer Zone
Figure 27 TCE Concentration-versus-Time Graph, Extraction Well NASA-1A
Figure 28 TCE Concentration-versus-Time Graph, Extraction Well NASA-3A
Figure 29 TCE Concentration-versus-Time Graph, Extraction Well NASA-2A
Figure 30 *C*is-1, 2-DCE Concentration Contours, A1-Aquifer Zone
Figure 31 *Cis*-1,2-DCE Concentration-versus-Time Graph, Extraction Well NASA-1A
Figure 32 *Cis*-1,2-DCE Concentration-versus-Time Graph, Extraction Well NASA-2A
Figure 33 *Cis*-1,2-DCE Concentration-versus-Time Graph, Extraction Well NASA-3A
Figure 34 Vinyl Chloride Concentration Contours, A1-Aquifer Zone
Figure 35 Vinyl Chloride Concentration-versus-Time Graph, Extraction Well NASA-1A
Figure 36 Vinyl Chloride Concentration-versus-Time Graph, Extraction Well NASA-2A
Figure 37 Comparison of Mapped Capture Zones versus Modeled Capture Zone
Figure 38 TCE Concentration Contours with Capture Zones
Figure 39 *Cis*-1,2-DCE Concentration Contours with Capture Zones
Figure 40 TCE and *cis*-1,2-DCE Concentration-versus-Time Graph, Well NASA-1A
Figure 41 TCE and *cis*-1,2-DCE Concentration-versus-Time Graph, Well NASA-2A
Figure 42 TCE and *cis*-1,2-DCE Concentration-versus-Time Graph, Well NASA-3A
Figure 43 VOC Concentration-versus-Time Graph (2001-Present), NASA GWTS Influent
Figure 44 VOC Concentration-versus-Time Graph (2005-Present), NASA GWTS Influent
Figure 45 AOI 17 TCE Plume
Figure 46 Location of AOI 17 Air Sparge Barrier
Figure 47 N211 Aircraft Ramp Site Detail

List of Figures (cont.)

Figure 48 Regional VOC and Fuel Co-Mingled Plumes
Figure 49 AOI 4 Site Detail
Figure 50 TCE and *cis*-1,2-DCE Concentration-versus-Time Graph, Well 14D09A
Figure 51 PCE Concentration-versus-Time Graph, Well 14D28A

List of Tables

Table 1 Areas of Investigation Summary
Table 2 2010 Site Activities and Deliverables Summary
Table 3 Groundwater Cleanup Levels
Table 4 NASA Extraction Well Pump Rate Details
Table 5 2010 System Shutdown Data
Table 6 Flow Budget Calculations
Table 7 TCE Concentration Trends at Selected Wells
Table 8 *Cis*-1,2-DCE Concentration Trends at Selected Wells
Table 9 Vinyl Chloride Concentration Trends at Selected Wells
Table 10 AOI 17 Groundwater VOC Concentrations
Table 11 Petroleum Hydrocarbons in Groundwater, AOI 4 Area

List of Appendixes

Appendix A NASA 2010 Annual GWTS NPDES Report
Appendix B NASA 2010 Depth-to-Water Measurements
Appendix C NASA Well Hydrographs
Appendix D Flow Budget Calculations
Appendix E NASA 2010 Groundwater Analytical Results
Appendix F NASA Concentration-verses-Time Graphs
Appendix G 2010 Chain-of-Custody Forms, Analytical Result Reports, and Quality Assurance/Quality Control

List of Plates

Plate 1 NASA Ames Groundwater Monitoring Well Locations

Acronyms

1,1,1-TCA	1,1,1-Trichloroethane
1,1-DCA	1,1-Dichloroethane
1,1-DCE	1,1-Dichloroethene
1,2-DCA	1,2-Dichloroethane
1,2-DCE	1,2-Dichloroethene (*cis*- and *trans*- isomers)
AOI	Area of Investigation
BRAC	Base Closure and Realignment Commission
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CUP	Comprehensive Use Plan
DTSC	Department of Toxic Substance Control
EPA	Environmental Protection Agency
Freon 113	1,1,2-Trichloro-1,2,2-trifluoroethane
GAC	Granular Activated Carbon
gpm	gallons per minute
GWTS	Groundwater Treatment System
HRS	Hazardous Ranking System
IRP	Installation Restoration Program
LSA	Local Study Area
LSI	Listing Site Inspection
MCL	Maximum Contaminant Level
MEW	Middlefield-Ellis-Whisman
µg/L	micrograms per liter
mg/L	milligrams per liter
NAS	Naval Air Station
NASA	National Aeronautics and Space Administration
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
O&M	Operation and Maintenance
PCE	Tetrachloroethene (Perchloroethene)
RGRP	Regional Groundwater Remediation Program
TCE	Trichloroethene
TPH	Total Petroleum Hydrocarbons
TPH-D	Total Petroleum Hydrocarbons as Diesel
TPH-G	Total Petroleum Hydrocarbons as Gasoline
TPH-JP5	Total Petroleum Hydrocarbons as Jet Fuel #5
TPH-JP8	Total Petroleum Hydrocarbons as Jet Fuel #8
TPH-MO	Total Petroleum Hydrocarbons as Motor Oil
VOCs	Volatile Organic Compounds
VTOL	Vertical Takeoff and Landing
WATS	West Side Aquifer Treatment System (Navy)

1.0 INTRODUCTION

The United States (US) Environmental Protection Agency (EPA) Region IX issued guidance establishing submission dates and reporting format for facility-specific Annual Regional Groundwater Remediation Program (RGRP) reports. The National Aeronautics and Space Administration (NASA) Ames Research Center (Ames) Environmental Management Division has requested that Integrated Science Solutions, Inc. (ISSi) prepare this 2010 Annual RGRP Progress Report (Annual Report). The purpose of this facility-specific Annual Report is to document the effectiveness of the NASA Ames groundwater extraction and treatment system (GWTS). This Annual Report summarizes the NASA GWTS operation and maintenance; associated hydrogeologic flow and groundwater chemical data; other related, miscellaneous activities; and upcoming 2011 activities. This Report also summarizes additional groundwater-related investigations at NASA Ames, including Area of Investigation (AOI) 4 and AOI 17 (NASA Ames AOI 4/Orion Park Boundary Zone Air Sparge System) groundwater sampling programs.

1.1. Site Background

NASA Ames is a federal aerospace facility located approximately 35 miles southeast of San Francisco, California, and 10 miles northwest of San Jose, California (Figure 1). NASA Ames is located at the southern end of the San Francisco Bay in Santa Clara County and adjacent to the cities of Mountain View and Sunnyvale

Construction of Naval Air Station (NAS) Sunnyvale was initiated in 1930, with the base being commissioned in 1933. NAS Sunnyvale was used to support the Navy's lighter-than-air program on the west coast. The dirigible USS Macon was stationed at NAS Sunnyvale. After the loss of the Macon in 1935, the airfield was transferred to the US Army as an air training field. The facility was returned to the Navy during World War II and was renamed NAS Moffett Field (NASMF) (Figure 2). In 1991, the Federal Base Closure and Realignment Commission (BRAC) decided to close NASMF. In accordance with the BRAC, the U.S. Department of Defense transferred stewardship of the property, except for the military housing, to NASA. NASA took over administration of the former NASMF on July 1, 1994. The reuse of NASMF was originally addressed in the Moffett Field Comprehensive Use Plan (CUP) and its associated Environmental Assessment, which resulted in a Finding of No Significant Impact in 1994. The CUP was replaced by the NASA Ames Development Plan and its associated Environmental Impact Statement and Record of Decision in 2002.

Since 1988, numerous investigations have been performed at NASA Ames to study suspected sources of soil and groundwater contamination. During 1992, Erler & Kalinowski, Inc. (EKI, 1992) completed an EPA Listing Site Inspection (LSI). The primary objective of the 1992 LSI was to generate a preliminary site ranking using the revised Hazardous Ranking System (HRS) developed by the EPA. The HRS is the primary method used by the EPA to determine whether a site is to be included on the National Priorities List (NPL), commonly known as Superfund. Based on the final HRS score of 15.77, the NASA Ames site was classified as a non-NPL site.

Figure 1
Site Location Map

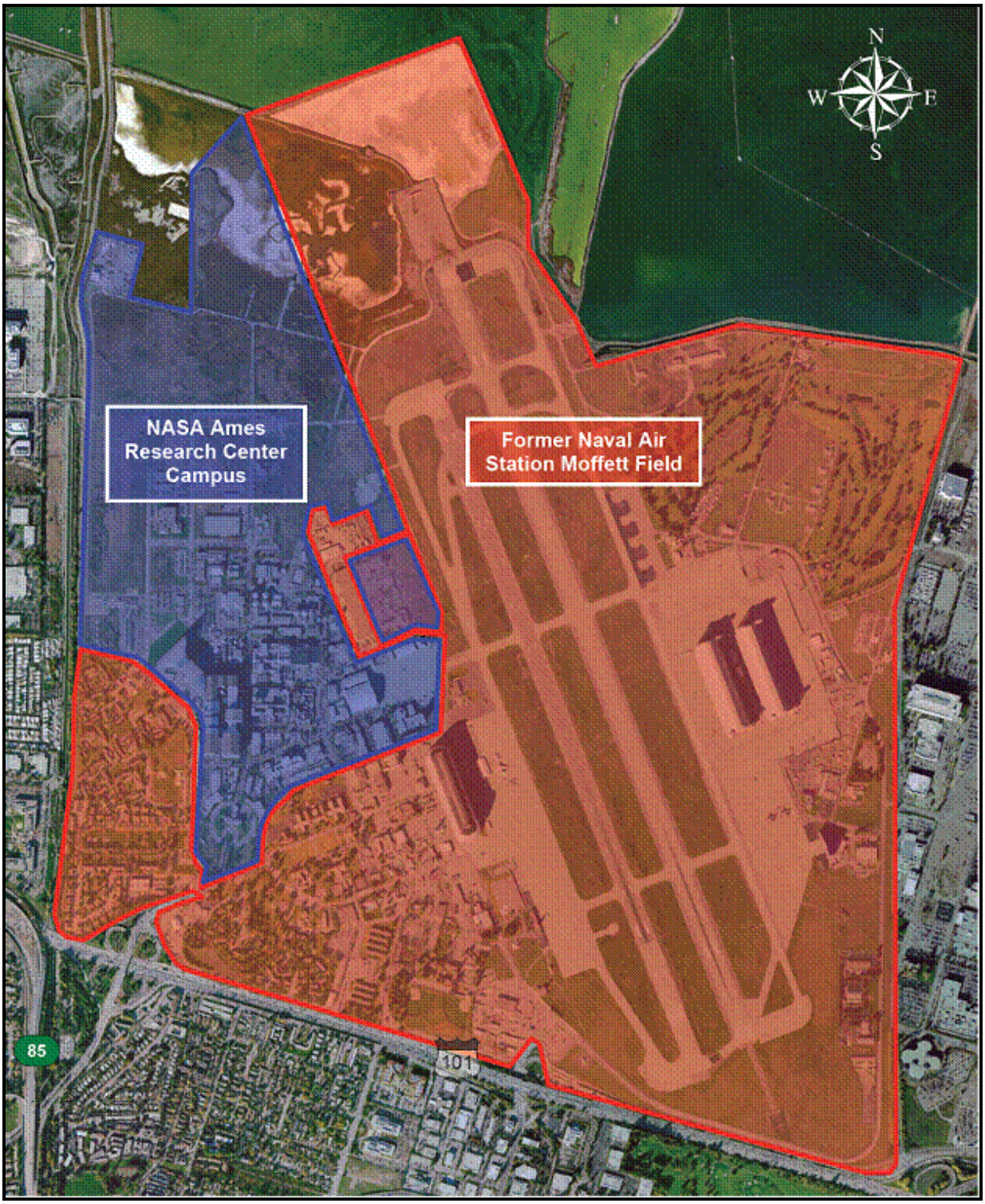


Figure 2
Aerial View of NASA Ames Research Center

Additional site work was completed in 1994. The "*Center-Wide Sampling and Analysis Program"* (EKI, 1994a) provided an overview of the requirements for a comprehensive site evaluation. As part of this plan, NASA Ames was divided into 12 Areas of Investigation (AOIs) for detailed studies that currently are in various stages of characterization, cleanup, or have received closure (Figure 3). Table 1 indicates the regulatory oversight agency, the AOI-specific contaminated media, the primary chemical of concern, and the current status of the original 12 AOIs, as well as the status of additional AOIs identified by NASA since the initial EKI designations.

Table 1
Area of Investigation Summary

AOI	Agency	Media	Primary COC	Status
1 - Fuel Farm	EPA/RWQCB	Soil & GW	TPH	Combined with AOI 3
2 – N239A Area	EPA	Soil	VOC	Combined with AOI 3
3 - N211 Area	EPA/RWQCB	Soil & GW	TPH/VOC	Investigation
4 - NFAC	DTSC	Soil & GW	TPH	O&M
4 - TCE	EPA	GW	VOC	Remediation (AOI 17)
5 - N225B	DTSC	Soil	TPH	Closed
5 - N225B	DTSC	GW	VOC	Investigation
6 - Lindbergh Ditch	EPA	Soil & GW	Lead/PCBs	No Further Action
7 - VTOL Pad Area	EPA	GW	VOC	O&M
8 - Navarro Farms	DTSC	Soil & GW	TPH	Closed
9 - N245 Area	EPA	GW	VOC	O&M
10 - Substations	DTSC	Soil	PCBs	Closed
11 - USTs	DTSC	Soil & GW	TPH	Closed
12 - USTs	EPA/RWQCB	Soil & GW	TPH/VOC	Combined with AOI 3
13 - Wetlands	EPA	Soil	PCBs/Lead	Navy Site 25
14 - Soil Fill Areas	EPA	Soil	PCBs/Lead	Remedial Design
15 – NASA Fuel Line	EPA	Soil	TPH	Remediation
16 – N218 Demo	EPA	Soil	PCBs/Lead	Closed
17 – Orion Park Plume	EPA	GW	VOC	Remediation

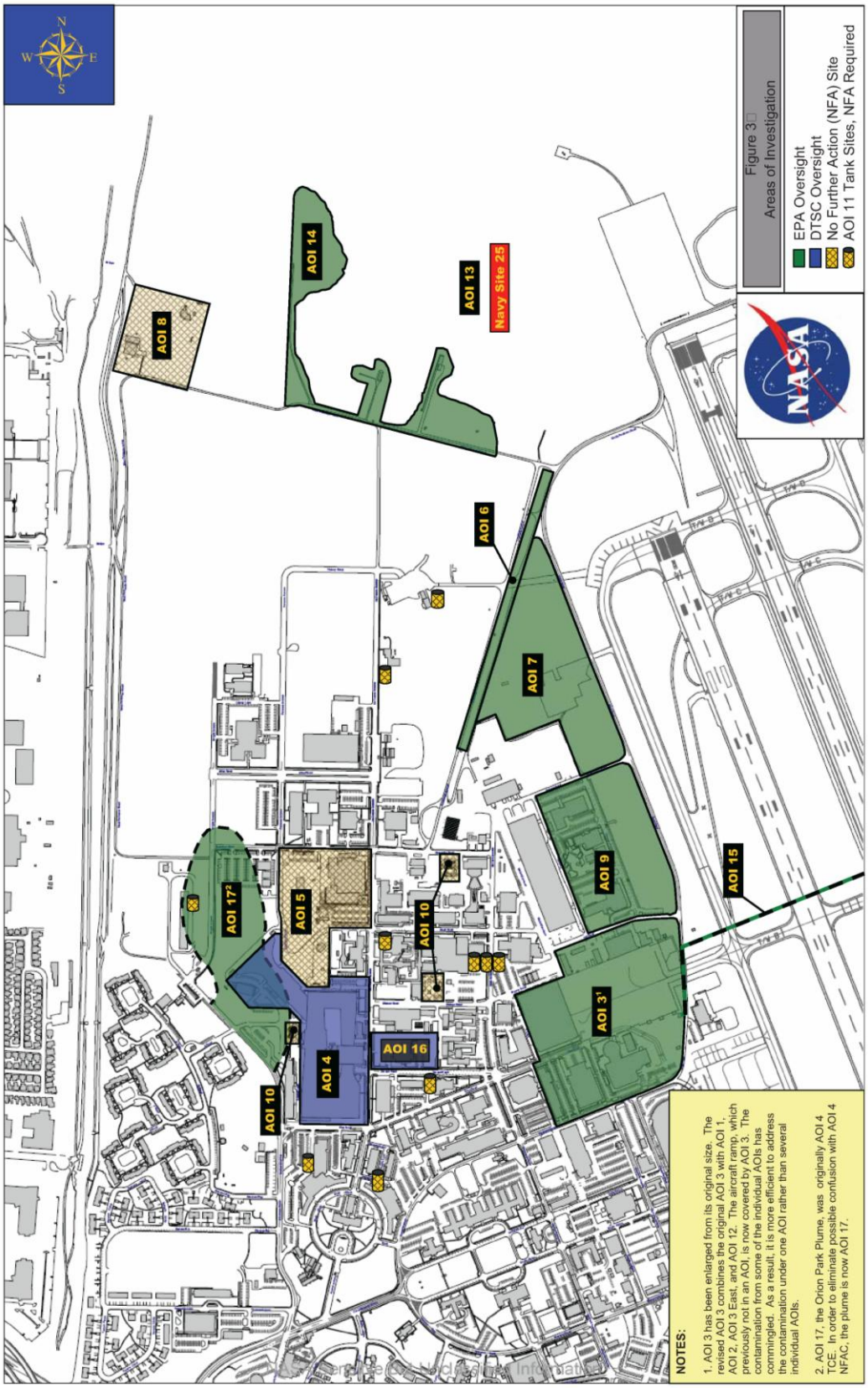


Figure 3
NASA Ames Areas of Investigation

The MEW Local Study Area (LSA) is located adjacent to (south of) NASA Ames. The LSA consists of three NPL sites, as well as several non-Superfund sites. The MEW Regional Study Area includes the LSA, as well as the former NASMF and NASA Ames. Various owners or occupants in the LSA are or were involved in the manufacture of semiconductors, metal finishing operations, parts cleaning, aircraft maintenance, and other activities requiring the use of a variety of chemicals. During 1981 and 1982, preliminary investigations of facilities within the LSA indicated significant concentrations of contaminants in soil and groundwater. The primary cause of the subsurface contamination was from leaking storage tanks and lines, and poor waste management practices. By 1985, three sites within the LSA were proposed for the NPL (EPA, 1989).

At NASMF, wastes had been generated through maintenance operations, fuel management, and fire training since the early 1930s. An Initial Assessment Study for NASMF was conducted from July 1983 to April 1984 as part of the Navy's Installation Restoration Program. Based on information from historical records, aerial photographs, surface surveys, and personnel interviews, it was concluded that numerous sites could pose a threat to human health or to the environment (IT, 1991). NASMF was placed on the NPL in July 1987.

At present, NASA Ames has a network of 133 shallow and four deep groundwater monitoring wells throughout the facility (Plate 1) which are screened in the following aquifer zones (shallowest to deepest): A1, A2/B1 (shallow wells) and C (deep wells). Definitions for these aquifer zones are provided in Section 1.3. Figure 4 shows the locations of NASA Ames' 13 RGRP long-term monitoring wells, four groundwater extraction wells, and existing non-RGRP monitoring wells in the area. Various wells are sampled throughout the year, with the frequencies depending on regulatory or data requirements. The sampling schedule for NASA Ames monitoring wells is designed to provide geographically relevant and comprehensive data that will allow more accurate characterization of specific locations associated with activities at NASA Ames, the former NASMF, and MEW sites. NASA Ames, the Navy, and the MEW companies routinely sample specified wells and participate in a data exchange program, which facilitates the evaluation of remedial effectiveness of the overall RGRP. Additionally, analytical results are used to characterize NASA's AOIs, to monitor shifts in local and regional plume boundaries, to monitor operation of NASA Ames' GWTS, and to define trends in groundwater chemistry.

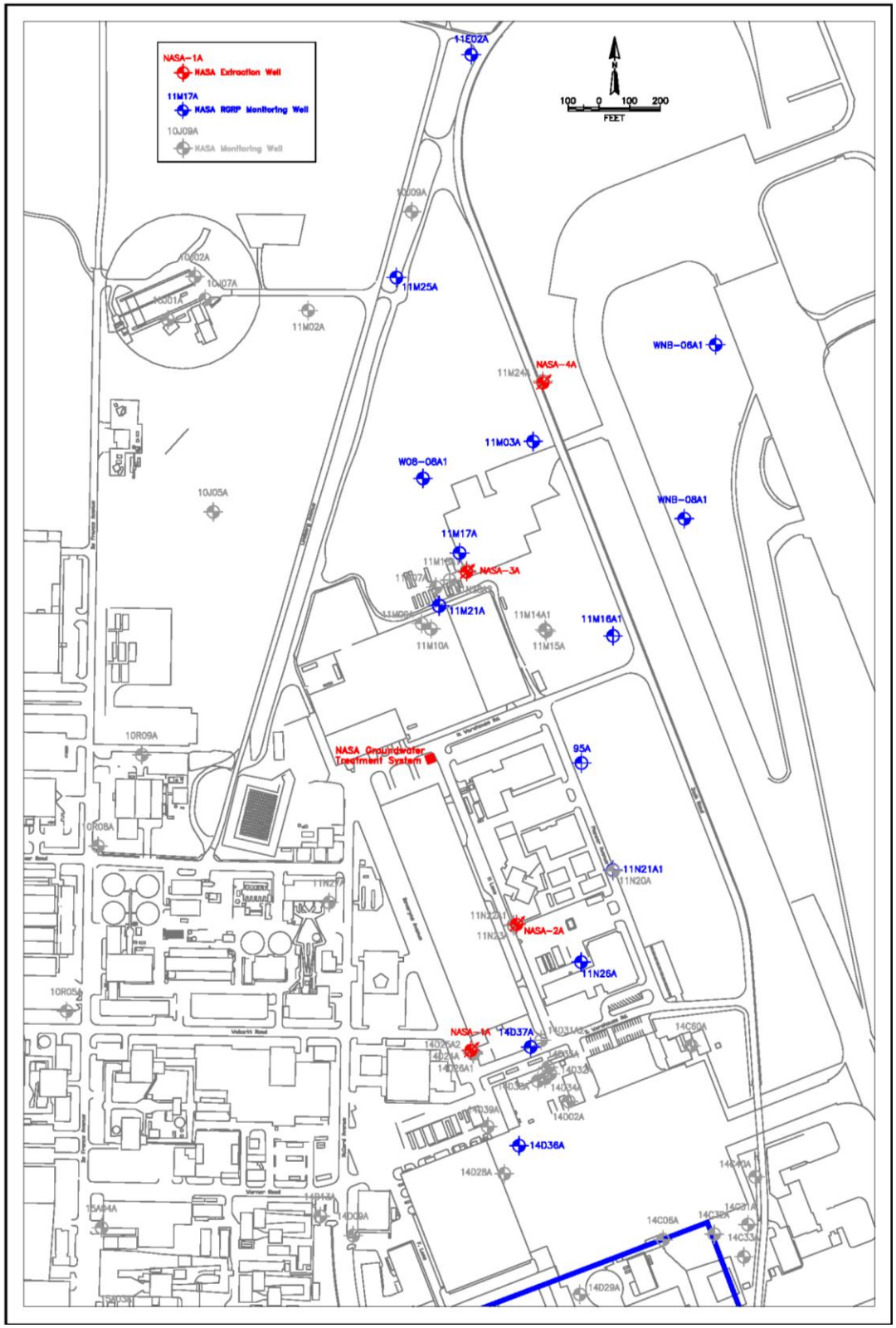


Figure 4
NASA Ames Monitoring and Extraction Well Locations

1.2. Remedy Description and Remedial Action Summary

In 1998, NASA entered into an "*Allocation and Settlement Agreement For Remedial Program Management Between NASA and Fairchild Semiconductor Corporation, Raytheon Company, and Intel Corporation*" (NASA, 1998). Under this Agreement, various geographical divisions of responsibility**,** chemicals of concern, and system design, installation, operations, and maintenance responsibilities were allocated between the parties. This Agreement pertained to the requirements established under the "*Record of Decision*" for the RGRP (EPA, 1989).

The locations selected for NASA's groundwater extraction wells were based on lithologic, chemical, and groundwater modeling data as presented in the 1995 EKI document "*Proposed Locations of NASA Ames Groundwater Extraction Wells in the VTOL Pad and South Navy Warehouse Areas*."

Final design calculations and details were provided in the 1999 Locus Technologies report "*100 Percent Design, NASA-ARC/RGRP Groundwater Treatment System*." For the basis of design, Locus used the 1995 EKI report and Smith Environmentals' "*Revised Final Design, Regional Ground Water Remediation Program, North of U.S. Highway 101, Middlefield-Ellis-Whisman Site*" (Smith, 1996).

The remedial objective of the NASA GWTS is to extract and treat the groundwater contaminants down-gradient of known and/or suspected sources located on NASA Ames and to fulfill NASA's portion of the RGRP. Two areas have been identified to address NASA's contribution to the Regional Plume.

NASA RGRP extraction wells NASA-1A and NASA-2A are located down-gradient from a suspected source area near building N240, north of building N211. Although historic soils data do not identify a source in local soils, historic groundwater data available during the time of the design phase for the "*North of US Highway 101 RGRP*" (Smith, 1996) indicated the presence of TCE in groundwater at concentrations above cleanup levels in this area. Wells NASA-1A and NASA-2A were installed in 2000 and groundwater extraction was initiated in late 2001.

NASA RGRP extraction wells NASA-3A and NASA-4A are located down-gradient from a known source area in the vicinity of Navy Site 8 North and NASA's Vertical Takeoff and Landing (VTOL) Pad. Historic information and data revealed contamination of both soil and groundwater in this area where drums of miscellaneous oils and solvents had previously been stored. Previous actions in this area included the removal of both contaminated soil (excavation and disposal) and groundwater (excavation pit dewatering, treatment, and discharge). Wells NASA-3A and NASA-4A were installed in 2000 and groundwater extraction began in late 2001.

To date, the NASA RGRP GWTS has functioned as designed, in that the GWTS appears to be capturing the majority of contaminated groundwater within the localized sand channels into which the extraction wells were installed.

1.3. Site Hydrogeology

NASA Ames lies at the northern end of the Santa Clara Valley along the southwestern rim of San Francisco Bay. The Santa Clara Valley is located between the Santa Cruz Mountains to the west and the Diablo Range to the east. The area is underlain by a sequence of Pliocene-Pleistocene and Upper Quaternary unconsolidated sediments up to 1,500 feet thick. Sediments underlying NASA Ames were derived from the Santa Cruz Mountains and deposited in alluvial, estuarine and sublittoral environments. Additionally, fine-grained sediments were transported by waters of the San Francisco Bay.

Underlying NASA Ames are alluvial or fluvial aquifers separated by lower permeability silts and clays. These aquifers are divided into two sequences based on the location of a laterally-extensive clayey layer which separates the shallower, unconfined or semi-confined sequence from the deeper, confined sequence. The shallower sequence consists of the “A” and “B” aquifers, while the lower sequence is comprised of the “C” and “Deep” aquifers. Groundwater is encountered at the site from 5 to 7 feet below ground surface (bgs). Groundwater generally flows to the northeast.

The “A” aquifer consists of stringer-like alluvial channel deposits composed of sand and gravel inter-bedded with fine-grained flood plain deposits. These channel deposits, oriented generally south to north, provide complex pathways for groundwater and contaminant transport. Although the degree of channel continuity is variable, the depositional environment of the A1 aquifer materials has been interpreted as a low-lying flood basin subject to periodic flooding events (PRC, 1997). The A1 aquifer extends from about 5 to 25 feet bgs. Most of NASA Ames groundwater monitoring wells have been installed to monitor contaminants in the A1 aquifer. A few wells have been screened in the deeper A2 aquifer, which generally extends from 30 to 50 feet bgs.

According to the “*West-Side Aquifer Treatment System, Long-Term Groundwater Monitoring Plan*” (PRC, 1997), the A1-zone is separated from the A2/B1-aquifer by a discontinuous, lower permeability horizon located between 25 and 30 feet bgs. Subsequent to deposition of these discontinuous aquitard materials, a cemented caliche horizon formed at the top of the aquitard that, in turn, provided increased resistance to future scouring flood events. The caliche zone marks the top of this horizon, and although it is not a hydraulic boundary, where present, it is useful in delineating the A1/A2 boundary.

Groundwater flow in the A1 aquifer is greatly affected by the presence of engineered structures in the subsurface (deep, gravel-filled pipe trenches; compacted, engineered fill; and building basements). At the northern edge of NASA Ames, the alluvial aquifers inter-finger with relatively impermeable marine and estuarine sediments that restrict groundwater flow towards San Francisco Bay. A schematic of the generalized depositional environment characteristic of the subsurface at NASA Ames is shown in Figure 5.

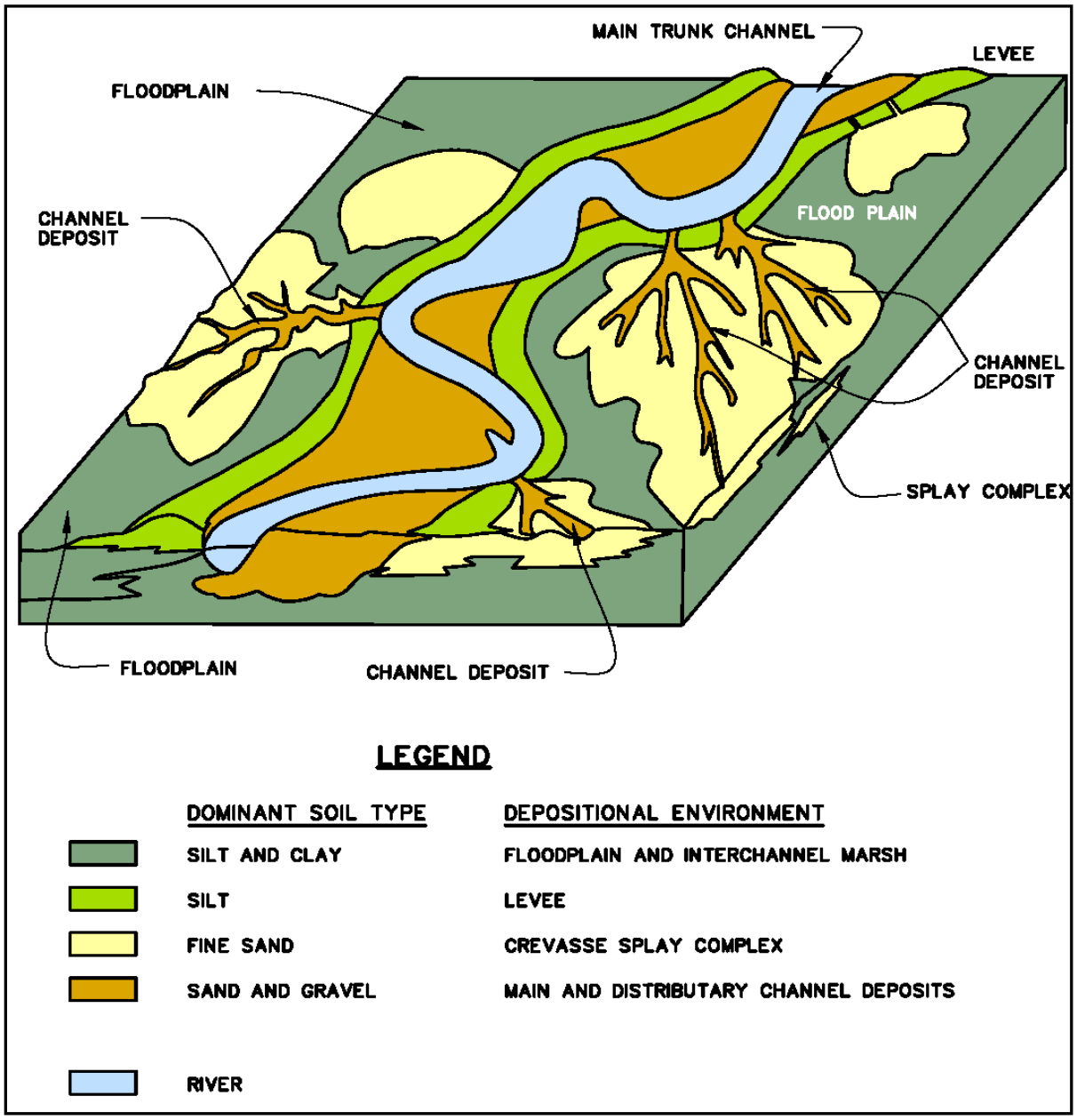


Figure 5
Generalized Depositional Environment

1.4. 2010 Site Activities and Deliverables Summary

Site activities associated with the RGRP conducted by NASA during 2010 are summarized in Table 2.

Table 2
2010 Site Activities and Deliverables Summary

Activity	Date
Continuing groundwater extraction and treatment	On-Going
Continuing routine system operations and maintenance	On-Going
Monthly GWTS NPDES Sampling	January 25, 2010
Quarter 4, 2009 NPDES Self-Monitoring Report	January 28, 2010
2009 Annual NPDES Self-Monitoring Report	January 28, 2010
Monthly GWTS NPDES sampling	February 25, 2010
Quarter 1 groundwater sampling	March 15-17, 2010
Monthly GWTS NPDES sampling	March 24, 2010
Regional depth-to-water gauging	March 25, 2010
Monthly GWTS NPDES sampling	April 21, 2010
Quarter 1 NPDES Self-Monitoring Report	April 26, 2010
Monthly GWTS NPDES sampling	May 25, 2010
Quarter 2 groundwater sampling	June 22-25, 2010
Monthly GWTS NPDES sampling	June 23, 2010
2009 Annual Report	May, 30,2010
Monthly GWTS NPDES sampling	July 22, 2010
Quarter 2 NPDES Self-Monitoring Report	August 4, 2010
NASA GWTS GAC replacement	August 9, 2010
Monthly GWTS NPDES sampling	August 24, 2010
Quarter 3 groundwater sampling	September 20-24, 2010
Monthly GWTS NPDES sampling	September 27, 2010
Monthly GWTS NPDES sampling	October 25, 2010
Quarter 3 NPDES Self-Monitoring Report	October 28, 2010
Regional depth-to-water gauging	November 18, 2010
Monthly GWTS NPDES sampling	November 22, 2010
Quarter 4 groundwater sampling	December 13-16, 2010
Monthly GWTS NPDES sampling	December 13, 2010

2.0 2010 REMEDIAL ACTION PROGRESS

This section provides a greater level of detail regarding NASA Ames RGRP GWTS related activities, performance and remedial progress. For reference purposes, a copy of the "*2010 Annual NPDES Self-Monitoring Report for the NASA Ames RGRP GWTS*" (ISSi, 2011) is attached as Appendix A. This report includes system configuration information, figures, and tables.

2.1. Remedial Action Objective

The remedial objective of the NASA Ames GWTS is to extract and treat contaminated groundwater down-gradient from known and/or suspected sources located at NASA Ames. The site VOC and TPH groundwater cleanup levels are shown in Table 3.

Table 3
Groundwater Cleanup Levels

Chemical	Cleanup Level (µg/L)
Volatile Organic Compounds[1]	
1,1-DCA	5.0
1,1-DCE	6.0
1,1,1-TCA	200
1,2-DCA	0.50
cis-1,2-DCE	6.0
trans-1,2-DCE	10
Chloroform	80
Freon 11	150
Freon 113	1,200
PCE	5.0
TCE	5.0
Vinyl Chloride	0.50
Petroleum Hydrocarbons	
Benzene[1]	1.0
Ethylbenzene[1]	300
Toluene[1]	150
Xylenes[1]	1,750
TPH-gasoline[2]	50
TPH-diesel[2]	700
TPH-jet fuel[2]	700
TPH-motor oil[3]	640

[1] Federal/State Drinking Water Maximum Contaminant Level
[2] PRC, 1994, Petroleum Sites Cleanup Level Analysis Technical Memorandum, NAS Moffett Field, CA
[3] DTSC, 2005, Comments on Draft AOI 8 Operation and Maintenance Summary Report

2.2. Groundwater Extraction and Treatment System Description and Performance

The NASA Ames GWTS is located at the corner of North Warehouse Road and H Lane (Figure 6). Quarterly and annual 2010 system Operations and Maintenance (O&M) reports were prepared in accordance with the Self-Monitoring Program reporting requirements contained in the National Pollutant Discharge Elimination System (NPDES) Permit Number CAG912003, Order R2-2009-0059, issued by the California Regional Water Quality Control Board to NASA on December 3, 2009.

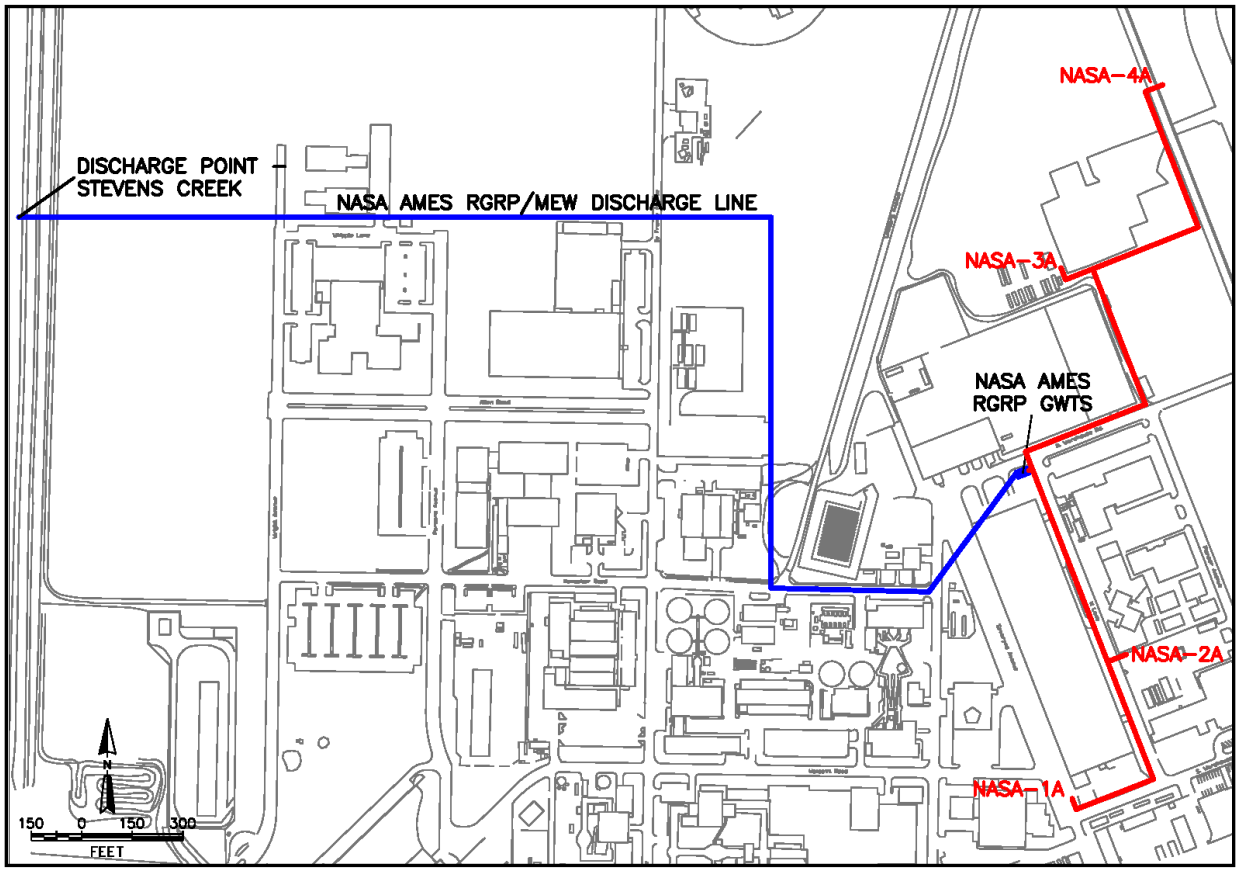


Figure 6
NASA Ames GWTS Location and Layout

2.2.1. System Description

Groundwater extracted from NASA extraction wells NASA-1A, NASA-2A, NASA-3A is pre-filtered by two 10-micron bag filters operating in parallel, prior to passing through two 5,000-pound granulated activated carbon vessels operating in series. Treated groundwater is then discharged to Stevens Creek in accordance with the NPDES permit. Figure 6 presents NASA's extraction wells and the discharge route to Stevens Creek. The construction of the NASA Ames GWTS was completed in August 2001 and started operations on September 10, 2001. Figure 7 shows the treatment process and influent (NASA-I) and effluent (NASA-E) sample points.

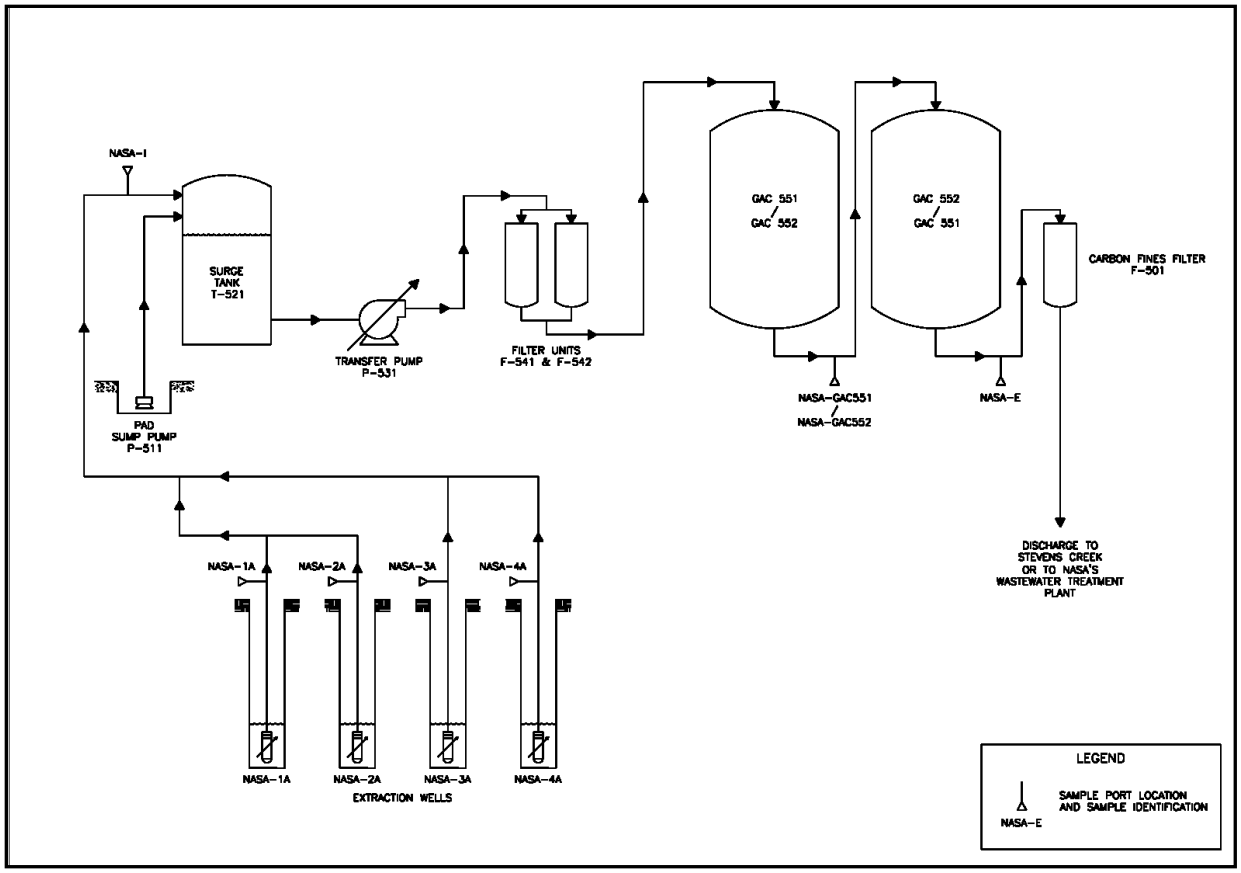


Figure 7
NASA Ames GWTS Treatment Process and Sample Points

2.2.2. NASA Extraction Well Pump Rates

During the 2010 reporting period, the pump rates were periodically adjusted. The designed pump rate for each extraction well is provided in Table 4. It is noted here that extraction well NASA-2A operates in a cyclical fashion due to slow recharge of the local aquifer (see Section 4.1.1 for further discussion). Average annual flow rates and total gallons extracted for 2010 are also summarized in Table 4.

Table 4
NASA Extraction Well Pump Rate Details

Well Number	Designed Pump Rate (gpm)	Average Annual Flow Rate (gpm)	Total Gallons Extracted in 2009[1]
NASA-1A	8.0	7.2	3,827,871
NASA-2A	3.0	0.2	135,377
NASA-3A	6.0	6.0	3,191,631
NASA-4A	3.0	0.3	167,326

1 note: values may not add up to total discharge volume due to meter differences

2.2.3 System Influent and Effluent Data

Table 3 of Appendix A summarizes the results of water quality analyses of influent and effluent water samples collected from the NASA Ames RGRP GWTS during 2010. Table 4 of Appendix A details the results of temperature, pH, and other water quality analyses conducted during 2010. The influent and effluent sample points are shown in Figure 7**.**

During 2010, the NASA Ames RGRP GWTS removed a total of 4.55 pounds of total VOCs from 7,852,577 gallons of groundwater. The average flow rate into the system was 14.9 gpm. The monthly influent VOC concentrations for selected chemicals are presented in Figure 8. Figure 9 presents the monthly effluent flow for 2010. Figure 10 presents the monthly total VOC and TCE mass removal information for 2010.

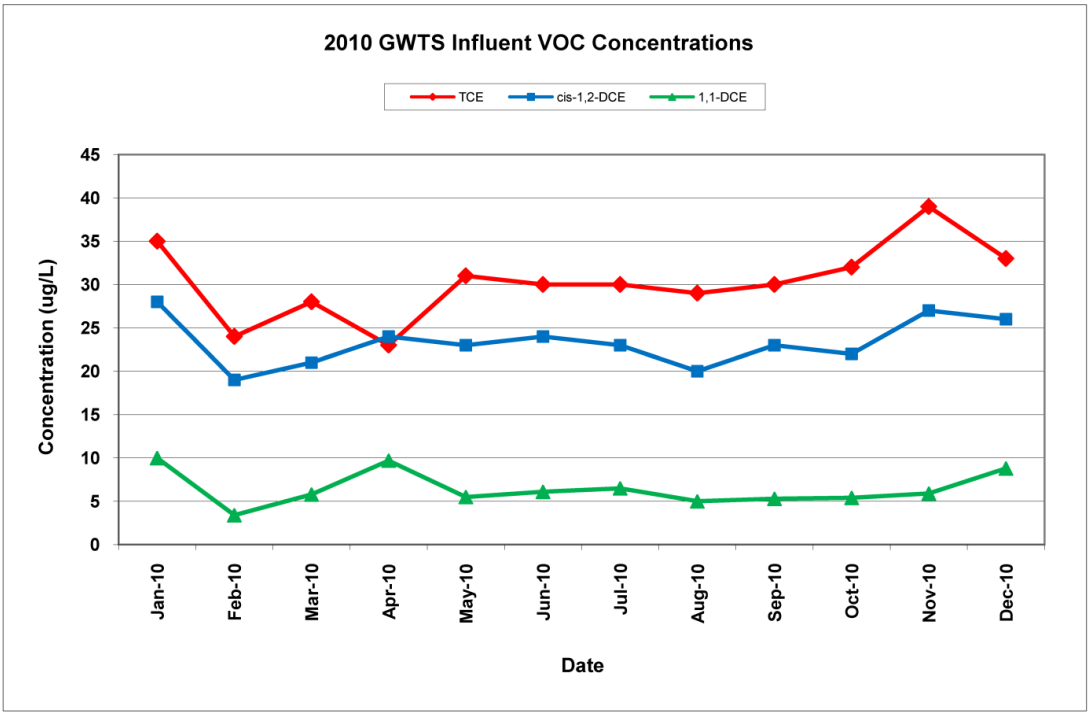


Figure 8
NASA Ames GWTS Monthly Influent VOC Concentrations

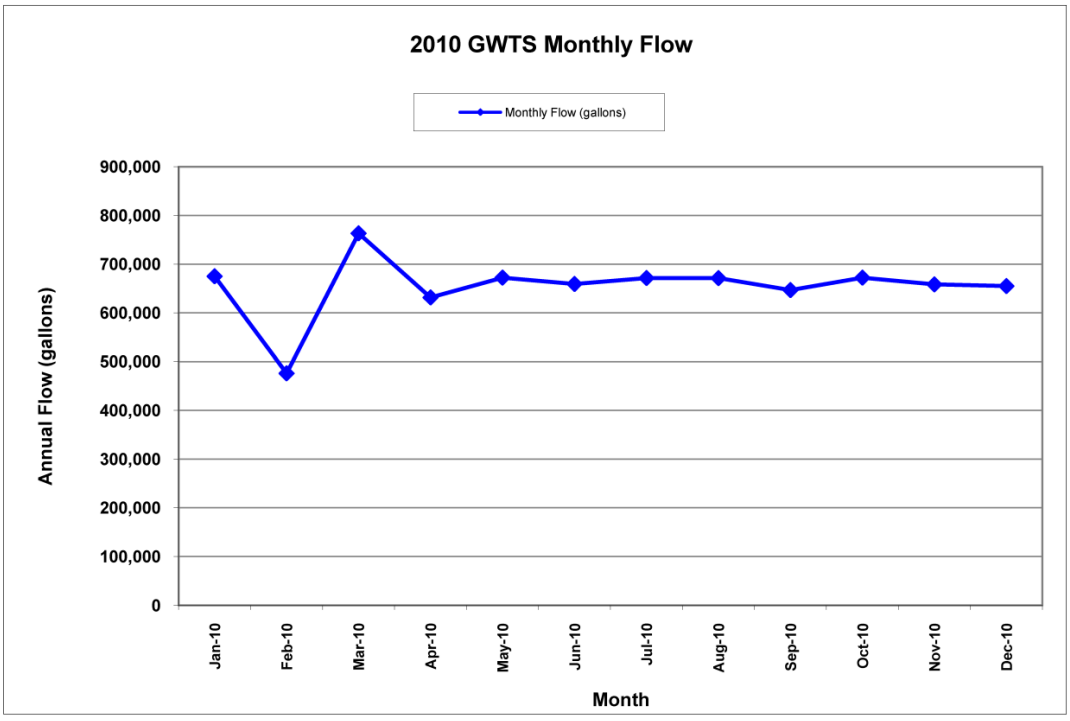


Figure 9
2010 NASA Ames GWTS Monthly Groundwater Extraction

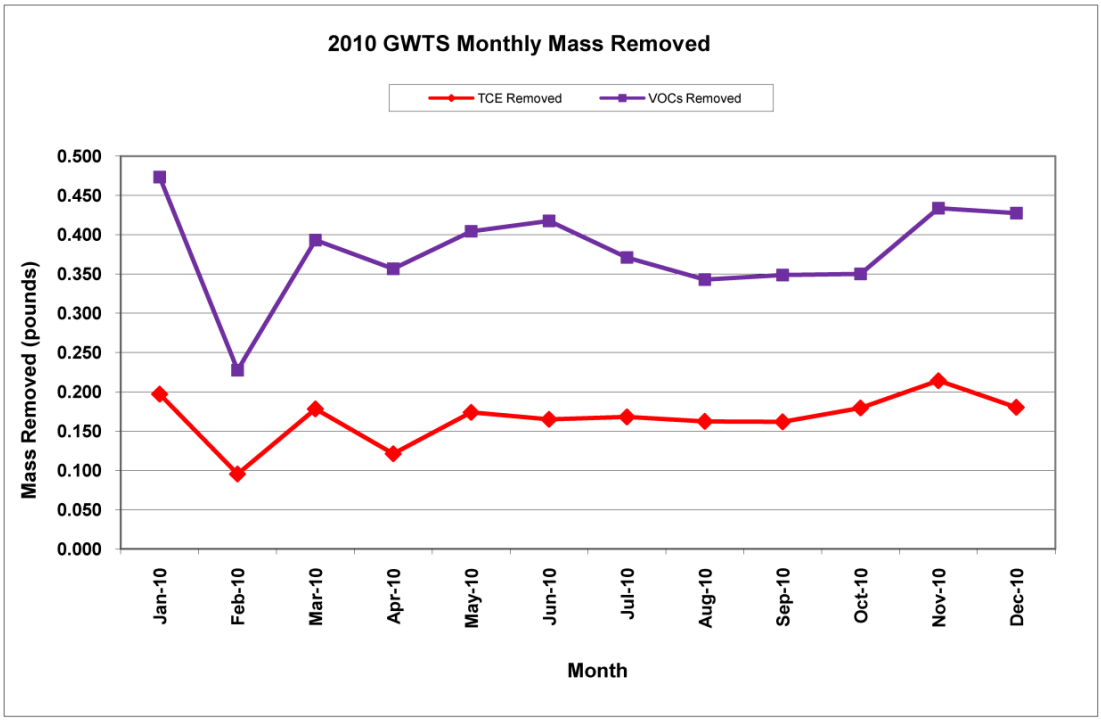


Figure 10
2010 NASA Ames GWTS Monthly Mass Removed

2.2.4. System Performance

The NASA Ames GWTS was fully operational for 92% of calendar year 2010 and partially operational (at least one extraction well operating) for 99% of the year.

During 2010, the NASA Ames GWTS experienced several automatic system-wide shutdowns. These automatic system-wide shutdowns resulted from problems with electrical systems and/or power disruptions. Dates and durations of these shutdowns are detailed below in Table 5.

Table 5
2010 NASA Ames GWTS
System Shutdown Data

Date(s)	Duration (hours)	Cause
1/28/10	10	Electrical Problem (NASA-1A only)
1/30/10 – 2/1/10	43	Electrical Problem (NASA-1A only)
2/4/10 – 2/7/10	63	Electrical Problem (NASA-1A only)
2/7/10 – 2/8/10	33	Electrical Problem
2/10/10 – 2/12/10	20	Electrical Problem (NASA-1A only)
2/14/10 – 3/22/10	426	Unknown Electrical Problem (NASA-3A only)
2/15/10 – 2/16/10	29	Electrical Problem
2/23/10	6	Electrical Problem
3/7/10	7	Electrical Problem
4/7/10	7	Electrical Problem (NASA-1A only)
4/8/10	1	Electrical Problem
4/12/10 – 4/13/10	22	Electrical Problem (NASA-3A only)
4/20/10	2	Electrical Problem (NASA-1A only)
4/21/10 – 4/22/10	15	Electrical Problem (NASA-1A only)
4/30/10	2	Electrical Problem (NASA-1A only)
5/10/10 – 5/11/10	13	Electrical Problem (NASA-1A only)
10/8/10	5	Electrical Problem (NASA-1A only)
10/21/10	5	Electrical Problem (NASA-1A only)
12/11/10	44	Electrical Power Disruption to GWTS

2.2.5. System Operations and Maintenance

During 2010, the NASA Ames RGRP GWTS treated influent groundwater as designed.

2.2.5.1. Suspension of Pumping at NASA-2A and NASA-4A

On April 28, 2009, after discussions with the US EPA and California Regional Water Quality Control Board, NASA suspended operation of extraction wells NASA-2A and NASA-4A. As discussed in NASA's "*2008 Draft Regional Groundwater Remediation Program Progress Report,*" the performance of these wells had been less than designed and anticipated. In addition, groundwater extracted from NASA-4A had been below cleanup levels.

The extraction rates from wells NASA-1A and NASA-3A were adjusted to maintain NASA's 15 gallons per minute (gpm) discharge limit. NASA-1A is currently operating at 7.5 gpm and NASA-3A is operating at 6.5 gpm. Wells NASA-2A and NASA-4A are turned on periodically to maintain operability.

2.2.5.2. Carbon Replacement

On August 9, 2010, the granulated activated carbon (GAC) within vessel GAC-551 was replaced. Vessel GAC-551 served as the secondary GAC vessel from September 30, 2008 to August 6, 2009 (10 months of service) and served as the primary GAC vessel from August 6, 2009 to August 9, 2010 (12 months of service). No system shutdown was required during the carbon replacement.

2.3. Hydraulic Control and Capture Zone Analyses

The following sections describe how the capture zones for the NASA Ames GWTS area were estimated and discuss the effectiveness of the capture zones. Capture zones have been estimated for NASA's four extraction wells using flow net analyses of March 25 and November 18, 2010 groundwater elevation data and potentiometric surfaces in the A1 aquifer. The four NASA Ames extraction wells are completed in the A1 aquifer; therefore, the following sections are relative only to the A1 aquifer.

2.3.1. Analysis Methodology

The capture zone of an extraction well may be interpreted graphically from the shape of the potentiometric surface. The shape of the potentiometric surface is influenced by many factors, especially the extraction well zone of influence, aquifer/aquitard heterogeneities, geologic materials, and discharge/recharge boundaries.

The use of the flow-net analysis methodology is considered most appropriate for estimating capture zones at NASA Ames. The flow net analysis method provides a simple graphical solution that reflects site-specific aquifer heterogeneities and hydraulic interference effects from other extraction wells that cannot be incorporated into an analytical estimate of capture zones without the development of an extensive groundwater model (which also involves making assumptions for geologic and hydrogeologic variables). The limitation of using flow-net analysis is that groundwater and contaminant transport through preferential pathways and "channelized" groundwater flow is not adequately reflected (e.g. effects may be minimized). The graphical depictions of capture zones for the March 25 and November 18, 2010 gauging events are provided in Section 2.3.2.3.

2.3.2. Estimated 2010 Capture Zones

2.3.2.1. Step 1 – Review Site Data, Conceptual Model, Remedial Objectives

The evaluation of the NASA Ames GWTS is based on the following site data reviews:

- Water level data
- Chemical concentrations
- Mass of VOCs removed
- Extent of dissolved chemicals of concern (COCs) exceeding cleanup standards
- Hydraulic capture and control of plumes
- Groundwater balance in extraction well capture zones
- Treatment system effectiveness and efficiency in removing COCs from extracted groundwater

2.3.2.2. Step 2 – Define Site-Specific Target Capture Zones

The NASA Ames GWTS was designed to address two areas that were discussed in the "*Proposed Locations of NASA Ames Groundwater Extraction Wells in the VTOL Pad and South Navy Warehouse Areas*" (EKI, 1995). The first area of concern is located south of the former Navy Warehouse (building N144), between buildings N240 and N259. Although no soil source area was identified, a suspected source area of TCE groundwater contamination was identified in the A1 aquifer during groundwater investigations conducted in 1994. The suspected source area is shown in Figure 11. NASA extraction wells NASA-1A and NASA-2A were installed in the A1 aquifer to address this area. Although the installation of NASA-2A was initially designed to be dependent on the performance of NASA-1A (EKI, 1995), NASA decided to install and operate it concurrent with NASA-1A.

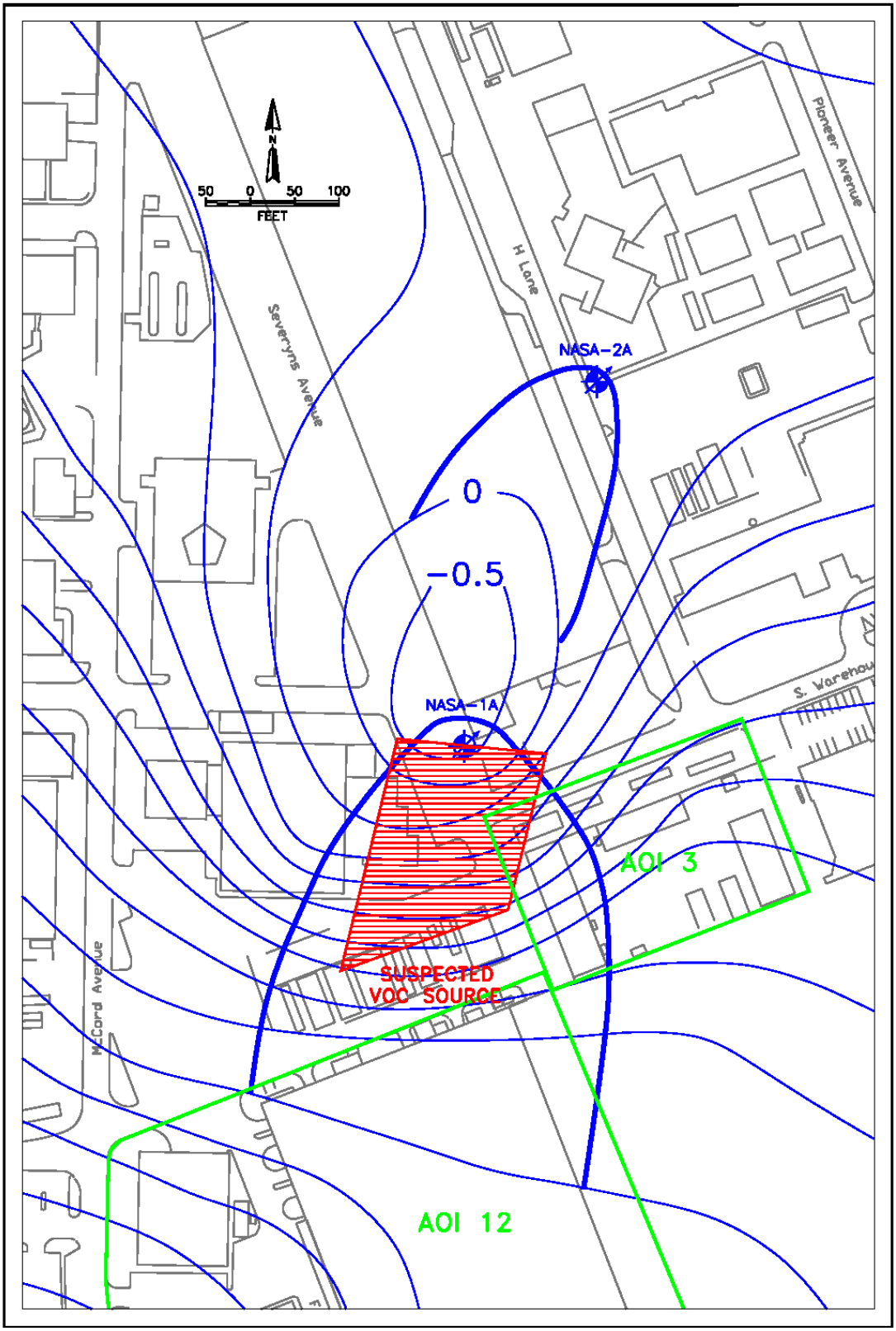


Figure 11
Suspected Source Area, Former Navy Warehouse Area

The second area of concern is located down-gradient of Navy Site 8 North, near the southwest corner of the Vertical Take-Off and Landing (VTOL) pad. According to the "*Center-Wide Sampling and Analysis Program, Volume VII: Work Plan for Area of Investigation 7*" (EKI, 1994b), "…the source for the chemicals present in the area north of the Navy Storage Yard [Navy IRP Site 8] is likely to be the Navy storage yard. However, NASA indicated to EKI that NASA has assumed responsibility for the characterization and remediation, if needed, of this area…" In 1994, NASA removed solvent-contaminated soil exceeding cleanup levels by excavating over 3,000 cubic yards of soil ("*Site 8-North Soil Excavation & Source Removal*" (NASA, 1994). The area of excavation is shown on Figure 12. NASA extraction wells NASA-3A and NASA-4A were installed in the A1 aquifer to address residual groundwater contamination down-gradient of this area. Although the installation of NASA-4A was initially designed to be dependent on the performance of NASA-3A (EKI, 1995), NASA decided to install and operate it concurrent with NASA-3A.

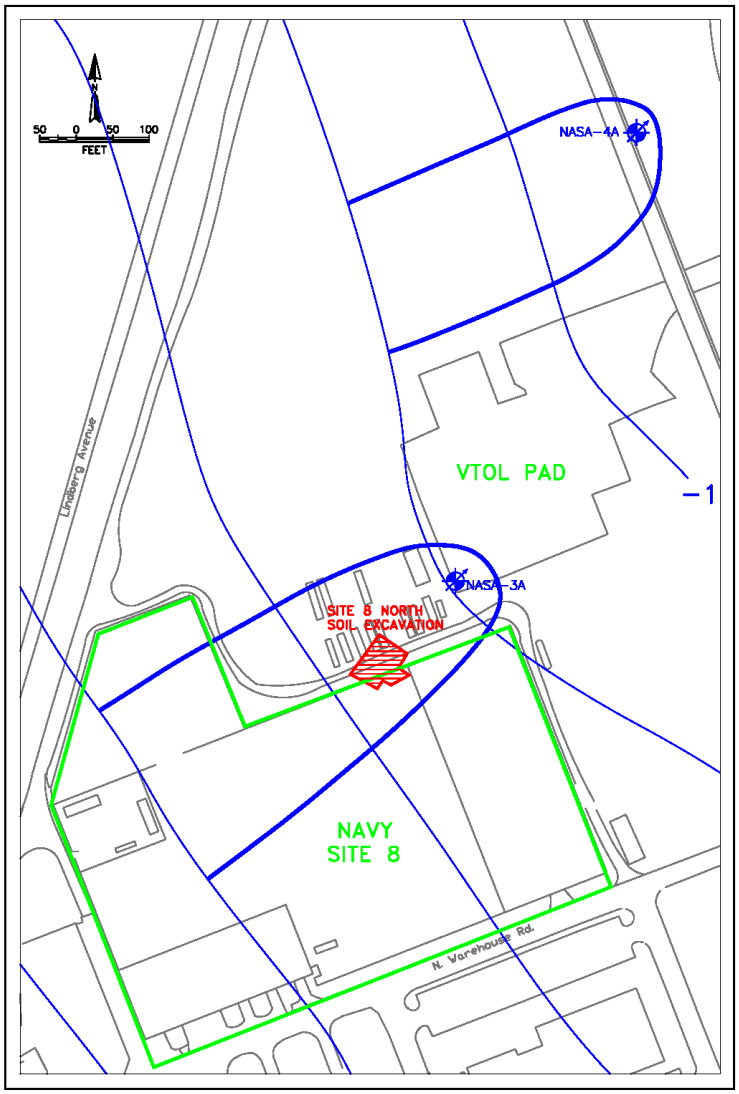


Figure 12
Navy Site 8 North/VTOL Pad, Removed Source Area

2.3.2.3. Step 3 – Interpret Water Levels

NASA, the Navy and the MEW companies collect semi-annual groundwater elevation data on a pre-arranged day. Depth-to-water measurements were recorded for NASA Ames monitoring wells in the A1 aquifer as part of the MEW site data exchange program. Depth-to-water measurements were collected on March 25 and November 18, 2010 and are included in Appendix B. These data were used to generate groundwater elevation contour maps of the A1 aquifer (see Horizontal and Vertical Gradients Section below). The maps were generated using AutoCAD and contoured using GIS\Key Solutions with QuickSurf v. 5 using the following settings: Grid-Standard, Derivative-None, Blend Order-First, Weighting-Honor Local Extrema.

Hydrographs

Hydrographs were prepared from the groundwater elevation data to aid in the evaluation of local and site-specific trends and to illustrate the hydraulic impact of groundwater extraction. The hydrographs are included in Appendix C. Well selections were based on monitoring well location (relation to plume and proximity to extraction wells) and completeness of data. Groundwater elevation measurements for some wells (outliers) were not used in the generation of some hydrographs. These wells were excluded due to miss-measurement, incorrect well identification, and close spacing with adjacent monitoring wells completed at similar depths.

All of the A1 aquifer monitoring wells exhibit seasonal groundwater elevation trends. During the wet season (November 2009 through March 2010), groundwater levels rose an average of 1.37 feet, ranging from 0.45 feet to 2.10 feet. During the dry season (March 2010 through November 2010), groundwater levels dropped an average of 1.26 feet, ranging from 0.49 feet to 2.36 feet. Overall, groundwater levels rose an average of 0.11 feet from 2009 to 2010.

All of the hydrographs for the wells show a slight rise in groundwater elevations from the early 1990s until the initiation of groundwater extraction by the Navy and MEW Companies beginning in 1998. NASA groundwater monitoring wells in the vicinity of the Navy's WATS area and the MEW RGRP area demonstrated a decline in groundwater elevation beginning in December 1998, most likely attributable to extraction well operation. Figure 13 illustrates the hydrogeologic response in well 14D12A, which is located approximately 15 feet up-gradient of MEW extraction well REG-6A. Depressed water levels have persisted in these wells, although a gradual rise in water levels is occurring. The decline in groundwater elevation is greatest in the wells closest to the extraction wells and decreases with distance from the extraction wells. The declines in groundwater levels in the distal monitoring wells is most likely due to a general lowering of the local water table caused by the pumping of extraction wells.

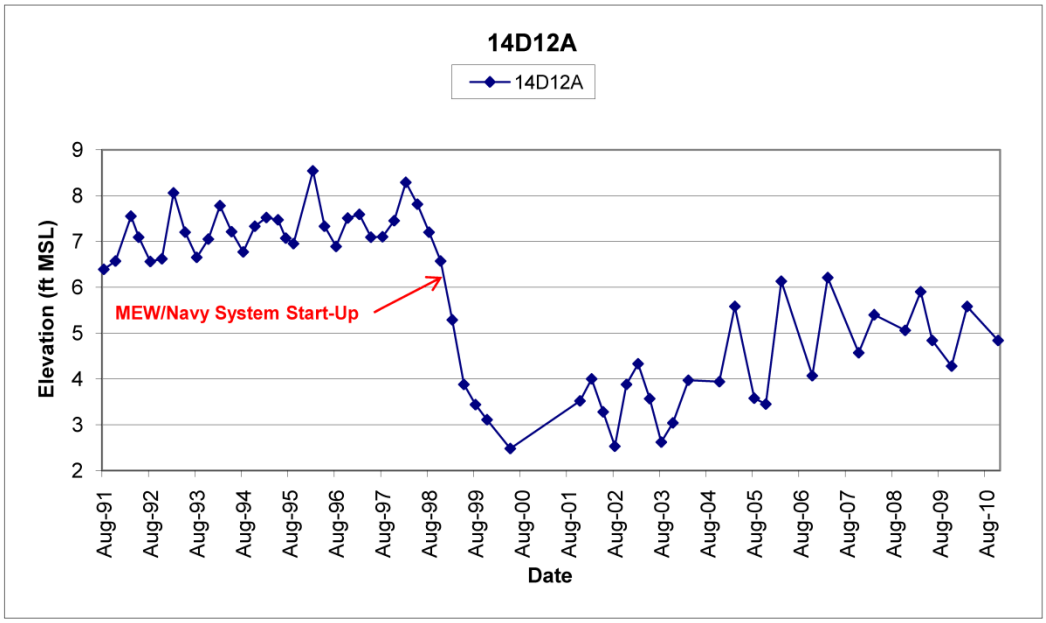


Figure 13
Hydrograph of Well 14D12A

A similar observation was noted in the vicinity of NASA's four extraction wells, coinciding with the initiation of NASA groundwater extraction in September 2001. A water level decline of 2.5 feet occurred near NASA-1A. Figure 14 illustrates the hydrogeologic response in well 14D26A1, which is located approximately 10 feet up-gradient of NASA extraction well NASA-1A.

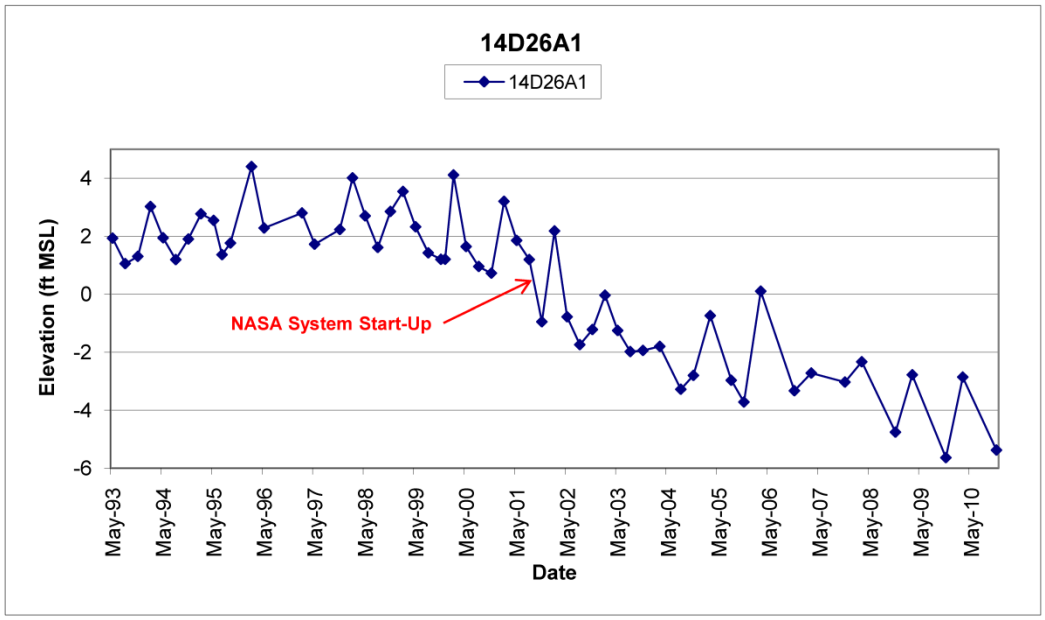


Figure 14
Hydrograph of Well 14D26A1

Horizontal and Vertical Gradients

Depth-to-water measurements collected on March 25 and November 18, 2010 (Appendix B) were used to monitor local and regional groundwater gradients and to generate groundwater elevation contour maps of the A1 aquifer (Figures 15 and 18, respectively). The following sections provide a discussion of the groundwater gradients estimated for each gauging event.

Quarter 1, 2010

A groundwater elevation contour map was generated from water levels measured on March 25 and is shown on Figure 15. Groundwater generally flows north to northeast, toward San Francisco Bay. During Quarter 1, 2010, the average horizontal gradient was approximately 0.0027 feet/foot (ft/ft). The groundwater gradient in the southern portion of NASA Ames (south of Hunsaker Road) was approximately 0.0050 ft/ft, while the average gradient in the northern portion was approximately 0.0015 ft/ft.

Vertical gradients between the A1 aquifer and A2 aquifer were determined using the March 25 groundwater elevation data (Appendix B). Wells located within eight horizontal feet of each other are considered a pair. In the eastern portion of NASA Ames, a local upward groundwater gradient of 6.00 feet exists between the A2 aquifer and the A1 aquifer (well pair 14D25A2/14D26A1). This well pair is located within 10 feet of extraction well NASA-1A (Figure 15). The relationship between well 14D25A2, 14D26A1, and the A1/A2 boundary is illustrated in Figure 16. Prior to groundwater extraction, this well pair indicated a local upward gradient of about 1.0 feet. The upward vertical gradient of 6.00 feet means that the water level in well 14D25A2 is 6.00 feet higher than the water level in well 14D26A1. This observed upward vertical gradient indicates that at this location groundwater from the lower A2 aquifer would prefer to be at a higher elevation. However, because of the low vertical hydraulic conductivity of the clay materials comprising the A1/A2 aquitard and its thickness, upward vertical flow can be regarded as negligible. Figure 17 shows that while well 14D26A1 experienced a noticeable response to initiation of pumping, well 14D25A2 exhibited little response.

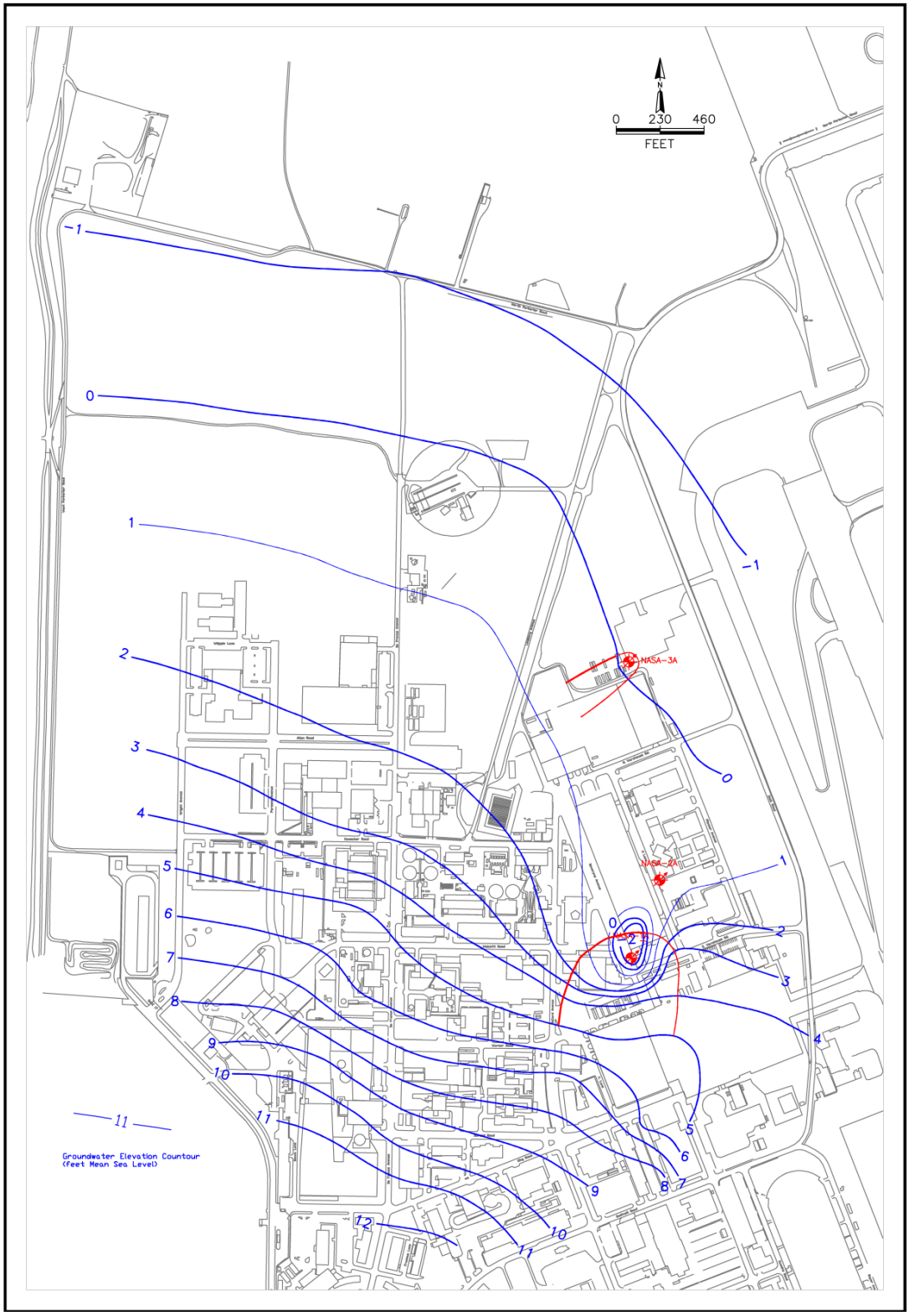


Figure 15
Groundwater Elevation Contours and Capture Zones
March 25, 2010

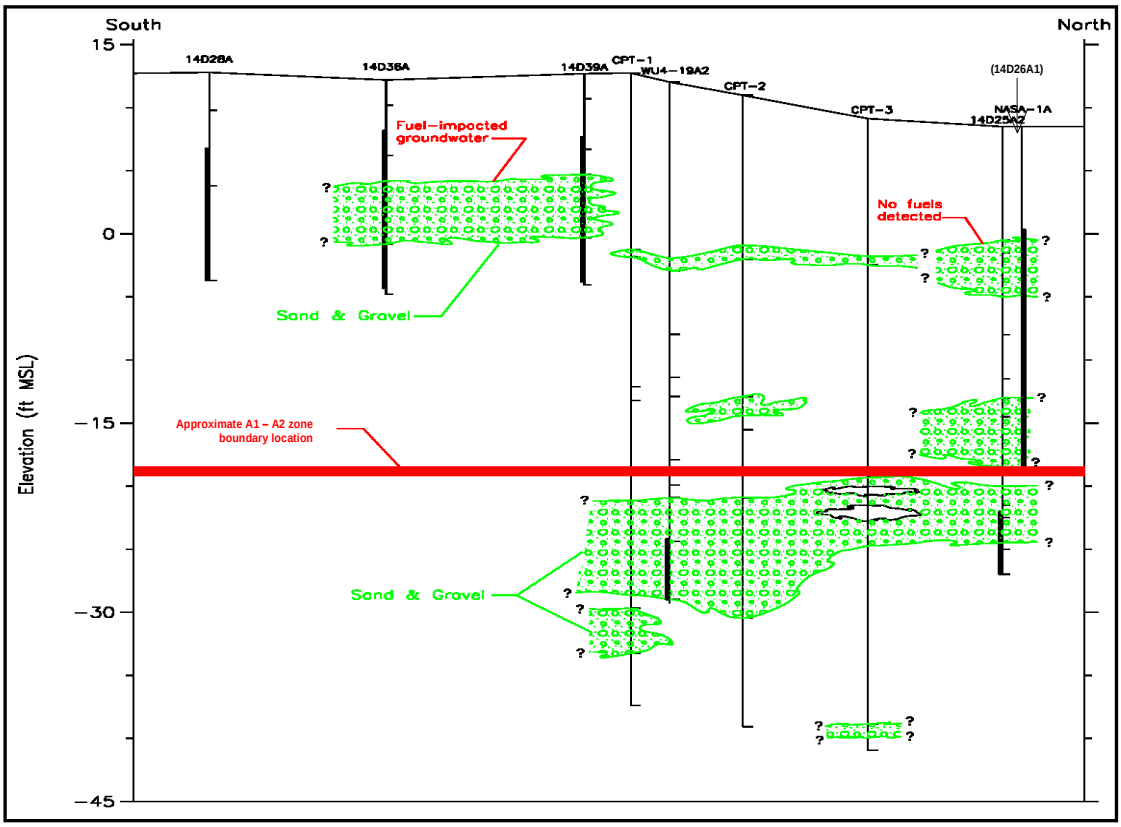


Figure 16
Geologic Cross Section near Extraction Well NASA-1A

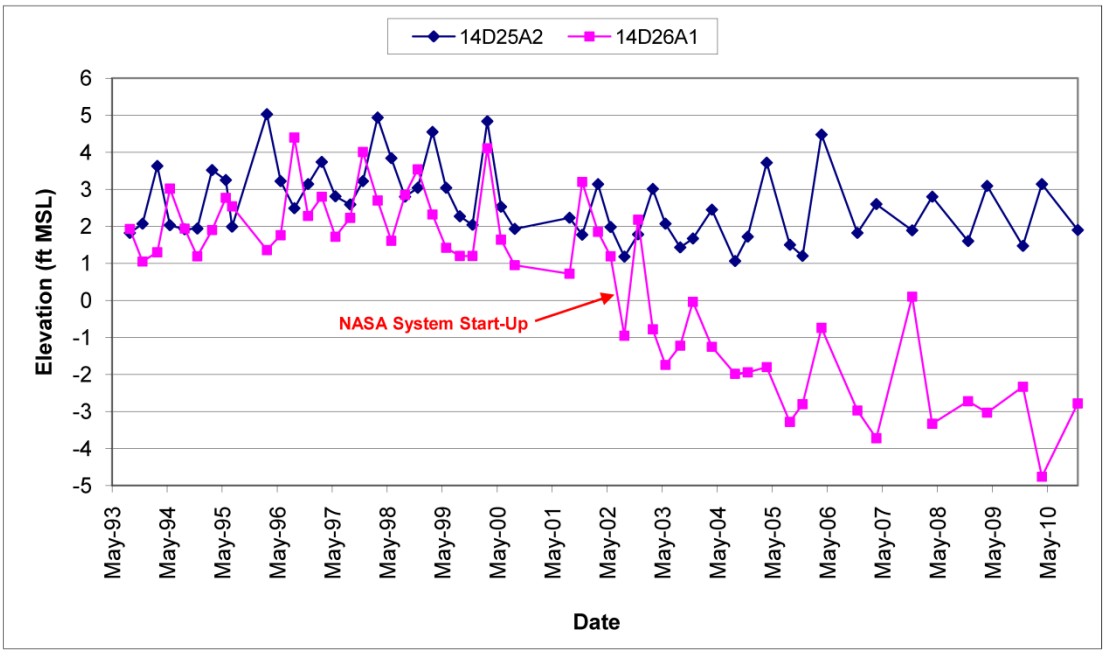


Figure 17
Hydrograph of Wells 14D25A2 and 14D26A1

Quarter 4, 2010

A groundwater elevation contour map was generated from water levels measured on November 18 and is shown on Figure 18. Based on information obtained during the Quarter 4, 2010 monitoring event, groundwater generally flowed north to northeast toward the San Francisco Bay at an average horizontal gradient of approximately 0.0024 ft/ft. However, along the western edge of the site, the groundwater flow direction changed to a more northerly orientation. During this quarter, the groundwater gradient in the southern portion of NASA Ames was approximately 0.0054 ft/ft, while the average gradient in the northern portion was approximately 0.0015 ft/ft.

Vertical gradients between the A1 aquifer and A2 aquifer were determined using the November 18 groundwater elevation data (Appendix B). In the eastern portion of NASA Ames, a local upward groundwater gradient of 7.29 ft/ft exists between the A2 aquifer and the A1 aquifer (well pair 14D25A2/14D26A1).

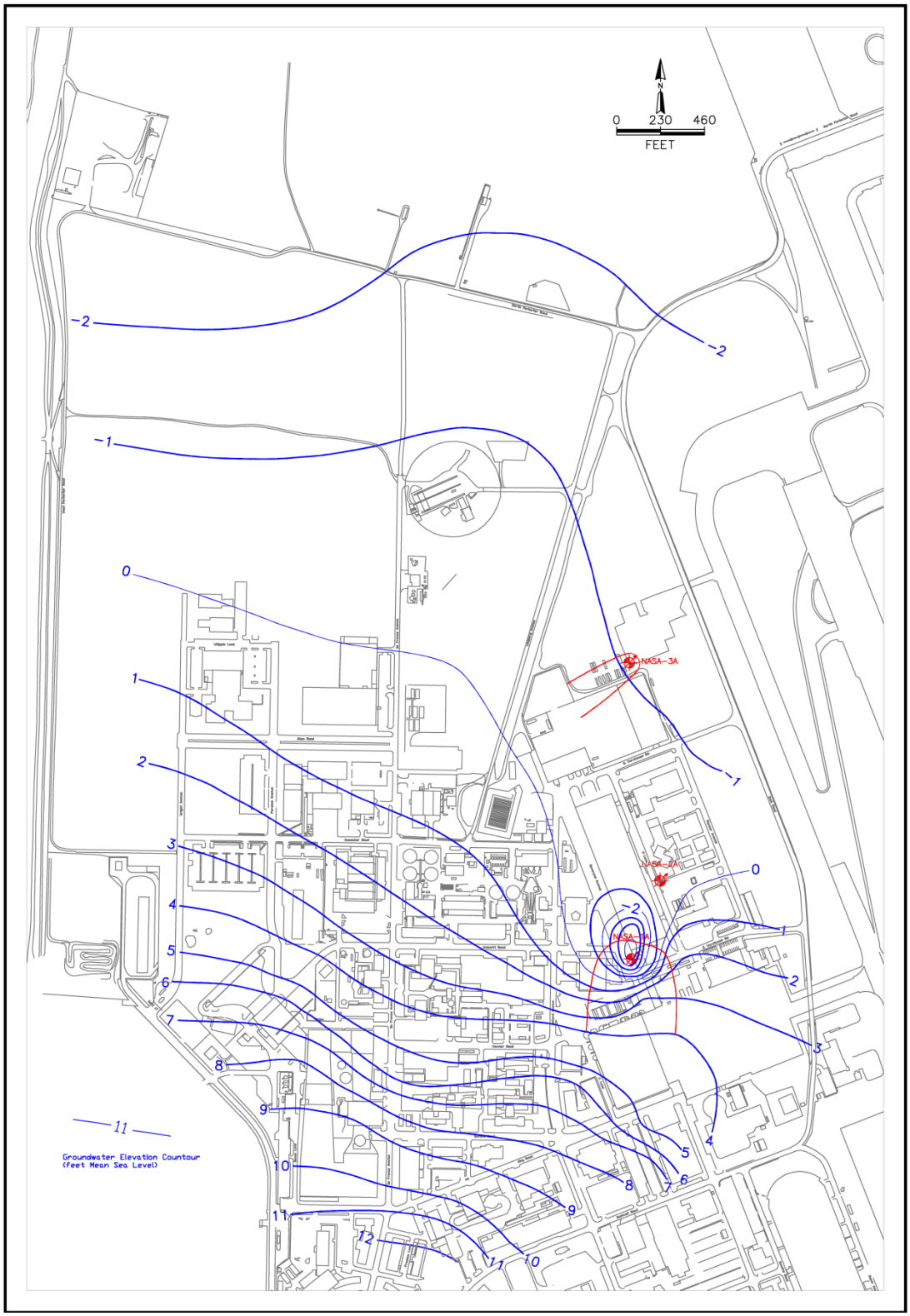


Figure 18
Groundwater Elevation Contours and Capture Zones
November 18, 2010

2.3.2.4. Step 4 – Perform Appropriate Calculations

A horizontal capture zone analysis was completed for the NASA GWTS area to estimate the pumping rates required for capture based on groundwater flow through the mapped plume extent. Flow budget calculations were completed for effectiveness evaluation of the system as originally designed (EKI, 1995) and also relative to capture of the Regional Plume component on NASA Ames.

Data values used for completion of the flow budget calculations were selected from *"Proposed Locations of NASA Ames Groundwater Extractions Wells in the VTOL Pad and South Navy Warehouse Areas"* (EKI, 1995) for the "Designed" component of the calculations, and from the 2010 NASA Ames groundwater data (included in this report) for the "Regional" component of the calculations. The system effectiveness evaluations for NASA-1A and NASA-3A are presented in the following Table 6, while the flow budget calculations are included as Appendix D. Since NASA-2A and NASA-4A were originally proposed as potential "contingent" wells only (EKI 1995), flow budget calculations were not completed for these wells.

A simple horizontal capture zone analyses method was used to complete the NASA GWTS flow budget calculations and is based on the following formula where **Q** = (**K**) x (**b** x **w**) x ***i*** x **factor** (Q = well extraction rate; K = aquifer hydraulic conductivity; b = aquifer saturated thickness; w = plume width; ***i*** = regional hydraulic gradient; and factor **=** "rule of thumb" is 1.5 to 2.0, intended to account for other contributions to the pumping well, such as induced vertical flow from another unit).

As shown in the Appendix D flow budget calculations, data values selected for use in the calculations are from the original system "Designed" document (EKI, 1995) or from the 2010 NASA Ames groundwater data presented in this report. When reviewing the "Designed" portion of the calculations, it is noted here that the hydraulic conductivity "**K**" is 300 ft/day for NASA-1A and 250 ft/day for NASA-3A. The lower "**K**" value for NASA-3A is based on the extraction well location within the "distal", finer grained portion of the depositional system compared to the more "central", coarser grained, up-gradient location of the NASA-1A extraction well. The plume width "**w**" for the "Designed" component is based on the width of the hydraulically conductive aquifer materials located at the two extractions wells, NASA-1A (see Figure 19) and NASA-3A (see Figure 23), not the originally modeled "capture zones," which included adjacent sediments with low to no hydraulic conductivity.

When reviewing the "Regional" portion of the calculations, it is noted here that the hydraulic conductivity "**K**" is 150 ft/day for NASA-1A and 130 ft/day for NASA-3A. The lower "**K**" value for NASA-3A verses NASA-1A "Regional" component is based on the same premise as for the "Designed" component, the "distal" location of NASA-3A extraction well. The "**K**" values for the "Regional" calculations are also lower based on "actual" well pumping data for each well area and not the "model" hydraulic conductivities (EKI, 1995). The plume width "**w**" for the "Regional" component is based on the width of the 5 µg/L TCE contour line near the two extractions wells (see Figure 26).

A “contribution” factor or “**f**” value of 1.5 was selected for both “Designed” and “Regional” calculations based on potential contribution to groundwater from the underlying aquifer materials, plus seasonal rainwater, site surface watering, and storm-drain system “leakage” in the extraction well area.

As shown in Table 6**,** the system pumping rates exceeded the calculated flow budgets in the A1 aquifer when evaluating the system effectiveness relative to the sand channels into which the extraction wells were installed. However, as also shown in Table 6, the system pumping rates were inadequate when compared to the flow budgets of the Regional Plume. This would indicate, as stated in the EPA Five-Year Review, that the Regional Plume in this area is not being completely captured by any of the three existing onsite groundwater treatment systems (EPA, 2004).

Table 6
Flow Budget Calculations

Capture Zone Calculations and Analysis
NASA RGRP GWTS, Moffett Field, California

A1 Aquifer	Designed		Regional	
Well	**NASA-1A**	**NASA-3A**	**NASA-1A**	**NASA-3A**
K	300 ft/day	250 ft/day	150 ft/day	130 ft/day
b	10 ft.	11 ft.	18 ft.	20 ft.
w	120 ft	175	411 ft.	850 ft.
I	0.002	0.0014	0.0049	0.0015
factor	1.5	1.5	1.5	1.5
flow budget (gpm)	5.61 gpm	5.25 gpm	42.3 gpm	25.8 gpm
Well pumping rate (gpm)	8 gpm	6 gpm	7.2 gpm	6.0 gpm

(see Notes below table)

LINE OF EVIDENCE	IS CAPTURE SUFFICIENT?		COMMENTS
Water Levels	***Designed***	***Regional***	
Potentiometric surface maps	Yes	No	Potentiometric maps indicate horizontal capture is present at NASA-1A. Regional Plume not fully captured.
water level pairs	Yes at -1A No at other 3 (-2A &-3A)	No	Potentiometric maps and low gpm at NASA-2A indicate non-capture. No significant draw-down at NASA-3A.
Calculations flow budgets	Yes	No	Current pumping rates sufficient for capture based on system design criteria. Flow budget calculations indicate lack of Regional Plume capture (see Note #2).
Concentration Trends downgradient monitoring wells	No	No	NASA-3A extraction appears sufficient to capture the "channelized" plume from Site 8 North/VTOL Pad area; No appreciable decrease in down-gradient wells. NASA GWTS area effected by Regional Plume.

Note #1: The flow budget calculations for NASA-1A and NASA-3A are presented in Appendix D
"Designed" values from EKI 1995 Report. "Regional" values from 2010 NASA groundwater data, unless otherwise stated.

Note #2: "Designed" plume width based on hydraulically conductive aquifer material at extraction well (EKI 1995).
"Regional" plume width based on 5.0 ug/l TCE contour (2010 TCE Plume Map).

Note #3: The NASA RGRP GWTS was originally designed to capture local and "suspected" source areas located on NASA Ames but not the Regional Plume. Therefore, the "Regional" component of the flow budget calculations is not applicable to the NASA GWTS performance.

Note # 4: Since NASA-2A was originally proposed as potential "contingent" wells only (EKI 1995), flow budget calculations were not completed for these wells.

2.3.2.5. Step 5 - Concentration Trends at monitoring wells

TCE, *cis*-1,2-DCE, and vinyl chloride are the major VOCs of concern in site groundwater. A more detailed discussion of these three groundwater contaminants is included in Section 2.4.1. In general, TCE concentrations have been decreasing at NASA extraction well NASA-1A and NASA-3A, and have become relatively stable at NASA-2A. C*is*-1,2-DCE concentrations have been decreasing in wells NASA-1A, NASA-2A, and NASA-3A. At the two NASA extraction wells that contain vinyl chloride (NASA-1A and NASA-2A), concentrations of vinyl chloride are decreasing.

2.3.2.6. Step 6 – Interpret Actual Capture

The water levels in the extraction wells were not used to calculate/map groundwater capture zones due to possible cascading effect of groundwater within the well casing possible differential effects due to formation verses filter-pack permeability, and/or pump cycling due to aquifer recharge limitations. These conditions might indicate a greater interpreted draw-down than truly exists at the extraction well location.

To best illustrate the hydrogeology that controls the performance of the NASA GWTS extraction wells, the “Distribution of Sand and Gravel Thickness” maps from the 1995 EKI system design document are included as Figures 19 and 23. As shown on these figures, there appears to be depositional trends where relatively permeable sandy and gravelly sediments were deposited adjacent to silty and clayey sediments. Based upon the thicknesses and distributions of these differing sediment types, especially the linear-like nature of the thicker sandy, gravely sediment trends, these sediments were most likely deposited originally by localized stream or “channelized” flow. It is assumed that there is an appreciable amount of inter-connection among the sand and gravel deposits within a channel boundary.

NASA-1A Extraction Well

In general, the capture zone for NASA-1A (Figures 15 and 18) is considered conservative because the groundwater elevation from the extraction well is not used to derive the potentiometric surface and resultant capture zone.

NASA-1A is located in an approximately 120-foot wide channel deposit (Figure 19) and is screened across approximately 4 feet of fine- to medium-grained sand, 2 feet of coarse-grained sand, and 4 feet of fine-grained gravel (Figure 20).

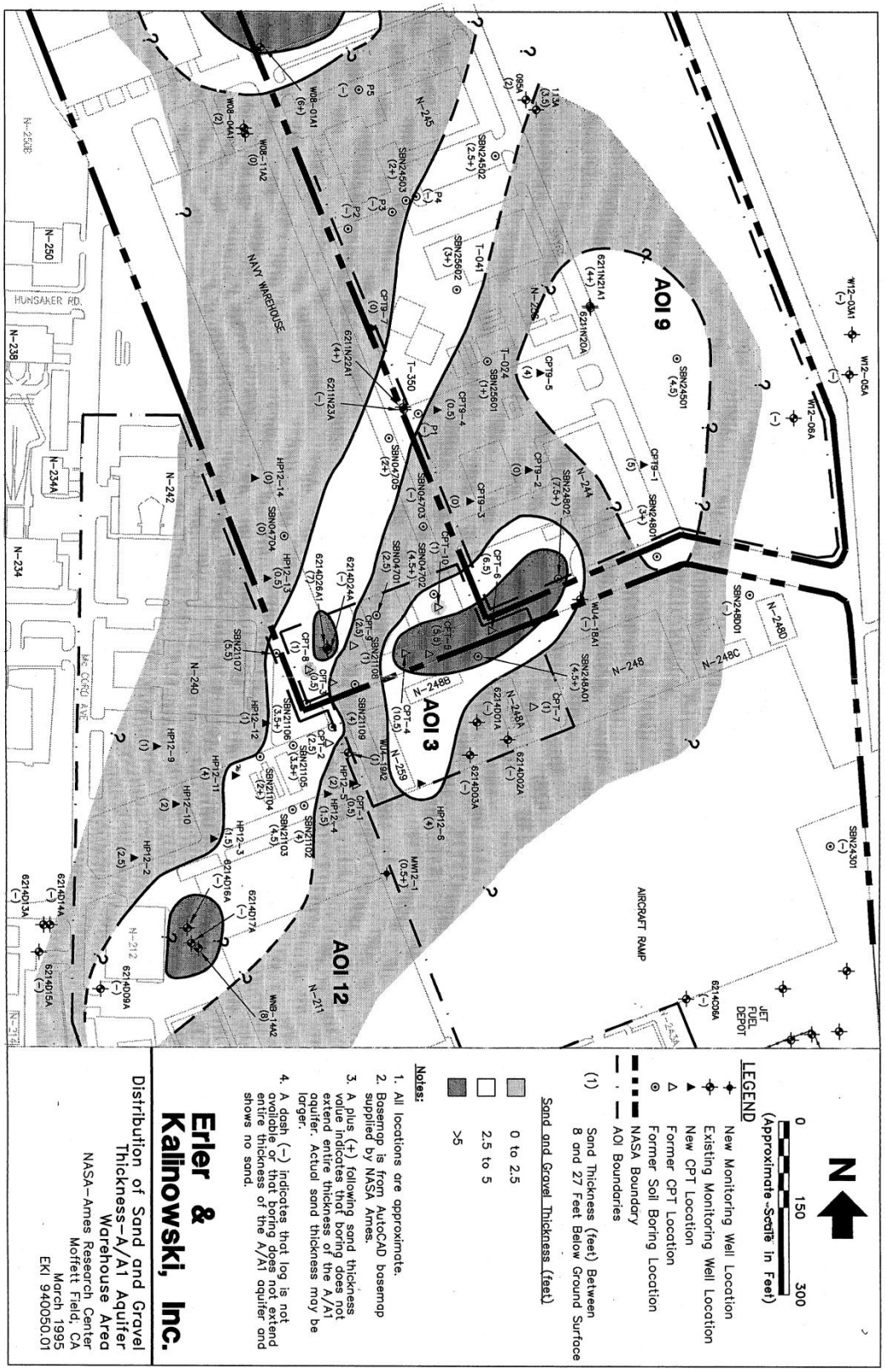


Figure 19
Distribution of Sand and Gravel Thickness, A/A1 Aquifer, Warehouse Area

	Permit No.: 99W00195	Site Id: NASA-1A	Purpose: Extraction Well, Shallow
	Permit Date: 03/15/99	Location: AOI 3/9	
	Consulting Firm: SAIC	X Coordinate: 1547985.50	Y Coordinate: 337820.90
	Logged By: BR/SAIC	Total Depth: 28.00'	Completed Depth: 28.00'
	Certified By: GMT/SAIC	Conductor Casing: type: dia: 0.00in fm: 0.00' to: 0.00'	
Date(s): 04/14/99 - 04/14/99	Measuring Point: 7.84'		
Contractor: Gregg Drilling	Datum: Mean Sea Level	Blank Casing: type: Stainless dia: 6.00in fm: -0.5' to: 6.50'	
Borehole Dia.: 14.50in	Static Water Level:	Screens: type: Slotted size: 0.010india: 6.00in fm: 6.50' to: 26.50'	
Drilling Method: Hollow Stem Auger		Annular Fill: type: Grout fm: 0.50' to: 4.50' type: Betonite fm: 4.50' to: 5.50' type: #2/12 Sand fm: 5.50' to: 28.00' type: fm: to:	
Remarks: 14D50A			

Elevation (ft)	Recovery	Sample No.	Blow Count	Depth (ft)	Well Construction (MP. EL. 7.84')	Graphic Log	USCS Code	Material Description
10							CL	SILTY CLAY: dusky yellow green becoming mottled grayish green at 6.5' and light olive brown at 8.5'; slightly to moderately plastic; moist, becoming wet with depth. Trace to no sand, calcareous nodules from 6.5' to 8.0', trace organics at 9.0'.
		N/A	10 11 14	5				
		N/A	10 13 18					
		N/A	9 12 17				SC	CLAYEY SAND: moderate olive brown; approximately 70% very fine-grained sand; saturated.
		N/A	10 15 17	10				
0		N/A	11 22 25				SP	SAND with SILT: olive gray; sand is well sorted, subrounded fine- to medium-grained. Saturated. Iron-stained clay lenses below 11.5'.
		N/A	8 11 11					
		N/A	9 10 13	15			CL	CLAY: moderate yellowish brown; abundant organics; slightly to moderately plastic, plasticity increases with depth. Ocassional small (<1/8") decomposed sandstone fragments.
		N/A	4 6 6					
		N/A	5 6 8				ML	CLAYEY SILT: light olive brown; slightly plastic; sticky; trace very fine-grained sand; saturated.
		N/A	18 26 30	20			CL	SILTY CLAY with SAND: light olive brown; 10% sand at 20'. Grades to CLAYEY SAND with GRAVEL.
-10		N/A	15 29 35					
		N/A	40 40 40				SP	SAND grading to GRAVEL: olive gray; well sorted sand from 21.5' to 23.0'; approximately 80% very coarse-grained, subangular; grades to FINE GRAVEL near 23.0' (most 1/4", up to 1/2").
		N/A	48 32 25					
		N/A	18 24 31	25			GP	
							CL	SILTY CLAY: grayish olive with moderate yellow-brown staining (iron staining); nonplastic.

Page 1 of 1

Figure 20
NASA-1A Well Construction Detail and Lithology

Figures 15 and 18 show that wells 14D36A and 14D39A are within the graphically-derived capture zone of NASA-1A. These two monitoring wells have historically contained elevated concentrations of various fuel constituents. JP5/JP8 was detected at concentrations as high as 2,100 µg/L during 2009. However, fuel constituents have not been detected in groundwater samples collected from NASA-1A, nor adjacent monitoring wells 14D24A and 14D26A1. This highlights one of the limitations of using flow-net analysis to determine capture zones. In this instance, "channelized" flow is the controlling factor.

These observations suggest that the groundwater capture near NASA-1A is controlled by the hydrogeology of the site. In the "*Proposed Locations of NASA Ames Groundwater Extraction Wells*" report (EKI, 1995), two distinct channel deposits are shown (see Figure 19), one in which NASA-1A is located, and one to the south where the AOI 3 fuel contamination is located. This channelization is illustrated in the geologic cross-section shown in Figure 21.

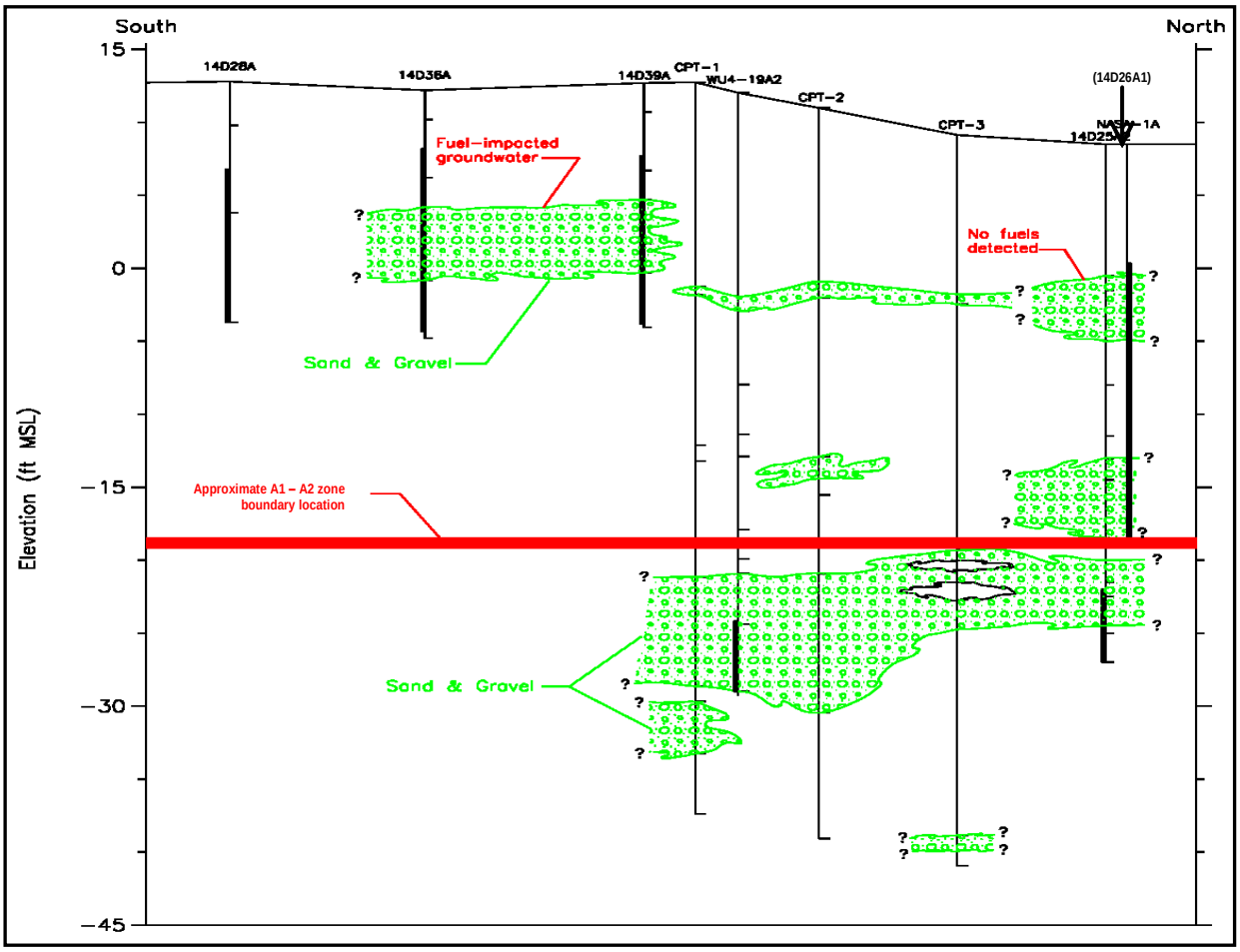


Figure 21
Geologic Cross Section Near Extraction Well NASA-1A

Although a slight lowering in groundwater levels in the adjacent channel is observed, it appears that the fuel contamination in this adjacent channel sequence has limited ability to migrate across the inter-channel boundary to the NASA-1A extraction well. Actual capture is limited to the channel boundaries, with limited hydraulic control being exerted outside of the channel.

NASA-2A Extraction Well

According to the 1995 EKI report, NASA-2A is located down-gradient from NASA-1A, in the same channel deposit. Figure 19 shows a general pinching and thinning of the channel deposit, which may explain the poor extraction rates sustainable in this well. Even though the extraction rate of this well is 1.0 gpm, draw-down in the well is such that the pump cycles on and off on a regular basis. The resultant capture zone for NASA-2A is, therefore, smaller than indicated by the flow-net analysis (Figures 15).

NASA-2A is in the same channel as NASA-1A, but at a location where the channel has narrowed to approximately 90 feet in width and has thinned somewhat (Figure 19). The extraction well is screened across approximately 4 feet of fine- to medium-grained silty and clayey sands, inter-bedded with clays and silts (Figure 22).

Actual capture and hydraulic control at NASA-2A is limited to the immediate vicinity of the extraction well.

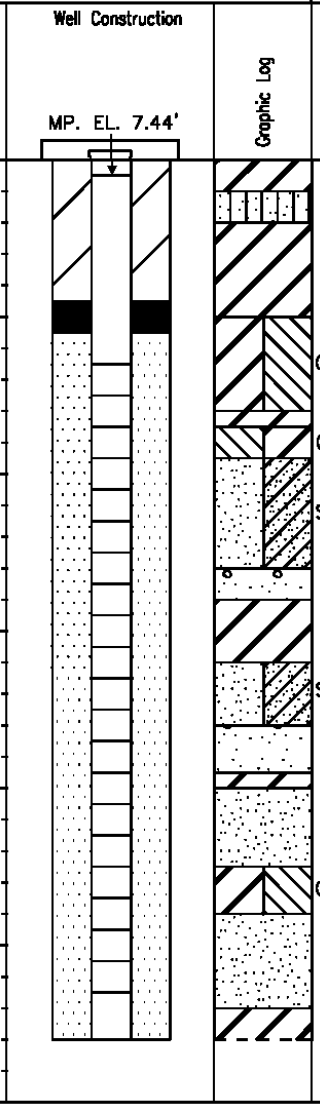
NASA-3A Extraction Well

In general, the capture zone for NASA-3A (Figures 15 and 18) is also considered conservative because the groundwater elevation from the extraction well is not used to derive the potentiometric surface and resultant capture zone.

Although the extraction rate from this well is 6.0 gpm, little draw-down is observed in the adjacent groundwater monitoring wells. NASA-3A is located in a thick, coarse-sand and gravel channel immediately down-gradient from Navy Site 8 North. NASA-3A is located in an approximately 175-foot wide channel deposit (Figure 23) and is screened across approximately 5 feet of fine- to medium-grained silty sand, 4 feet of medium- to coarse-grained sand, and 2 feet of sandy gravel (Figure 24). A geologic cross section near NASA-3A is provided in Figure 25.

High hydraulic conductivity at this location allows for relatively high groundwater extraction rates, but makes lateral capture difficult, especially when considering the relatively large width of the channel. Because of its proximity to the former spill site, and the decreasing TCE levels in down-gradient well 11M03A, it is assumed that this well is capturing the majority of the residual dissolved solvent. However, additional piezometers are needed to further define the capture zone.

	Permit No.: 99W00196	Site Id: NASA-2A	Purpose: Extraction Well, Shallow
	Permit Date: 03/15/99	Location: AOI 9/Child Care Center	
	Consulting Firm: SAIC	X Coordinate: 1548134.20	Y Coordinate: 338229.30
	Logged By: BR/SAIC	Total Depth: 28.00'	Completed Depth: 28.00'
	Certified By: GMT/SAIC	Conductor Casing: type: dia: 0.00in fm: 0.00' to: 0.00'	
Date(s): 04/16/99 - 04/16/99	Measuring Point: 7.44'	Blank Casing: type: Stainless dia: 6.00in fm: 0.5' to: 6.50'	
Contractor: Gregg Drilling	Datum: Mean Sea Level		
Borehole Dia.: 14.00in	Static Water Level: 7.70'	Screens: type: Slotted size: 0.010in dia: 6.00in fm: 6.50' to: 26.50'	
Drilling Method: Hollow Stem Auger		Annular Fill: type: Grout fm: 0.00' to: 4.50'; type: Betonite fm: 4.50' to: 5.50'; type: #2/12 Sand fm: 5.50' to: 28.00'; type: fm: to:	
Remarks: 11N28A			



Elevation (ft)	Recovery	Sample No.	Blow Count	Depth (ft)	USCS Code	Material Description
					CH	SANDY CLAY: very dark gray (7.5YR 3/0); well graded sand (medium to fine); 5% angular gravel to 1/2"; roots; firm; high plasticity.
					SM	SILTY SAND: yellowish brown (10YR 5/4); poorly graded fine sand; 5-10% rounded gravel to 3/4"
					CH	SILTY CLAY: very dark gray; 5% fine sand; organic matter; high plasticity.
				5	CH/CL	SILTY CLAY: very dark gray mottled light gray (10YR 7/2); firm to stiff; medium plasticity.
					CH	CLAY: very dark gray; stiff; very high plasticity.
					CL/CH	SILTY CLAY: light olive brown (2.5Y 5/3); 10% fine sand; stiff; medium plasticity; very moist.
				10	SP/SC	SAND with Clay: dark gray; 3% rounded gravel to 1/4"; poorly graded sand (1% coarse; 14% medium; 74% fine sand); 8% fines; wet.
					SW	SAND with Gravel: dark gray; 36% subrounded gravel to 3/4"; well graded sand (4% coarse; 26% medium; 29% fine sand); 5% fines; wet.
				15	CH	SILTY CLAY: brown (7.5YR 5/4); sticky; firm; high plasticity; wet.
					SP/SC	SAND with Clay: dark gray; 2% subrounded gravel to 1/2"; poorly graded sand (1% coarse; 13% medium; 71% fine sand); 13% fines; wet.
					SW	SAND: dark gray; 1% rounded gravel to 5/8"; well graded sand (2% coarse; 32% medium; 62% fine sand); 3% fines; wet.
				20	CH	CLAY: yellowish brown; 5% gravel to 1/2"; stiff; high plasticity; very moist.
					SP	SAND: 3% gravel to 5/8"; poorly graded sand (2% coarse; 15% medium; 76% fine sand); 4% fines; wet.
					CH/CL	SILTY CLAY: brown (10YR 5/3); 10% fine sand; soft; medium plasticity; very moist.
				25	SP	SAND: 1% gravel to 1/4"; poorly graded sand (1% coarse; 11% medium; 82% fine sand); 5% fines; wet.
					CH	SILTY CLAY: brown; <5% fine sand; high plasticity; moist.

Page 1 of 1

Figure 22
NASA-2A Well Construction Detail and Lithologic Log

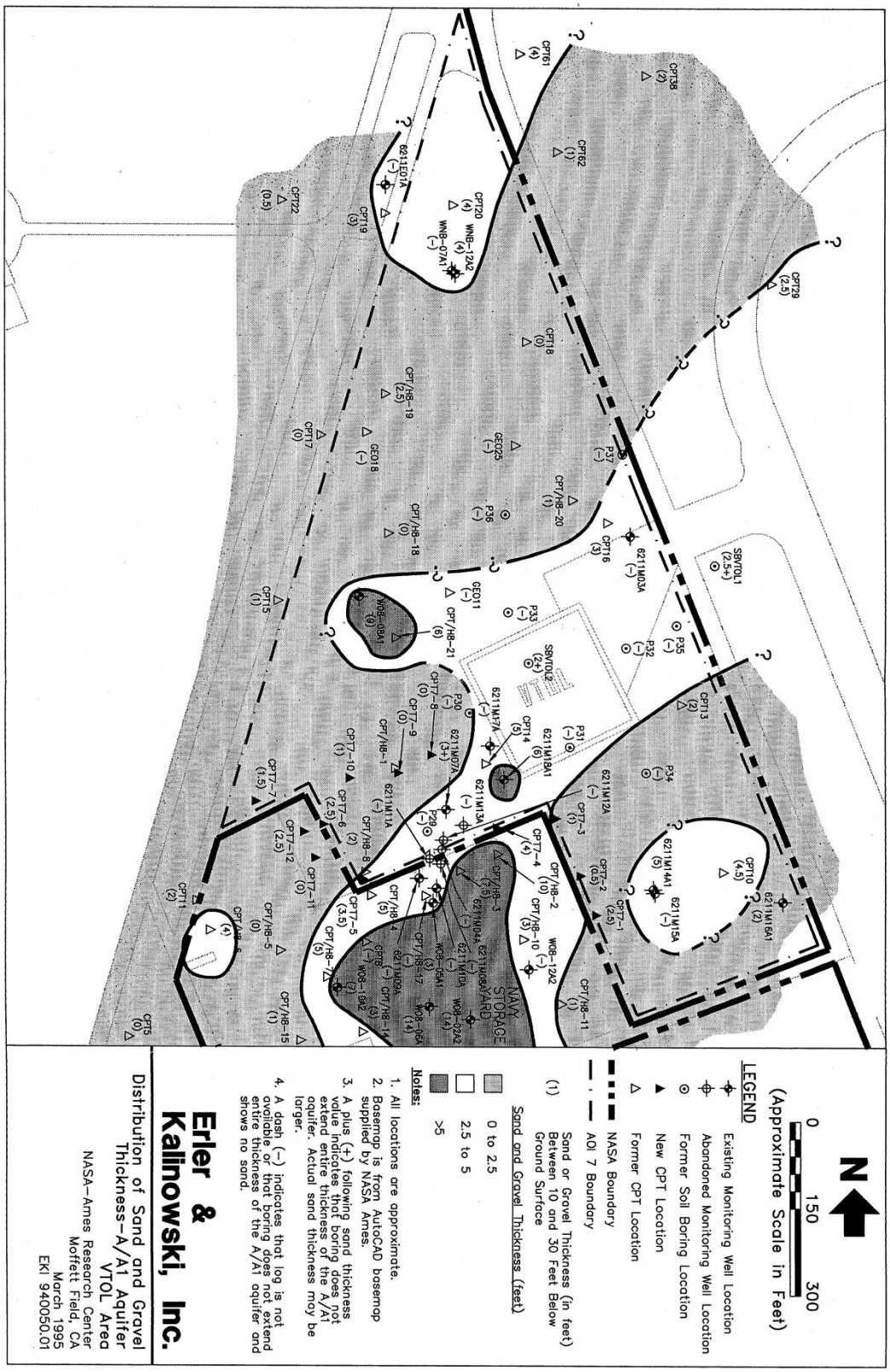
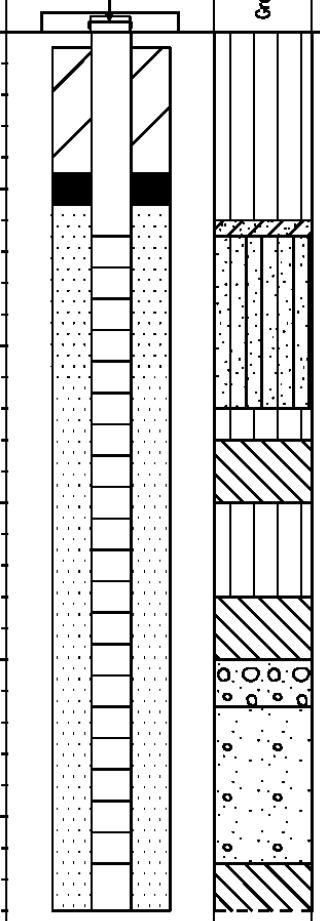


Figure 23
Distribution of Sand and Gravel Thickness, A/A1 Aquifer, VTOL Area

	Permit No.: 99W00155	Site Id: NASA-3A	Purpose: Extraction Well, Shallow
	Permit Date: 03/02/99	Location: VTOL pad	
	Consulting Firm: SAIC	X Coordinate: 1547972.10	Y Coordinate: 339370.80
	Logged By: BR/SAIC	Total Depth: 28.00'	Completed Depth: 28.00'
	Certified By: GMT/SAIC	Conductor Casing: type: dia: 0.00in fm: 0.00' to: 0.00'	
Date(s): 03/02/99 - 03/02/99	Measuring Point: 3.49'		
Contractor: Gregg Drilling	Datum: Mean Sea Level	Blank Casing: type: Stainless dia: 6.00in fm: -0.5' to: 6.50'	
Borehole Dia.: 14.50in	Static Water Level:	Screens: type: Slotted size: 0.010in dia: 6.00in fm: 6.50' to: 26.50'	
Drilling Method: Hollow Stem Auger		Annular Fill: type: Grout fm: 0.50' to: 4.50' type: Betonite fm: 4.50' to: 5.50' type: #2/12 Sand fm: 5.50' to: 28.00' type: fm: to:	
Remarks: 11M22A			

Elevation (ft)	Recovery	Sample No.	Blow Count	Depth (ft)	USCS Code	Material Description
					ML	GRAVELLY SILT: light olive gray; nonplastic; moist becoming saturated at 6.0'.
0				5	SC	CLAYEY SAND: light olive gray; 50% to 60% sand.
				10	SM	SILTY SAND: moderate olive brown grading to light olive brown; 50% sand; 50% fines; saturated; sticky; large calcareous nodules at 7.5'; stiff clay interbedded from 7.7' to 8.0'.
					ML	SANDY SILT: 30% sand.
					CL	CLAY: light olive brown mottled moderate olive brown; abundant organics; slightly plastic; very stiff.
-10				15	ML	SANDY SILT: light olive brown; 20% to 30% sand; soft. Sand is poorly sorted. Gravel becomes abundant from 16.5' to 18.0'.
					CL	CLAY grading to SANDY CLAY with GRAVEL: light olive brown; iron stained; stiff; slightly plastic; gravel with serpentinites.
				20	GW	SANDY GRAVEL with SILT: olive gray; poorly sorted. CLAYEY SAND interbedded from 20.5' to 21.0'.
					SW	SAND: olive gray; moderately sorted, medium to coarse grained; 5% fine gravel; 5% or less fines.
				25		SAND: clean sand, very poorly sorted with CLAY. 5% or less fines.
-20					CL	CLAY: light olive brown mottled with light olive gray; soft; slightly plastic to moderately plastic.

Well Construction



Page 1 of 1

Figure 24
NASA-3A Well Construction Detail and Lithologic Log

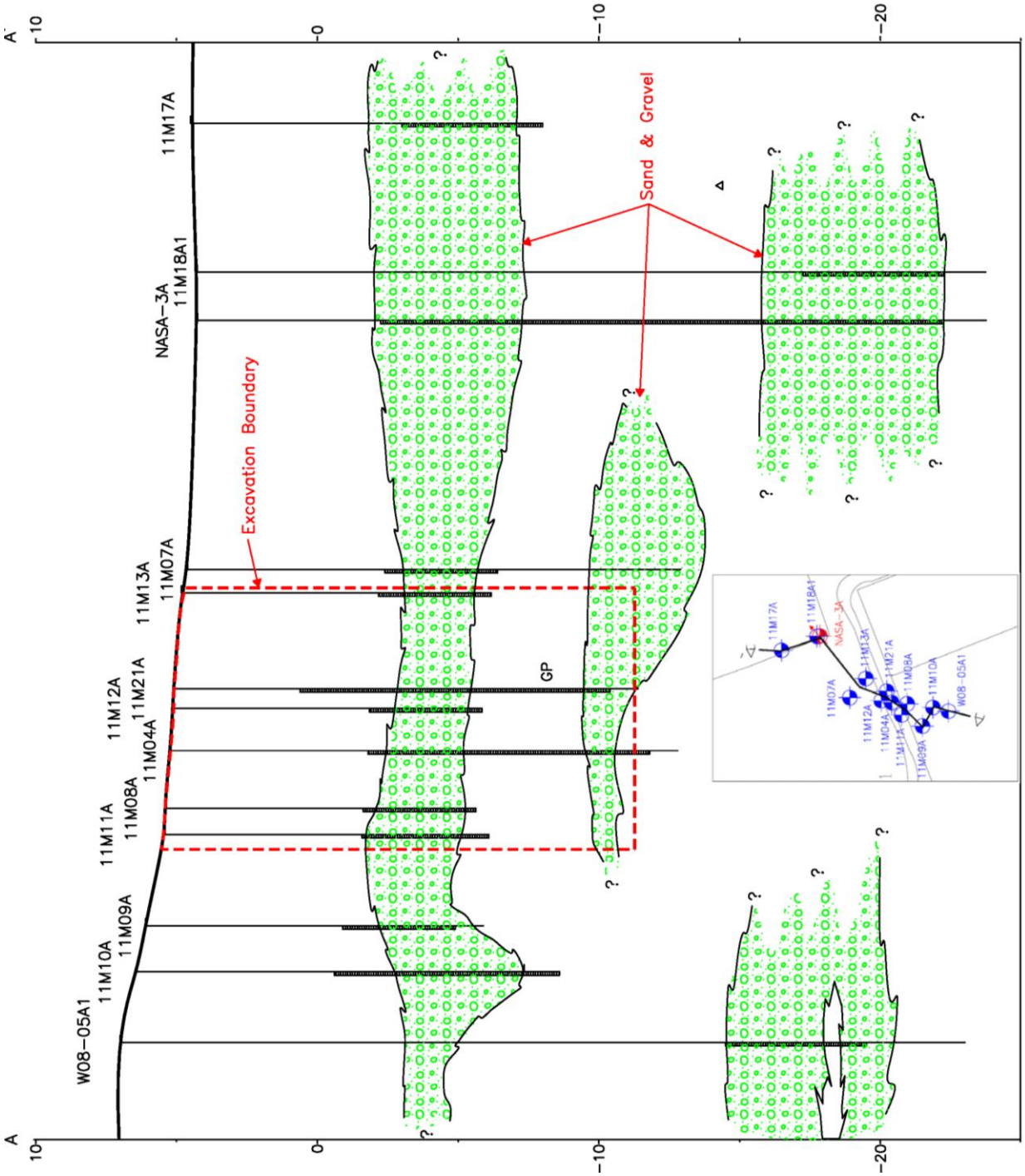


Figure 25
Geologic Cross Section near Extraction Well NASA-3A

NASA-4A Extraction Well

Because of the relatively low sustainable pump rate and the sub-MCL concentrations present at NASA-4A, groundwater extraction was terminated on April 28, 2009.

2.4. System Analytical Results

2.4.1. Chemical Data Evaluation and Trend Analysis

The impacts from local and regional groundwater contaminant plumes in NASA's GWTS area have been evaluated to assess conditions during 2010 and changes that have taken place from previous years. Based on the prevalence of TCE, *cis*-1,2-DCE and vinyl chloride in site groundwater, discussion of these three groundwater contaminants are included in this section. Limiting the analysis to these compounds is appropriate based on the following:

- TCE is specified as the indicator compound in the MEW Record of Decision.
- *Cis*-1,2-DCE is a degradation product of TCE and is present in most wells. At most locations, *cis*-1,2-DCE is present at concentrations greater than TCE. Some locations may contain *cis*-1,2-DCE without detectable TCE concentrations.
- TCE and *cis*-1,2-DCE made up approximately 78 percent of the contaminant mass being removed by NASA.
- Vinyl chloride is an indicator of enhanced TCE degradation and is prevalent in areas of VOC and petroleum hydrocarbon co-mingling. Vinyl chloride is often the only remaining VOC in areas of co-mingling.
- Petroleum hydrocarbons are also a common contaminant in NASA's GWTS area. Although not directly addressed in this report, reference is made to their distribution where appropriate.

Analytical data for 2010 is summarized in Appendix E. Concentration-versus-Time graphs for selected wells are presented in Appendix F. Copies of the chains-of-custody, laboratory analytical reports, quality assurance/quality control measures, and validation results are presented in Appendix G.

2.4.1.1. Evaluation of TCE

This section describes TCE plume boundaries in the A1 aquifer. It also summarizes the range of TCE concentrations. Figure 26 provides concentration contours for TCE, including the highest and lowest concentrations of TCE recorded for each well during 2010. The mapped extent of TCE in groundwater is based on the 5 µg/L maximum contaminant level (MCL) for TCE.

TCE Boundaries

The TCE component of the regional plume in the A1 aquifer extends down-gradient (north) from south of US Highway 101, past monitoring well 11E02A (near northwest corner of airfield), with an axis that generally trends south to north (Figure 26). The northern leading edge is delineated by low concentrations in well 11E02A. The western margin of TCE in the A1 aquifer is delineated by low concentrations in wells 14E14A and 14D13A and non-detectable concentrations in well 11N27A, 10J05A, and 11M02A. The eastern margin of TCE in groundwater is less well defined due to co-mingling with local petroleum hydrocarbons sources. Although TCE is not detected in wells 14C33A, 14C40A, and 14C60A (fuel-impacted areas), historic data from wells WNB-06A1 and WNB-08A1 (runway area) indicates that the eastern TCE boundary extends well onto the runway area.

The “depression” in the eastern margin of the TCE boundary (N211 Aircraft Ramp area) is most likely the result of enhanced degradation of TCE as it co-mingles with petroleum hydrocarbons from Navy Site 9 and NASA AOIs 1 and 3. The absence of TCE, combined with the presence of petroleum hydrocarbons and TCE degradation products *cis*-1,2-DCE and vinyl chloride (discussed in Sections 2.4.1.2 and 2.4.1.3, respectively), indicates that the Regional VOC plume is present in this area, but is masked by the enhanced degradation of TCE. The eastern margin of the TCE plume in the N211 Aircraft Ramp area was delineated using data collected during NASA’s 2004 groundwater investigation in that area (PAI, 2004a).

The overall shape and extent of the TCE concentration contours shown in Figure 26 has not changed significantly since 2004 and is nearly identical to that mapped for 2009.

The highest concentration of TCE in the NASA GWTS area was reported at a concentration of 91 µg/L in well 14D24A. This well is located within ten feet of extraction well NASA-1A.

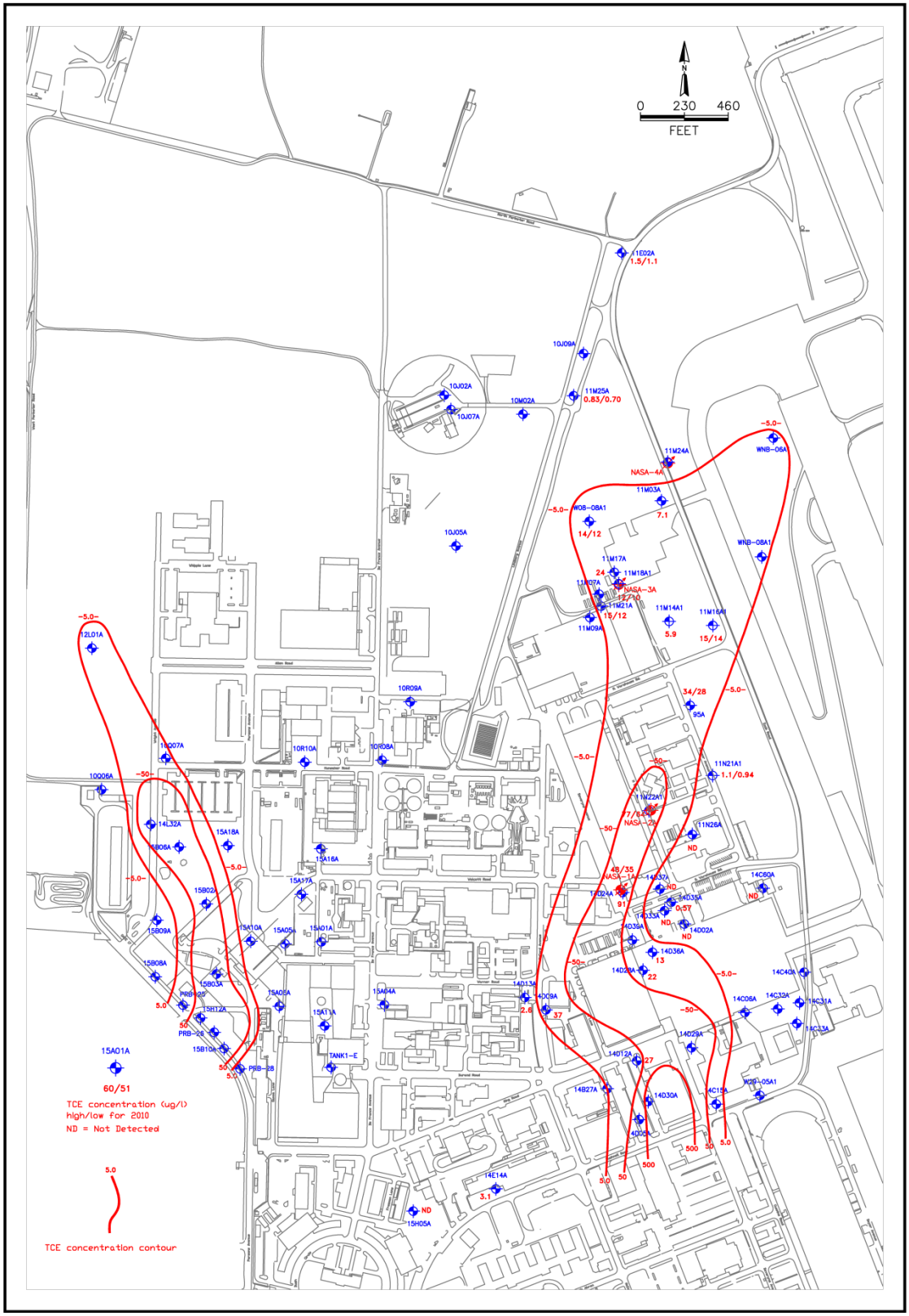


Figure 26
TCE Concentration Contours, A1 Aquifer

TCE Trends

The following section presents an evaluation of historical TCE data. Analysis and interpretation of the TCE data are based on a visual inspection of the historical concentration graphs. If available, data gathered prior to the baseline years are presented and evaluated. Trend discussion is based on the statistical evaluation of data using best-fit linear trend analysis. The locations of wells graphed are included in Figure 4 and in a larger copy as Plate 1. The concentration-versus-time graphs are presented in Appendix F.

Twelve monitoring wells in the vicinity of NASA's extraction wells provided TCE concentration data going back to 1994 and were selected as representative of chemical concentrations in the A1-aquifer. The wells are 11E02A, 11M03A, 11M14A1, 11M16A1, 11M17A, 11M21A, 11N21A1, 11N22A1, 14D24A, 14D26A1, 14D28A, and W08-08A1. Evaluation of concentration data going back to 1994 indicates that prior to the initiation of groundwater extraction (September 2001), TCE concentrations were declining in five of the 12 selected wells (see Table 7). TCE concentrations in five of the wells remained relatively constant. Two of the 12 selected wells, 11M14A1 and 14D28A, exhibited long-term increasing TCE concentrations.

With the installation of NASA's four groundwater extraction, additional monitoring wells were installed to assist with the evaluation of the remedial system. In addition to the 12 monitoring wells discussed above, TCE data for more recently installed wells 11M25A and 14D36A, was used to evaluate TCE concentration trends since the initiation of pumping at NASA's four extraction wells in September 2001.

- Increasing TCE concentrations continued in wells 11M14A1, 11M17A, 11M25A, and 14D24A.

- Decreasing TCE concentrations continued in wells 11M03A, 11M21A, and 14D26A1.

- Wells 11E02A, 11M16A1, 11M24A, 11N21A1, 11N22A1, 14D28A, 14D36A, and W08-08A1 continue to show relatively stable concentration trends.

There does not, however, appear to be any correlation between well location and observed concentration trends in the well. The wells with increasing trends can both be found adjacent to NASA's extraction wells and at the margins of the plume.

Table 7
TCE Concentration Trends at Selected Wells

Well	TCE trend prior to NASA groundwater extraction	TCE trend since NASA groundwater extraction
11E02A	=	=
11M03A	⇩	⇩
11M14A1	⇧	⇧
11M16A1	=	=
11M17A	⇩	⇧
11M21A	=	⇩
11M25A	NA	⇧
11N21A1	=	=
11N22A1	⇩	=
14D24A	⇩	⇧
14D26A1	=	⇩
14D28A	⇧	=
14D36A	NA	=
W08-08A1	⇩	=
NASA-1A	NA	⇩
NASA-2A	NA	⇧
NASA-3A	NA	⇩

⇩ Decreasing TCE concentration trend

⇧ Increasing TCE concentration trend

= Stable TCE concentration trend

NA = not applicable (data not available)

Concentrations of TCE have been declining at extraction wells NASA-1A (Figure 27) and NASA -3A (Figure 28).

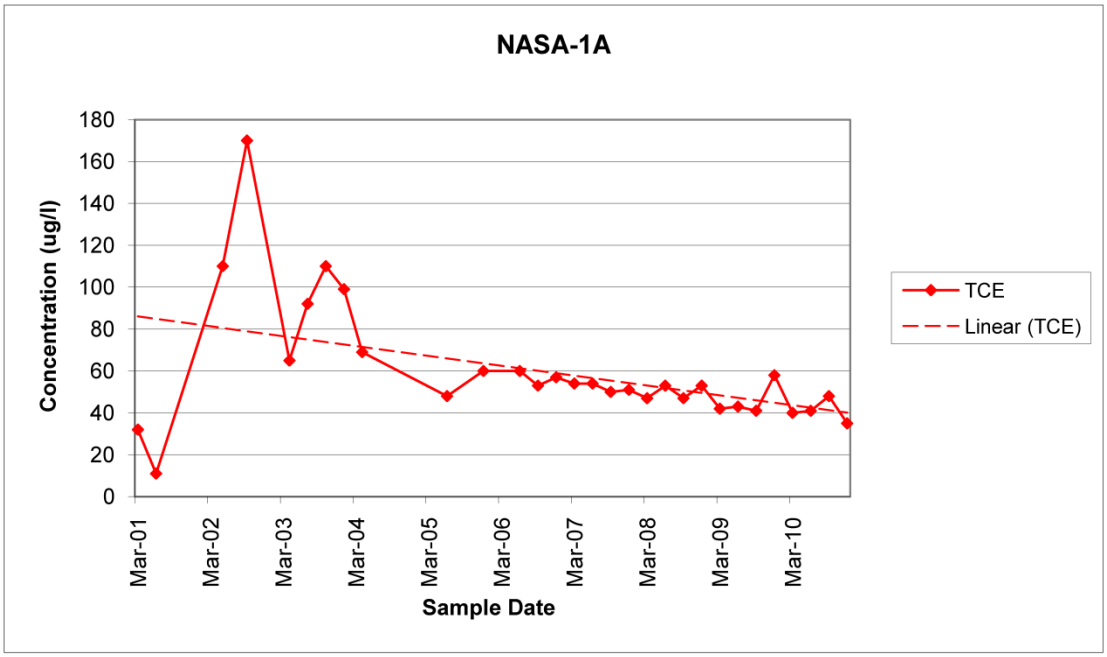


Figure 27
TCE Concentration-versus-Time Graph, Extraction Well NASA-1A

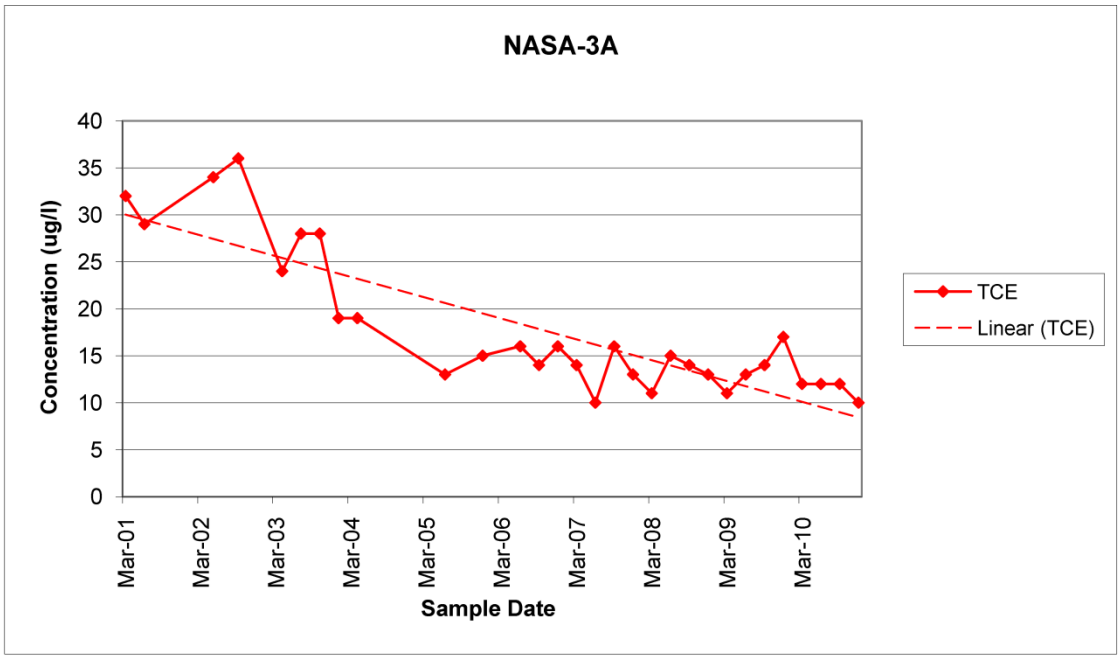


Figure 28
TCE Concentration-versus-Time Graph, Extraction Well NASA-3A

At extraction well NASA-2A, the TCE concentrations show a slight increasing trend (Figure 29).

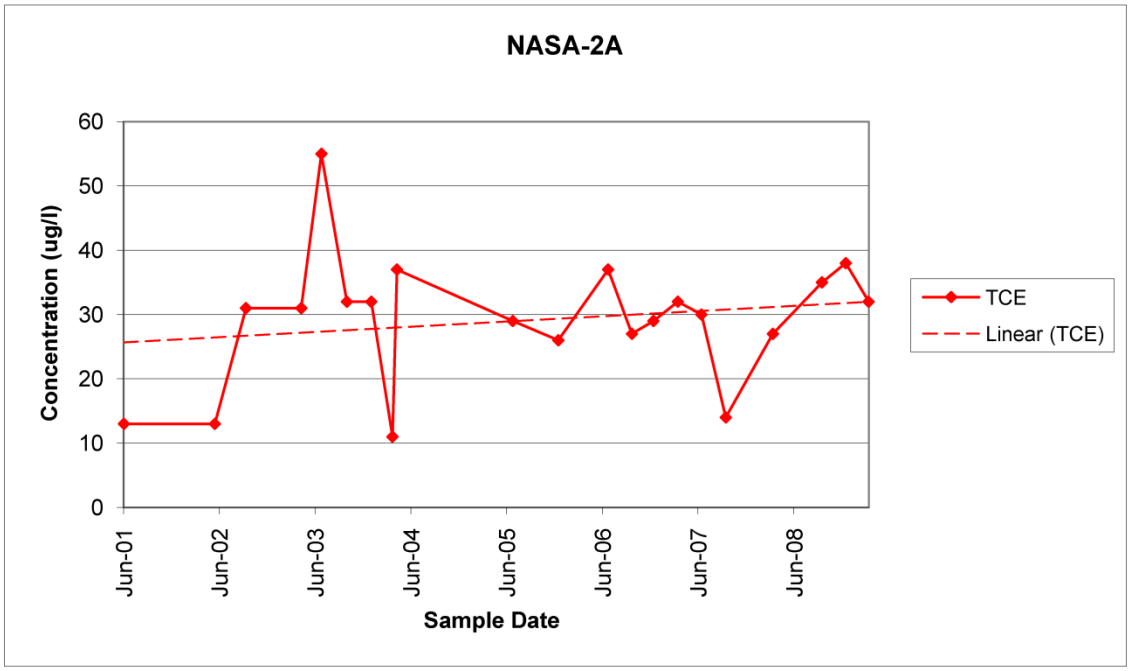


Figure 29
TCE Concentration-versus-Time Graph, Extraction Well NASA-2A

2.4.1.2. Evaluation of *cis*-1,2-DCE

This section describes *cis*-1,2-DCE plume boundaries in the A1 aquifer. It also summarizes the range of *cis*-1,2-DCE concentrations. Figure 30 provides concentration contours for *cis*-1,2-DCE, including the highest and lowest concentrations of *cis*-1,2-DCE recorded for each well during 2010. The mapped extent of *cis*-1,2-DCE in groundwater is based on the 6 µg/L MCL for *cis*-1,2-DCE.

***Cis*-1,2-DCE Boundaries**

The *cis*-1,2-DCE component of the Regional Plume in the A1 aquifer extends down-gradient (north) from south of US Highway 101. The northern leading edge is delineated by trace concentrations in well 11E02A (Figure 30). The western margin of the *cis*-1,2-DCE boundary is delineated by low concentrations in wells 14E14A, 14D13A and 11M07A, and non-detectable concentrations in wells 15H05A, 11N27A, and W08-08A1. As previously discussed for TCE, the eastern *cis*-1,2-DCE margin is less well defined due to co-mingling with local petroleum hydrocarbons sources. C*is*-1,2-DCE was detected in wells 14C60A and 95A at concentrations of 6.0 µg/L and 7.6 µg/L, respectively. Historic data from wells 93A, WNB-06A1, and WNB-08A1 indicates that the eastern *cis*-1,2-DCE boundary has historically extended well onto the runway area.

The depression in the eastern *cis*-1,2-DCE margin (vicinity of AOI 3) is most likely the result of enhanced degradation of *cis*-1,2-DCE as it co-mingles with petroleum hydrocarbons from NASA AOIs 1 and 3. The absence of *cis*-1,2-DCE, combined with the presence of petroleum hydrocarbons and the *cis*-1,2-DCE degradation product vinyl chloride (see Section 2.4.1.3), suggests that the Regional Plume is present in this area, but is masked by the enhanced degradation of *cis*-1,2-DCE. The eastern margin of the *cis*-1,2-DCE plume in the N211 Aircraft Ramp area was delineated using data collected during NASA's 2004 groundwater investigation in that area (PAI, 2004a).

The overall shape and extent of the *cis*-1,2-DCE concentration contours shown in Figure 30 has not changed significantly since 2004 and is nearly identical to that mapped for 2009.

The highest concentration of *cis*-1,2-DCE in the NASA GWTS area was reported at a concentration of 94 µg/L in well 14D24A. This well is located within ten feet of extraction well NASA-1A.

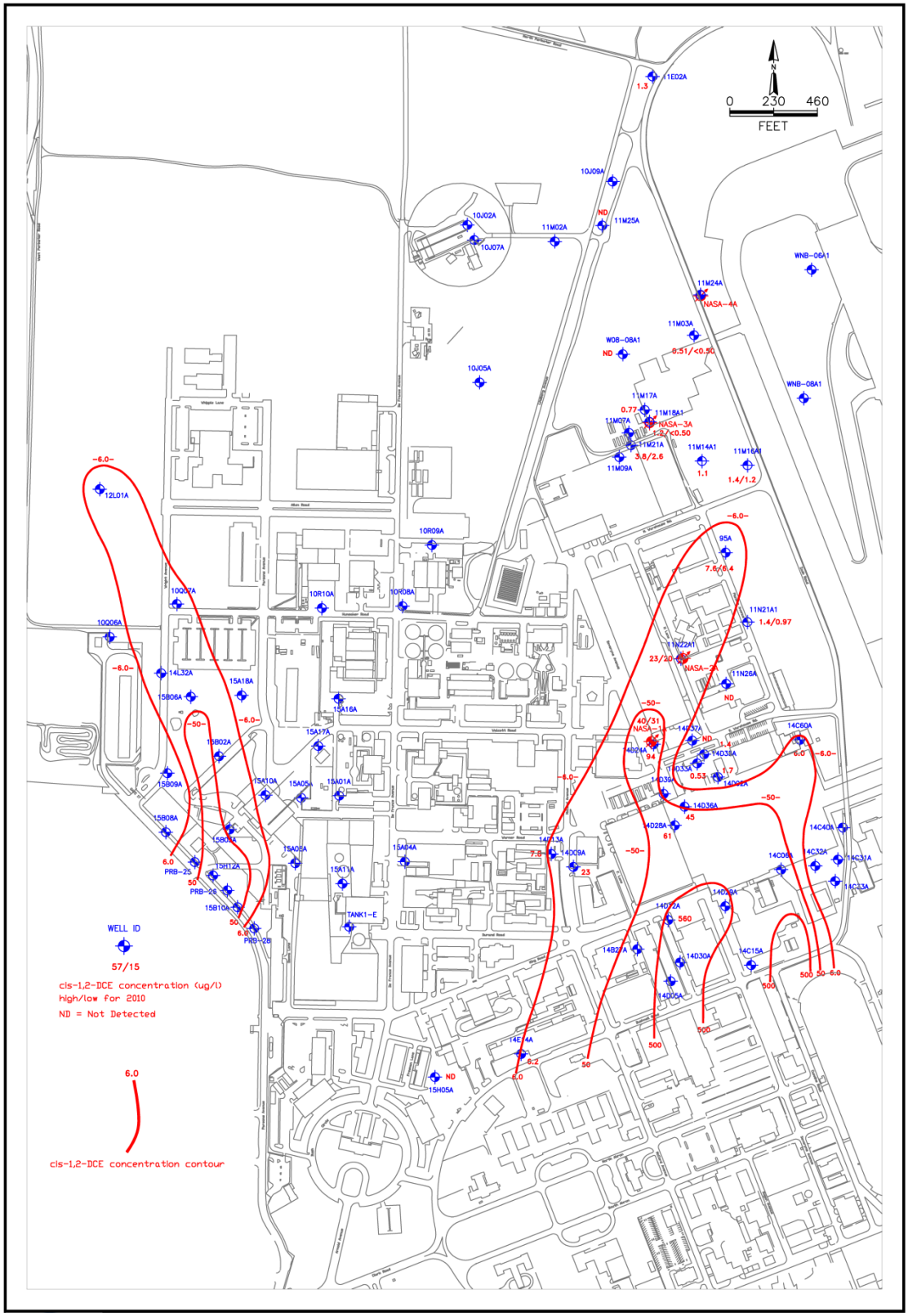


Figure 30
***Cis*-1,2-DCE Concentration Contours, A1 Aquifer**

Cis-1,2-DCE Trends

The following section presents an evaluation of historical *cis*-1,2-DCE data. Analysis and interpretation of the *cis*-1,2-DCE data are based on a visual inspection of the historical concentration graphs. If available, data gathered prior to the baseline years are presented and evaluated. Trend discussion is based on the statistical evaluation of data using best-fit linear trend analysis. The locations of wells graphed are included in Figure 4 and Plate 1. The concentration-versus-time graphs are presented in Appendix F.

Eleven monitoring wells in the vicinity of NASA's extraction wells provided *cis*-1,2-DCE concentration data going back to 1994 and were selected as representative of chemical concentrations in the A1-aquifer zone. The wells are 11E02A, 11M03A, 11M14A1, 11M16A1, 11M17A, 11M21A, 11N21A1, 11N22A1, 14D24A, 14D26A1, and 14D28A. Evaluation of concentration data going back to 1994 indicates that prior to the initiation of groundwater extraction (September 2001), *cis*-1,2-DCE concentrations were declining in three of the eleven selected wells (Table 8). Four of the eleven wells indicated increasing *cis*-1,2-DCE concentrations. *Cis*-1,2-DCE concentrations in four of the wells remained relatively constant.

With the installation of NASA's four groundwater extraction, additional monitoring wells were installed to assist with the evaluation of the remedial system. In addition to the ten monitoring wells discussed above, *cis*-1,2-DCE data for more recently installed wells 14C60A and 14D36A was used to evaluate *cis*-1,2-DCE concentration trends since the initiation of pumping at NASA's four extraction wells in September 2001.

- Increasing *cis*-1,2-DCE concentrations continued in wells 11M14A1 and 14D24A.

- Decreasing *cis*-1,2-DCE concentrations continued in wells 11E02A, 11M21A, 11N21A1, 11N22A1, 14D26A1.

- Four wells (11M03A, 11M16A1, 11M17A, and 14C60A) show relatively stable concentrations since the initiation of pumping.

- Previously declining *cis*-1,2-DCE concentrations in wells 14D28A and 14D36A have become relatively stable.

There does not appear to be any correlation between well location and observed concentration trends in the well. The wells with increasing trends can both be found adjacent to NASA's extraction wells and at the margins of the plume. .

Table 8
***Cis*-1,2-DCE Concentration Trends at Selected Wells**

Well	*Cis*-1,2-DCE trend prior to NASA groundwater extraction	*Cis*-1,2-DCE trend since NASA groundwater extraction
11E02A	⇩	⇩
11M03A	⇩	=
11M14A1	=	⇧
11M16A1	=	=
11M17A	=	=
11M21A	⇩	⇩
11N21A1	⇧	⇩
11N22A1	⇧	⇩
14C60A	NA	=
14D24A	⇧	⇧
14D26A1	=	⇩
14D28A	⇧	=
14D36A	NA	=
NASA-1A	NA	⇩
NASA-2A	NA	⇩
NASA-3A	NA	⇩

⇩ Decreasing *cis*-1,2-DCE concentration trend

⇧ Increasing *cis*-1,2-DCE concentration trend

= Stable *cis*-1,2-DCE concentration trend

NA = not applicable (data not available)

Concentrations of *cis*-1,2-DCE have been declining in extraction wells NASA-1A (Figure 31), NASA-2A (Figure 32) and NASA-3A (Figure 33).

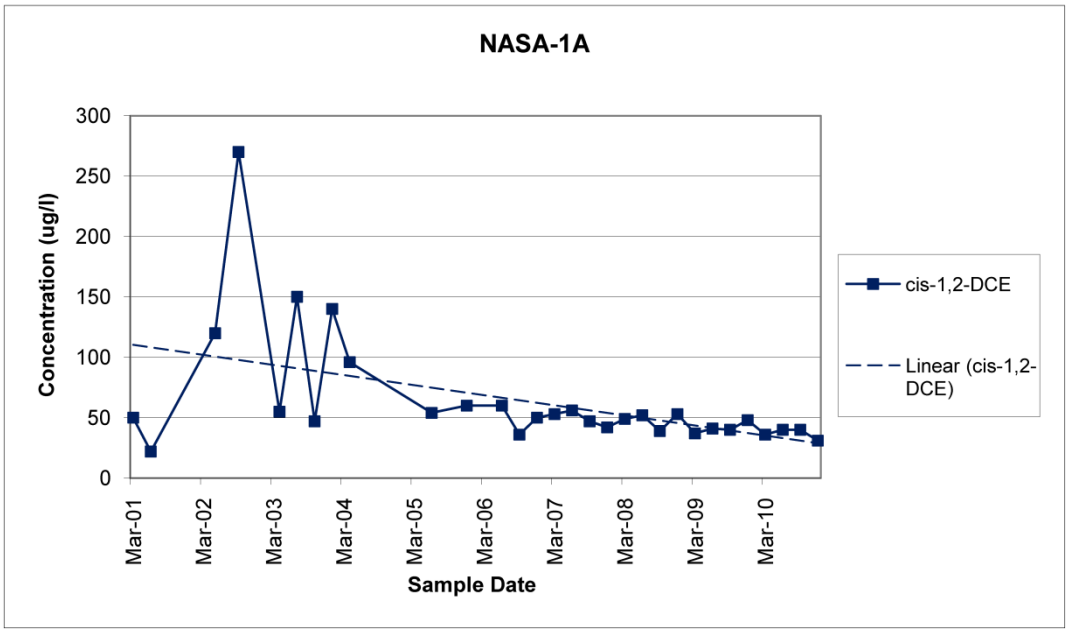


Figure 31
***Cis*-1,2-DCE Concentration-versus-Time Graph, Extraction Well NASA-1A**

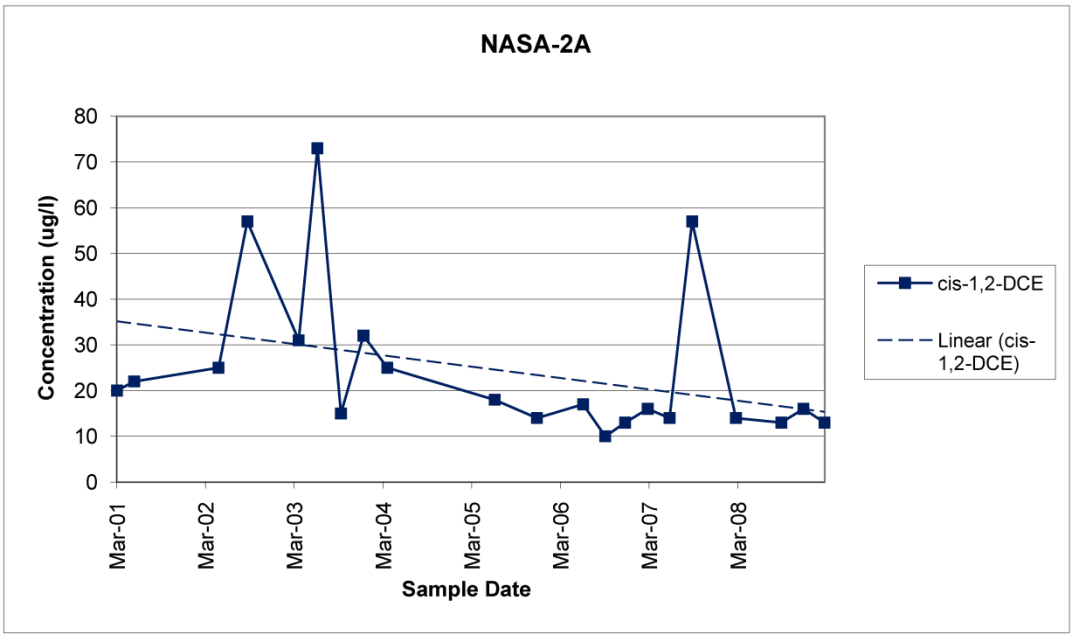


Figure 32
***Cis*-1,2-DCE Concentration-versus-Time Graph, Extraction Well NASA-2A**

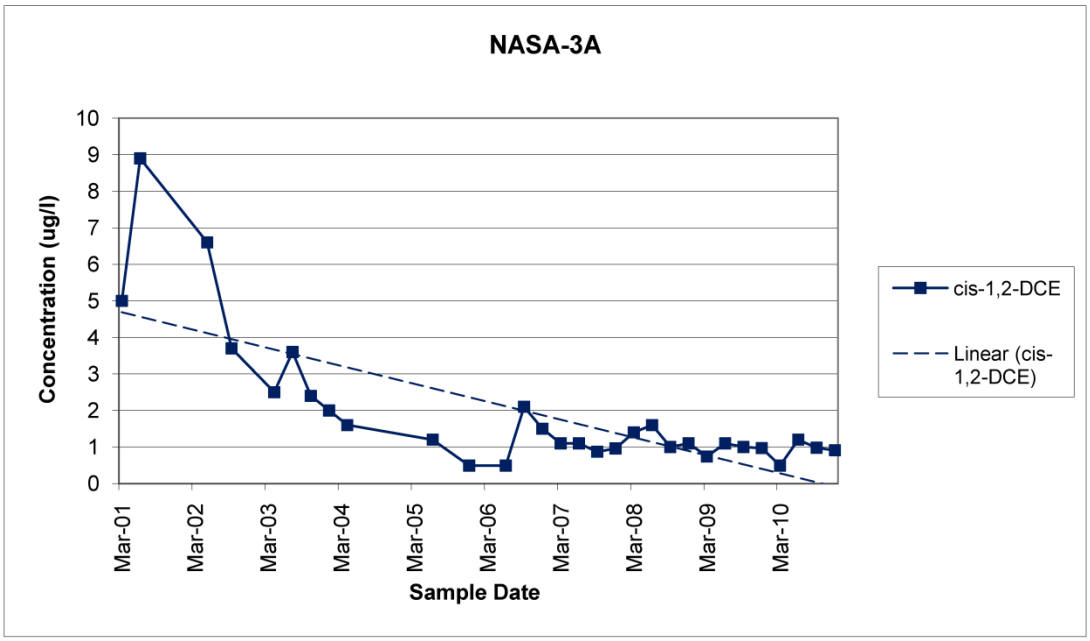


Figure 33
***Cis*-1,2-DCE Concentration-versus-Time Graph, Extraction Well NASA-3A**

2.4.1.3. Evaluation of Vinyl Chloride

This section describes vinyl chloride plume boundaries in the A1 aquifer. It also summarizes the range of vinyl chloride concentrations. Figure 34 provides concentration contours for vinyl chloride, including the highest and lowest concentrations of vinyl chloride recorded for each well during 2010.

Vinyl Chloride Boundaries

The vinyl chloride component in the regional VOC plume in the A1 aquifer extends down-gradient (north) from south of US Highway 101, extending north to well NASA-1A, with an axis that generally trends south to north (Figure 34). The northern margin is delineated by non-detectable concentrations at wells 11N22A1 and 11N26A. The western margin of vinyl chloride in groundwater is delineated by non-detectable concentrations at well 14D13A. The eastern margin is defined by low concentrations at wells 14C32A and 14C60A, and non-detectable concentrations in wells 14C31A, 14C33A, and 14C40A. The eastern margin of vinyl chloride in the N211 Aircraft Ramp area was delineated using data collected during NASA's 2004 groundwater investigation in that area (PAI, 2004a).

The overall shape and extent of the vinyl chloride concentration contours shown in Figure 34 has not changed significantly since 2004. The only notable changes from the plume boundaries mapped for 2009 is the inclusion of well 11N22A1 from the 0.50 µg/L contour at the leading edge of the vinyl chloride plume.

The highest concentration of vinyl chloride in the NASA GWTS area was reported at a concentration of 4.6 µg/L in well 14C33A. This well is located in the northwest portion of the N211 Aircraft Ramp area.

Vinyl Chloride Trends

The following section presents an evaluation of historical vinyl chloride data. Analysis and interpretation of the vinyl chloride data are based on a visual inspection of the historical concentration graphs. If available, data gathered prior to the baseline years are presented and evaluated. Trend discussion is based on the statistical evaluation of data using best-fit linear trend analysis. The locations of wells graphed are included in Figure 4 and Plate 1. The concentration-versus-time graphs are presented in Appendix F.

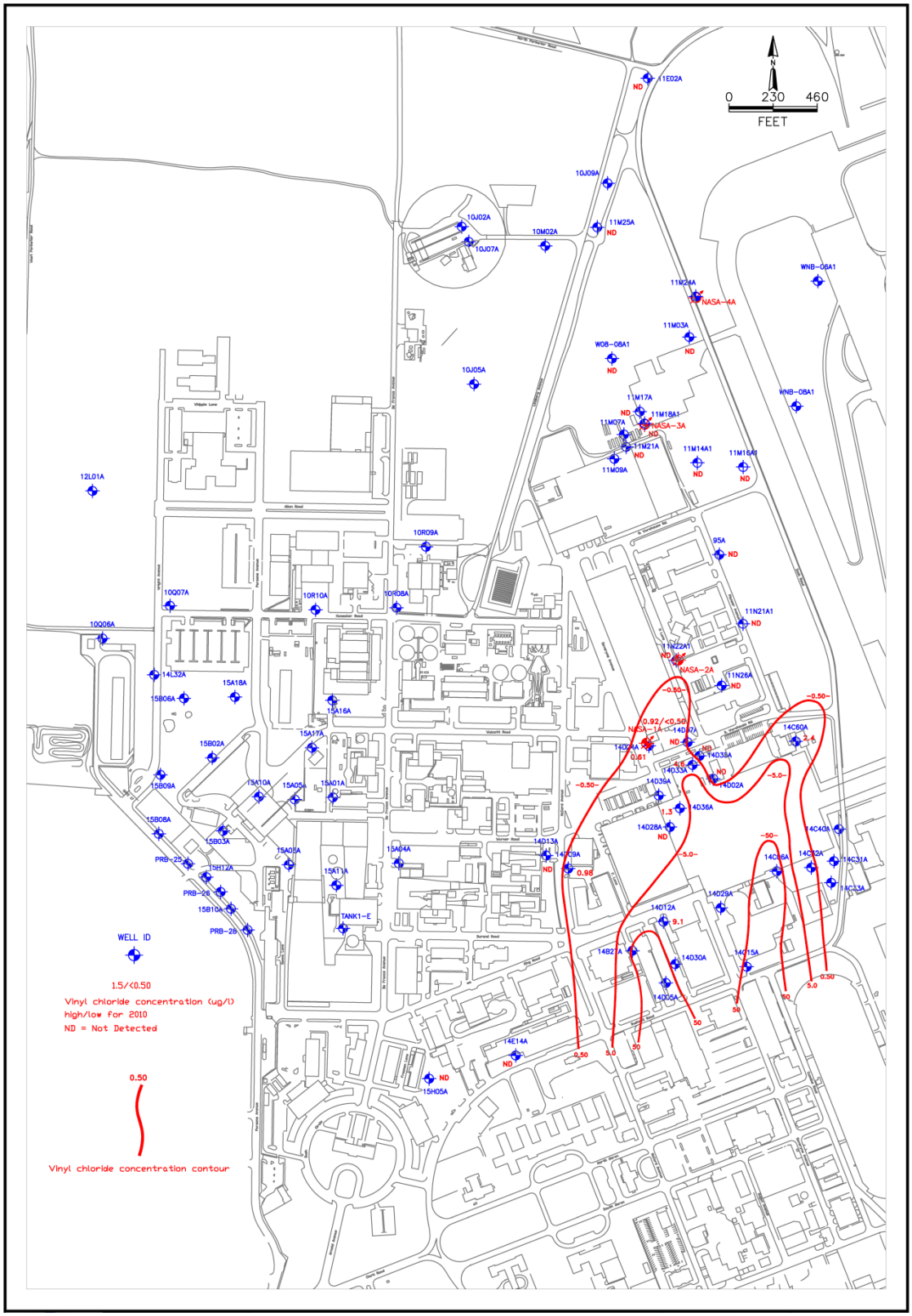


Figure 34
Vinyl Chloride Concentration Contours, A1 Aquifer

Four monitoring wells in the vicinity of NASA's extraction wells provided vinyl chloride concentration data going back to 1994 and were selected as representative of chemical concentrations in the A1 aquifer. The wells are 11N21A1, 14D24A, 14D26A1, and 14D28A. Evaluation of concentration data going back to 1994 indicates that prior to the initiation of groundwater extraction (September 2001), vinyl chloride concentrations were increasing in all four of the selected wells (Table 9).

With the installation of NASA's four groundwater extraction, additional monitoring wells were installed to assist with the evaluation of the remedial system. In addition to the four monitoring wells discussed above, vinyl chloride data for more recently installed wells 14C60A, 14D33A, 14D35A, and 14D36A, was used to evaluate vinyl chloride concentration trends since the initiation of pumping at NASA's four extraction wells in September 2001.

- Vinyl chloride concentrations continued to increase in well 14D36A.
- Decreasing trends continued in wells 11N21A1, 14C60A, 14D26A1, 14D28A, and 14D35A.
- Concentrations of vinyl chloride in well 14D33A have remained relatively stable.
- Previously stable vinyl chloride concentrations in well 14D24A appear to have begun a decreasing trend.

Table 9
Vinyl Chloride Concentration Trends at Selected Wells

Well	Vinyl chloride trend prior to NASA groundwater extraction	Vinyl chloride trend since NASA groundwater extraction
11N21A1	⇧	⇩
14C60A	NA	⇩
14D24A	⇧	⇩
14D26A1	⇧	⇩
14D28A	⇧	⇩
14D33A	NA	=
14D35A	NA	⇩
14D36A	NA	⇧
NASA-1A	NA	⇩
NASA-2A	NA	⇩

⇩ Decreasing vinyl chloride concentration trend

⇧ Increasing vinyl chloride concentration trend

= Stable vinyl chloride concentration trend

NA = not applicable (data not available)

Two NASA extraction wells contain vinyl chloride (NASA-1A and NASA-2A). Concentrations of vinyl chloride continue to decrease in NASA-1A (Figure 35) and are NASA-2A (Figure 36).

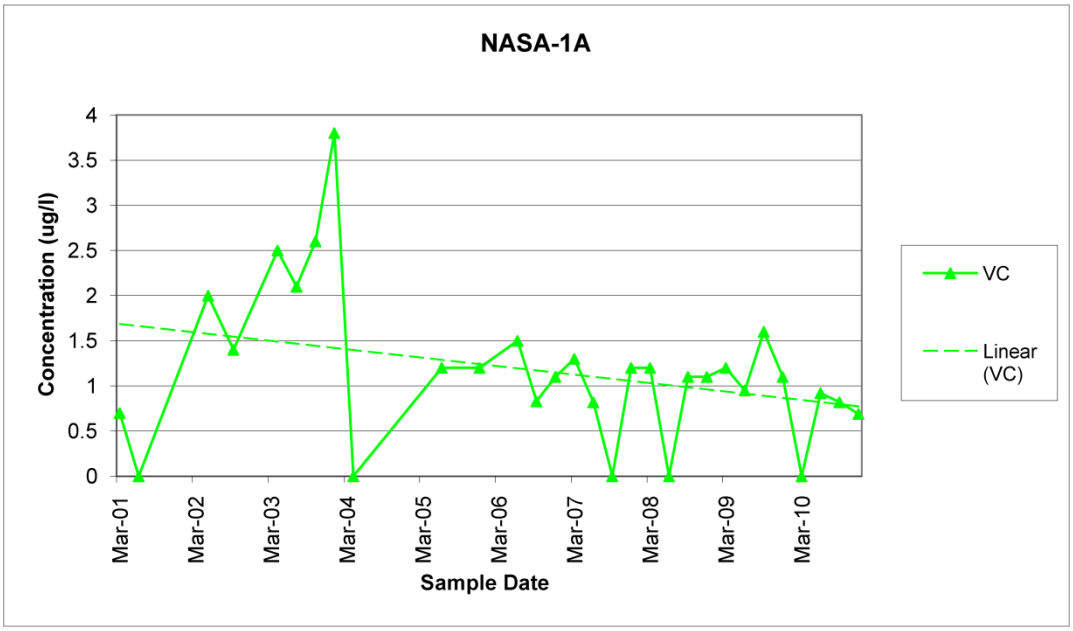


Figure 35
Vinyl Chloride Concentration-versus-Time Graph, Extraction Well NASA-1A

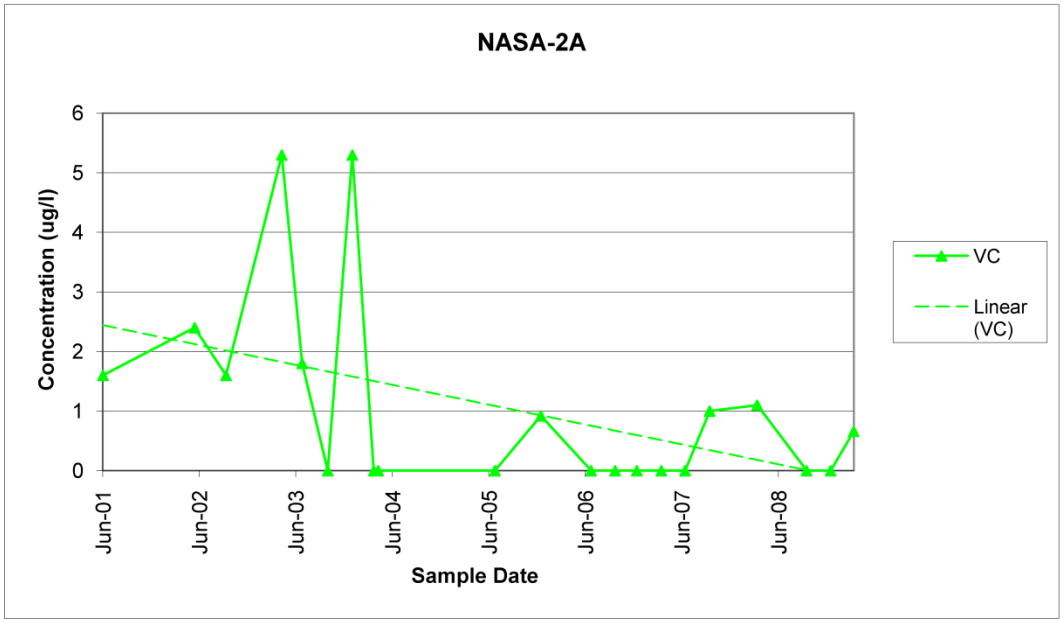


Figure 36
Vinyl Chloride Concentration-versus-Time Graph, Extraction Well NASA-2A

3.0 OPERATIONS AND MAINTENANCE PROBLEMS

Other than the system shutdowns as presented in Section 2.2.3, no significant treatment system problems or exceedances were encountered during the 2010 calendar year.

4.0 TECHNICAL ASSESSMENT

4.1. Remedy Functionality

The NASA GWTS functioned as designed in capturing groundwater contamination from the suspected source up-gradient of extraction well NASA-1A and the former VTOL Pad/Navy Site 8 North documented source area up-gradient of NASA-3A. The NASA GWTS was not designed, however, to capture the Regional Plume.

Due to low hydraulic capacity of the A1 aquifer at the NASA-2A and NASA-4A extraction well locations, capture of the distal portion of the Regional Plume is limited at these well locations. Based on groundwater VOC concentrations below cleanup levels at NASA-4A, pumping at this well was suspended on April 28, 2009. Due to low hydraulic capacity of the A1 aquifer at NASA-2A and the resultant poor performance of this well, pumping was also suspended on April 28, 2009.

Concentrations trends of TCE, *cis*-1,2-DCE, and vinyl chloride present in Section 2.4.1 are predominantly decreasing for the 2010 calendar year. TCE concentrations appear to be evenly distributed between up-trending and down-trending concentration trends (five wells with increasing trends, five wells with decreasing trends, seven wells with stabilizing concentrations). Concentration trends of *cis*-1,2-DCE appear to be trending downward in the majority of wells (eight wells with decreasing trends, two wells with increasing trends, six wells with stabilizing concentrations). Vinyl chloride concentration trends are also trending downward in the majority of wells (eight wells with decreasing trends, one well with increasing trend, one well with stabilizing concentrations). Overall, more wells are exhibiting decreasing concentrations in 2010 compared to 2009.

The NASA GWTS was based on the installation of four extraction wells to remediate two specific areas discussed in the 1995 EKI report. Below is a discussion of the effectiveness of the remedy at each of the two specific areas.

4.1.1. Suspected Source Area, Area of Investigation 9

NASA-1A

The location of NASA-1A was selected to control a suspected source area (Figure 11) of relatively high TCE groundwater concentrations in the area between buildings N259 and N240.

The estimated capture zone for NASA-1A, as interpreted by flow-net analysis, is shown in Figures 15 and 18. From the March and November water level data, the estimated capture zone of NASA-1A is similar in extent to the capture zone predicted in 1995 EKI report (Figure 37). However, the orientation of the estimated capture zone is also more north-south than the modeled capture zone, which was predicted to achieve a more northeast-southwest configuration.

A comparison to the predicted capture zone in the "*Revised Final Design, Regional Groundwater Remediation Program, North of US Highway 101"* (Smith, 1996) cannot be made because the location of NASA-1A was moved from the original location (southeast corner of Building N144) to the southwest corner.

Based on the flow-net analysis and channel geometry presented by EKI, it appears that NASA-1A is capturing the majority of groundwater flowing through the suspected source area. After an initial spike in COC concentrations during the first year of operation, concentrations appear to have stabilized and began a declining trend.

In NASA-1A, concentrations of TCE, *cis*-1,2-DCE and vinyl chloride show declining linear trends since pumping began. However, concentrations still persist above cleanup levels. Adjacent monitoring well 14D26A1 also shows declining TCE, *cis*-1,2-DCE and vinyl chloride concentrations. However, adjacent well 14D24A, which is screened in only the uppermost sand layer, shows increasing TCE and *cis*-1,2-DCE, with stabilizing vinyl chloride concentrations.

NASA-1A is currently operating at an extraction rate of 7.2 gpm. The proposed extraction rate was 8.0 gpm. It is uncertain if this well can sustain a rate of 8.0 gpm.

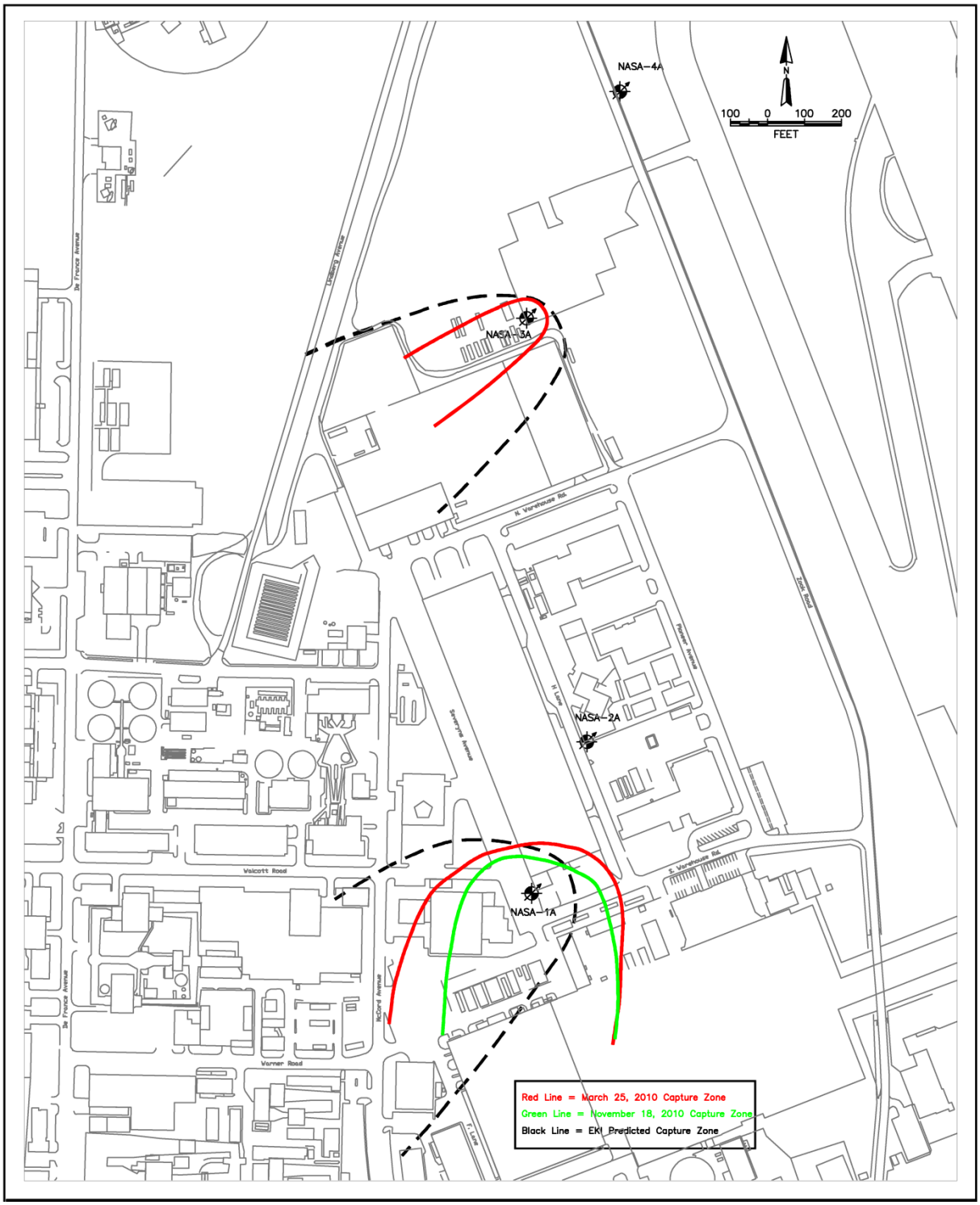


Figure 37
Comparison of Mapped Capture Zones versus Modeled Capture Zone

NASA-2A

NASA-2A was originally intended to be a “contingency” well, dependent on the performance of NASA-1A (EKI, 1995). However, NASA-2A was installed and operations began at the same time as the other NASA extraction wells.

Based on the geologic mapping in the EKI report, NASA-2A is located in the same channel as NASA-1A, approximately 400 feet down-gradient. Prior to installation, additional subsurface investigation was conducted at the proposed location of NASA-2A. Because of a lack of significant coarse-grained material at the original proposed location, the final well location was moved approximately 225 feet “up-channel” (up-gradient).

NASA-2A has historically shown poor performance. Before suspension of pumping on April 28, 2009, this well was cycling at 1.0 gpm (~20 minutes pumping, 60 minutes recovering), compared to the modeled 3 gpm expected extraction rate. Therefore, the capture zone for this well was much smaller than originally anticipated. The relatively poor performance of NASA-2A is most likely because of a combination of the following factors: 1) although sand deposits are abundant at the extraction well location (Figure 22), the majority of the sand is fine-grained; 2) there are numerous, relatively thin clay and silty clay layers present at the extraction well location, suggesting that the lateral continuity of the permeable sand may be limited (i.e., pinching sands, bifurcation, etc.); and 3) the extraction well may be located near the edge of a channel deposit resulting in limited recharge from non-channel deposits (silts and clays).

NASA-2A experienced a spike in COC concentrations after startup. Concentrations of TCE appear to be increasing, while the *cis*-1,2-DCE and vinyl chloride concentration trends are declining. Concentrations of TCE, *cis*-1,2-DCE, vinyl chloride persist above cleanup levels.

However, because this well is down-gradient and down-channel from NASA-1A, which appears to be capturing the majority of groundwater flowing through this “channelized” area, suspension of pumping at NASA-2A is not considered critical. However, NASA is concerned that concentrations of TCE at this location have not shown significant decreases. NASA will evaluate the possibility of relocating NASA-2A to a more productive location in the future.

4.1.2. VTOL Pad/Navy Site 8 North Source Area, Area of Investigation 7

NASA-3A

The location of NASA-3A was selected to control residual TCE contamination from the VTOL Pad/Navy Site 8 North area.

The estimated capture zone for NASA-3A, as interpreted by flow-net analysis on Figures 15 and 18 is somewhat smaller than the capture zone predicted in EKI 1995 report (Figure 37). It is, however, comparable to that predicted in the "*Revised Final Design*" (Smith, 1996). However, limited groundwater elevation data lateral to NASA-3A makes it difficult to accurately define the actual capture zone.

Figure 12 shows the location of NASA-3A and its estimated capture zone in relation to the former excavation boundary of the VTOL Pad/Site 8 North source removal action. NASA-3A is located approximately 110 feet down-gradient from the former spill area, and based on EKI mapping, within the same channel. Based on the proximity of NASA-3A to the spill area, the estimated capture zone, and the channelized flow through the area, it appears that NASA-3A is capturing the majority of contaminated groundwater flowing through this area.

NASA-3A is currently operating at an extraction rate of 6.0 gpm. The proposed extraction rate was 6 gpm. It is likely that this well could sustain pump rates of at least 10 gpm; however, the design installed pump is only capable of a 9.0 gpm maximum rate (60 Hz). Due to pump limitations, the pump will only run at this rate for several hours before it automatically shuts down.

At NASA-3A, concentrations of TCE and *cis*-1,2-DCE have been in steady decline since startup. TCE still persists above cleanup levels. Down-gradient monitoring well 11M03A shows similar trends. Additional COCs 1,1-DCE and 1,1-DCA concentrations are showing slight declining trends at NASA-3A, but remain present at concentrations above cleanup levels.

4.2. Are Capture Zones Adequate?

As previously discussed, the capture zones for NASA-1A and NASA-3A appear to be capturing the majority of groundwater flowing through the two NASA areas of concern. However, based on Figures 38 and 39, a large portion of the plume mass is bypassing the NASA GWTS extraction wells. These wells were not intended to address the larger Regional plume mass.

It appears that WATS and/or RGRP (MEW) extraction wells are not capturing the western margin of the Regional VOC plume (EPA, 2004). Concentrations of TCE and *cis*-1,2-DCE have been increasing in well 14D09A (west of building N211) since the startup of the WATS and RGRP extraction system. In addition, PCE concentrations have been increasing in well 14D28A (east of N211). NASA extraction wells NASA-1A and NASA-2A were not located nor designed to address this contamination.

Similarly, it appears that *cis*-1,2-DCE and vinyl chloride, as well as up-gradient petroleum hydrocarbons, along the eastern margin of the Regional VOC plume may not be fully captured (EPA, 2004).

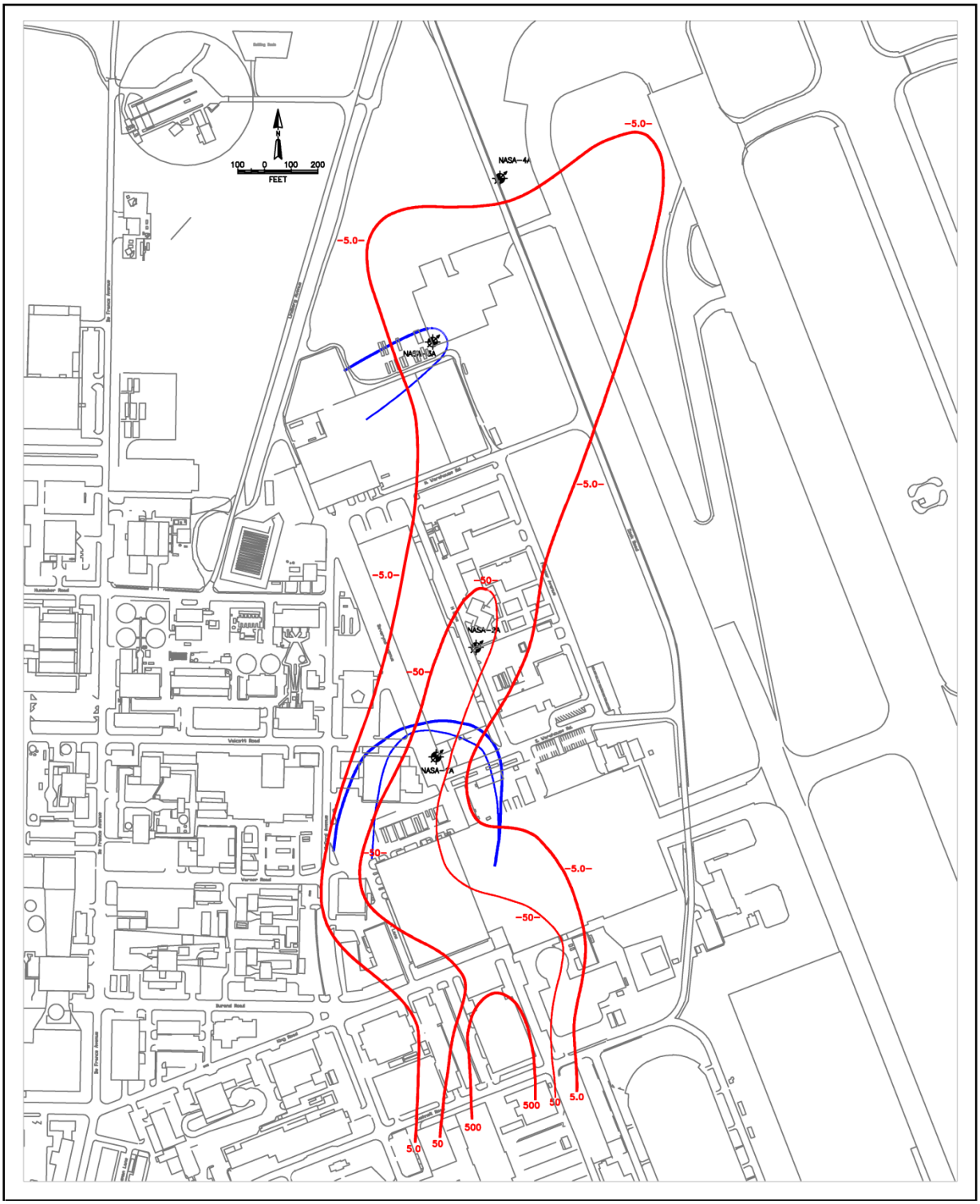


Figure 38
TCE Concentration Contours with Capture Zones

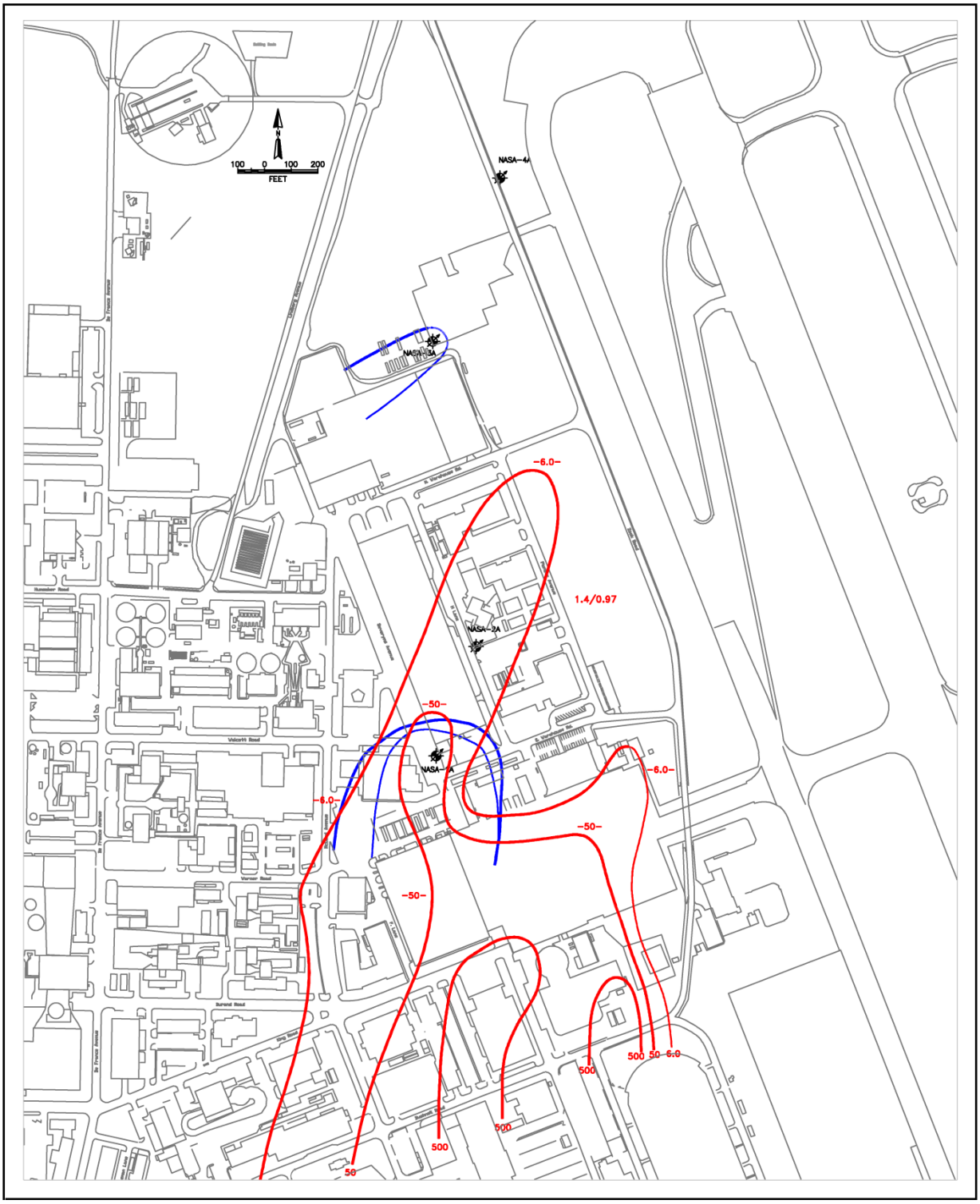


Figure 39
***Cis*-1,2-DCE Concentration Contours with Capture Zones**

4.3. Are Concentrations Decreasing Over Time?

NASA-1A

After an initial spike in concentrations after system start up, TCE and *cis*-1,2-DCE, concentrations in the vicinity of this well have been decreasing (Figure 40). However, the linear trend in concentrations has been relatively flat since mid-2005.

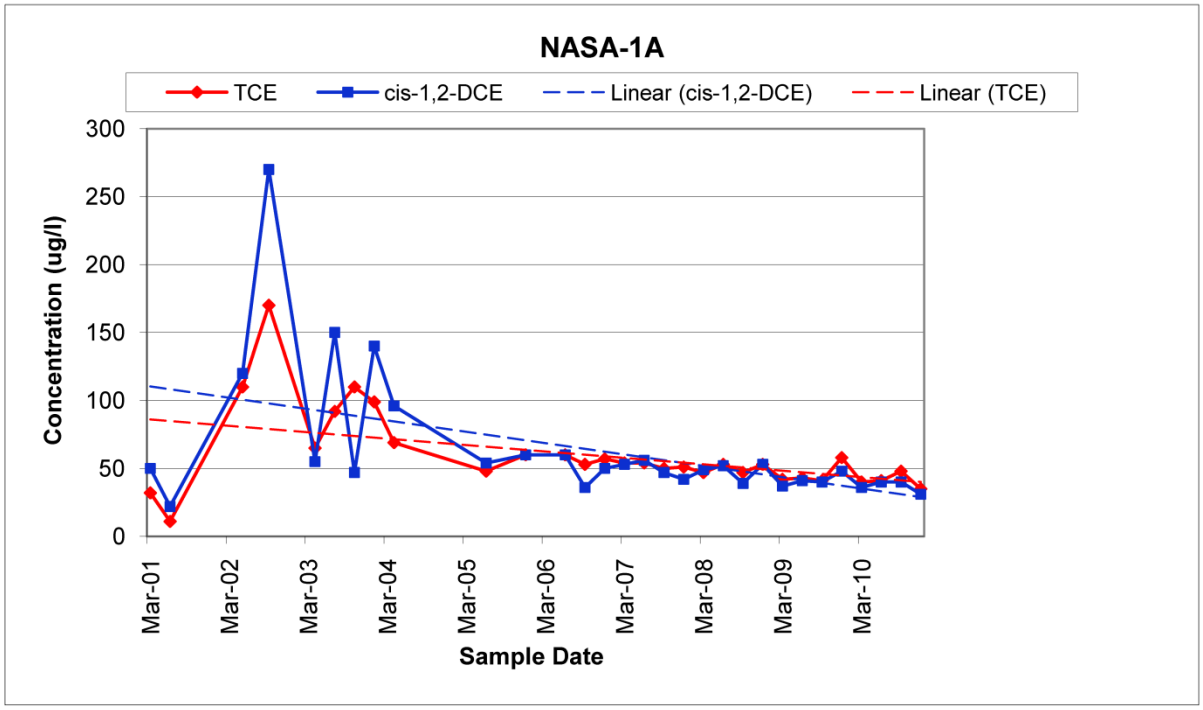


Figure 40
TCE and *cis*-1,2-DCE Concentration-versus-Time Graph
Extraction Well NASA-1A

NASA-2A

After an initial spike in concentrations after system start up, TCE and *cis*-1,2-DCE, concentrations in the vicinity of this well have stabilized. The long-term linear trend of TCE concentrations, as indicated in Figure 41, shows a slight increase. The long-term linear trend of *cis*-1,2-DCE concentrations shows a significant decline.

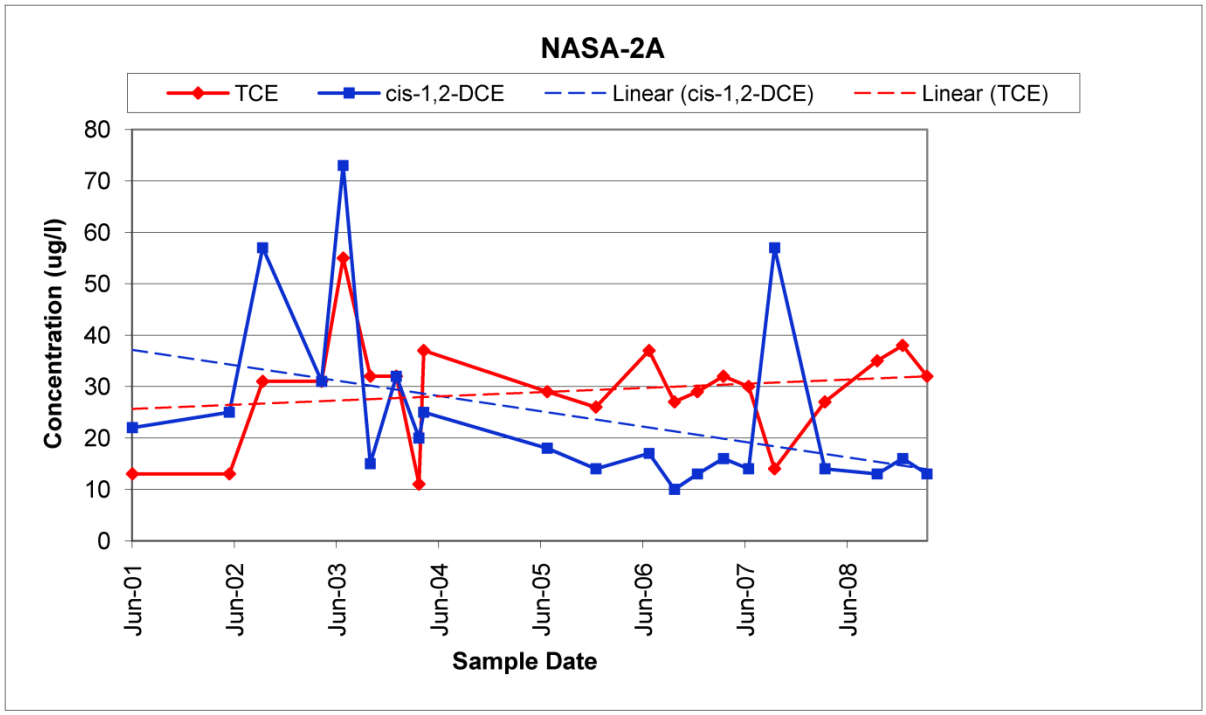


Figure 41
TCE and *cis*-1,2-DCE Concentration-versus-Time Graph
Extraction Well NASA-2A

NASA-3A

Since startup, there have been a significant overall declining trends in TCE and *cis*-1,2-DCE concentrations. Recent sampling events (2006-2009) indicate that the concentration trends may be stabilizing. The trends are illustrated in Figure 42.

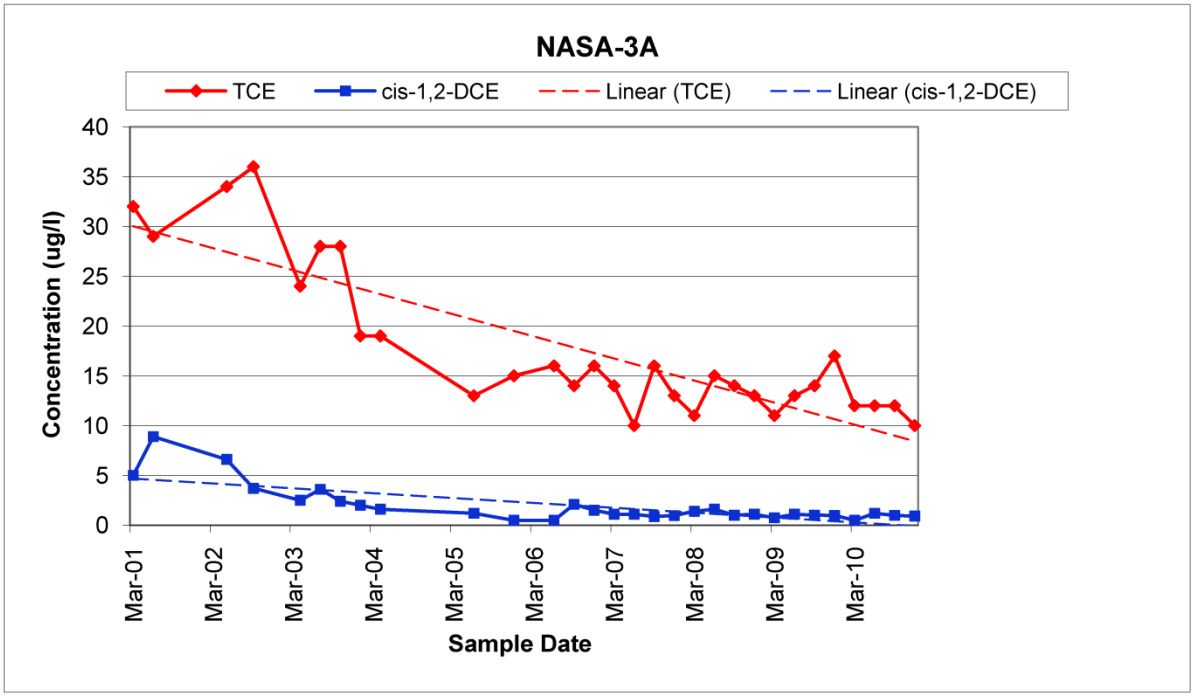


Figure 42
TCE and *cis*-1,2-DCE Concentration-versus-Time Graph
Extraction Well NASA-3A

Concentration Trends at NASA GWTS

The overall trend for total VOC concentrations (EPA 8260 analytes) measured from the influent at NASA's GWTS during monthly NPDES compliance shows a significant decrease since system startup in September, 2001 (Figure 43). A decline of 60 percent has occurred from the highest reported concentration of 197 µg/L (October 2001) to the most recent of 78.20µg/L (December 2010).

TCE concentrations have declined 51 percent from the high 67 µg/L (October 2001) to the most recent of 33 µg/L (December 2010).

Cis-1,2-DCE concentrations have declined 73 percent from the high 95 µg/L (October 2001) to the most recent of 26 µg/L (December 2010).

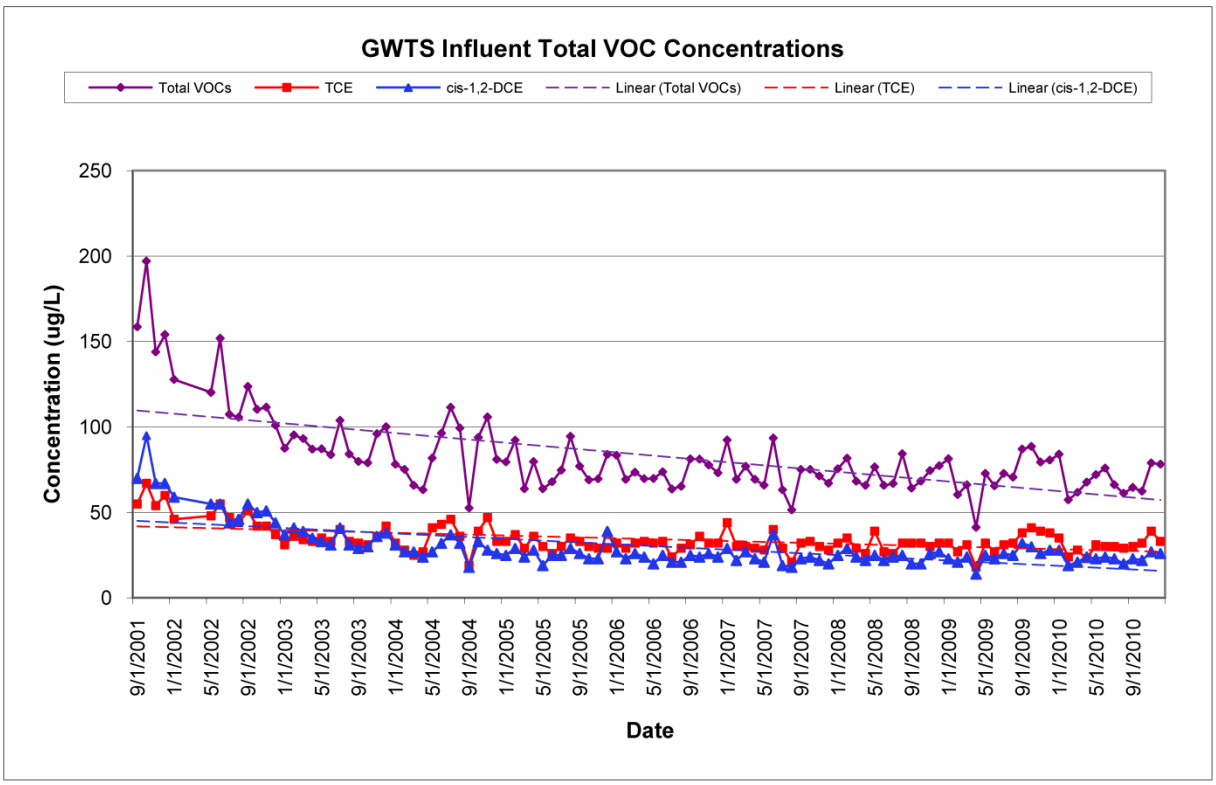


Figure 43
Volatile Organic Compounds Concentration-versus-Time Graph (2001-Present)
NASA Groundwater Treatment System Influent

However, Figure 44 shows that the majority of contaminant reductions occurred from 2001 through 2004. Since the beginning of 2005, concentrations of total VOCS, TCE, and *cis*-1,2-DCE have become relatively stable.

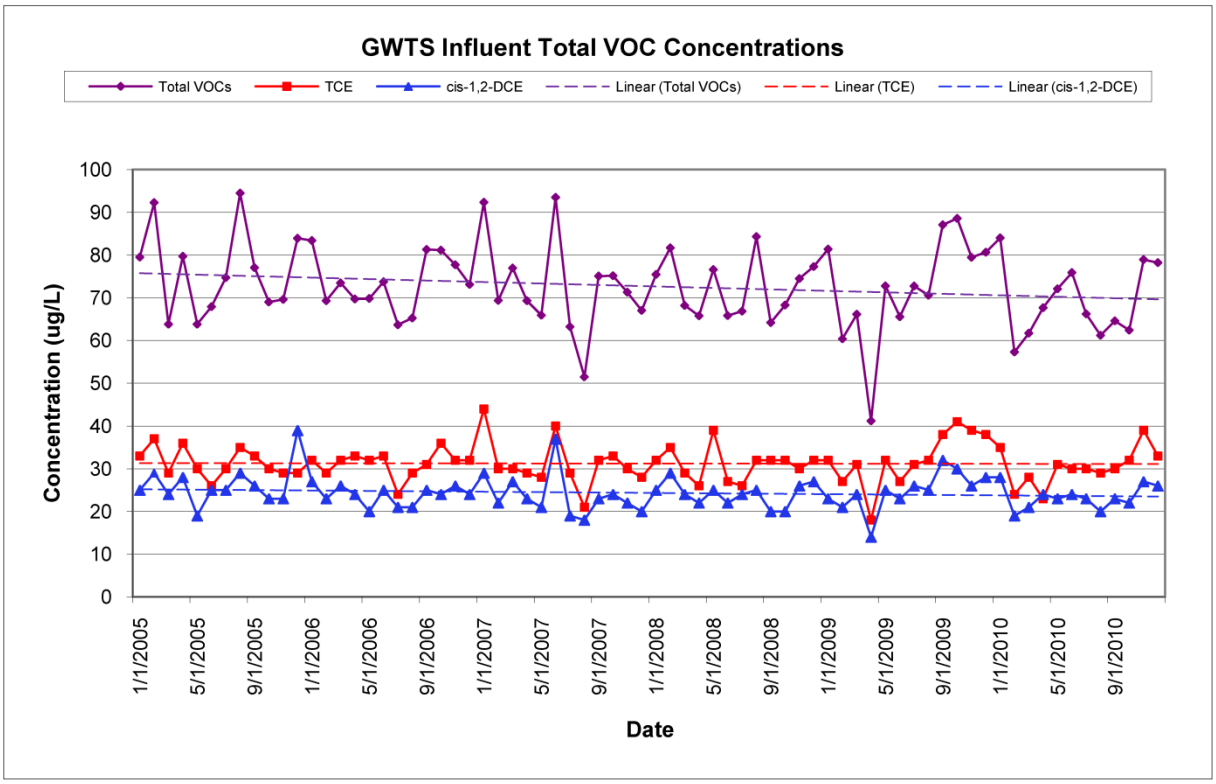


Figure 44
Volatile Organic Compounds Concentration-versus-Time Graph (2005-Present)
NASA Groundwater Treatment System Influent

In-Situ Mass

The following section discusses the procedures and presents the results of calculating the in-situ dissolved mass of TCE, *cis*-1,2-DCE and vinyl chloride in the NASA GWTS area.

The in-situ dissolved mass in the A1 aquifer was estimated for the NASA GWTS area. The estimate is based on the 2010 iso-concentration contours surface area located within the 5 µg/L (TCE), 6 µg/L (*cis*-1,2-DCE) and 0.50 µg/L (vinyl chloride) boundaries (Figures 26, 30, and 34) located within the NASA GWTS area boundary. AUTOCAD was used to measure the surface area between adjacent iso-concentration contours. It was assumed (based on boring log information) that the thickness of the A1 aquifer is 20 feet (generalized thickness from the top of the water table to the bottom of the A1 aquifer). A porosity of 30 percent was used to calculate in-situ water volume. The geometric mean concentration for each iso-concentration contour interval was multiplied by the calculated water volume within that interval to estimate the in-situ mass for the chemicals within an iso-concentration contour interval. Where iso-concentration contours do not increase to the next concentration interval, the interval was taken to be the highest concentration within that interval. The in-situ dissolved mass within each iso-concentration contour interval was then summed to calculate the total analyte dissolved mass within the NASA GWTS area.

The estimated total mass of dissolved TCE in the A1 aquifer of the NASA GWTS area in 2010 was approximately 18.0 pounds, compared to 19.5 pounds estimated for 2009. Although the concentration contours shown in Figure 26 are relatively unchanged from 2009, concentrations of TCE have generally declined across the site, resulting in the drop of in-situ TCE mass. Based on the above in-situ TCE mass estimates, a total of 1.5 pounds of TCE mass was removed from the NASA GWTS area during 2010. Based on monthly flow data and analytical results from the 2010 Annual NPDES report, approximately 2.0 pounds of TCE was removed via groundwater extraction and treatment at the NASA GWTS.

The estimated total mass of dissolved *cis*-1,2-DCE in the A1 aquifer in 2010 was approximately 15.1 pounds, compared to 18.0 pounds estimated for 2009. Although the concentration contours shown in Figure 30 are similar to 2009, concentrations of *cis*-1,2-DCE have generally declined across the site, resulting in the drop of in-situ *cis*-1,2-DCE mass. Based on the above in-situ *cis*-1,2-DCE mass estimates, a total of 2.9 pounds of *cis*-1,2-DCE mass was removed from the NASA GWTS area during 2010. Based on monthly flow data and analytical results from the 2010 Annual NPDES report, approximately 1.6 pounds of *cis*-1,2-DCE was removed via groundwater extraction and treatment at the NASA GWTS

The estimated total mass of dissolved vinyl chloride in the A1 aquifer in 2010 was approximately 1.85 pounds, compared to 1.9 pounds estimated for 2009. Although the concentration contours shown in Figure 34 are similar to 2009, concentrations of vinyl chloride have declined across the site, resulting in the drop of in-situ vinyl chloride mass. Based on the above in-situ vinyl chloride mass estimates, a total of 0.05 pounds of vinyl chloride mass was removed from the NASA GWTS area during 2010. Based on monthly flow data and analytical results from the 2010 Annual NPDES report, approximately 0.02 pounds of vinyl chloride was removed via groundwater extraction and treatment at the NASA GWTS

Based on these calculations, 7.7% of the dissolved in-situ TCE, 16.1% of the dissolved in-situ *cis*-1,2-DCE, and 2.6% of the dissolved in-situ vinyl chloride was removed during 2010. Assuming no contaminant inflow (and other simplifying conditions such as adsorption/desorption, complete capture of the plume, etc.), and using vinyl chloride as the controlling chemical, an additional 39 years of groundwater extraction is required to achieve cleanup (compared to the 20-year estimate in last year's report). However, as previously discussed, VOC inflow onto NASA Ames from existing up-gradient source areas is very likely.

As can be noted from the above discussion, the mass of TCE, *cis*-1,2-DCE, and vinyl chloride removed through groundwater extraction and treatment is not equal to the change in mass determined through the in-situ mass calculation. The in-situ mass calculation is based on a number of assumptions and estimations. Two major assumptions are a uniform aquifer thickness and no in-flow of contaminant mass. Estimations that have a significant impact on the in-situ mass calculation include location of concentration contours (professional judgment applied based on limited data, distance between contoured wells, etc.), the use of geometric means in performing the calculation, and the use of the highest compound concentration in upper range of concentration contours (bias to the high side). Large changes in the calculated in-situ mass can be observed if the concentration of a chemical in just one well changes to above or below a mapped contour interval. In addition, the in-situ mass of TCE concentrations can decrease naturally through chemical degradation. *Cis*-1,2-DCE concentrations can increase through conversion of TCE or decrease through degradation. Vinyl chloride concentrations can increase through degradation of TCE and its daughter products. Therefore, in-situ mass, as calculated using the method described above, provides only a general order of magnitude estimation of the amount of a chemical in the groundwater and can be used as a general indicator for overall conditions and changes in conditions.

5.0 IMPACT OF UP-GRADIENT SOURCES

5.1. Northern WATS Area – MEW and Navy Capture Zones

Based on observed soil and groundwater conditions in the N211 Aircraft Ramp area, NASA reviewed existing data to evaluate the effectiveness of the up-gradient WATS and MEW extraction systems. Based on discrepancies between mapped estimations of MEW and Navy capture zones, discrepancies between estimated groundwater capture efficiencies and observed field conditions, and upon reviewing lithologic logs and concentration-versus-time graphs of nearby wells, NASA believes that contaminated groundwater containing both VOCs and fuels is continuing to by-pass these up-gradient extraction systems. This is also supported by statements contained in the EPA's 5-Year Review (EPA, 2004)

Potential continuing sources into the NASA GWTS area to be considered include:

- Regional VOC Plume – Portions of the Regional Plume by-passing capture in the Northern WATS area (EPA, 2004).

- Building 88 – PCE concentrations in groundwater are increasing in wells 14D28A and 14D36A, which are down-gradient from the Northern WATS area. Building 88 is a potential source of this contamination (EPA, 2004).

- Site 9 – Petroleum hydrocarbons, especially gasoline, appear to be migrating from this area and by-passing capture in the Northern WATS area.

6.0 OTHER 2010 ACTIVITIES

6.1. Center-Wide Groundwater Sampling Program

As part of the ongoing site-wide groundwater monitoring program, additional information is included in this section that discusses areas of contaminated groundwater at the site not associated with the Regional Plume. These areas include the Orion Park plume (AOI 17), the N211 Aircraft Ramp (AOI 3), and AOI 4 contaminated groundwater areas.

6.1.1. Orion Park Plume

The "Orion Park Plume" is located along NASA'S western property boundary and is named after the Navy's Orion Park Housing area, from where it is migrating onto NASA property (see Figure 45). NASA has designated this area as Area of Investigation 17 (AOI 17). The source of this VOC plume has not been identified.

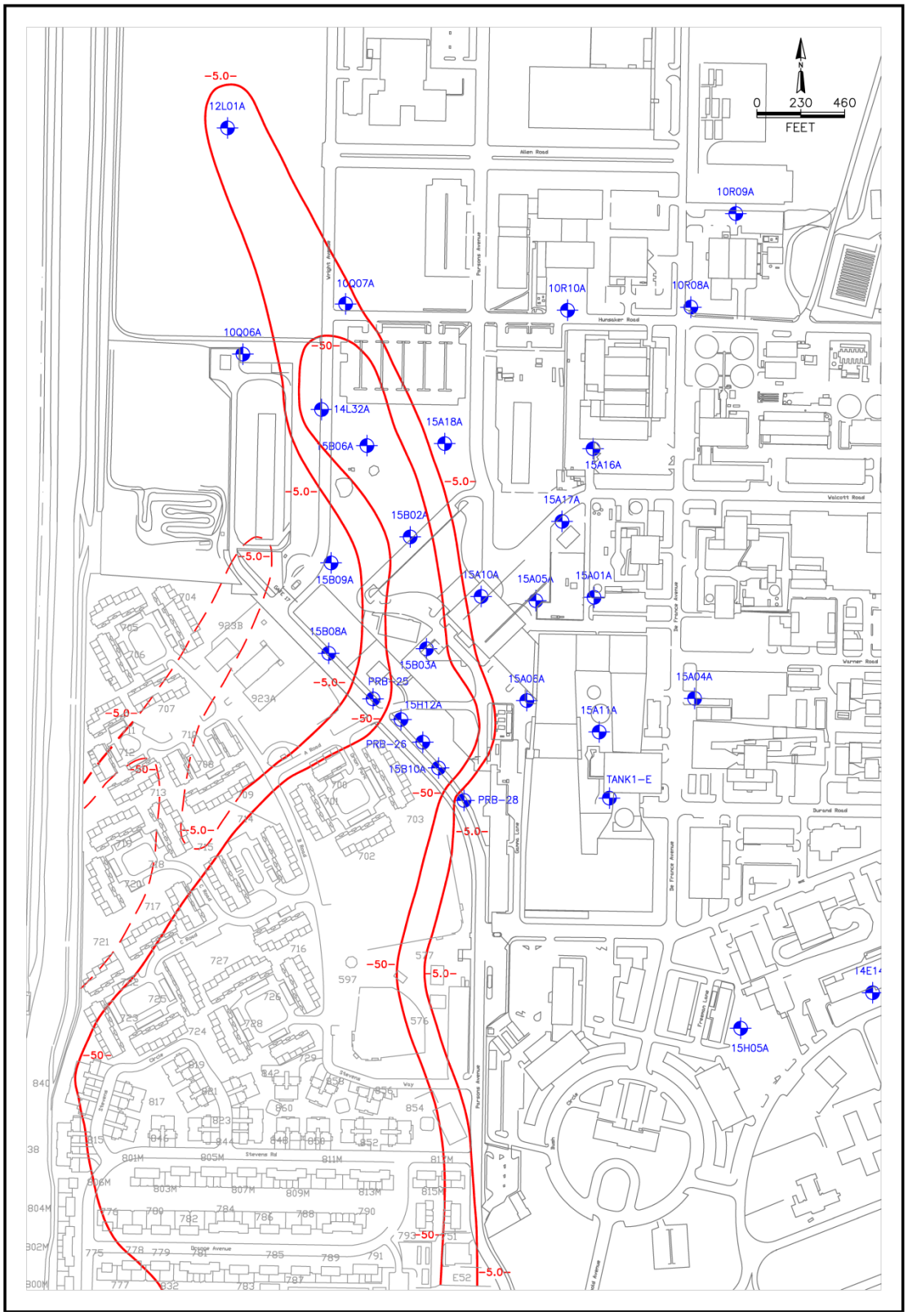


Figure 45
AOI 17 TCE Plume

NASA has requested the Navy, EPA, and the RWQCB to take action to stop the flow of these contaminants onto NASA property. The Navy installed eight new monitoring wells of varying depths to better determine the source of the Orion Park Housing area groundwater plume (TTECI, 2006). Analytical results appear to indicate both an offsite source and an onsite source for the solvent-contaminated groundwater underlying the Housing area.

NASA installed an air sparge barrier along the NASA property boundary (Figure 46) between May and August, 2008. Continuous operation began on September 12, 2008. Details of the air sparge system can be found in "*Draft Boundary Treatment Zone, Air Sparge Barrier, Operation and Maintenance Plan*" (TTEMI, 2008).

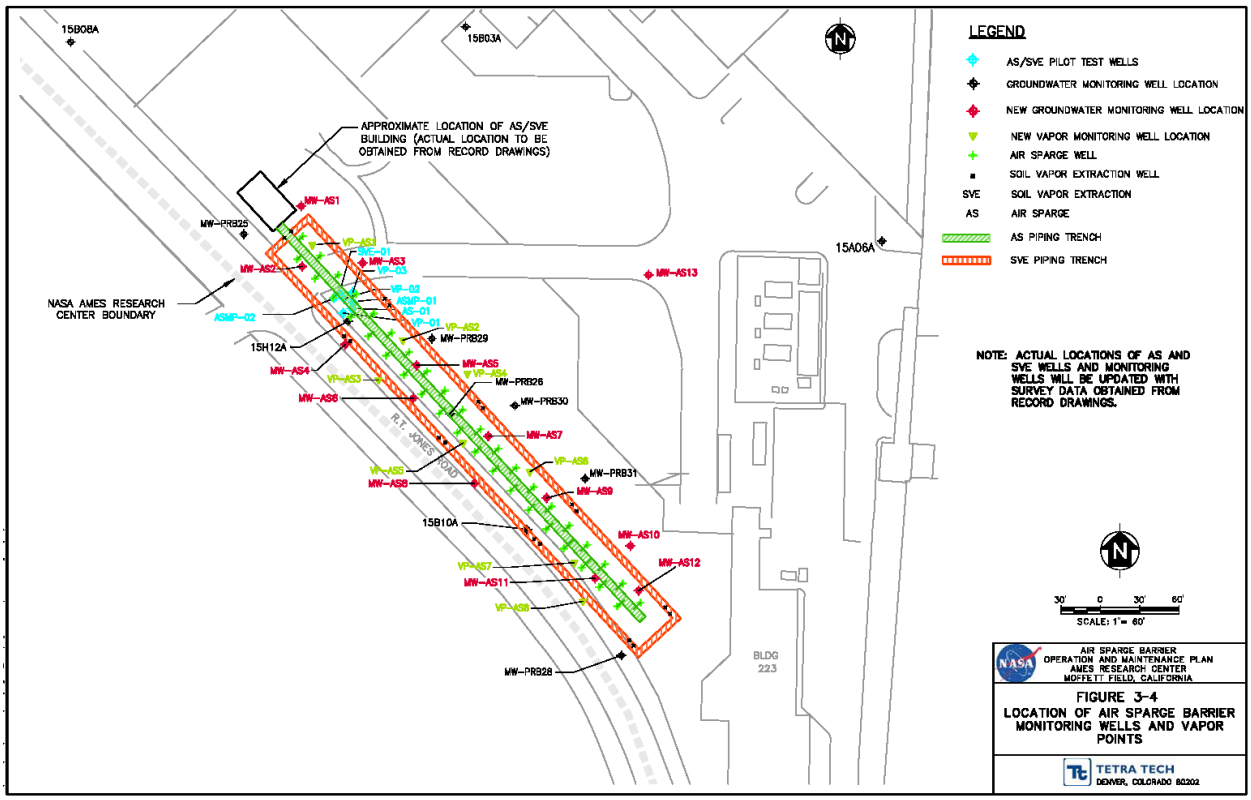


Figure 46
Location of AOI 17 Air Sparge Barrier

The majority of wells in this area were sampled prior to the initiation of sparging. In addition, selected wells are being sampled quarterly and semi-annually to evaluate the effectiveness of the sparging operations. The distribution of TCE in the A1 aquifer is shown in Figure 45. The plume boundary for *cis*-1,2-DCE is similar to that shown for TCE. For a preliminary evaluation of the effectiveness of the air-sparge barrier, a comparison between the pre-sparge and post-sparge analytical results from 2010 are summarized in Table 10.

Table 10
AOI 17 Groundwater VOC Concentrations

Well	Pre-Sparge TCE (µg/L)	Post-Sparge TCE (µg/L)	Pre-Sparge *cis*-1,2-DCE (µg/L)	Post Sparge *cis*-1,2-DCE (µg/L)
15A06A	1.8	<0.50	<0.50	<0.50
15B03A	35	54	5.9	11
15B10A	180	160	71	81
15H12A	240	77	120	63
MW-AS1	220	27	91	13
MW-AS2	78	26	60	23
MW-AS3	200	28	100	11
MW-AS4	150	92	82	80
MW-AS5	220	54	89	29
MW-AS6	240	71	99	44
MW-AS7	180	83	100	38
MW-AS8	210	180	84	110
MW-AS9	130	46	43	24
MW-AS10	34	23	5.0	4.7
MW-AS11	42	41	5.6	8.6
MW-AS12	0.54	<0.50	<0.50	<0.50
MW-AS13	73	68	13	14
PRB-25	14	21	25	29
PRB-26	200	6.3	87	6.8
PRB-28	<0.50	<0.50	<0.50	<0.50
PRB-29	200	37	82	17
PRB-30	150	110	56	61
PRB-31	100	81	22	37

6.1.2. N211 Aircraft Ramp

The N211 Aircraft Ramp is located in the east central portion of NASA Ames (Figure 47). The N211 Aircraft Ramp is bound to the north by AOIs 3 and 3 East. The southeast portion of the Aircraft Ramp is bound by AOI 1. In the past, two groups of USTs were located within AOI 3: two tanks near Building 248A and four tanks under Building N259. Both groups of tanks were known to have leaked aviation gas and/or jet fuel. AOI 1 historically contained four underground storage tanks used to store jet fuel. In 1994, this area was designated an "Area of Investigation" in response to an accidental jet fuel release in May 1992.

Although no additional work has been conducted within the N211 Aircraft Ramp area since 2006, this summary is provided to support the discussion made in Section 2.4.1.1 regarding the absence of TCE in this area. Additional details of the previous investigations can be found in the "*Area of Investigation 3 East, Up-Gradient Source Investigation, Soil and Groundwater Sampling & Analysis Report of Findings"* (ISSi, 2005a), "*2006 Regional Groundwater Remediation Program Progress Report*" (ISSi, 2007b), and the "*Draft Report of Findings, N211 Aircraft Ramp/Northern West-Side Aquifer Treatment System Area, Soil and Groundwater Investigation"* (ISSI, 2006a).

The results of these investigations indicate that a significant source area on the N211 Aircraft Ramp was highly unlikely. It appears that the source of jet fuel in groundwater originates from combined sources, including NASA's AOI 1 and up-gradient Navy sources. Since AOI 1 USTs stored only jet fuel, the gasoline contamination in groundwater appears to originate from up-gradient Navy sources. Based on the results of this investigation, the following conclusions were made:

- Groundwater containing both jet fuel, gasoline and VOCs at concentrations above cleanup levels are migrating past the WATS capture zone in the vicinity of Navy extraction well EA1-6.

- Groundwater containing gasoline, VOCs, and probably jet fuel, at concentrations above cleanup levels are migrating past the WATS capture zone in the vicinity of Navy extraction well EA1-4.

- Groundwater containing concentrations of 1,1-DCA, 1,1-DCE, *cis*-1,2-DCE, TCE, and vinyl chloride in excess of cleanup levels appears to be escaping capture at REG-6A (especially to the west).

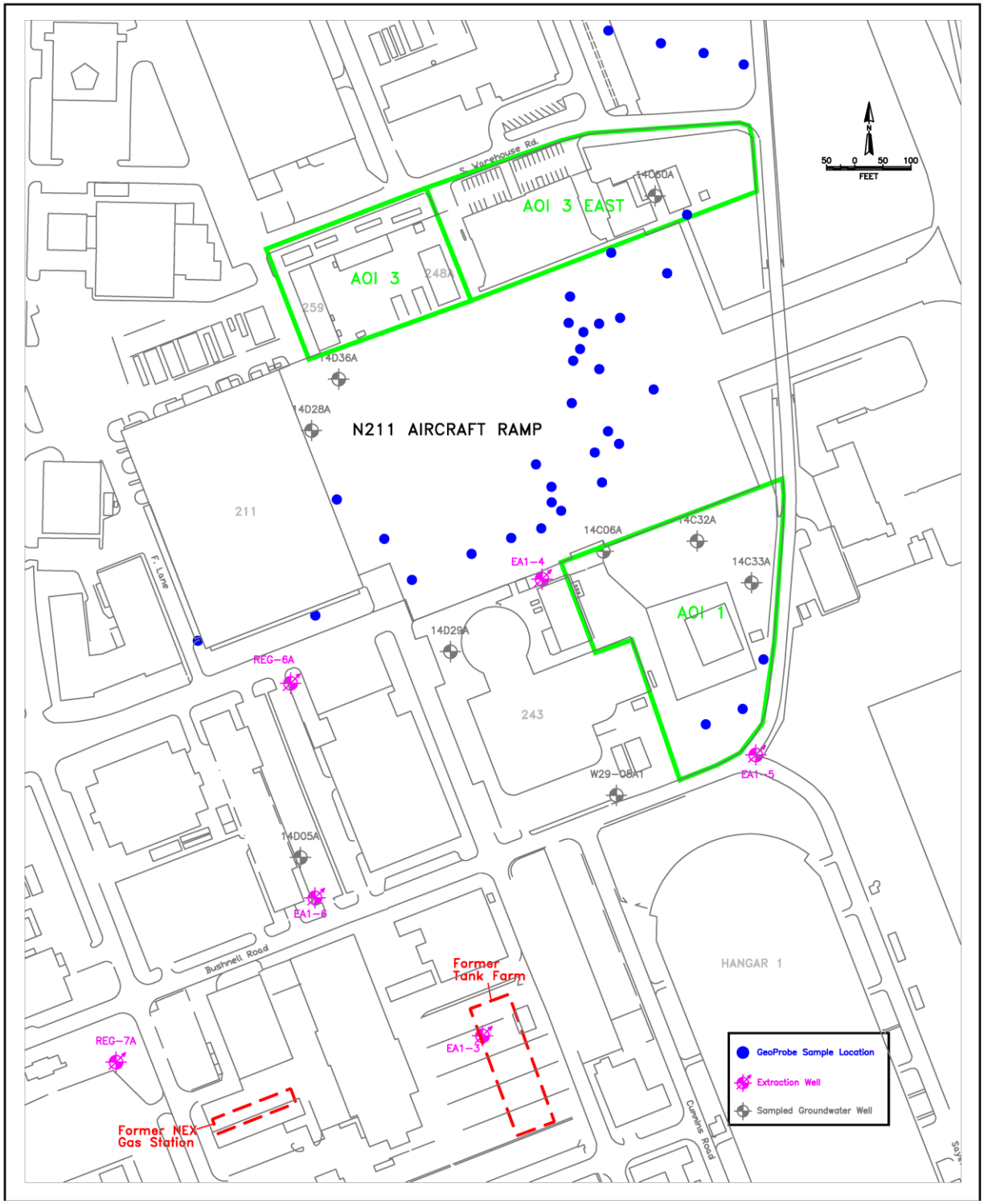


Figure 47
N211 Aircraft Ramp Site Detail

To provide a more comprehensive view of the distribution of VOCs and petroleum hydrocarbons in groundwater at the site, Figure 48 is provided. In this figure, the chemical data gathered during the N211 Aircraft Ramp investigation was combined with the most recent groundwater data from monitoring wells. Figure 52 illustrates the distributions of TCE, *cis*-1,2-DCE, vinyl chloride, jet fuel, and gasoline where they are present at concentrations exceeding cleanup levels.

Figure 48 illustrates that large portions of the plume, both along the western and eastern margins, as well as within the interior of the plume, are escaping capture. Concentrations of TCE and *cis*-1,2-DCE exceeding cleanup levels in well 14D09A (west of building N211) indicate non-capture along the western margin of the plume. Concentrations of *cis*-1,2-DCE and vinyl chloride, as well as co-mingled gasoline and jet fuel in the eastern portion of the plume, reside outside projected capture zones. Furthermore, based on the results of the 2004 and 2006 N211 Aircraft Ramp investigations, VOCs and/or petroleum hydrocarbons are escaping capture in the vicinity of MEW extraction well REG-6A and Navy extraction wells EA1-4 and EA1-5.

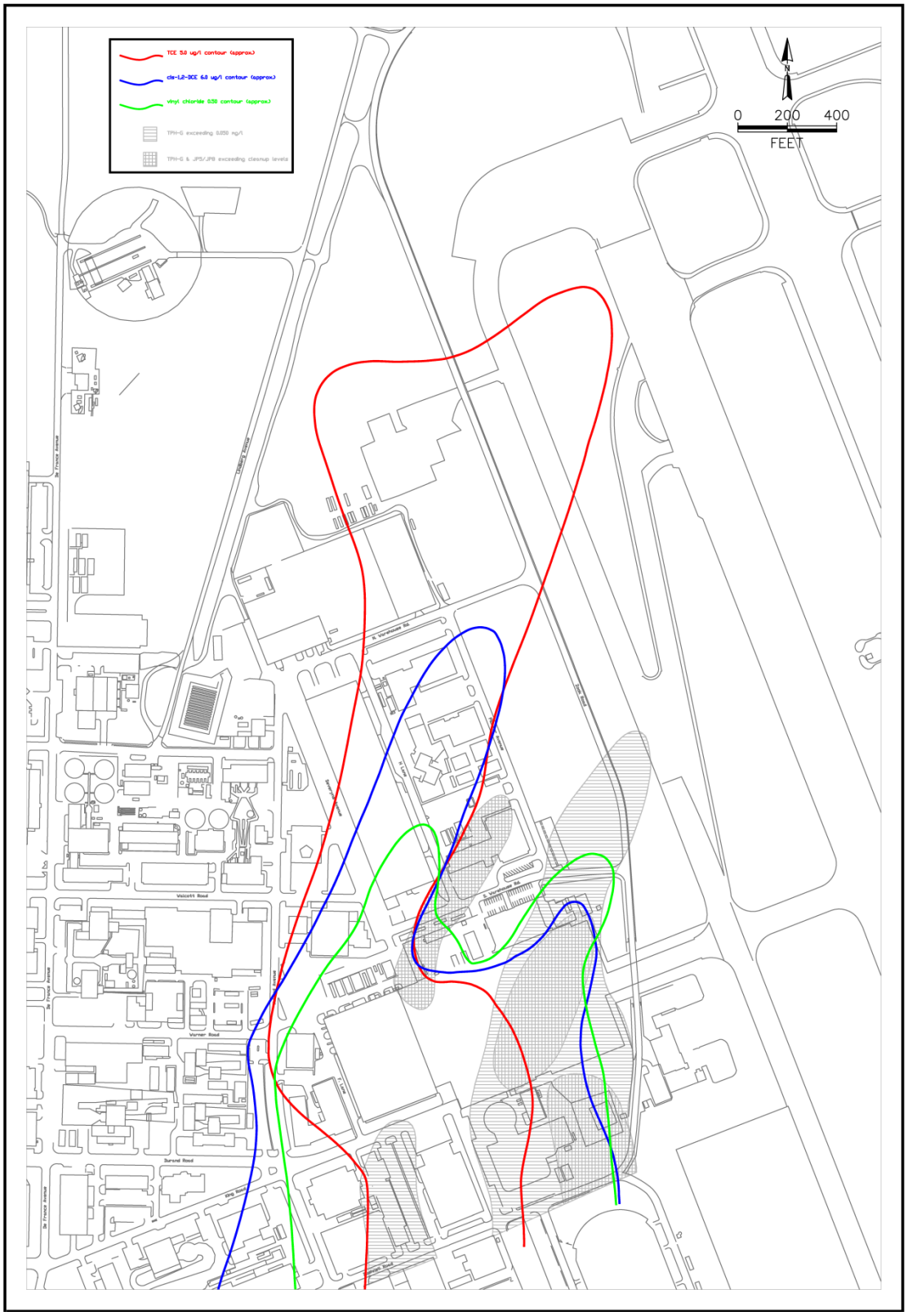


Figure 48
Regional VOC and Fuel Co-Mingled Plumes

6.1.3. Area of Investigation 4

Area of Investigation 4 is located in the southwest portion of the facility and includes the National Full-Scale Aerodynamics Complex (NFAC) wind tunnel testing (Figure 49). Much of AOI 4 is occupied by the NFAC. Surface areas within AOI 4 consist mostly of paved areas for roads and parking lots (asphalt and concrete), gravel- and grass-covered fields, and some light landscaping.

In the "*Final AOI 4 2004 O&M Summary Report*" (ISSi, 2005b), NASA recommended discontinuing the sampling of selected monitoring wells because they had met the monitoring requirements as outlined in the Final O&M Plan. The sampling frequency of the selected wells was reduced to semi-annual, pending approval by the Department of Toxic Substances Control (DTSC). On November 3, 2005, NASA submitted a formal request to discontinue the sampling of wells 15A01A, 15A05A, 15A06A, 15A10A, and 15B02A. The DTSC responded with a November 17, 2005-dated letter that approved the request to discontinue monitoring these wells. The DTSC letter requires that wells 15A11A and Tank1-E continue to be sampled on a quarterly basis until the monitoring requirements of four consecutive quarters of concentrations of chemicals of concern (COCs) below cleanup goals are achieved. The COCs for AOI 4 were identified as BTEX, TPH-G, TPH-D, TPH-JP5/JP8 and TPH-MO. Well 15A04A was also reduced to annual sampling (Quarter 4). On March 14, 2007, DTSC reviewed the "*Area of Investigation 4, 2006 Draft Operation and Maintenance Report*" (ISSi, 2007c) and provided comments (DTSC, 2007). The DTSC stated that the collection on natural attenuation parameters proposed in the 2006 O&M Report was not appropriate at that time. However, the DTSC did approve the termination of groundwater monitoring at well 15A04A.

During 2010, groundwater monitoring wells 15A11A and TANK1-E were sampled quarterly. The analytical results for groundwater samples collected during 2010 are summarized in Table 11. TPH-D, TPH-MO, benzene, ethylbenzene, toluene, and xylenes were not detected in any of the samples and have been omitted from the table. NASA will continue to monitor AOI 4 O&M wells 15A11A and TANK1-E as required by the O&M Agreement.

Table 11
Petroleum Hydrocarbons in Groundwater, AOI 4 Area

Well ID	Date	TPH-JP5/JP8 (µg/l)	TPH-G (µg/l)
15A11A	3/16/2010	220	**79**
15A11A	6/22/2010	440	**<50**
15A11A	9/21/2010	<50	**99**
15A11A	12/13/2010	130	**86**
TANK1-E	3/16/2010	<50	<50
TANK1-E	6/22/2010	<50	<50
TANK1-E	9/21/2010	<50	<50
TANK1-E	12/13/2010	<50	<50
Cleanup Level		**700**	**50**

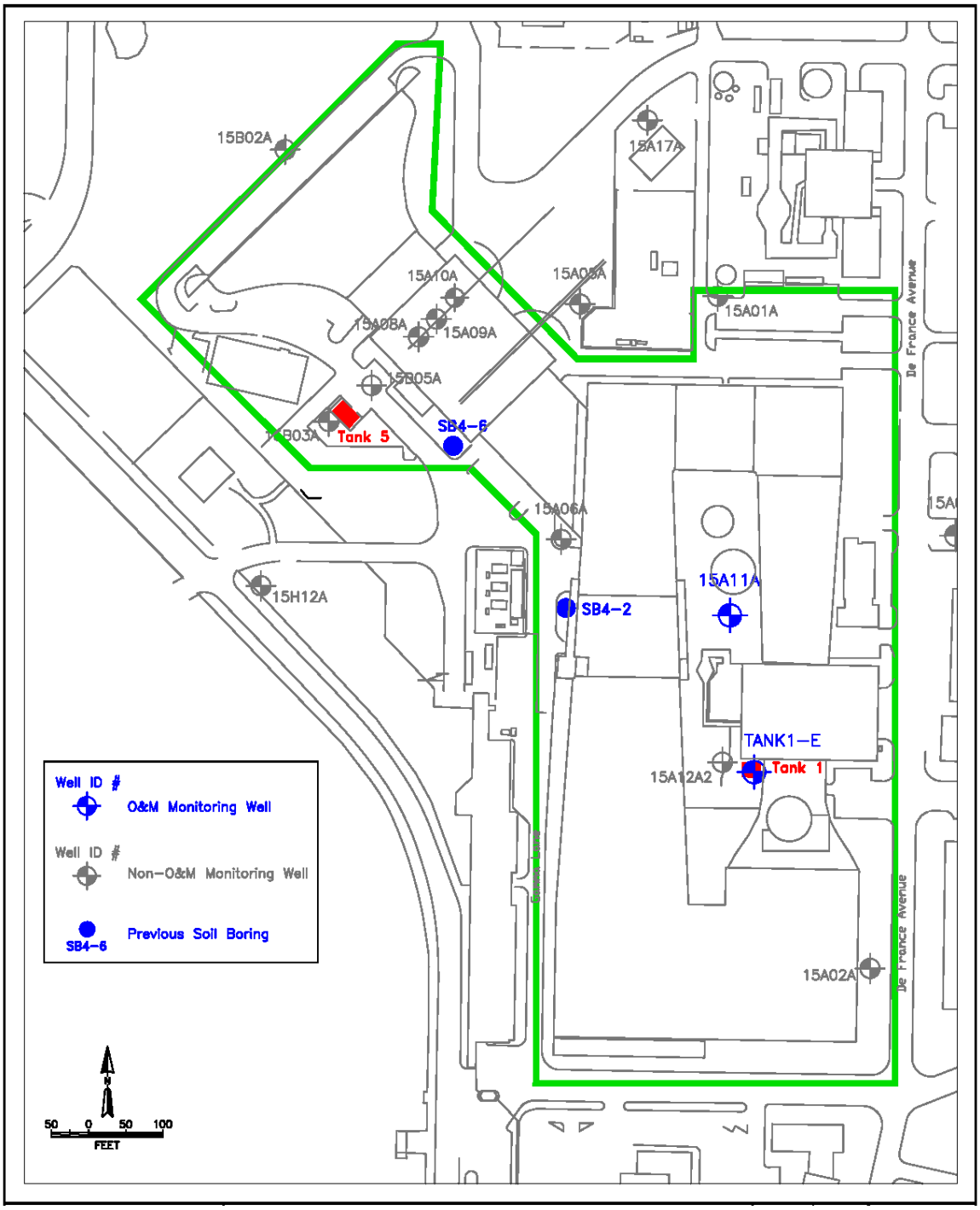


Figure 49
AOI 4 Site Detail

6.2. Treated Effluent Reuse

Previously, treated water from the MEW and NASA groundwater treatment systems was utilized in NASA's Arc Jet Wind Tunnel cooling towers and boiler or discharged to Stevens Creek. A pipeline was constructed in 1998 for diversion of treated groundwater through the onsite Industrial Waste Water Treatment Plant at N271 for treatment prior to reuse by the Arc Jet facility. During 2010, modifications were made to the Industrial Waste Water Treatment Plant, preventing the re-use of the extracted groundwater. NASA anticipates that upon completion of modifications to NASA's Industrial Wastewater Pre-Treatment Facility, reuse will resume in 2011.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the current capture zone analysis and the effectiveness of the current NASA GWTS system configuration, further assessment of the existing hydrogeologic conditions within the NASA GWTS area is appropriate.

Based on the information contained within this report, the following conclusions and recommendations are made:

7.1. Suspected Source Area, Area of Investigation 9

NASA-1A appears to be functioning as intended. Based on capture zone analysis, the majority of contaminated groundwater from the suspected source area is being captured. However, increasing TCE concentrations near down-gradient well NASA-2A suggests that groundwater may be bypassing of this well.

Since down-gradient contingency well NASA-2A is not functioning as intended, NASA has replaced the pump at NASA-1A with a slightly higher capacity pump and has increased the pumping rate of NASA-1A from 6.9 gpm to 7.2 gpm.

NASA intends to identify a more effective location for well NASA-2A using CPT and GeoProbe testing. NASA also intends to install piezometers near NASA-1A to provide additional groundwater level data for better capture zone analysis.

As previously discussed, NASA extraction wells NASA-1A and NASA-2A were not intended to address the larger Regional Plume mass migrating through this area.

7.2. VTOL Pad/Navy Site 8 North Source Area, Area of Investigation 7

NASA-3A is pumping at a rate equal to its design parameters of 6.0 gpm. However, because of the high hydraulic conductivity of the channel deposits in this area and limited extraction rate of the existing pump, draw-down, and therefore the propagation of a capture zone, is limited.

NASA intends to identify a more effective location for well NASA-4A using CPT and GeoProbe testing. NASA also intends to install piezometers near NASA-3A to provide additional groundwater level data for better capture zone analysis.

As previously discussed, NASA extraction wells NASA-3A and NASA-4A were also not intended to address the larger Regional Plume mass migrating through this area.

7.3. Northern WATS Area

It appears that WATS and/or RGRP extraction wells are not capturing the western margin of the Regional Plume (EPA, 2004). Concentrations of *cis*-1,2-DCE have been increasing in well 14D09A (west of building N211) since the startup of the WATS and RGRP extraction systems (Figure 50) and TCE concentrations are relatively consistent. In addition, PCE concentrations have been increasing in well 14D28A (Figure 51). A review of Navy and MEW capture zone analyses indicate that capture of the Regional Plume may not be complete. NASA extraction wells NASA-1A and NASA-2A were not located nor designed to address this contamination.

Similarly, it appears that *cis*-1,2-DCE and vinyl chloride, as well as up-gradient petroleum hydrocarbons, along the eastern margin of the Regional Plume may not be fully captured (EPA, 2004).

The results of NASA's 2006 N211 Aircraft Ramp investigations also suggest that VOCs and/or petroleum hydrocarbons are escaping capture near Navy extraction wells EA1-4 and EA1-5 and MEW extraction well REG-6A.

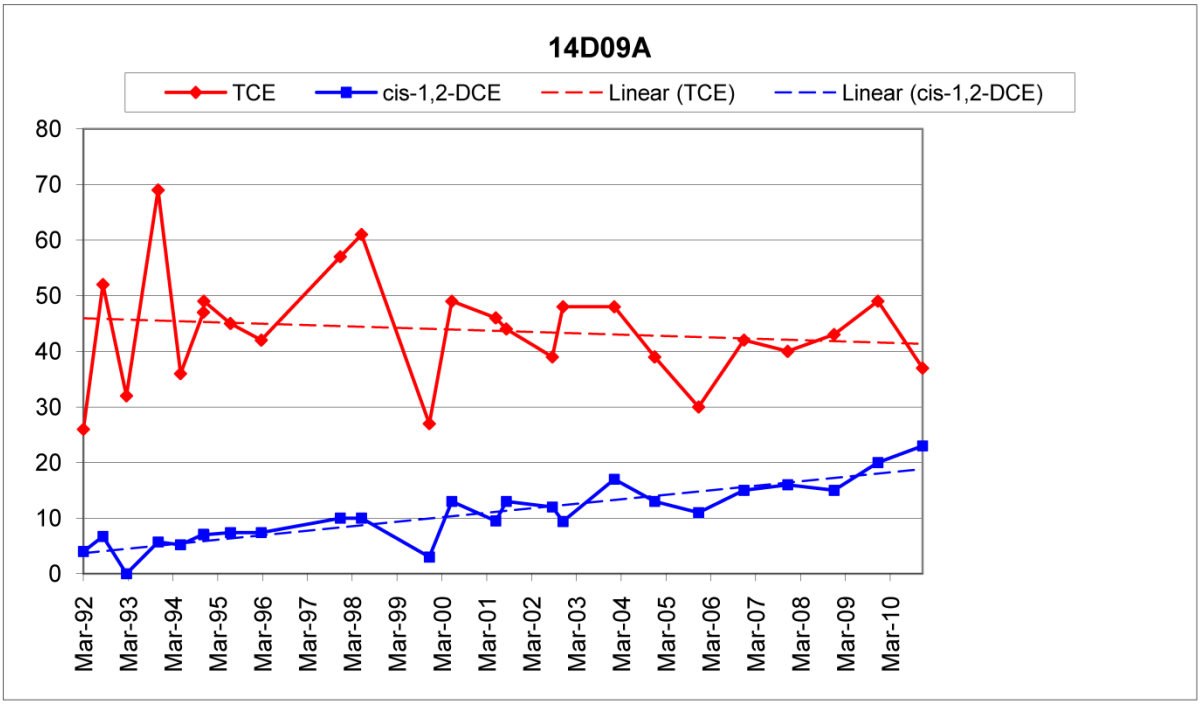


Figure 50
TCE and *cis*-1,2-DCE Concentration-versus-Time Graph, Well 14D09A

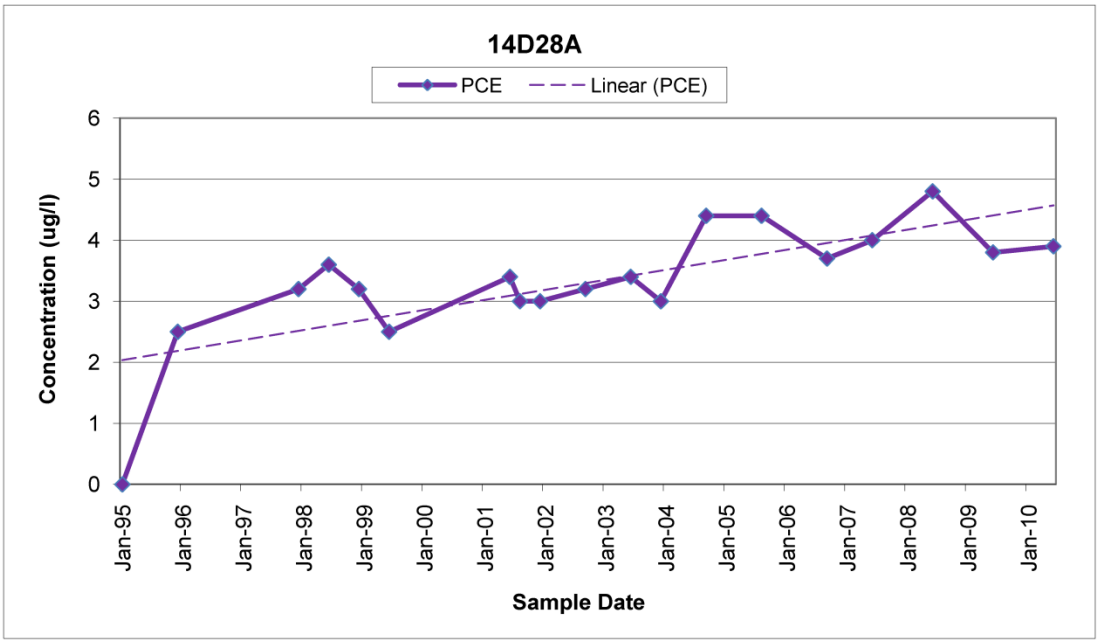


Figure 51
PCE Concentration-versus-Time Graph, Well 14D28A

8.0 FOLLOW-UP ACTIONS

As stated in Section 7, NASA has optimized the performance of extraction wells NASA-1A and NASA-3A to within design limitations, and is proposing the installation of piezometers near these wells to further evaluate the effectiveness of the NASA GWTS and to evaluate potential alternative locations for extraction wells NASA-2A and NASA-4A. NASA anticipates that the investigation will be conducted during 2011.

9.0 UPCOMING 2011 WORK AND PLANNED FUTURE ACTIVITIES

NASA has scheduled the following tasks for completion during 2010/2011:

- Monthly GWTS NPDES influent and effluent sampling in 2011.
- Quarterly GWTS NPDES reporting in April, July, October 2011 and January 2012.
- Annual GWTS NPDES reporting in January 2011 and January 2012.
- Quarterly groundwater sampling in March, June, September, and December 2011.
- Semi-annual site-wide groundwater level measurements in March and November 2011.
- Develop “Sand and Gravel Distribution and Thickness Maps” and geologic cross sections for AOIs 7 and 9 using existing lithologic data in preparation of future piezometers installations and potential extraction well relocation investigations.
- Future installation of piezometers in the vicinity of NASA extraction wells NASA-1A and NASA-3A.
- Future installation of exploratory CPT and GeoProbe borings in the vicinity of existing NASA extraction wells to determine appropriate locations for the replacement of wells NASA-2A and NASA-4A.

10.0 REFERENCES

DMJM, 1997. "*Installation of Monitoring Wells, Soil & Groundwater Sampling at AOIs 3, 6 & the OARF (AOI 11)*."

DTSC, 2007. "*Comments on Draft 2006 Area of Investigation 4 Operations and Maintenance Summary Report*."

EKI, 1992. "*Listing Site Inspection for NASA Ames Research Center, Moffett Field, California.*"

EKI, 1994a. "*Center-Wide Sampling and Analysis Program, Program Overview, NASA Ames Research Center, Moffett Field, California*"

EKI, 1994b. "*Center-Wide Sampling and Analysis Program, Volume VII: Work Plan for Area of Investigation 7, NASA Ames Research Center, Moffett Field, CA*."

EKI, 1995. "*Proposed Locations of NASA Ames Groundwater Extraction Wells in the VTOL Pad and South Navy Warehouse Areas, NASA Ames Research Center, Moffett Field, California*."

EPA, 1989. "*Record of Decision, Fairchild, Intel, and Raytheon Sites, Middlefield/Ellis/ Whisman (MEW) Study Area, Mountain View, California*."

EPA, 2004. "*Final First Five-Year Review Report for Middlefield-Ellis-Whisman (MEW) Superfund Study Area, Mountain View, California*."

ISSi, 2005a. "*Final, Area of Investigation 3 East, Up-Gradient Source Investigation, Soil and Groundwater Sampling and Analysis Report of Findings, August 2005*."

ISSi, 2005b. "*Final AOI 4 2004 O&M Summary Report*."

ISSi, 2006a. "*Sampling and Analysis Plan, N211 Aircraft Ramp/Northern West-Side Aquifer Treatment System Area, Soil and Groundwater Investigation.*"

ISSi, 2006b. "*Draft Report of Findings, N211 Aircraft Ramp/Northern West-Side Aquifer Treatment System Area, Soil and Groundwater Investigation."*

ISSi, 2007a. "*Draft Orion Park/AOI 4 Baseline Groundwater Sampling and Analysis Plan.*"

ISSi, 2007b. "*2006 Regional Groundwater Remediation Program Progress Report*"

ISSi, 2007c. *"Area of Investigation 4, 2006 Draft Operation and Maintenance Report*"

ISSi, 2011. "*2010 Annual NPDES Self-Monitoring Report for the NASA Ames RGRP GWTS.*"

IT, 1991. "*Phase I Characterization Report, NAS Moffett Field, Volume 1, Text, April 1991*."

Locus Technologies, 1999. "*100 Percent Design, NASA-ARC/RGRP Groundwater Treatment System, NASA Ames Research Center, Moffett Field, California*."

NASA, 1994. "*Site 8-North Soil Excavation & Source Removal, NASA Ames Research Center*."

NASA, 1995. "*Storm Drain Channel Soil Sampling*"

NASA, 1998. "*Allocation and Settlement Agreement for MEW Remedial Program Management between the National Aeronautics and Space Administration and Fairchild Semiconductor Corporation, Raytheon Company, and Intel Corporation*."

NASA, 2004. "*Final Operation and Maintenance Plan, Area of Investigation 8, NASA Ames Research Center, Moffett Field, California*"

NASA, 2005a. "*Draft, 2004 Area of Investigation 8 Operation & Maintenance Summary Report, NASA Ames Research Center, Moffett Field, California*."

NASA, 2005b. "*Final Draft, 2004 Area of Investigation 8 Operation & Maintenance Summary Report, NASA Ames Research Center, Moffett Field, California*."

PAI, 2004a. "*Area of Investigation 3 East, Up-Gradient Source Investigation, Soil and Groundwater Sampling & Analysis Report of Findings, NASA Ames Research Center, Moffett Field, California*."

PAI, 2004b. "*Area Of Investigation 3 East, Potential Source Investigation, Report Of Findings*."

PAI, 2005. "*Draft Implementation Report, Area of Investigation AOI6, Surface Soils*."

PRC, 1997. "*West-Side Aquifer Treatment System, Long-Term Groundwater Monitoring Plan*."

SAIC, 1996. "*North Aircraft Ramp Soil Excavation and Source Removal.*"

SAIC, 1997. "*Soil Removal Project, Storm Drain Channel Area of Investigation 6*."

Smith Environmental, 1996. "*Revised Final Design, Regional Ground Water Remediation Program, North of U.S. Highway 101, Middlefield-Ellis-Whisman Site, Mountain View, California*."

TTECI, 2006. "*Draft Groundwater Monitoring Well Installation and Sampling Report (Orion Park Housing Area)*." August 4, 2006.

TTEMI, 2008, "*Draft Boundary Treatment Zone Air Sparge Barrier, Operation and Maintenance Plan*."

APPENDIX A

2010 NASA GWTS NPDES REPORT

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, CA 94035-1000

Reply to Attn of: JQ:237-14

JAN 3 1 2011

Ms. Lourdes Gonzales
Regional Water Quality Control Board
NPDES Division
San Francisco Bay Region
1515 Clay Street, Suite 1400
Oakland, CA 94612

Dear Ms. Gonzales:

Enclosed is the *Draft Annual 2010 Self-Monitoring Report* for NPDES Permit CAG912003. This permit is for the discharge of treated groundwater from the groundwater treatment system located at the National Aeronautics and Space Administration Ames Research Center.

I certify under penalty of law that this document and attachments are prepared under my direction or supervision in accordance with the system designed to assure that qualified personnel gathered and evaluated the information submitted. Based on my inquiry of the person or persons who managed the system, or those persons directly responsible for gathering the information, the information is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing the violations.

If you have any questions, you can contact me at 650-604-0237 or by e-mail at Donald.M.Chuck@nasa.gov.

Cordially,

Donald M. Chuck
Restoration Project Manager
Environmental Management Division

Enclosure

cc: (electronically)
Alana Lee, USEPA
Sarah Kloss, USEPA
Rich Howard, Tech Law, Inc.
Elizabeth Wells, RWQCB

Xavier Bryant, DTSC
Scott Anderson, US Navy
Angela Lind, US Navy
Joyce Adams, Weiss Associates
John Gallinatti, Geosyntec Consultants
Maile Smith, Northgate Environmental Management
Elie Haddad, Haley & Aldrich
Bill Berry, Moffett RAB Community Co-Chair
Lenny Siegel, CPEO
Peter Strauss, PM Strauss and Associates
237-14\A. Clarke
237-14\M. Hightower
237-14\L. Pirbazari
T20G-4\J. Lukas
T20G-4\B. Reddig
File
Chron

National Aeronautics and Space Administration

DRAFT
SELF MONITORING REPORT
ANNUAL 2010

REGIONAL GROUNDWATER REMEDIATION PROGRAM

NPDES PERMIT NUMBER CAG912003

NASA Ames Research Center
Moffett Field, CA

January 2011

SELF MONITORING REPORT
ANNUAL 2010

REGIONAL GROUNDWATER REMEDIATION PROGRAM

NPDES PERMIT NUMBER CAG912003

NASA Ames Research Center
Moffett Field, California

Prepared by:

Mail Stop T20G-4
NASA Ames Research Center
Moffett Field, California 94035-1000

Prepared for:

NASA Ames Research Center
Environmental Management Division
Mail Stop N237-1
Moffett Field, California 94035-1000

January 2011

1.0 INTRODUCTION

The Environmental Management Division at National Aeronautics and Space Administration (NASA) Ames Research Center (NASA Ames) has requested Integrated Science Solutions, Inc. (ISSi) to prepare this Annual Report for the NASA Ames Groundwater Treatment System (GWTS) located at the corner of North Warehouse Road and H Lane at Moffett Field, California. This Annual Report was prepared in accordance with the Self-Monitoring Program reporting requirements contained in the National Pollutant Discharge Elimination System (NPDES) Permit Number CAG912003, (VOC General Permit, Order R2-2009-0059, CIWQS Place Identification 243875) issued by the California Regional Water Quality Control Board (RWQCB) to NASA on December 3, 2009. This Annual Report details the results of water quality analyses and operational data obtained from the NASA Ames GWTS during calendar year 2010.

2.0 BACKGROUND

Groundwater extracted from extraction wells NASA-1A and NASA-3A is pre-filtered by two 25-micron bag filters operating in parallel, prior to passing through two 5,000-pound granulated activated carbon (GAC) vessels operating in series. Treated groundwater is then discharged to Stevens Creek in accordance with the NPDES permit. Figure 1 shows the locations of the treatment system outfall and discharge route to Stevens Creek. Figure 2 details the treatment process and influent and effluent sample points. The construction of the NASA Ames GWTS was completed in August 2001 and operations began on September 10, 2001. Groundwater extraction from wells NASA-2A and NASA-4A was suspended on April 18, 2009.

3.0 SYSTEM OPERATIONAL STATUS, CALENDAR YEAR 2010

The NASA Ames GWTS was fully operational for 92% of calendar year 2010 and partially operational (at least one extraction well operating) for 99% of the year.

3.1 System-Wide Shutdowns

During 2010, the NASA Ames GWTS experienced several automatic system-wide shutdowns. These shutdowns resulted from problems with electrical systems and/or power disruptions. Dates and durations of these shutdowns are detailed below in Table 1.

Table 1

2010 NASA Ames GWTS
System Shutdown Data

Date(s)	Duration (hours)	Cause
1/28/10	10	Electrical Problem (NASA-1A only)
1/30/10 – 2/1/10	43	Electrical Problem (NASA-1A only)
2/4/10 – 2/7/10	63	Electrical Problem (NASA-1A only)
2/7/10 – 2/8/10	33	Electrical Problem
2/10/10 – 2/12/10	20	Electrical Problem (NASA-1A only)
2/14/10 – 3/22/10	426	Unknown Electrical Problem (NASA-3A only)
2/15/10 – 2/16/10	29	Electrical Problem
2/23/10	6	Electrical Problem
3/7/10	7	Electrical Problem
4/7/10	7	Electrical Problem (NASA-1A only)
4/8/10	1	Electrical Problem
4/12/10 – 4/13/10	22	Electrical Problem (NASA-3A only)
4/20/10	2	Electrical Problem (NASA-1A only)
4/21/10 – 4/22/10	15	Electrical Problem (NASA-1A only)
4/30/10	2	Electrical Problem (NASA-1A only)
5/10/10 – 5/11/10	13	Electrical Problem (NASA-1A only)
10/8/10	5	Electrical Problem (NASA-1A only)
10/21/10	5	Electrical Problem (NASA-1A only)
12/11/10 – 12/13/10	44	Electrical Power Disruption to GWTS

3.2 Quarter 3, 2010 Carbon Replacement

On August 9, 2010, the granulated activated carbon (GAC) within vessel GAC-551 was replaced (see Figure 2). Vessel GAC-551 served as the secondary GAC vessel from September 30, 2008 to August 6, 2009 (10 months of service) and served as the primary GAC vessel from August 6, 2009 to August 9, 2010 (12 months of service). No system shutdown was required during the carbon replacement.

3.3 Suspension of Pumping at NASA-2A and NASA-4A

On April 28, 2009, after discussions with the US EPA and California Regional Water Quality Control Board, NASA suspended operation of extraction wells NASA-2A and NASA-4A. As discussed in NASA's "*2008 Draft Regional Groundwater Remediation Program Progress Report,*" the performance of these wells had been less than designed and anticipated. In addition, groundwater extracted from NASA-4A had been below cleanup levels.

The extraction rates from wells NASA-1A and NASA-3A were adjusted to maintain NASA's 15 gallons per minute (gpm) discharge limit. NASA-1A is currently operating at 8 gpm and NASA-3A is operating at 6 gpm. Wells NASA-2A and NASA-4A are turned on periodically to maintain operability.

3.4 VOC Mass Removal

During calendar year 2010, the NASA Ames GWTS removed a total of 4.55 pounds of Volatile Organic Compounds (VOCs) from 7,852,577 gallons of groundwater. Table 2 summarizes the volume of groundwater and VOC mass removal for the NASA Ames GWTS.

Table 2

2010 NASA Ames GWTS Flow and Mass Removal Data

Month	Total System Influent (gallons)	Average Flow (gpd)	Average Flow (gpm)	Influent VOC Concentration (µg/L)	Total VOC Mass Removed (pounds)
January	675,095	21,777	15.12	84.01	0.47
February	476,081	17,003	11.81	57.30	0.23
March	763,246	24,641	17.10	61.70	0.39
April	631,555	21,052	14.62	67.66	0.36
May	672,258	21,686	15.06	72.07	0.40
June	659,216	21,974	15.26	75.88	0.42
July	671,543	21,663	15.04	66.19	0.37
August	671,287	21,654	15.04	61.19	0.34
September	646,689	21,556	14.97	64.58	0.36
October	672,290	21,687	15.06	62.40	0.35
November	658,381	21,946	15.24	78.93	0.43
December	654,936	21,127	14.67	78.20	0.43
Yearly Average	**654,381**	**21,514**	**14.94**	**69.18**	**0.38**
Yearly Sum	**7,852,577**	**---**	**---**	**---**	**4.55**

gpd = gallons per day
gpm = gallons per minute
µg/L = micrograms per liter

4.0 WATER QUALITY ANALYSES

Table 3 summarizes the results of quarterly VOC analyses of influent and effluent water samples collected from the NASA Ames GWTS during calendar year 2010. Laboratory-certified analytical reports can be found with the previously submitted Quarterly Reports. The influent and effluent sample points are shown in Figure 2.

Table 3

2010 NASA Ames GWTS Analytical Results
Volatile Organic Compounds
First Quarter 2010

Sample Location	Sample Date	1,1-DCA (µg/L)	1,1-DCE (µg/L)	*cis*-1,2-DCE (µg/L)	TCE (µg/L)	Other VOCs (µg/L)
NASA-I	1/25/10	4.3	10	28	35	*trans*-1,2-DCE = 1.6 1,1,1-TCA = 0.74[J] Freon 11 = 1.0[J] Freon 113 = 2.4[J] Vinyl Chloride = 0.97
NASA-E	1/25/10	ND	ND	ND	ND	ND
NASA-I	2/25/10	4.2	3.4	19	24	*trans*-1,2-DCE = 2.9 Freon 113 = 3.8[J]
NASA-E	2/25/10	ND	ND	ND	ND	ND
NASA-I	3/24/10	3.3	5.8	21	28	*trans*-1,2-DCE = 0.59[J] 1,1,1-TCA = 0.65[J] Freon 11 = 0.66[J] Freon 113 = 1.7[J]
NASA-E	3/24/10	ND	ND	ND	ND	ND

NASA-I = Influent
NASA-E = Effluent
ND = Not Detected
цg/L = micrograms per liter
1,1-DCA = 1,1-Dichloroethane
1,1-DCE= 1,1-Dichloroethene
cis-1,2-DCE = cis-1,2-Dichloroethene
TCE = Trichloroethene

VOC = Volatile Organic Compound
trans-1,2-DCE = *trans*-1,2- Dichloroethene
1,1,1-TCA = 1,1,1-Trichloroethane
Freon 11 = Trichlorofluoromethane
Freon 113 = 1,1,2-Trichloro-1,2,2-trifluoroethane
[J] = detected, but below the Report Limit; therefore, result is an estimated concentration

Table 3 (continued)

2010 NASA Ames GWTS Analytical Results
Volatile Organic Compounds
Second Quarter 2010

Sample Location	Sample Date	1,1-DCA (µg/L)	1,1-DCE (µg/L)	*cis*-1,2-DCE (µg/L)	TCE (µg/L)	Other VOCs (µg/L)
NASA-I	4/21/10	4.4	9.7	24	23	*trans*-1,2-DCE = 0.91[J] 1,1,1-TCA = 0.79[J] Freon 11 = 0.86[J] Freon 113 = 4.0[J]
NASA-E	4/21/10	ND	ND	ND	ND	ND
NASA-I	5/25/10	3.6	5.5	23	31	*trans*-1,2-DCE = 0.86[J] 1,1,1-TCA = 0.68[J] Freon 11 = 0.63[J] Freon 113 = 6.8[J]
NASA-E	5/25/10	ND	ND	ND	ND	ND
NASA-I	6/23/10	3.7	6.1	24	30	*trans*-1,2-DCE = 0.77[J] 1,1,1-TCA = 0.61[J] Freon 11 = 0.80[J] Freon 113 = 9.9[J]
NASA-E	6/23/10	ND	ND	ND	ND	ND

NASA-I = Influent
NASA-E = Effluent
ND = Not Detected
µg/L = micrograms per liter
1,1-DCA = 1,1-Dichloroethane
1,1-DCE= 1,1-Dichloroethene
cis-1,2-DCE = cis-1,2-Dichloroethene
TCE = Trichlororethene

VOC = Volatile Organic Compound
trans-1,2-DCE = *trans*-1,2- Dichloroethene
1,1,1-TCA = 1,1,1-Trichloroethane
Freon 11 = Trichlorofluoromethane
Freon 113 = 1,1,2-trichloro-1,2,2-trifluoroethane
[J] = detected, but below the Report Limit; therefore, result is an estimated concentration

Table 3 (continued)

2010 NASA Ames GWTS Analytical Results
Volatile Organic Compounds
Third Quarter 2010

Sample Location	Sample Date	1,1-DCA (µg/L)	1,1-DCE (µg/L)	cis-1,2-DCE (µg/L)	TCE (µg/L)	Other VOCs (µg/L)
NASA-I	7/22/10	3.2	6.5	23	30	*trans*-1,2-DCE = 0.97[J] 1,1,1-TCA = 0.52[J] Freon 113 = 1.4[J] Vinyl Chloride = 0.60
NASA-E	7/22/10	ND	ND	ND	ND	ND
NASA-I	8/24/10	3.0	5.0	20	29	Chloromethane = 0.60[J] *trans*-1,2-DCE = 0.73[J] Freon 11 = 0.61[J] Freon 113 = 1.7[J] Vinyl Chloride = 0.55
NASA-E	8/24/10	ND	ND	ND	ND	ND
NASA-I	9/27/10	2.8	5.3	23	30	*trans*-1,2-DCE = 0.77[J] 1,1,1-TCA = 0.40[J] Freon 11 = 0.61[J] Freon 113 = 1.7[J]
NASA-E	9/27/10	ND	ND	ND	ND	ND

NASA-I = Influent
NASA-E = Effluent
ND = Not Detected
µg/l = micrograms per liter
1,1-DCA = 1,1-Dichloroethane
1,1-DCE= 1,1-Dichloroethene
cis-1,2-DCE = cis-1,2-Dichloroethene
TCE = Trichlororethene

VOC = Volatile Organic Compound
trans-1,2-DCE = *trans*-1,2- Dichloroethene
1,1,1-TCA = 1,1,1-Trichloroethane
Freon 11 = Trichlorofluoromethane
Freon 113 = 1,1,2-trichloro-1,2,2-trifluoroethane
[J] = detected, but below the Report Limit; therefore, result is an estimated concentration

Table 3 (continued)

2010 NASA Ames GWTS Analytical Results
Volatile Organic Compounds
Fourth Quarter 2010

Sample Location	Sample Date	1,1-DCA (µg/L)	1,1-DCE (µg/L)	cis-1,2-DCE (µg/L)	TCE (µg/L)	Other VOCs (µg/L)
NASA-I	10/25/10	3.0	5.4	22	32	ND
NASA-E	10/25/10	ND	ND	ND	ND	ND
NASA-I	11/22/10	3.4	5.9	27	39	*trans*-1,2-DCE = 0.86[J] Freon 11 = 0.57[J] Freon 113 = 2.2[J]
NASA-E	11/22/10	ND	ND	ND	ND	ND
NASA-I	12/13/10	3.7	8.8	26	33	*trans*-1,2-DCE = 0.92[J] Freon 11 = 0.81[J] Freon 113 = 3.0[J] Vinyl Chloride = 0.57
NASA-E	12/13/10	ND	ND	ND	ND	ND

NASA-I = Influent
NASA-E = Effluent
ND = Not Detected
µg/l = micrograms per liter
1,1-DCA = 1,1-Dichloroethane
1,1-DCE= 1,1-Dichloroethene
cis-1,2-DCE = cis-1,2-Dichloroethene
TCE = Trichlororethene
VOC = Volatile Organic Compound
trans-1,2-DCE = *trans*-1,2- Dichloroethene
Freon 11 = Trichlorofluoromethane
Freon 113 = 1,1,2-trichloro-1,2,2-trifluoroethane
[J] = detected, but below the Report Limit; therefore, result is an estimated concentration

Table 4 summarizes the results of petroleum hydrocarbon and related compounds analyses.

Table 4

2010 NASA Ames GWTS Analytical Results
Petroleum Hydrocarbons and Related Compounds

Sample Location	Sample Date	Total Petroleum Hydrocarbons (µg/L)	BTEX (µg/L)	MTBE (µg/L)	Fuel Oxygenates (µg/L)
NASA-I	1/25/10	ND	ND	ND	---
NASA-E	1/25/10	ND	ND	ND	---
NASA-I	2/25/10	ND	ND	ND	---
NASA-E	2/25/10	ND	ND	ND	---
NASA-I	3/24/10	ND	ND	ND	---
NASA-E	3/24/10	ND	ND	ND	---
NASA-I	4/21/10	ND	ND	ND	---
NASA-E	4/21/10	ND	ND	ND	---
NASA-I	5/25/10	ND	ND	ND	---
NASA-E	5/25/10	ND	ND	ND	---
NASA-I	6/23/10	ND	ND	ND	ND
NASA-E	6/23/10	ND	ND	ND	ND
NASA-I	7/22/10	ND	ND	ND	---
NASA-E	7/22/10	ND	ND	ND	---
NASA-I	8/24/10	ND	ND	ND	---
NASA-E	8/24/10	ND	ND	ND	---
NASA-I	9/27/10	ND	ND	ND	---
NASA-E	9/27/10	ND	ND	ND	---
NASA-I	10/25/10	ND	ND	ND	---
NASA-E	10/25/10	ND	ND	ND	---
NASA-I	11/22/10	ND	ND	ND	---
NASA-E	11/22/10	ND	ND	ND	---
NASA-I	12/13/10	ND	ND	ND	DIPE = 1.4
NASA-E	12/13/10	ND	ND	ND	ND

NASA-I = Influent
NASA-E = Effluent
ND = Not Detected
-- = Analysis/analyses not required
Total Petroleum Hydrocarbons includes motor oil, diesel, JP4/5/8, and gasoline
BTEX = Benzene, Toluene, Ethylbenzene, Xylenes
MTBE = Methyl Tertiary Butyl Ether
Fuel Oxygenates = TAME, DIPE, ETBE, TBA, Ethanol, and Methanol
DIPE = Di-isopropyl Ether

Table 5 summarizes the analytical results of the detected Priority Pollutant Metals (triennial sampling requirement).

Table 5

2010 NASA Ames GWTS Analytical Results
Detected Priority Pollutant Metals

Sample Location	Sample Date	Arsenic (µg/L)	Copper (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Thallium (µg/L)	Zinc (µg/L)
NASA-E	12/13/10	1.7	1.2	5.5	2.3[J]	0.13[J]	1.5[J]
Trigger Level	12/13/10	**10**	**4.7**	**8.3**	**5.0**	**1.7**	**86**

NASA-E = Effluent
µg/L = micrograms per liter
[J] = detected, but below the Report Limit; therefore, result is an estimated concentration

Table 6 summarizes the results of all other required analysis, including SVOCs (semi-annual sampling requirement), 1,4-Dioxane (semi-annual sampling requirement), turbidity (annual sampling requirement), fuel oxygenates (semi-annual sampling requirement), and cyanide (triennial sampling requirement).

Table 6

2010 NASA Ames GWTS Analytical Results
Other Analyses

Sample Location	Sample Date	SVOCs (µg/L)	1,4-Dioxane (µg/L)	Cyanide (µg/L)	Turbidity (NTU)
NASA-I	6/23/10	ND	1.1	---	---
NASA-E	6/23/10	ND	1.7	---	---
NASA-I	12/13/10	ND	ND (<1.0)	---	---
NASA-E	12/13/10	ND	ND (<1.0)	ND (<5.0)	ND (<5.0)

NASA-I = Influent
NASA-E = Effluent
SVOCs = Semi-Volatile Organic Compounds
µg/L = micrograms per liter
NTU = Nephelometric Turbidity Units
ND = Not Detected above applicable Laboratory Detection Limits
--- = Not Analyzed

Table 7 summarizes the analytical results of the Static Percent Survival Aquatic Toxicity Screening (annual sampling requirement).

Table 7

2010 NASA Ames GWTS Analytical Results
Static Percent Survival

Static % Survival Aquatic Toxicity Screening (Rainbow Trout)	
NASA-E-121310 (12/13/2010)	
Parameter	**Result**
96-Hour % Survival	100%
Dissolved Oxygen	7.20 mg/L
pH	7.20 standard units
Conductivity	1237 µS/cm
Salinity	0.60 ppt
Temperature	5.60° C
Total Chlorine	<0.03 mg/L
Ammonia	<0.03 mg/L
Alkalinity	448 mg/l as $CaCO_3$
Hardness	588 mg/l as $CaCO_3$

NASA-E = Effluent
mg/L = milligrams per litter
µS/cm = micro Siemens per centimeter
ppt = parts per trillion
°C = degrees Celsius
$CaCO_3$ = calcium carbonate

Table 8 details the results of field parameters temperature and pH.

Table 8

2010 NASA Ames GWTS Monitoring Data
Field Parameters

Sample Location	Sample Date	Temperature (^{o}C)	pH (Standard Units)
NASA-I	1/25/10	17.1	7.50
NASA-E	1/25/10	16.2	7.49
NASA-I	2/25/10	17.2	7.47
NASA-E	2/25/10	16.4	7.48
NASA-I	3/24/10	17.7	7.44
NASA-E	3/24/10	16.4	7.49
NASA-I	4/21/10	16.5	7.58
NASA-E	4/21/10	15.3	7.57
NASA-I	5/25/10	17.6	7.60
NASA-E	5/25/10	16.7	7.55
NASA-I	6/23/10	18.2	7.62
NASA-E	6/23/10	17.5	7.59
NASA-I	7/22/10	18.9	7.60
NASA-E	7/22/10	17.9	7.58
NASA-I	8/24/10	19.5	7.54
NASA-E	8/24/10	19.5	7.52
NASA-I	9/27/10	20.2	7.57
NASA-E	9/27/10	19.1	7.55
NASA-I	10/25/10	18.9	7.38
NASA-E	10/25/10	18.3	7.35
NASA-I	11/22/10	18.5	7.20
NASA-E	11/22/10	16.5	7.24
NASA-I	12/13/10	15.5	7.40
NASA-E	12/13/10	15.0	7.35

NASA-I = Influent
NASA-E = Effluent
^{o}C = degrees Celsius

Table 9 summarizes the standard observations reported during this quarter.

Table 9

2010 NASA Ames GWTS Monitoring Data
Standard Observations

Sample Location	Sample Date	Floating/ Suspended Material	Deposits, Discoloration and/or Plugging	Prevention of Overflow or Bypass	Odor
NASA-I	1/25/10	--	--	--	No
NASA-E	1/25/10	No	No	OK	No
NASA-I	2/25/10	--	--	--	No
NASA-E	2/25/10	No	No	OK	No
NASA-I	3/24/10	--	--	--	No
NASA-E	3/24/10	No	No	OK	No
NASA-I	4/21/10	--	--	--	No
NASA-E	4/21/10	No	No	OK	No
NASA-I	5/25/10	--	--	--	No
NASA-E	5/25/10	No	No	OK	No
NASA-I	6/23/10	--	--	--	No
NASA-E	6/23/10	No	No	OK	No
NASA-I	7/22/10	--	--	--	No
NASA-E	7/22/10	No	No	OK	No
NASA-I	8/24/10	--	--	--	No
NASA-E	8/24/10	No	No	OK	No
NASA-I	9/27/10	--	--	--	No
NASA-E	9/27/10	No	No	OK	No
NASA-I	10/25/10	--	--	--	No
NASA-E	10/25/10	No	No	OK	No
NASA-I	11/22/10	--	--	--	No
NASA-E	11/22/10	No	No	OK	No
NASA-I	12/13/10	--	--	--	No
NASA-E	12/13/10	No	No	OK	No

NASA-I = Influent
NASA-E = Effluent
-- = Analysis/analyses not required

5.0 DISCUSSION

5.1 Effluent Sample Detections

5.1.1 1,4-Dioxane Detection in June Effluent Sample

During the June sampling event, 1,4-Dioxane was detected in the effluent sample at a concentration of 1.7 µg/L. 1,4-Dioxane was detected in the influent sample at a concentration of 1.1µg/L. The "trigger" value for 1,4-Dioxane, as provided in Table 3 (Trigger Pollutants) of the NPDES permit, is 3.0 µg/L. No further action is required.

5.1.2 Priority Pollutant Metals Detections in December Effluent Sample

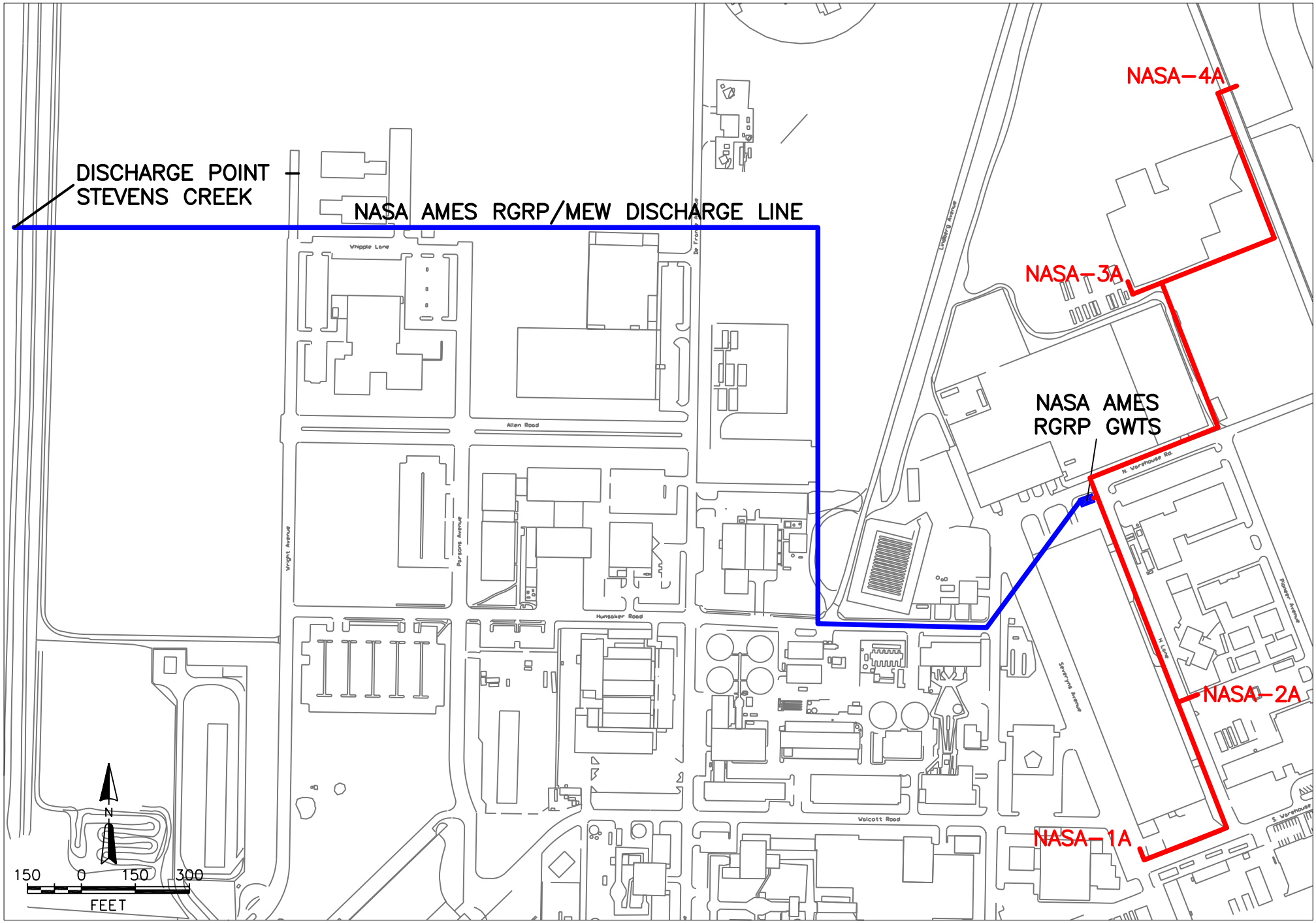
During the December sampling event, arsenic, copper, nickel, selenium, thallium, and zinc were detected in the effluent sample (see Table 5). All concentrations were below their respective "trigger" value, as provided in Table 3 (Trigger Pollutants) of the NPDES permit. No further action is required.

5.2 Treated Groundwater Reuse

None of NASA's treated groundwater was reused during this reporting period. NASA anticipates that upon completion of modifications to NASA's Industrial Wastewater Pre-Treatment Facility, reuse will resume in 2011.

6.0 CONCLUSIONS

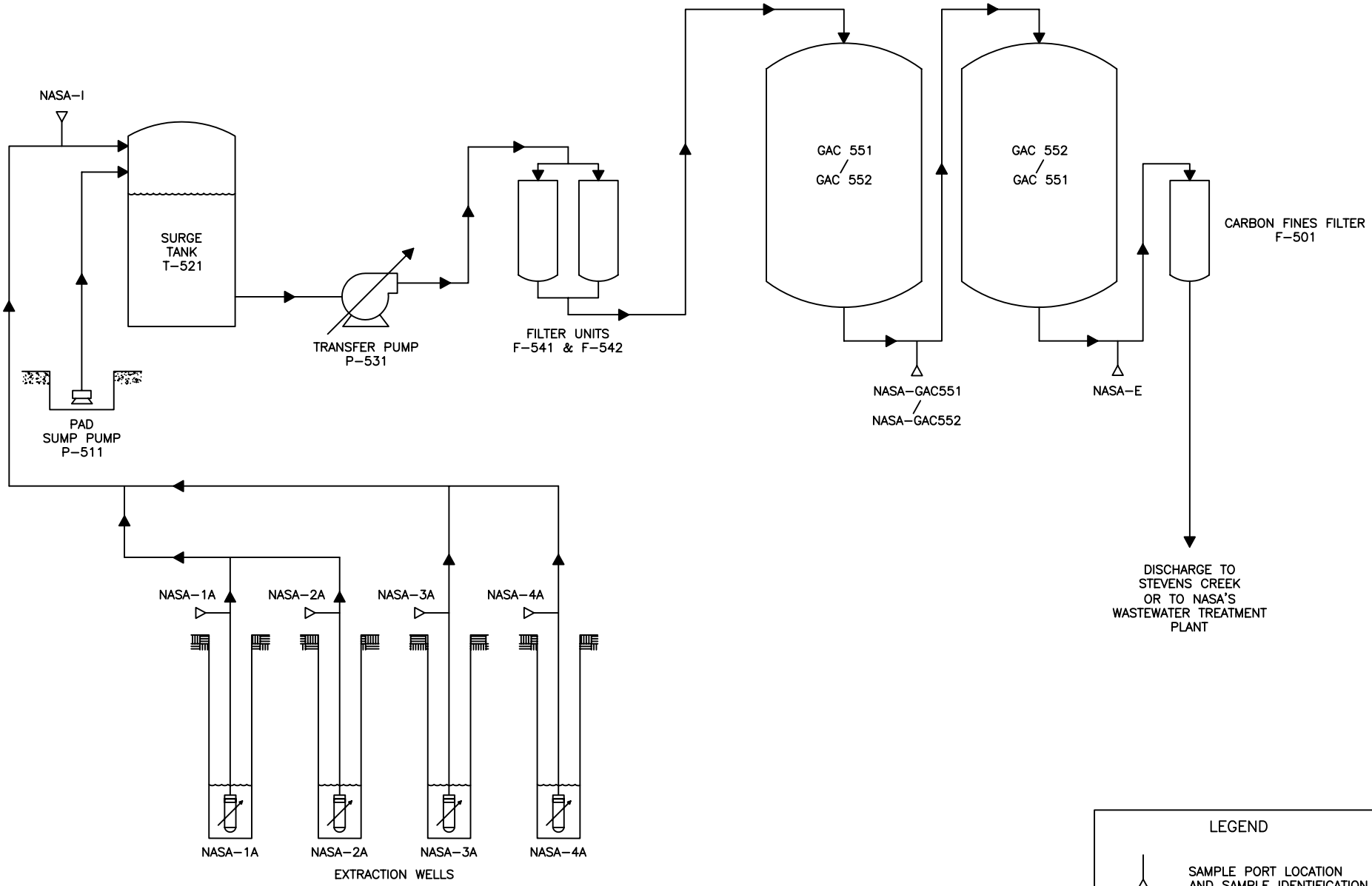
Data presented in Tables 3 through 9 indicate that the NASA Ames GWTS was in compliance with the effluent discharge limitations set forth in the December 3, 2009 NPDES permit during calendar year 2010.



Ames Research Center
Moffett Field, California 94035

TITLE:
NASA AMES RGRP GWTS
SYSTEM, DISCHARGE LINE, AND DISCHARGE POINT LOCATIONS

DWN: CNF	DES.: CNF	PROJECT NO.: RGRP GWTS
CHKD: DHV	APPD: JRL	FIGURE NO.: 1
DATE: 12/2003	REV.: 04	



Ames Research Center
Moffett Field, California 94035

TITLE:
NASA AMES RGRP GWTS
GWTS FLOW DIAGRAM AND SAMPLE PORT LOCATIONS

DWN: CNF	DES.: CNF	PROJECT NO.: RGRP GWTS
CHKD: DHV	APPD: JRL	
DATE: 03/2003	REV.: 02	FIGURE NO.: 2

APPENDIX B

2010 DEPTH-TO-WATER MEASUREMENTS

2010 Depth-to-Water Measurements

Well ID	Date	Measuring Point Elevation (ft MSL)	Depth to Water (ft)	Groundwater Elevation (ft MSL)
10B01A	11/18/2010	5.85	8.67	-2.82
10B04A	3/25/2010	1.76	3.15	-1.39
10B04A	11/18/2010	1.76	4.68	-2.92
10G04A	3/25/2010	3.59	4.40	-0.81
10G04A	11/18/2010	3.59	6.30	-2.71
10H01A	3/25/2010	5.16	6.16	-1.00
10H01A	11/18/2010	5.16	6.65	-1.49
10H02A	3/25/2010	2.26	3.36	-1.10
10H02A	11/18/2010	2.26	4.84	-2.58
10J04A	3/25/2010	3.89	3.68	0.21
10J04A	11/18/2010	3.89	5.03	-1.14
10J05A	3/25/2010	6.34	5.23	1.11
10J05A	11/18/2010	6.34	6.40	-0.06
10J09A	3/25/2010	3.70	4.33	-0.63
10J09A	11/18/2010	3.70	4.94	-1.24
10Q06A	11/18/2010	12.12	NM	NA
10Q08A	3/25/2010	6.54	3.65	2.89
10Q08A	11/18/2010	6.54	NM	NA
10R07A2	3/25/2010	10.70	7.95	2.75
10R07A2	11/18/2010	10.70	8.27	2.43
10R09A	3/25/2010	8.78	6.68	2.10
10R09A	11/18/2010	8.78	8.28	0.50
10R10A	3/25/2010	9.15	6.09	3.06
10R10A	11/18/2010	9.15	7.61	1.54
10R11A	3/25/2010	9.25	6.97	2.28
10R11A	11/18/2010	9.25	8.82	0.43
11E02A	3/25/2010	4.76	6.07	-1.31
11E02A	11/18/2010	4.76	6.67	-1.91
11M02A	3/25/2010	4.27	4.07	0.20
11M02A	11/18/2010	4.27	4.97	-0.70
11M03A	3/25/2010	6.51	7.24	-0.73
11M03A	11/18/2010	6.51	8.14	-1.63

2010 Depth-to-Water Measurements

Well ID	Date	Measuring Point Elevation (ft MSL)	Depth to Water (ft)	Groundwater Elevation (ft MSL)
11M07A	3/25/2010	5.86	5.74	0.12
11M07A	11/18/2010	5.86	6.80	-0.94
11M14A1	3/25/2010	8.26	8.36	-0.10
11M14A1	11/18/2010	8.26	9.43	-1.17
11M16A1	3/25/2010	8.79	9.23	-0.44
11M16A1	11/18/2010	8.79	10.15	-1.36
11M17A	3/25/2010	4.16	4.30	-0.14
11M17A	11/18/2010	4.16	5.32	-1.16
11M18A1	3/25/2010	3.72	4.12	-0.40
11M18A1	11/18/2010	3.72	5.07	-1.35
11M21A	3/25/2010	7.10	6.86	0.24
11M21A	11/18/2010	7.10	7.98	-0.88
11N21A1	3/25/2010	6.14	5.74	0.40
11N21A1	11/18/2010	6.14	6.84	-0.70
11N22A1	3/25/2010	10.75	9.93	0.82
11N22A1	11/18/2010	10.75	11.07	-0.32
11N27A	3/25/2010	12.25	10.51	1.74
11N27A	11/18/2010	12.25	11.68	0.57
14C06A	3/25/2010	15.02	10.38	4.64
14C06A	11/18/2010	15.02	11.46	3.56
14C15A	3/25/2010	13.39	9.96	3.43
14C15A	11/18/2010	13.39	10.31	3.08
14C33A	3/25/2010	13.55	8.66	4.89
14C33A	11/18/2010	13.55	9.97	3.58
14C40A	3/25/2010	11.49	7.45	4.04
14C40A	11/18/2010	11.49	8.67	2.82
14C60A	3/25/2010	10.27	7.65	2.62
14C60A	11/18/2010	10.27	8.94	1.33
14D02A	3/25/2010	10.15	6.30	3.85
14D02A	11/18/2010	10.15	7.57	2.58
14D05A	3/25/2010	14.68	6.21	8.47
14D05A	11/18/2010	14.68	6.79	7.89

2010 Depth-to-Water Measurements

Well ID	Date	Measuring Point Elevation (ft MSL)	Depth to Water (ft)	Groundwater Elevation (ft MSL)
14D09A	3/25/2010	15.81	8.80	7.01
14D09A	11/18/2010	15.81	9.84	5.97
14D12A	3/25/2010	14.78	9.20	5.58
14D12A	11/18/2010	14.78	9.94	4.84
14D13A	11/18/2010	13.19	7.54	5.65
14D24A	3/25/2010	8.29	9.57	-1.28
14D24A	11/18/2010	8.29	11.86	-3.57
14D25A2	3/25/2010	8.30	5.16	3.14
14D25A2	11/18/2010	8.30	6.40	1.90
14D26A1	3/25/2010	8.35	11.21	-2.86
14D26A1	11/18/2010	8.35	13.73	-5.38
14D29A	3/25/2010	13.93	8.52	5.41
14D29A	11/18/2010	13.93	9.50	4.43
14D31A2	3/25/2010	8.02	5.51	2.51
14D31A2	11/18/2010	8.02	6.83	1.19
14D33A	3/25/2010	10.00	6.39	3.61
14D33A	11/18/2010	10.00	7.70	2.30
14D35A	3/25/2010	9.29	5.92	3.37
14D35A	11/18/2010	9.29	7.25	2.04
14D36A	3/25/2010	12.05	7.16	4.89
14D36A	11/18/2010	12.05	8.39	3.66
14D37A	3/25/2010	8.19	5.20	2.99
14D37A	11/18/2010	8.19	6.54	1.67
14D39A	3/25/2010	12.51	8.26	4.25
14D39A	11/18/2010	12.51	9.25	3.26
14E14A	3/25/2010	21.64	11.02	10.62
14E14A	11/18/2010	21.64	11.59	10.05
15A01A	3/25/2010	15.36	9.12	6.24
15A01A	11/18/2010	15.36	10.98	4.38
15A02A	3/25/2010	17.14	6.45	10.69
15A02A	11/18/2010	17.14	7.28	9.86

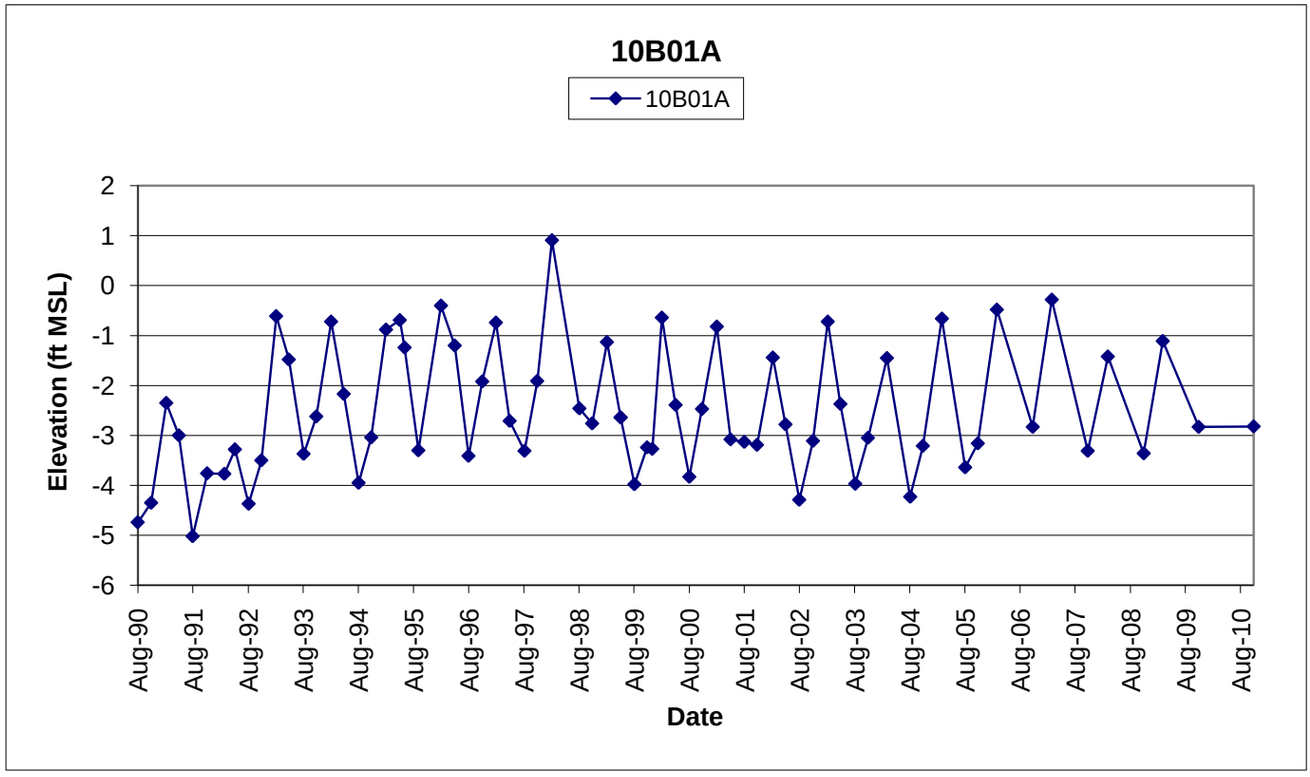
2010 Depth-to-Water Measurements

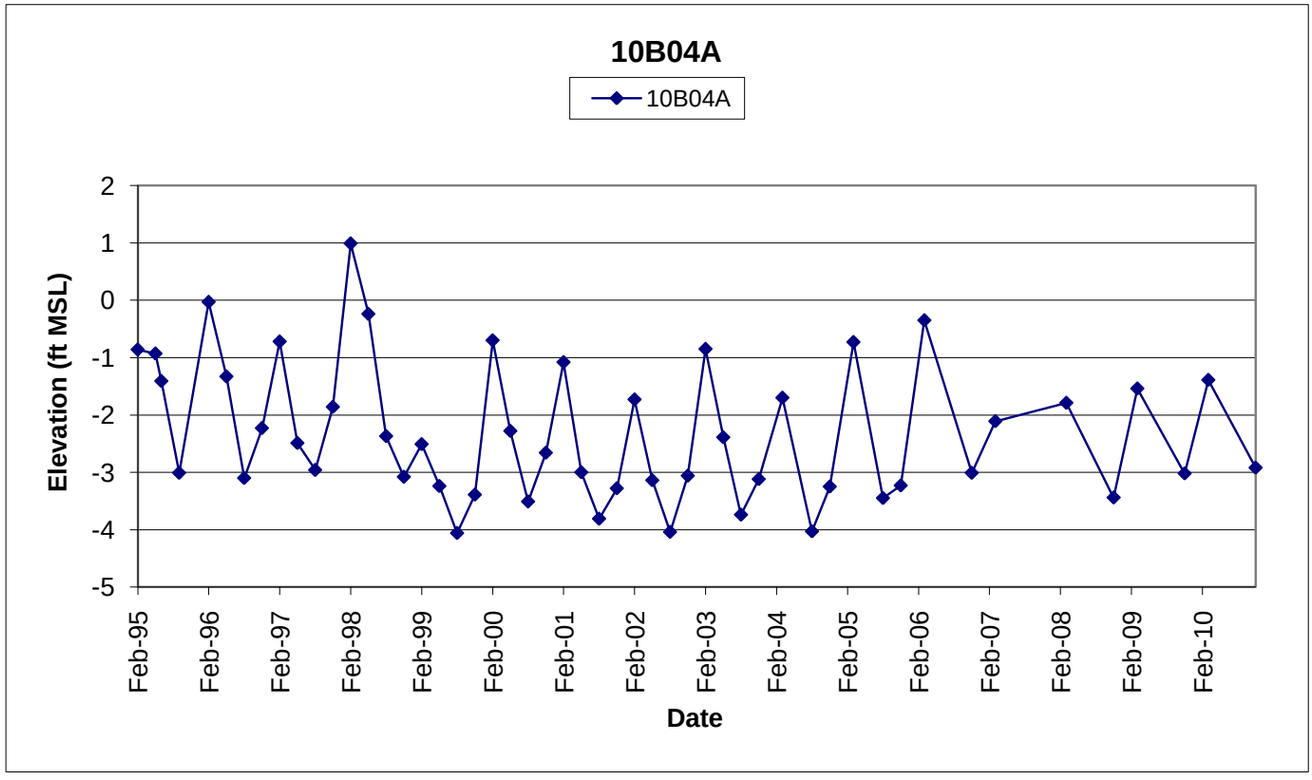
Well ID	Date	Measuring Point Elevation (ft MSL)	Depth to Water (ft)	Groundwater Elevation (ft MSL)
15A04A	3/25/2010	14.24	7.10	7.14
15A04A	11/18/2010	14.24	9.46	4.78
15A06A	3/25/2010	15.24	5.65	9.59
15A06A	11/18/2010	15.24	7.14	8.10
15A08A	3/25/2010	14.31	6.18	8.13
15A08A	11/18/2010	14.31	7.79	6.52
15A12A2	3/25/2010	16.94	7.47	9.47
15A12A2	11/18/2010	16.94	7.73	9.21
15A15A2	3/25/2010	12.35	8.00	4.35
15A15A2	11/18/2010	12.35	9.42	2.93
15A16A	3/25/2010	12.21	6.69	5.52
15A16A	11/18/2010	12.21	9.47	2.74
15A18A	3/25/2010	12.67	7.07	5.60
15A18A	11/18/2010	12.74	8.89	3.85
15B08A	3/25/2010	14.74	5.98	8.76
15B08A	11/18/2010	14.75	7.59	7.16
15B09A	3/25/2010	13.19	5.55	7.64
15B09A	11/18/2010	13.20	7.15	6.05
15B10A	3/25/2010	15.37	4.62	10.75
15B10A	11/18/2010	15.30	6.51	8.79
15B17A2	3/25/2010	14.82	4.89	9.93
15B17A2	11/18/2010	14.83	6.46	8.37
15B18A2	3/25/2010	15.20	4.87	10.33
15B18A2	11/18/2010	15.20	6.49	8.71
15H05A	3/25/2010	18.69	5.79	12.90
15H05A	11/18/2010	18.69	6.34	12.35
15H12A	3/25/2010	14.77	4.59	10.18
15H12A	11/18/2010	14.77	6.70	8.07
TANK1-E	3/25/2010	16.45	6.20	10.25
TANK1-E	11/18/2010	16.45	7.36	9.09

APPENDIX C

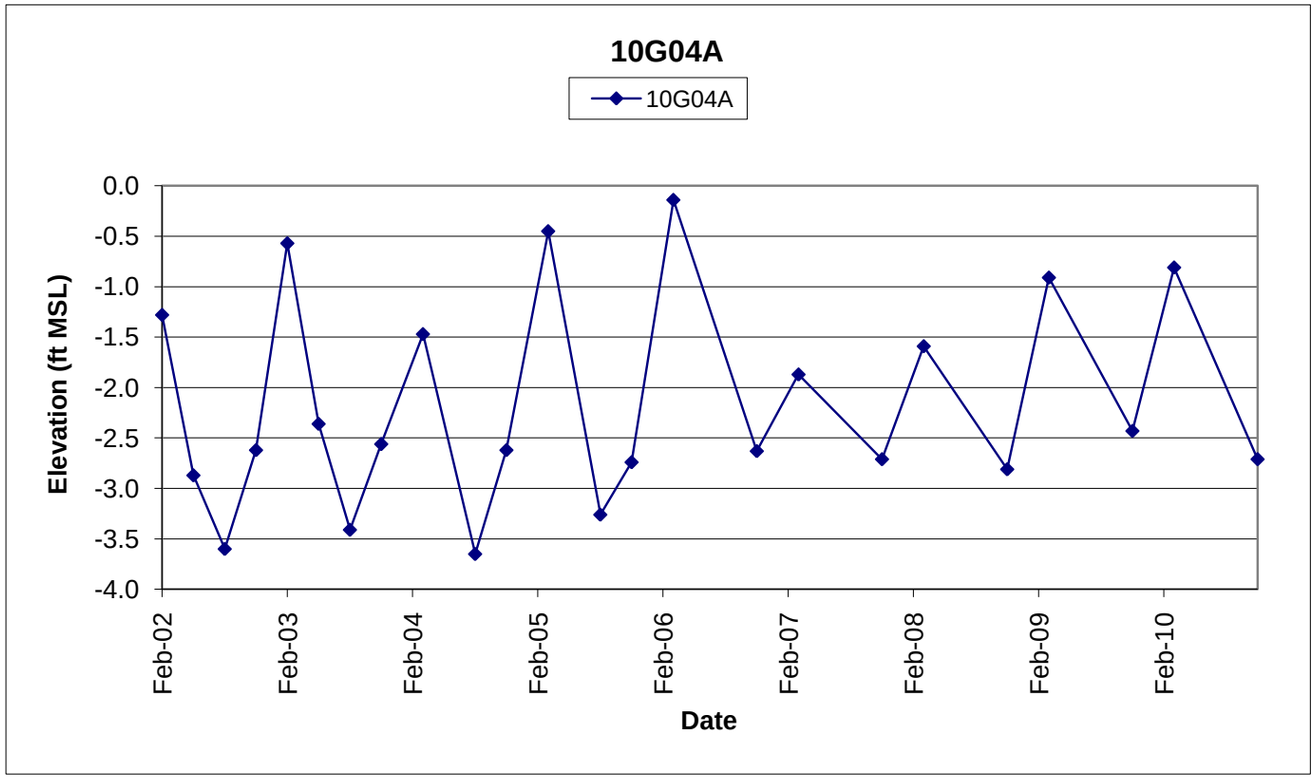
2010 HYDROGRAPHS

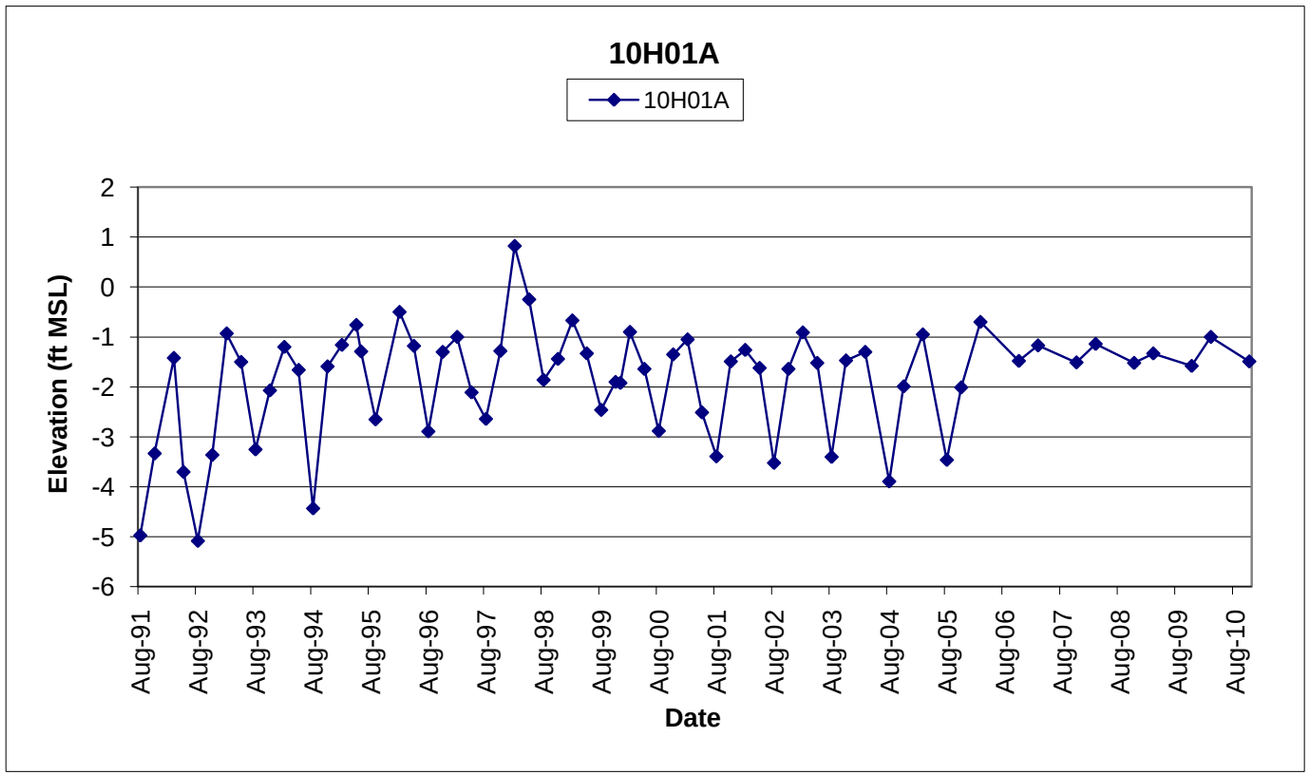
APPENDIX C
2010 Hydrographs



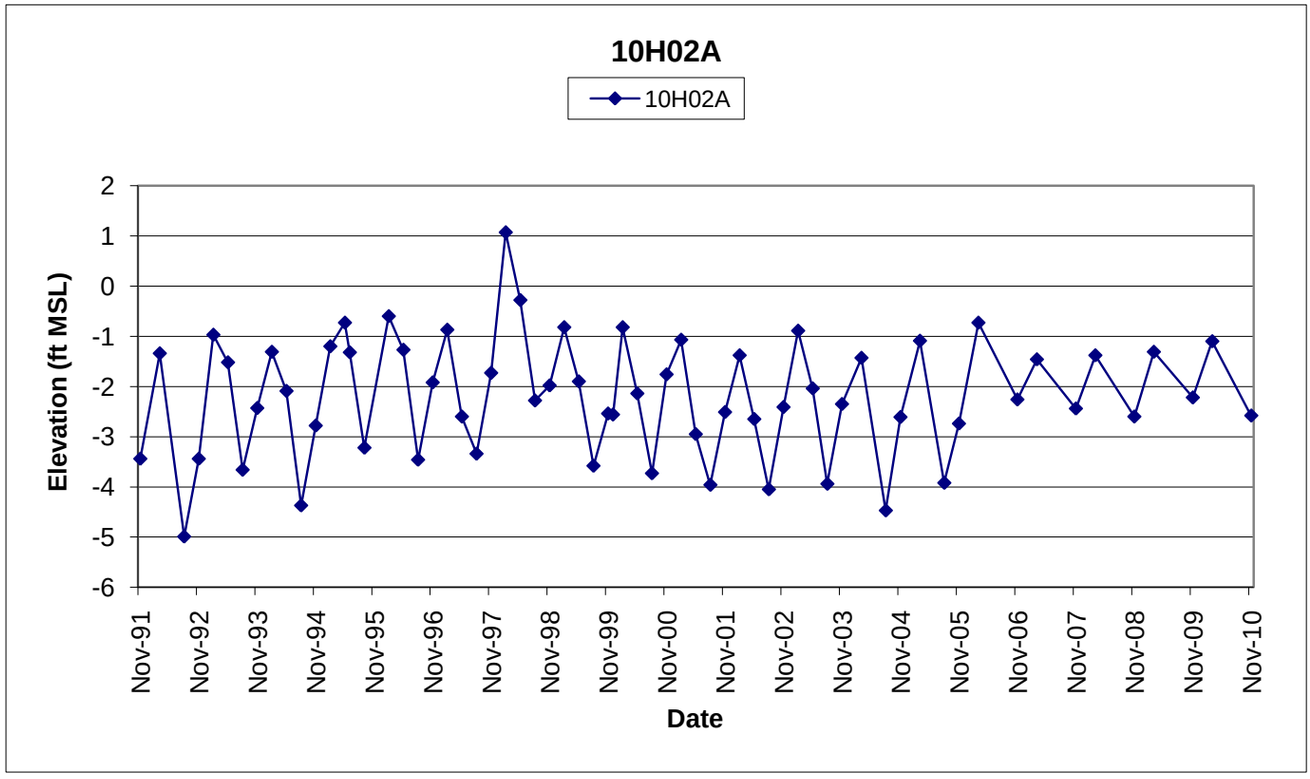


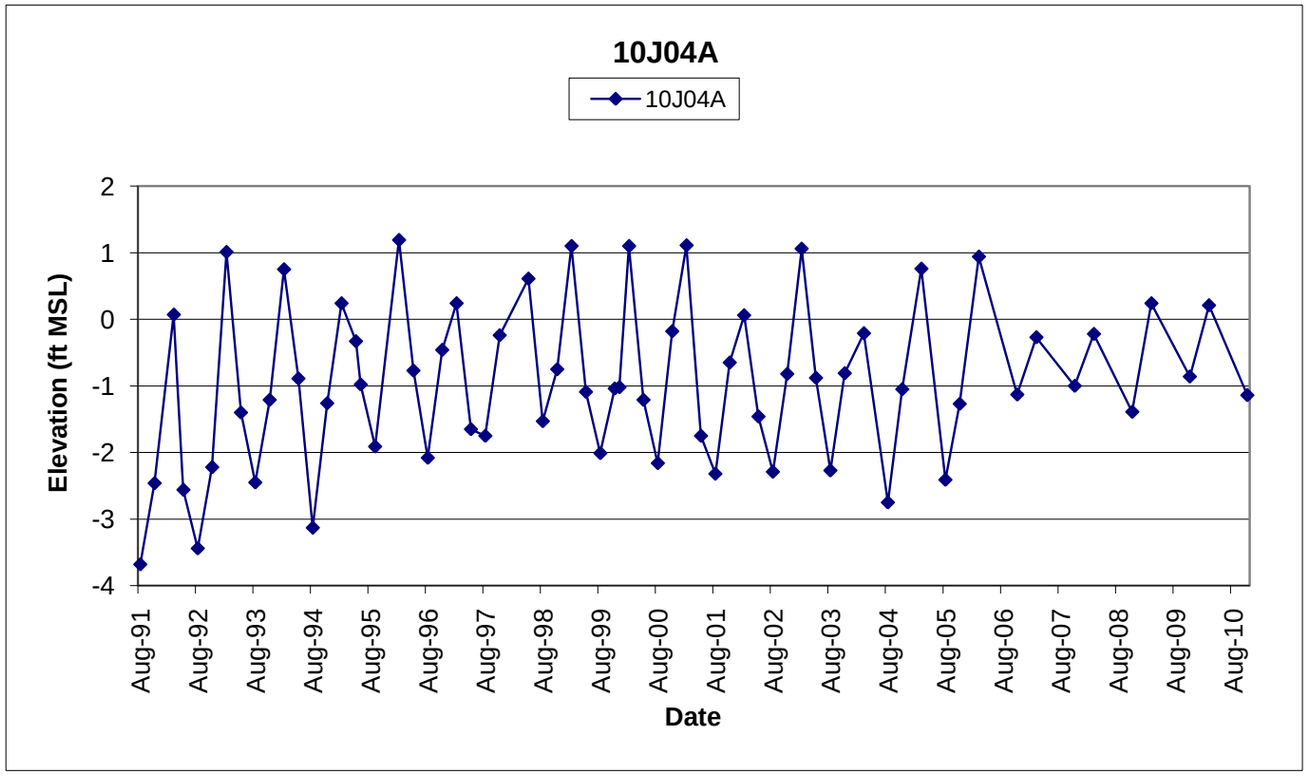
APPENDIX C
2010 Hydrographs



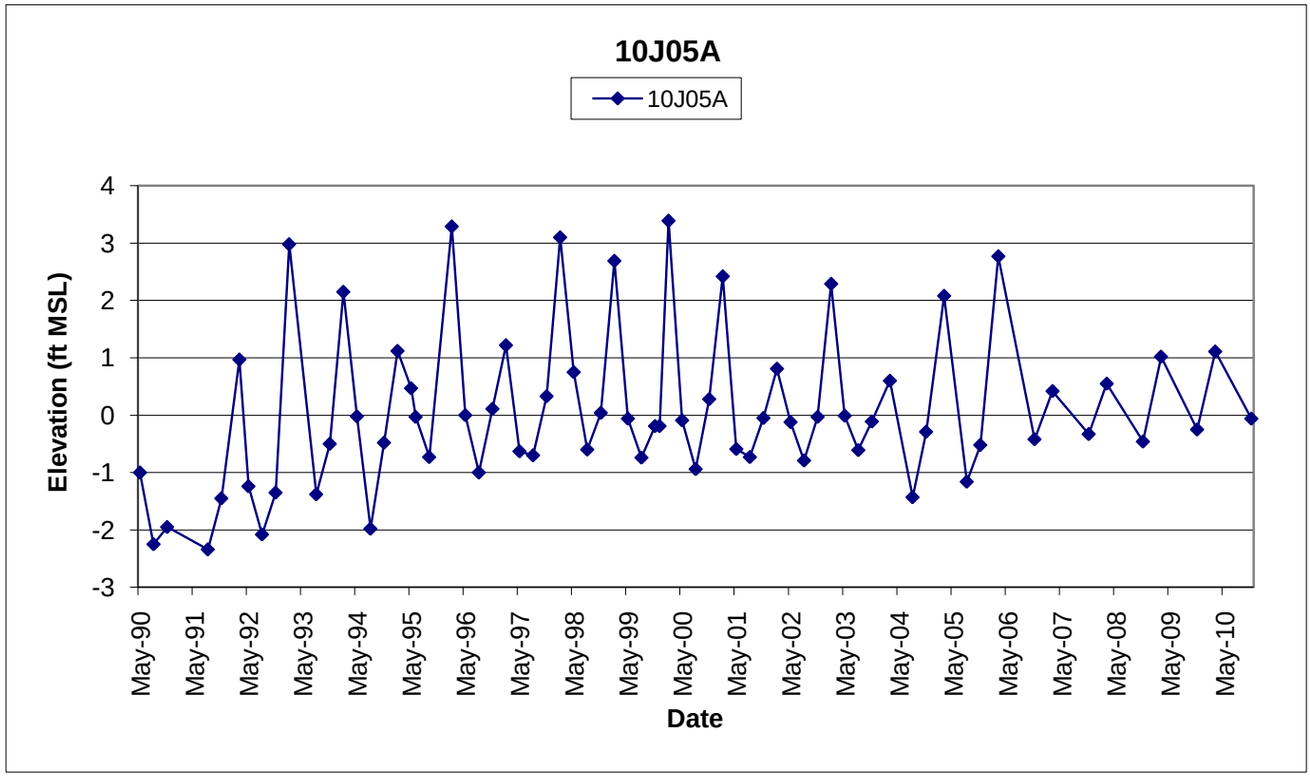


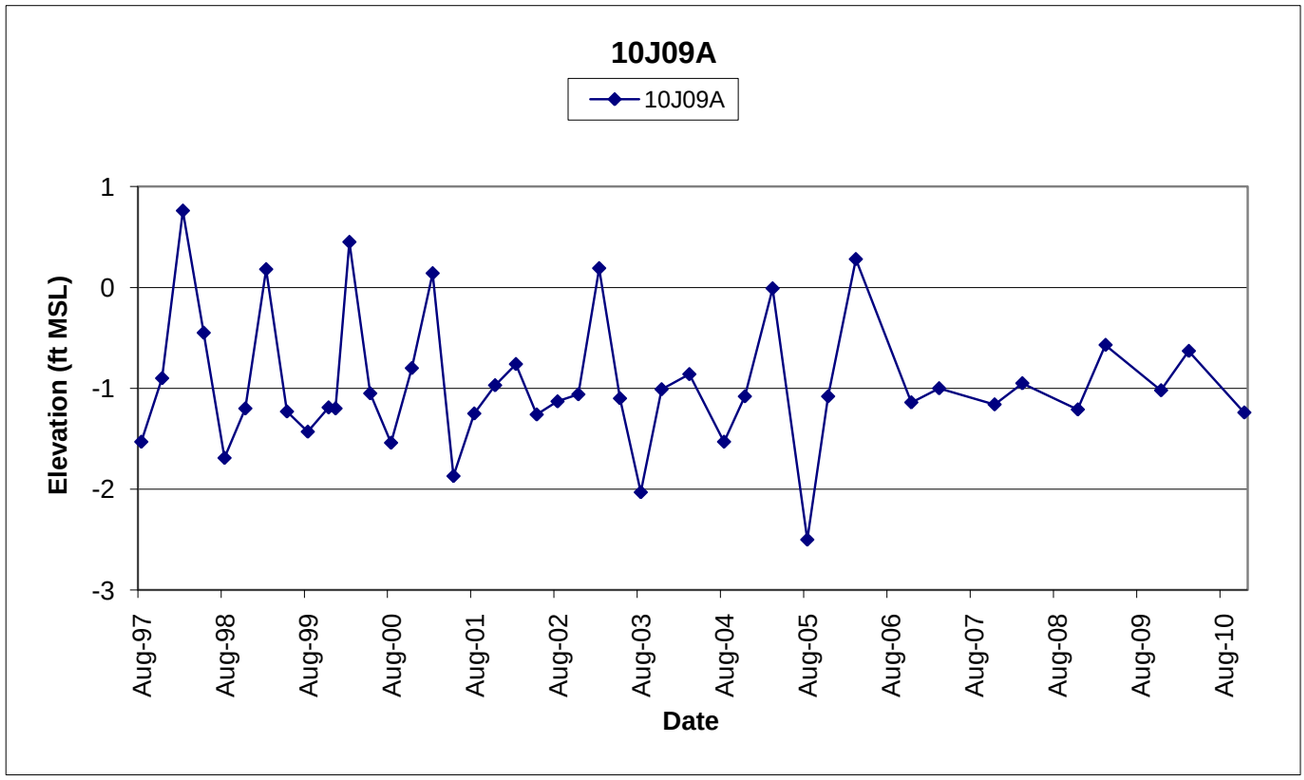
APPENDIX C
2010 Hydrographs



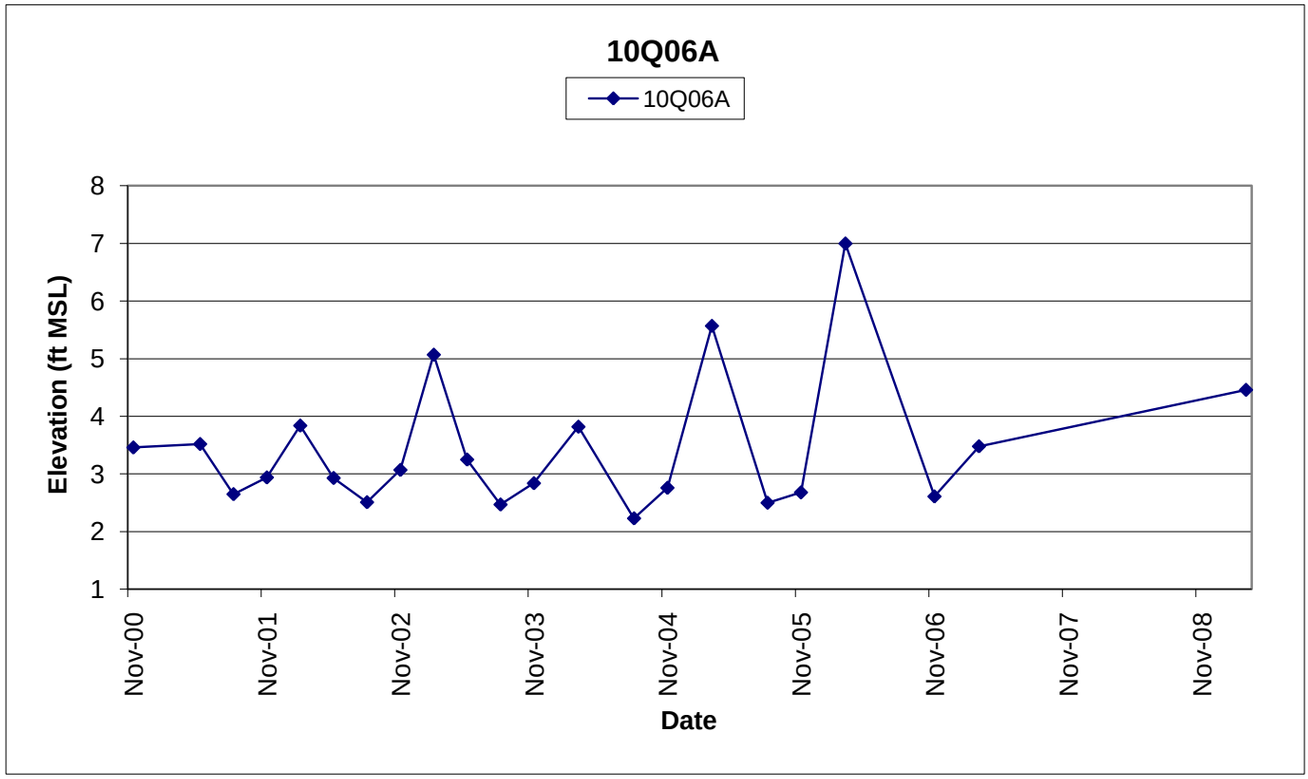


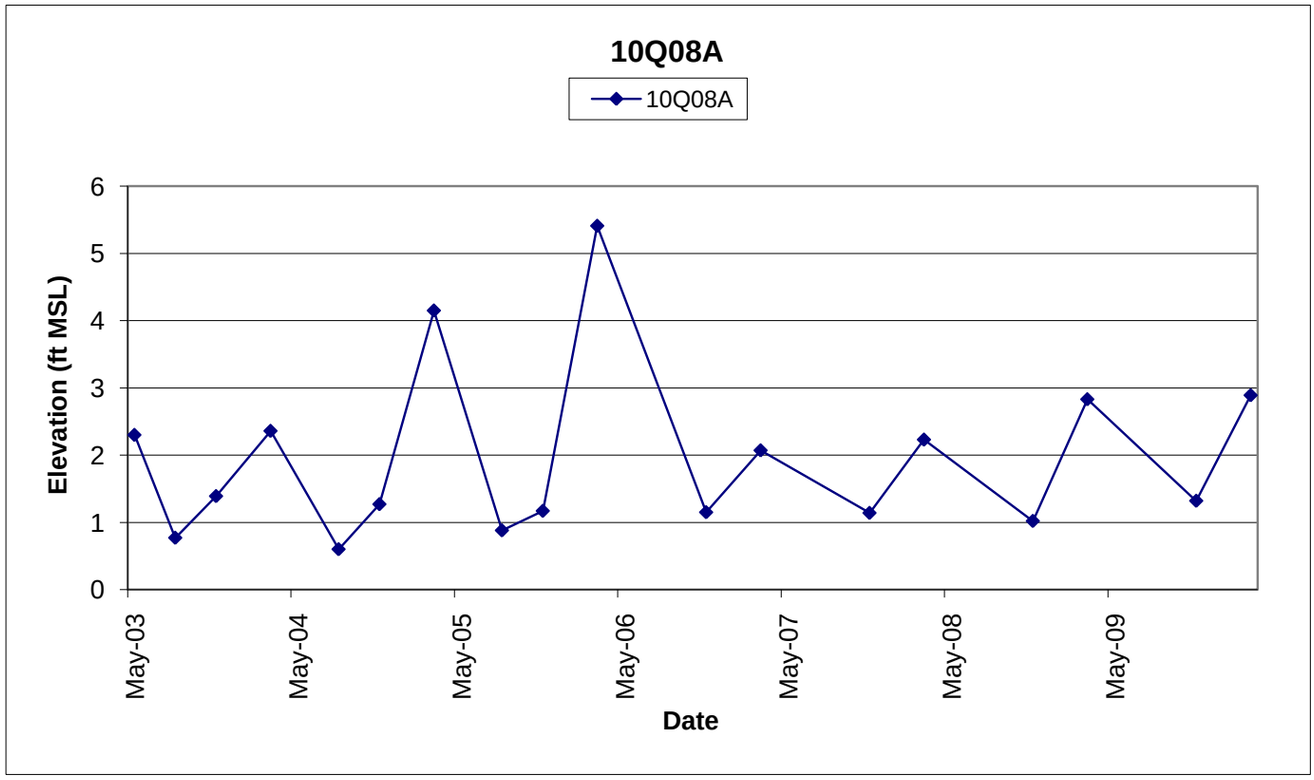
APPENDIX C
2010 Hydrographs



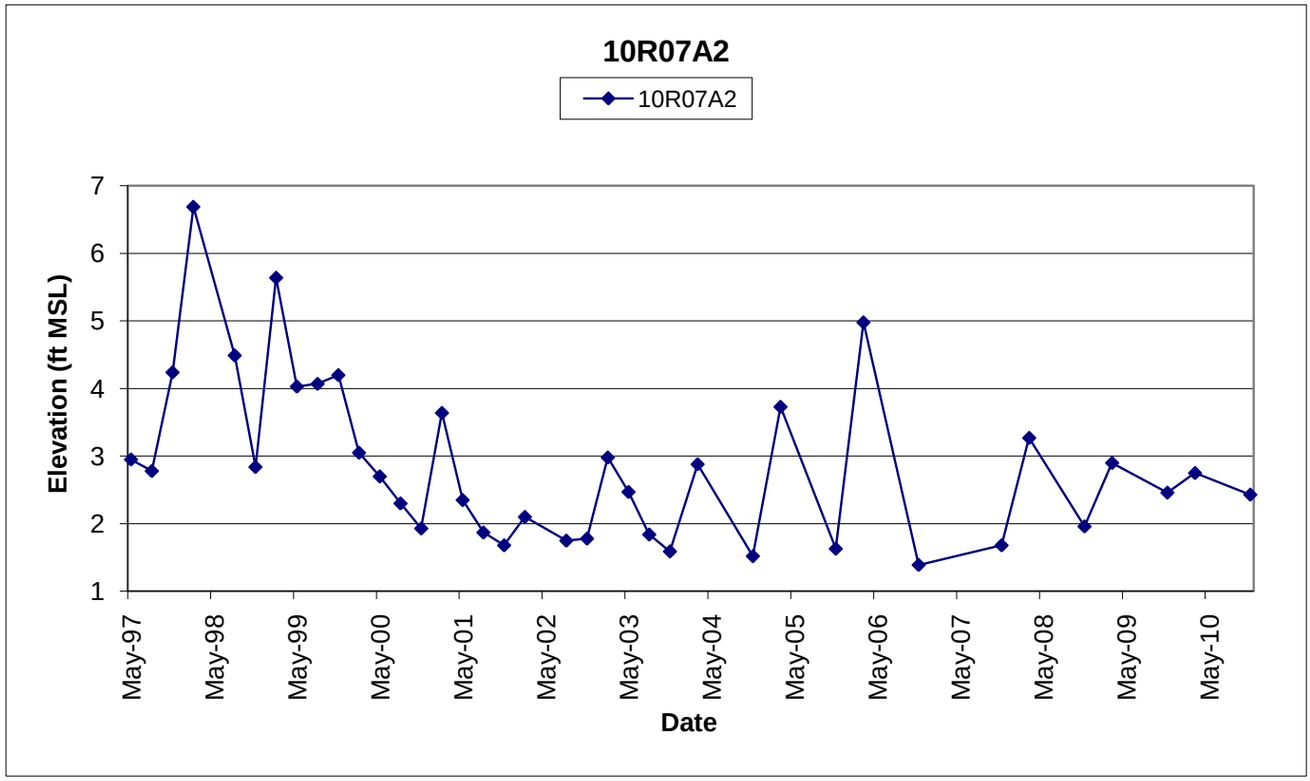


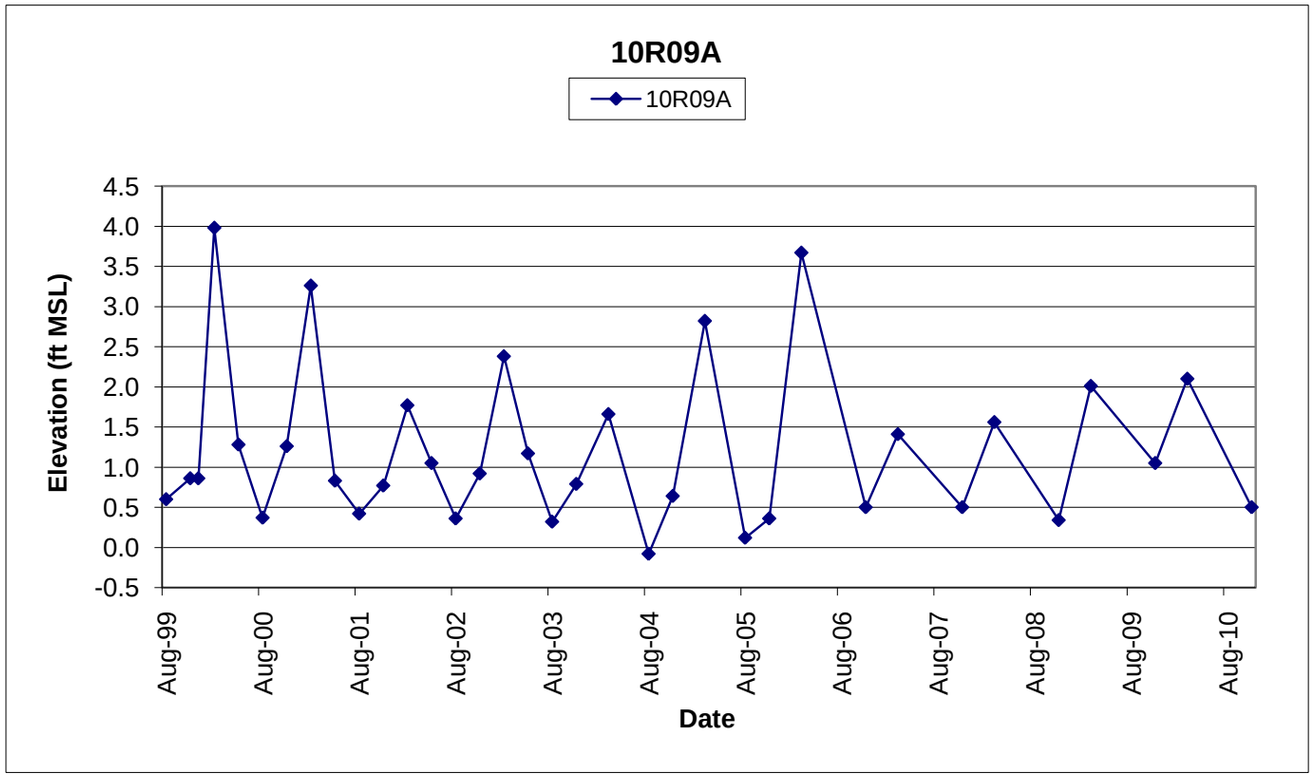
APPENDIX C
2010 Hydrographs



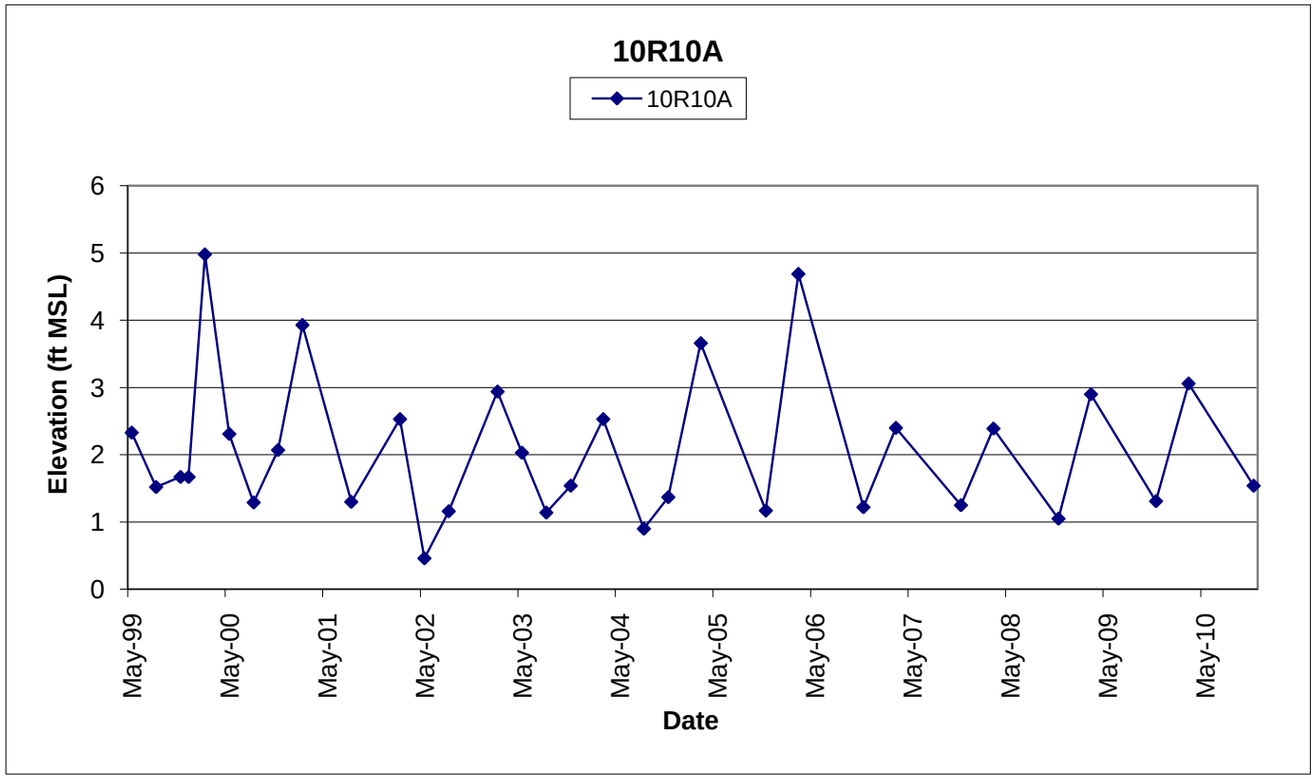


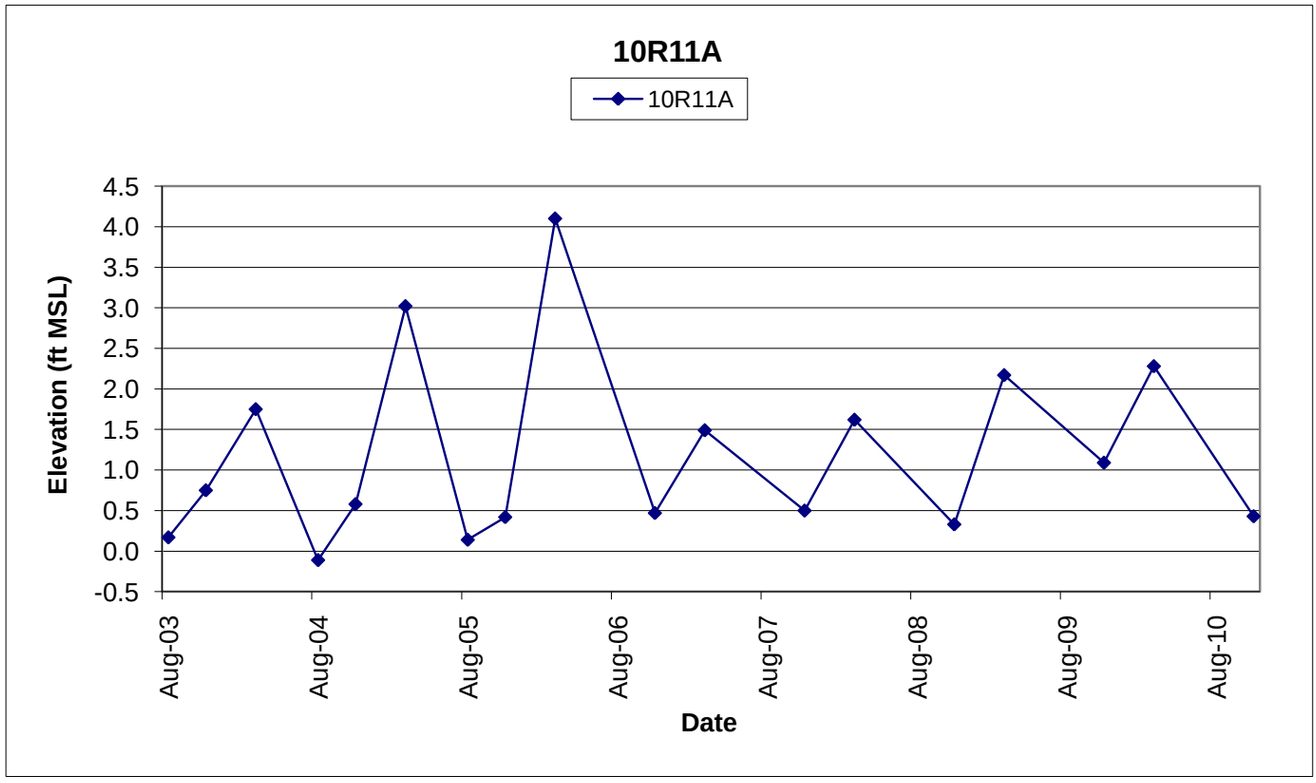
APPENDIX C
2010 Hydrographs



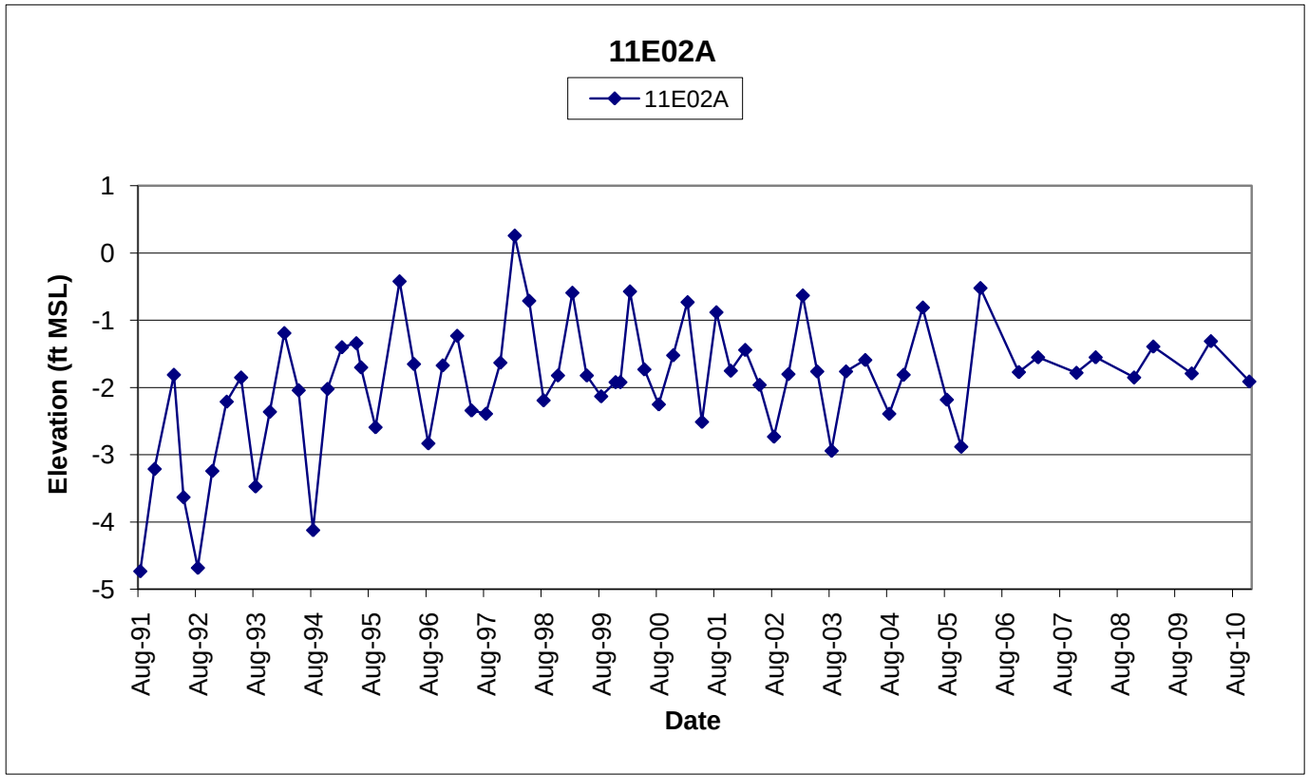


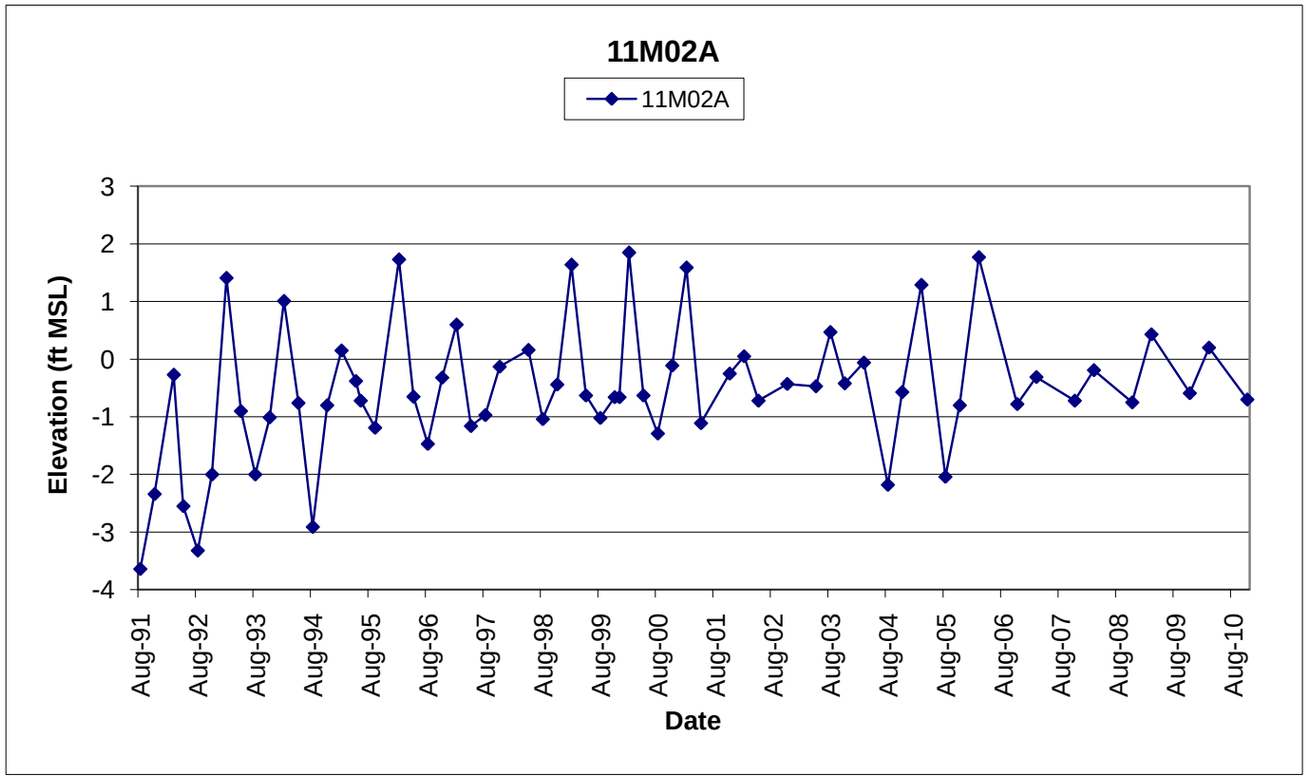
APPENDIX C
2010 Hydrographs



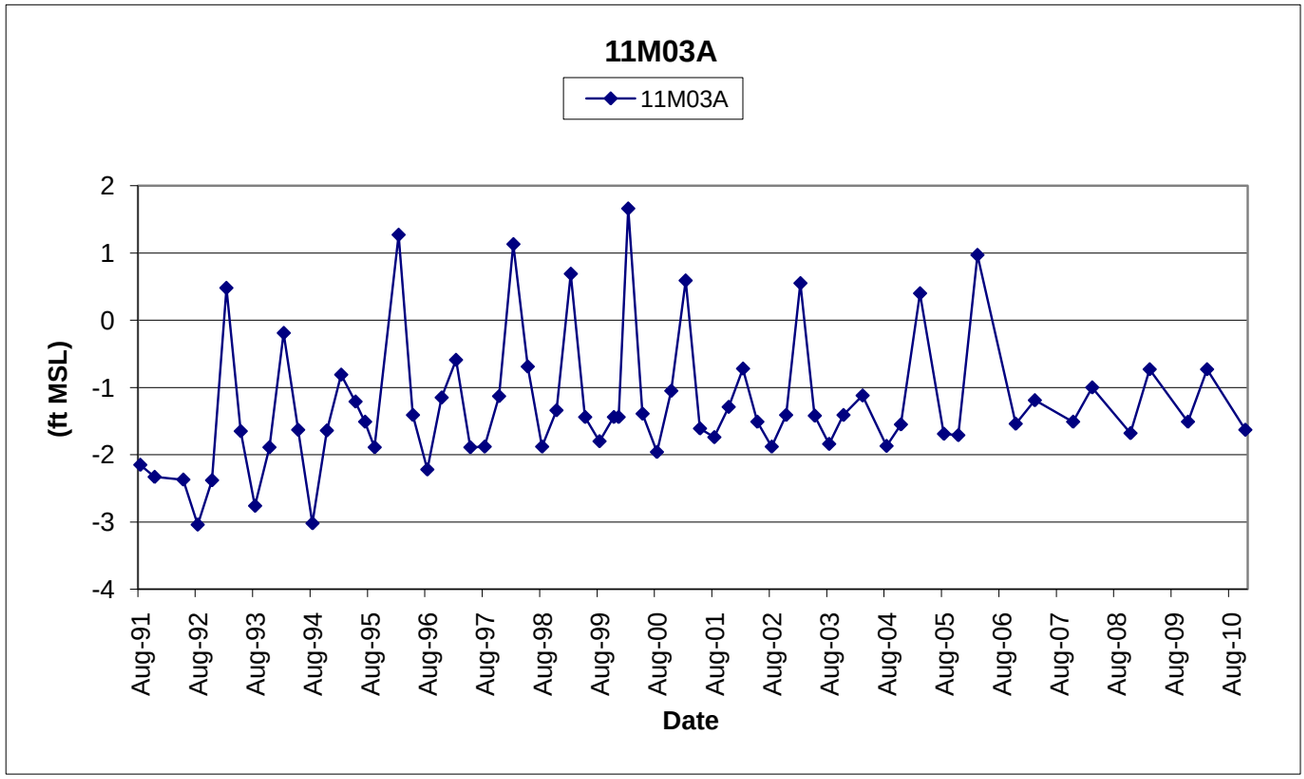


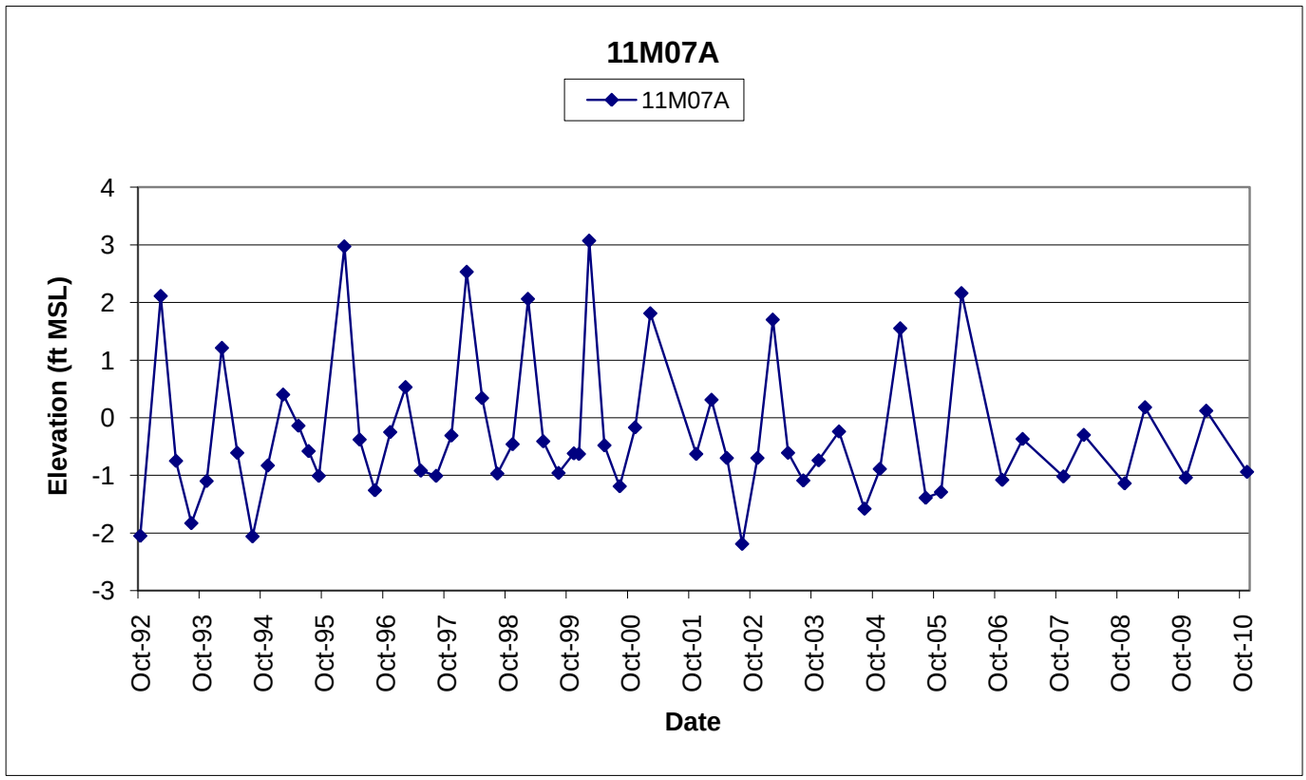
APPENDIX C
2010 Hydrographs



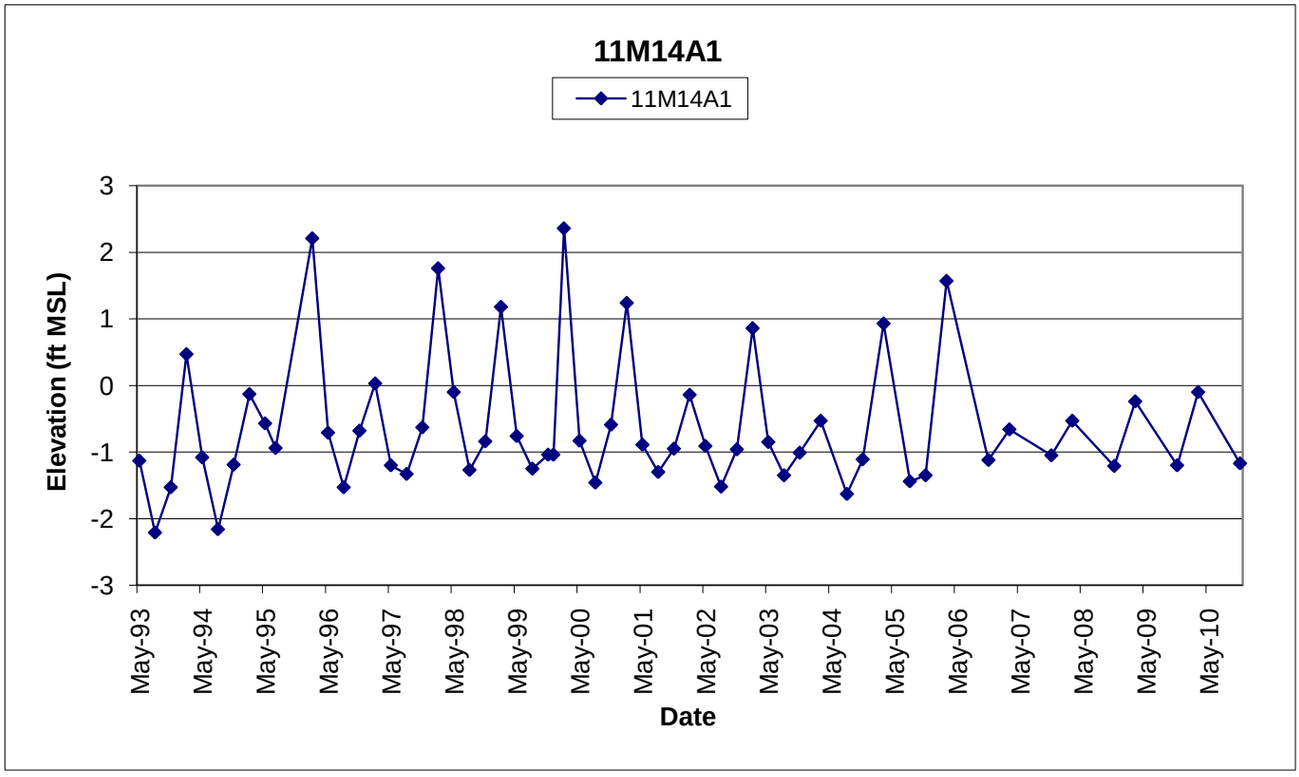


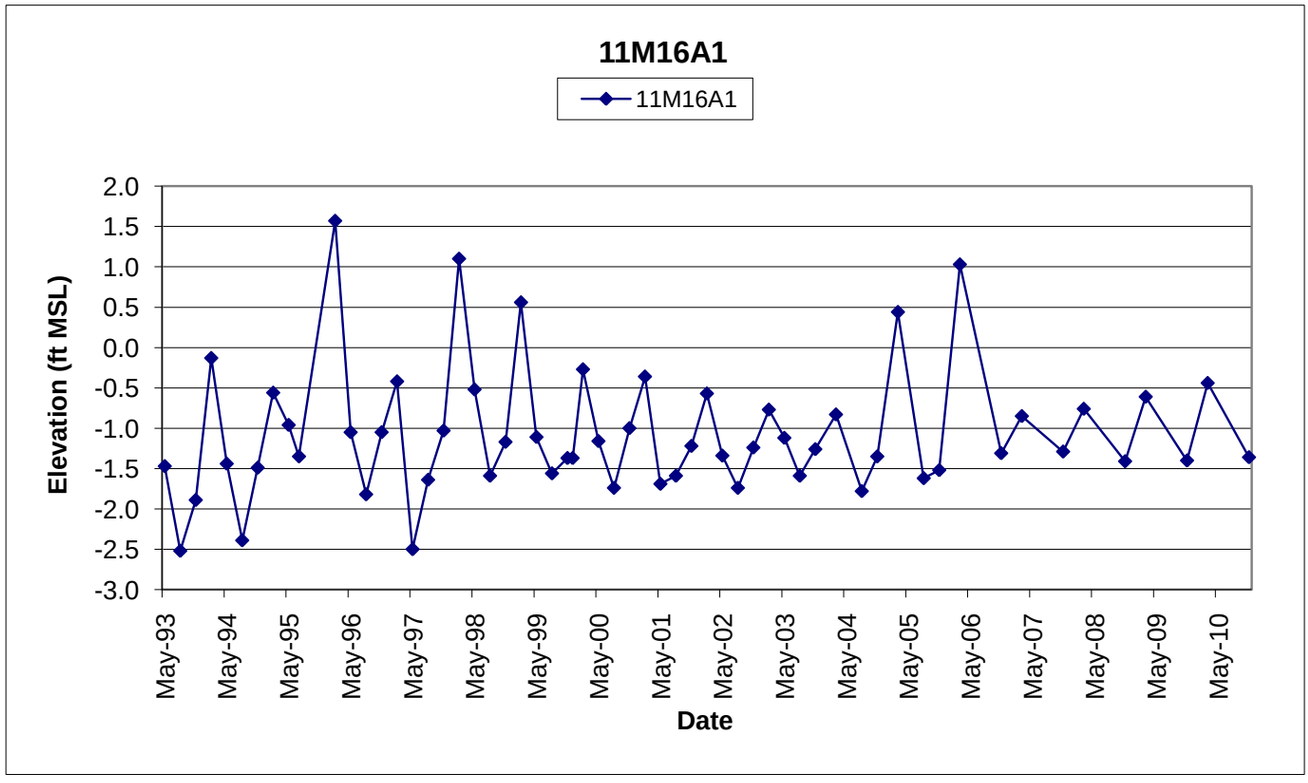
APPENDIX C
2010 Hydrographs



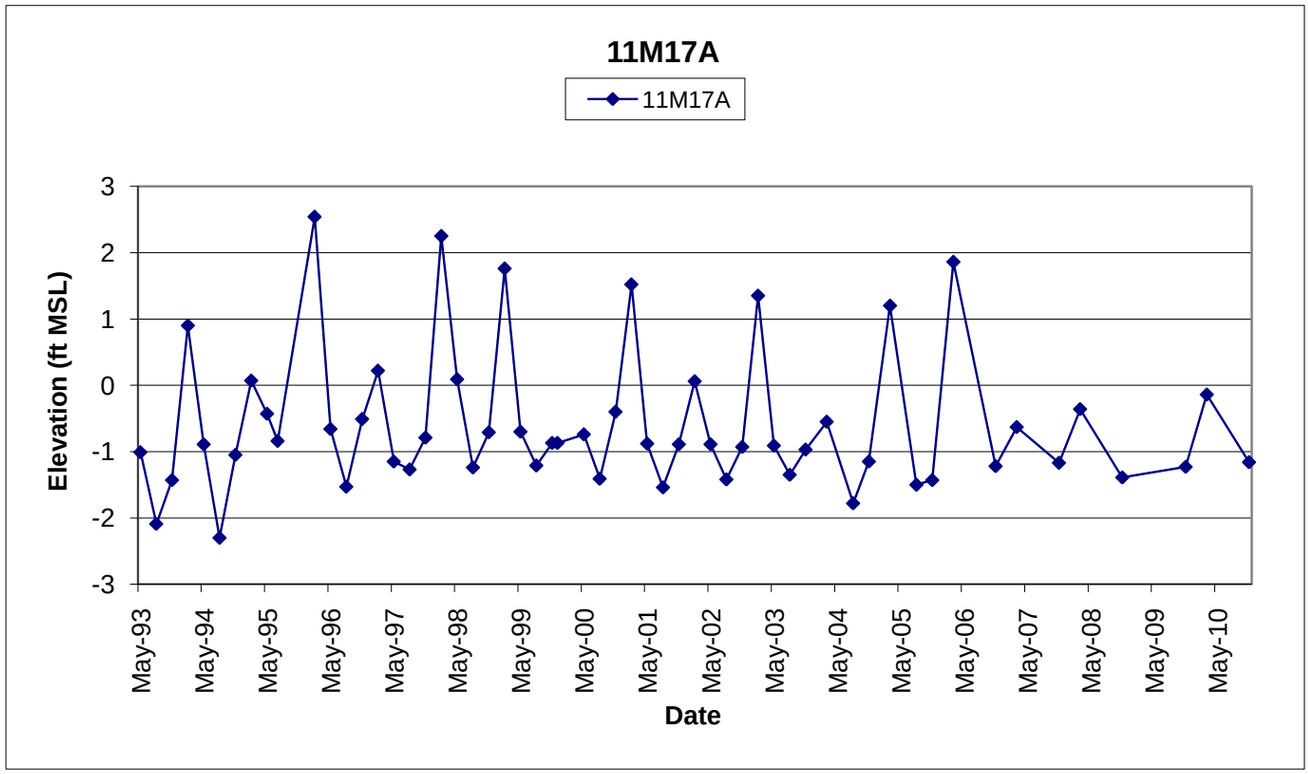


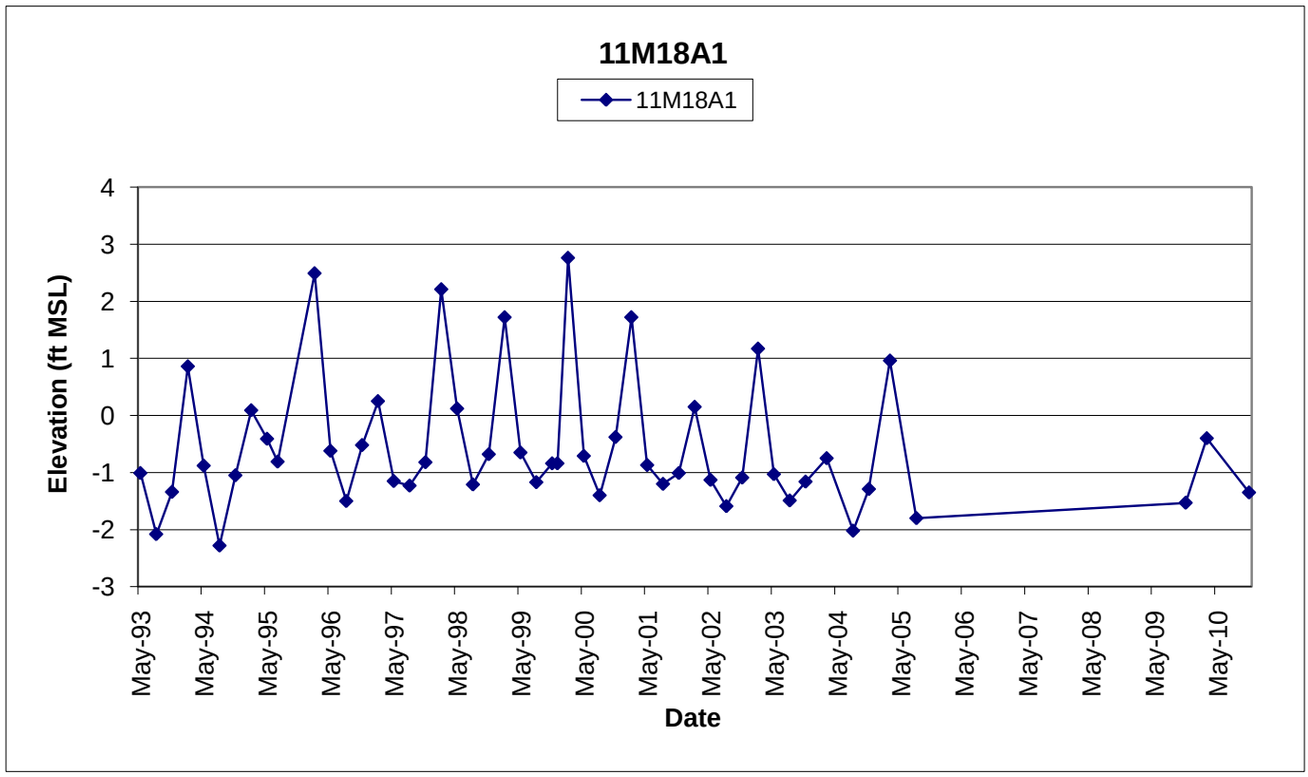
APPENDIX C
2010 Hydrographs



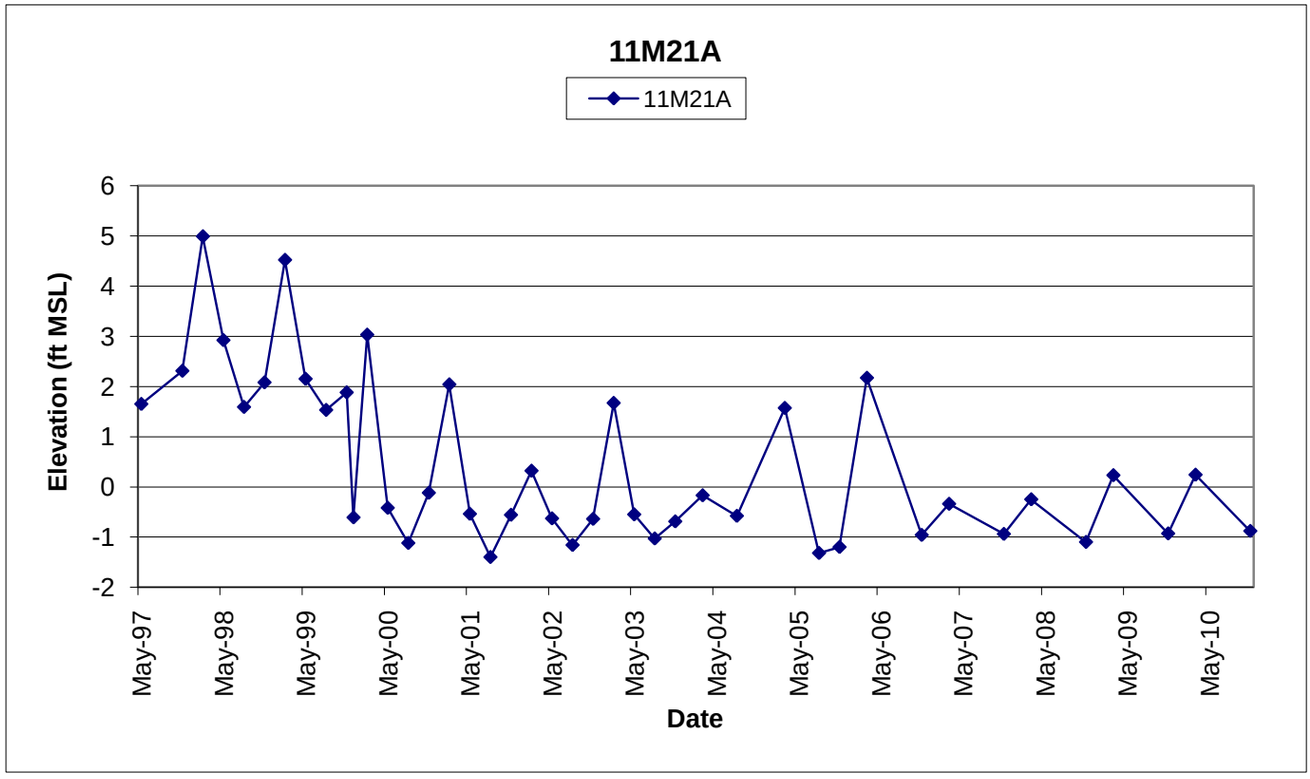


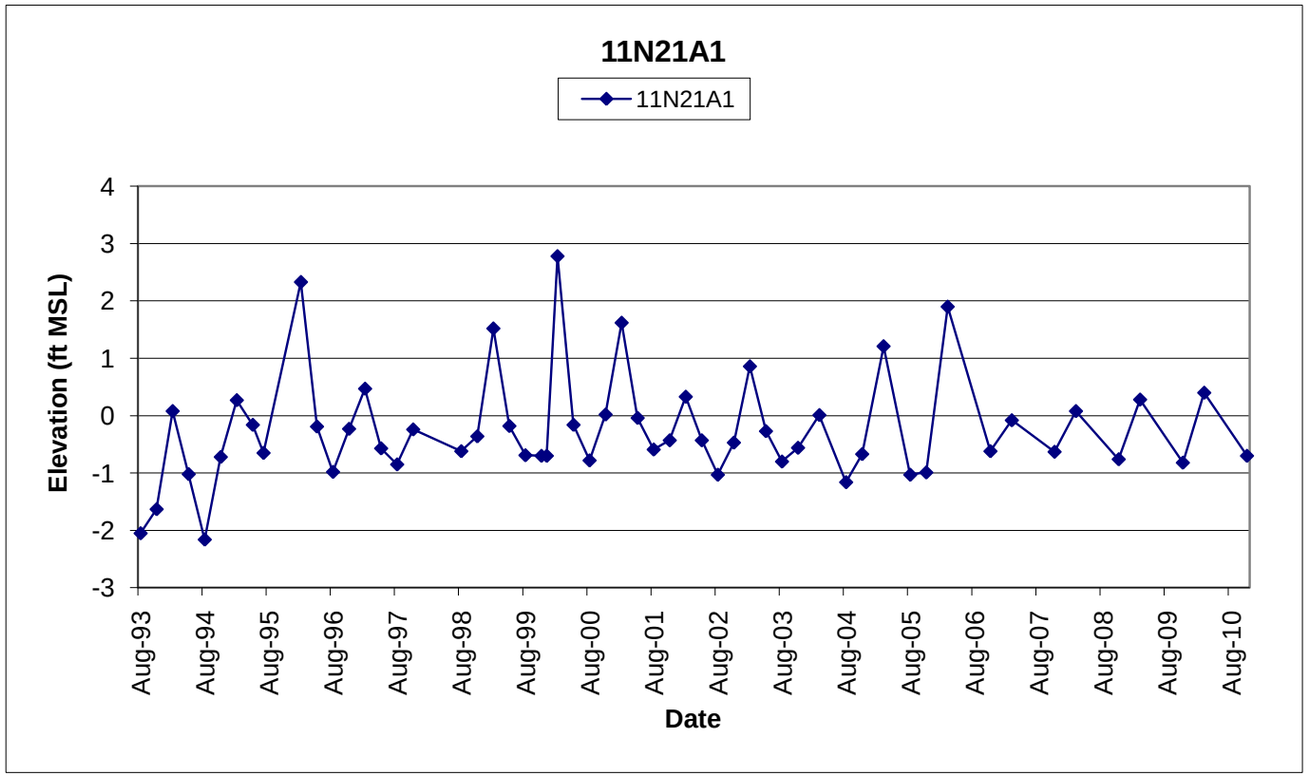
APPENDIX C
2010 Hydrographs



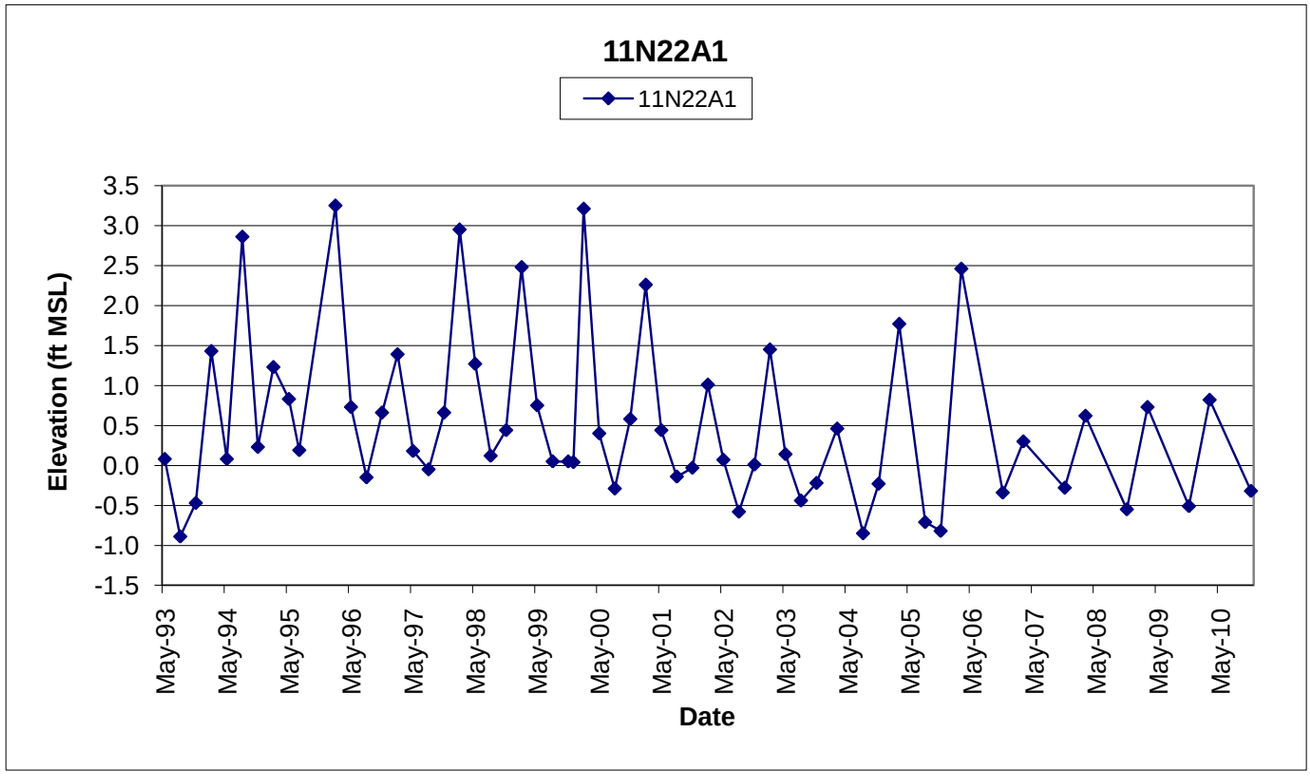


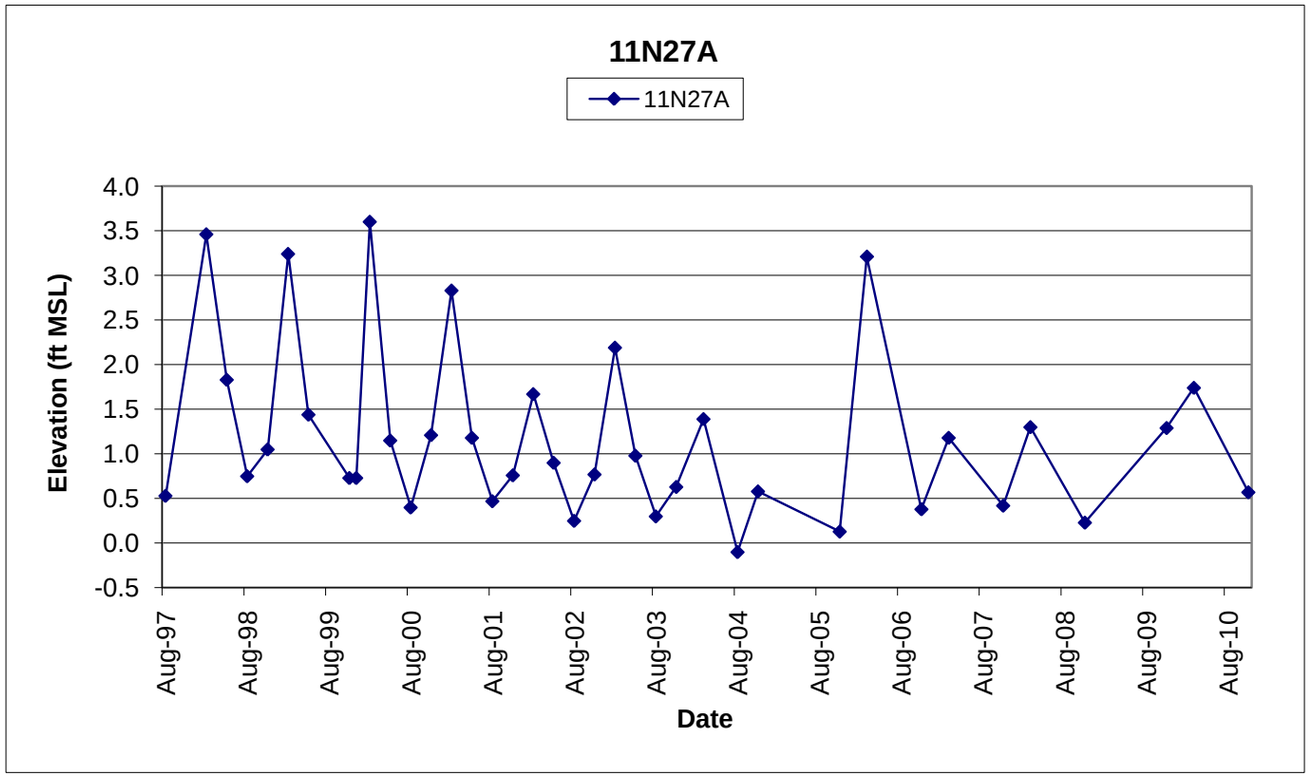
APPENDIX C
2010 Hydrographs



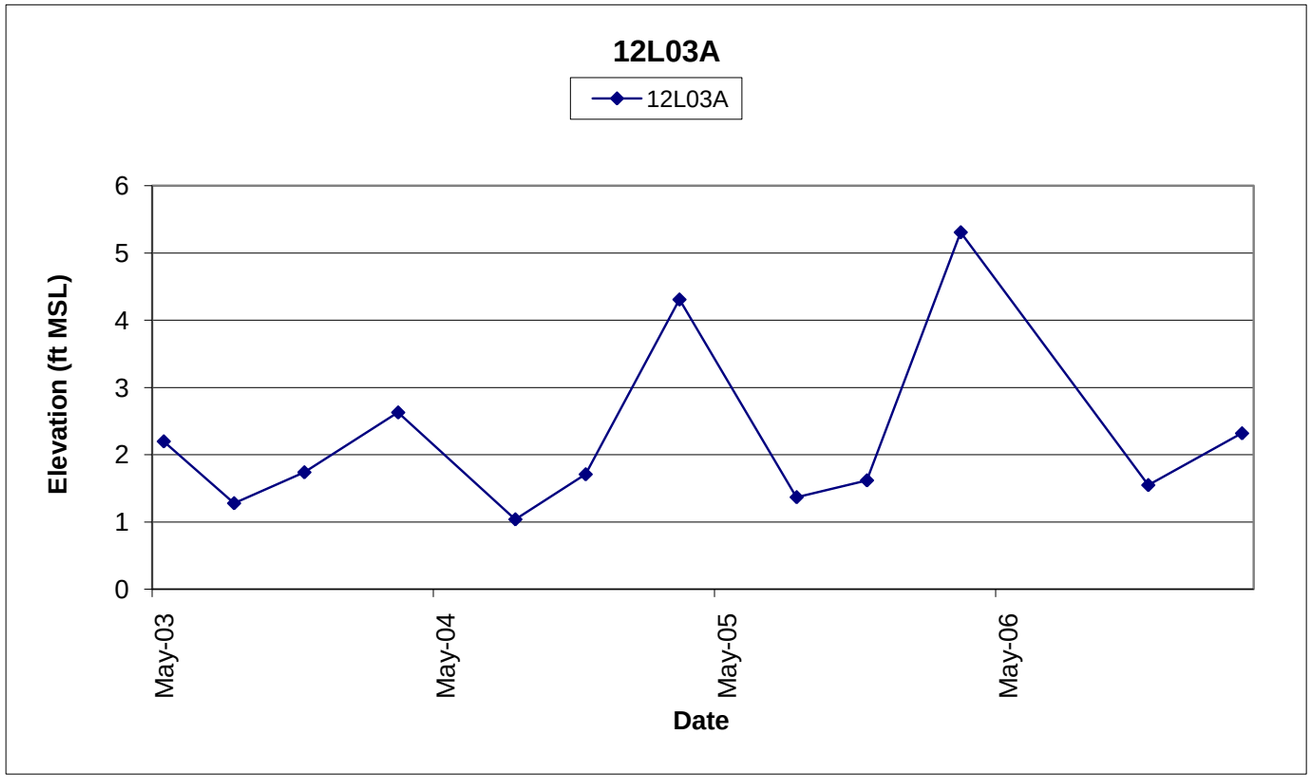


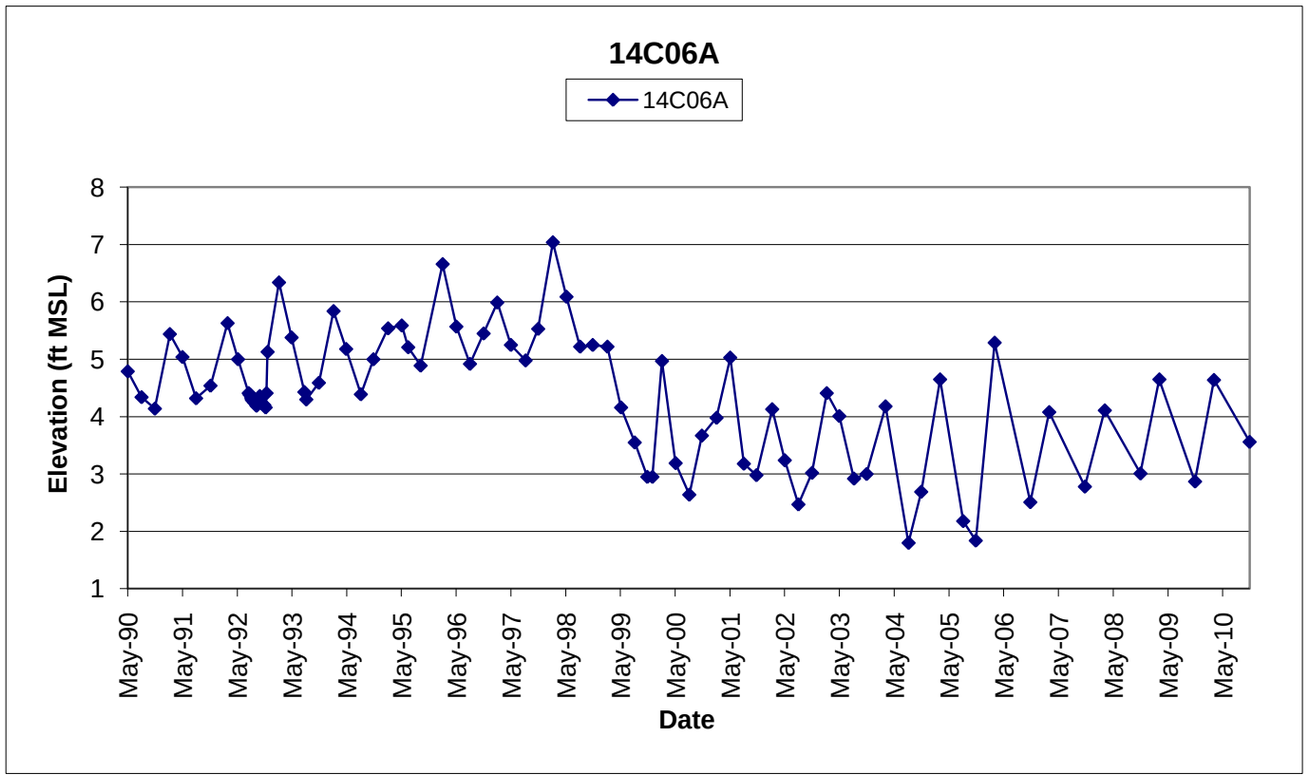
APPENDIX C
2010 Hydrographs



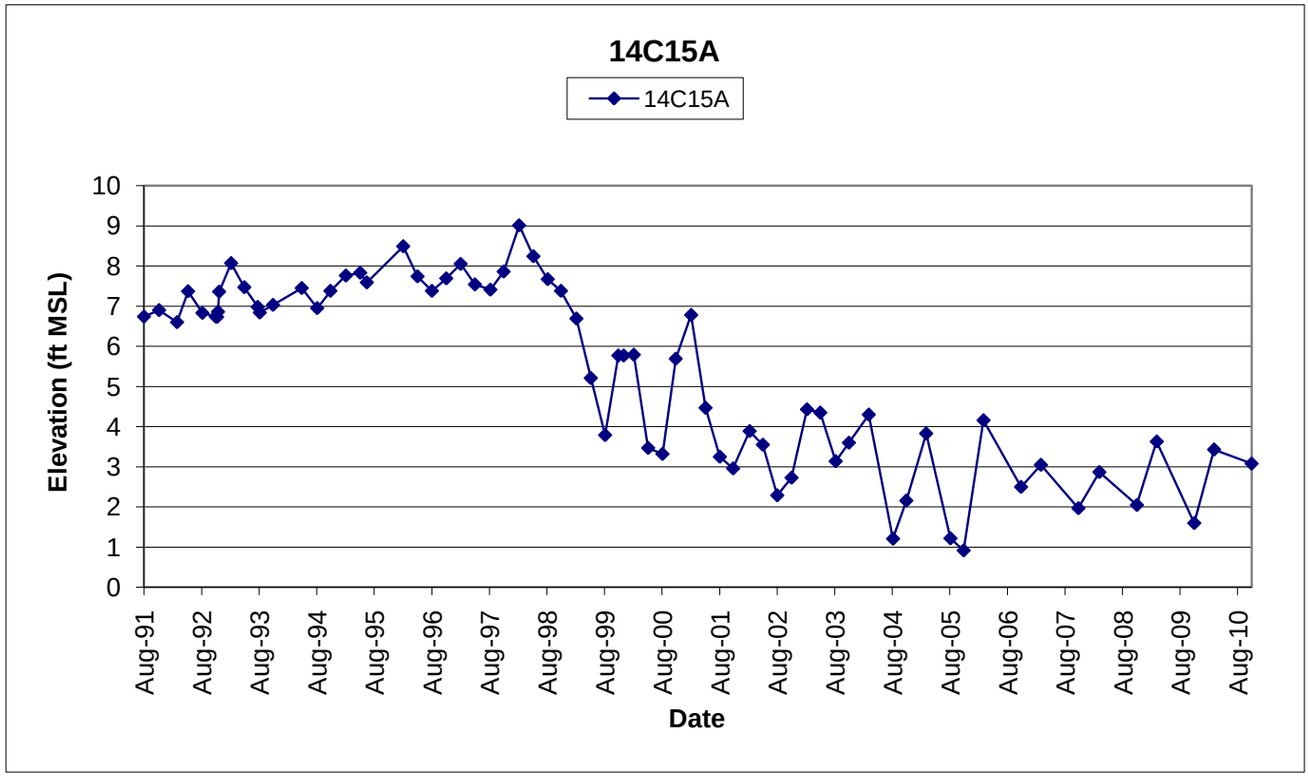


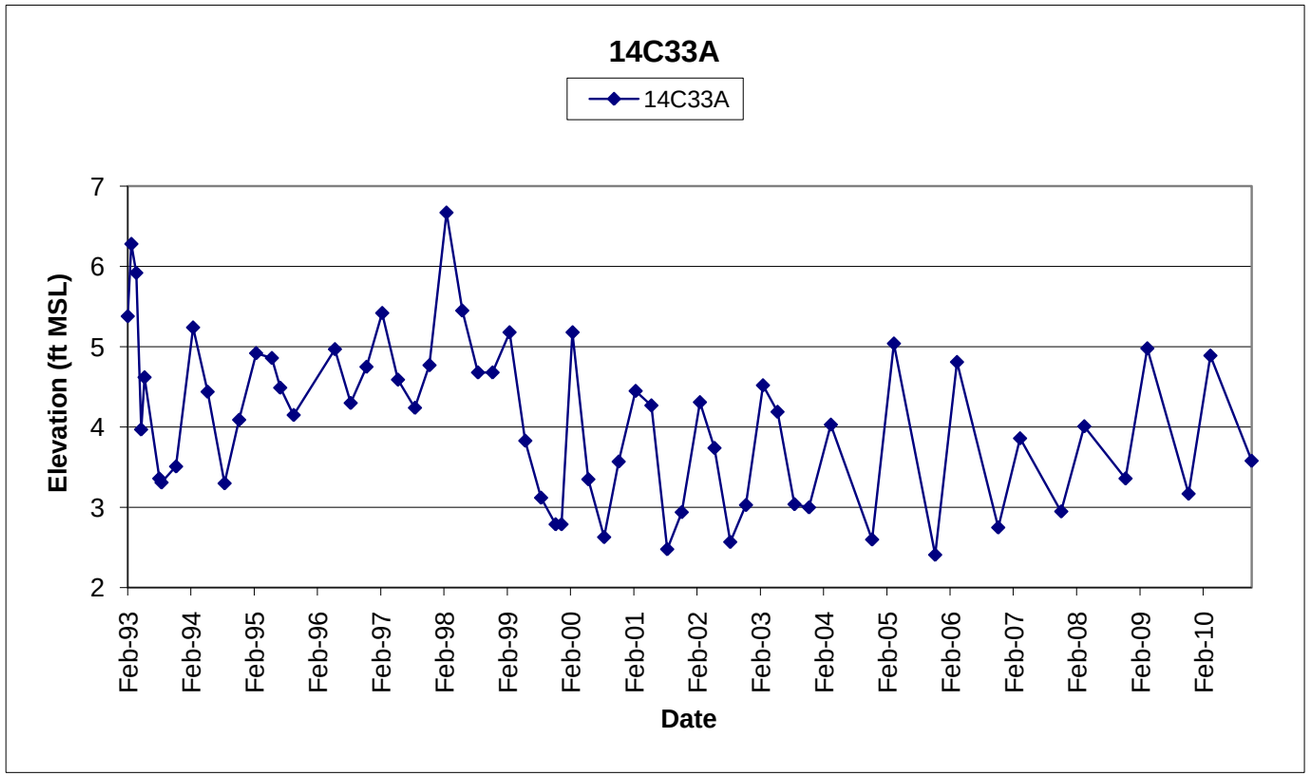
APPENDIX C
2010 Hydrographs



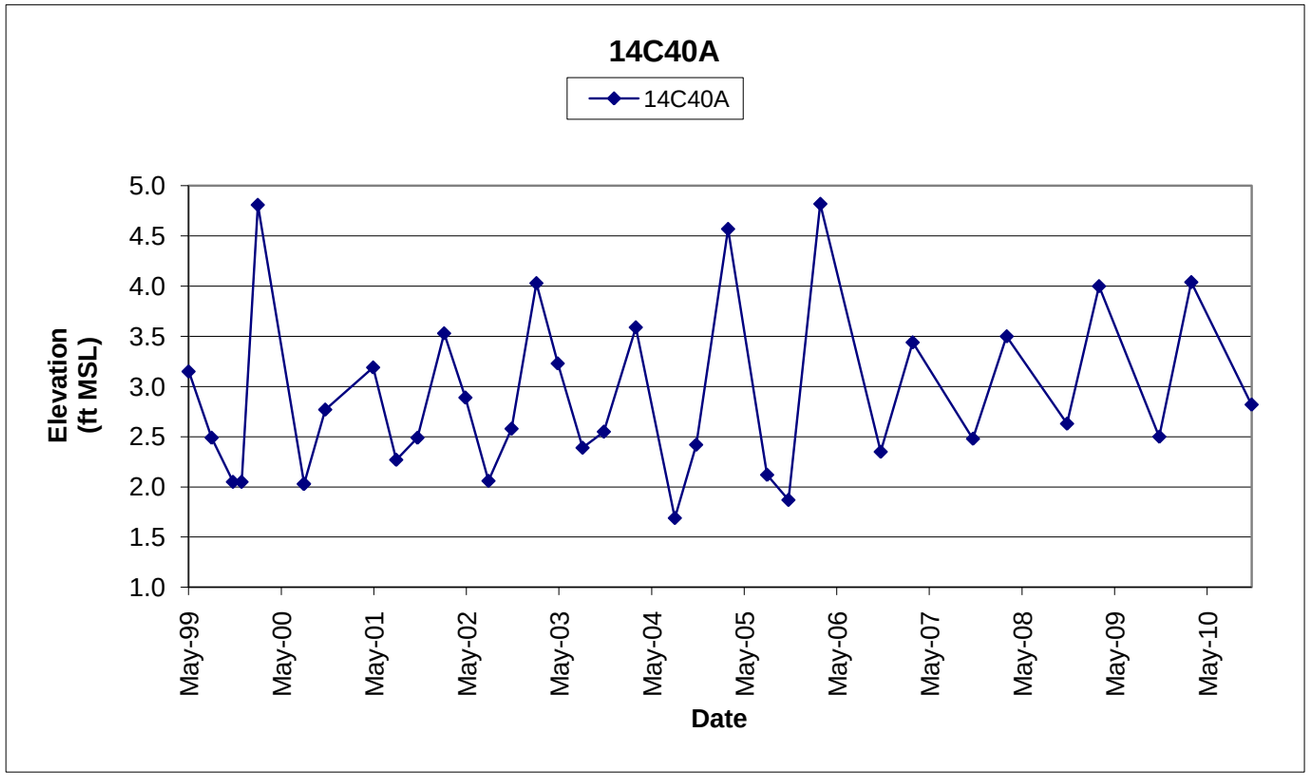


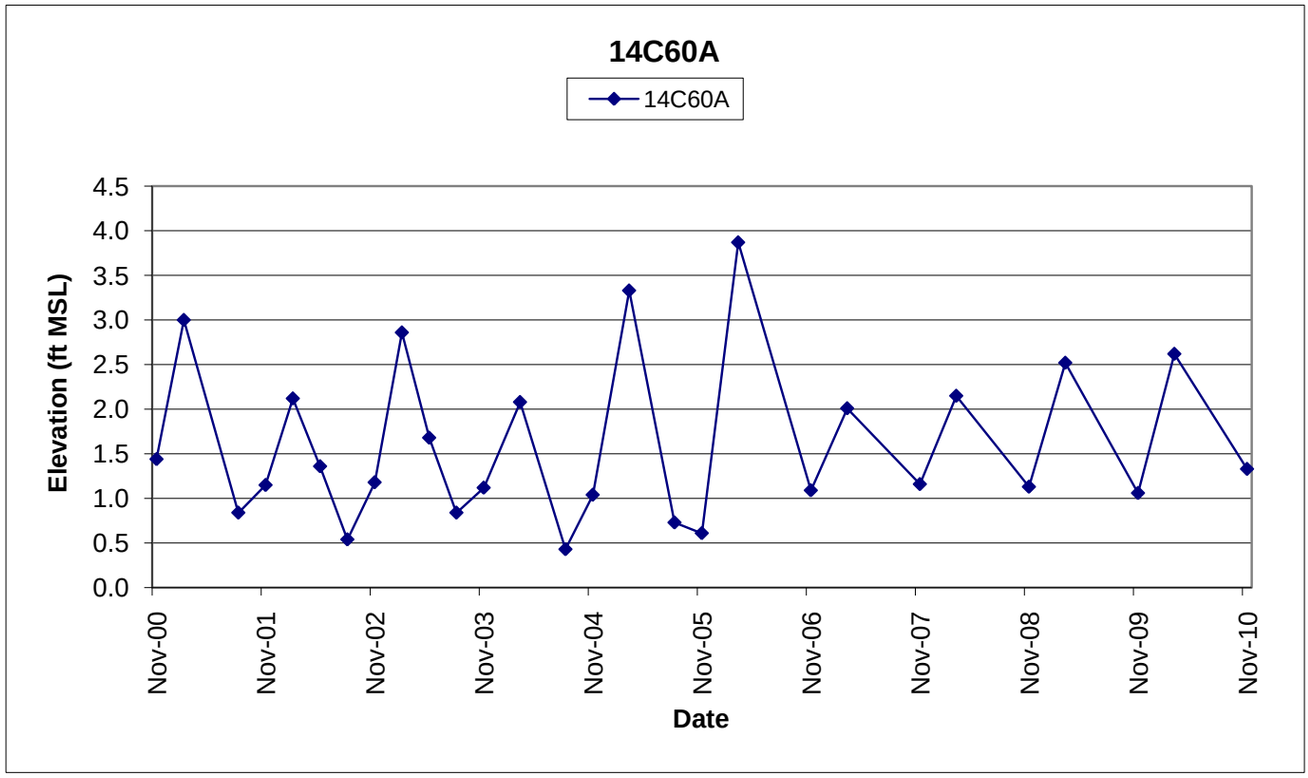
APPENDIX C
2010 Hydrographs



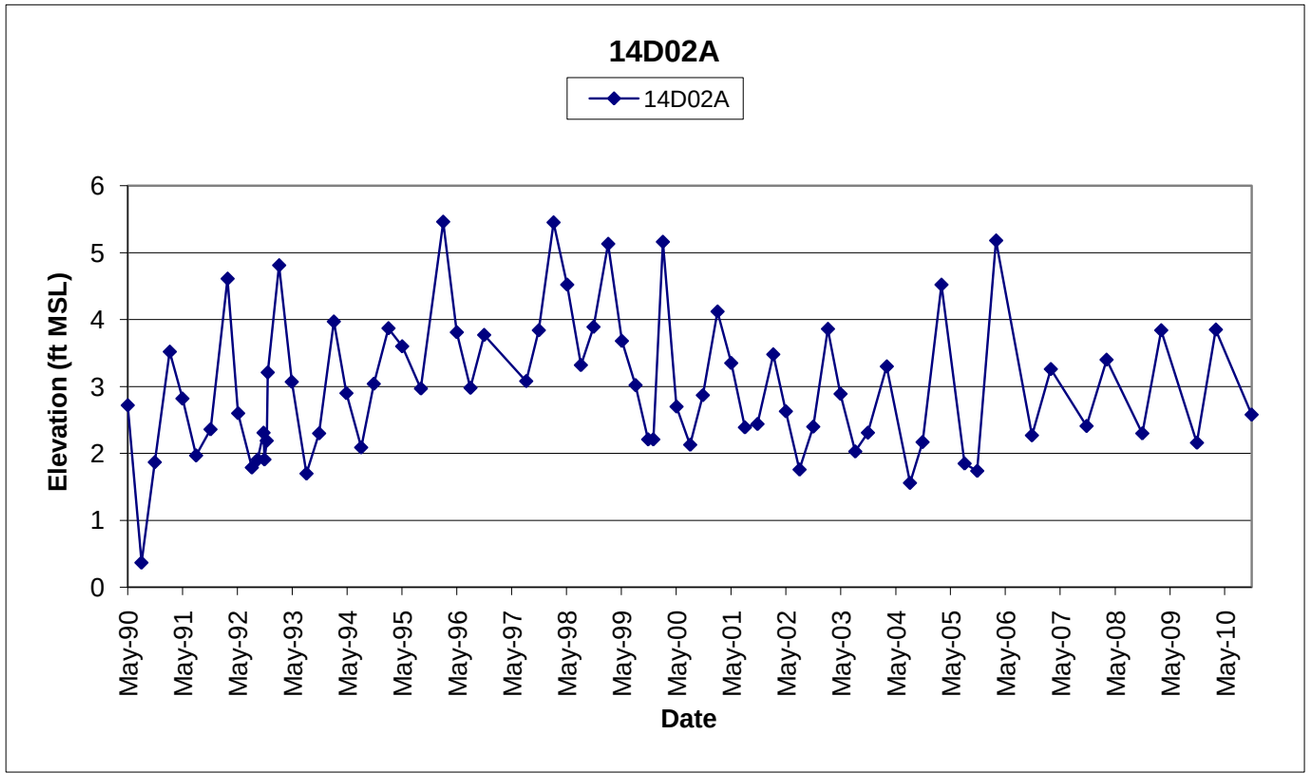


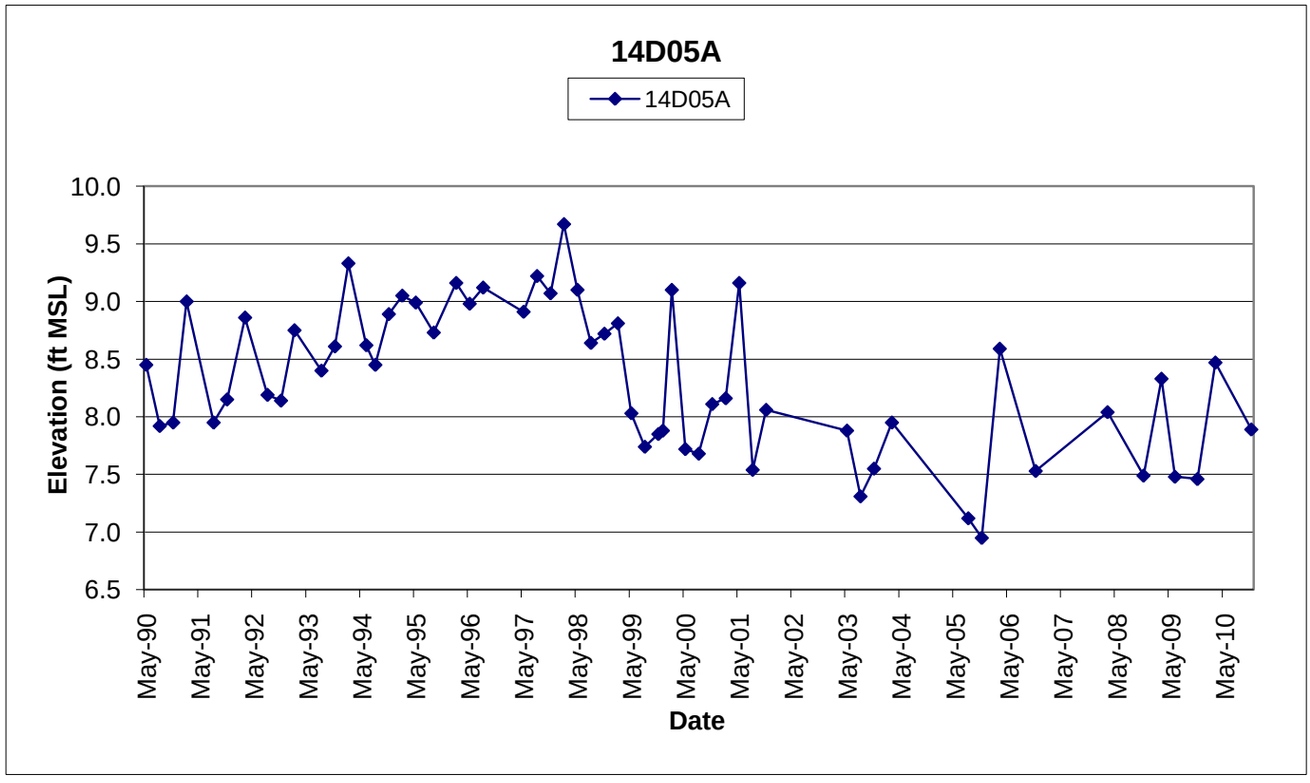
APPENDIX C
2010 Hydrographs



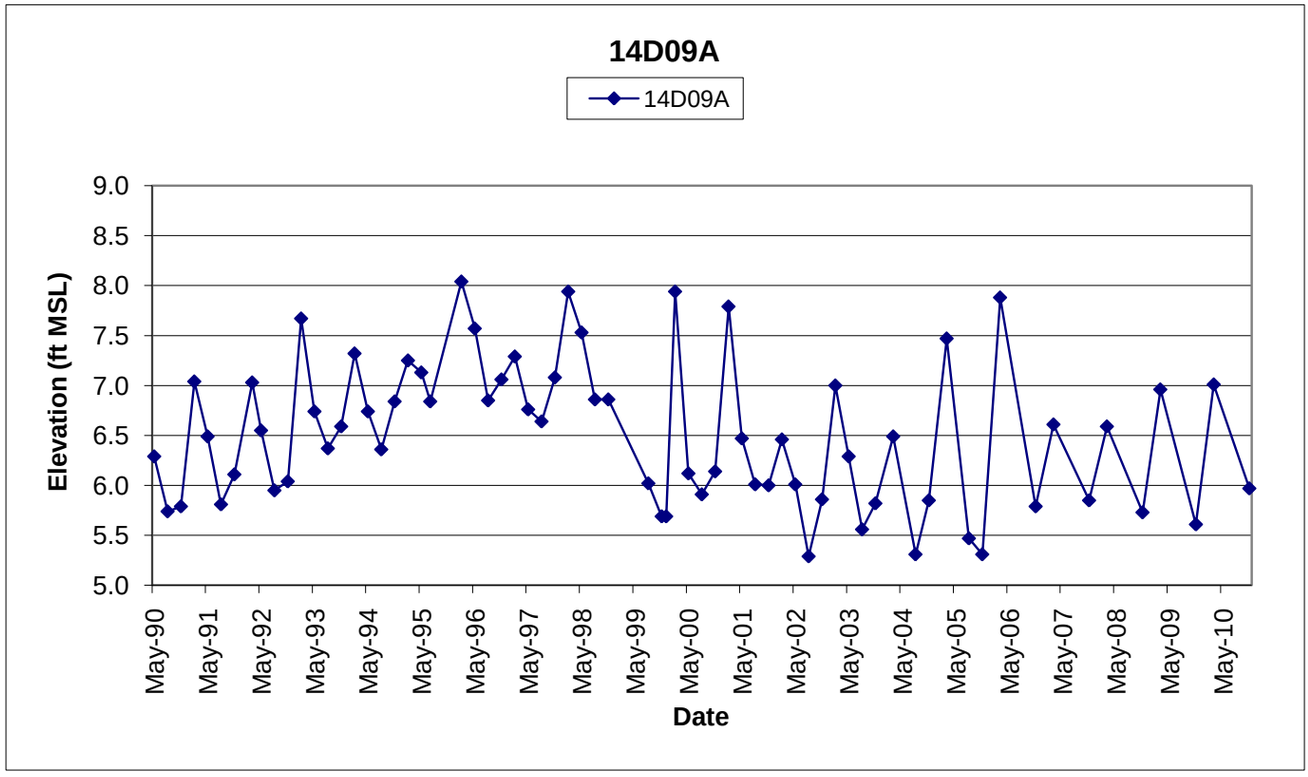


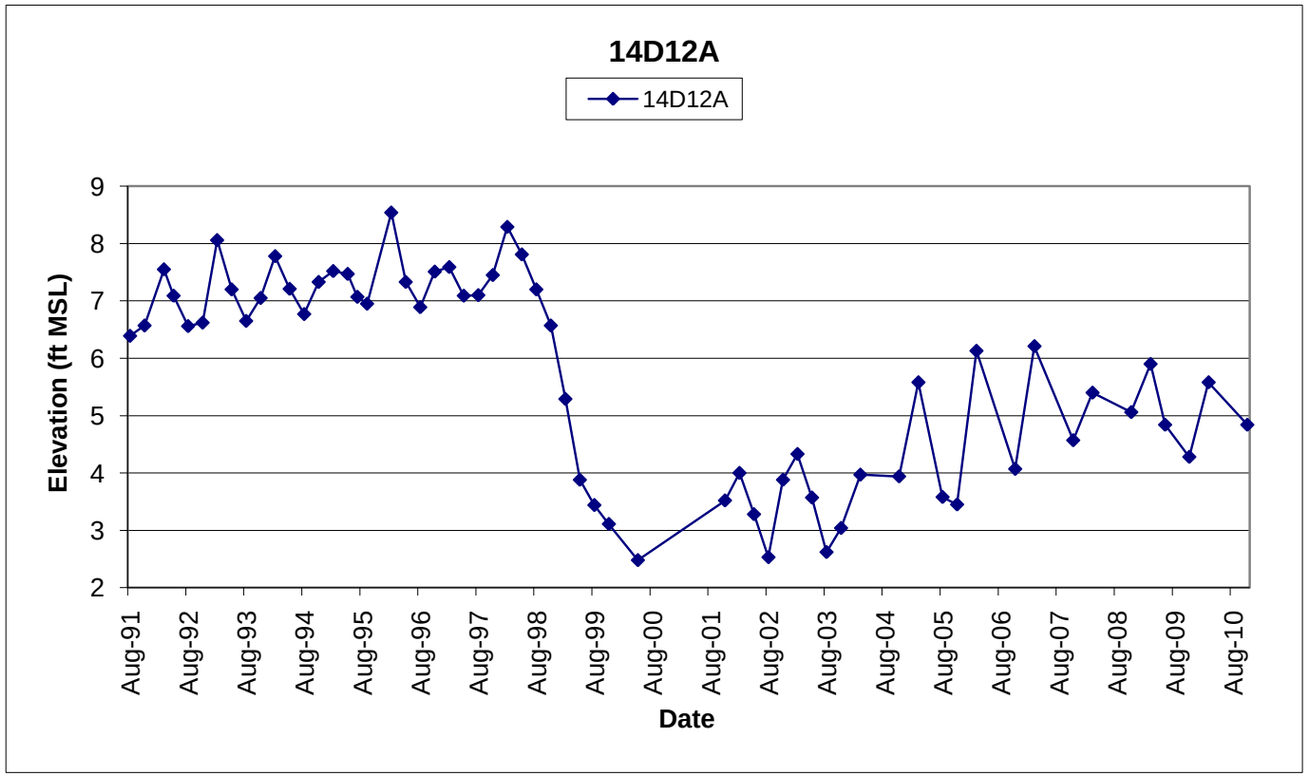
APPENDIX C
2010 Hydrographs



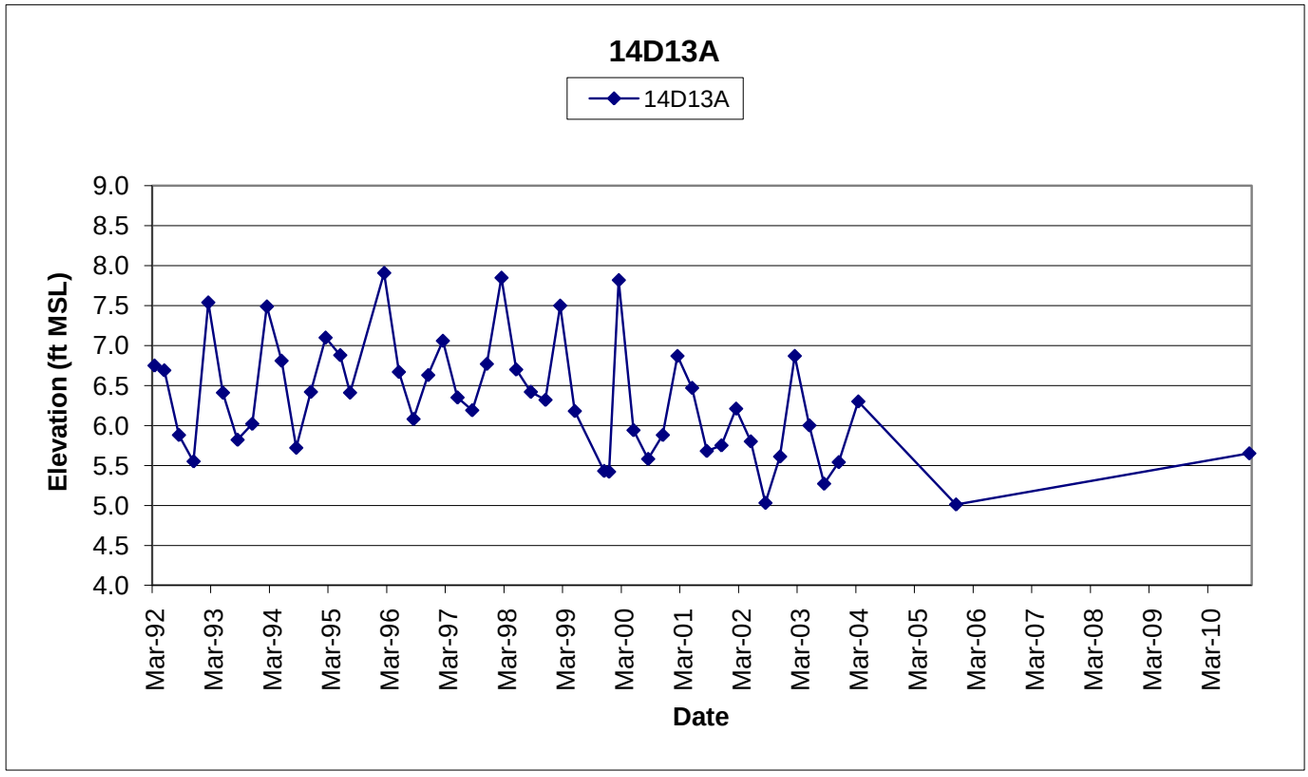


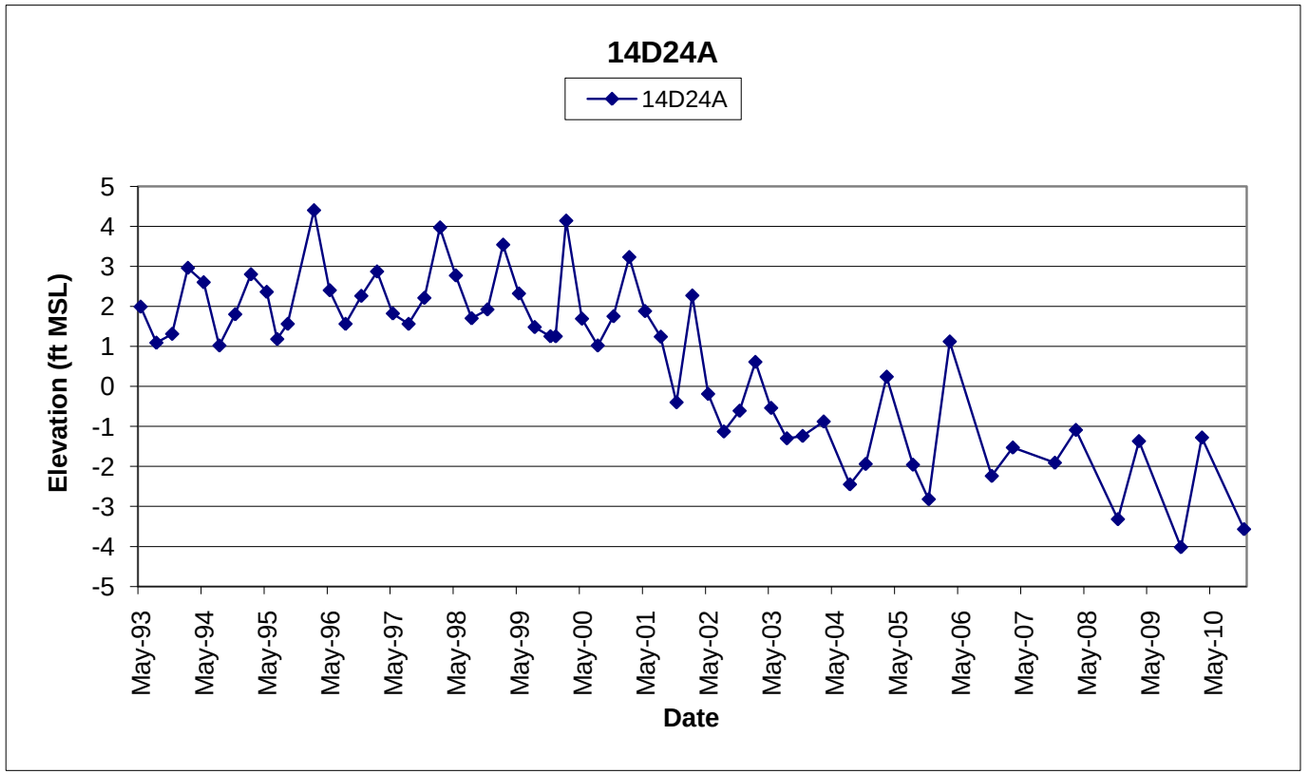
APPENDIX C
2010 Hydrographs



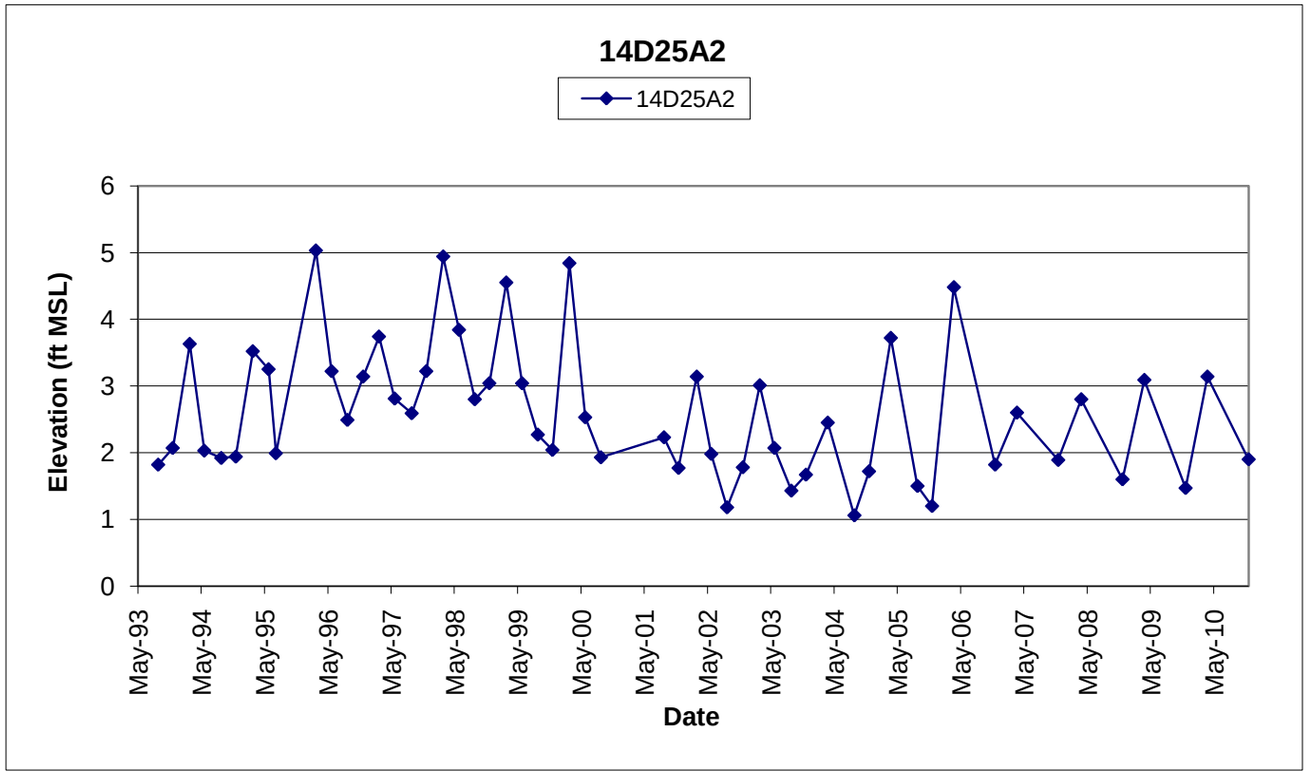


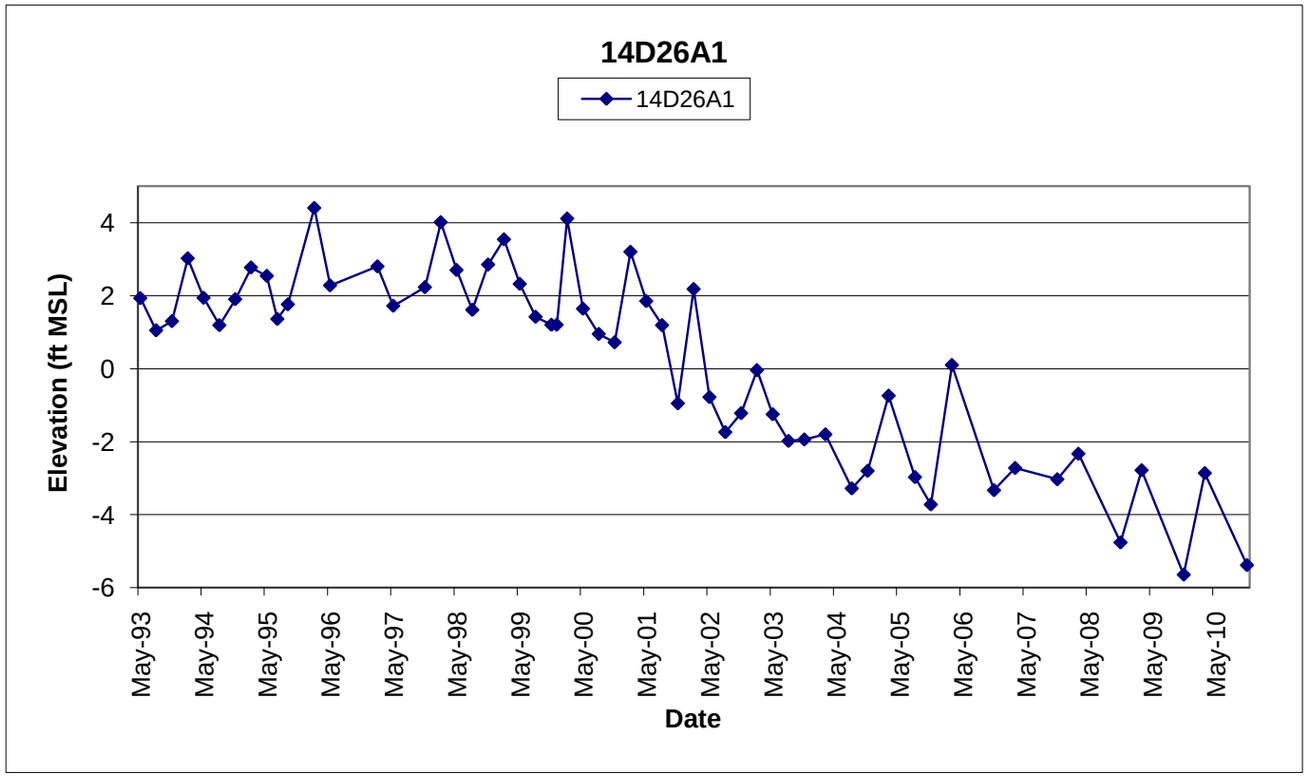
APPENDIX C
2010 Hydrographs



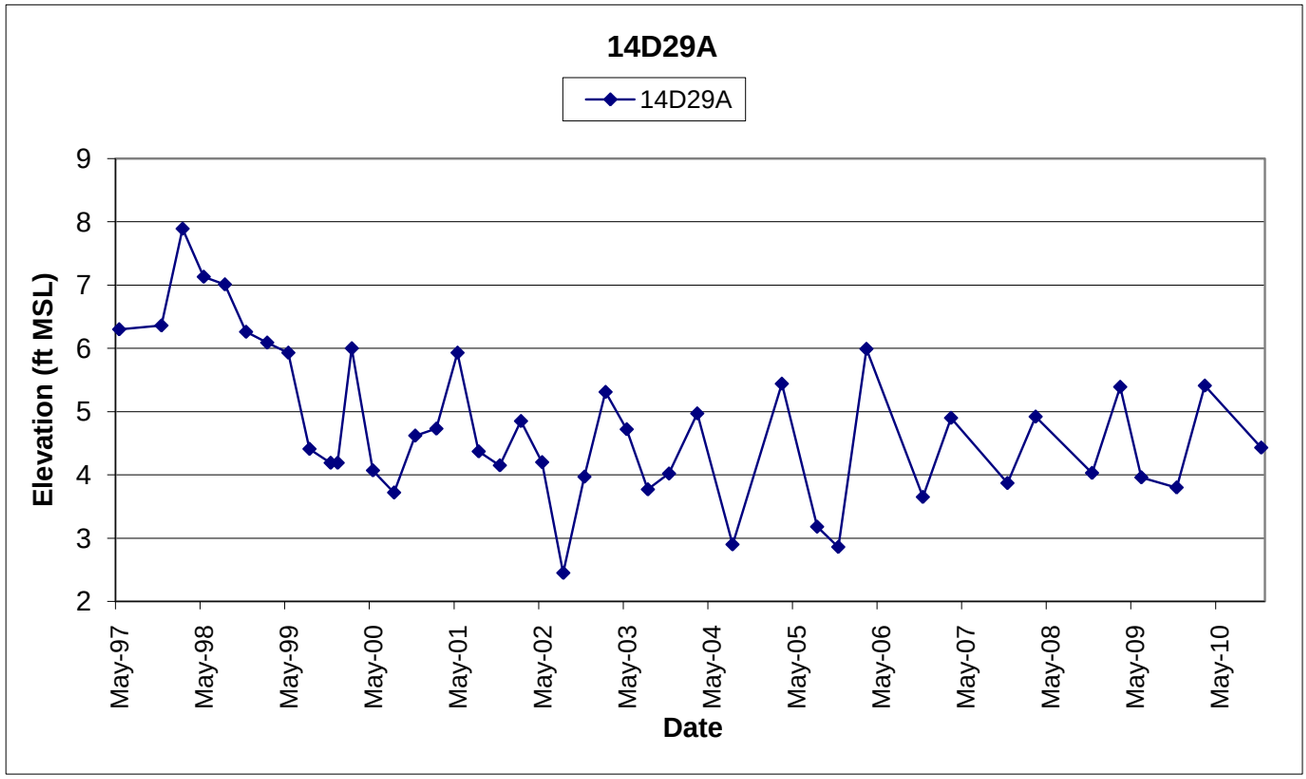


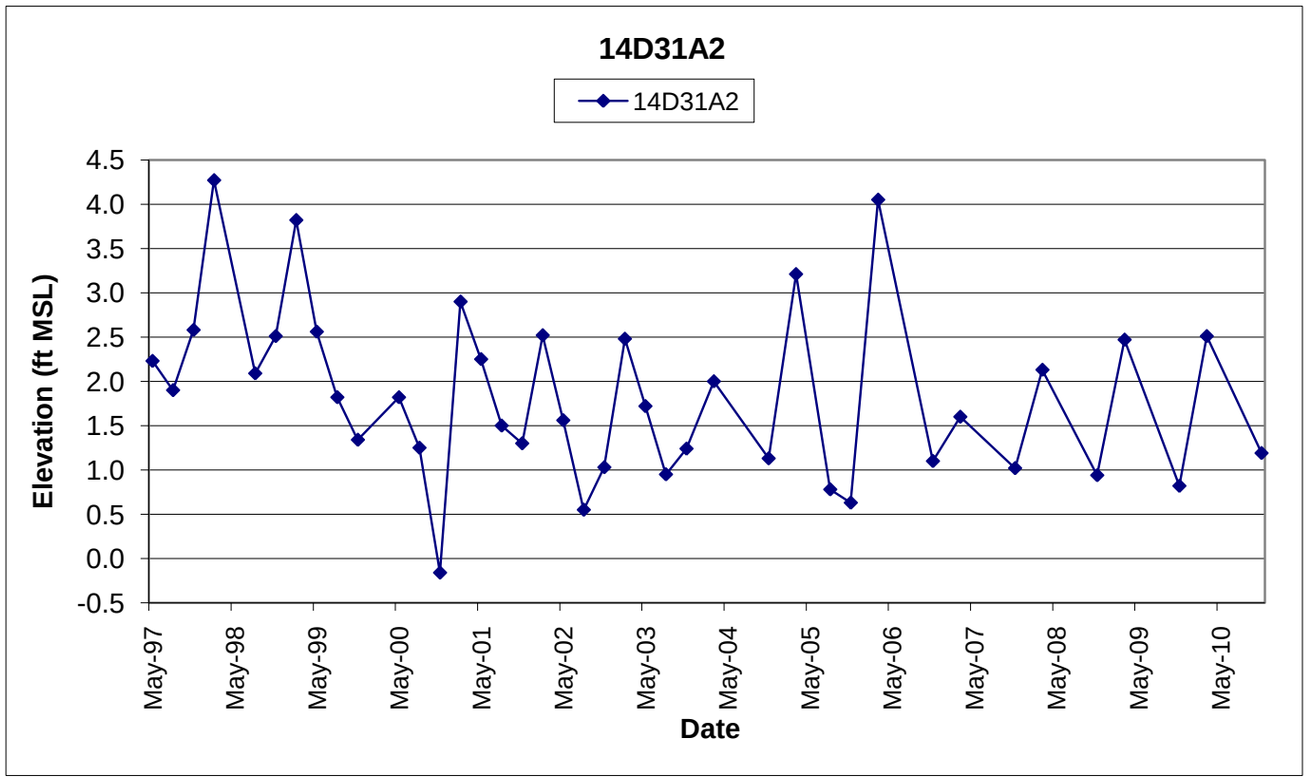
APPENDIX C
2010 Hydrographs



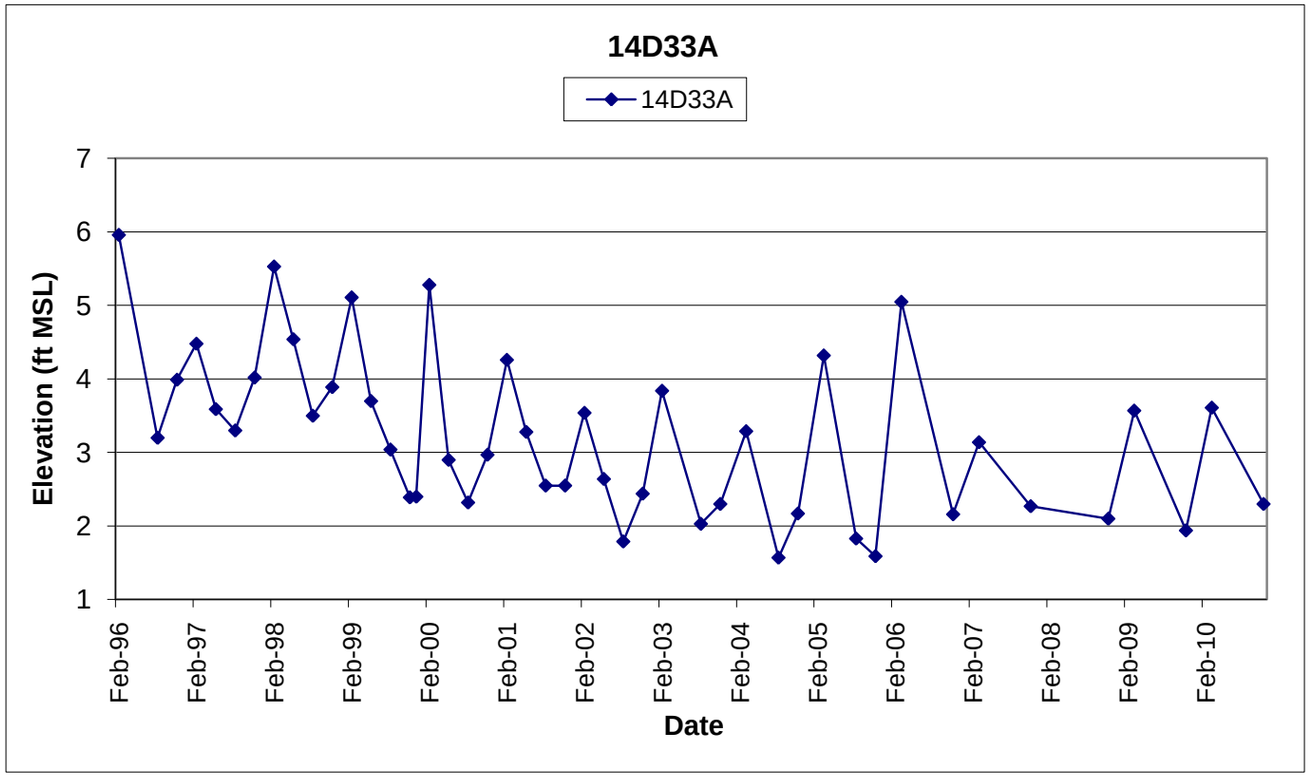


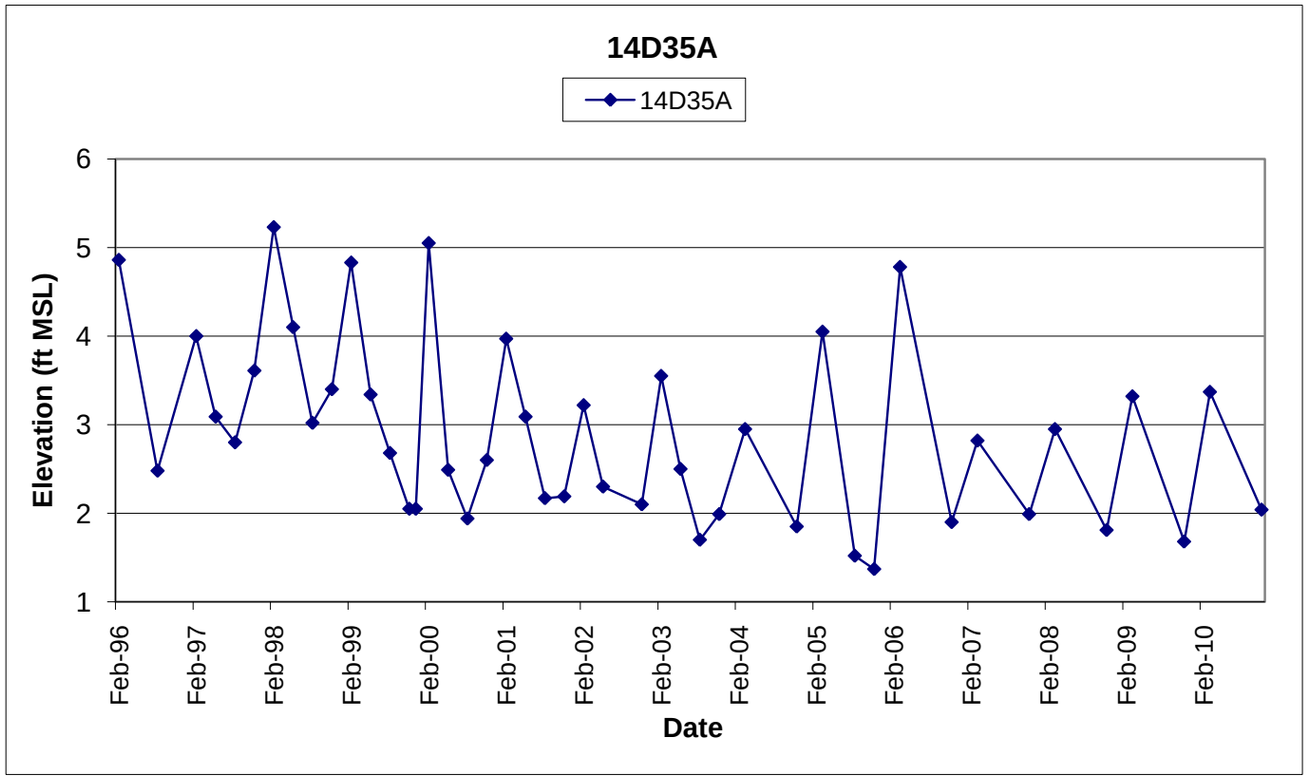
APPENDIX C
2010 Hydrographs



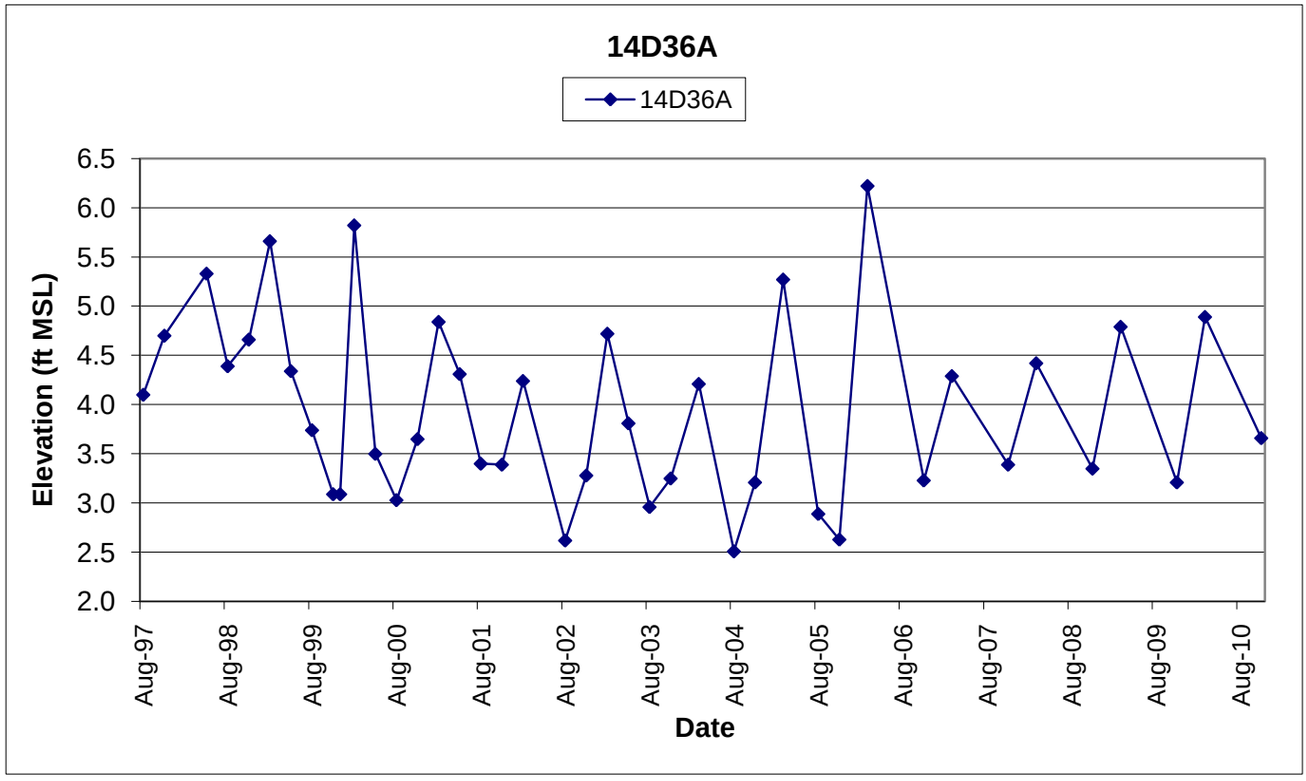


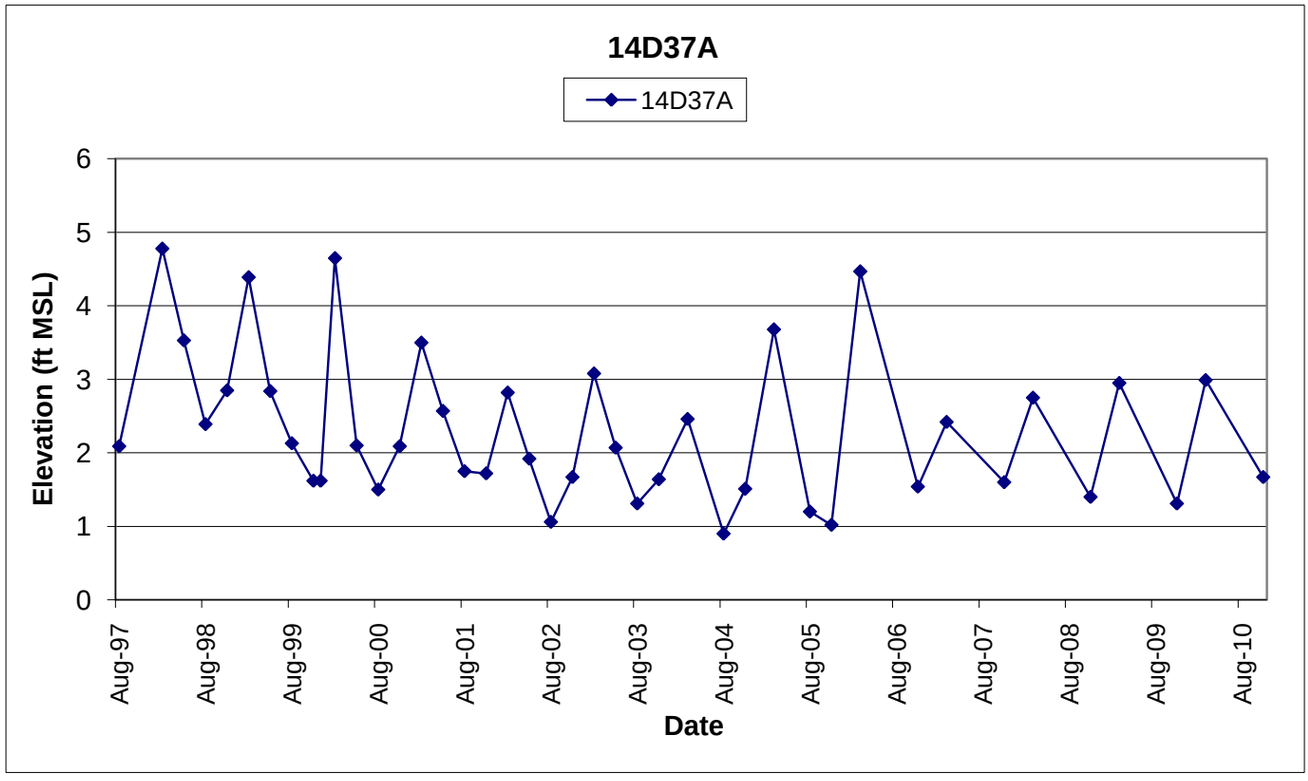
APPENDIX C
2010 Hydrographs



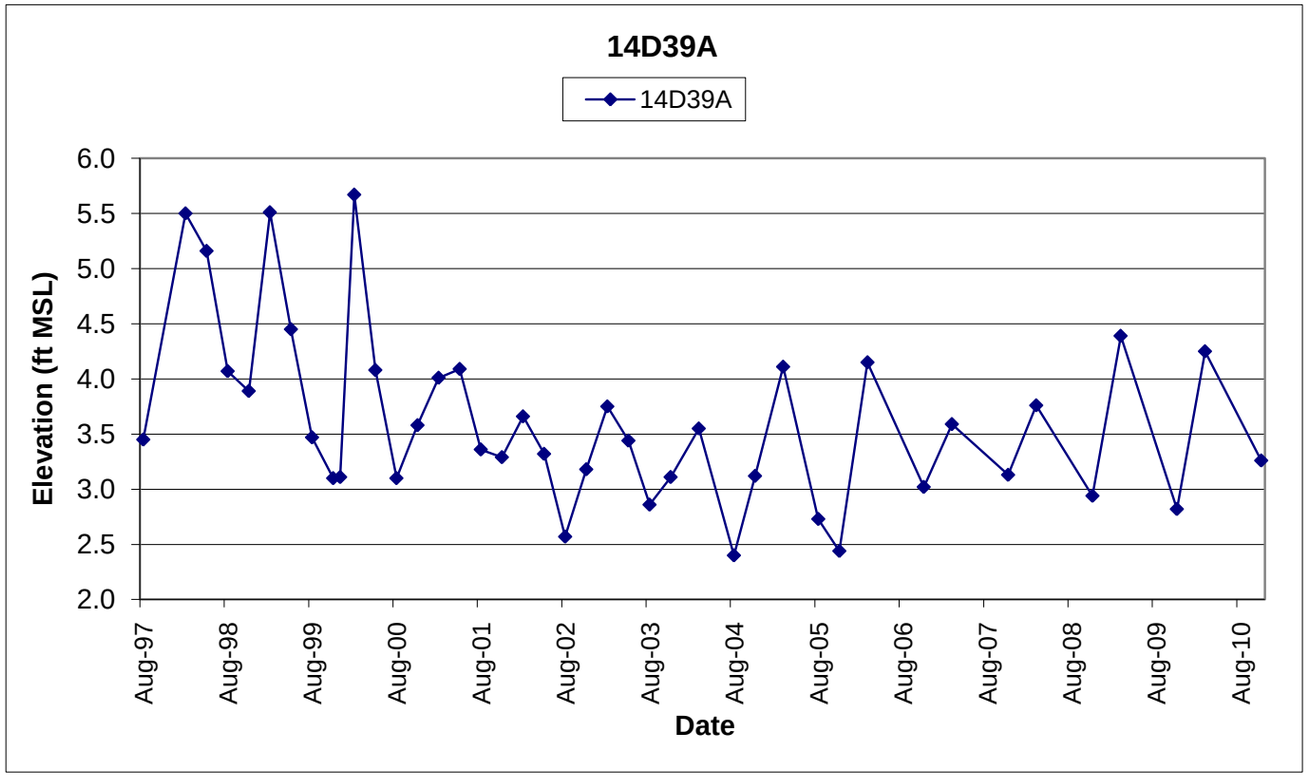


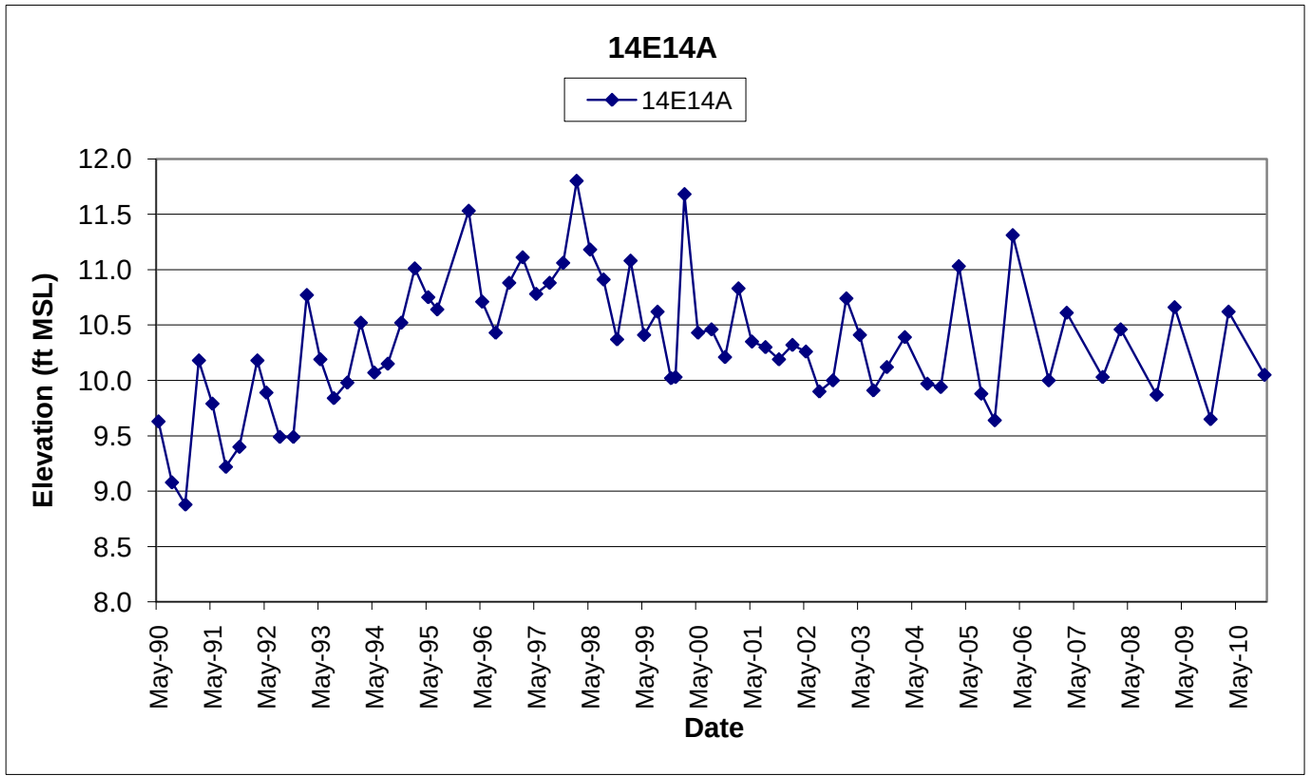
APPENDIX C
2010 Hydrographs



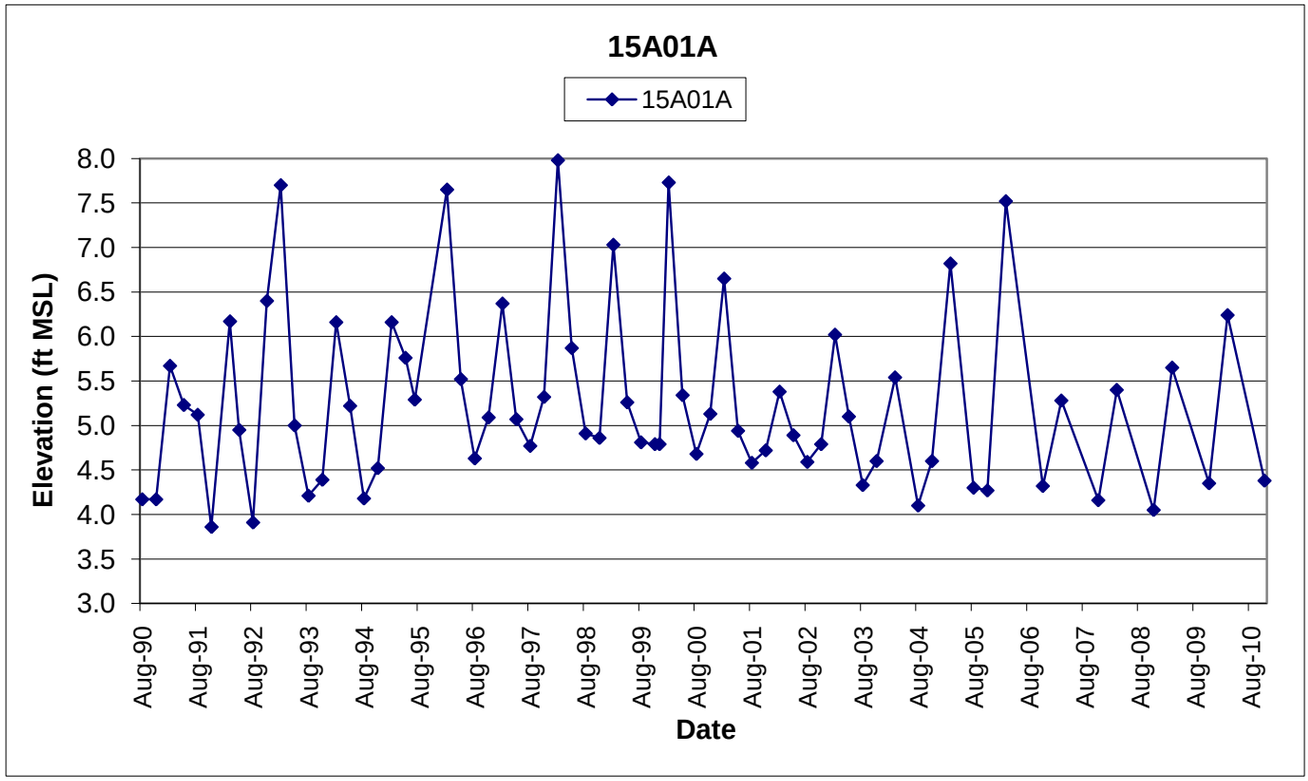


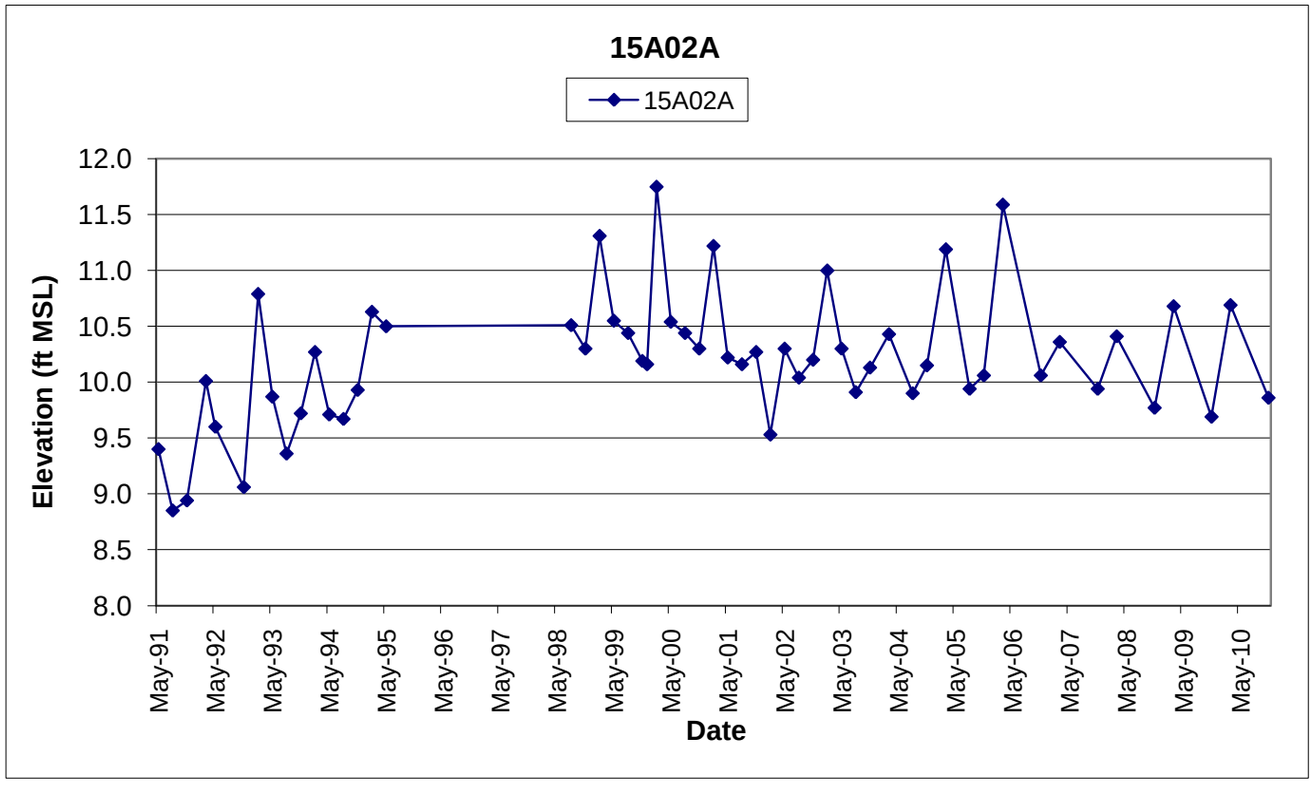
APPENDIX C
2010 Hydrographs



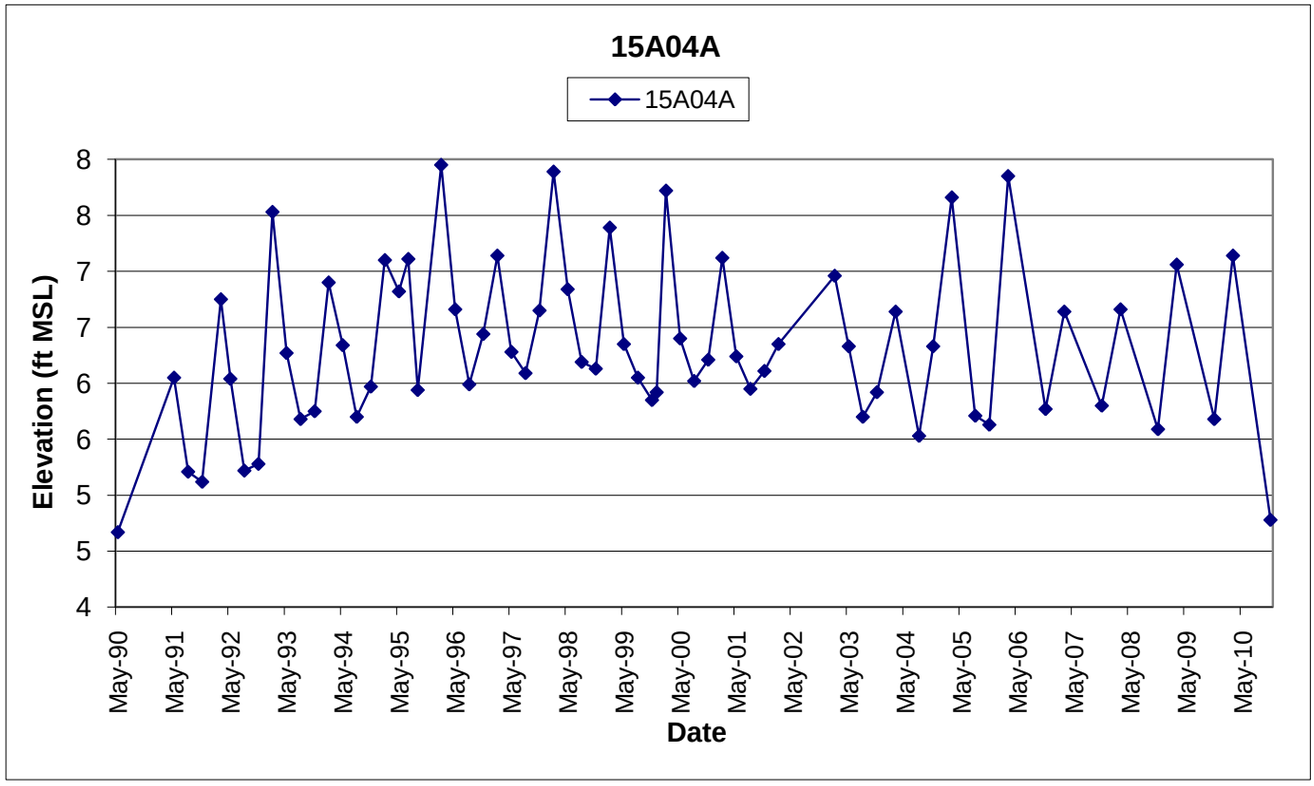


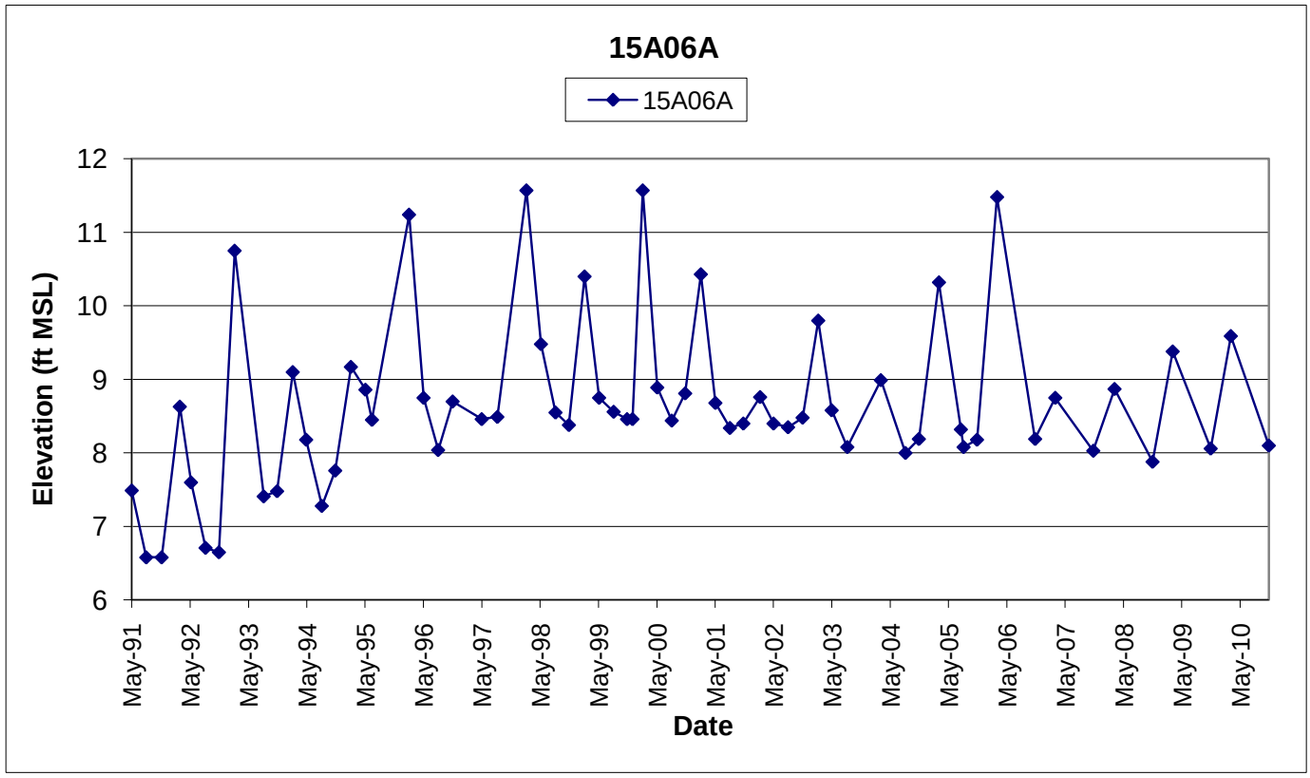
APPENDIX C
2010 Hydrographs



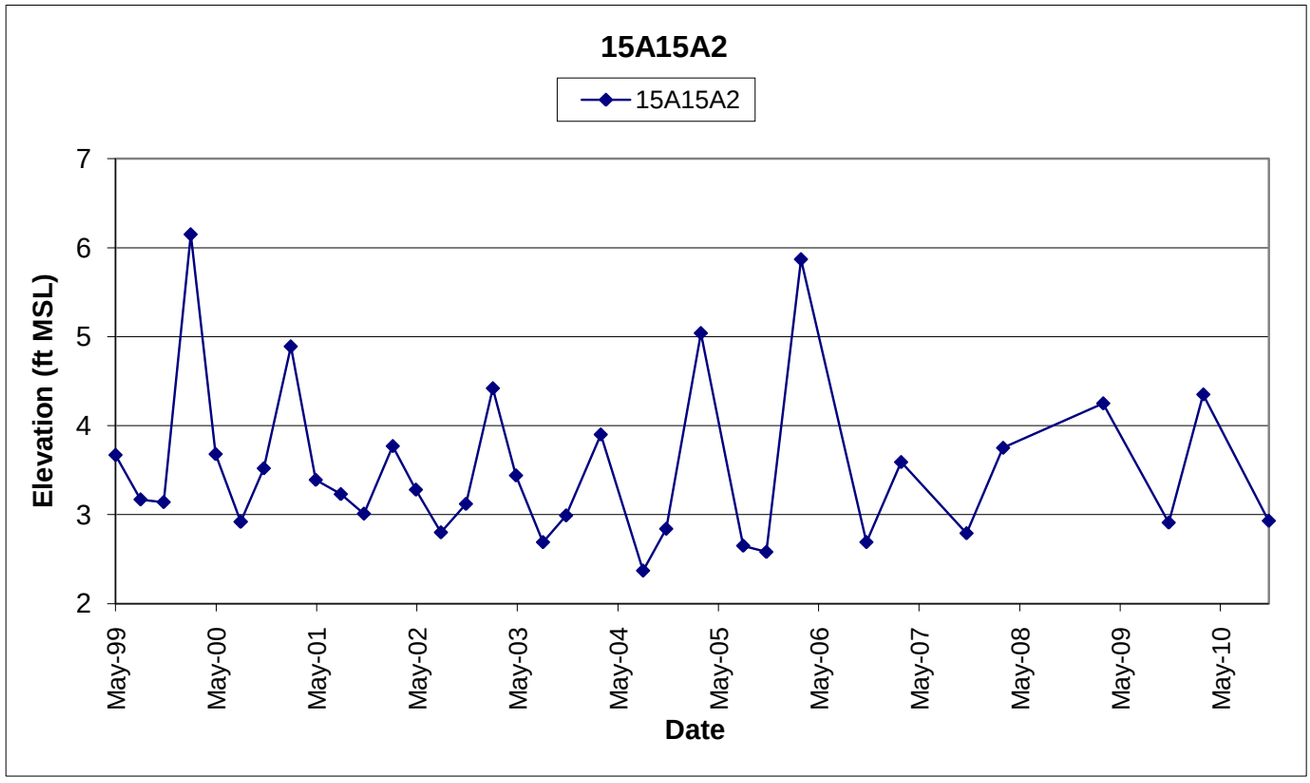


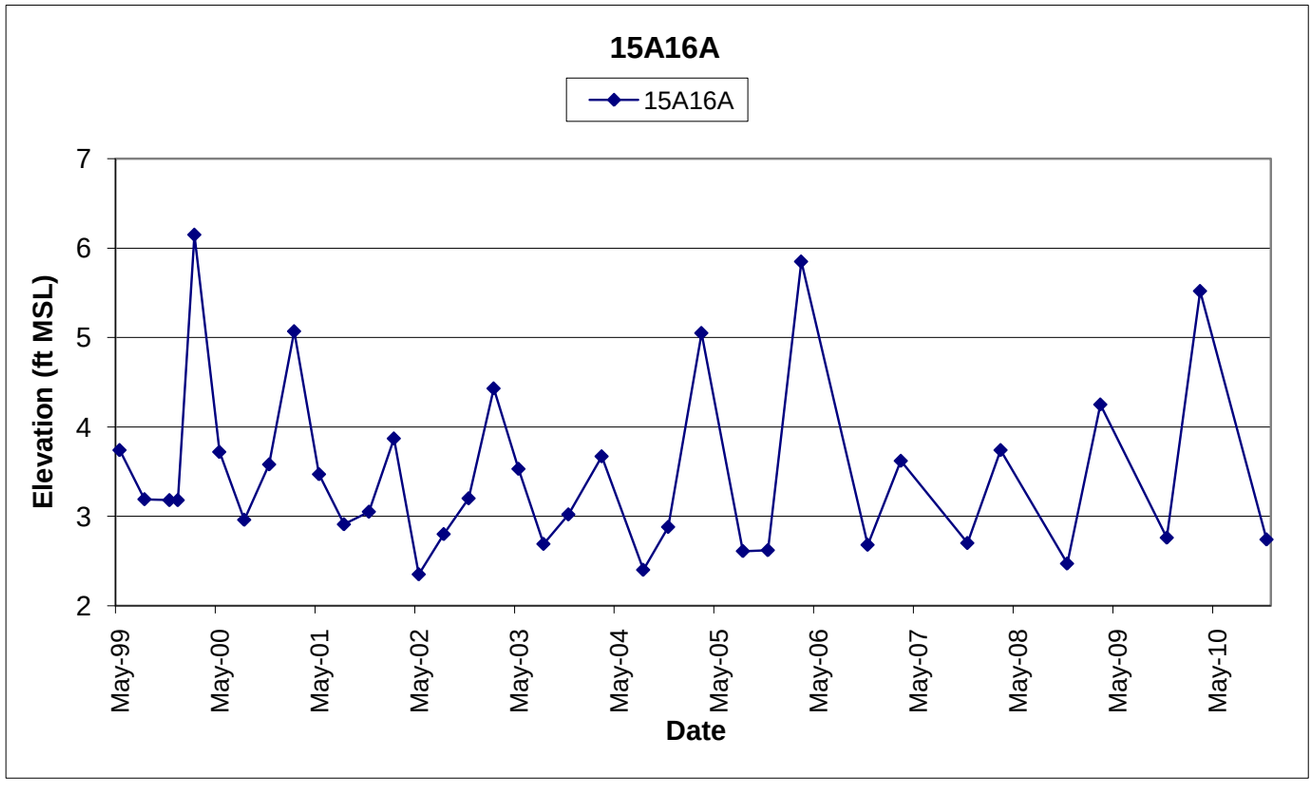
APPENDIX C
2010 Hydrographs



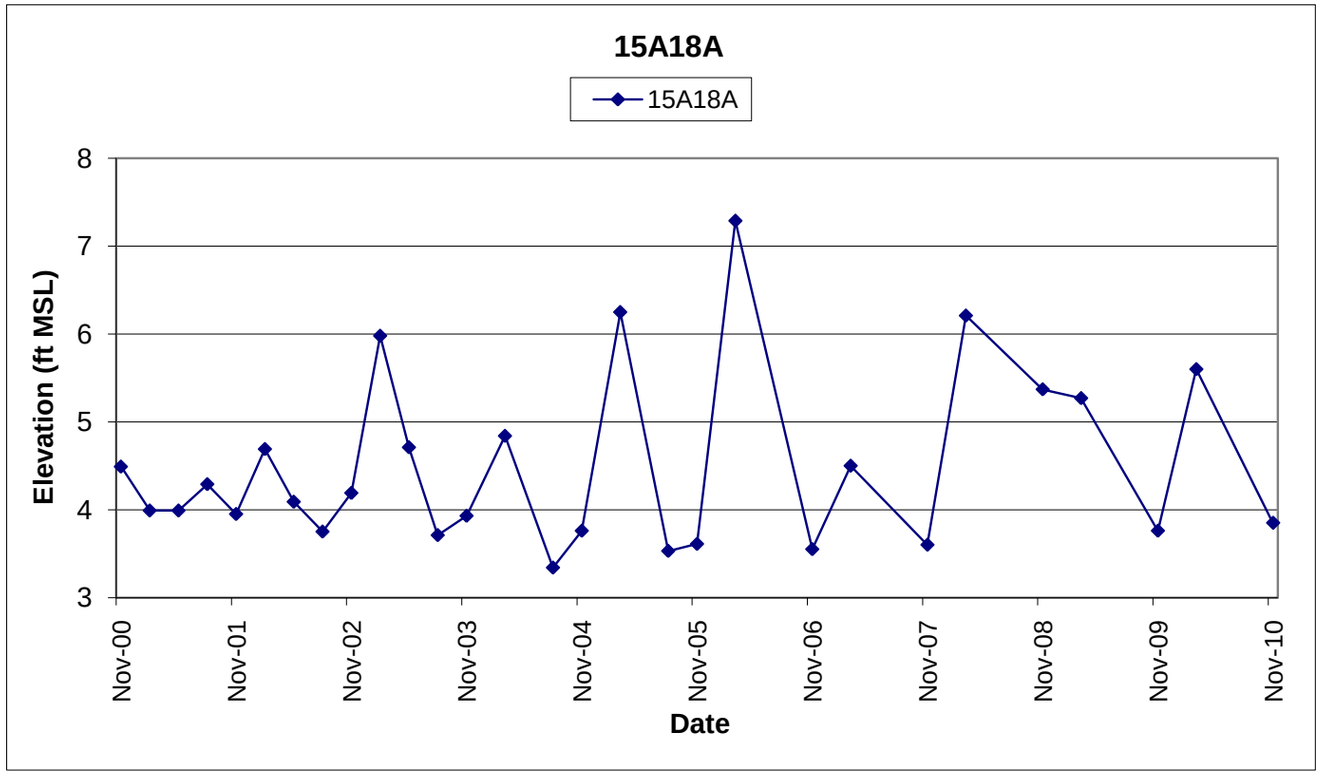


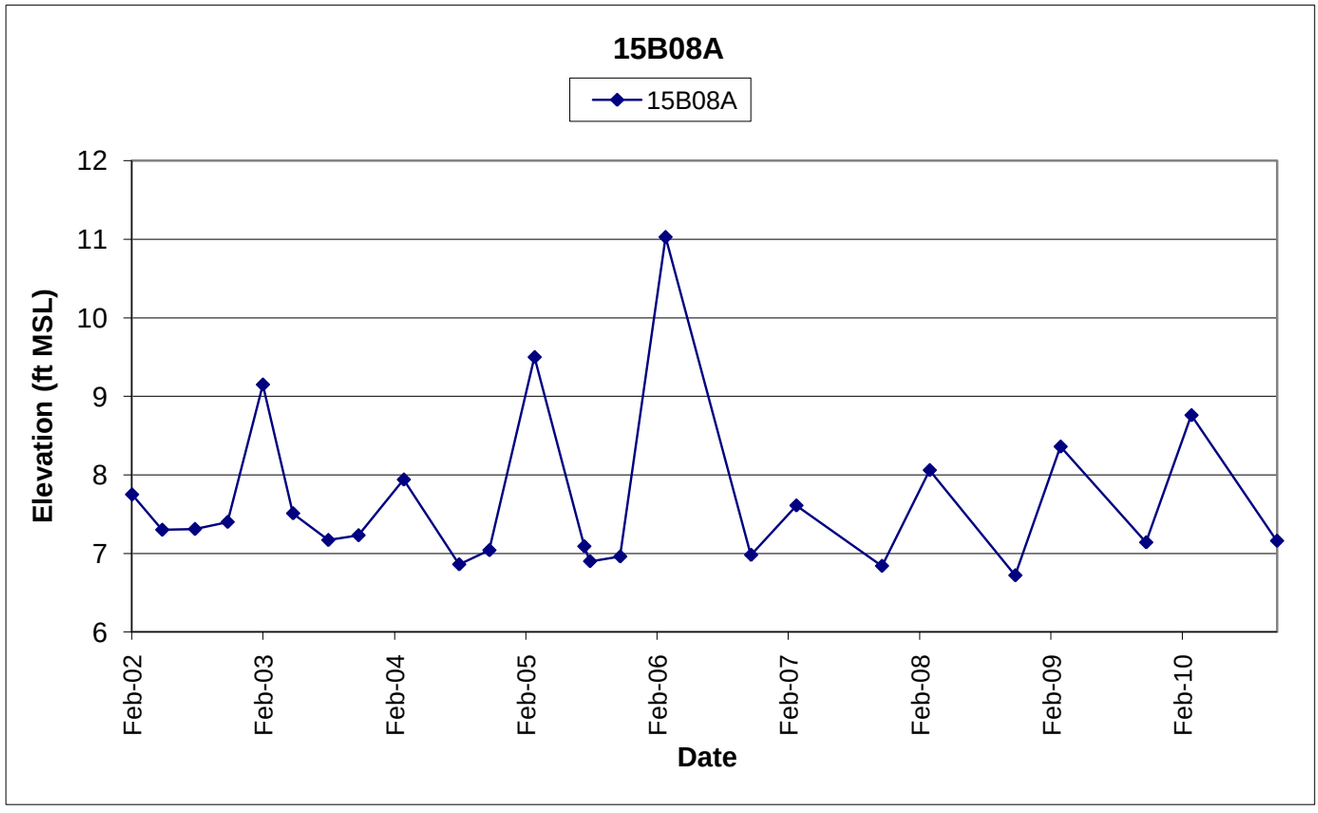
APPENDIX C
2010 Hydrographs



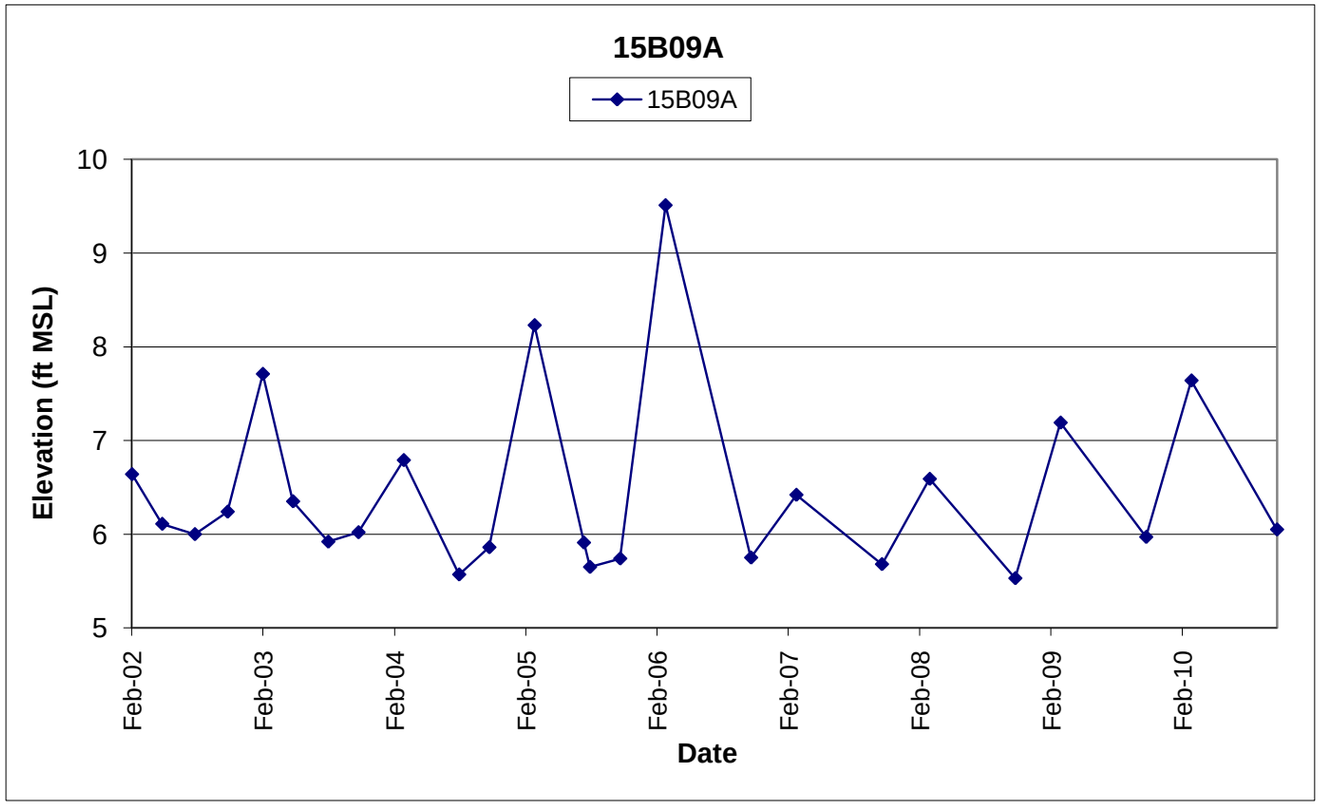


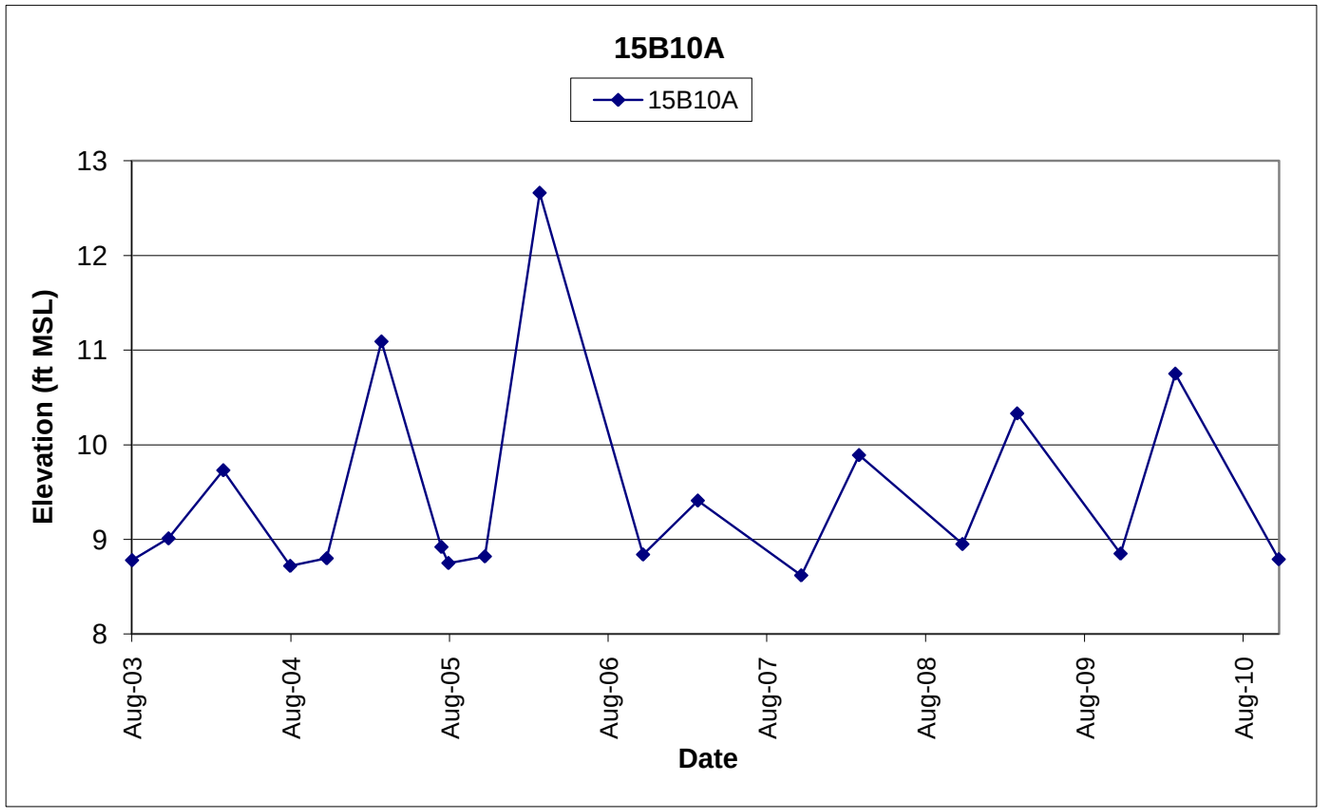
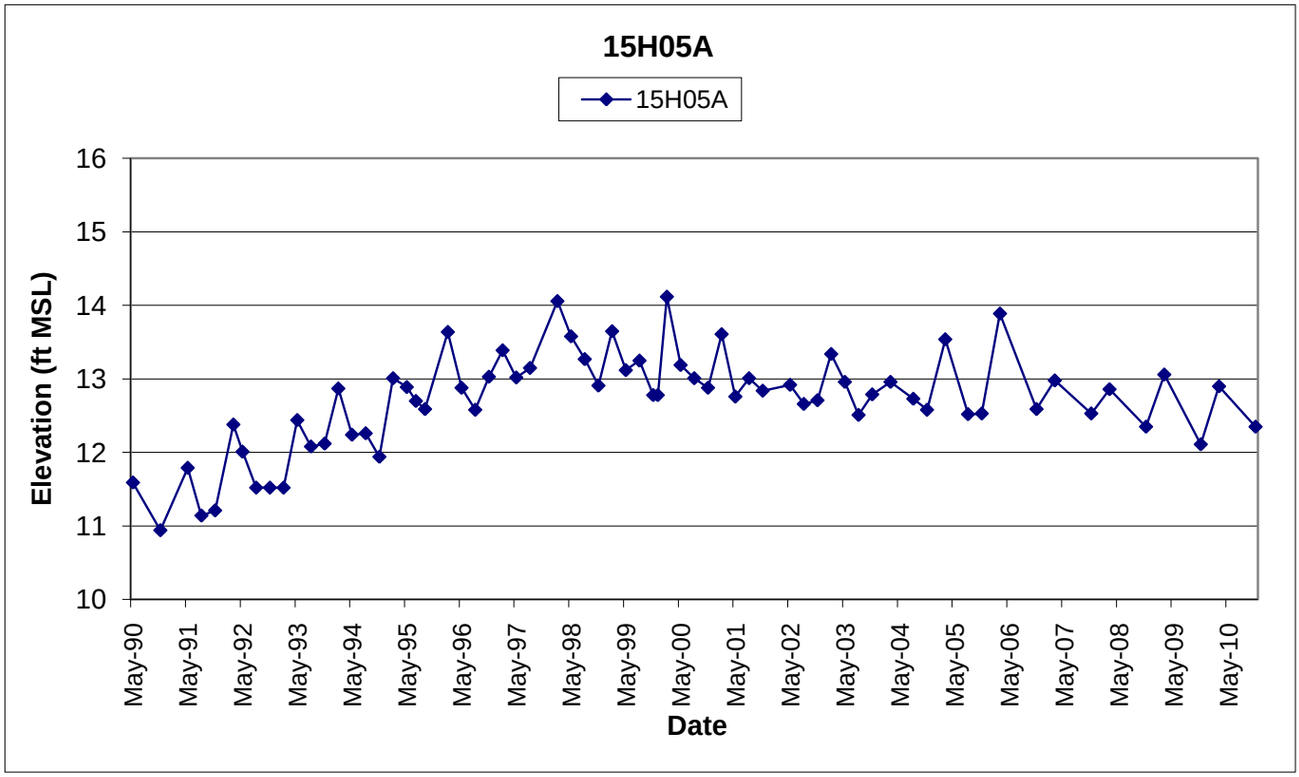
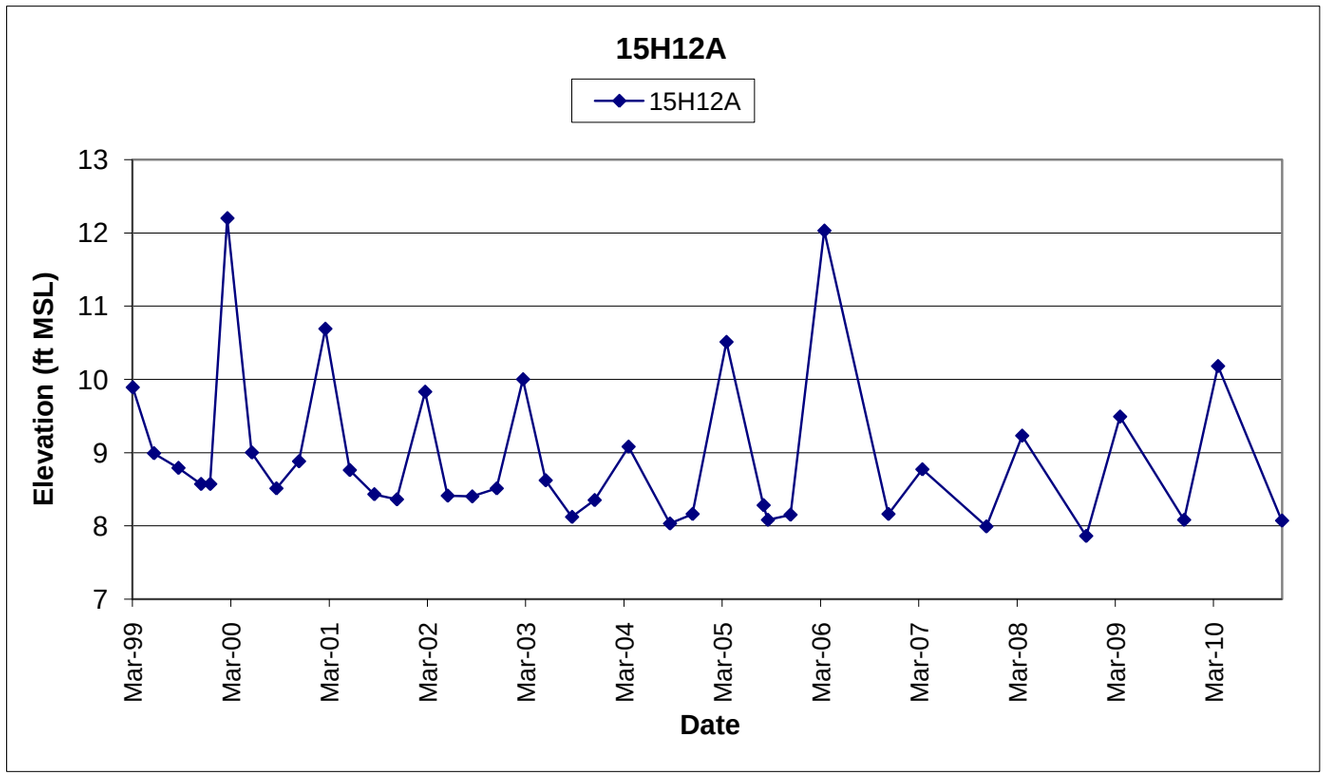
APPENDIX C
2010 Hydrographs





APPENDIX C
2010 Hydrographs





APPENDIX C
2010 Hydrographs