REPORT

MODELING OF GROUNDWATER FLOW AND BUNKER C OIL MIGRATION

PRE-WORLD WAR II TANK FARM

AMAKNAK ISLAND, ALASKA

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TABLE OF CONTENTS

SECTION **PAGE**

ACRONYMS AND ABBREVIATIONS vi

EXECUTIVE SUMMARY ES-1

1.0 INTRODUCTION 1-1

2.0 OVERVIEW OF GROUNDWATER CHARACTERIZATION FIELDWORK 2-1

3.0 SITE CHARACTERIZATION 3-1

- 3.1 SITE RECONNAISANCE 3-1
- 3.2 WATER TABLE CONFIGURATION 3-1
  - 3.2.1 Observed Water Levels 3-2
  - 3.2.2 Water Table Maps 3-7
- 3.3 TIDAL INFLUENCE 3-19
  - 3.3.1 Data Collection 3-19
  - 3.3.2 Calculations 3-19
  - 3.3.3 Results 3-21
  - 3.3.4 Inferred Hydraulic Conductivity 3-22
- 3.4 HYDRAULIC CONDUCTIVITIES FROM SLUG TESTS 3-23
  - 3.4.1 Data Collection 3-24
  - 3.4.2 Calculations 3-25
  - 3.4.3 Results 3-26
  - 3.4.4 Summary 3-28
- 3.5 GEOMETRY OF THE FRESHWATER/SEAWATER INTERFACE 3-31
  - 3.5.1 Data Collection 3-32
  - 3.5.2 Results and Conceptual Interface Geometry 3-34
- 3.6 GROUNDWATER ANALYSES FROM THE DISCHARGE ZONE 3-38
- 3.7 PHYSICAL PROPERTIES OF THE BUNKER C FUEL OIL CONTAMINANT 3-45

4.0 GROUNDWATER FLOW MODEL 4-1

- 4.1 SITE COORDINATE SYSTEM 4-1
- 4.2 MODEL DOMAIN AND GRID 4-2
- 4.3 BEDROCK TOPOGRAPHY 4-4
- 4.4 BOUNDARY CONDITIONS 4-7

TABLE OF CONTENTS
(continued)

SECTION **PAGE**

4.4.1 Freshwater/Seawater Interface 4-7
4.4.2 Constant-Flux Boundaries, Areal Recharge, and Dry Wells 4-8
4.5 HYDROLOGIC ZONES 4-12
4.6 CALIBRATION 4-15
4.6.1 Matching Observed Heads 4-15
4.6.2 Simulating Tidal Influence 4-22
4.7 SCHEMATIC MODEL THROUGH MW-11 4-25
4.8 GROUNDWATER FLOW MODELING RESULTS AND CONCLUSIONS 4-28
5.0 LNAPL FLOW MODEL 5-1
5.1 SOFTWARE 5-2
5.2 MODEL CONFIGURATION 5-2
5.2.1 Boundary Conditions 5-5
5.2.2 Bulk Properties 5-5
5.3 MODEL RUNS 5-7
5.3.1 Base Case (Run 01) 5-9
5.3.2 High Density (Run 05) 5-10
5.3.3 High Viscosity (Run 02) 5-14
5.3.4 Low Van Genuchten Parameters (Run 06) 5-14
5.3.5 Actual Density (Run 07) 5-21
5.3.6 High Anisotropy (Run 10) 5-22
5.4 IMPLICATIONS OF LNAPL FLOW MODELING 5-27
6.0 REVIEW OF NATURAL ATTENUATION 6-1
7.0 SUMMARY AND RECOMMENDATIONS 7-1
8.0 REFERENCES 8-1

TABLES

Table 3-1 Water Level Measurements from June 2001 to November 2004 in Selected Monitoring Wells 3-3
Table 3-2 Water Level Averaging for 2002 3-7
Table 3-3 Summary of Investigation of Tidal Influence 3-21

TABLE OF CONTENTS
(continued)

SECTION **PAGE**

Table 3-4 Analytically Calculated Hydraulic Conductivities from Tidal Lag Times and Efficiencies 3-24

Table 3-5 Well and Aquifer Parameters for Bouwer-Rice Slug Test Analyses 3-27

Table 3-6 Results of Slug Test Analyses 3-29

Table 3-7 Field Parameters from Sampling Locations in the Groundwater Discharge Zone 3-39

Table 3-8 Chemical Analyses of Groundwater Samples from the Discharge Zone 3-40

Table 3-9 Physical Properties of Free Product at the Pre-WWII Tank Farm 3-45

Table 3-10 Estimated Physical Properties of Bunker C and Bunker C/Diesel at Ambient Temperature 3-48

Table 4-1 Estimated Coordinates of Dry Wells near the Pre-WWII Tank Farm 4-11

Table 4-2 Observed and Calibrated Heads for October 2003 Mean Tide Water Levels 4-17

Table 4-3 Calibrated Properties for Hydrologic Zones and Water Sources 4-18

Table 4-4 Time Steps Used for Tidal Simulations 4-23

Table 4-5 Tidal Efficiency in the TF05 Model with Specific Yield Equal to 0.001 4-24

Table 4-6 Tidal Efficiency in the Schematic Model 4-27

Table 5-1 Grid Spacing for the TFslice MOFAT Model 5-4

Table 5-2 Base-Case Input Parameters for the TFslice MOFAT Model 5-7

Table 5-3 TFslice MOFAT Modeling Summary of Oil Mobility 5-8

Table 6-1 Sample Results for Natural Attenuation Parameters 6-3

FIGURES

Figure 1-1 Pre-WWII Tank Farm Site Map 1-3

Figure 3-1 Heads over Time in Selected Monitoring Wells 3-5

Figure 3-2 Average 2002 Low-Tide Water Table 3-9

Figure 3-3 August 2002 Low-Tide Water Table 3-10

Figure 3-4 November 2002 Low-Tide Water Table 3-11

Figure 3-5 June 2001 Low-Tide Water Table 3-12

Figure 3-6 September 2003 Low-Tide Water Table 3-13

Figure 3-7 August 2004 Low-Tide Water Table 3-14

Figure 3-8 September and October 2003 Mean-Tide Water Table 3-15

TABLE OF CONTENTS
(continued)

SECTION **PAGE**

Figure 3-9 Tidal Efficiency and Lag Times 3-16

Figure 3-10 Inferred Hydraulic Conductivity as a Function of Grain Size and Compaction 3-31

Figure 3-11 Conductivity Profiles near the Shoreline 3-33

Figure 3-12 Conceptual Cross-Section Freshwater/Seawater Interface 3-37

Figure 3-13 Free-Product Sample Locations 3-46

Figure 4-1 Domain and Discretization of the 2004 Tank Farm Model 4-3

Figure 4-2 Bedrock Topography in the Groundwater Model 4-5

Figure 4-3 The Model Freshwater/Seawater Interface in Cross Section 4-8

Figure 4-4 Peripheral Recharge Zones to Simulate Constant Flux Boundaries 4-10

Figure 4-5 Hydrologic Zones in the Groundwater Flow Model 4-13

Figure 4-6 Steady-State Calibrated Water Table, Residual Heads, and Particle Tracks 4-19

Figure 4-7 Transient Specified Heads at the Shoreline Compared to Tidal Data 4-23

Figure 4-8 Schematic Flow Model Grid and Boundary Conditions 4-26

Figure 4-9 Tidal Response in the Schematic Model at MW-11 and MW-10 with High Hydraulic Conductivity 4-27

Figure 5-1 TFslice Model Grid and Boundary Conditions 5-3

Figure 5-2 Base Case (Run 01) for Modeled Bunker C Migration 5-11

Figure 5-3 Water and Oil Volumes for the Base Case (Run 01) of the TFslice Model 5-13

Figure 5-4 High Density (Run 05) for Modeled Bunker C Migration 5-15

Figure 5-5 High Viscosity (Run 02) for Modeled Bunker C Migration 5-17

Figure 5-6 Low van Genuchten Parameters (Run 06) for Modeled Bunker C Migration 5-19

Figure 5-7 Actual Density (Run 07) for Modeled Bunker C Migration 5-23

Figure 5-8 High Anisotropy (Run 10) for Modeled Bunker C Migration 5-25

TABLE OF CONTENTS
(continued)

SECTION **PAGE**

APPENDICES

Appendix A Figures for Tidal Influence Evaluations, and Details and Figures for Slug Tests

Appendix B Field Notes

Appendix C Historical Boring and Test Pit Logs

Appendix D Responses to Comments on the Draft Report

Attachment — CD-ROM: Animations of LNAPL Modeling Results

Run_01_BaseCase.avi

Run_02_HighViscosity.avi

Run_03_LowDensity.avi

Run_04_HighDensity.avi

Run_05_HighDensity.avi

Run_06_LowVGenuchten.avi

Run_07_ActualDensity.avi

Run_08_LowKh.avi

Run_09_VHighViscosity.avi

Run_10_HighAnisotropy

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ACRONYMS AND ABBREVIATIONS

α	thermal coefficient of viscosity or density
α_{vG}	van Genuchten α parameter for air-water capillary retention
β_{ao}	MOFAT scaling coefficient for the air/oil interface
β_{ow}	MOFAT scaling coefficient for the oil/water interface
°C	degrees Celsius
cm	centimeters
cSt	centi-Stokes
DO	dissolved oxygen
DRO	diesel-range organics
EPA	U.S. Environmental Protection Agency
ft/day	feet per day
ϕ	porosity
g/mL	grams per milliliter
h	pressure head
in/yr	inches per year
K_h	horizontal hydraulic conductivity
K_v	vertical hydraulic conductivity
K_h/K_v	hydraulic anisotropy
LNAPL	light non-aqueous-phase liquid
lb	pounds
MLLW	mean lower low water
mS/cm	milli-Siemens per centimeter
msl	mean sea level
mV	millivolts
v	viscosity
v_{oil}	viscosity of oil
n_{vG}	van Genuchten n parameter for air-water capillary retention
NOAA	National Oceanic and Atmospheric Administration

ACRONYMS AND ABBREVIATIONS
(continued)

PAH	polynuclear aromatic hydrocarbon
psi	pounds per square inch
ρ	density
ρ_{oil}	density of oil
RhoP	density of product (Bunker C or Bunker C/diesel mixture) in g/mL
RRO	residual-range organics
Sr_w	residual saturation of water
Sr_{oil}	residual saturation of oil
S	storage coefficient
S_s	specific storage (confined)
S_y	specific yield (unconfined storage)
T	temperature
TOC	top of casing, measured in feet msl
USACE	US Army Corps of Engineers
USAED	US Army Engineer District, Alaska
VOC	volatile organic compound
WWII	World War II
z_s	depth of the freshwater/seawater interface below sea level
z_w	height of the water table above sea level

EXECUTIVE SUMMARY

Numerical modeling of groundwater and free-product flow improve the understanding of the long-term persistence and migration of Bunker C fuel-oil contamination related to the Pre-World War II (WWII) Tank Farm on Amaknak Island, Alaska. Released during WWII, Bunker C is still present after 60 years as free product between the Pre-WWII Tank Farm and the shoreline of Dutch Harbor. Although extensive monitoring and characterization has been conducted since 1989, new fieldwork in October 2003 and November 2004 focused on characterizing the groundwater flow system. This fieldwork investigated water levels and tidal influence, hydraulic conductivity, groundwater discharge-zone geometry and chemistry, and free-product physical properties and distribution. Based on this work, a three-dimensional MODFLOW groundwater flow model estimated groundwater travel times and trajectories to Dutch Harbor along the probable trajectories of free-product migration. In addition, to provide a more realistic assessment of Bunker C migration as a light non-aqueous-phase liquid (LNAPL), a two-dimensional slice of the flow system from the tank farm to the bay was modeled using MOFAT, explicitly accounting for the three phases present in the subsurface (groundwater, Bunker C, and air) and their physical interface in capillary fringes. Finally, geochemical indicators of natural attenuation (biodegradation) in groundwater were evaluated to estimate the efficacy of natural attenuation and steps that may be taken to enhance it.

The groundwater flow model, calibrated to mean-tide water levels in October 2003, suggests that present groundwater flow from the eastern portion of the site is to the east, past MW-11, while flow from the western portion of the site is to the south, beneath Building 551 and toward MW-13. Calibrated hydraulic conductivities, consistent with an analytical interpretation of tidal influence measurements but much higher than slug-test results, ranged from 3 to 400 feet per year. Modeled travel time for water is rapid, no more than 2.5 years from the upgradient edge of the tank farm site to the shoreline. The unconfined groundwater flow model could simulate only weak tidal influences, not the observed strong influences, suggesting that the groundwater system may behave in a semi-confined manner over the short term. The effects of silt and peat lenses could explain this. If such horizons, common in the vadose zone, are also present below the water table, vertical hydraulic conductivity would be two to three orders of magnitude lower than horizontal hydraulic conductivity, rather than only a factor of three lower as in the model. Finally, the groundwater model was calibrated with 13 inches of recharge per year, a low value for a site that receives 60 inches per year precipitation, but higher recharge would have required comparably higher hydraulic conductivities. The model provides useful qualitative insights in the groundwater flow system, but would require improved determinations of recharge, boundary flows, and hydraulic conductivity for defensible quantitative simulations.

The LNAPL flow model reveals that, in spite of rapid groundwater flow, Bunker C released at the tank farm may have required 20 years or more to migrate to MW-11, and may have reached Dutch Harbor after 54 years or may still be en route. Because migrating oil leaves a trail of trapped oil at residual saturation, it is attenuated as it moves and can never discharge to Dutch Harbor at a high rate. If the oil contamination observed at the shoreline during the October 2003 field effort is derived from the tank farm, then the leading edge of the migrating oil, where the degree of oil saturation is the highest, must already have discharged, and current rates of discharge will only decline with time. Discharge will persist for decades, however. Groundwater samples from the discharge zone in October 2003 did not exceed regulatory criteria; therefore, physical contamination by oil globules is the only source of concern.

Geochemical parameters in groundwater suggest that some biodegradation is occurring, but too slowly to mitigate the remaining subsurface contamination in the near future. Rates appear to be limited by the availability of oxygen and nutrients, as well as cold ambient temperatures and the refractory nature of the long-chain hydrocarbons that comprise the bulk of Bunker C. Over the long term (several decades), the degradation rate will eventually overtake the discharge rate, and the residual oil will be increasingly viscous, finally terminating discharge to Dutch Harbor even though some oil will remain in the subsurface.

If no further action is taken at the Pre-WWII Tank Farm, the modeling presented here suggests that conditions are unlikely to worsen, but will improve slowly over several decades.

Additional site data are needed to strengthen this conclusion. Accurate determination of the present extent of Bunker C contamination could provide direct evidence of whether oil is discharging to Dutch Harbor and could delineate the average migration directions of oil in the past, enabling better calibration of the groundwater and LNAPL flow models.

The Focused Feasibility Study developed for the Pre-WWII Tank Farm evaluates remedial technologies (alternatives) to address the Bunker C-related soil, groundwater, and LNAPL contamination at the site (USAED 2005a). The Proposed Plan, which will be open to public review and comment, will discuss the preferred alternative(s). Following receipt of comments on the Proposed Plan, a Decision Document will be developed to document the remedial alternatives evaluation.

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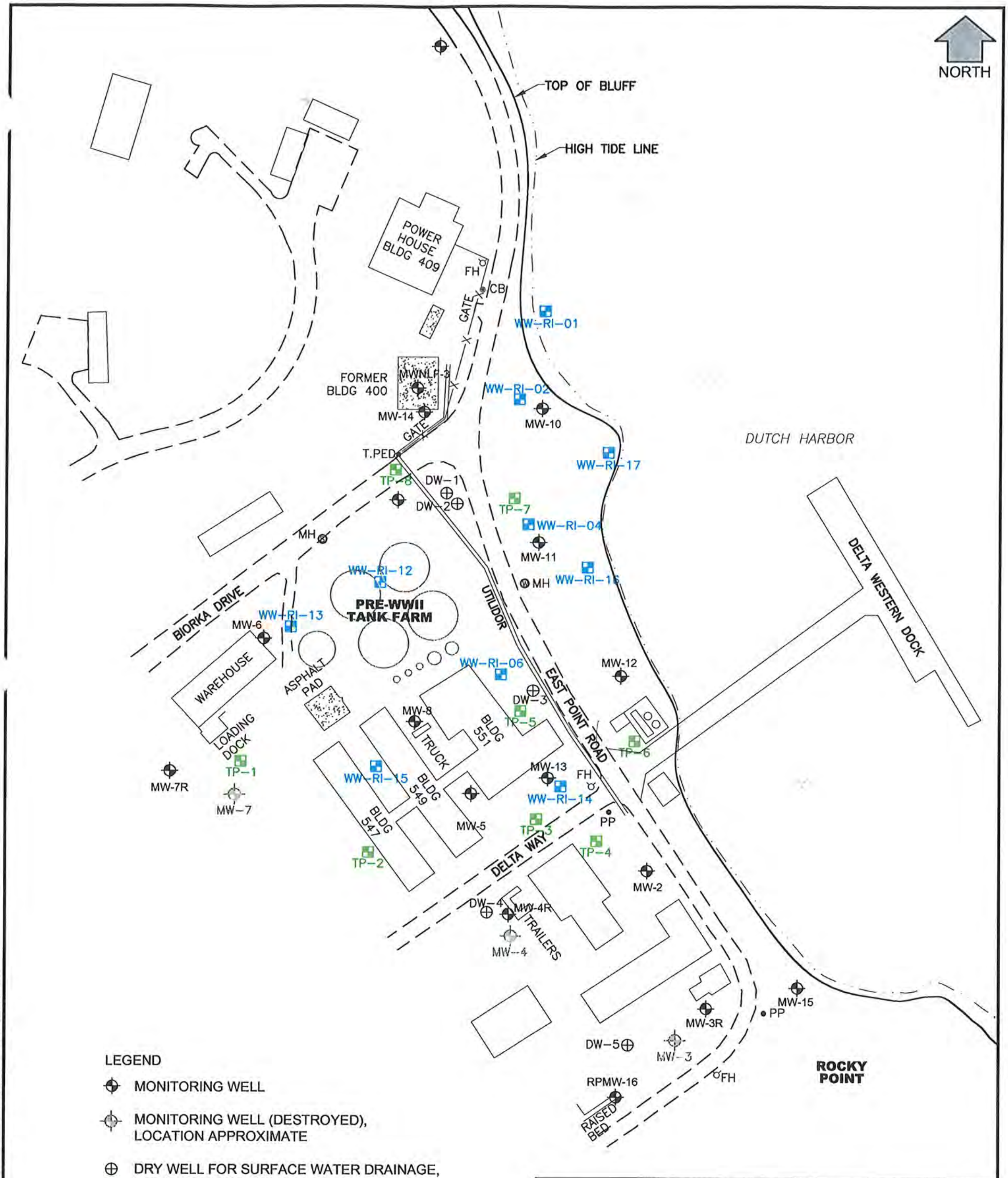
1.0 INTRODUCTION

Numerical modeling of groundwater and free-product flow provide an improved understanding of the long-term persistence and migration of Bunker C fuel-oil contamination related to the Pre-World War II (WWII) Tank Farm on Amaknak Island, Alaska (Figure 1-1). Bunker C is the heavy residual oil remaining after distillation of lighter fuels from crude oil, with density of 0.95 to 1.03 grams per milliliter (g/mL) and molasses-like consistency. Released during WWII, Bunker C is still present after sixty years as free product between the Pre-WWII Tank Farm and the shoreline of Dutch Harbor. Although extensive monitoring and characterization has been conducted during site investigations, remedial investigations, and removal actions beginning in 1989, further fieldwork and analysis was needed to estimate likely future discharge rates of free and dissolved product to Dutch Harbor and the adjacent shoreline. This report presents the results of fieldwork conducted during October 2003 and November 2004, and presents numerical models for groundwater flow and free-product (light non-aqueous phase liquid [LNAPL]) migration.

This investigation is comprised of the following components:

- Fieldwork — Important gaps in pre-existing characterization data from the site were filled by additional fieldwork during October 2003 and November 2004. Activities included water-level measurements, slug testing, tidal-influence monitoring, groundwater sampling and conductivity probing of the freshwater/seawater interface, product-level measurements, and product sampling.
- Groundwater flow modeling — A calibrated groundwater flow model provides estimates of groundwater travel times and trajectories to Dutch Harbor, and can be used to infer the probable trajectories of free-product migration.
- LNAPL flow modeling — An LNAPL flow model incorporating both saturated and unsaturated flow provides estimates of the rate of free-product migration toward Dutch Harbor, constraining scenarios of long-term contaminant loading to surface water and sediments.
- Evaluation of natural attenuation — Geochemical indicators of biodegradation permit qualitative evaluation of the efficacy of natural attenuation and steps that may be taken to enhance it.

This report provides an overview of field activities in Section 2, detailed descriptions of data analysis and site characterization insights derived from the field activities in Section 3, groundwater flow modeling in Section 4, LNAPL flow modeling in Section 5, an evaluation of natural attenuation in Section 6, and conclusions and recommendations in Section 7.



LEGEND

- ⊕ MONITORING WELL
- ⊕ MONITORING WELL (DESTROYED), LOCATION APPROXIMATE
- ⊕ DRY WELL FOR SURFACE WATER DRAINAGE, LOCATION APPROXIMATE
- 🟦 1996 TEST PIT
- 🟩 1998 TEST PIT

0 100 200 400
SCALE IN FEET

PRE-WW II TANK FARM SITE MAP

AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen	FILE NAME: Site Map.dwg	DATE: Feb. 09, 05
DRAWN BY: DBW	LAYOUT TAB: Site Map	FIGURE NO. : 1-1
	FILE LOCATION: Amaknak \ 05M30225 \ GW Model \ Final Rpt	

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2.0 OVERVIEW OF GROUNDWATER CHARACTERIZATION FIELDWORK

This report relies heavily upon water levels and other observations made during the course of periodic groundwater sampling from 2001 to the present, along with subsurface information obtained during excavation of the Tank Farm site, installation of monitoring wells, and excavation of test pits. Fieldwork to collect data specifically to support the groundwater and LNAPL flow modeling was conducted from 15 to 23 October 2003. Fieldwork consisted of the following elements:

- Locating all remaining monitoring wells relevant to the site (see Figure 1-1). Located wells include MW-2, MW-6, MW-8, MW-10, MW-11, MW-12, MW-13, MW-14, MW-15, and RPMW-16.
- Measuring tidal influence at monitoring wells. Water levels in all located wells were monitored using recording transducers.
- Performing slug tests to evaluate hydraulic conductivity. All located monitoring wells except those with a measurable thickness of free product (i.e., MW-11 and MW-13) were tested.
- Evaluating the utilidor (a WWII-era shallowly buried utility corridor) and foundation of Building 551 as potential barriers to groundwater or free-product flow. Neither of these was found to reach the water table, and therefore do not directly affect groundwater flow patterns.
- Checking the shoreline geometry compared to the site base map and checking the shoreline position at high tide and low tide. The beach was steep enough that changes in position were not significant given the size of the site.
- Evaluating the geometry of the freshwater/saltwater interface via conductivity probing.
- Collecting product samples from MW-11, MW-13, and from the crawlspace beneath Building 551 for laboratory analysis of density and viscosity.
- Collecting two water samples from the seepage zone at the shoreline, one near MW-10 and one near MW-11.

Additional field activities in 2004 facilitated the understanding of hydraulic and geologic relationships at the site:

- Wells MW-3R, MW-4R, and MW-7R were installed to replace the destroyed wells MW-3, MW-4, and MW-7.
- Tidal influence was measured in two of the newly installed monitoring wells (MW-3R and MW-7R) on 11 and 12 November 2004, in conjunction with biannual water sampling.

- A professional land surveyor surveyed the site-related wells and structures to provide accurate and internally consistent locations and elevations in North American Datum 1983 (NAD83) state plane coordinates.

3.0 SITE CHARACTERIZATION

Site characterization supports the development of the groundwater and LNAPL flow models. Site reconnaissance identified and delineated important hydrologic boundaries, tidal influence measurements provided a broad assessment of hydraulic properties, and slug tests provided local assessments of hydraulic conductivities. A review of current and historical water level measurements formed the basis of an average water table map, and a review of test-pit and boring logs developed a conceptual model of the hydrostratigraphy.

3.1 SITE RECONNAISANCE

The Pre-World War II Tank Farm site occupies a small embayment in the bedrock of Amaknak Island. With reference to features depicted in Figure 1-1, bedrock rises to the northwest of the tank farm, outcropping just west of the Powerhouse (Building 409), and forms an arc of higher terrain extending south and west from there to Biorka Drive. To the south of the site, the terrain rises south of East Point Road, likely reflecting rising bedrock. The terrain (and bedrock) also rises to the west of MW-7/7R. Within the embayment, the terrain is nearly level at about 12 feet above mean sea level (msl), with a steep embankment or bluff at the shoreline. Historical borehole data (see Appendix C) show that the embayment is filled with silty sands and gravels, with interbedded organic-rich silt or peat layers at or above the water table. Broad correlations are possible, as shown in cross sections included in Appendix C, but the detailed stratigraphy below the water table is not available.

3.2 WATER TABLE CONFIGURATION

The patterns of observed water levels in monitoring wells are critical to developing an understanding of likely groundwater flow patterns. Although only the observations themselves will be calibration targets of the numerical groundwater flow model, the exercise of manually contouring the observations induces an in-depth appraisal of realistic head gradients and groundwater flow directions. The contouring process also reveals the larger data quality problems, such as erroneous top-of-casing (TOC) elevations or unusual depth measurements.

3.2.1 Observed Water Levels

Water levels have been measured in all located wells as part of each quarterly sampling event. Unfortunately, industrial activities at the site frequently obscure and sometimes destroy wells, resulting in a fragmentary record. The available data and calculated heads from June 2001 through November 2004 are listed in Table 3-1. Earlier data were not readily available and are not needed at this stage; the listed data encompass several feet of water table fluctuation, presenting a wide range of conditions for evaluation. To minimize tidal influences, all measurements except those in October 2003 and November 2004 were collected within 45 minutes before or after low tide. In October 2003 and November 2004, tide was not considered. In wells with product, the equivalent thickness of water was found by multiplying the product thickness by the product density (RhoP, measured in product from MW-13 and from surface seeps beneath Building 551).

Water levels respond dynamically to climatic factors, with increases of more than 2 feet between the August and November 2002 sampling rounds in most wells, and up to 5 feet in MW-14 and RPMW-16. (Although RPMW-16 is a Rocky Point well, it is included here to replace nearby MW-3, which has been destroyed.) Other wells responded less dramatically, but showed at least a foot of change. Heads for selected wells are plotted versus time in Figure 3-1. Rainfall records from Dutch Harbor (Western Regional Climate Center 2005) show that October 2002 was about three times wetter than normal, with total precipitation of 18.12 inches, compared to the 1971 to 2000 average of 6.42 inches. Other months in 2002 had near-normal precipitation.

Figure 3-1 shows that there is no predominant set of water levels that might represent an average or most common water table geometry. Nevertheless, the concept of average water levels is useful because groundwater flow integrated over time reflects the time-integrated water table and associated average gradients. Although there is no guarantee that averaging periodically measured water levels will produce the time-integrated water table, an average water table is the best available approximation, providing a useful starting point for developing a conceptual model of site hydrology.

Table 3-1
Water Level Measurements from June 2001 to November 2004 in Selected Monitoring Wells

Well ID	Date Time	PL	WL	TOC	RhoP	Head
MW-2	6/21/2001 11:02	12.55	12.58	11.94	0.9483	-0.61
	9/5/2001 14:15	12.19	12.25			-0.25
	8/21/2002 9:57		11.56			0.38
	11/17/2002 14:00		10.14			1.80
	10/19/2003 18:05		10.82			1.12
	10/21/2003 17:25		11.12			0.82
	6/4/2004 16:04	12.59	12.60		0.9483	-0.65
MW-3R	8/26/2004 10:00		12.41	11.78		-0.63
	11/11/2004 11:45		10.52			1.26
MW-4R	8/26/2004 10:00		11.65	11.43		-0.22
	11/10/2004 18:02		9.62			1.81
MW-5	6/21/2001 11:50		10.63	10.59		-0.04
	11/17/2002 13:00		7.73			2.86
	9/10/2003 13:00		10.25			0.34
	6/4/2004 11:00		10.25			0.34
MW-6	6/21/2001 10:40		12.94	19.57		6.63
	8/21/2002 8:57		9.48			10.09
	10/16/2003 16:38		12.92			6.65
	10/18/2003 9:45		12.94			6.63
	10/21/2003 16:47		12.95			6.62
	6/4/2004 13:13		13.00			6.57
	11/10/2004 15:48		12.49			7.08
MW-7R	8/26/2004 10:00		10.91	13.44		2.53
	11/10/2004 16:02		7.59			5.85
MW-8	6/21/2001 10:54		12.11	12.30		0.19
	9/5/2001 10:04	11.71	11.72		0.997	0.59
	2/8/2002 18:00	11.26	11.35			1.04
	5/10/2002 14:23	13.24	13.29			-0.94
	8/21/2002 10:46	11.43	11.80			0.87
	11/17/2002 14:40	10.04	10.06			2.26
	2/24/2003 18:10	11.25	11.35			1.05
	5/1/2003 14:50	12.77	12.80			-0.47
	9/10/2003 12:25	11.94	11.95			0.36
	10/16/2003 17:56		10.44			1.86
	10/18/2003 10:55		11.79			0.51
	10/21/2003 17:00		11.54			0.76
	6/4/2004 13:25	Trace	13.90			-1.60
	8/26/2004 10:00	12.35	12.59		0.997	-0.05
MW-10	6/21/2001 10:09		11.66	10.13		-1.53
	9/5/2001 16:26		10.92			-0.79
	2/8/2002 18:10		9.51			0.62
	5/10/2002 13:50		10.97			-0.84
	8/21/2002 8:17		9.86			0.27
	11/17/2002 14:30		7.89			2.24
	2/24/2003 17:25		11.20			-1.07
	5/1/2003 13:25		11.51			-1.38
	9/10/2003 11:30		11.33			-1.20
	10/18/2003 13:35		9.11			1.02
	6/4/2004 16:40		12.18			-2.05
	8/26/2004 10:00		12.21			-2.08
	11/10/2004 14:43		8.94			1.19
MW-11	6/21/2001 12:20	12.27	12.57	15.01	0.997	2.74
	9/5/2001 9:50	15.84	16.04			-0.83
	2/8/2002 18:20	14.77	14.85			0.24
	5/10/2002 14:37	16.08	16.14			-1.07
	8/21/2002 10:59	15.31	19.51			-0.31
	11/17/2002 14:55	12.65	12.67			2.36
	2/24/2003 19:20	14.30	14.45			0.71
	5/1/2003 15:20	15.37	15.55			-0.36
	9/10/2003 13:30	11.23	11.25			3.78
	10/16/2003 18:17	13.34	13.51			1.67
	10/20/2003 16:15	14.01	14.18			1.00
	8/26/2004 10:00	15.51	15.52			-0.50
	6/4/2004 14:42	15.59	15.60			-0.58
	11/10/2004 17:33	14.10	14.29			0.91
MW-12	6/21/2001 10:03		11.51	11.32		-0.19
	9/5/2001 14:55		11.81			-0.49
	2/8/2002 18:30		10.53			0.79
	2/24/2003 17:40		10.35			0.97
	5/1/2003 14:00		12.05			-0.73
	9/10/2003 11:45		11.65			-0.33
	10/19/2003 15:05		10.67			0.65
	6/4/2004 12:07		10.90			0.42
	8/26/2004 10:00		11.65			-0.33

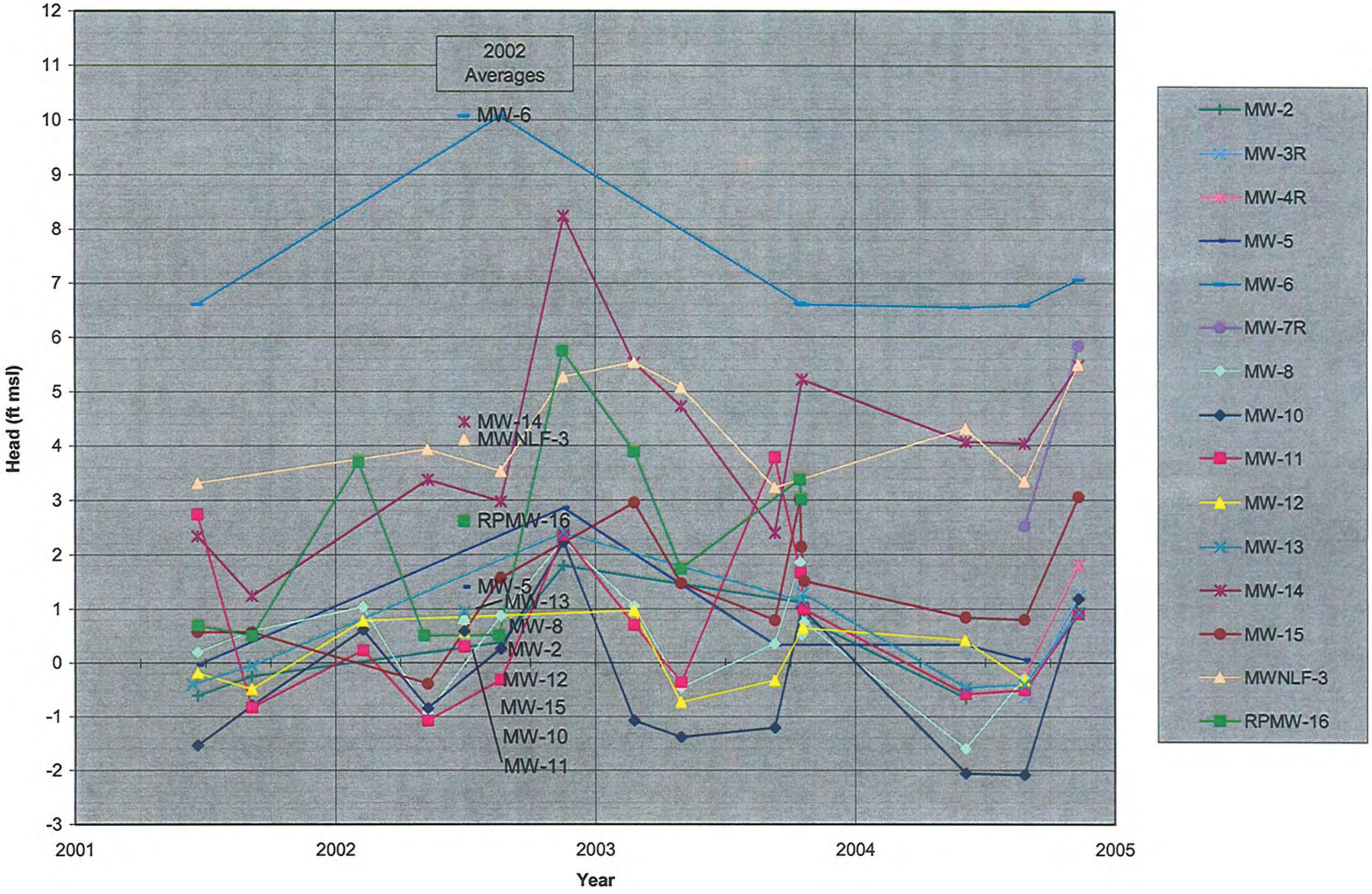
Table 3-1
Water Level Measurements from June 2001 to November 2004 in Selected Monitoring Wells
(continued)

Well ID	Date Time	PL	WL	TOC	RhoP	Head
MW-13	6/14/2001 11:27	12.38	15.18	12.12	0.9483	-0.41
	9/5/2001 16:41	12.04	14.54			-0.05
	11/17/2002 15:40	9.62	11.30			2.41
	10/17/2003 12:34	10.91	11.80			1.16
	10/19/2003 17:01	10.74	12.37			1.29
	6/4/2004 14:07	12.50	13.90			-0.45
	8/26/2004 10:00	12.45	13.80			-0.40
	11/10/2004 0:00	11.10	12.60			0.94
MW-14	6/21/2001 10:15		11.29	13.63		2.34
	9/5/2001 15:45		12.39			1.24
	5/10/2002 13:10		10.26			3.37
	8/21/2002 8:28		10.66			2.97
	11/17/2002 12:50		5.39			8.24
	2/24/2003 17:00		8.10			5.53
	5/1/2003 14:35		8.90			4.73
	9/10/2003 11:00		11.23			2.40
	10/18/2003 14:05		8.41			5.22
	6/4/2004 16:57		9.57			4.06
	8/26/2004 10:00		9.60			4.03
	11/10/2004 13:43		8.15			5.48
MW-15	6/21/2001 9:55		12.30	12.87		0.57
	9/5/2001 14:45		12.30			0.57
	5/10/2002 14:02		13.26			-0.39
	8/21/2002 7:58		11.30			1.57
	2/24/2003 18:25		9.92			2.95
	5/1/2003 14:10		11.40			1.47
	9/10/2003 12:05		12.08			0.79
	10/15/2003 19:28		9.86			3.01
	10/17/2003 16:20		10.73			2.14
MW-15	10/21/2003 17:50		11.36	12.87		1.51
	6/4/2004 13.45		12.03			0.84
	8/26/2004 10:00		12.07			0.80
	11/10/2004 18:35		9.82			3.05
MW-16	8/26/2004 10:00		11.50	15.28		3.78
	11/10/2004 15:36		6.59			8.69
RPMW-16	6/22/2001 11:50		11.10	11.80		0.70
	9/5/2001 17:04		11.29			0.51
	2/2/2002 15:00		8.09			3.71
	5/5/2002 10:45		11.29			0.51
	8/18/2002 17:55		11.28			0.52
	11/16/2002 17:55		6.04			5.76
	2/24/2003 15:40		7.91			3.89
	5/1/2003 15:40		10.05			1.75
	10/15/2003 19:02		8.41			3.39
	10/17/2003 12:41		8.78			3.02
	11/10/2004 15:36		8.69			3.11
MWNLF-3	6/21/2001 10:21		9.77	13.09		3.32
	5/10/2002 10:50		9.16			3.93
	8/21/2002 8:32		9.56			3.53
	11/17/2002 8:55		7.82			5.27
	2/24/2003 17:20		7.55			5.54
	5/1/2003 14:30		8.01			5.08
	9/10/2003 10:50		9.86			3.23
	6/4/2004 17:10		8.78			4.31
	11/10/2004 13:51		7.60			5.49

Notes:

PL = product level, in ft below TOC
WL = water level, in ft below TOC
TOC = 2004 surveyed top of casing elevation, in ft msl
RhoP = product density, in g/mL
Head = elevation of top of equivalent water column, in ft msl

Figure 3-1
Heads over Time in Selected Monitoring Wells



(intentionally blank)

Representative water levels for 2002 were estimated for all monitoring wells, as outlined in Table 3-2. Out of 12 wells, only 5 were measured in each of the 4 quarters. Most of the remaining wells have two or three quarters of data, permitting some averaging, but three wells (MW-6, MW-6, and MW-13) were measured only once during the year. Representative values for these wells were qualitatively estimated from the single measured values combined with trends from nearby wells. The resulting set of averaged water levels is displayed on Figure 3-1.

Table 3-2
Water Level Averaging for 2002

Well ID	2002 Head (ft msl)					Method of Averaging
	February	May	August	November	Average	
MW-2			0.38	1.80	0.74	Weighted 0.75 Aug, 0.25 Nov.
MW-5				2.86	1.41	Estimated behavior relative to MW-8 in November
MW-6			10.09		10.09	Use August value.
MW-8	1.04	-0.94	0.87	2.26	0.81	Average of all four quarters.
MW-10	0.62	-0.84	0.27	2.24	0.57	Average of all four quarters.
MW-11	0.24	-1.07	-0.31	2.36	0.30	Average of all four quarters.
MW-12	0.79				0.79	Use February value.
MW-13				2.41	0.96	Estimated behavior relative to MW-8 in November
MW-14		3.37	2.97	8.24	4.44	Weighted 0.375 May and August, 0.25 November.
MW-15		-0.39	1.57		0.59	Average of May and August
RPMW-16	3.71	0.51	0.52	5.76	2.62	Average of all four quarters.
MWNLF-3		3.93	3.53	5.27	4.11	Weighted 0.375 May and August, 0.25 November.

3.2.2 Water Table Maps

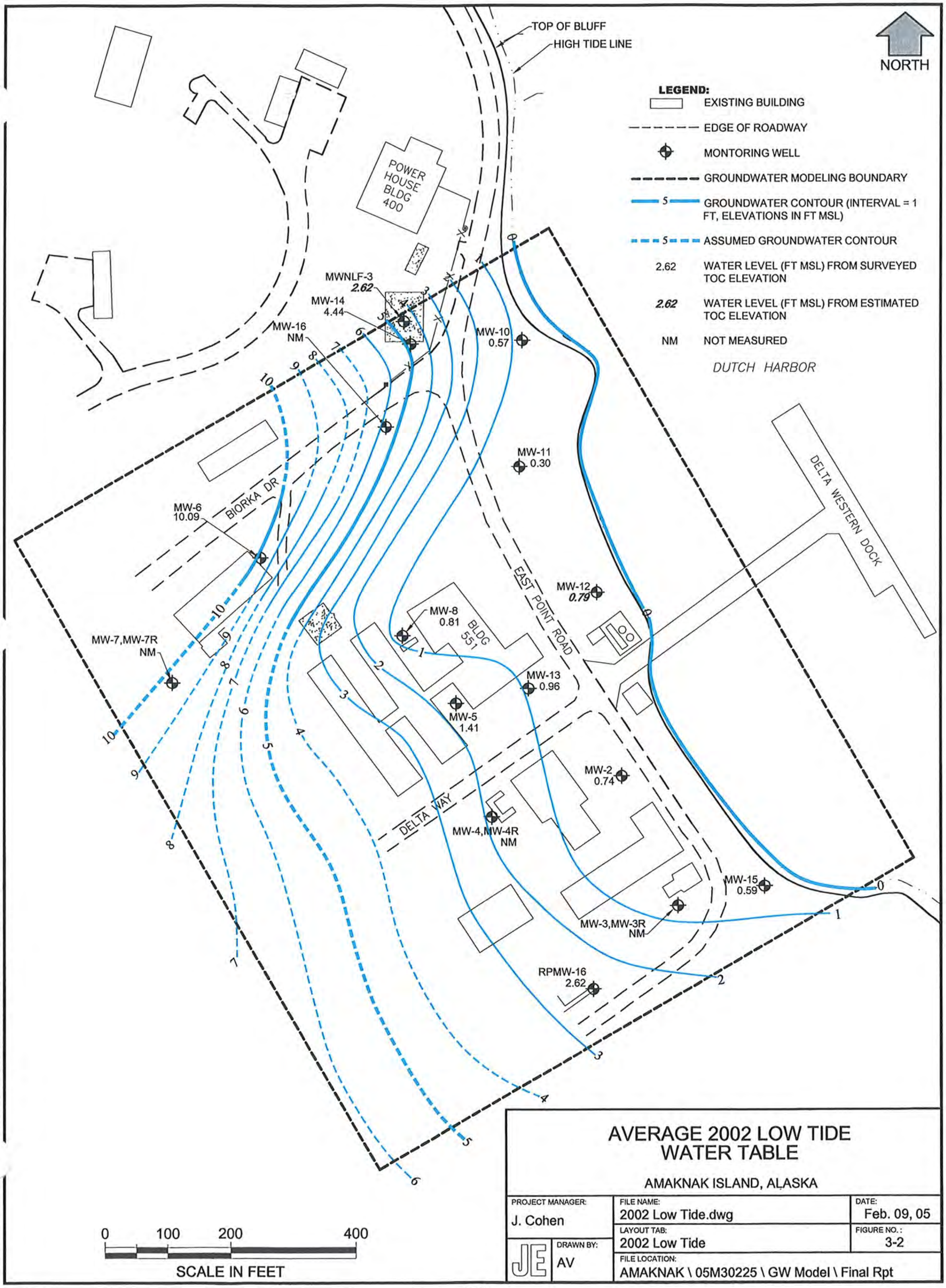
Contour maps of the water table inferred from monitoring-well observations are provided in Figures 3-3 to 3-9. The following discussion proceeds from the general to the specific, examining broad features across the site common to all periods, and then detailing the major variations at specific times. The maps depict low-tide water tables averaged for all of 2002, August 2002, November 2002, June 2001, September 2003, and November 2004. The final map (Figure 3-9) depicts mean-tide water table contours in September and October 2003 (mean water levels were calculated during the course of tidal-influence analysis, and are presented in Section 3.3).

Average Water Table in 2002

The average 2002 low-tide water table (Figure 3-2) shows low gradients adjacent to the shoreline and extending inland to MW-8. Gradients become steeper to the west and north of MW-8, based on observations at MW-14, MW-6, and RPMW-16. No water levels were measured during 2002 at MW-7, the westernmost well. Because the near-shoreline area must transmit all water from upgradient as well as any additions due to direct recharge, low gradients here must correspond to higher transmissivity (defined as the ability of the aquifer to transmit groundwater, equal to the product of the average hydraulic conductivity and the thickness). Gradients at the south, near MW-15, are much steeper, suggesting lower transmissivity here. To the northwest, MW-6 is a short distance up the ridge from the Pre-WWII Tank Farm. The high water table there indicates that MW-6 is just beyond the edge of the embayment.

Water Tables in August and November 2002

The water tables in August 2002 (Figure 3-3) and November 2002 (Figure 3-4) closely resemble the average 2002 water table in pattern, but are offset with respect to elevation. The August water table is lower by 0.3 feet at MW-10 in the north and 2.1 feet at RPMW-16 in the south. At MW-8, at the northwest corner of Building 551, there is almost no difference (only 0.06 feet). The 1-foot contour line meanders broadly across the site, reflecting the water levels measured in MW-8, MW-2, and RPMW-16. The absence of the meander around RPMW-16 in any of the other mapped water tables suggests that it is either uncommon or caused by a measurement error in that water level. At MW-11, the tidal influence was great enough at low tide to lower the water level to –0.31 feet msl.



AVERAGE 2002 LOW TIDE WATER TABLE

AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen

FILE NAME: 2002 Low Tide.dwg

DATE: Feb. 09, 05

LAYOUT TAB: 2002 Low Tide

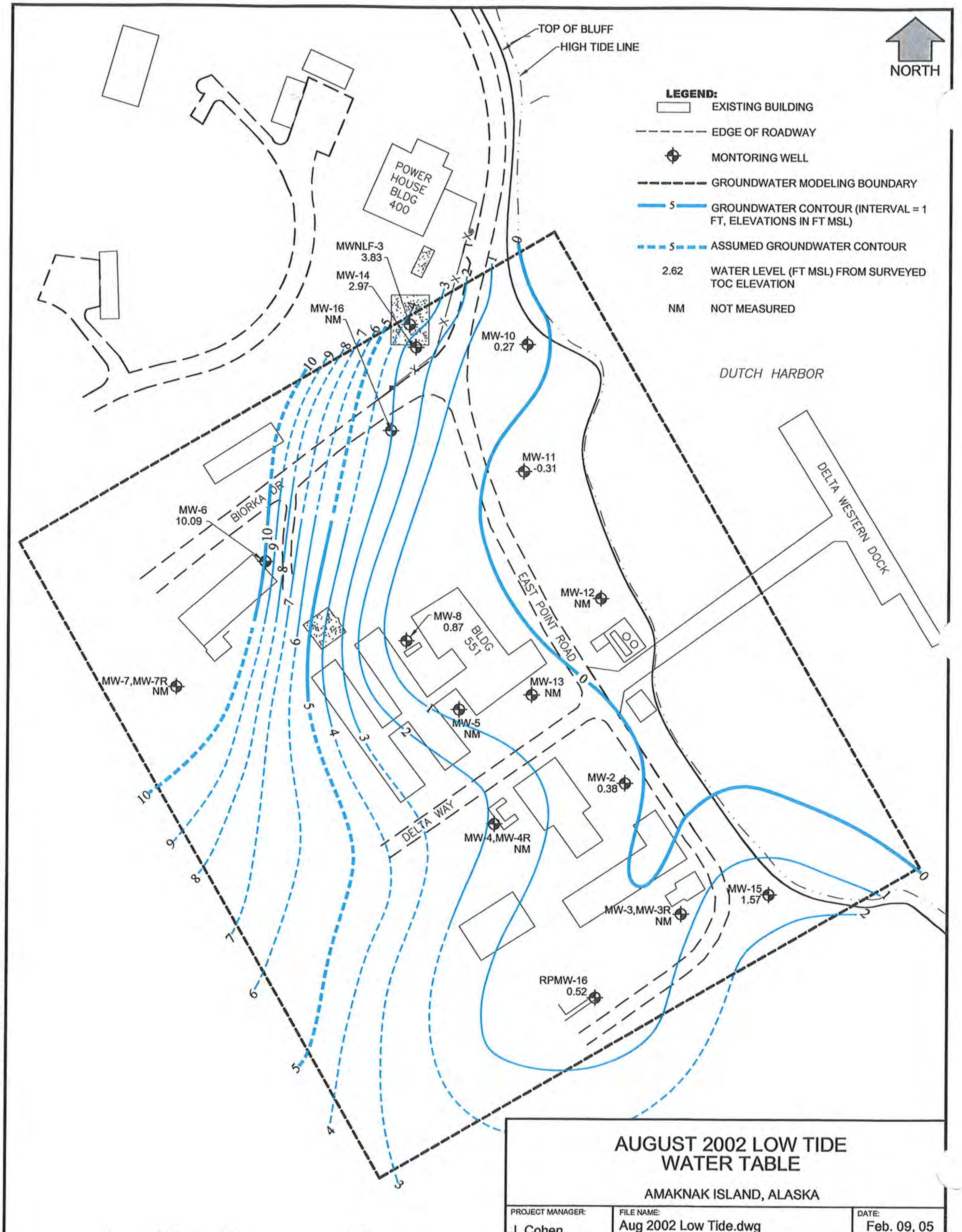
FIGURE NO.: 3-2

JE

DRAWN BY: AV

FILE LOCATION: AMAKNAK \ 05M30225 \ GW Model \ Final Rpt

G:\Autocad\AMAKNAK\05M Model\FINAL RPT\2002 LOW TIDE.dwg Feb 10,2005 -avakarcs

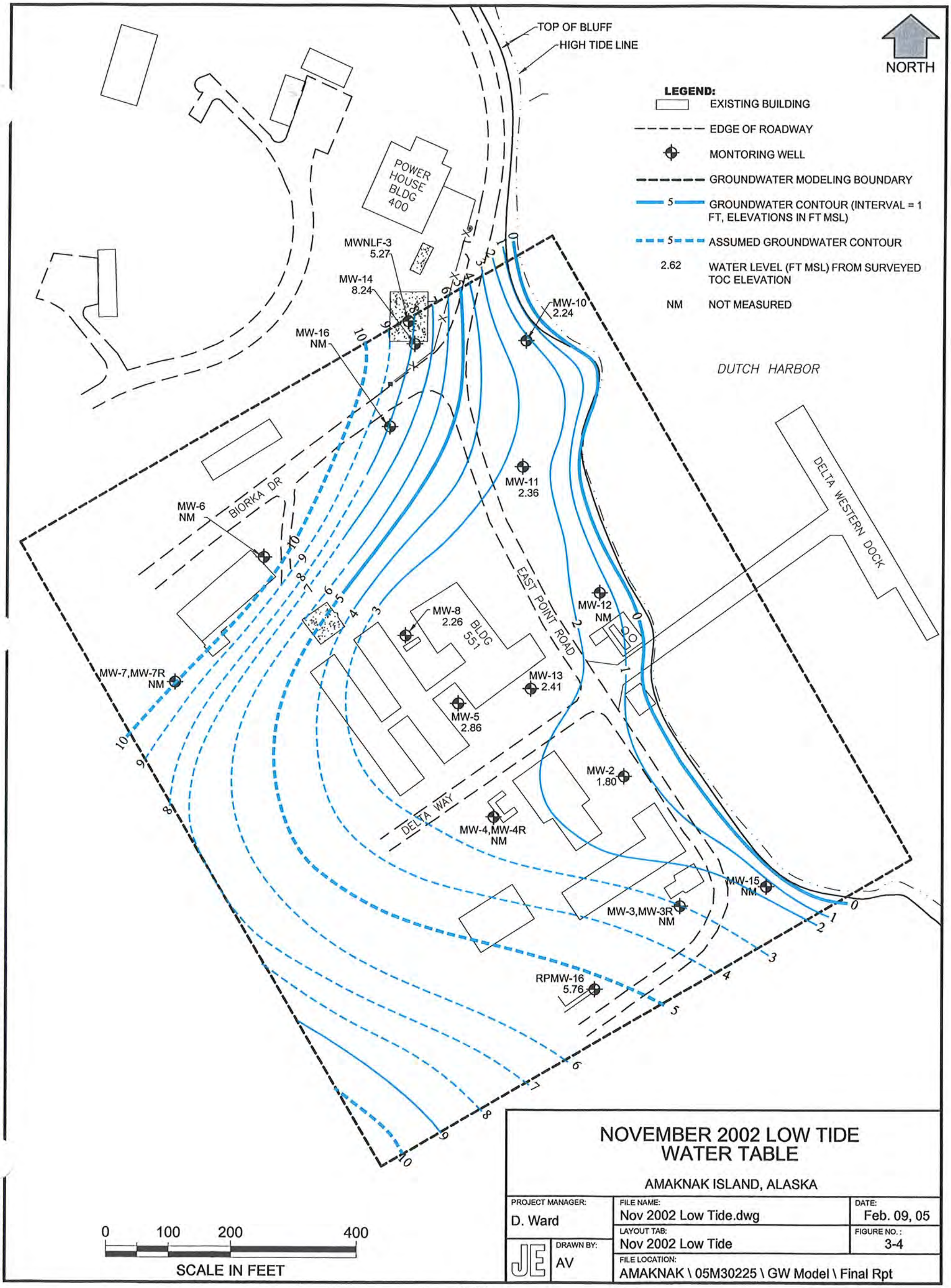


AUGUST 2002 LOW TIDE WATER TABLE

AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen	FILE NAME: Aug 2002 Low Tide.dwg	DATE: Feb. 09, 05
DRAWN BY: AV	LAYOUT TAB: Aug 2002 Low Tide	FIGURE NO.: 3-3
	FILE LOCATION: AMAKNAK \ 05M30225 \ GW Model \ Final Rpt	

G:\Autocad\AMAKNAK\05M30225\GW Model\FINAL RPT\AUG 2002 LOW TIDE.dwg Feb 10,2005 -avakarcs



NOVEMBER 2002 LOW TIDE WATER TABLE

AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: D. Ward

FILE NAME: Nov 2002 Low Tide.dwg

DATE: Feb. 09, 05

JE

DRAWN BY: AV

LAYOUT TAB: Nov 2002 Low Tide

FIGURE NO.: 3-4

FILE LOCATION: AMAKNAK \ 05M30225 \ GW Model \ Final Rpt

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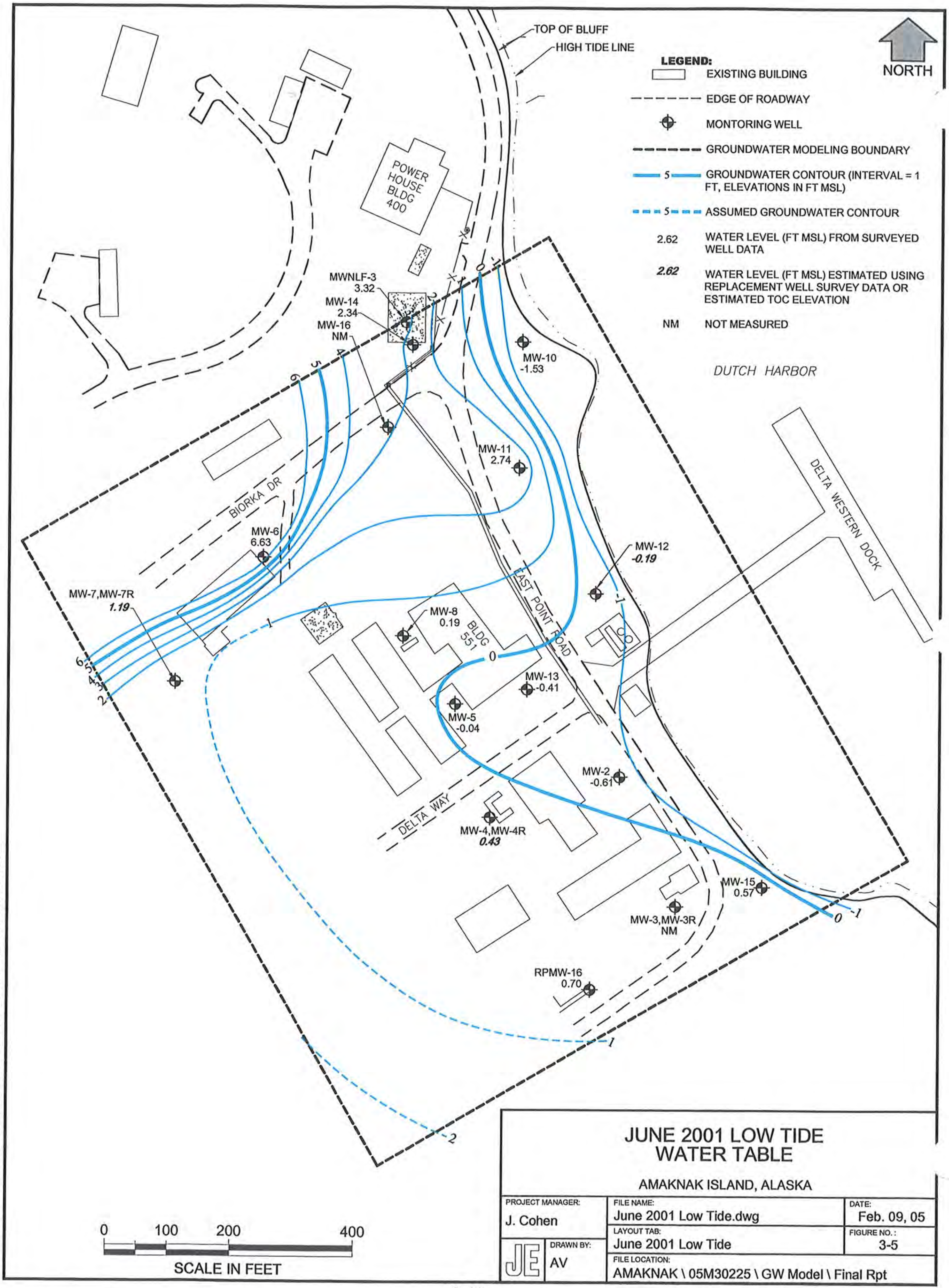
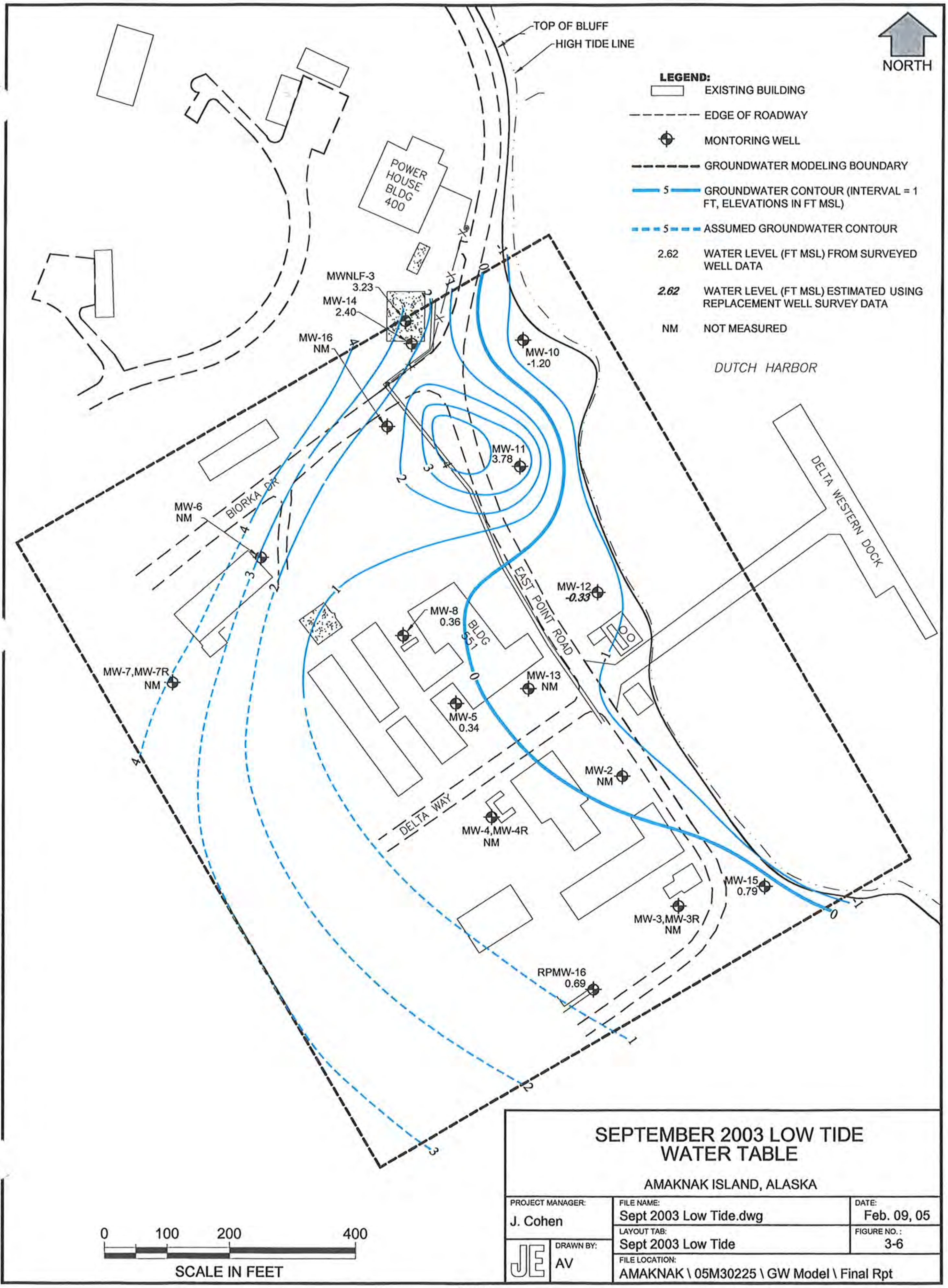


JUNE 2001 LOW TIDE WATER TABLE

AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen	FILE NAME: June 2001 Low Tide.dwg	DATE: Feb. 09, 05
JE DRAWN BY: AV	LAYOUT TAB: June 2001 Low Tide	FIGURE NO.: 3-5
	FILE LOCATION: AMAKNAK \ 05M30225 \ GW Model \ Final Rpt	

G:\Autocad\AMAKNAK\05M30225\GW Model\FINAL RPT\JUNE 2001 LOW TIDE.dwg Feb 10,2005 -avakarcs



SEPTEMBER 2003 LOW TIDE WATER TABLE

AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen

DRAWN BY: AV

FILE NAME: Sept 2003 Low Tide.dwg

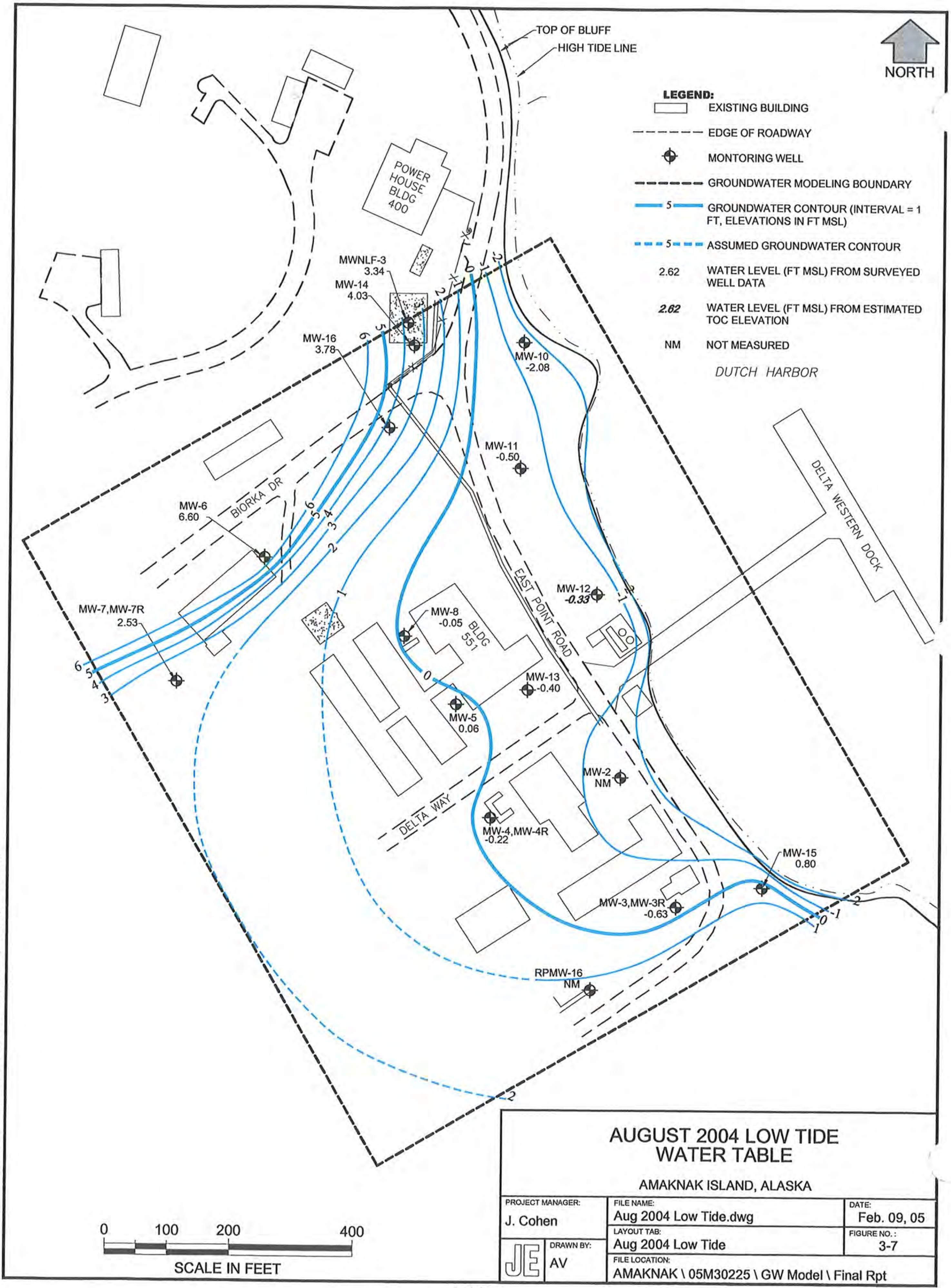
LAYOUT TAB: Sept 2003 Low Tide

FILE LOCATION: AMAKNAK \ 05M30225 \ GW Model \ Final Rpt

DATE: Feb. 09, 05

FIGURE NO.: 3-6

G:\Autocad\AMAKNAK\05 W Model\FINAL RPT\SEPT 2003 LOW TIDE.dwg Feb 10,2005 -avakarcs

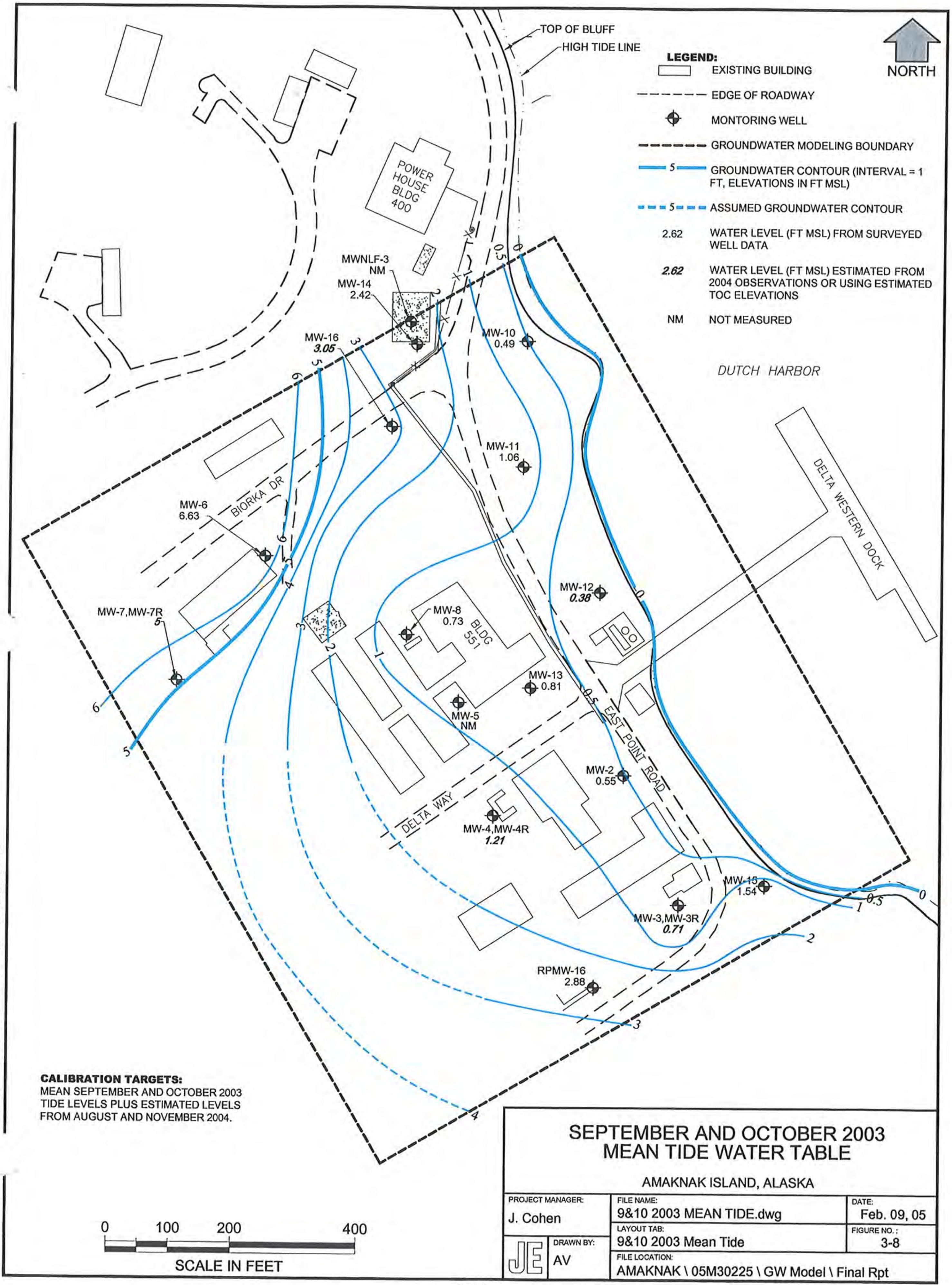


AUGUST 2004 LOW TIDE WATER TABLE

AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen	FILE NAME: Aug 2004 Low Tide.dwg	DATE: Feb. 09, 05
JE	LAYOUT TAB: Aug 2004 Low Tide	FIGURE NO.: 3-7
DRAWN BY: AV	FILE LOCATION: AMAKNAK \ 05M30225 \ GW Model \ Final Rpt	

G:\Autocad\AMAKNAK\05M30225\GW Model\FINAL RPT\AUG 2004 LOW TIDE.dwg Feb 10,2005 -avakarcs



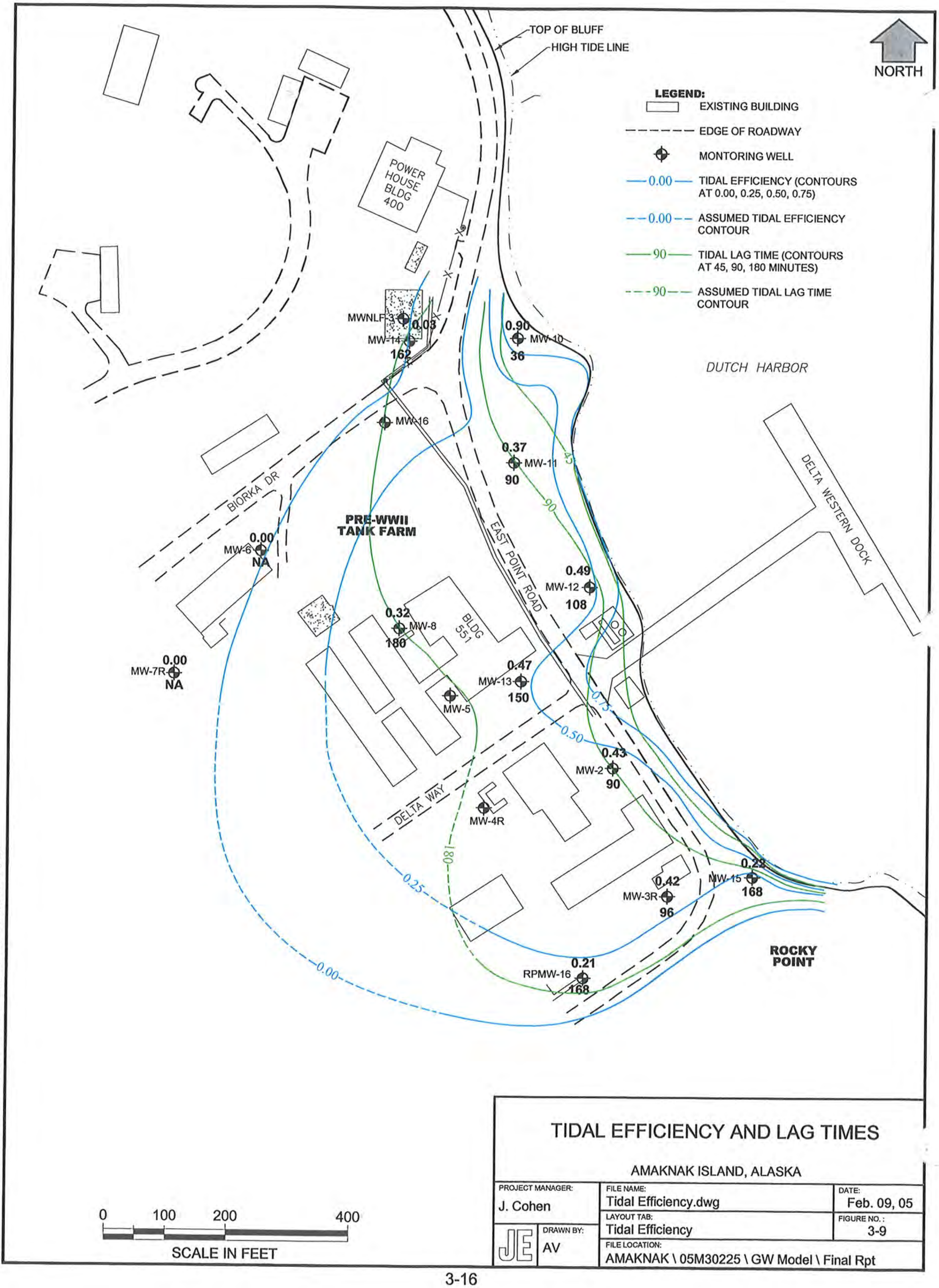
CALIBRATION TARGETS:
MEAN SEPTEMBER AND OCTOBER 2003
TIDE LEVELS PLUS ESTIMATED LEVELS
FROM AUGUST AND NOVEMBER 2004.

SEPTEMBER AND OCTOBER 2003 MEAN TIDE WATER TABLE

AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen	FILE NAME: 9&10 2003 MEAN TIDE.dwg	DATE: Feb. 09, 05
JE — DRAWN BY: AV	LAYOUT TAB: 9&10 2003 Mean Tide	FIGURE NO.: 3-8
	FILE LOCATION: AMAKNAK \ 05M30225 \ GW Model \ Final Rpt	

G:\Autocad\AMAKNAK\05 GW Model\FINAL RPT\9&10 2003 MEAN TIDE.dwg Feb 10,2005 -avakarcs



TIDAL EFFICIENCY AND LAG TIMES

AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen
FILE NAME: Tidal Efficiency.dwg
DATE: Feb. 09, 05
LAYOUT TAB: Tidal Efficiency
FIGURE NO.: 3-9
JE
DRAWN BY: AV
FILE LOCATION: AMAKNAK \ 05M30225 \ GW Model \ Final Rpt

G:\Autocad\AMAKNAK\05M30225\GW Model\FINAL RPT\TIDAL EFFECIENCY.dwg Feb 10,2005 -avakarcs

The November water table is higher than the average by about 2 feet near the shoreline, 3 feet at RPMW-16 in the south, and 3.8 feet at MW-14 in the north. Near Building 551 (MW-8 and MW-5), the increase was subdued, as small as 1.5 feet. Compared to the August water table, there is no meander of contour lines south of Building 551, and water levels are up to 5.3 feet higher (e.g., MW-14). The increase in water levels reflects the unusually high precipitation in October 2002 (18.12 inches compared to the 1971 to 2000 average of 6.42 inches), but the subdued response near Building 551 is intriguing. Several factors could be at work:

- The building prevents direct infiltration of precipitation. Runoff from the roof could be carried away as overland flow rather than infiltrating the subsurface. Although evidence of such flow was not observed, significant ponding around the building during investigations in October 2003 suggests low infiltration rates there.
- The subsurface beneath the building could be entirely plugged with Bunker C down to bedrock, inhibiting water table response. Seeps of Bunker C are ubiquitous in the building's crawl space, the density of Bunker C is very close to that of water, and excavations at the adjacent tank farm encountered Bunker C down to bedrock or significant groundwater flow. However, groundwater does not seem to have piled up on the upgradient side of the putative Bunker C plug.
- If not plugged with Bunker C, hydraulic transmissivity could be very high, requiring only a shallow head gradient to transmit the necessary groundwater flow.

Water Tables in June 2001, September 2003, and August 2004

Water tables in June 2001 (Figure 3-5) and September 2003 (Figure 3-6) share unusually high water levels in MW-11, located on the shortest path between the Pre-WWII Tank Farm and Dutch Harbor. Elsewhere, the water table patterns resemble those seen in 2002. Although measurement errors resulting from the pervasive coating of Bunker C in the well bore of MW-11 cannot be completely ruled out, the similarities of product thickness and water level suggest that the measurements are valid, and that some physical explanation must be sought. Field reconnaissance in October 2003 identified two large dry wells or sumps nearby at the intersection of Biorka Drive and East Point Loop Road. The dry wells are intended to facilitate infiltration of surface runoff, thus serving as significant point sources of groundwater recharge. There may have been an intense storm within a few days preceding each of these rounds of water level measurement, but climatic records are not readily available to confirm this hypothesis. Substantial surface runoff generated by such storms might have flooded the subsurface at these dry wells, causing local mounding at the water table of 3 or 4 feet.

The set of water-table measurements in August 2004 is the most complete. It includes water levels from the four newly installed wells (MW-3R, MW-4R, MW-7R, and MW-16) and all previously measured wells except MW-2 and RPMW-16. The water table constructed from these measurements is depicted in Figure 3-7. This water table shows a steep gradient near the shoreline, reflecting the transient influence of a strong low tide (the observed water level in MW-10 was –2.08 feet msl). Gradients across the tank farm site are nearly flat, but steepen to the north (toward MW-16) and northwest (toward MW06). The gradient toward the west is gentle, showing that the bedrock embayment encompasses MW-7R. Gradients near MW-15, to the south, are steep, indicating either low transmissivity or high groundwater flow. This well is a good producer during sampling, lending support to the latter hypothesis.

Calibration Water Table — Mean-Tide Water Table in September and October 2003

The water table for September and October 2003 in Figure 3-8 is based on the mean water level in each well after averaging the tidal influence, as discussed in Section 3.3. Because these water levels have had tidal influences removed, they are suitable calibration targets for steady-state groundwater modeling of average flow patterns. As expected, these mean-tide water levels are somewhat higher than the low-tide water levels, particularly near the shoreline. Overall gradients across the site remain relatively flat, and the head at MW-11 has dropped 2.7 feet since September 2003 in spite of the difference in tide stage and wetter surface conditions evident during the October sampling.

This data set has been augmented with 2004 measurements for MW-3R, MW-4R, MW-7R, and MW-16. August 2004 water levels were lower than in October 2003, whereas November 2004 levels were higher and were continuing to rise (see tidal influence monitoring for MW-7R in Appendix A). For MW-3R, the water level offset from November 2004 tidal monitoring was used. For MW-4R, -7R, and -16, intermediate elevations were estimated.

Note that the mean water level for MW-12 also was estimated. It is based on an estimated TOC elevation of 11.32 feet msl, 0.5 feet below the surveyed top of vault (ground surface) elevation. The vault could not be opened because of crab pots stacked on it at the time of the survey.

3.3 TIDAL INFLUENCE

Water levels in monitoring wells fluctuate in concert with the daily tidal cycle in adjacent Dutch Harbor. At a basic level, the tidal influence is comprised of a lag time, describing the time interval between tide stages in the bay and in a well, and an efficiency, which compares the amplitude of tide stages in a well to those in the bay. Strong tidal effects (efficiencies greater than 0.75) and short lag times (less than an hour) indicate a strong hydraulic connection between the well and the bay. The pattern of tidal effects will guide the pattern of hydraulic properties in the flow model, and the observed efficiencies will become calibration targets during development of the groundwater flow model.

3.3.1 Data Collection

Water levels were measured over several days in each monitoring well using downhole data-logging pressure transducers (vented miniTROLLs, In-Situ Inc.). The pressure of the overlying water (and product) column was recorded automatically at 6-minute intervals coinciding with the tidal observations recorded by National Oceanic and Atmospheric Administration (NOAA) in nearby Unalaska. The elevation of the top of the water column (and product column, where present) was determined manually before or after the monitoring period, providing a reference elevation and permitting calculation of water-level elevations (heads) from the logged pressures.

3.3.2 Calculations

Raw data from the miniTROLLs consisted of a list of times and pressures. All miniTROLLs were set to local clock time, so data from October 2003, based on Alaska Daylight Time, required subtraction of 1 hour to match the time basis in the published tidal data (Alaska

Standard Time). Pressures, recorded in pounds per square inch (psi) relative to atmospheric pressure, were converted to feet of water by multiplying by 144 inch^2/feet^2 / 62.42796 pounds/feet^3 = 2.307 feet/psi. The resulting records of water depths versus time were converted to records of water level changes relative to the initial (or final) reading and then combined with the initial (or final) manual elevation measurement to produce records of water elevations versus time. (In MW-13, where there was approximately 1 foot of a Bunker C/diesel product mixture, the equivalent water elevation was calculated using the measured product density of 0.9485 g/mL at 15 degrees Celsius (°C) (see Section 3.7). No correction was made in MW-11, which contained less than 0.2 feet of pure Bunker C, which has a density very close to 1 g/mL.)

Tidal influence was simulated at each monitoring well using a three-parameter model consisting of a lag time, an offset, and an efficiency. The lag time is the delay time between tide changes in the bay and in the monitoring well, the offset is the average difference between water elevation in the well and in the bay after accounting for the lag time, and tidal efficiency is the ratio of tidal fluctuations in the monitoring well compared to those in the bay. Values for the three parameters were found by simultaneous optimization. The optimal values minimized the total error between the observed and simulated tide. The total error was expressed as the sum of the absolute value of the difference between the observed and simulated water levels at each 6-minute datum throughout the monitoring period. The quality of the simulation can be seen graphically, comparing plots of the observed and simulated water levels, and also is expressed by the mean error, calculated from the total error divided by the number of observations and the range of observed water levels.

Next, the absolute water levels used to anchor the start (or end) of transducer measurements were adjusted. This was done to compensate for tidal changes during the few minutes between the manual water level measurements and the transducer records. These absolute water levels were refined using the tidal parameters, the tidal record, and the time difference between the manual measurement and the transducer record. Finally, the three tidal simulation parameters, including their influence on the adjusted manual water levels, were reoptimized. All calculations were automated using Microsoft Excel spreadsheets.

3.3.3 Results

Twelve monitoring wells in and around the site were evaluated for tidal influences. Results for each well are displayed in Appendix A (Figures 1-1 through 1-12). These figures display observed water levels based on the transducer measurements, the tidal record measured by NOAA nearby in Unalaska, and the simulated water level calculated from the three-parameter model. Results for all wells are summarized in Table 3-3. Tidal efficiencies range from zero in MW-6 and MW-7R and nearly zero (0.03) in MW-14, to 0.90 in MW-10. Lag times are inversely correlated with efficiencies, ranging from a low of 36 minutes in MW-10 to 180 minutes in MW-8. Tidal efficiencies and lag times, posted and contoured on a site map in Figure 3-9, show that tidal fluctuations affect the area between Biorka Drive and Rocky Point for up to 500 feet from the shoreline. Bedrock rises to the north and south of this area, pinching the aquifer and causing the water table to rise, eliminating any tidal influence.

Table 3-3
Summary of Investigation of Tidal Influence

Well ID	Start	End	Mean Water Level (ft msl)	Lag Time (min)	Efficiency (ratio)	Mean Error (%)
MW-2	10/19/2003 17:42	10/21/2003 16:24	0.55	90	0.43	8.7
MW-3R	11/11/2004 13:12	11/12/2004 13:18	0.71	96	0.42	4.6
MW-6	10/18/2003 21:30	10/21/2003 15:48	6.63	0	0.00	5.1
MW-7R	11/13/2004 16:24	11/14/2004 16:30	6.54	0	0.00	27.0
MW-8	10/18/2003 10:18	10/21/2003 16:00	0.73	180	0.32	9.3
MW-10	9/5/2003 11:30	9/10/2003 10:24	0.49	36	0.90	1.5
MW-11	10/16/2003 17:24	10/20/2003 15:12	1.06	90	0.37	8.4
MW-12	9/5/2003 10:24	9/10/2003 9:30	0.38	108	0.49	6.0
MW-13	10/17/2003 11:48	10/19/2003 15:30	0.81	90	0.47	6.4
MW-14	9/7/2003 23:00	9/10/2003 9:54	2.42	162	0.03	7.8
MW-15	10/17/2003 16:36	10/21/2003 16:48	1.54	168	0.22	12.5
RPMW-16	10/17/2003 17:18	10/20/2003 17:00	2.88	168	0.22	12.8

3.3.4 Inferred Hydraulic Conductivity

The average horizontal hydraulic conductivity (K_h) between each well and the shoreline can be calculated analytically by making the following assumptions:

- The aquifer is uniform in thickness and hydraulic properties.
- The aquifer is approximated as a semi-infinite slab bounded on its edge by the shoreline.
- Water level fluctuations are small compared to the saturated thickness of the aquifer.
- Tidal fluctuations are approximately sinusoidal.
- The storage coefficient (S) for the aquifer is known.

Although site conditions satisfy the first assumptions only roughly, the greatest uncertainty is related to S. Over the long term, the aquifer almost certainly behaves as an unconfined system, with water draining from and refilling pore spaces as the water level fluctuates. Over the course of a tidal cycle, however, drainage and refilling could be inhibited to an unknown extent by silt and peat lenses with low vertical hydraulic conductivity. Thus, plausible a priori estimates of S range over several orders of magnitude, from 0.1 to 0.0001.

The analytical solution for the hydraulic conductivity of a semi-infinite slab with a periodic changing-head boundary has long been known in the hydrologic literature (as well in the physical literature for an analogous problem in heat flow). The solution presented here was taken from Ferris (1963). Two forms of the solution for K_h are used. The first finds K_h from the tidal lag time (t_{lag}):

$$K_h = \frac{x^2 S\, t_{Tide}}{4\pi\, t_{lag}^2\, z} \qquad (0\text{-}1)$$

where x is the shortest distance from the well to the shoreline, t_{Tide} is the tidal period (taken to be 12.5 hours or 0.521 days), and z is the thickness of the aquifer. The second equation finds K_h from the tidal efficiency (f_{Tide}, the fractional tidal response):

$$K_h = \frac{\pi S}{t_{Tide}\, z}\left(\frac{x}{\ln\left(\frac{1}{2} f_{Tide}\right)}\right)^2 \qquad (0\text{-}2)$$

Calculated K_h values are presented in Table 3-4. For each well, values for x were taken from the base map for the site (Figure 1-1), and values for z are based on the average water level and estimated average depth to bedrock between the well and the shoreline (see Section 4.3 for a discussion of bedrock topography). The value for S was adjusted so that the minimum and maximum calculated K_h values were plausible for naturally occurring sediments. For the selected S value of 0.01, the lag-time K_h values ranged from 10 ft/day (in MW-15) to 426 ft/day (in RPMW-16), whereas the tidal-efficiency K_h values ranged from 4 ft/day (in MW-15) to 239 ft/day (in MW-8). The selected S value corresponds to semi-confined conditions, and the wide range in K_h values implies substantial lateral heterogeneity in the aquifer. The difference between the lag-time and tidal-efficiency K_h values may be partly attributable to the difficulty in selecting the applicable tidal period. During most of the lunar month, Dutch Harbor tides are highly asymmetric, with only one prominent low tide, poorly approximating a sine wave. In detail, the calculated K_h values are subject to substantial uncertainty in other parameters in addition to S. Although x was chosen as the shortest distance between a well and the shoreline, actual groundwater flow trajectories could be significantly longer due to deflection by intervening zones of low K_h. Somewhat lesser uncertainty accompanies the z values. Differences in x and z could change the calculated K_h values by 50 percent. Nevertheless, this analysis provides useful insights into the likely variations of K_h across the site.

3.4 HYDRAULIC CONDUCTIVITIES FROM SLUG TESTS

After an instantaneous change (displacement) of the water level in a well, the record of its return to equilibrium provides information about the hydraulic conductivity of the nearby aquifer. A slug rapidly lowered or withdrawn from a well produced the initial displacement, and a downhole transducer recorded water pressure periodically, capturing the baseline water level, the initial displacement, and the pattern of re-equilibration. Hydraulic conductivity was estimated using the Bouwer and Rice method for an unconfined aquifer with a partially penetrating well (Bouwer and Rice 1976, Bouwer 1989, Zlotnik 1994) as implemented in AQTESOLV (HydroSOLVE Inc., 2000).

Table 3-4
Analytically Calculated Hydraulic Conductivities from Tidal Lag Times and Efficiencies

Well ID	t_{lag} (day)	f_{Tide} (ratio)	x (ft)	Z (ft)	S (ratio)	K_h (ft/day)	
						from t_{lag}	from f_{Tide}
MW-2	0.063	0.43	110	15	0.01	86	21
MW-3R	0.067	0.42	165	11		231	61
MW-8	0.125	0.32	365	10		353	239
MW-10	0.025	0.90	50	5		332	48
MW-11	0.063	0.37	115	15		94	19
MW-12	0.075	0.49	55	11		20	8
MW-13	0.063	0.47	200	15		283	78
MW-14	0.113	0.03	210	5		289	31
MW-15	0.117	0.22	40	5		10	4
RPMW-16	0.117	0.22	355	9		426	170

Notes:

t_{lag} is the lag time calculated from tidal influence measurements
f_{Tide} is the fractional tidal efficiency calculated from tidal influence measurements
x is the approximate distance from the well to the shoreline
z is the estimated average aquifer thickness between the well and the shoreline
S is the groundwater storage coefficient for the aquifer
K_h is the horizontal hydraulic conductivity

3.4.1 Data Collection

Slug tests were conducted successfully at MW-2, MW-8, MW-10, MW-12, MW-14, MW-15, and RPMW-16. MW-6 was not tested because it contained only 0.75 feet of water. MW-11 and MW-13 were not tested because free product would have prevented meaningful interpretation of test results. No attempt was made to locate and test MWNLF-2 or MWNLF-3. MWNLF-2 has not been found since September 2001, and MWNLF-3 typically contains very little water. These wells are near MW-14 and would not have significantly increased the spatial coverage of slug testing.

At each well, at least one pair of falling head/rising head slug tests was conducted. A transducer (vented miniTROLL, In-Situ, Inc.) was placed downhole and set to record the pressure of the overlying water column at 1-second intervals. The depth to water was manually measured to provide a point of reference. Next, the slug (a weighted solid plastic cylinder with a length of 36 inches and a diameter of 1.50 inches [for 2-inch wells] or 3.00 inches [for 4-inch wells]) was lowered to near the water level and then allowed to drop freely to produce a rapid upward displacement of the water level, initiating the falling head portion of the test. After a few minutes, when the water pressure had returned to near its original level and was stable to ±0.002 psi for at least a minute or had settled down to a constant rate of change, the slug was quickly lifted out of the water. This produced a rapid downward displacement of the water level, initiating the rising head portion of the test. As before, water pressure monitoring continued until readings were stable or changing at a constant rate. At most wells, a second pair of slug tests were conducted by repeating the process.

3.4.2 Calculations

Preliminary processing converted raw pressure readings to sets of corrected absolute displacements versus time for each falling- or rising-head test. Pressure readings were converted to water depths using the conversion factor of 2.307 feet/psi (see Section 3.3.2 for derivation). This assumes a water density of 1.0 g/mL. The actual water density would have been only negligibly different due to the small and offsetting effects of dissolved solids, dissolved gasses, and temperatures slightly different from 4°C (at which water achieves maximum density). The transducer record for each well was subdivided into separate test segments, each consisting of at least one baseline reading, the initial displacement, the equilibration period, and a final baseline period to quantify the rate of water level change due to tides, infiltration, or drainage. A linear trend, calculated by least-squares regression of the post-equilibration baseline readings, was applied to readings during the equilibration period to correct for these factors. Finally, artifacts related to inserting or withdrawing the slug were identified and excluded from the final data sets. Such artifacts included extremely high or low water levels produced as water sloshed in the well for a second or two following insertion or withdrawal of the slug, and erratic equilibration for as much as 45 seconds, attributed to the slug settling on top of or slowly sliding past the transducer.

Hydraulic conductivities were obtained from log-linear plots of absolute displacement versus time. Manually determined best-fit straight lines provided slopes and intercepts needed for the Bouwer and Rice method, as implemented in AQTESOLV. Other necessary well and aquifer parameters are included in Table 3-5. Early data (the first 10 to 45 seconds) usually defined very steep trends, reflecting the high conductivities of the sand packs around the well screens, and so were ignored. Equilibration was generally complete after 50 to 170 seconds, although one well (MW-12) required up to 700 seconds to stabilize.

AQTESOLV offers two other methods of slug-test analysis in unconfined aquifers: the Hvorslev method and the KGS Model. Neither method could produce consistent results from multiple tests on the same well, and appeared to be overly sensitive to parameters with limited precision, such as the exact time of the initial displacement. Thus, neither method was pursued.

3.4.3 Results

Interpretations of the slug tests need to consider the simplifying assumptions underlying the Bouwer and Rice method. These are:

- An aquifer of infinite areal extent, with a horizontal aquiclude at its base
- An initially horizontal water table
- Uniform and horizontally isotropic hydraulic properties
- Partial penetration of the aquifer by the test well, which may be screened across the water table
- Instantaneous water displacement
- Steady flow, enabling omission of storage terms

In practice, although inserting or withdrawing the slug is not instantaneous, variations in aquifer properties are the most important departure from the ideal case.

Table 3-5
Well and Aquifer Parameters for Bouwer-Rice Slug Test Analyses

Well ID	Top of Casing (ft msl)	Total Depth Installed (ft)	Top of Screen (ft BTOC)	Bottom of Screen (ft BTOC)	Screen Length (ft)	Depth to Water (ft)	Screen Length Below Water Table (ft)	Estimated Bedrock Depth (ft bgs)	Saturated Thickness (ft)	Casing/ Screen Inside Diameter (in)	Casing/ Screen Radius (ft)	Borehole Diameter (in)	Borehole Radius (ft)	Expected Initial Displacement (ft)
MW-2	11.94	18.00	8.3	17.3	9.0	10.82	6.48	27.0	16.18	1.939	0.0808	8.0	0.33	1.80
MW-8	12.30	16.00	6.2	15.2	9.0	11.79	3.41	19.5	7.71	1.939	0.0808	4.0	0.17	1.80
MW-10	10.13	16.00	6.2	15.2	9.0	9.11	6.09	15.2	6.09	3.826	0.1594	8.0	0.33	1.84
MW-12	11.32	15.50	5.7	14.7	9.0	10.67	4.03	22.0	11.33	3.826	0.1594	8.0	0.33	1.84
MW-14	13.63	16.00	6.2	15.2	9.0	8.41	6.79	15.0	6.59	3.826	0.1594	8.0	0.33	1.84
MW-15	12.87	16.00	6.2	15.2	9.0	10.73	4.47	18.5	7.77	3.826	0.1594	8.0	0.33	1.84
RPMW-16	11.80	16.40	6.4	16.0	9.6	8.78	7.22	18.9	10.12	1.939	0.0808	4.0	0.17	1.80

Notes:

Assume gravel pack porosity = 0.4
Expected Initial Displacement calculated from Casing/Screen Inside Diameter and dimensions of the slug (1.50 in or 3.00 in diameter x 36 in long).
Anisotropy (Kv//Kh) assumed to be 0.5

Test pits and boreholes have shown that the aquifer at the Pre-WWII Tank Farm varies in thickness and especially in lithology, with silt and peat layers interbedded with sands and gravels. Lithologies noted on boring logs may change rapidly within a few feet to tens of feet away from the hole. This possibility may explain unusual trends near the tails of displacement curves. Because the radius of influence of a slug test increases with time, later times reflect relatively more distant parts of the aquifer. The radius of influence of a 2-minute slug test is probably less than 5 feet, however.

Detailed discussions of results for individual wells may be found in Section 2.0 of Appendix A.

3.4.4 Summary

Slug-test results for each of the seven tested wells are summarized in Table 3-6. Using the Bouwer-Rice method in AQTESOLV, high horizontal hydraulic conductivity (K_h) values of 23 and 28 ft/day were estimated for MW-10 and MW-15, which the dominant lithologies are loose sandy gravel or loose gravelly sand. Other wells completed in gravelly sand or sandy gravel have estimated K_h values of 4.9 to 8.3 ft/day, but have been described as having medium dense or very dense compaction. One well (MW-12) is completed in loose sandy silt, with an estimated K_h of 3.2 ft/day. These trends are portrayed graphically in Figure 3-10, plotting qualitative compaction versus qualitative grain size. Loose gravel would exhibit the maximal K_h of more than 30 ft/day, and dense silt would exhibit the minimal K_h of less than 1 ft/day. For gravel, the degree of compaction is critical; densely compacted gravel may have a K_h less than 1 ft/day. In contrast, the degree of compaction for silt may make little difference relative to the range of K_h values covered by this figure; K_h for all silts regardless of compaction are expected to be much less than 1 ft/day. These trends will form the basis for assigning hydraulic properties to hydrostratigraphic units delineated from boreholes and test pits across the site.

Table 3-6
Results of Slug Test Analyses

Well ID	Test ID	K_h (ft/day)	Lithology	Compaction	Comments
MW-2	Falling Head #1	6.1	Gravelly Sand	Very Dense	Very scattered after 45 s
	Falling Head #2	5.5			Stairstep pattern after 30 s
	Rising Head #1	5.4			Consistent behavior from 10 s to 80 s
	Rising Head #2	4.4			Consistent behavior from 20 s to 70 s
	Value for Flow Model	*4.9*			Arithmetic average of rising-head tests, but low value may reflect effects of silt washed into well in preceding days
MW-8	Falling Head	23	Gravelly Sand	Medium Dense	Anomalous pattern may reflect high K_h in the unsaturated zone, globules of Bunker C deeper.
	Rising Head	6.6			Consistent behavior from 20 s to 50 s
	Value for Flow Model	*6.6*			Rising-head value should be most representative of the saturated zone
MW-10	Falling Head #1	16	Sandy Gravel	Loose	Consistent behavior from 40 s to 90 s
	Falling Head #2	20			Consistent behavior from 40 s to 60 s
	Rising Head #1	25			Consistent behavior from 25 s to 60 s
	Rising Head #2	21			Consistent behavior from 20 s to 60 s
	Value for Flow Model	*23*			Average of rising-head values because they should be most representative of the saturated zone
MW-12	Falling Head #1 early	4.0	Sandy Silt	Loose	Consistent behavior from 2 s to 80 s
	Falling Head #1 late	1.5			Consistent behavior from 300 s to 700 s
	Rising Head #1 early	2.5			Consistent behavior from 2 s to 80 s
	Rising Head #1 late	4.1			Consistent behavior from 130 s to 400 s
	Value for Flow Model	*3.2*			Early data reflects silt of screened interval, not affected by underlying gravel.
MW-14	Falling Head #1	28	Silty Gravelly Sand	Loose	Consistent behavior from 20 s to 50 s
	Falling Head #2	28			Consistent behavior from 20 s to 50 s
	Rising Head #1	27			Consistent behavior from 30 s to 70 s
	Rising Head #2	28			Consistent behavior from 30 s to 70 s
	Value for Flow Model	*28*		Loose	Average all values because of their similarity

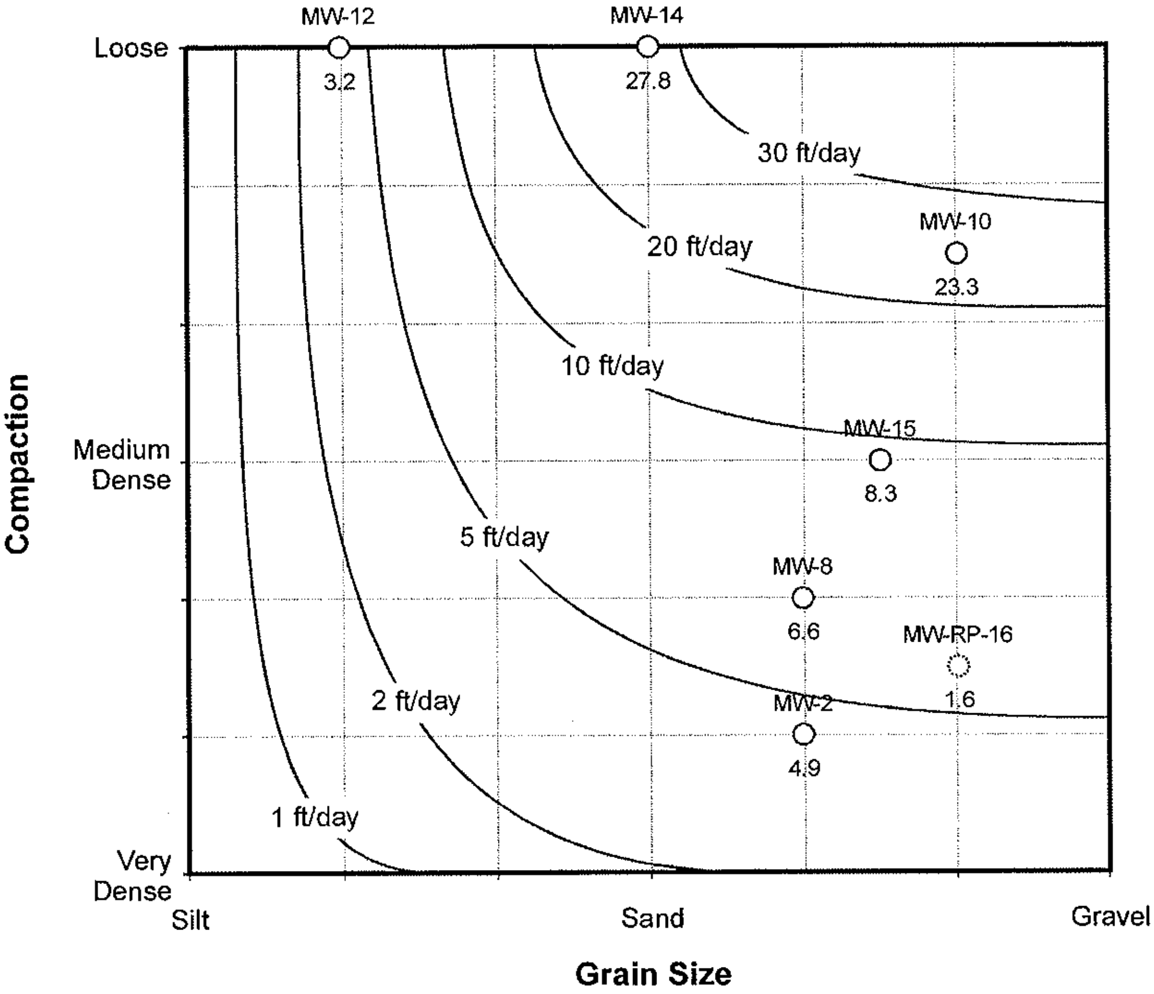
Table 3-6
Results of Slug Test Analyses
(continued)

Well ID	Test ID	K_h (ft/day)	Lithology	Compaction	Comments
MW-15	Falling Head #1	4.8	Gravelly Sand	Medium Dense	Consistent behavior from 40 s to 170 s
	Falling Head #2	5.0			Consistent behavior from 55 s to 125 s
	Rising Head #1	8.1			Consistent behavior from 40 s to 85 s
	Rising Head #2	8.4			Consistent behavior from 50 s to 110 s
	Value for Flow Model	*8.3*			Arithmetic average of rising-head tests; low values of falling-head tests reflect effects of silt noted in boring log just above the present water table.
RPMW-16	Falling Head #1	3.5	Sandy Gravel	Dense	Slug did not fall cleanly, but consistent behavior from 45 s to 115 s
	Falling Head #2	2.2			Consistent behavior from 50 s to 90 s
	Rising Head #1	1.6			Consistent behavior from 20 s to 130 s, but later recovery is very slow
	Rising Head #2	1.4			Consistent behavior from 10 s to 165 s, but later recovery is very slow, and initial displacement is impossibly large
	Value for Flow Model	*1.6*			Substantial hysteresis between falling and rising-head tests, implying a nearby but unseen silt zone; use Rising Head #1.

RPMW-16 is an exception to these trends; although it is completed in dense sandy gravel, its estimated K_h is only 1.6 ft/day, more like a silty sand or sandy silt. It is possible that the hydraulic behavior of this well is governed by a nearby but unseen silt unit, or the lithology may have been categorized differently than the other wells because the boring for this well was logged by a different consultant.

Compared to most sands and gravels elsewhere in the world, these sands and gravels would appear to have very low hydraulic conductivities, based on the slug test analyses. Whereas typical K_h values for gravelly sands are on the order of 100 to 300 ft/day, the values here of 28 ft/day or less imply that the aquifer is choked with a substantial fraction of fine material. Alternatively, the Bouwer and Rice method may simply underestimate the bulk hydraulic conductivity of the aquifer.

Figure 3-10
Inferred Hydraulic Conductivity as a Function of Grain Size and Compaction



3.5 GEOMETRY OF THE FRESHWATER/SEAWATER INTERFACE

The geometry of the freshwater/seawater interface can be approximated by assuming hydrostatic equilibrium in the vertical direction. Consider the case of a freshwater lens floating in seawater. The weight of the freshwater lens will depress the saltwater surface by an amount related to its thickness and density contrast with seawater. Much like an iceberg, the height of the freshwater lens above sea level is supported by a much greater thickness of freshwater below the level of seawater. Known as the Ghyben-Herzberg relation, it may be stated as:

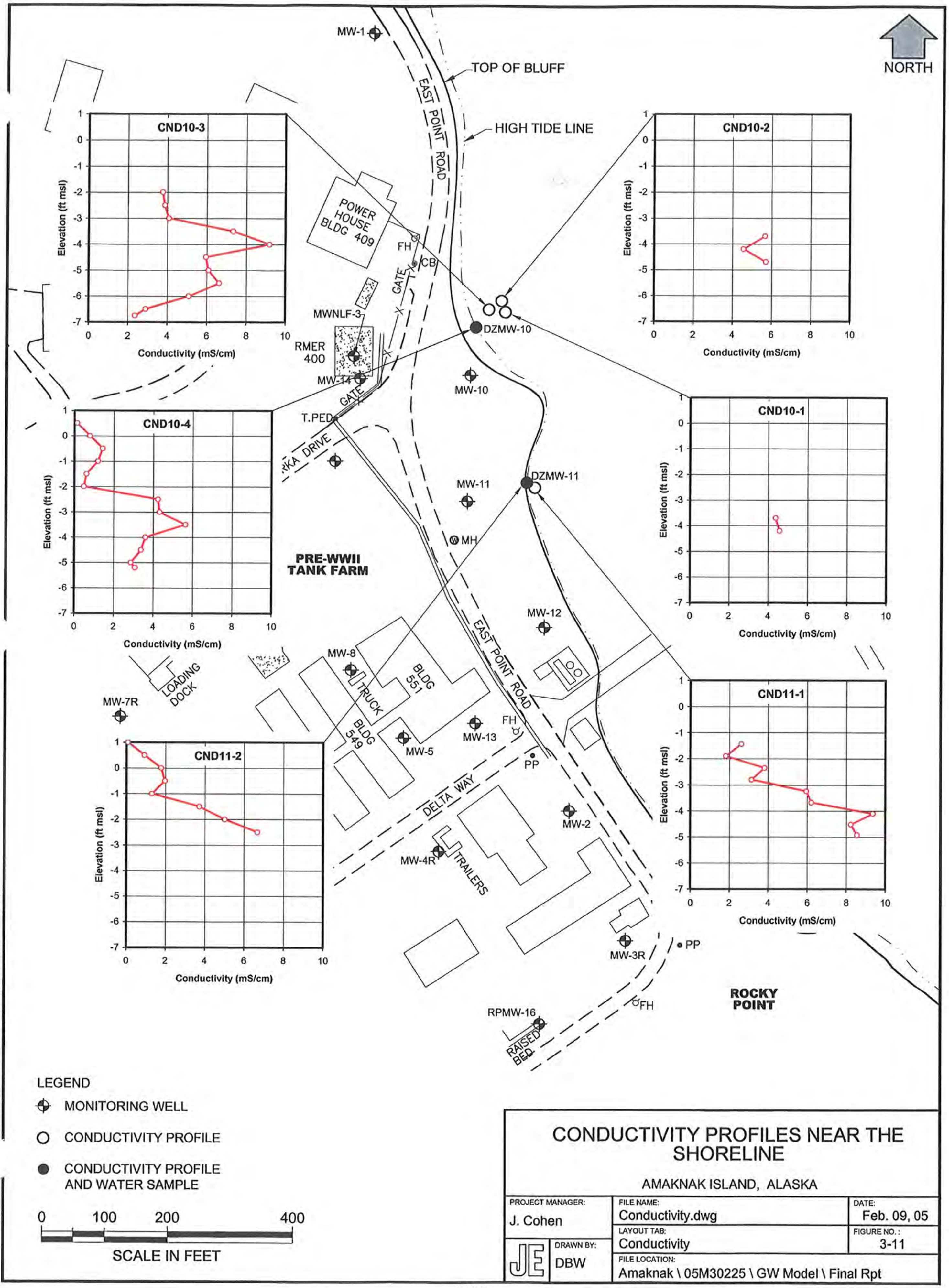
$$z_s = 40\, z_w \tag{0-3}$$

where z_s is the depth of the freshwater/seawater interface below sea level, and z_w is the height of the water table above sea level. The factor of 40 is derived from the ratio of the density of freshwater to the difference in density between seawater and freshwater, assuming the density of freshwater to be 1.000 g/mL and that of seawater to be 1.025 g/mL. Thus, the Ghyben-Herzberg relation states that for every foot of elevation of the water table above sea level, the freshwater/saltwater interface will be depressed approximately 40 feet below sea level.

Real freshwater/seawater interfaces, including that at the Pre-WWII Tank Farm, are dynamic rather than static, with horizontal and vertical head gradients towards the groundwater discharge zone along the shore, tidal fluctuations in sea level, fluctuations in the water table in response to precipitation, and a broad rather than line-like discharge zone that may extend from seeps above the high-tide line to some distance seaward beneath the ocean. Knowledge of these features can be used to construct a cross-section of the interface with estimated flow lines and lines of equipotential head. Neglecting the mixing zone, Equation 0-3 must hold along equipotential lines and permits calculation of the depth to seawater given the elevation of the water table.

3.5.1 Data Collection

To ascertain whether the freshwater lens extended seaward of the intertidal zone, electrical conductivity profiles were measured at six locations along the beach (Figure 3-11). Although not precisely surveyed, the field relationships among each group of wells were recorded as bearings and distances to landmarks at the high-tide line. Each group was then located approximately on the map to be consistent with observed relationships to the nearby monitoring wells. Beach surface elevations were estimated from the high-tide line, tide stage during monitoring, and water depth.



CONDUCTIVITY PROFILES NEAR THE SHORELINE

AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen	FILE NAME: Conductivity.dwg	DATE: Feb. 09, 05
	LAYOUT TAB: Conductivity	FIGURE NO.: 3-11
JE DRAWN BY: DBW	FILE LOCATION: Amaknak \ 05M30225 \ GW Model \ Final Rpt	

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Conductivities were measured using a Geoprobe® SC200 4-pole probe connected to a Geotech® 330i conductivity meter. The probe was manually driven into soils and sediments using a 30-pound slide hammer, reaching depths of up to 6.7 feet before refusal. Meter readings were recorded manually every 0.5 feet. The meter-probe combination was pre-calibrated in the Anchorage office before fieldwork, and is believed to have an absolute accuracy of ±20 percent or better. Relative accuracy is believed to be ±5 percent or better.

Conductivity profiles were measured offshore in water depths up to 1.5 feet. Chest waders provided sufficient protection from the cold water and wind waves, but buoyancy made footing somewhat uncertain in the face of 1-foot wind waves and uneven bottom topography; measuring greater depths was deemed impractical. Although planned work included the use of a small boat in water depths up to 8 feet, high winds and large waves made this too risky. Conductivity profiles from such depths would have been useful, but were not critical to developing an understanding of the freshwater/saltwater interface.

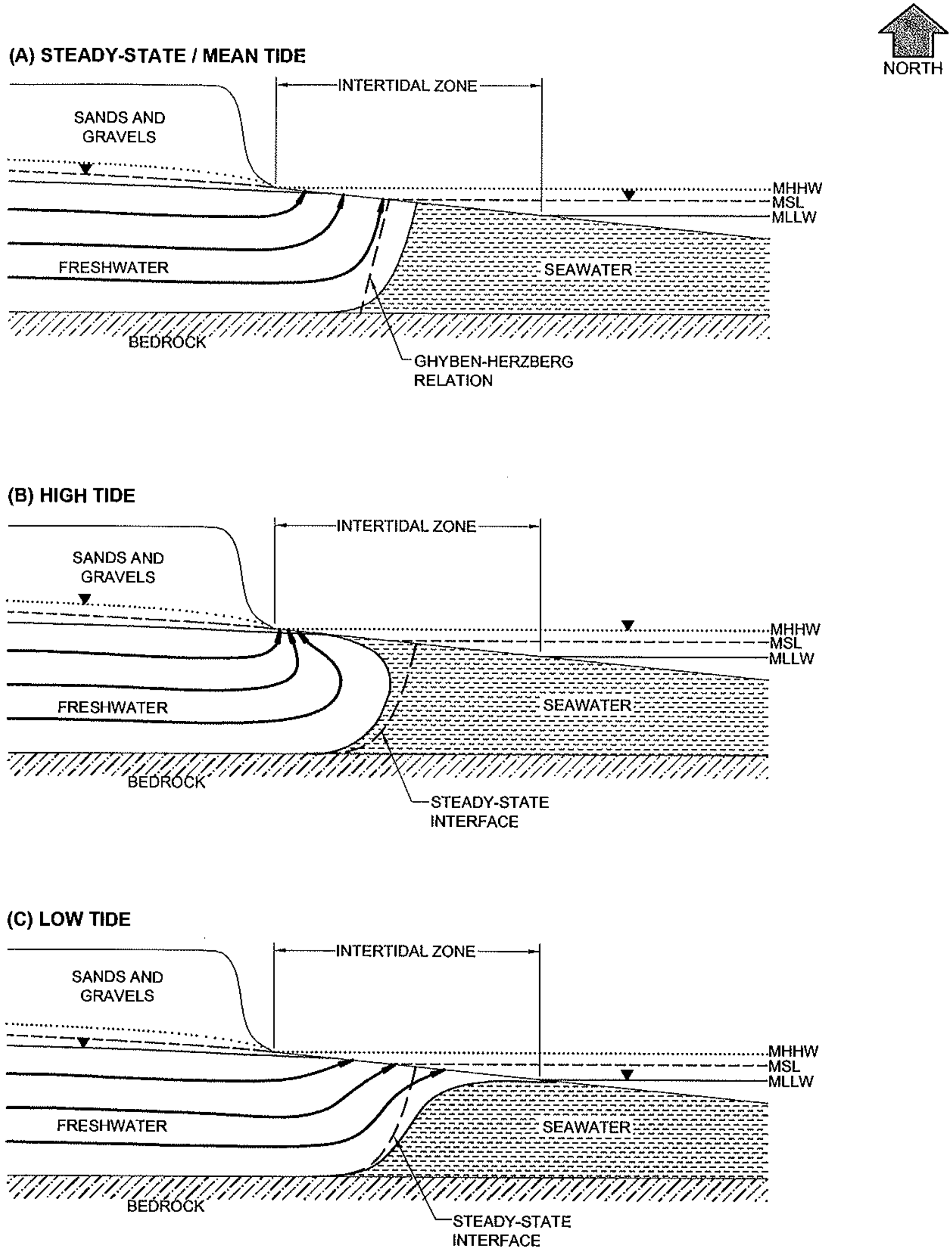
3.5.2 Results and Conceptual Interface Geometry

Conductivities in aquifer materials near the shoreline could range from values associated with undiluted groundwater to values indicating pure seawater, depending on the groundwater flow field and the extent of mixing of the two end members. Groundwater conductivities in MW-10 and MW-12, measured in September 2003 (USAED 2003a) were near 0.1 milli-Siemens per centimeter (mS/cm), and the conductivity probe used here gave a reading of 30.6 mS/cm when placed in Dutch Harbor. When driven into the subsurface, however, the measured conductivity will be reduced relative to pure liquid because the aquifer matrix (sand) is relatively non-conductive. The magnitude of the effect likely depends on porosity, grain size, and mineralogy. Assuming the matrix to be non-conductive and sufficiently fine-grained, the conductivity should be reduced in proportion to the porosity. The porosity probably ranged between 0.3 and 0.5, so the maximum anticipated conductivity in the subsurface would be 9.2 to 15.3 mS/cm. The minimum conductivity would be similarly affected.

Profiles of conductivity as a function of elevation are posted on Figure 3-11 for each of the six locations, two near MW-11 and four near MW-10. All profiles begin at 1 foot below ground surface and continue to the depth of refusal. Profiles at the high-tide line (CND10-4 and CND11-2) begin with conductivities near 0.1 mS/cm, indicating the presence of nearly pure groundwater with a negligible seawater component. At CND10-4, conductivities increase erratically with depth, reaching values as high as 5.6 mS/cm, although the deepest readings near –5 feet msl are near 3 mS/cm. At CND11-2, conductivities increase more smoothly with depth, reaching 6.7 mS/cm at –2.5 feet msl (the depth of refusal). Profiles from locations near msl (CND10-3 and CND11-1, which penetrate deeper parts of the aquifer because they start from a lower elevation, show a freshening trend with depth near MW-10 and an increasing proportion of seawater near MW-11. At CND10-3, conductivity reaches 9.2 mS/cm at –4 feet msl, but declines to only 2.4 mS/cm at –6.7 feet msl. Similarly, conductivity at CND11-1 climbs steadily with depth, reaching values near 9 mS/cm at –4 to –4.9 feet msl. Lack of deeper data leaves open the possibility that conductivities at greater depths might decline here as well. Offshore measurements in 1.5 feet of water were possible only near MW-10; the bottom was too rocky and steep near MW-11. These short profiles encountered conductivities near 5 mS/cm, suggesting a substantial freshwater component beneath parts of the beach that would be exposed or just barely submerged during only the very lowest tides.

Conceptually, the profiles are consistent with a broad discharge and mixing zone for groundwater entering Dutch Harbor, extending across the beach from the highest high-water mark to the lowest low-water mark. Tidal flooding causes periodic flow reversal, permitting groundwater drainage as the beach is uncovered and driving seawater a short distance into the aquifer as the beach is flooded. The resulting mixing zone is dominated by freshwater at the high-tide line, becoming progressively saltier with distance into the bay. The two measurements at the low-tide line (CND10-1 and CND10-2) appear to contain a substantial fraction of freshwater (0.45 to 0.67 if saturation with pure seawater is presumed to give conductivities of 9 to 15 mS/cm). These two sites are 50 feet down the beach from the high-tide line. It seems probable that the fraction of seawater rapidly will approach unity a short distance beyond the low-tide line because that portion of the beach is never exposed subaerially, and thus would never be affected by groundwater seepage flowing near the surface of the beach. Groundwater seepage at low tide followed by seawater inundation at high tide is probably responsible for the erratic salinity trends seen in CND10-3 and CND10-4, near MW-10. Near MW-11, the beach is somewhat steeper, which may reduce the effectiveness of tidal flooding and produce less pronounced conductivity variations with depth. When the intertidal zone is exposed, the discharge zone here resembles a classical seepage face.

The conceptual model of the freshwater/seawater interface is depicted in cross sections in Figure 3-12. The steady-state configuration, depicted in panel (a), represents the long-term average geometry of the interface, neglecting mixing effects at the interface and in the near-surface intertidal zone. The angle of the interface is closely approximated by the Ghyben-Herzberg relation (Equation 0-3), but its location is shifted seaward because of the finite width of the groundwater discharge zone. Rather than occurring at a point, discharge occurs across the exposed intertidal zone because transmissivity of the aquifer cross section that conducts groundwater flow must remain approximately constant. At high tide, depicted in panel (b), the intertidal zone is inundated completely by seawater, blocking most of the discharging groundwater, focusing discharge (if any) at the high-tide line. Seawater begins to infiltrate the previously exposed intertidal zone. At low tide, depicted in panel (c), the intertidal zone is exposed completely, permitting drainage of seawater and its replacement by discharging groundwater. Deeper in the aquifer, the position of the freshwater/seawater interface moves only slightly, as dictated by probable hydraulic conductivities and head gradients. The maximum horizontal gradient is probably similar to the slope of the beach, i.e., 0.1, and the maximum hydraulic conductivity may be 28 ft/day (Table 3-6). Assuming a porosity of 0.3, the groundwater particle velocity is 9.3 ft/day. Tidal cycles at the site are characterized by a single significant low tide each day (e.g., Figures 1-5 and 1-6 in Appendix A) with an 8-hour ebb and 8-hour flood, so the interface may move seaward and back again by 3.1 feet for each cycle.



LEGEND

▽	LEVEL OF GROUNDWATER OR SEAWATER
➔	GROUNDWATER FLOW
MHHW	MEAN HIGHER HIGH WATER
MSL	MEAN SEA LEVEL
MLLW	MEAN LOWER LOW WATER

0 10 20 40

SCALE IN FEET

CONCEPTUAL CROSS-SECTION FRESHWATER / SEAWATER INTERFACE

AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen	FILE NAME: Ditch Section.dwg	DATE: Feb. 09, 05
	LAYOUT TAB: Ditch Section	FIGURE NO.: 3-12
JE DRAWN BY: DBW	FILE LOCATION: Amaknak \ 05M30225 \ GW Model \ Final Rpt	

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3.6 GROUNDWATER ANALYSES FROM THE DISCHARGE ZONE

Wellpoints installed in two locations in the groundwater discharge zone along the shoreline were sampled: DZMW10 near MW10, and DZMW11 near MW11 (see Figure 3-11 for locations). DZMW11 was purged at 600 mL/min for approximately 20 minutes until the parameters (except turbidity) were stabilized per standard protocol (EPA 1996). Field parameters were measured using a Horiba U-22 multi-function analyzer. Suspended material was eliminated by immediate filtration through a 0.4 micron filter before transfer to an acidified sample bottle. In DZMW11, water in the purge bucket exhibited a coagulated brown sheen, but the sample collected for analysis had no sheen.

Field parameters are presented in Table 3-7, and analytical results for polynuclear aromatic hydrocarbons (PAHs), diesel-range organics (DRO), residual-range organics (RRO), iron, manganese, and volatile organic compounds (VOCs) are presented in Table 3-8. There are no exceedances of Alaska Department of Environmental Conservation Table C groundwater cleanup levels (18 Alaska Administrative Code 75.345) for analytes with specified cleanup levels; the most significant detection is for dibenzo(a,h)anthracene at slightly over half the cleanup level of 0.1 micrograms per liter. DRO at both locations was near the detection limit, and RRO was non-detect. Iron and manganese were barely detectable in samples from DZMW10, and were absent from DZMW11. Only six VOCs, present at very low levels, were found in samples from DZMW10, and none in DZMW11. It is possible that the similar PAH concentrations seen in water samples from both locations reflect seawater rather than groundwater influences; seawater concentrations have not been measured, but detectable values seem likely given the heavy maritime industrial activity in Dutch Harbor and Iliuliuk Bay.

Field parameters (Table 3-7) provide an indication of the extent of mixing with seawater and clues to upgradient geochemical conditions. Conductivity and its related parameters (salinity and total dissolved solids) are indicators of the extent of mixing with seawater. Salinity, which provides the most direct basis of comparison, is near 1 percent at both locations. The salinity of seawater is approximately 3.5 percent and the salinity of groundwater is near zero,

Table 3-7
Field Parameters from Sampling Locations in the Groundwater Discharge Zone

	Location:	DZM10	DZM11
	Date:	10/21/03	10/21/03
Parameter	Units	Result	Result
Depth to water	ft bgs	2.81	1.33
Total Depth	ft bgs	3.42	3.30
Turbidity	NTU	13	169
DO	mg/L	7.6	10.3
Temperature	°C	7.4	7.2
Salinity	%	1.3	0.9
Total Dissolved Solids	g/L	14	10
Oxidation-Reduction Potential	mV	353	335
pH	$-\log_{10}$ molarity	6.13	6.8
Conductivity	mS/cm	21.5	16.6

Notes:
mV = millivolts
NTU = nephelometric turbidity units
For additional definitions see Acronyms and Abbreviations list.

so the observed values indicate that sampled waters contain a seawater fraction of approximately 0.3. Dissolved oxygen (DO) and oxidation-reduction potential both indicate aerobic, oxidizing conditions. Turbidity is the only major difference between the two sites, with water at DZMW10 running nearly clear (13 nephelometric turbidity units [NTU]) whereas DZMW11 water was a cloudy orange suspension (almost certainly iron oxyhydroxides) that slowly flocculated in the purge-water bucket.

During conductivity probing near MW-11, brown globules of product and a slight sheen were noted emanating from a used probe hole at the water's edge. Similar contamination was noted during purging of DZMW11. Although these product traces could be the remnants of a surface water spill, the suspended iron oxyhydroxides are evidence of upgradient reducing conditions, probably engendered by the Bunker C contamination near MW-11 and farther upgradient. Iron, ubiquitous in aquifer materials and readily soluble under reducing conditions, would dissolve wherever microbes degrading the Bunker C have consumed the

Table 3-8
Chemical Analyses of Groundwater Samples from the Discharge Zone

		Location	DZMW10		DZMW10 DUP		DZMW11		DZMW11	
		Sample ID	AM-A200001		AM-A200002		AM-A200101		AM-A200102	
		Laboratory	NCAB		NCAB		NCAB		NCAB	
		Lab Sample ID	B3J0710-01		B3J0710-02		B3J0710-03		B3J0710-04	
		Collection Date	10/21/03		10/21/03		10/21/03		10/21/03	
		Matrix	WG		WG		WG		WG	
Analyte	Cleanup Level[1]	Units	Result	DL	Result	DL	Result	DL	Result	DL
PAHs (Method 8270SIM)										
1-Methylnaphthalene		µg/L	ND	[0.1]	ND	[0.1]	ND	[0.1]	-	-
2-Methylnaphthalene		µg/L	ND	[0.1]	ND	[0.1]	ND	[0.1]	-	-
Acenaphthene		µg/L	0.489	[0.1]	0.647	[0.1]	ND	[0.1]	-	-
Acenaphthylene	2200	µg/L	ND	[0.1]	ND	[0.1]	ND	[0.1]	-	-
Anthracene	11000	µg/L	ND	[0.1]	0.121	[0.1]	ND	[0.1]	-	-
Benzo(a)anthracene	1	µg/L	0.0912	[0.01]	0.127	[0.01]	0.0664	[0.01]	-	-
Benzo(a)pyrene	0.2	µg/L	0.0714	[0.01]	0.0835	[0.01]	0.0625	[0.01]	-	-
Benzo(b)fluoranthene	1	µg/L	0.0566	[0.01]	0.0713	[0.01]	0.0365	[0.01]	-	-
Benzo(g,h,i)perylene	1100	µg/L	ND	[0.1]	ND	[0.1]	ND	[0.1]	-	-
Benzo(k)fluoranthene	10	µg/L	ND	[0.01]	ND	[0.01]	ND	[0.01]	-	-
Chrysene	100	µg/L	0.0545	[0.01]	0.0888	[0.01]	0.0357	[0.01]	-	-
Dibenzo(a,h)anthracene	0.1	µg/L	0.0509	[0.01]	0.064	[0.01]	0.0508	[0.01]	-	-
Fluoranthene	1460	µg/L	0.375	[0.1]	0.727	[0.1]	0.111	[0.1]	-	-
Fluorene	1460	µg/L	0.21	[0.1]	0.295	[0.1]	ND	[0.1]	-	-
Indeno(1,2,3-cd)pyrene	1	µg/L	0.0512	[0.01]	0.0723	[0.01]	0.0513	[0.01]	-	-
Naphthalene	1460	µg/L	ND	[0.1]	ND	[0.1]	ND	[0.1]	-	-
Phenanthrene	11000	µg/L	0.128	[0.1]	0.18	[0.1]	ND	[0.1]	-	-
Pyrene	1100	µg/L	0.203	[0.1]	0.387	[0.1]	ND	[0.1]	-	-
HCs (Method AK102)										
Diesel Range Organics	1500	mg/L	0.116	[0.1]	0.112	[0.1]	0.19	[0.1]	-	-
Residual Range Organics	1100	mg/L	ND	[0.75]	ND	[0.75]	ND	[0.75]	-	-
Metals (Method SW6010B)										
Iron		µg/L	188	[150]	190	[150]	ND	[150]	-	-
Manganese		µg/L	23.6	[10]	24	[10]	ND	[10]	-	-

Table 3-8
Chemical Analyses of Groundwater Samples from the Discharge Zone
(continued)

		Location	DZMW10		DZMW10 DUP		DZMW11		DZMW11	
		Sample ID	AM-A200001		AM-A200002		AM-A200101		AM-A200102	
		Laboratory	NCAB		NCAB		NCAB		NCAB	
		Lab Sample ID	B3J0710-01		B3J0710-02		B3J0710-03		B3J0710-04	
		Collection Date	10/21/03		10/21/03		10/21/03		10/21/03	
		Matrix	WG		WG		WG		WG	
Analyte	Cleanup Level^1	Units	Result	DL	Result	DL	Result	DL	Result	DL
VOCs (Method SW8021B)										
Benzene	5	µg/L	-	-	-	-	ND	[0.5]	-	-
Ethylbenzene	700	µg/L	-	-	-	-	ND	[0.5]	-	-
Toluene	1000	µg/L	-	-	-	-	ND	[0.5]	-	-
Xylenes	10000	µg/L	-	-	-	-	ND	[1]	-	-
VOCs (Method SW8260B)										
1,1,1,2-Tetrachloroethane		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
1,1,1-Trichloroethane		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
1,1,2,2-Tetrachloroethane		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
1,1,2-Trichloro-1,2,2-trifluoroethane		µg/L	ND	[2]	ND	[2]	-	-	ND	[2]
1,1,2-Trichloroethane		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
1,1-Dichloroethane		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
1,1-Dichloroethene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
1,1-Dichloropropene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
1,2,3-Trichlorobenzene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
1,2,3-Trichloropropane		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
1,2,4-Trichlorobenzene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
1,2,4-Trimethylbenzene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
1,2-Dibromo-3-chloropropane		µg/L	ND	[5]	ND	[5]	-	-	ND	[5]
1,2-Dibromoethane		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
1,2-Dichlorobenzene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
1,2-Dichloroethane		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
1,2-Dichloropropane		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
1,3,5-Trimethylbenzene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
1,3-Dichlorobenzene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]

Table 3-8
Chemical Analyses of Groundwater Samples from the Discharge Zone
(continued)

		Location	DZMW10		DZMW10 DUP		DZMW11		DZMW11	
		Sample ID	AM-A200001		AM-A200002		AM-A200101		AM-A200102	
		Laboratory	NCAB		NCAB		NCAB		NCAB	
		Lab Sample ID	B3J0710-01		B3J0710-02		B3J0710-03		B3J0710-04	
		Collection Date	10/21/03		10/21/03		10/21/03		10/21/03	
		Matrix	WG		WG		WG		WG	
Analyte	Cleanup Level[1]	Units	Result	DL	Result	DL	Result	DL	Result	DL
1,3-Dichloropropane		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
1,4-Dichlorobenzene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
1-Chlorohexane		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
2,2,4-Trimethylpentane (Isooctane)		µg/L	31.3	TI[0] N	49.4	TI[0] N	-	-	-	-
2,2-Dichloropropane		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
2,3,3-Trimethylpentane		µg/L	23.9	TI[0] N	30.6	TI[0] N	-	-	-	-
2,3,4-Trimethylpentane		µg/L	15.3	TI[0] N	20.9	TI[0] N	-	-	-	-
2-Butanone	22000	µg/L	ND	[20]	ND	[20]	-	-	ND	[20]
2-Chlorotoluene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
2-Hexanone		µg/L	ND	[5]	ND	[5]	-	-	ND	[5]
3-Ethyl-2,2-dimethylpentane		µg/L	-	-	2.22	TI[0] N	-	-	-	-
4-Chlorotoluene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
4-Isopropyltoluene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
4-Methyl-2-pentanone		µg/L	ND	[20]	ND	[20]	-	-	ND	[20]
Acetone	3650	µg/L	ND	[20]	ND	[20]	-	-	ND	[20]
Benzene	5	µg/L	ND	[0.5]	ND	[0.5]	-	-	ND	[0.5]
Bromobenzene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Bromochloromethane		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Bromodichloromethane	100	µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Bromoform	100	µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Bromomethane		µg/L	ND	[2]	ND	[2]	-	-	ND	[2]
Carbon disulfide	3650	µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Carbon tetrachloride	5	µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Chlorobenzene	100	µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Chloroethane		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]

Table 3-8
Chemical Analyses of Groundwater Samples from the Discharge Zone
(continued)

Location			DZMW10		DZMW10 DUP		DZMW11		DZMW11	
Sample ID			AM-A200001		AM-A200002		AM-A200101		AM-A200102	
Laboratory			NCAB		NCAB		NCAB		NCAB	
Lab Sample ID			B3J0710-01		B3J0710-02		B3J0710-03		B3J0710-04	
Collection Date			10/21/03		10/21/03		10/21/03		10/21/03	
Matrix			WG		WG		WG		WG	
Analyte	**Cleanup Level[1]**	**Units**	**Result**	**DL**	**Result**	**DL**	**Result**	**DL**	**Result**	**DL**
Chloroform	100	µg/L	ND	[0.5]	ND	[0.5]	-	-	ND	[0.5]
Chloromethane		µg/L	ND	[5]	ND	[5]	-	-	ND	[5]
Dibromochloromethane		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Dibromomethane		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Dichlorodifluoromethane		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Ethylbenzene	700	µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Hexachlorobutadiene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Isopropylbenzene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Methyl iodide		µg/L	ND	[5]	ND	[5]	-	-	ND	[5]
Methylene chloride	5	µg/L	ND	[2]	ND	[2]	-	-	ND	[2]
Naphthalene	1460	µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Styrene	100	µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Tetrachloroethene (PCE)	5	µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Toluene	1000	µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Trichloroethene (TCE)	5	µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Trichlorofluoromethane		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Unknown Amine		µg/L	-	-	2.64	TI[0] N	-	-	-	-
Unknown Branched alkane #1		µg/L	3.47	TI[0] N	5.6	TI[0] N	-	-	-	-
Vinyl chloride	2	µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
Xylene, Isomers m & p		µg/L	ND	[2]	ND	[2]	-	-	ND	[2]
cis-1,2-Dichloroethene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
cis-1,3-Dichloropropene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
n-Butylbenzene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
n-Propylbenzene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
o-Xylene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]

Table 3-8
Chemical Analyses of Groundwater Samples from the Discharge Zone
(continued)

Location			DZMW10		DZMW10 DUP		DZMW11		DZMW11	
Sample ID			AM-A200001		AM-A200002		AM-A200101		AM-A200102	
Laboratory			NCAB		NCAB		NCAB		NCAB	
Lab Sample ID			B3J0710-01		B3J0710-02		B3J0710-03		B3J0710-04	
Collection Date			10/21/03		10/21/03		10/21/03		10/21/03	
Matrix			WG		WG		WG		WG	
Analyte	Cleanup Level[1]	Units	Result	DL	Result	DL	Result	DL	Result	DL
sec-Butylbenzene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
tert-Butylbenzene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
trans-1,2-Dichloroethene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]
trans-1,3-Dichloropropene		µg/L	ND	[1]	ND	[1]	-	-	ND	[1]

Notes:

[1] Groundwater cleanup level

DL = detection limit
mg/L = milligrams per liter
ND = nondetect
µg/L = micrograms per liter
- = analyte not analyzed for

available DO and turned to ferric iron as an electron acceptor. The resulting dissolved ferrous iron is stable until oxygen is encountered, probably near the groundwater discharge zone along the shoreline. Tidal water-level fluctuations in the aquifer and mixing in the intertidal zone likely equilibrate groundwater with air, returning DO levels to 8 to 10 milligrams per liter (mg/L). If the zone of oxygenation were farther upgradient, the iron oxyhydroxides would probably have plated out on aquifer materials and not appeared in the discharge-zone water.

3.7 PHYSICAL PROPERTIES OF THE BUNKER C FUEL OIL CONTAMINANT

In October 2003, free-product samples of hydrocarbon contamination were collected from three locations for determinations of viscosity and density. Two additional samples were characterized in 1996 (USAED 1998). All five sample locations are indicated in Figure 3-13, and viscosities and densities are listed in Table 3-9.

Table 3-9
Physical Properties of Free Product at the Pre-WWII Tank Farm

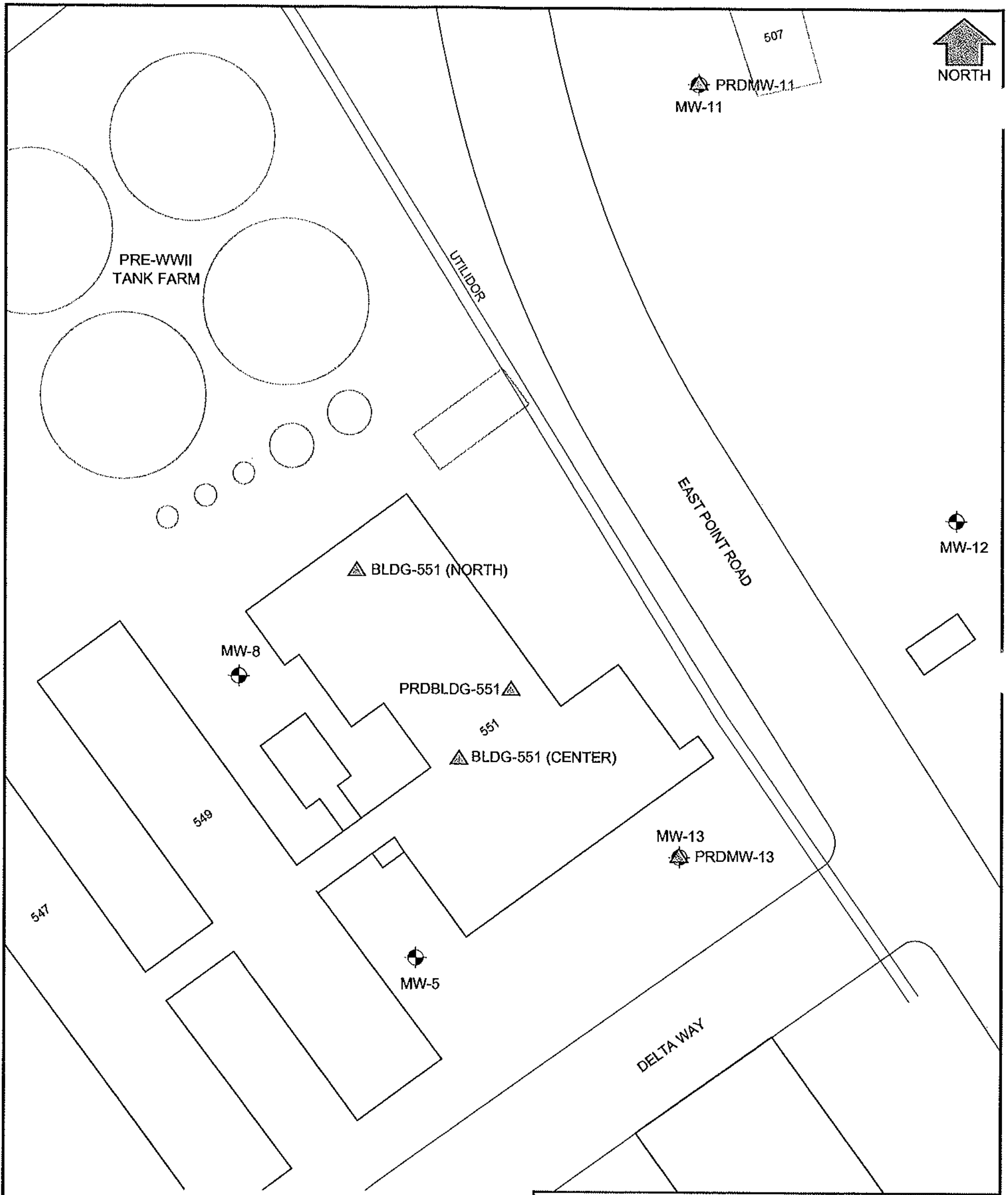
		Sample ID:	PRDMW-11	PRDMW-13	PRDBLDG-551	BLDG-551 (Center)	BLDG-551 (North)
		Date Sampled	10/20/03	10/19/03	10/19/03	8/26/96	8/26/96
		Laboratory ID:	B3K0218-1	B3K0218-2	B3K0218-3		
		Date Analyzed:	10/20/03	10/19/03	10/19/03		
Test	**Method**	**Units**					
Viscosity at 21°C (70°F)	ASTM D445	cSt	NA[1]	298.3	NA[3]		
Viscosity at 50°C (122°F)	ASTM D445		1085.7	56.52	2137.7		
Viscosity (Temperature not specified; 20°C assumed)	ASTM D445					3050	3330
Density at 16°C (60°F)	ASTM D1298	g/mL	NA[2]	0.9483	1.0044		
	ASTM D287					0.9930	1.0200

Notes:

[1] Sample was too thick at room temperature to perform viscosity determination
[2] Insufficient sample quantity to perform density determination
[3] Sample contained a high proportion of solids, which plugged the viscometer

Results from USAED 1998

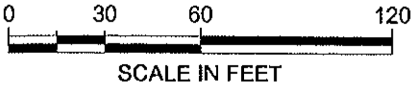
cSt = centi-Stokes



LEGEND

◆ MONITORING WELL

▲ FREE-PRODUCT SAMPLE



SCALE IN FEET

FREE-PRODUCT SAMPLE LOCATIONS

AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen	FILE NAME: Product Sample.dwg	DATE: Feb. 09, 05
DRAWN BY: DBW	LAYOUT TAB: Product Sample	FIGURE NO.: 3-13
	FILE LOCATION: Amaknak \ 05M30225 \ GW Model \ Final Rpt	

G:\Autocad\AMAKNAK\05M30225\GW Model\FINAL RPT\Product Sample.dwg Feb 10,2005 -avakarcs

Both 1996 samples (BLDG-551 (Center) and BLDG-551 (North)) and one current sample (PRDBLDG-551) were obtained from surface seeps beneath Building 551, the historical Navy mess hall from WWII. The building is constructed with a raised 1-foot thick concrete floor, with walk-in access to the entire sub-floor area. This area is unfinished, with a dirt floor, and partially obstructed by piping runs and numerous footings. The area is well ventilated by numerous openings in the outer foundation walls. Large but shallow pools of Bunker C encumber access to some parts of the sub-floor area.

Viscosities measured in the 1996 samples were slightly over 3000 cSt (presumably at 20°C, since temperature was not stated), whereas the current sample provided a viscosity near 2100 cSt but only at an elevated temperature of 50°C. Its viscosity could not be measured at room temperature because entrained solids plugged the viscometer. For all three samples, densities were within the range 0.9930 to 1.0200 g/mL. Much of the seepage beneath Building 551 is weathered, as evidenced by a thick covering of dust and lack of imprint when stepped on, but some appears fresh and is very sticky, providing evidence of continued mobility. Seepage was first noted in 1994, and the investigation in 1996 described "a black, highly viscous substance" at least an inch thick (USAED 1998). In some places, water was observed below the product (USAED 1998), suggesting that the product density at that time was slightly less than that of water. Although the current sample was taken from a fresh-looking seep, it apparently was exposed long enough to have entrained sufficient dust to interfere with the viscosity measurement. Soil dust has an expected density near 2.6 g/ml, so dust contamination also would lead to an elevated density. Weathering also will contribute to higher viscosity and density as shorter-chain hydrocarbons are preferentially degraded or volatilized.

As part of the current study, product samples were obtained from MW-11 (PRDMW-11) and MW-13 (PRDMW-13). MW-11 is the only well with a measurable thickness of what appears to be pure Bunker C, and MW-13 is the only other well with a measurable thickness of product, but with an obviously lower viscosity. PRDMW-11 was too viscous for the instrumentation for viscosity determination at room temperature (21°C), but yielded a viscosity near 1100 cSt at 50°C. The laboratory could not determine density from the small amount of sample provided. PRDMW-13 had much lower viscosities (near 300 cSt at 21°C and 57 cSt at 50°C) and density (0.9483 g/mL at 60°C), consistent with chemical evidence of a significant diesel component (USAED 2001). Diesel fuel typically ranges in density from 0.825 to 0.904 g/mL (Nelson 1958), implying a diesel fraction in this sample of 0.34 to 0.63 (assuming that the other component is Bunker C with a density of 1 g/mL).

In summary, two sets of physical properties must be considered in order to evaluate product mobility, one for pure Bunker C representing contamination present beneath Building 551 and along flow paths from the tank farm past MW-11, and one for a mixture of Bunker C and diesel representing contamination along flow paths near MW-13 to Dutch Harbor. Pure Bunker C probably is best represented by BLDG-551 (Center) because its low density and viscosity suggest that it is minimally contaminated with dust, and the sample from MW-13 is the only sample of the mixture. Estimated in-situ physical properties, extrapolated to ambient subsurface temperatures of 5 to 8°C (based on groundwater temperatures, USAED 2003a, b) are listed in Table 3-10.

Table 3-10
Estimated Physical Properties of Bunker C and Bunker C/Diesel at Ambient Temperature

Property	T (°C)	Bunker C	Bunker C/Diesel	Units
Viscosity	50	**546**	56.52	cSt
	21	**2880**	298.3	
	20	3050	**316**	
	8	**7643**	**629**	
	5	**7211**	**747**	
Density	16	0.993	0.948	g/mL
	8	**1.000**	**0.955**	
	5	**1.002**	**0.957**	

Notes:

Bold values are extrapolated from observed values.

Viscosity is assumed to be geometrically related to temperature, with a coefficient of -0.025 log cSt/°C calculated from the observed values for the Bunker C/Diesel mixture

Density is assumed to linearly relate to temperature, with a coefficient of -0.000828 /°C obtained from literature from Chevron for diesel.

The temperature dependence of viscosity (v) was estimated by assuming a geometric relationship:

$$\log v_T = \log v_0 + \alpha_v (T - T_0) \tag{0-4}$$

where v_T is the viscosity at some temperature T, v_0 is the viscosity at some known temperature T_0, and α_v is the temperature coefficient of viscosity, found to be –0.025 log cSt/°C from the MW-13 data at 21 and 50°C. Extrapolated viscosities are lower limits; viscosities of standards at various temperatures (ANSI 1988) show slightly greater increases with declining temperature than predicted by Equation 0-4. More realistic values at 5°C might be 9100 cSt for pure Bunker C and 940 cSt for the Bunker C/diesel mixture.

The temperature dependence of density for both types of product was assumed to resemble that of diesel. The temperature dependence of density (ρ) is given by:

$$\rho_T = \rho_0 + \alpha_\rho (T - T_0) \tag{0-5}$$

where ρ_T is the density at some temperature (T), ρ_0 is the density at some known temperature T_0, and α_ρ is the temperature coefficient of density, i.e., –0.000828 /°C for diesel (Chevron 2003). After applying this correction, the density of Bunker C at 5°C is slightly higher than that of water, suggesting that admixed dust might affect the selected measured density, even though the sample appeared to be fresh. A realistic density for Bunker C at 5°C is probably 0.98 to 1.00 g/mL. Water level calculations for MW-11 assume a density of 0.997 g/mL.

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4.0 GROUNDWATER FLOW MODEL

Development of a groundwater flow model for the Pre-WWII Tank Farm and surrounding area requires a detailed assessment of hydrostratigraphy, water levels, and hydraulic boundaries. Integration of these data sets into a quantitative model provides insights into plausible groundwater flow patterns and highlights remaining areas of uncertainty. Although generalized flow patterns may be inferred from manually contoured water table maps (e.g., Figures 3-5 to 3-8), they may be inconsistent with known or estimated hydraulic conductivities, aquifer thickness, recharge rates, and fluxes from upgradient. A quantitative groundwater flow model reflects the synergy among these parameters, explicitly illustrating the tradeoffs and side effects that accompany assumptions about boundary conditions and hydrostratigraphy, ultimately leading to a refined conceptual model of the site.

The 2005 Tank Farm groundwater flow model (the TF05 model) presented here was developed using GMS (EMS-i 2004) as a graphical user interface for MODFLOW-2000 (Harbaugh et al. 2000). MODFLOW-2000 and its predecessors are well established and thoroughly tested tools for simulating groundwater flow. As with previous versions of MODFLOW, MODFLOW-2000 uses the finite-difference approach to solve the equations for three-dimensional groundwater flow. MODFLOW-2000 offers enhancements over previous versions of MODFLOW, including built-in parameter estimation and explicit definition of vertical hydraulic conductivity (K_v) for each cell instead of the inter-cell leakage, among others. The improved specified-head boundary facilitated realistic simulation of tidal influences.

4.1 SITE COORDINATE SYSTEM

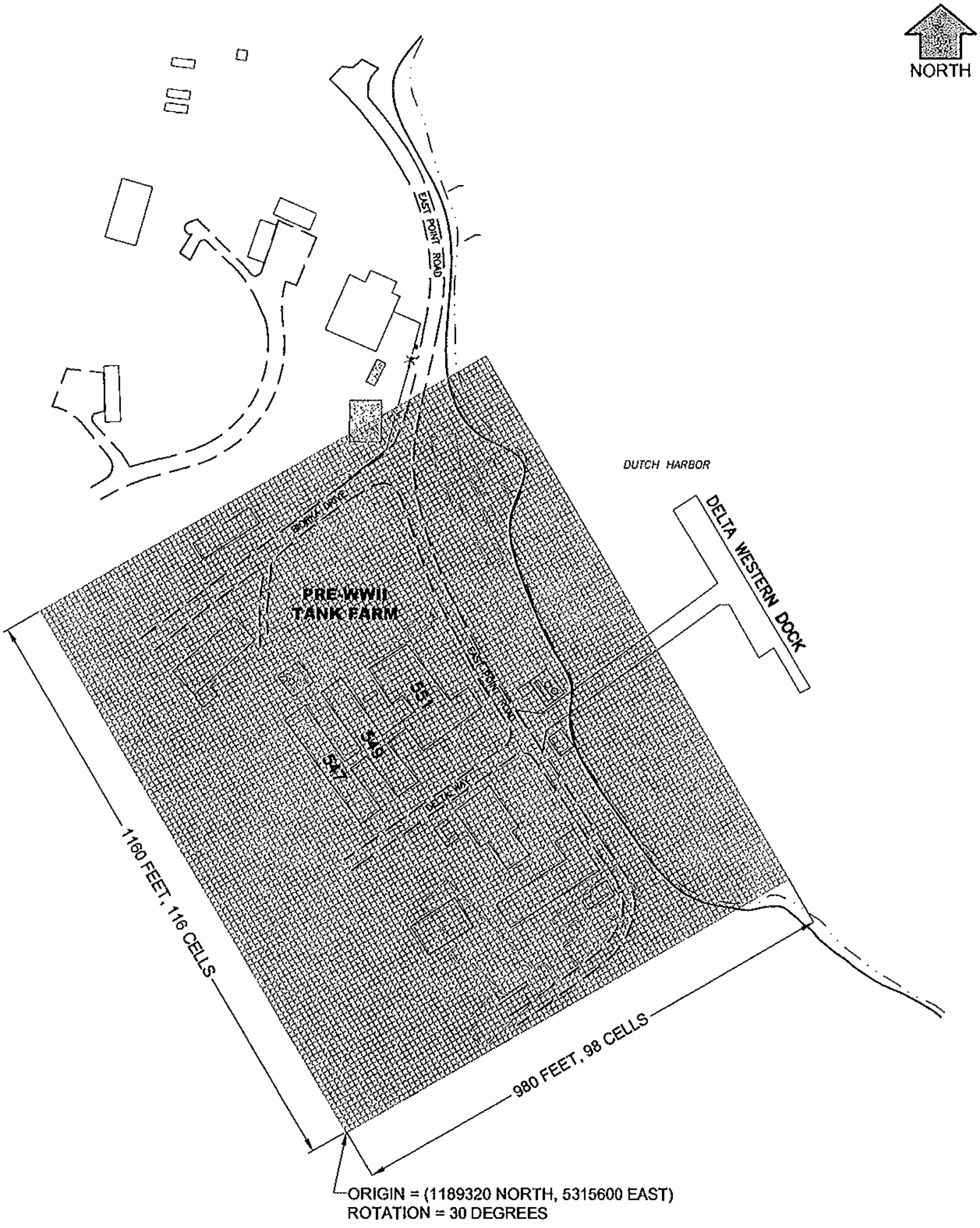
Numerous coordinate systems have been used at the Pre-WWII Tank Farm. Design drawings for the WWII-era utilidor use a local coordinate system in which northings and eastings are less than 15000 feet, whereas the 1996 Remedial Investigation (USAED 1998) used a different local system with coordinates of less than 1000 feet, and a 2002 re-survey of monitoring wells by Foster-Wheeler (USAED 2003c) used state-plane coordinates with values over 1,000,000 feet. Finally, design drawings for a proposed drainage system under consideration by the City of Unalaska use a local system measured in meters.

To obtain reliable elevations for all monitoring wells, and to eliminate discrepancies arising from transforming coordinates from one system to another, a new survey was performed in August 2004 by a professional land surveyor (St. Denny Surveying, Kodiak, Alaska). All onsite monitoring wells, key building corners, and roads were surveyed in the NAD83 Alaska State Plane coordinate system. Ground surface and TOC elevations were measured relative to mean sea level using leveling data tied to the benchmark in the nearby City of Unalaska referenced by NOAA for tidal observations. All coordinates in this report use the NAD83 system for eastings and northings, with elevations reported relative to the mean sea level datum.

4.2 MODEL DOMAIN AND GRID

The model domain, portrayed in Figure 4-1, extends from northwest of the tank farm, where topography rises toward Standard Oil Hill, across the tank farm and other level terrain collectively known as Ptarmigan Flats, to the break in slope to Rocky Point on the southeast. The model is bounded by Dutch Harbor on the northeast. These features form natural hydrologic boundaries. The southwest boundary of the model cuts across Ptarmigan Flats because no subsurface information was available farther to the west. The domain encompasses all known past and present monitoring wells hydrologically related to the site. MW-1 is not included because it is too far to the north.

The model coordinate system has its origin at NAD83 state plane coordinates of 5315600.0 east and 1189320.0 north, and is rotated 30 degrees counter-clockwise. The grid is 980 feet in the x direction by 1160 feet in the y direction, and is subdivided into 10 feet by 10 feet cells, resulting in 98 columns and 116 rows. The top and bottom faces of the grid are flat, at 9.0 feet msl and –16.0 feet msl, respectively. There are 15 layers, each 1.67 feet thick, for a total of 170,520 cells, of which 82,144 are active initially. With this uniform grid, the bottom



NOTES:

TOP OF GRID: 9 FEET MEAN SEA LEVEL (MSL)

BOTTOM OF GRID: -16 FEET MSL

15 LAYERS, EACH 1.67 FEET THICK

TOTAL CELLS = 98x116x15=170,520

0 150 300 600

SCALE IN FEET

DOMAIN AND DISCRETIZATION OF THE 2004 TANK FARM MODEL

AMAKNAK ISLAND, ALASKA

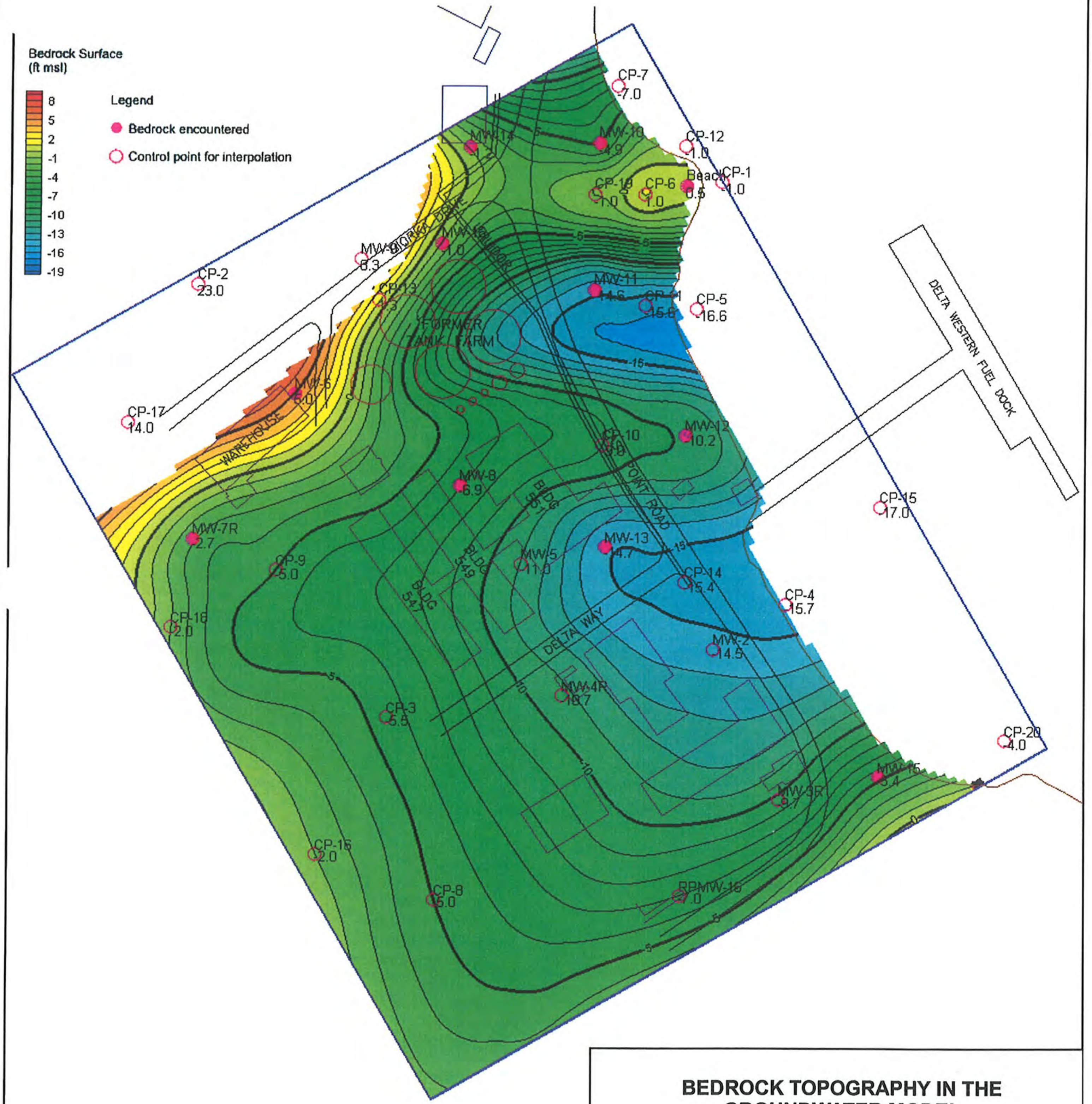
PROJECT MANAGER: J. Cohen	FILE NAME: Model Grid.dwg	DATE: Feb. 09, 05
JE DRAWN BY: DBW	LAYOUT TAB: Model Grid	FIGURE NO. : 4-1
	FILE LOCATION: Amaknak \ 05M30225 \ GW Model\Fianl Rpt	

G:\Autocad\AMAKNAK\05M302 odel\FINAL RPT\ModelGrid.dwg Feb 09,2005 -avakarcs) of the aquifer is represented by selectively inactivating cells whose center lies below the aquifer/bedrock interface. An alternate model configuration with variable-thickness layers draped over the bedrock topography was tested. In this model, there was no significant difference in the calculated water table, but the shoreline boundary could not accommodate head changes needed to simulate tidal stages. The selected cell size produces a compact model that runs quickly and has manageable file sizes, yet is capable of representing potential flow barriers such as the utilidor. The vertical range of the model is sufficient to accommodate the lowest bedrock elevations and the highest groundwater elevations.

4.3 BEDROCK TOPOGRAPHY

The Unalaska Formation constitutes bedrock at the site, and has been studied in detail in exposures several miles to the west (Lankford and Hill 1979, Drewes et al. 1961). It consists predominantly of volcanic rocks (breccia, flows, and tuff) with some intercalated sedimentary rocks (mainly turbidites and debris flows). Bedrock has been noted in some boring logs for tank farm monitoring wells, in which it is described as dense gray-green volcanic rock. Nearby outcrops near the Powerhouse (Building 409) form steep slopes and cliffs suggestive of one of the volcanic members of the Unalaska Formation. The bedrock is assumed to be impermeable compared to the overlying sediments.

Bedrock topography was contoured from bedrock elevations noted in 11 boreholes drilled in preparation for installation of monitoring wells, and an outcrop on the beach noted during site reconnaissance in October 2003. Only those boring locations surveyed in 2004 were included, ensuring an internally consistent set of elevations all relative to the same datum (msl). These were augmented with 20 control points manually placed to manipulate the interpolation process and produce a plausible surface. The bedrock surface is illustrated in Figure 4-2. Inverse-distance weighting in GMS gave the best results with a minimal number of control points. The bedrock topography, interpolated to a two-dimensional grid matching the x-y discretization of the model grid, was used to inactivate model cells if their centers lay below the bedrock surface.



BEDROCK TOPOGRAPHY IN THE GROUNDWATER MODEL

AMAKNAK ISLAND, ALASKA

PROJ. MGR: J. Cohen	FILE NAME: Fig4-02_Bedrock.cdr	FIGURE NO: 4-2
	LAYOUT TAB: Bedrock	DATE: Feb. 09, 05
JE DRAWN BY: XXX	FILE LOCATION: G:\AutoCad\Amaknak\05M30225\GW Model\Final Rpt	

4.4 BOUNDARY CONDITIONS

Conceptually, the TF05 model is configured with five types of boundaries:

- The freshwater/seawater interface where all groundwater discharges to Dutch Harbor
- Constant-flux boundaries around the remaining borders where groundwater flows into the model from upgradient
- Areal recharge representing infiltration of precipitation
- Dry wells that provide conduits to the aquifer for surface drainage
- A no-flow boundary at the bottom of the model representing the interface between the aquifer and comparatively impermeable bedrock.

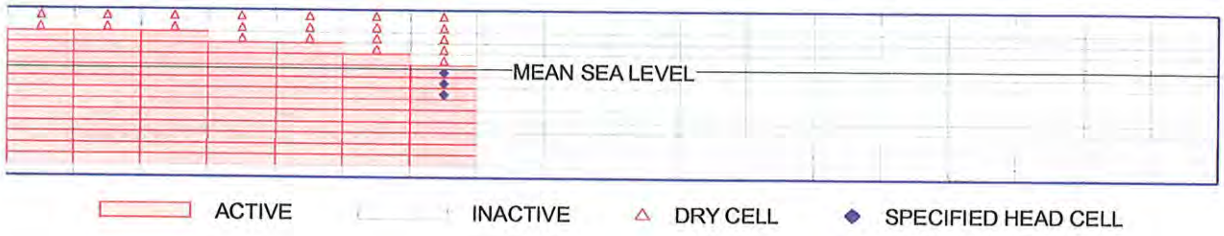
The first four are discussed in detail in the following subsections; the last is self-explanatory.

4.4.1 Freshwater/Seawater Interface

The groundwater flow model requires a representation of the freshwater/seawater interface that can be used both for steady-state simulations representing long-term average conditions and for transient simulations evaluating aquifer response to tidal forcing. From the conceptual model of the freshwater/seawater interface developed in Section 3.5 and portrayed in Figure 3-12 vertical movement of groundwater toward the intertidal discharge zone occurs primarily beneath the intertidal zone. At steady state, with seawater at msl, discharge likely occurs across the exposed intertidal zone and extends slightly seaward of msl. At high tide and low tide, flow lines are alternately compressed toward the upper edge of the intertidal zone and then spread over the entire intertidal zone. It seems plausible that most of this reorganization of flow lines is confined to the upper few feet of the aquifer beneath the intertidal zone, leading to the idea that this interface could be incorporated in the model as a vertical boundary with flow permitted only in layers intersecting the intertidal zone.

A cross section of the TF05 model through the freshwater/seawater boundary is presented in Figure 4-3. Cells without shading or symbols are inactive, representing bedrock below the shaded cells or Dutch Harbor to the right of the shaded cells. Shaded cells are active and saturated, and unshaded cells with triangles were initially active but became dry and inactive during a model run when the water table fell below their bottoms. Shaded cells with diamonds are the specified-head cells serving as the discharge zone to Dutch Harbor. These cells have their heads fixed at a specified value (i.e., 0 feet msl for steady-state simulations) and serve as sinks (or sources) for whatever quantity of water is needed to maintain the specified head.

Figure 4-3
The Model Freshwater/Seawater Interface in Cross Section



The highest layer of specified-head cells (layer 6) has a top elevation of 0.67 ft msl. Although mean lower low water (MLLW) is less than three feet below msl, the specified-head cells extend one layer deeper than this, to layer 8, where the bottom elevation is –4.33 ft msl. The intent of this vertical distribution was to ensure that sufficient cells remained active during simulations of low tide. However, subsequent experience showed that the model would crash if a constant-head cell became dry. This behavior limits the lowest tide that can be simulated to a water level above the bottom of the highest layer of specified-head cells. The model could be improved with respect to tidal simulation by placing specified-head cells only in layers 7 and 8. Restricting the height of the discharge zone to two layers instead of three would intensify vertical gradients and flows in the model near the shoreline, but would probably not affect the overall groundwater flow patterns. Nevertheless, the TF05 model can still provide meaningful simulations of relative tidal effects, as discussed later in Section 4.6.2

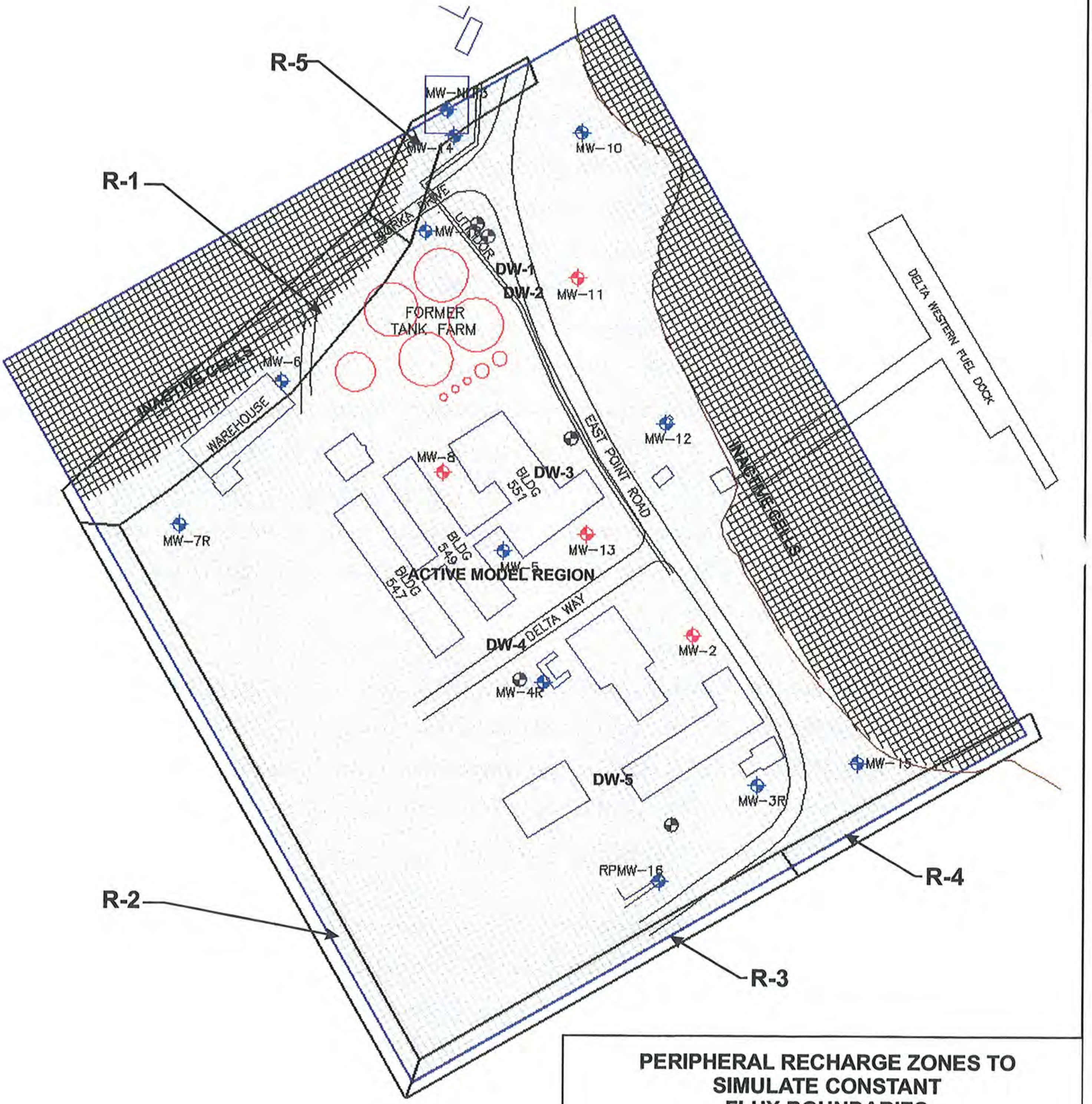
4.4.2 Constant-Flux Boundaries, Areal Recharge, and Dry Wells

Water enters the model from upgradient areas to the northwest, west, and south of the active area of the model, from infiltrating precipitation across the active surface of the model, and from five dry wells intended to drain surface runoff into the subsurface. These features are illustrated in Figure 4-4.

Conceptually, the model boundaries that accommodate water flowing in from upgradient are of the constant-flux type. The rate of water inflow is a constant value unaffected by heads within the model. Although MODFLOW provides a constant-flux specification for cells, drying of such cells during a model run removes the flux from the model. An alternate approach using additional recharge was adopted. Recharge is applied to the uppermost wetted cell at the specified location, so the flux in a given column of cells would remain the same even if one or more cells at the top dried out. Additional recharge was applied in the areas designated R-1, R-2, R-3, R-4, and R-5 in Figure 4-4. The additional recharge within each area was assumed to be constant. Each area was laid out to include an active width of two to three cells, permitting rough comparisons of specified recharge rates among the areas. The recharge flux is applied to the highest active cell in a column, so drying of one or more cells leaves the flux unchanged. A disadvantage of this approach is that vertical gradients are induced because the flux is focused at the uppermost layer of active cells rather than distributed across all layers, but the aquifer is relatively thin and the vertical gradients dissipate within a few cells.

Areal recharge is assumed to be constant over the active region of the model, indicated by the shaded cells in Figure 4-4. No adjustments were made for topography or buildings; omission of such detail had negligible effect on modeling results because of the large uncertainties in most other model parameters. Total recharge along the constant-flux boundaries is the sum of areal recharge and the specified additional recharge.

Dry wells are open-bottomed sumps that collect surface runoff and let it seep into the aquifer. From the surface, they look like storm drains full of standing water (see photograph below). They are not particularly effective; the City of Unalaska is planning to install actual storm drains in the near future. Their hydraulic properties are unknown. During fieldwork in October 2003, their water levels were essentially constant, within a foot or two of the ground surface and therefore several feet above the water table. This condition likely reflects partial



PERIPHERAL RECHARGE ZONES TO SIMULATE CONSTANT FLUX BOUNDARIES

AMAKNAK ISLAND, ALASKA

PROJ. MGR: J. Cohen	FILE NAME: Fig4-04_PeriphRechge.cdr	FIGURE NO: 4-4
	LAYOUT TAB: Peripheral Recharge	DATE: Feb. 09, 05
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plugging of the wells by fine silt washed in from the gravel roads and parking areas, combined with accumulation of additional runoff from the frequent rain, hail, and snow squalls. Locations of the five dry wells noted during site reconnaissance were estimated relative to nearby buildings and roadways, resulting in the coordinates given in Table 4-1. The dry wells were modeled as injection wells in model layers 6, 7, and 8, corresponding to depths of 3.5 to –1.0 feet msl; actual depths of the dry wells were not plumbed.

Photograph of Dry Well DW-3, Adjacent to the Utilidor near Building 551, in October 2003

Table 4-1
Estimated Coordinates of Dry Wells near the Pre-WWII Tank Farm

ID	State Plane Coordinates	
	Easting (ft)	Northing (ft)
DW-1	5315682	1190523
DW-2	5315698	1190506
DW-3	5315814	1190222
DW-4	5315745	1189885
DW-5	5315957	1189682

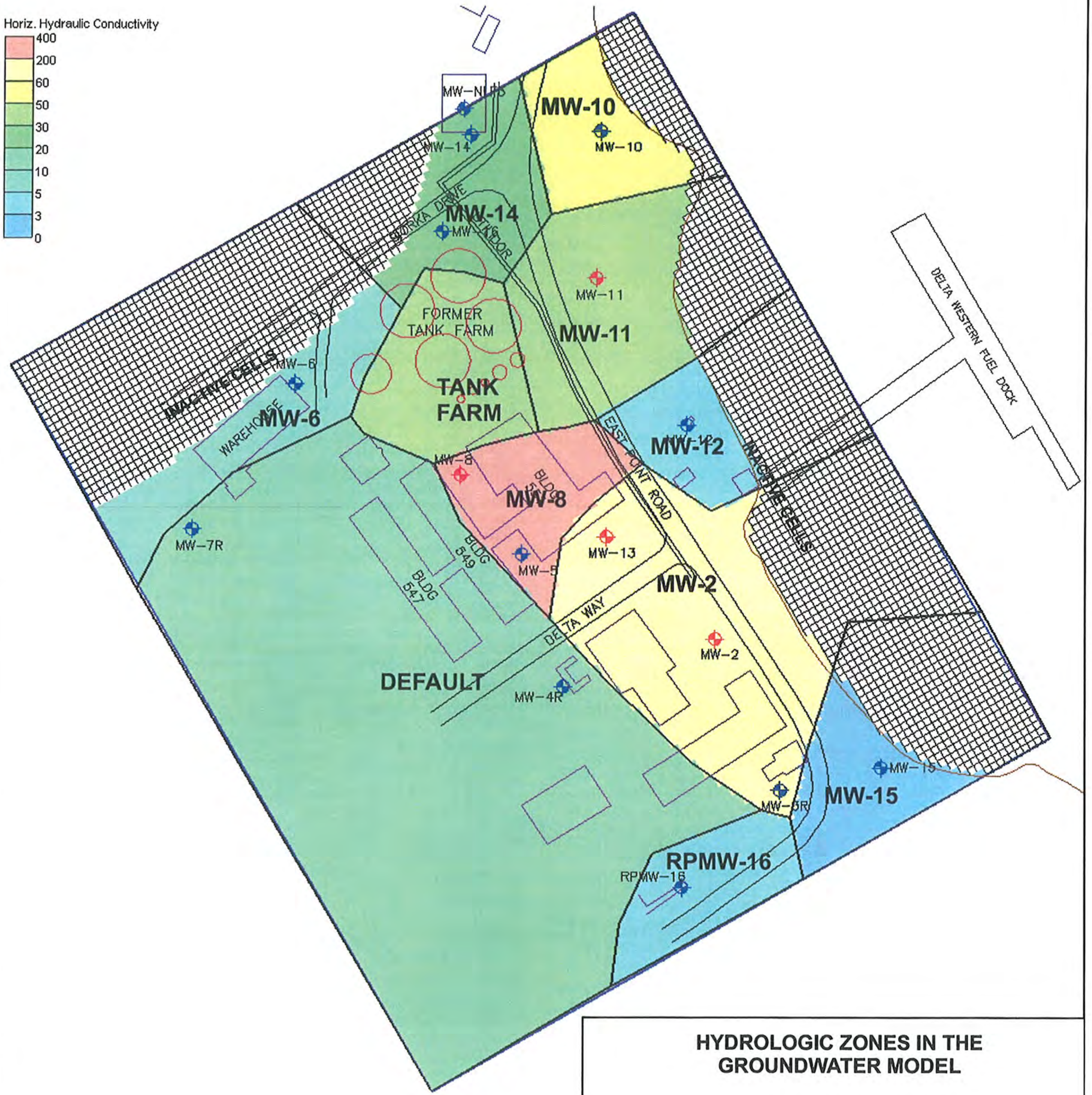
4.5 HYDROLOGIC ZONES

Developing correlations between lithology and hydraulic properties was not practical for the 2004 tank farm model given the paucity of lithologic information below the water table. Numerous test pits have been excavated near the tank farm (USAED 1999), providing views of the subsurface lithology and distribution of contamination down to the water table, but only the soil borings that subsequently became monitoring wells provide a glimpse of the lithology between the water table and bedrock. These borings are widely spaced compared to stratigraphic variability, however, precluding correlations of silts and sands between borings.

Because a hydrostratigraphic representation of the site is not possible based on the available data, hydraulic properties were assigned using a functional approach initially based on the slug-test hydraulic conductivities. Assuming that the slug tests are an indicator of the average hydraulic conductivities near the monitoring wells, the model domain was divided into polygons (zones) delimiting the regions under the influence of each monitoring well. Hydraulic properties (K_h, K_v, specific storage [S_s], and specific yield [S_y]) are constant with each zone.

The final zone configuration is shown in Figure 4-5. Zones are named after the monitoring wells within them. No slug-test results are available in the southwestern portion of the model, so this area was named the Default zone, with the idea that hydraulic properties there might be near the average of the existing slug tests. Model-calibration efforts suggested that a large swath in the central part of the model, called the Tank Farm zone and encompassing the tank farm site and MW-5, MW-8, and MW-13, has comparatively high hydraulic conductivity in order to reproduce the shallow water-table gradients seen there.

At a general level, the relationship between hydraulic conductivity, water-table elevation, and water-table gradient is simple when groundwater is traced backward from the shoreline. The constant-head shoreline boundary anchors the water table to mean sea level there. Water-table gradients across each zone are determined by the rate of inflow from upgradient zones or boundaries, the rate of recharge, the hydraulic conductivity of the zone. In contrast, the



HYDROLOGIC ZONES IN THE GROUNDWATER MODEL

AMAKNAK ISLAND, ALASKA

PROJ. MGR: J. Cohen	FILE NAME: Fig4-05_HydroZones.cdr	FIGURE NO: 4-5
	LAYOUT TAB: HydroZones	DATE: Feb. 09, 05
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water-table elevations at the downgradient boundaries of a zone are determined by the adjoining downgradient zones or boundaries, not by the internal properties of the zone. Thus, the hydraulic properties of upgradient zones have no effect on the downgradient water table configuration. For example, the Default zone serves primarily to conduct water from the western portion of the model to the Tank Farm, MW-2, and RPMW-16 zones. Because the water-table gradient is inversely proportional to the hydraulic conductivity, if a higher conductivity were assigned, the gradient would flatten, but no additional water would be delivered to downgradient zones. Additionally, heads along the downgradient margins of the Default zone would be unaffected because they are controlled by the downgradient hydraulic properties and the shoreline boundary condition.

4.6 CALIBRATION

Calibration is the process of adjusting parameters for each of the boundary conditions and hydrologic zones to obtain the best possible match to physical hydrologic data from the site while maintaining reasonable values for the adjustable parameters. Three sets of physical data are available: water table measurements, tidal influences, and hydraulic conductivities from slug tests. Slug testing measures the response of only a small volume of aquifer around each monitoring well, and is therefore used as an indicator of hydraulic conductivities to initialize the calibration process. Average water table elevations are the targets for the first stage of calibration, in which the model is run in steady-state mode with constant inputs and discharge-zone heads. At this stage, the relative magnitudes of input fluxes and hydraulic conductivities are adjusted to minimize the differences between observed and predicted water levels. Tidal influences are the targets for the second stage of calibration, in which the model is run in transient mode with changing discharge-zone heads. This dynamic stress on the aquifer permits assessment of the specific yield and the absolute magnitude of the hydraulic conductivities in the model.

4.6.1 Matching Observed Heads

The set of mean-tide monitoring-well water levels from October 2003, augmented with 2004 water levels from the four new wells, was used as the steady-state calibration target. As discussed in Section 3.3, water levels from wells with tidal influence measurements have been corrected to remove any bias due to tidal stage or measurement timing, thereby producing a set of water levels relative to mean sea level. The August 2004 water levels for the MW-4R and MW-16 and the November 2004 mean tide levels in MW-3R and MW-7R were extrapolated to their likely values in October 2003 based on their water levels relative to those in the other onsite wells. These mean-tide water levels are broadly similar to those measured at other times near low tide (compare Figure 3-8 to Figure 3-5 through Figure 3-6), with a relatively high water level at MW-11, similar to that in MW-8 and MW-13.

Calibrated heads are listed in Table 4-2 and graphically portrayed in Figure 4-6, along with the calibrated water table. Residuals are portrayed as bars on scales of ±0.5 ft next to each well. Calibrated versus observed heads near the tank farm show residuals (calibrated minus observed) ranging from –0.40 to 0.37 ft. This range of 0.97 ft is 35 percent of the range in observed heads across the tidally influenced area (a range of 2.77 ft, obtained from 3.05 ft at MW-16 minus 0.38 ft at MW-12). Ideally, residuals should be a small fraction of the range. The significant residuals reflect the difficulty in calibrating to accommodate two puzzling features of the observed water levels: (1) the gradient across the tank farm site is very gentle to the south, toward MW-13 and MW-2, and (2) the gradient between MW-11 and MW-8 is toward MW-8 even though this well is much farther inland.

To transmit groundwater at a given rate, steep gradients imply relatively low hydraulic conductivity whereas gentle gradients imply high hydraulic conductivity. A reversed gradient requires a local source of water to the groundwater system. The calibrated properties for the hydrologic zone and water sources in the model, listed in Table 4-3, reflect these principles. The calibrated hydraulic conductivities bear little relation to the slug test measurements, indicating that the aquifer properties are highly heterogeneous; properties of the local aquifer around each monitoring well do not appear to persist for more than a few tens of feet at most. This is especially evident at MW-2, where the slug test indicated a K_h of 4.9 ft/day, yet the calibrated K_h is 200 ft/day (a value consistent with the strong tidal influence in this well, discussed in the next section).

Table 4-2
Observed and Calibrated Heads for October 2003 Mean Tide Water Levels

Well ID	Easting (ft)	Northing (ft)	Elevation (ft msl)	Observed Head (ft msl)	Calibrated Head (ft msl)	Residual (ft)
MW-2	5315985	1189947	0	0.55	0.34	-0.21
MW-3R	5316075	1189738	0	0.71	0.55	-0.16
MW-4R	5315778	1189881	0	1.21	1.28	0.07
MW-6	5315409	1190301	6	6.63	7.00	0.37
MW-7R	5315268	1190098	0	5.00	5.37	0.37
MW-8	5315636	1190175	0	0.73	1.00	0.27
MW-10	5315826	1190652	0	0.49	0.48	-0.01
MW-11	5315821	1190447	0	1.06	0.79	-0.27
MW-12	5315945	1190244	0	0.38	0.38	0.00
MW-13	5315836	1190089	0	0.81	0.68	-0.13
MW-14	5315648	1190646	0	2.42	2.69	0.27
MW-15	5316215	1189769	0	1.54	1.79	0.25
MW-16	5315609	1190512	-0.01	3.05	2.65	-0.40
RPMW-16	5315940	1189603	0	2.88	2.74	-0.14
					Mean	0.02
					Standard Deviation	0.25

Calibrated K_h values range from 3.0 ft/day for the Shoreline zone to 400 ft/day for the Tank Farm zone. In the absence of information about vertical hydraulic gradients and K_v, a uniform hydraulic anisotropy (K_h/K_v) of 3 was used, selected as a compromise between higher anisotropies that likely characterize natural sediments and anisotropies near unity for the fill material that may comprise a significant portion of the uppermost aquifer. This results in sufficient vertical communication in the model that vertical gradients were negligible except within a few cells of the boundaries.

Table 4-3
Calibrated Properties for Hydrologic Zones and Water Sources

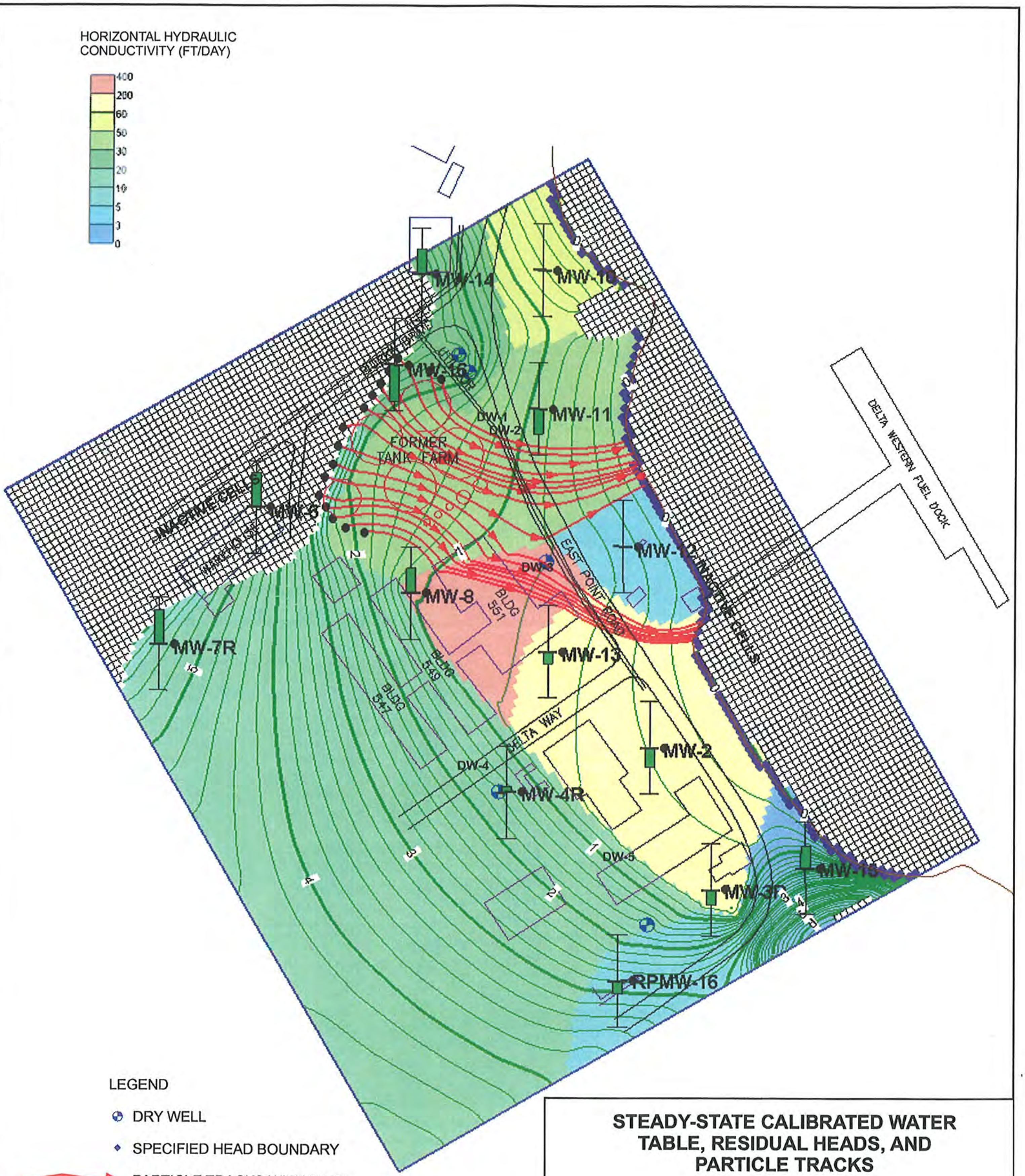
Hydrologic Zone	Slug Test K_h (ft/day)	Calibration Results		
		K_h (ft/day)	K_v (ft/day)	K_h/K_v
Default	na	20.0	7.00	3
MW-2	4.9	200.0	66.67	3
MW-6	nm	10.0	3.33	3
MW-8	6.6	400.0	133.33	3
MW-10	23.0	60.0	10.00	3
MW-11	nm	60.0	10.00	3
MW-12	3.2	5.0	3.00	3
MW-14	28.0	30.0	10.00	3
MW-15	8.3	3.0	1.00	3
RPMW-16	1.6	5.0	3.00	3
Tank Farm	6.6	50.0	10.00	3

Water Source		Value	Units
Name	Type		
DW-1	dry well	275	ft^3/day
DW-2		275	ft^3/day
DW-3		100	ft^3/day
DW-4		50	ft^3/day
DW-5		100	ft^3/day
R_0	areal recharge	0.003	ft/day
		13.14	in/yr
R_1	WNW boundary recharge	0.02	ft/day
R_2	SW boundary recharge	0.01	ft/day
R_3	SSE boundary recharge	0.01	ft/day
R_4	ESE boundary recharge	0.05	ft/day
R_5	NNW boundary recharge	0.05	ft/day

Notes:

The MW-8 slug test result is reported here because MW-8 lies within the Tank Farm zone.

K_h = horizontal hydraulic conductivity
K_h/K_v = hydraulic anisotropy
K_v = vertical hydraulic conductivity
na = not applicable
nm = not measured



LEGEND

🔵 DRY WELL

◆ SPECIFIED HEAD BOUNDARY

PARTICLE TRACKS WITH TIME MARKERS AT 0.5 YR. INTERVALS

CALIBRATION TARGET DEPICTING RESIDUAL HEAD (SCALE 15 ±0.5 FT)

STEADY-STATE CALIBRATED WATER TABLE, RESIDUAL HEADS, AND PARTICLE TRACKS

AMAKNAK ISLAND, ALASKA

PROJ. MGR: J. Cohen	FILE NAME: Fig4-06_SteadyStateResults.cdr	FIGURE NO: 4-6
	LAYOUT TAB: SteadyState	DATE: Feb. 09, 05
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The Tank Farm and MW-2 zones are assigned the highest conductivities in order to achieve some degree of calibration at monitoring well MW-8. Because the water level at MW-11 is higher than at MW-8, and K_h near MW-12 is low, water from the western portion of the tank farm site cannot drain directly to the east, but must flow south near MW-13 on its way to Dutch Harbor. These trajectories are indicated by the particle tracks in Figure 4-6, with time markers at 6-month intervals. Simulated groundwater requires 1 to 1.5 years to flow from the northwest corner of the tank farm site to Dutch Harbor, passing south of MW-12. From the northeast side of the tank farm site, simulated groundwater requires 1 to 2.5 years to reach Dutch Harbor, flowing past MW-11, north of the low-K_h MW-12 zone. From MW-11, transit time is on the order of five months to Dutch Harbor.

Areal recharge was used as a free parameter in the model. Although precipitation in the western Aleutians is on the order of 60 in/yr, the fraction reaching groundwater is a complex interplay of runoff, conductivity through the vadose zone, and evaporation. These factors have not been measured because of the difficulties involved in their accurate determination. Field observations in October 2003 noted extensive and persistent ponding in low-lying areas, with slow drainage toward the dry wells (and possibly other points of focused recharge), suggesting that conductivity of surficial materials is low, raising the possibility that runoff may be substantial. Given the cool damp climate, evaporation is unlikely to play a major role. The calibrated recharge rate of 13.14 in/yr represents slightly less than 25 percent of annual precipitation, but still seems somewhat low. Higher recharge levels in the model resulted in excessive water levels near the tank farm at MW-8 and MW-13, or impossibly high K_h values for the MW-8 and MW-2 zones.

Recharge from each dry well also was used as a free parameter, although modeled heads were not very sensitive to these values. Calibrated recharge rates were 275 ft^3/day for DW-1 and DW-2 at the northeast corner of the tank farm site, and 100 ft^3/day for DW-3 and DW-5, and 50 ft^3/day for DW-4. To put these values in perspective, annual rainfall (60 in/yr) on 100 model cells (100 feet by 100 feet) corresponds to a flux of 137 ft^3/day, so the calibrated values are physically reasonable if a substantial portion of the precipitation falling on the site drains into the aquifer through the dry wells.

Boundary recharge values representing groundwater fluxes from upgradient were free parameters as well, and ranged from 0.01 to 0.05 ft/day. These values are three to fifteen times greater than areal recharge, with the lower values occurring along the west-northwest, southwest, and south-southeast boundaries (R-1, R-2, and R-3). The higher values occur near the shoreline, on the east-southeast boundary (R-4) and the north-northwest boundary (R-5). Although probably unrealistically high, they serve mainly to improve calibration at MW-15, MW-14, and MW-10, and have little effect on heads across the tank farm site. Therefore, no additional calibration effort was expended in this area.

4.6.2 Simulating Tidal Influence

To simulate tidal influence, addition of storage parameters and time-dependent heads along the shoreline boundary converted the TF05 model from steady state to transient. Storage parameters in the model consist of the specific yield (S_y, the fractional volume of water that can drain from the aquifer as the water table falls) and specific storage (S_s, the fractional volume of water produced from within the aquifer by a unit drop in head). Storage parameters were the same for all hydrologic zones. Simulations explored a range of specific yields, ranging from realistic values for unconfined aquifers of 0.1 to 0.3, to very small values of 0.001. The specific storage was set to a very small number (1×10^{-9}), effectively eliminating its effects from the model.

Time-dependent heads at the shoreline simulated tidal variations over one full tidal cycle using four time steps:

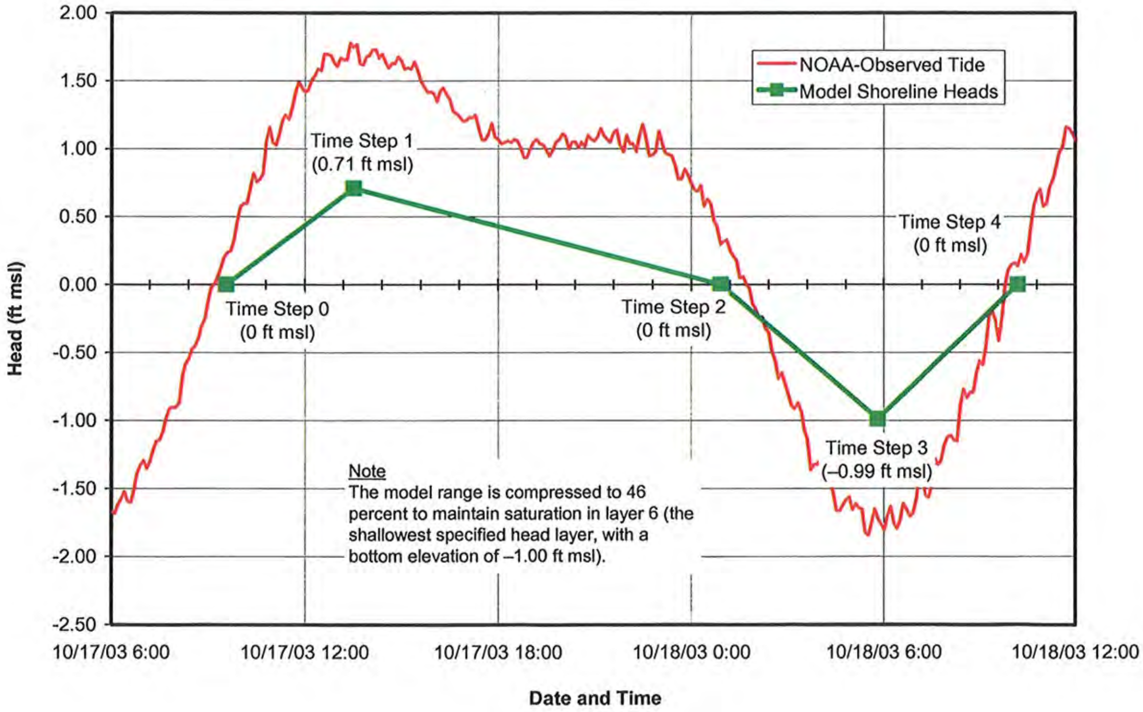
- Mean tide to high tide
- High tide to mean tide
- Mean tide to low tide
- Low tide to mean tide

The applied time intervals and specified head values are listed in Table 4-4, and are depicted graphically relative to the observed tides on 17-18 October 2003 in Figure 4-7. The specified heads were scaled from the observed tidal range to provide a minimum value just above the bottom elevation of layer 6 (i.e., just above –1.0 ft msl), avoiding drying of specified-head cells in that layer. Although the resulting simulated tidal range is only 46 percent as large as the observed tidal range, the simulated tidal efficiencies are still valid because they are the ratios of simulated tidal responses in the wells compared to the specified tidal range at the shoreline.

Table 4-4
Time Steps Used for Tidal Simulations

Time Step	Time			Specified Head (ft msl)	Description
	Hours	Days	del (days)		
0	0.00	0.00		0.00	Initial mean tide
1	3.95	0.16	0.16	0.93	High tide
2	15.35	0.64	0.47	0.00	Return to mean tide
3	20.25	0.84	0.20	-1.30	Low tide
4	24.65	1.03	0.18	0.00	Final mean tide

Figure 4-7
Transient Specified Heads at the Shoreline Compared to Tidal Data



Note
The model range is compressed to 46 percent to maintain saturation in layer 6 (the shallowest specified head layer, with a bottom elevation of –1.00 ft msl).

Simulated tidal efficiencies in the TF05 model are very small. In an effort to maximize the model response, a very small specific yield of 0.001 was selected. Conceptually, this produces behavior much like that of a confined aquifer, maximizing the propagation of head changes because little water is stored in or drained from the aquifer as the water table rises or falls. As listed in Table 4-5 the model responses ranged from 0 to 18.6 percent of the observed efficiencies. The worst performance occurred at RPMW-16, likely indicating that the calibrated K_h for that hydrologic zone of 5 ft/day is much too small, and the best performance occurred at MW-2, suggesting that the relatively high K_h there of 200 ft/day is qualitatively correct. Poor response in the southern portion of the model, near MW-15 and RPMW-16, is of little concern given the large distance to the tank farm site. More puzzling is the physical mechanism for the large observed tidal efficiencies in MW-13 and MW-8 just to the south of the tank farm site. At about 400 ft from the shoreline, MW-8 has an observed efficiency of 0.32, whereas the TF05 simulated efficiency is only 0.001 in spite of the high K_h in the hydrologic zones along the flow path (400 ft/day in the MW-8 zone and 200 ft/day in the MW-2 zone). This indicates that the conceptualization of the aquifer remains incomplete, suggesting that the aquifer behaves more like a confined system, or (less likely) might contain an unidentified zone of high K_h linking the tank farm site more directly to the shoreline.

Table 4-5
Tidal Efficiency in the TF05 Model with Specific Yield Equal to 0.001

ID	Model Results				Observed Efficiency	Efficiency Difference
	Minimum Head (ft msl)	Maximum Head (ft msl)	Head Change (ft)	Efficiency		
MW-2	0.32	0.46	0.1358	0.080	0.430	-0.350
MW-3R	0.55	0.58	0.0295	0.017	0.420	-0.403
MW-6	7.03	7.03	0.0000	0.000	0.000	NA
MW-7R	5.39	5.39	0.0000	0.000	0.000	0.000
MW-8	1.00	1.01	0.0022	0.001	0.320	-0.319
MW-10	0.45	0.54	0.0906	0.053	0.904	-0.851
MW-11	0.79	0.81	0.0258	0.015	0.374	-0.359
MW-12	0.36	0.36	0.0062	0.004	0.490	-0.487
MW-13	0.68	0.70	0.0248	0.015	0.474	-0.460
MW-14	2.70	2.70	0.0001	0.000	0.032	-0.032
MW-15	1.72	1.73	0.0050	0.003	0.216	-0.213
RPMW-16	2.76	2.76	0.0000	0.000	0.216	-0.216
Tide	-0.99	0.71	1.70			

Notes:
Efficiency = (head change in a well) / (Tide head change)

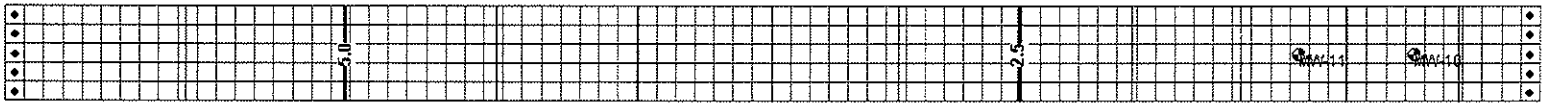
4.7 SCHEMATIC MODEL THROUGH MW-11

A schematic groundwater flow model representing a vertical slice from the western edge of the site to the shoreline facilitated investigation of the effects of hydraulic conductivity, S_y, and recharge on modeled tidal efficiency and to develop a set of parameters that would more accurately simulate the observed tidal efficiencies. The schematic model is 800 feet long by 50 feet wide, with no-flow lateral boundaries and constant-head boundaries upgradient and downgradient, as illustrated in Figure 4-8. K_h is uniform throughout, and K_v is equal to $K_h/3$. There are two layers: –13 to –0.5 feet, and –0.5 to 12 feet. Surrogates for MW-10 and MW-11 are at 65 feet and 125 feet, respectively, from the downgradient boundary.

Initially, K_h was set to 50 ft/day. Maximum tidal efficiency was obtained with very small S_y (0.0001) and zero recharge. Even under these conditions, the maximum tidal efficiency at MW-10 is 0.88, slightly less than the observed 0.90. At MW-11, the model tidal efficiency at 0.76 is much greater than the observed value of 0.37. More reasonable parameters, i.e., S_y = 0.1 and recharge = 0.007 ft/day (30 in/yr), produced much smaller tidal efficiencies: only 0.04 for MW-11 and 0.18 for MW-10. With high K_h (150 ft/day) the tidal efficiencies increased to 0.14 for MW-11 and 0.34 for MW-12, but were still much less than observed efficiencies. These findings are compiled in Table 4-6 and illustrated in Figure 4-9.

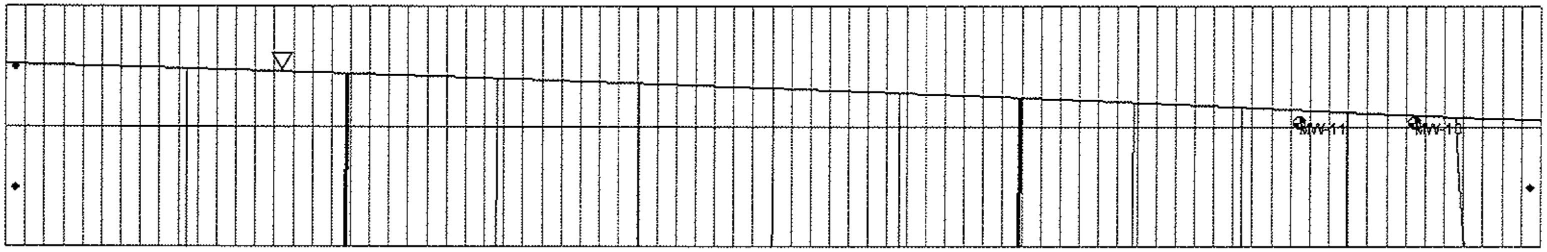
This exercise shows that very high hydraulic conductivity and very low specific is needed in order to successfully simulate the tidal efficiencies observed in MW-10 and MW-11. The highest tested value of 150 ft/day was inadequate, and trends suggest that K_h of 300 ft/day or more may be needed.

Plan View



STEADY-STATE HEADS (FEET MSL)

Side View Looking North



STEADY-STATE HEADS (FEET MSL)

MODEL GRID:

DOMAIN: 800 FEET LONG x 50 FEET WIDE x 25 FEET THICK.

BOTTOM ELEVATION IS -13 FEET MSL, TOP ELEVATION IS 12 FEET MSL.

ALL CELLS ARE 10 FEET x 10 FEET LATERALLY, 12.5 FEET THICK.

HYDRAULIC PROPERTIES:

K_h is uniform, $K_v = K_h/3$

BOUNDARY CONDITIONS:

- CONSTANT-HEAD CELLS @ 6 FEET MSL ALONG THE LEFT END OF THE MODEL, 0 FEET (VARIABLE FOR TRANSIENT SIMULATIONS) ALONG THE RIGHT END OF THE MODEL

▽ STEADY-STATE WATER TABLE

NOTES:

VERTICAL EXAGGERATION = 5x
MSL = MEAN SEA LEVEL

SCHEMATIC FLOW MODEL GRID AND BOUNDARY CONDITIONS

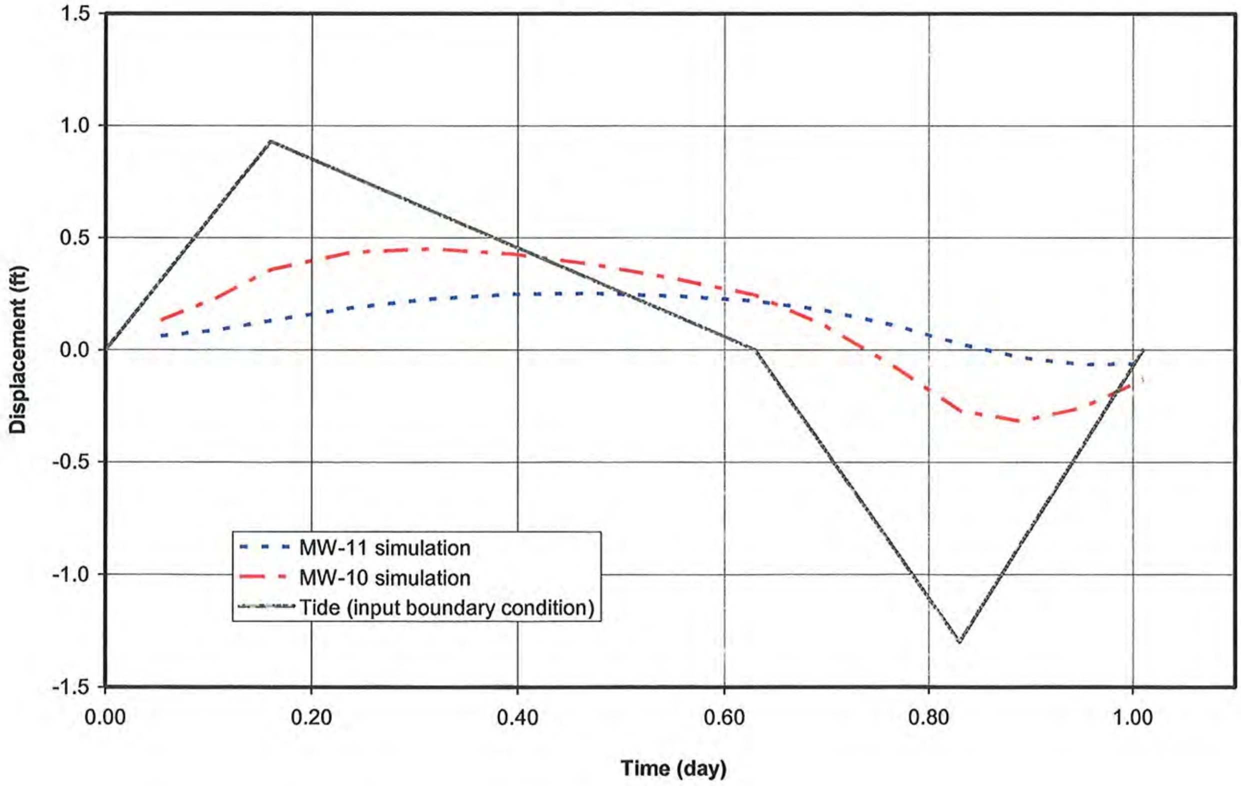
AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen	FILE NAME: Schematic Model.cdr	DATE: Feb. 07, 05
JE	LAYOUT TAB: Schematic Model	FIGURE NO.: 4-8
DRAWN BY: DBW	FILE LOCATION: Amaknak \ 05M30225 \ GW Model \ Final Rpt	

Table 4-6
Tidal Efficiency in the Schematic Model

ID	Minimum Head (ft msl)	Maximum Head (ft msl)	Range (ft)	Efficiency	Observed Efficiency	Difference
Maximum Attainable Efficiency						
MW-11	0.09	1.80	1.70	0.76	0.37	0.39
MW-10	-0.58	1.37	1.95	0.88	0.90	-0.02
Tide	-1.30	0.93	2.23	1	1	0
Efficiency with Reasonable Parameters						
MW-11	1.47	1.56	0.09	0.04	0.37	-0.33
MW-10	0.61	1.01	0.39	0.18	0.90	-0.72
Tide	-1.30	0.93	2.23	1	1	0
Efficiency with High Kh						
MW-11	1.09	1.41	0.32	0.14	0.37	-0.23
MW-10	0.23	1.00	0.77	0.34	0.90	-0.56
Tide	-1.30	0.93	2.23	1	1	0

Figure 4-9
Tidal Response in the Schematic Model at MW-11 and MW-10 with High Hydraulic Conductivity



4.8 GROUNDWATER FLOW MODELING RESULTS AND CONCLUSIONS

Groundwater flow modeling supports the following ideas:

- The high water level at MW-11 and lower water levels at MW-8, MW-5, MW-13, and MW-2 require that groundwater from the western portion of the tank farm site drains to the south, and require very high hydraulic conductivity in the vicinity of the latter wells.
- Areal recharge was modeled at 0.003 ft/day (13.14 inches/yr). The active portion of the model has an area of 853,000 squared feet, thus capturing areal recharge of 2,559 ft^3/day. The dry wells contribute a combined total of 800 ft^3/day, accounting for the equivalent of 4.1 in/yr across the active model area. Actual recharge is probably at least 30 in/yr, so slightly more than half the recharge may be missing from the model. If recharge in the model were doubled, hydraulic conductivities also would need to be doubled in order to maintain calibration with observed water levels. Such values, ranging up to 800 ft/day, are near the limits for coarse beach deposits, and seem too extreme unless required by other lines of evidence.
- Particle tracks show that water from the west side of the tank farm site is presently draining to the southeast in the model, beneath Bldg 551. The longest forward track, from the northern end of the tank farm, is 612 feet long, with a transit time of about 500 days, corresponding to 0.82 ft/day. From the east side of the tank farm site, slightly lower velocities hold in the vicinity of MW-11 (427 ft in 475 days, or 0.90 ft/day). These are minimum values, based on low recharge and low hydraulic conductivity and/or low gradients.
- Tidal efficiencies in the TF05 model are very low, and cannot be raised adequately even with the selection of extreme model parameters (very high hydraulic conductivity, very low specific yield). The schematic model could reproduce the observed tidal efficiencies in MW-10 and MW-11 only with high hydraulic conductivity and low specific yield. Suitable values for K_h were much higher than the largest K_h from slug testing (28 ft/day in MW-14) but are consistent with those obtained from calibration of the TF05 model. This suggests that the slug test results may be biased low. In order to explain the observed tidal efficiencies, the aquifer may be behaving as a confined groundwater system over the period of a single tidal cycle, or highly transmissive channels in the subsurface may be required.
- Major uncertainties affecting the modeling of groundwater flow are (a) the lack of agreement among hydraulic conductivities inferred from slug testing, hydraulic evaluation of the water table, and the calibrated TF05 model; and (b) lack of a quantitative understanding of appropriate values for recharge (areal, dry well, and model boundary).

5.0 LNAPL FLOW MODEL

The goal of modeling the flow of an LNAPL is to evaluate the rate at which the Bunker C might be expected to migrate toward and discharge to Dutch Harbor. The model presented here simulates Bunker C migration from its time of release in mid-1942 until 2012, a period of 70 years. Migration is modeled in two stages: an initial period of infiltration during which 3.3 feet of oil seep into the ground, followed by a long period of slow migration as the oil spreads downgradient toward Dutch Harbor. Calibration targets are limited; Bunker C was already present at MW-11 when it was first drilled in 1998 (USAED 1999), and traces of heavy oil were observed at the shoreline in October 2003 (see Section 3.6) that may or may not originate from the tank farm.

Because of the complexity of interactions between the three fluid phases (water, air, and oil), the aqueous flow portion of the model has been greatly simplified compared to the 2004 tank farm MODFLOW model and even the schematic model. The model represents a two-dimensional vertical slice of the aquifer from the center of the tank farm through MW-11 to Dutch Harbor, with fixed heads at each end to simulate a constant gradient toward the bay. Tidal fluctuations are omitted, and flow is confined to the plane of the model. Although the 2004 tank farm model cast some doubt as to whether present flow patterns would result in transport from the tank farm to MW-11, the presence of Bunker C in MW-11 indicates that such transport has occurred in the past.

The complexity of three-phase modeling arises from the need to account for the physical interactions for each of the three possible pairings of phases, simulating displacement of water by oil, air by oil, air by water, oil by water, oil by air, and water by air. The resulting capillary fringes have unique properties resulting from the interplay of interfacial tensions, viscosities, densities, aquifer porosity, pore size, tortuosity, and wettability. Accurate quantification of all input parameters is impractical for all but the simplest systems, but some simplifying assumptions permit informative semiquantitative calculations to place limits on the likely rate of Bunker C migration.

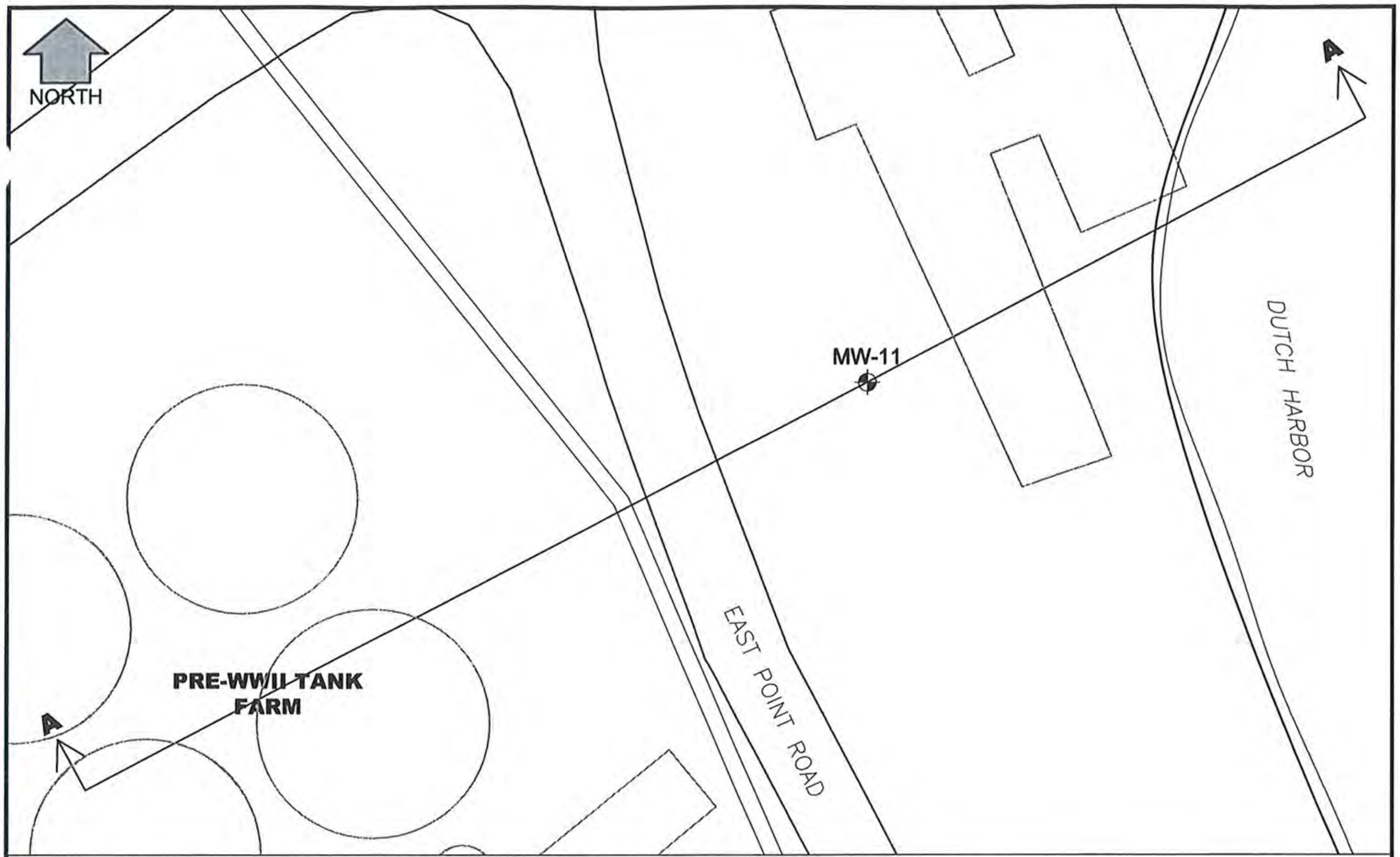
5.1 SOFTWARE

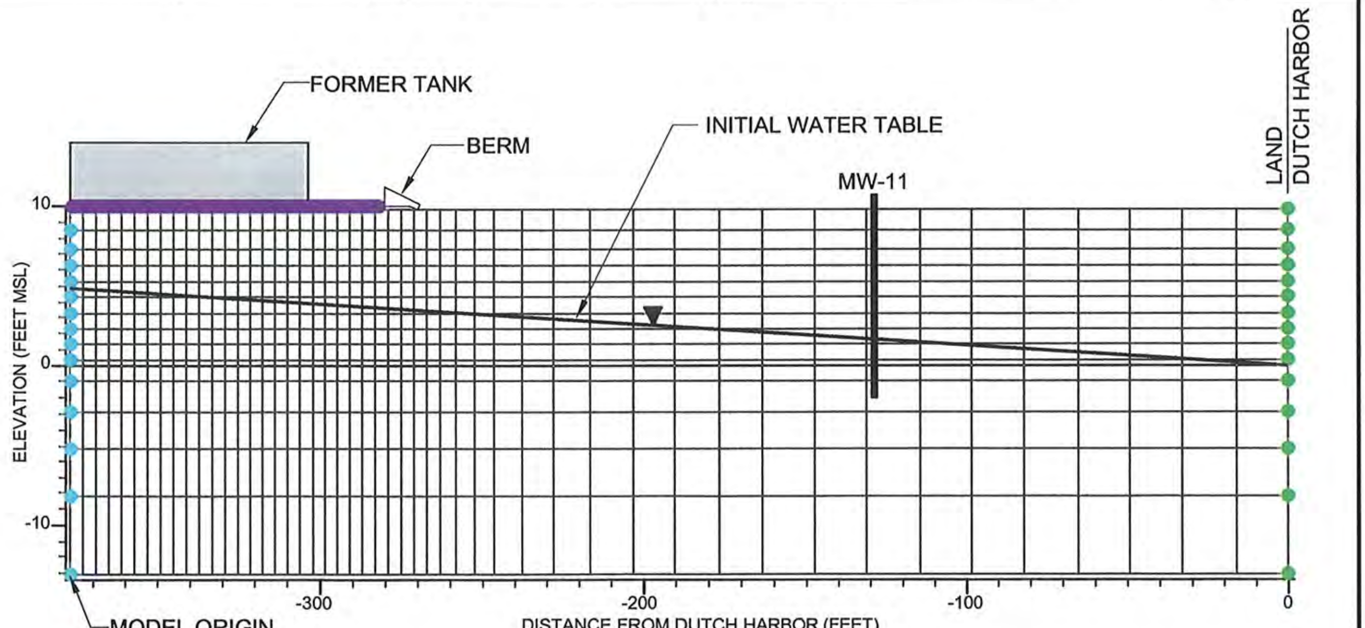
The groundwater modeling technical memorandum (USAED 2003b) indicated that UTCHEM (Pope et al. 1999) would be used for the LNAPL flow modeling. Although this model offers a highly detailed parameterization of the three-phase interactions in three dimensions, extensive testing suggested that it was quite sensitive to the selected input parameters when the gas phase was present. The model ran reliably when only water and oil were present, but always crashed when air was added. No timely assistance could be obtained from the software developer or user community, so UTCHEM was abandoned in favor of the less elaborate MOFAT (Katyal et al. 1991).

MOFAT, distributed by the U.S. Environmental Protection Agency (EPA), is a two-dimensional finite-difference three-phase flow simulator in which air and water are modeled using default parameters. Parameters need only be supplied to describe the characteristics of the oil phase. MOFAT also has the capability of partitioning chemical components among the three phases, but this feature was not used. The MOFAT source code was downloaded from the EPA and compiled after several modifications to facilitate program operation. No modifications were made to the flow algorithms. Input errors were minimized by developing a simple pre-processor to strip all comments from an input file, leaving only the formatted numerical values required for program operation. A post-processor was developed to translate MOFAT output for loading and visualization in Tecplot (Amtec 2003).

5.2 MODEL CONFIGURATION

The layout of the LNAPL flow model for the tank farm, designated the TFslice model, is illustrated in Figure 5-1, and grid dimensions are provided in Table 5-1. MOFAT requires lengths in meters rather than feet, resulting in somewhat cumbersome values after conversion. The model extends 377 feet from the center of the tank farm to Dutch Harbor, passing through MW-11, which presently contains several inches of free product. Vertically, the model extends from 10 ft msl to –13 feet msl, encompassing the aquifer and vadose zone as it existed in 1942 when the oil was released. For simplicity, bedrock is represented as a flat surface; although it undoubtedly has undulations. The bedrock surface contoured for the 2004





SECTION A-A

(VERTICAL EXAGGERATION = 5X)

BOUNDARY CONDITIONS:

- ● CONSTANT HEAD NODES AT 9.5 FT TOTAL HEAD FOR WATER, NO FLOW FOR OIL
- ● CONSTANT HEAD NODES AT 0.0 FT TOTAL HEAD FOR WATER AND OIL
- ● CONSTANT HEAD NODES AT 10.0 FT TOTAL HEAD FOR OIL UNTIL 3.3 FT INFILTRATES

0 30 60 120

SCALE IN FEET

TFSLICE MODEL GRID AND BOUNDARY CONDITIONS

AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen

FILE NAME: TFslice Model.dwg

DATE: Feb. 09, 05

LAYOUT TAB: TFslice Model

FIGURE NO.: 5-1

JE

DRAWN BY: DBW

FILE LOCATION: Amaknak \ 05M30225 \ GW Model \ Final Rpt

G:\Autocad\AMAKNAK\0: ;W Model\FINAL RPT\TFslice Model.dwg Feb 09,2005 -avakarcs) tank farm MODFLOW model in Figure 4-2 suggests that bedrock rises from –13 feet msl along the shoreline to –5 feet msl beneath the tank farm, but no borings or test pits penetrated to that depth near the tank farm. If bedrock is that shallow, then it would have forced the spilled oil to move laterally more rapidly during the early stages of migration.

Model discretization is refined vertically to focus on the vadose zone and shallow groundwater, and laterally to focus on the region beneath the tank farm. MOFAT uses a mesh-centered grid for many aspects of the flow calculation, and is limited to no more than 50 nodes in either direction, and no more than 750 nodes total. Grid dimensions in Table 5-1 are for spacings between mesh lines, otherwise known as cells or elements. The TFslice grid contains 49 columns of elements (and therefore 50 vertical mesh lines) and 14 rows of elements (15 horizontal mesh lines). Minimum element size beneath the tank farm is approximately 1.0 foot thick by 3.9 feet long, coarsening to 4.9 feet thick by 16.4 feet long at the base of the model near the bay. Some cells violate the suggested 5:1 aspect ratio, and may contribute to the minor numerical dispersion observed in some model runs.

Table 5-1
Grid Spacing for the TFslice MOFAT Model

Element Index	Number of Elements	Size	
		(m)	(ft)
Columns (x direction)			
1 to 29	29	1.2	3.94
30	1	1.5	4.92
31	1	1.7	5.58
32	1	2.0	6.56
33	1	2.5	8.20
34	1	3.0	9.84
35	1	3.5	11.48
36 to 39	4	4.0	13.12
40 to 49	10	5.0	16.40
Total	49	115.0	377.3

Element Index	Number of Elements	Size	
		(m)	(ft)
Rows (z direction)			
14	1	0.4	1.31
13	1	0.4	1.31
12	1	0.3	0.98
11	1	0.3	0.98
10	1	0.3	0.98
9	1	0.3	0.98
8	1	0.3	0.98
7	1	0.3	0.98
6	1	0.3	0.98
5	1	0.4	1.31
4	1	0.6	1.97
3	1	0.7	2.30
2	1	0.9	2.95
1	1	1.5	4.92
Total	14	7.0	23.0

5.2.1 Boundary Conditions

Although MOFAT permits both specified-head and specified-flux boundary conditions, the TFslice model utilizes only the former. Nodes with applied boundary conditions are illustrated in Figure 5-1. Boundary nodes without an applied condition are no-flow nodes. Pressure heads for water are set for each node along the left and right boundaries based on the node elevation relative to the desired initial water table. The water table is fixed at 4.9 feet msl at the left edge of the model, and at 0.0 feet msl and the right edge. Initial pressure heads throughout the mesh are interpolated from the boundary pressure heads, permitting calculation of initial water saturations. Pressure heads for oil are automatically initialized corresponding to zero oil saturation. For the initial infiltration period, nodes at the top of the model beneath the tank farm are set to a pressure head of 0.0 feet, corresponding to a total head of 10.0 feet msl, ensuring complete oil saturation but no over-pressure. After the initial infiltration period, these nodes revert to the pressure head consistent with zero oil saturation at this elevation in the model.

Recharge is not simulated in the TFslice model. In principle, it could be represented using the specified-flux boundary type in MOFAT for all elements across the top of the model, but run times were vastly increased to the point of impracticality. This omission is probably conservative, resulting in more rapid oil migration because all water enters at the left end of the model and flows to the right instead of some fraction percolating downward. In addition, the vadose contains water only at residual saturation levels, minimizing the extent of the capillary fringe and making more of the pore space available for oil migration.

5.2.2 Bulk Properties

Input parameters defining the bulk properties of the aquifer and oil are listed in Table 5-2. The listed values are for the Base Case scenario (Run 01 of the model), which were modified one at a time for subsequent model runs. The rationale for each value is as follows:

- K_h — The selected horizontal hydraulic conductivity is quite high, at 300 ft/day. Groundwater flow modeling (Section 4) did not successfully match the observed tidal responses in MW-11 or MW-10 with K_h as high as 150 ft/day, indicating that average K_h

values must be substantially higher, so the bulk K_h was doubled for the TFslice model. The value of 300 ft/day would be consistent with coarse sand and gravel with negligible fines.

- K_v — The vertical hydraulic conductivity is assumed to be one-fifth the value of K_h. This affects the infiltration rate but not lateral migration.
- ϕ — The porosity is assumed to be 0.35, typical for loosely consolidated material.
- ρ_{oil} — The density of oil is assumed to be 0.99 g/mL. Measured product densities at room temperature (excluding MW-13, which has a diesel component) range from 0.993 to 1.020 g/mL (Table 3-9) and temperature-corrected densities for ambient conditions are 1.000 g/mL or greater (Table 3-10), so the assumed value is a minimum.
- v_{oil} — The viscosity of oil is assumed to be 1,000 cSt. Measured product viscosities at room temperature and higher (excluding MW-13, which has a diesel component) range from 1086 to 3330 cSt (Table 3-9) and temperature-corrected viscosities for ambient conditions are 6,071 cSt or greater (Table 3-10), so the assumed value is a minimum.
- β_{ao} — The scaling coefficient for the oil/air surface tension is taken to be 2.4, based on the surface tension for water of 72 dynes/cm and a typical surface tension for hydrocarbons of 30 dynes/cm.
- β_{ow} — The scaling coefficient for the oil/water interfacial tension is taken to be 1.8, based on the surface tension for water of 72 dynes/cm and a typical interfacial tension for hydrocarbons of 40 dynes/cm.
- α_{vG}, n_{vG} — van Genuchten parameters for soil capillarity, in the equation relating the pressure head (h) to the effective water saturation (S_w, corrected for the irreducible residual water saturation):

$$S_w = [1 + (\alpha_{vG}\, h)^n]^{(1-1/n)} \tag{0-6}$$

A guidance equation provided in the MOFAT manual (Katyal et al. 1991) suggests that α_{vG} should be near 13.5 m^{-1} for material with K_h = 300 ft/day, although the largest value in a table of typical soil properties is 14.5 m^{-1} for a sand with K_h of only 23.3 ft/day. This latter value was chosen, but may be too small if K_h is truly as large as modeled. For n_{vG}, the largest tabulated or example value in the MOFAT manual is 2.8, so that value was selected, although it also may be too small. With the selected values for α_{vG} and n_{vG}, the capillary fringe is relatively compact and exerts only a small influence on oil mobility, so larger values would have little affect.

- Sr_w — The residual water saturation is assumed to be 10 percent of the pore space, a typical value for coarse sand with high K_h.
- Sr_{oil} — The residual oil saturation is assume to be 20 percent of the pore space, a value that is probably too low given the high viscosity of Bunker C. Increasing Sr_{oil} would reduce the mobility of the oil phase because the oil phase at residual saturation would be spread over a smaller volume of aquifer.

Table 5-2
Base-Case Input Parameters for the TFslice MOFAT Model

Symbol	Value	Units	Description
K_h	93.1	m/day	Saturated horizontal hydraulic conductivity. 93.1 m/day = 300 ft/day.
K_v	18.3	m/day	Saturated vertical hydraulic conductivity. 18.3 m/day = 60 ft/day, implying an anisotropy (K_h/K_v) of 5.
ϕ	0.35	—	Porosity.
ρ_{oil}	0.99	—	Density of oil relative to water. Assuming water to have a density of 1.000 g/mL, the relative density of oil is the same as its absolute density.
v_{oil}	1000	—	Viscosity of oil relative to water. Assuming water to have viscosity of 1.0 cSt and oil to have a density near 1 g/mL, the relative viscosity of oil is the same as its absolute viscosity.
β_{ao}	2.4	—	Scaling coefficient equal to the ratio of water/air interfacial tension to oil/air interfacial tension.
β_{ow}	1.8	—	Scaling coefficient equal to the ratio of water/air interfacial tension to water/oil interfacial tension.
α_{vG}	14.5	1/m	van Genuchten air-water capillary retention parameter.
n_{vG}	2.8	—	van Genuchten air-water capillary retention parameter.
Sr_w	0.1	—	Residual saturation of water displaced by air.
Sr_{oil}	0.2	—	Residual saturation of oil displaced by water.

5.3 MODEL RUNS

All runs followed the same sequence of events, beginning at the approximate date of release of Bunker C from the tank farm storage tanks (01 July 1942, or 1942.5). During an infiltration period lasting between 0.19 and 1.66 years, a standing pool of oil initially 3.3 feet deep saturated the ground surface and seeped into the subsurface. Subsequent migration with no further infiltration was simulated for approximately 70 years, ending in 2012 to 2014. Ten model runs were conducted, beginning with the Base Case parameters listed in Table 5-2 and changing one parameter at a time to investigate the consequences of variations in oil density and viscosity, hydraulic conductivity, and soil capillarity. These runs were evaluated by compiling snapshots of oil and water saturation at 6-month to 1-year intervals into animations depicting oil migration over time. The animations are provided in AVI format on the CD-ROM accompanying this report. Key milestones were extracted from the output files and animations, including the end of infiltration, the date that oil reaches MW-11, and the date that oil reaches Dutch Harbor. These milestones are listed in Table 5-3 for each run, along with the changed parameter.

Table 5-3
TFslice MOFAT Modeling Summary of Oil Mobility

Run	Title	Changed Parameter	End of Infiltration[1]		Arrival at MW-11[2]		Arrival at Dutch Harbor[2]	
			Date	Elapsed Time (yr)	Date	Elapsed Time (yr)	Date	Elapsed Time (yr)
01	Base Case	none	1942.69	0.19	1963.0	20.5	1996.7	54.2
02	High Viscosity	v_{oil} = 3000 Cst	1943.07	0.57	2014.0[3]	71.5[3]	nc	
03	Low Density	ρ_{oil} = 0.95 g/mL	1942.70	0.20	1963.4	20.8	crashed[4]	
04	High Density	ρ_{oil} = 1.02 g/mL	1942.70	0.20	1967.0[5]	24.5[5]	2006.5	64.0
05	High Density	ρ_{oil} = 1.01 g/mL	1942.70	0.20	1968.4[5]	25.9[5]	2008.4	65.9
06	Low van Genuchten	α_{vG} = 7.0, n_{vG} = 2.0	1942.72	0.22	1957.9	15.3	1982.1	39.6
07	Actual Density	ρ_{oil} = 0.997 g/mL	1942.70	0.20	1967.4	24.9	2010.1	67.6
08	Low Kh	K_h = 100 ft/day	1942.70	0.20	2015.7[3]	73.2[3]	nc	
09	Very High Viscosity	v_{oil} = 8000 Cst	1944.16	1.66	nc		nc	
10	High Anisotropy	K_v = 3 ft/day	1946.11	1.66	1969.9	27.4	2003.4	60.9

Notes:

[1] All model runs begin at 1942.5 (01 July 1942), approximately the date of release of Bunker C from the tank farm.

[2] Arrival times, estimated from animations, correspond to oil saturation exceeding 0.25.

[3] Extrapolated beyond the end of the modeled period (greater than about 2012 or 2013, depending on the run).

[4] MOFAT could not converge on a solution at later timesteps.

[5] Time that leading edge of oil phase passed beneath the location of MW-11.

nc - not calculated because the oil phase was not mobile enough.

The following subsections discuss six of the model runs in detail: Base Case (Run 01), High Density (Run 05), High Viscosity (Run 02), Low van Genuchten Parameters (Run 06), Actual Density (Run 07) and High Anisotropy (Run 10).

5.3.1 Base Case (Run 01)

Selected frames from the Base Case migration animation (Run_01_BaseCase.avi on the accompanying CD-ROM) are portrayed in Figure 5-2. The initial oil release is very dynamic, with infiltration complete after 0.19 years, shown in frame (a). Oil saturation beneath the tank farm is less than 1.0 because water and air are present at residual saturation levels. One year later, in frame (b), the oil has settled into the water table. Because its density at 0.99 g/mL is only 1 percent less than the water it displaces, only 1 percent of its mass floats above the water table. The zone of oil saturation exceeding 0.25 extends from 5 feet msl down to –7.5 feet msl, for a total contaminated thickness of 12.5 feet. In principle, the vadose zone beneath the tank farm should be uniformly contaminated at the residual saturation level for oil of 0.2; differences from this ideal likely reflect inaccuracies inherent in the numerical solution algorithm. Six years after the release, in frame (c), the leading edge of the oil zone has covered 80 of the 320 feet to Dutch Harbor and has reached its maximum depth of –12 feet msl, almost at the bottom of the aquifer. The trailing edge has thinned somewhat but has remained stationary, reflecting the flow patterns of the constant-head boundary (where the oil blocks flow near the water table, but flow into the model continues at depth). Ahead of the oil zone, the water table has fallen to nearly sea level, indicating that the oil is blocking much of the normal water flow.

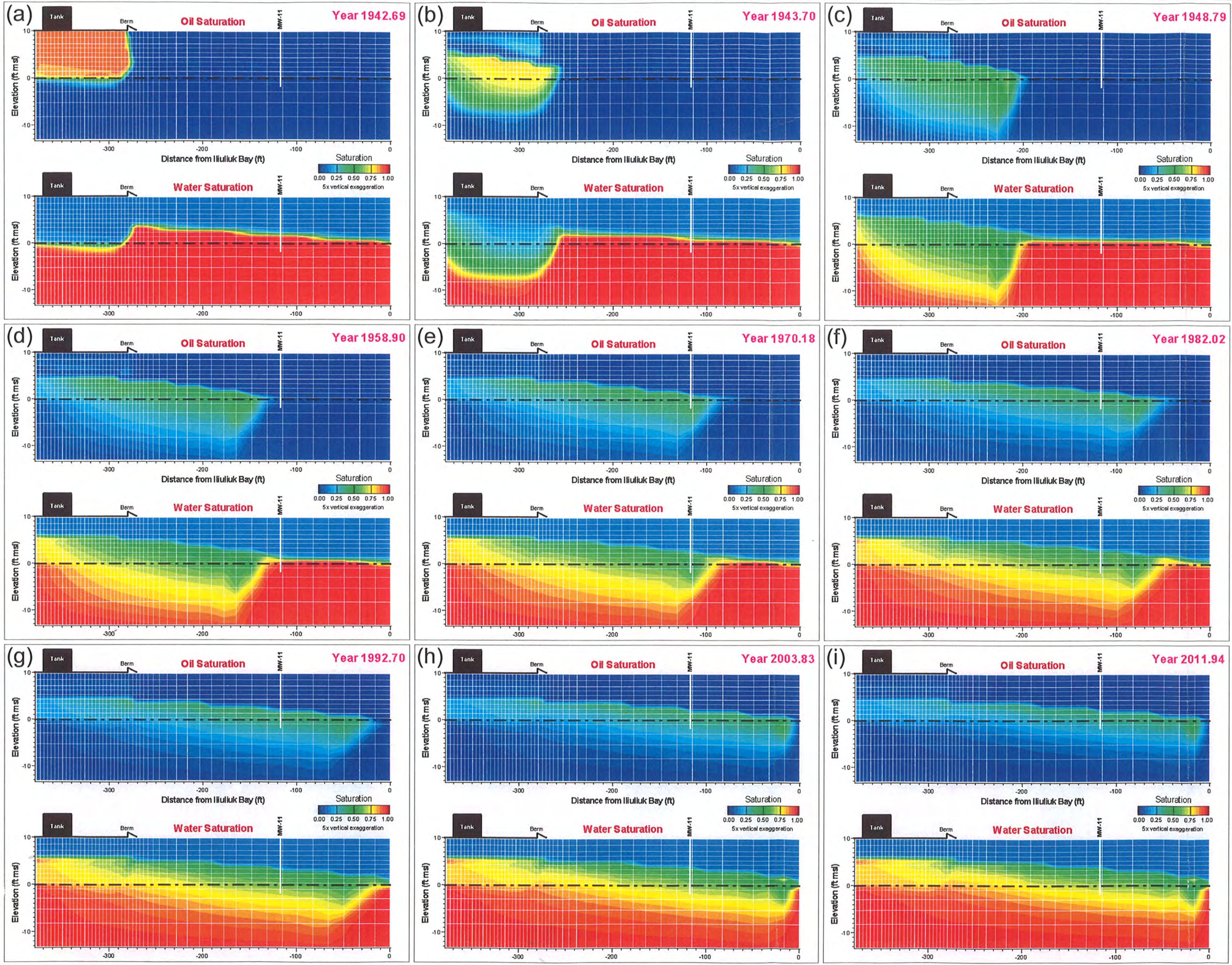
Subsequent migration is a long-continuing process that becomes progressively slower as the leading edge is attenuated. The leading edge leaves behind a trail of oil at residual saturation as it migrates downgradient. The leading edge (0.25 saturation) passes the location of MW-11 at 1963.0 (between frames [d] and [e] in Figure 5-2), and reaches Dutch Harbor at 1996.7 (between frames [g] and [h]). The final water table, taken as the elevation at which both water saturation and oil saturation fall off dramatically to residual levels or less, is significantly elevated at MW-11. The final water table here is almost 3 feet msl, whereas the initial water table was only 1.5 feet msl. This change occurred because the residual oil present in the upper part of the saturated zone has significantly reduced the hydraulic transmissivity of the aquifer.

The internal precision of the numerical simulation can be evaluated in part by examining the mass balance over the course of a run. In Figure 5-3, water volume and oil volume are plotted versus time for the Base Case run. Volumes are calculated for the TFslice model by assuming the model is 3.3 feet (1 meter) wide. During infiltration, the increasing oil volume is mirrored by decreasing water volume. At the end of infiltration, the small but sharp drop in oil volume is probably related to restarting the model, but the origin of similar offsets in the water curve near 1992 and at the end of the simulation is unknown. Between the end of infiltration and 1996, when oil begins discharging to the bay at a significant rate, the volume of oil should be constant. In practice, however, oil volume climbed very slowly. Convergence parameters in MOFAT probably could be adjusted to further minimize this mass-balance discrepancy, but it is not large enough to be of concern. The volume of water climbs continually after the initial displacement followed by several years of drainage downgradient of the oil zone. This increase in water volume reflects the rising water table induced by the lowered transmissivity related to oil migration and residual saturation.

5.3.2 High Density (Run 05)

In the High Density model run, the oil density was increased from 0.990 to 1.010 g/mL, which corresponds to the density that product beneath Building 551 would have at ambient temperatures (see Section 3.7). Given the occurrence of product floating in MW-11 and at the ground surface beneath Building 551, the actual density of fresh Bunker C must have been less than that of water (assumed to be 1.000 g/mL), but this run illustrates the migration pathway if the density had been greater.

Selected frames from the High Density migration animation (Run_05_HighDensity.avi on the accompanying CD-ROM) are portrayed in Figure 5-4. The infiltration period is nearly identical to the Base Case, but significant differences begin to emerge after 6 years (frame [c] at 1948.71). By this time, a substantial fraction of the oil has migrated to the bottom of the aquifer and ponded there. Subsequent frames show this process continuing until the zone of significant oil saturation (greater than 0.25) is confined to the bottom of the aquifer, below -7 feet msl. As the oil sinks, it is also advected toward Dutch Harbor by flowing



Hydraulic Parameters

K_h = 300 ft/day

K_v = 60 ft/day

Porosity = 0.35

Residual water saturation = 0.10

Residual oil saturation = 0.20

van Genuchten α = 14.5

van Genuchten n = 2.80

Oil viscosity = 1000 cSt

Oil density = 0.990 g/mL

Oil or Water Saturation

0.00 0.25 0.50 0.75 1.00

Fraction of Pore Space

Modeled using the Tank Farm TFslice model, which runs using MOFAT (EPA 1991). TFslice represents a 2-D vertical section through the aquifer, extending from the center of the Tank Farm through monitoring well MW-11 to Dutch Harbor. Oil infiltration begins in year 1942.5.

BASE CASE (RUN 01) FOR
MODELED BUNKER C MIGRATION
AT THE PRE-WWII TANK FARM
AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen
FILE NAME: Fig5-02_AnimBaseCase.cdr
DATE: Feb. 10, 05
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FIGURE NO.: 5-2
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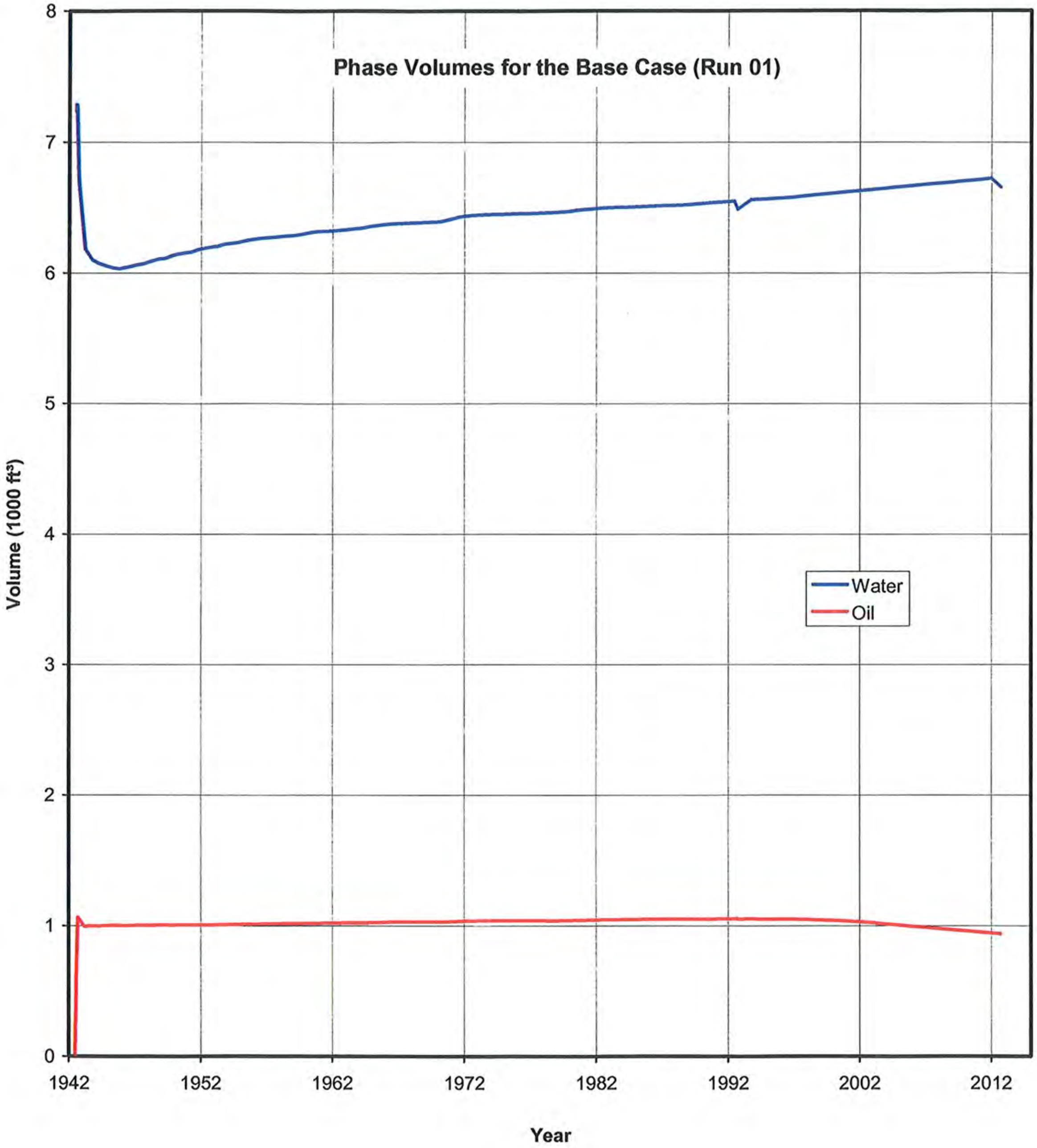
Figure 5-3
Water and Oil Volumes for the Base Case (Run 01) of the TFslice Model



groundwater, passing beneath MW-11 in 1968.4 and reaching the bay at 2008.4. Migration is about 25 percent slower than in the Base Case run because advection is the only driving force; there is no gravitational pull downhill at the water table.

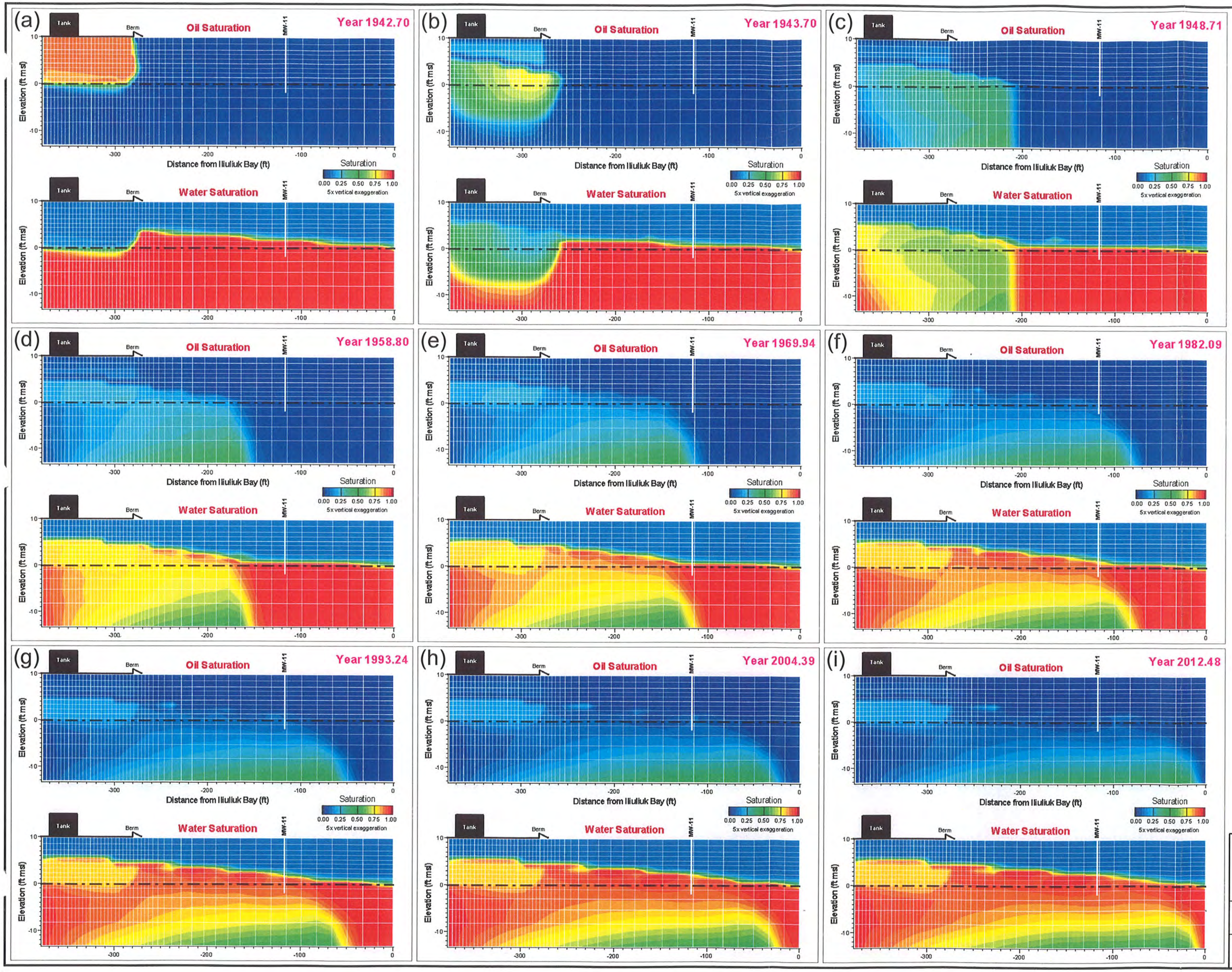
5.3.3 High Viscosity (Run 02)

In the High Viscosity model run, the oil viscosity was increased from 1,000 to 3,000 cSt, still lower than a realistic value for fresh Bunker C at ambient temperatures (see Section 3.7), but providing an illustration of the role of viscosity in oil migration. Selected frames from the High Viscosity migration animation (Run_02_HighViscosity.avi on the accompanying CD-ROM) are portrayed in Figure 5-5. The three-fold increase in viscosity has lengthened the infiltration period by slightly more than three-fold, from 0.19 to 0.68 years (frame [a]). Subsequent migration is nearly identical to the Base Case run, but at a similarly reduced rate. Oil arrives at MW-11 in about 71.5 instead of 20.5 years (about 2014 instead of 1963.0), and the model configuration in 2012 (frame [i]) is nearly identical to the Base Case run at 1958.9 (Figure 5-2, frame [d]). Because oil arrived at MW-11 by 1998, this viscosity is too large.

5.3.4 Low Van Genuchten Parameters (Run 06)

For the Low van Genuchten Parameters model run, α_{vG} was reduced to 7.0 from 14.5, and n_{vG} was reduced to 2.0 from 2.8, values that are appropriate for silty sands with hydraulic conductivities in the range indicated by the slug tests. Hydraulic conductivities in the model were not altered. Because of the exponential form of the van Genuchten equation (Equation 0-6), these changes represent a considerable shift in vadose-zone properties. The direct effect of these reductions is to significantly increase capillary effects, producing a much broader capillary fringe above the water table that extends to the top of the model.

Selected frames from the Low van Genuchten Parameters migration animation (Run_06_LowVGenuchten.avi on the accompanying CD-ROM) are portrayed in Figure 5-6. Initial infiltration (frame [a]) is complete in essentially the same period as for the Base Case, but the transition from oil to water occurs over a much broader zone vertically, and peak oil saturations are lower. The plot of water saturation in the same frame reveals the extent of the



Hydraulic Parameters

K_h = 300 ft/day

K_v = 60 ft/day

Porosity = 0.35

Residual water saturation = 0.10

Residual oil saturation = 0.20

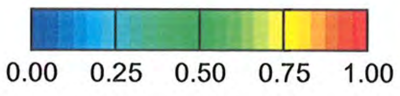
van Genuchten α = 14.5

van Genuchten n = 2.80

Oil viscosity = 1000 cSt

Oil density = 1.010 g/mL

Oil or Water Saturation



Fraction of Pore Space

Modeled using the Tank Farm TFslice model, which runs using MOFAT (EPA 1991). TFslice represents a 2-D vertical section through the aquifer, extending from the center of the Tank Farm through monitoring well MW-11 to Dutch Harbor. Oil infiltration begins in year 1942.5.

HIGH DENSITY (RUN 05) FOR MODELED BUNKER C MIGRATION AT THE PRE-WWII TANK FARM

AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen	FILE NAME: Fig5-04_AnimHighDensity.cdr	DATE: Feb. 10, 05
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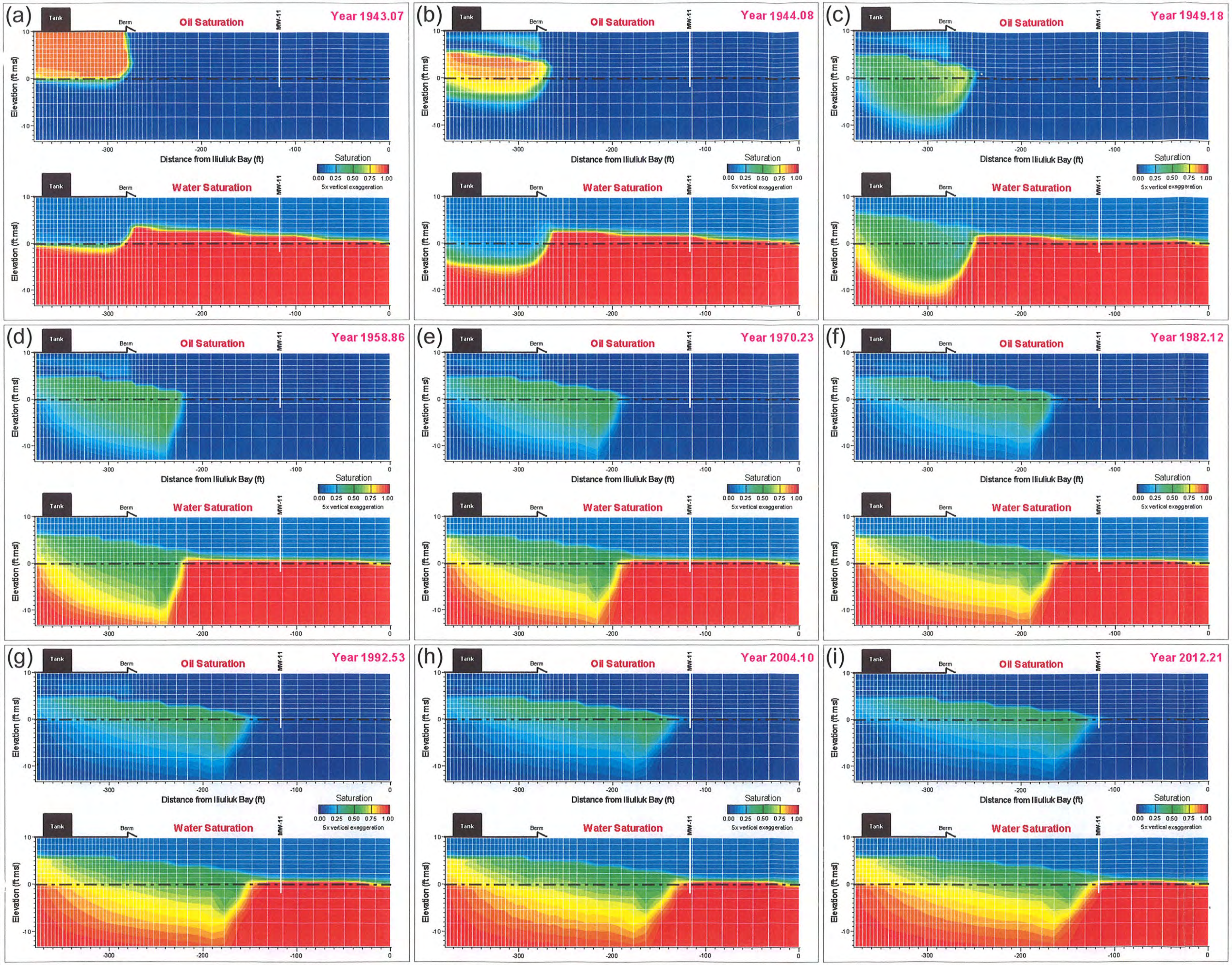


Hydraulic Parameters

K_h = 300 ft/day

K_v = 60 ft/day

Porosity = 0.35

Residual water saturation = 0.10

Residual oil saturation = 0.20

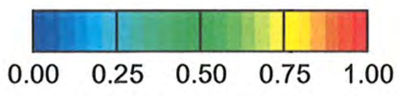
van Genuchten α = 14.5

van Genuchten n = 2.80

Oil viscosity = 3000 cSt

Oil density = 0.990 g/mL

Oil or Water Saturation



Fraction of Pore Space

Modeled using the Tank Farm TFslice model, which runs using MOFAT (EPA 1991). TFslice represents a 2-D vertical section through the aquifer, extending from the center of the Tank Farm through monitoring well MW-11 to Dutch Harbor. Oil infiltration begins in year 1942.5.

HIGH VISCOSITY(RUN 02) FOR
MODELED BUNKER C MIGRATION
AT THE PRE-WWII TANK FARM
AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen	Fig5-05_AnimHighViscosity.cdr	DATE: Feb. 10, 05
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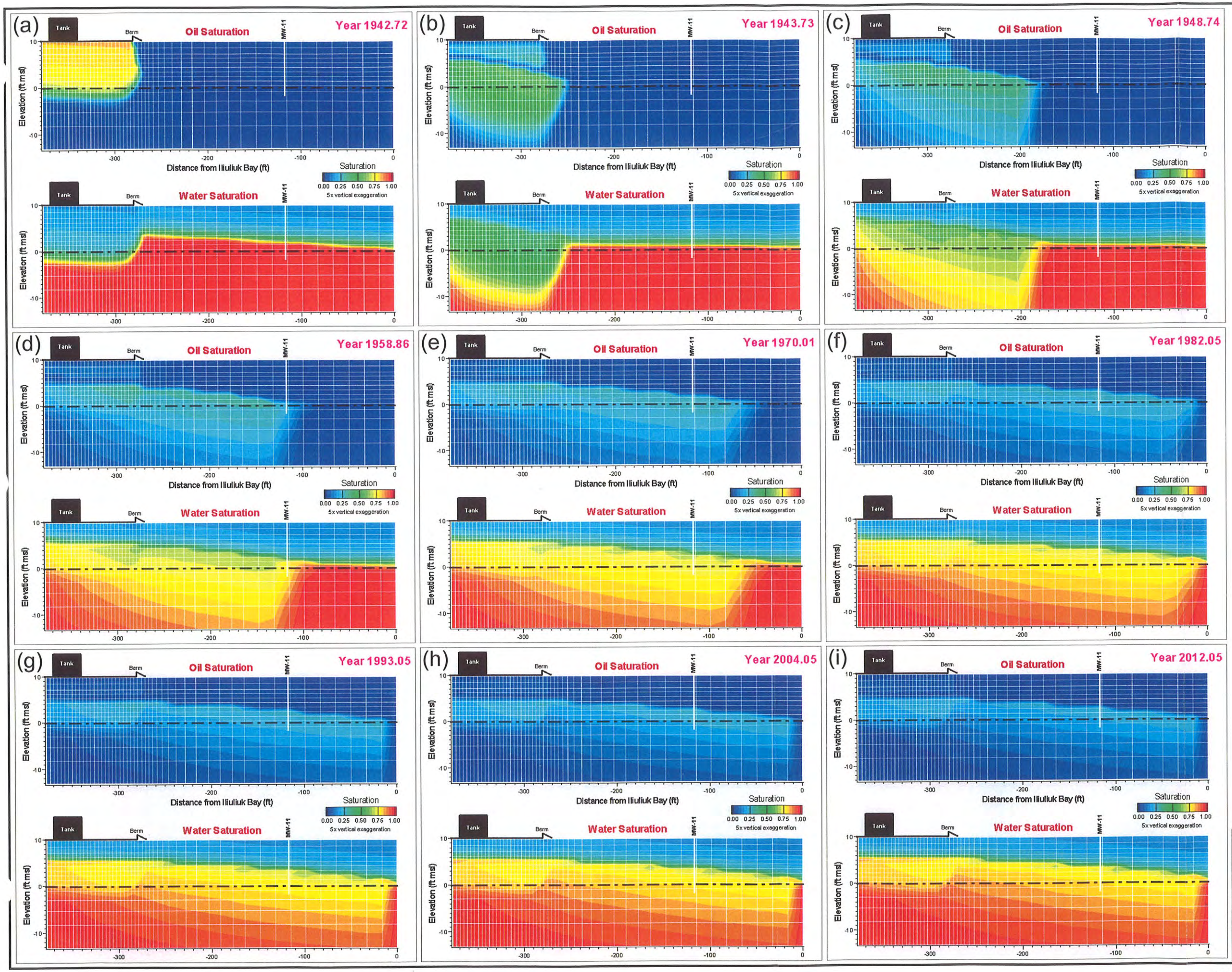

Hydraulic Parameters

K_h = 300 ft/day

K_v = 60 ft/day

Porosity = 0.35

Residual water saturation = 0.10

Residual oil saturation = 0.20

van Genuchten α = 7.0

van Genuchten n = 2.00

Oil viscosity = 1000 cSt

Oil density = 0.990 g/mL

Oil or Water Saturation

0.00 0.25 0.50 0.75 1.00

Fraction of Pore Space

Modeled using the Tank Farm TFslice model, which runs using MOFAT (EPA 1991). TFslice represents a 2-D vertical section through the aquifer, extending from the center of the Tank Farm through monitoring well MW-11 to Dutch Harbor. Oil infiltration begins in year 1942.5.

LOW VAN GENUCHTEN PARAMETERS (RUN 06) FOR MODELED BUNKER C MIGRATION AT THE PRE-WWII TANK FARM
AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen
Fig5-06_AnimLowVG.cdr
DATE: Feb. 10, 05
FIGURE NO.: 5-6
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broadened capillary fringe. These trends continue during the migration period, resulting in the oil-saturation zone (saturation greater than 0.25) extending to the bottom of the aquifer by 1948.7 (frame [c]). Mobility has been enhanced by the increased capillarity, with oil reaching MW-11 in only 15.3 years (1957.9) and Dutch Harbor in 39.6 years (1982.1), although the underlying mechanism for this is not clear. This model run shows that the rate of oil migration and distribution of oil saturation is strongly influenced by the properties assigned to the vadose zone. Such properties are difficult to measure, so the van Genuchten parameters may be considered adjustable within a reasonable range in order to calibrate the model to known or presumed site characteristics.

5.3.5 Actual Density (Run 07)

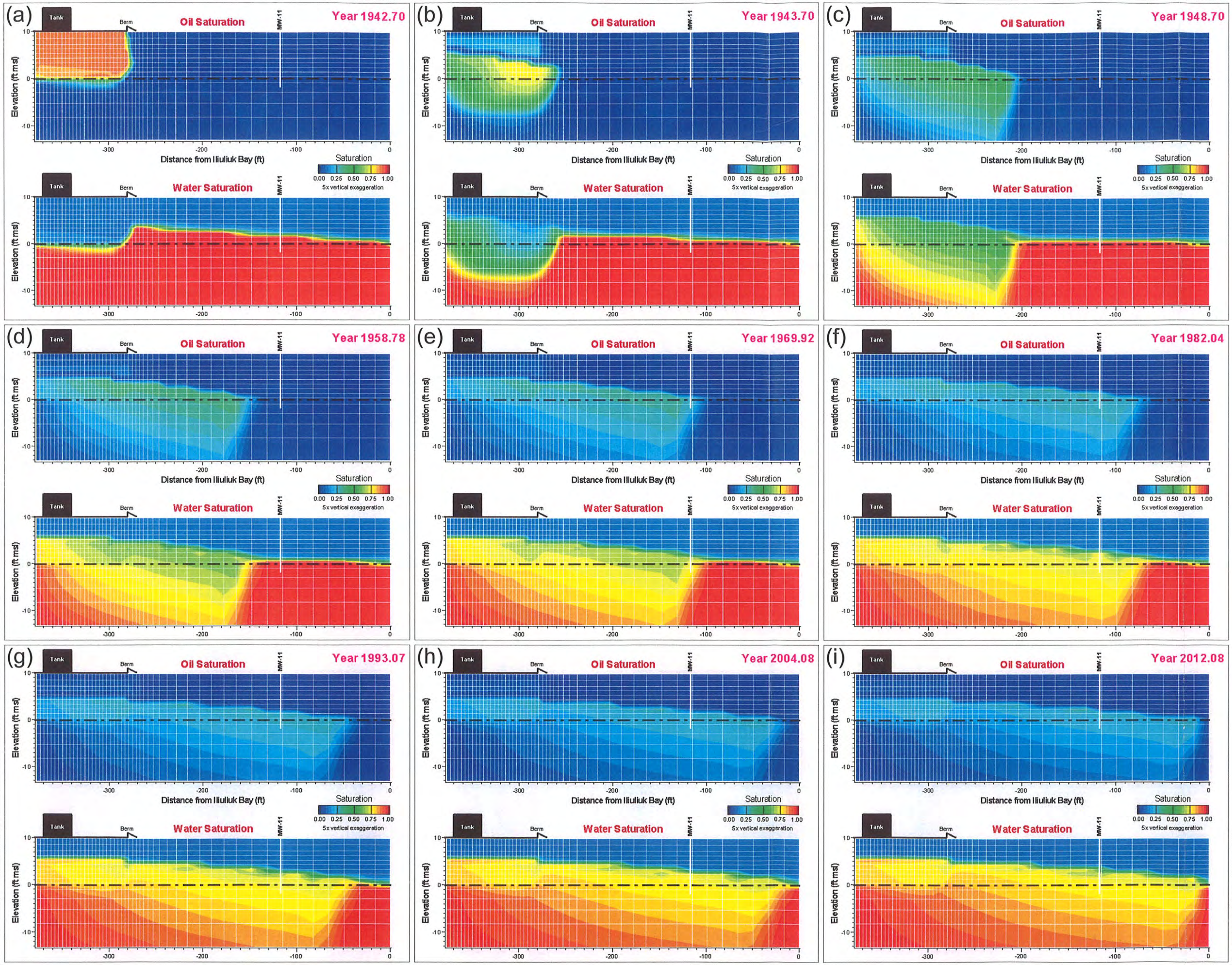
In the Actual Density run, the oil density was set to 0.997 g/mL, the most likely value for Bunker C at ambient temperatures based on the available site-specific measurements (Section 3.7). The difference between this density and that of water (assumed to be 1.000 g/mL) is only 0.003 g/mL, about three times smaller than the difference for the Base Case run. Thus, buoyancy effects will be correspondingly reduced; the oil will tend to displace the groundwater rather than float on it, but will not sink to the bottom of the aquifer.

Selected frames from the Actual Density migration animation (Run_07_ActualDensity.avi on the accompanying CD-ROM) are portrayed in Figure 5-7. Initial infiltration (frame [a]) is essentially identical with the Base Case run, but differences reflecting reduced buoyancy begin to be apparent in subsequent frames, in which the oil-saturation zone (saturation greater than 0.25) penetrates more deeply. The oil zone has reached the bottom of the aquifer after 6.3 years (frame [c]), and at later times continues to be distributed across a wider vertical range with lower peak saturations compared to the Base Case run. Migration is somewhat slower, with oil arriving at MW-11 after 24.9 years instead of 20.5 years (1967.4 instead of 1963.0), and reaching Dutch Harbor after 67.6 years instead of 54.2 years (2010.1 instead of 1996.7).

5.3.6 High Anisotropy (Run 10)

For the High Anisotropy run, K_v was set to 3 ft/day instead of 60 ft/day, yielding a vertical anisotropy (K_v/K_h) of 100 instead of 5. This change retards vertical fluid migration by a factor of 20 relative to the Base Case, but has no direct effect on horizontal fluid migration. Indirectly, reduced vertical oil migration changes the horizontal as well as the vertical distribution of oil. Although sands and gravels, which probably transmit the bulk of the groundwater flow, typically exhibit low anisotropies in the 3 to 10 range, the aquifer also contains silt and peat lenses that could greatly reduce vertical conductivity. The resulting high anisotropy would enhance the propagation of tidal influences by creating a semi-confined condition; vertical movement of water would be inhibited, aiding the lateral transmission of a head change.

Selected frames from the Actual Density migration animation (Run_10_Anisotropy100.avi on the accompanying CD-ROM) are portrayed in Figure 5-8. Initial infiltration (frames [a] and [b]) is much slower than for the Base Case, and the strong anisotropy prevents the oil from sinking deeply below the water table. Instead, the oil begins spreading laterally at the water table. In late 1948 (frame [c]), the oil has migrated only about 50 feet downgradient of the berm at the tank farm and still forms a compact zone with peak oil saturation greater than 80 percent. In contrast, the Base Case (Figure 5-2) in late 1948 depicts the leading edge of the oil plume at 85 feet downgradient of the berm. The difference in oil saturation and vertical distribution is striking; although peak oil saturation is lower for the Base Case (approximately 60 percent), oil is present throughout the entire thickness of the aquifer. The difference in migration rates between the two cases soon subsides, however, with oil reaching Dutch Harbor in 2003 in the High Anisotropy run compared to 1996 in the Base Case. The distribution of oil within the model is similar in both cases at this stage.



Hydraulic Parameters

K_h = 300 ft/day

K_v = 60 ft/day

Porosity = 0.35

Residual water saturation = 0.10

Residual oil saturation = 0.20

van Genuchten α = 14.5

van Genuchten n = 2.80

Oil viscosity = 1000 cSt

Oil density = 0.997 g/mL

Oil or Water Saturation

0.00 0.25 0.50 0.75 1.00

Fraction of Pore Space

Modeled using the Tank Farm TFslice model, which runs using MOFAT (EPA 1991). TFslice represents a 2-D vertical section through the aquifer, extending from the center of the Tank Farm through monitoring well MW-11 to Dutch Harbor. Oil infiltration begins in year 1942.5.

ACTUAL DENSITY (RUN 07) FOR
MODELED BUNKER C MIGRATION
AT THE PRE-WWII TANK FARM
AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen	Fig5-07_AnimActualDensity.cdr	DATE: Feb. 10, 05
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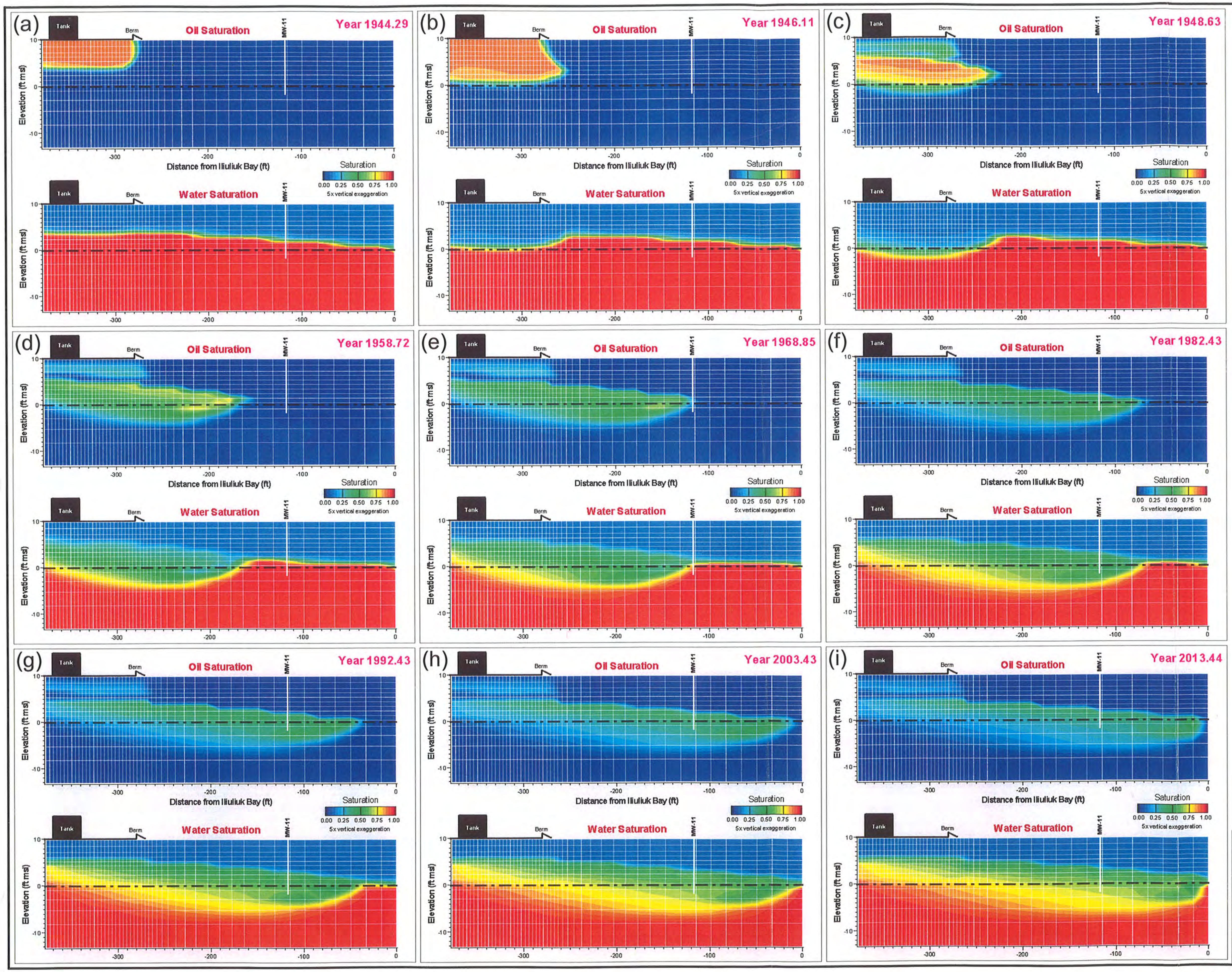

Hydraulic Parameters

K_h = 300 ft/day

K_v = 3 ft/day

Porosity = 0.35

Residual water saturation = 0.10

Residual oil saturation = 0.20

van Genuchten α = 14.5

van Genuchten n = 2.80

Oil viscosity = 1000 cSt

Oil density = 0.99 g/mL

Oil or Water Saturation

0.00 0.25 0.50 0.75 1.00

Fraction of Pore Space

Modeled using the Tank Farm TFslice model, which runs using MOFAT (EPA 1991). TFslice represents a 2-D vertical section through the aquifer, extending from the center of the Tank Farm through monitoring well MW-11 to Dutch Harbor. Oil infiltration begins in year 1942.5.

HIGH ANISOTROPY (RUN 10) FOR MODELED BUNKER C MIGRATION AT THE PRE-WWII TANK FARM
AMAKNAK ISLAND, ALASKA

PROJECT MANAGER: J. Cohen	Fig5-08_AnimAnistropy100.cdr	DATE: Feb. 10, 05
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5.4 IMPLICATIONS OF LNAPL FLOW MODELING

Several important conclusions can be inferred from the LNAPL flow modeling runs:

- Oil infiltration is rapid because of the steep downward pressure gradient, whereas lateral migration is slow because the water-table gradient is comparatively flat.
- Because the oil density is only slightly less than that of water, it mostly displaces water at the water table rather than floating on top of the water table.
- Model parameters (with the exception of oil density) that give reasonable migration rates are poorly constrained by the available data. Realistic model parameters consistent with the most direct observations result in unrealistically slow migration rates. Given the historical presence of oil at MW-11 since its original installation in 1998 (USAED 1999), the mobility of Bunker C must have been greater than that portrayed by the High Viscosity run. If the actual viscosity was 3,000 cSt or more, then other factors must have promoted oil migration.
- The rate of oil migration slows dramatically as the zone of oil saturation becomes progressively less saturated. As the oil zone migrates downgradient, it loses mass by leaving a trail of residual saturation. In the Actual Density run, 24.9 years elapsed before oil reached MW-11, 160 feet downgradient. Another 42.7 years elapsed before oil reached the shoreline, only 115 feet farther downgradient.
- Residual oil saturation will have a pronounced effect on the local transmissivity of the aquifer to groundwater flow. This effect will be superimposed on hydrostratigraphic variations, further complicating an already complex situation. This may offer a partial explanation of the calibration difficulties encountered during the MODFLOW groundwater flow modeling.
- Free product in MW-11 is probably a consequence of local well dynamics rather than reflecting free product (oil saturation approaching 0.9) in the aquifer at large. Capillary effects mean that the oil/water interface is a broad zone rather than a sharp front.
- Three key factors are not accounted for in the model: tidal smearing, recharge from precipitation, and biodegradation. Tidal smearing would spread the oil, reducing its saturation level and therefore its migration rate. Recharge would have a similar effect, piling clean water on top of the oil, resulting in interfingering and dispersal as the water and oil flow past each other to achieve hydrostatic equilibrium. Biodegradation would not only reduce the amount of oil in the subsurface, it would preferentially remove the relatively shorter-chain hydrocarbons, leaving a progressively more refractory and less mobile residue.

The LNAPL flow modeling cannot conclusively reveal whether Bunker C is presently discharging into Dutch Harbor. The available data for the Pre-WWII Tank Farm permit a wide latitude in the selection of most input parameters other than density, and the timing of

Bunker C arrival at offsite locations such as MW-11 is unknown, other than that it occurred sometime before 1998. Nevertheless, the Base Case run is consistent with the currently observed distribution of Bunker C in MW-11 and at the shoreline, suggesting that the two observations are connected, and provides important insights into future Bunker C discharges from the tank farm into Dutch Harbor:

- Bunker C may have recently arrived at the shoreline, indicating that the oil is migrating quite slowly. Therefore, the rate of discharge will never be very high. The leading edge of the oil zone is the most concentrated, so present discharge rates are probably the maximum discharge rates.
- Bunker C may have been discharging for some time. In this case, peak discharge would have occurred some time in the past, tapering to present discharge rates.

In either case, future discharge rates will be lower than present discharge rates. From the long trail of oil at near-residual saturation going back to the tank farm depicted by the LNAPL flow modeling, continuing low-level discharge can be extrapolated many decades into the future. Biodegradation, discussed in the next section, may become a major factor at such a time scale, however.

It is also possible that Bunker C from the tank farm has not yet arrived at the shoreline, implying that the observed heavy oil contamination drifted in with the tide. Model runs similar to the High Viscosity and Low K_h runs but with less extreme changes could simulate oil migration at the required rate. Future discharge along the shoreline, if any, would be at a very low rate, probably so low as to be undetectable compared to other local sources of petroleum.

6.0 REVIEW OF NATURAL ATTENUATION

The foregoing groundwater and LNAPL flow modeling suggests that petroleum contamination in the subsurface at the Pre-WWII Tank Farm is slowly migrating toward Dutch Harbor and may have begun discharging into the bay, where dilution (the simplest form of natural attenuation) will reduce contaminant concentrations to undetectable levels. Because of the high viscosity of the Bunker C coupled with the dynamics of oil migration, this process will likely continue at a slowly declining rate for many decades, providing ample opportunity for in-situ degradation. If degradation rates are high enough, this mechanism of natural attenuation may completely degrade the petroleum contamination in the subsurface, eventually eliminating any discharge to the bay.

Biodegradation is the primary mechanism by which the petroleum contamination could be degraded in the subsurface. Geochemical parameters that can provide evidence of biodegradation have been measured in groundwater samples (USAED 2004; Table 6-1). The following parameters have been measured:

- Ferric Iron (Fe^{3+}) — Most oxidized form of iron. Essentially insoluble; elevated values indicate particulate matter is present.
- Ferrous Iron (Fe^{2+}) — Reduced relative to ferric iron. Comparatively soluble; elevated values indicate reducing conditions.
- Total Iron — Ferric plus ferrous iron. Low unless particulate matter or ferrous iron is present.
- Nitrate (NO_3^-) — Most oxidized form of nitrogen. An essential nutrient that can also be used as an electron acceptor under anaerobic conditions.
- Nitrite (NO_2^-) — Moderately oxidized form of nitrogen, utilized much like nitrate.
- Nitrogen — Nitrate + nitrite. See nitrate and nitrite, above.
- Sulfate (SO_4^{2-}) — Most oxidized form of sulfur, used as an electron acceptor under anaerobic conditions after nitrate/nitrite has been depleted. Derived from weathering of sulfide minerals or of sulfur in the Bunker C.
- Sulfide (S^{2-}) — Most reduced form of sulfur, indicating strongly reducing conditions.
- Alkalinity — Increases during mineralization (conversion) of hydrocarbons to carbon dioxide or dissolution of carbonate minerals.

- Methane — Good indicator of degradation and reducing conditions. If methane is present, conditions are anaerobic; the hydrocarbons have not been completely oxidized.

Results for natural attenuation parameters (Table 6-1) suggest that some biodegradation is occurring near MW-8, MW-11, and MW-13. Evidence of biodegradation near these wells includes elevated alkalinity and methane concentrations, depressed sulfate concentrations compared to the other Pre-WWII Tank Farm wells, and occasional sulfide detections. These observations are consistent with petroleum biodegradation under mildly anaerobic to sulfate-reducing conditions, yielding either carbon dioxide or methane as metabolic endpoints. Although elevated methane concentrations were also measured in MW-10 and MW-12, these wells have not contained product in recent sampling rounds, and other biodegradation indicators are absent, suggesting that some methane is occurring naturally, probably related to the organic-rich clays and peat layers noted across the site in borehole and test-pit logs. (Anomalously, MW-12 also contains the highest dissolved oxygen reading, which at 11.3 mg/L suggests thorough equilibration with air, but this value is most likely an artifact of the sampling process.)

Strongly reducing anaerobic conditions are generally absent, as signified by the uniformly low ferrous iron concentrations, but a field observation in October 2003 of high levels of iron-oxyhydroxide particulates in a temporary sampling point along the shoreline near MW-11 suggests that iron-reducing conditions may exist upgradient. High dissolved ferrous iron concentrations from a zone of iron reduction would be oxidized to insoluble ferric iron and then precipitated as iron oxyhydroxides by the time groundwater reaches the shoreline.

Geochemical and circumstantial evidence suggest that biodegradation of the petroleum contamination is occurring only at a low rate, so free product will continue to be detected in MW-8, MW-11, and MW-13 during future monitoring events unless additional active remedial measures are pursued. Although low ambient temperatures contribute to the low biodegradation rate, geochemical conditions could be improved. Nitrogen is low in all of the wells sampled, not just those with product, suggesting that the rate of biodegradation may be limited by lack of nitrogen. Although phosphorus was not analyzed, it may be in short supply

Table 6-1
Sample Results for Natural Attenuation Parameters

Monitoring Well — *Sampling Date*	**Field Determinations (mg/L)**						**Laboratory Analyses**				
	Dissolved Oxygen	**Total Iron**	**Ferrous Iron**	**Ferric Iron**	**Nitrate**	**Nitrite**	**Sulfate**	**Alkalinity**	**Nitrate + Nitrite**	**Sulfide**	**Methane**
							(mg/L)				**(µg/L)**
MW-2											
2-Nov	0.9	0.0	0.0	0.0	N/A	0.00	38	58	0.4	ND	19
MW-8											
2-Feb	0.2	8.6	4.2	4.4	0.00	0.00	81.2	130	ND	ND	30
2-May	0.4	6.5	4.2	2.3	0.03	0.00	73.2	101	0.03	ND	110
2-Aug	0.3	7.0	4.6	2.4	ND	ND	53	128	ND	ND	170
2-Nov	0.5	5.2	4.2	1.0	N/A	0.00	68	138	0.03	0.05	55
MW-10											
2-Feb	0.8	2.1	1.0	1.1	0.00	0.00	61.2	104	0.1	ND	130
2-May	0.9	1.6	1.3	0.3	0.00	0.00	60.8	91	ND	ND	82
2-Aug	0.6	3.0	0.2	2.8	0.07	ND	61	90	0.07	ND	98
2-Nov	0.5	1.2	1.8	-0.6	N/A	0.01	98	95	0.05	ND	100
MW-11											
2-Feb	0.7	9.1	4.4	4.7	0.00	0.00	36.6	166	ND	ND	580
2-May	0.3	>10	2.9	7.1	0.00	0.00	2	172	ND	ND	970
2-Aug	0.5	>105	5.2	4.8	0.06	ND	0.3	142	0.06	ND	2300
2-Nov	0.3	3.0	4.0	-1.0	N/A	0.00	6.1	161	0.03	0.2	1400
MW-12											
2-Feb	11.6	3.4	2.4	1.0	0.00	0.00	272	136	0.6	ND	290
MW-13											
2-Nov	0.4	5.2	5.0	0.2	N/A	0.00	13	90	0.03	0.19	N/A
MW-14											
2-May	1.8	1.3	0.8	0.5	0.13	0.00	49.2	46	0.13	ND	14
2-Aug	1.0	1.6	1.2	0.4	ND	ND	39	62	ND	ND	32
2-Nov	7.3	0.0	0.0	0.0	N/A	0.00	45	39	0.3	ND	ND
MW-15											
2-May	1.4	0.7	0.2	0.5	0.06	0.00	21.4	38	0.06	ND	1.2
2-Nov	2.1	0.0	0.0	0.0	N/A	0.00	21	62	0.06	ND	ND
MWNLF-3											
2-May	7.3	>10	0.7	9.3	0.10	0.00	145	92	0.1	ND	0.8
2-Aug	5.4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2-Nov	5.2	0.0	0.0	0.0	N/A	0.00	63	61	0.2	ND	0.51

<u>Notes:</u>

See the Groundwater Monitoring Program 2003 Annual Report (USAED 2004) for data qualifiers and raw data.
N/A = not analyzed

as well. Finally, low oxygen levels force bacteria to use lower-yield electron acceptors. Thus, oxygenation and fertilization of the subsurface environment might accelerate biodegradation rates to useful levels.

7.0 SUMMARY AND RECOMMENDATIONS

Constructing and calibrating a groundwater flow model provides a structured means of evaluating and integrating the numerous and often disparate bits of information about the groundwater system. The modeling process starkly illuminates key parameters and conflicting observations, as was discovered at the Pre-WWII Tank Farm for estimates of recharge, storage coefficient (specific yield), slug-test hydraulic conductivity, vertical hydraulic conductivity, and interpretations of tidal influences. Water level measurements revealed a nearly flat water table across the former tank farm site. Flat gradients imply high transmissivity; otherwise, water from rainfall-derived recharge would pile up with time, leading to steep gradients. Slug-test results suggested that hydraulic conductivities were in the 1.5 to 25 ft/day range, but such values were found to be too low to be consistent with the nearly flat water table. Therefore, hydraulic conductivities were adjusted upward to accommodate a low but potentially plausible rate of recharge from precipitation (13 inches per year, or approximately 25 percent of annual precipitation). The resulting horizontal hydraulic conductivities ranged from 3 to 400 ft/day, broadly consistent with values inferred from an analytical evaluation of tidal influences. Finally, tidal influences were very strong in monitoring wells near the shoreline, and remained significant on the far side of the tank farm site at MW-8. The site-wide groundwater flow model could simulate only weak tidal influences, and an evaluation using a schematic groundwater flow model reinforced the idea that effective hydraulic conductivities may be on the order of 300 ft/day. These groundwater models assumed that the aquifer was unconfined, with good vertical hydraulic conductivity, but the low calibrated storage coefficients of 0.001 to 0.0001 imply that the aquifer is semiconfined at the tidal time scale. Physically, semiconfined behavior would be a natural consequence of silt and peat lenses interbedded with the sands and gravels, drastically reducing vertical — relative to horizontal — hydraulic conductivity.

General features of the hydrologic system at the Pre-World War II Tank Farm are well supported by this investigation:

- Groundwater flow from the eastern portion of the site is to the east, toward MW-11, whereas groundwater flow from the western portion of the site is to the south, beneath Building 551 and toward MW-13.
- The water table shows strong seasonal variability, with the water table rising by 2 feet or more in some wells during wetter seasons. The general flow usually persists, but local anomalies, perhaps related to recharge from the dry wells, have occurred.
- Groundwater moves rapidly across the site to the discharge zone along the shoreline, probably requiring only a year or two for the trip. Modeled travel time for water is between 1.0 and 2.5 years, and is directly related to assumptions about recharge. Higher recharge would only shorten travel times.
- Horizontal hydraulic conductivity to the south of the site must be large, but vertical hydraulic conductivity may be quite small

The LNAPL flow model reveals much about the dynamics of Bunker C migration. In spite of rapid groundwater flow, Bunker C released at the tank farm was simulated to arrive at MW-11 in 20 years or more, and may have reached Dutch Harbor after 54 years or possibly much longer. Migrating oil is attenuated as it moves because it leaves a trail of trapped oil at residual saturation. Thus, the rate of Bunker C discharge to the bay can never be very high. If the oil contamination observed at the shoreline during the October 2003 fieldwork is derived from the tank farm, then the leading edge of the migrating oil, where the degree of oil saturation is the highest, must already have discharged. This means that the current rates of discharge will only decline with time, although discharge will persist for many decades. In the more likely scenario where the observed oil contamination at the shoreline derives from maritime activities in Iliuliuk Bay and Dutch Harbor, the leading edge has probably not yet arrived at the shoreline. When it does arrive, discharge rates are likely to be imperceptibly low. Alternatively, it may never arrive because weathering and degradation along the flow path lead to increasing viscosity with time, eventually immobilizing it.

The evaluation of natural-attenuation geochemical parameters in groundwater suggests that some biodegradation is occurring, but not at rates that will mitigate the remaining subsurface contamination in the near future. Biodegradation rates appear to be limited by the availability of oxygen and nutrients, as well as by cold ambient temperatures and the refractory nature of the long-chain hydrocarbons that comprise the bulk of Bunker C.

If no further action is taken at the Pre-WWII Tank Farm, the groundwater flow modeling, LNAPL flow modeling, and natural-attenuation evaluation combine to indicate that conditions will not worsen, but will slowly improve on a decadal time scale.

Several actions could be implemented to treat soil, groundwater, and LNAPL contamination at the site. The Focused Feasibility Study developed for the Pre-WWII Tank Farm evaluates several remedial technologies (alternatives) to address the contamination (USAED 2005a). The Proposed Plan, which will be open to public review and comment, will discuss the preferred alternative(s). Following receipt of comments on the Proposed Plan, a Decision Document will be developed to document the remedial alternatives evaluation.

Lack of knowledge regarding a few key parameters prevents groundwater modeling from providing a more definitive assessment of Bunker C migration pathways and prediction of possible discharge to the surface environment. These data gaps are as follows:

- The current distribution of Bunker C in the subsurface is poorly known. A detailed investigation of the subsurface by numerous boreholes or direct-push laser-induced fluorescence profiling would accurately delineate the margins of the plume and help answer the question of whether Bunker C is presently discharging to Dutch Harbor.
- Recharge and boundary flows in the model are not based on site-specific data. These could be refined somewhat by developing a surface-water budget for the site to determine the fraction of precipitation that leaves as overland flow, the fraction that enters the aquifer via the dry wells, and the fraction that reaches the aquifer via infiltration. The City of Unalaska and the Alaska Department of Transportation and Public Facilities may have already collected and analyzed much of the data in preparation for upgrading storm drains and roads in the area.
- The ramifications of high anisotropy (low vertical hydraulic conductivity compared to horizontal conductivity) have not been thoroughly explored in the model. Future modeling should investigate whether high anisotropy can produce the short-term semi-confined conditions needed to simulate the observed tidal influences. Numerous soil borings or direct-push conductivity profiles to bedrock could identify the frequency and extent of silt and peat zones that likely are responsible for the apparent highly anisotropic semi-confined conditions.

- Hydraulic conductivity has not been satisfactorily measured. Although both the model calibration and the analysis of tidal influence measurements suggest that hydraulic conductivities are high, the slug-test results appear to be biased low. Although the slug-test data should be re-analyzed for confined conditions, those results likely would be even lower. A pumping test could provide a more reliable determination of hydraulic conductivity, but should be conducted only if quantitative defensible model results become critical to selecting an appropriate remedial action for the site.

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Appendix A

APPENDIX A

Figures for Tidal Influence Evaluations, and Details and Figures for Slug Tests

TABLE OF CONTENTS

SECTION **PAGE**

1.0 TIDAL INFLUENCE FIGURES A-1
2.0 SLUG TEST DETAILS AND FIGURES A-13
  2.1 MW-2 .... A-13
  2.2 MW-8 .... A-16
  2.3 MW-10 .... A-19
  2.4 MW-12 .... A-22
  2.5 MW-14 .... A-25
  2.6 MW-15 .... A-28
  2.7 RPMW-16 .... A-31
3.0 REFERENCES A-34

FIGURES

Figure 1-1 Observed and Simulated Tidal Influence in MW-2 .... A-1
Figure 1-2 Observed and Simulated Tidal Influence in MW-3R A-2
Figure 1-3 Observed and Simulated Tidal Influence in MW-6 .... A-3
Figure 1-4 Observed and Simulated Tidal Influence in MW-7R A-4
Figure 1-5 Observed and Simulated Tidal Influence in MW-8 .... A-5
Figure 1-6 Observed and Simulated Tidal Influence in MW-10 .... A-6
Figure 1-7 Observed and Simulated Tidal Influence in MW-11 .... A-7
Figure 1-8 Observed and Simulated Tidal Influence in MW-12 .... A-8
Figure 1-9 Observed and Simulated Tidal Influence in MW-13 .... A-9
Figure 1-10 Observed and Simulated Tidal Influence in MW-14 .... A-10
Figure 1-11 Observed and Simulated Tidal Influence in MW-15 .... A-11
Figure 1-12 Observed and Simulated Tidal Influence in RPMW-16 .... A-12
Figure 2-1 Slug-Test Raw Data and Displacements Measured in MW-2 .... A-14
Figure 2-2 Bouwer-Rice Analysis of MW-2 Slug Tests A-15
Figure 2-3 Slug-Test Raw Data and Displacements Measured in MW-8 .... A-17
Figure 2-4 Bouwer-Rice Analysis of MW-8 Slug Tests A-18
Figure 2-5 Slug-Test Raw Data and Displacements Measured in MW-10 .... A-20
Figure 2-6 Bouwer-Rice Analysis of MW-10 Slug Tests A-21
Figure 2-7 Slug-Test Raw Data and Displacements Measured in MW-12 .... A-23

TABLE OF CONTENTS
(continued)

SECTION **PAGE**

Figure 2-8 Bouwer-Rice Analysis of MW-12 Slug Tests..A-24
Figure 2-9 Slug-Test Raw Data and Displacements Measured in MW-14 ....A-26
Figure 2-10 Bouwer-Rice Analysis of MW-14 Slug Tests..A-27
Figure 2-11 Slug-Test Raw Data and Displacements Measured in MW-15 ....A-29
Figure 2-12 Bouwer-Rice Analysis of MW-15 Slug Tests..A-30
Figure 2-13 Slug-Test Raw Data and Displacements Measured in RPMW-16...................A-32
Figure 2-14 Bouwer-Rice Analysis of RPMW-16 Slug Tests...A-33

1.0 TIDAL INFLUENCE FIGURES

Figures 1-1 through 1-12 compare observed water levels in monitoring wells MW-2 through RPMW-16 to the tidal water level measured nearby at the City of Unalaska by NOAA. Simulated water levels from the tidal influence analysis discussed in Section 3.3 of the main body of this report are also plotted.

Figure 1-1
Observed and Simulated Tidal Influence in MW-2

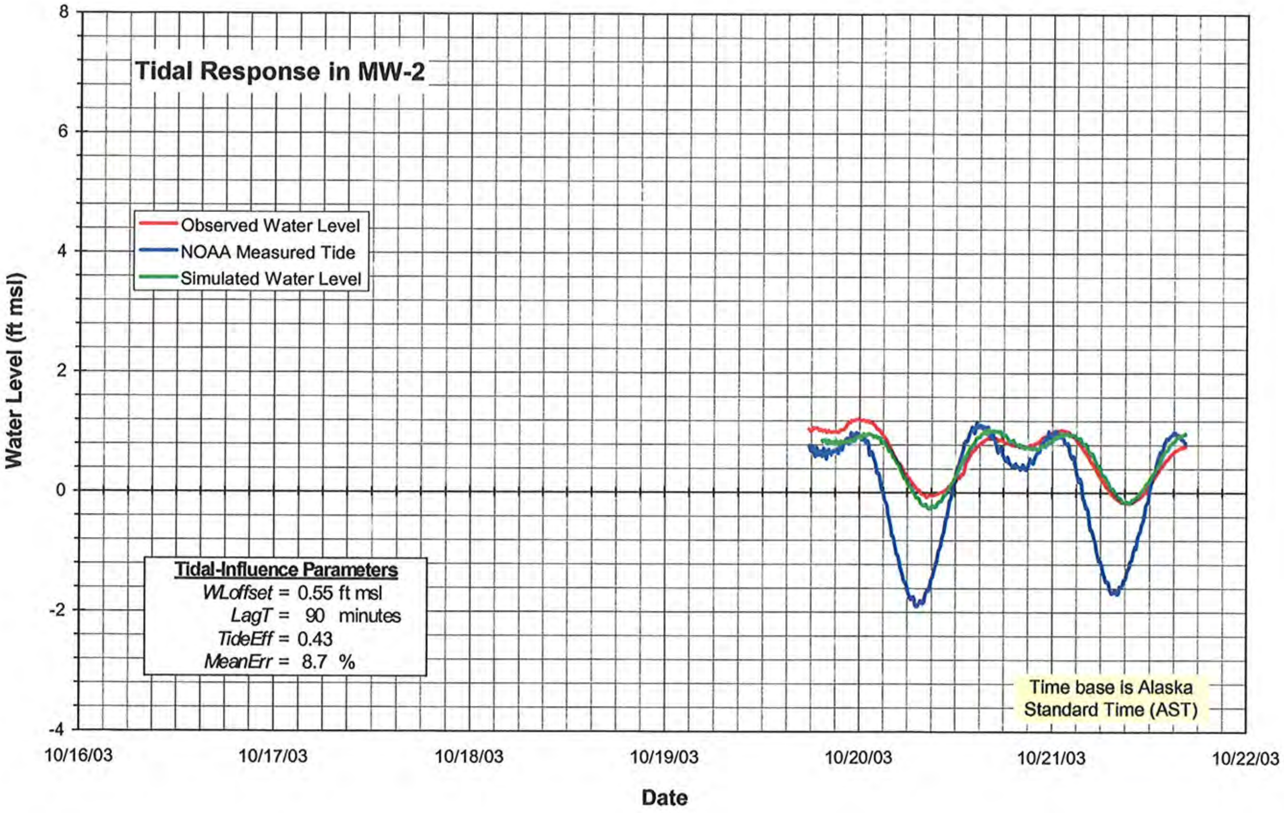


Figure 1-2
Observed and Simulated Tidal Influence in MW-3R

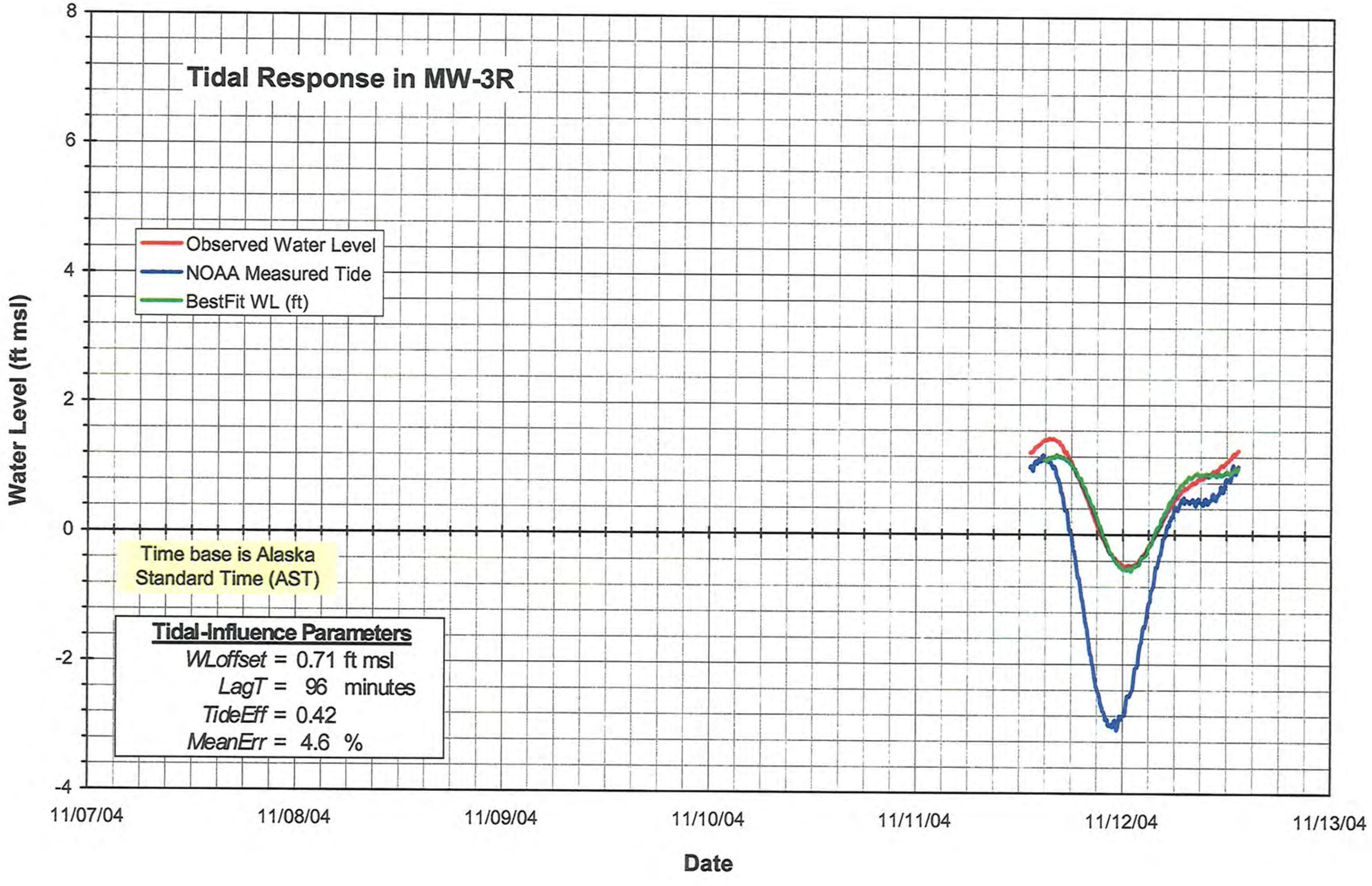


Figure 1-3
Observed and Simulated Tidal Influence in MW-6

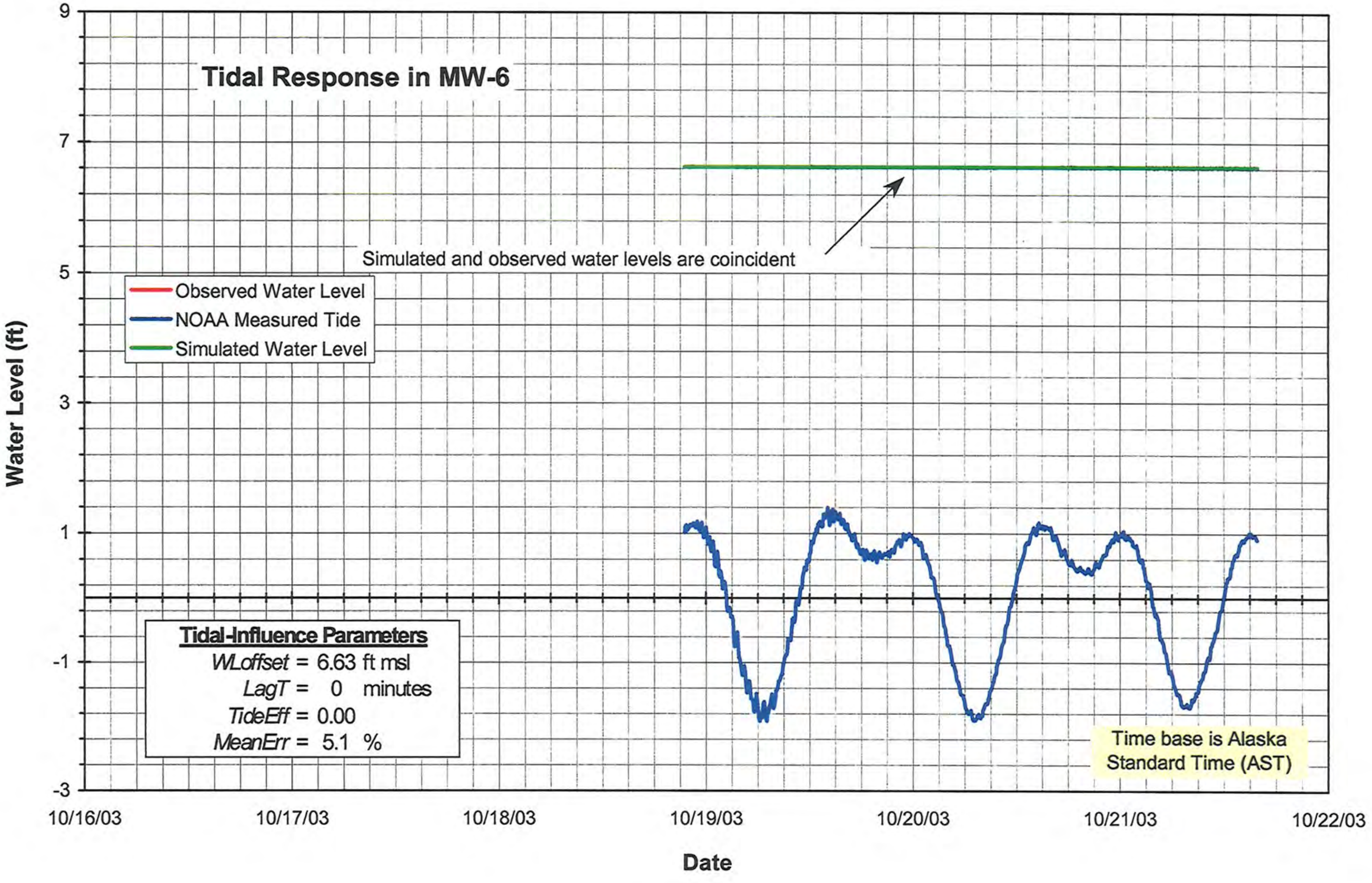


Figure 1-4
Observed and Simulated Tidal Influence in MW-7R

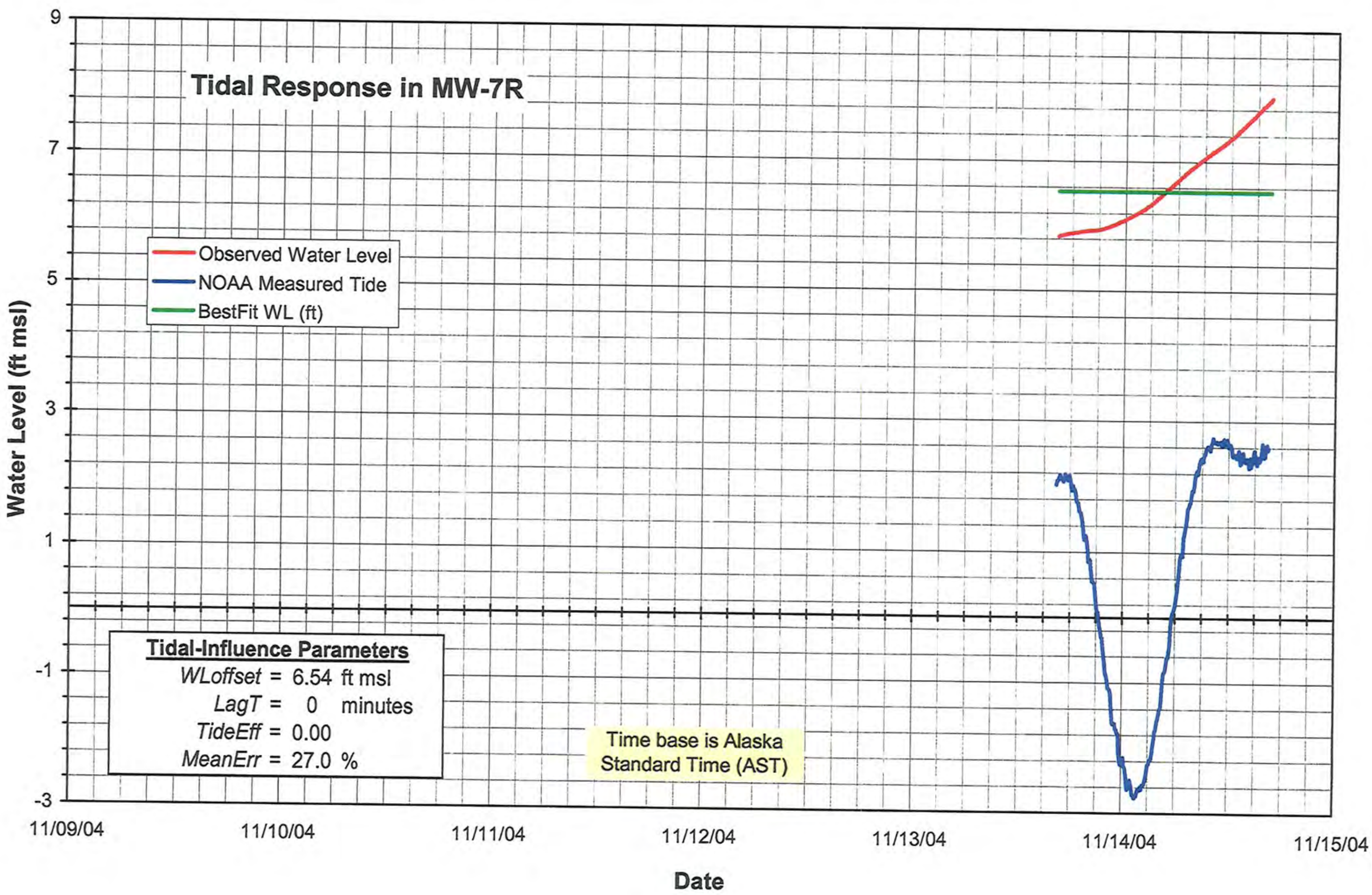


Figure 1-5
Observed and Simulated Tidal Influence in MW-8

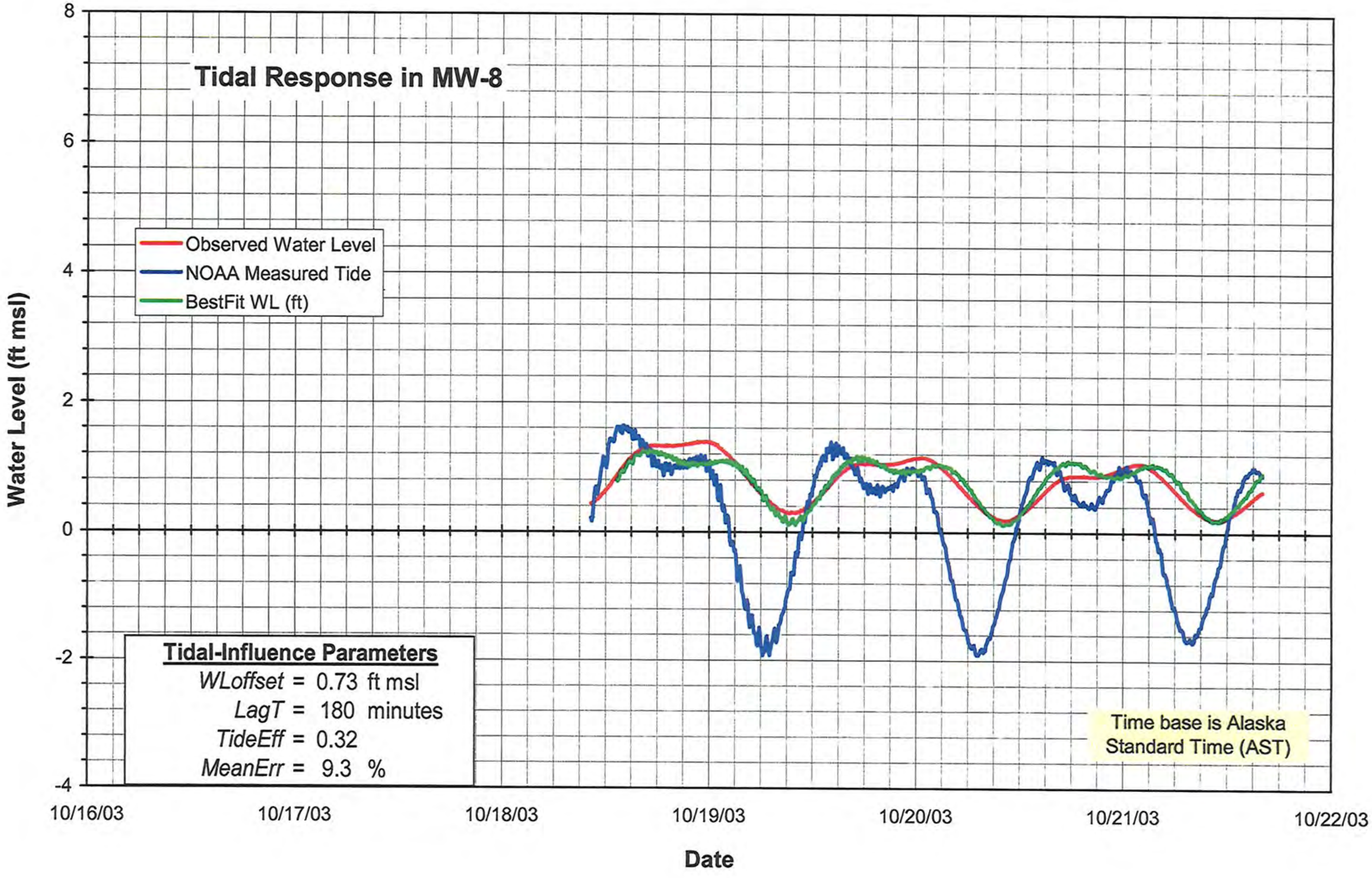


Figure 1-6
Observed and Simulated Tidal Influence in MW-10

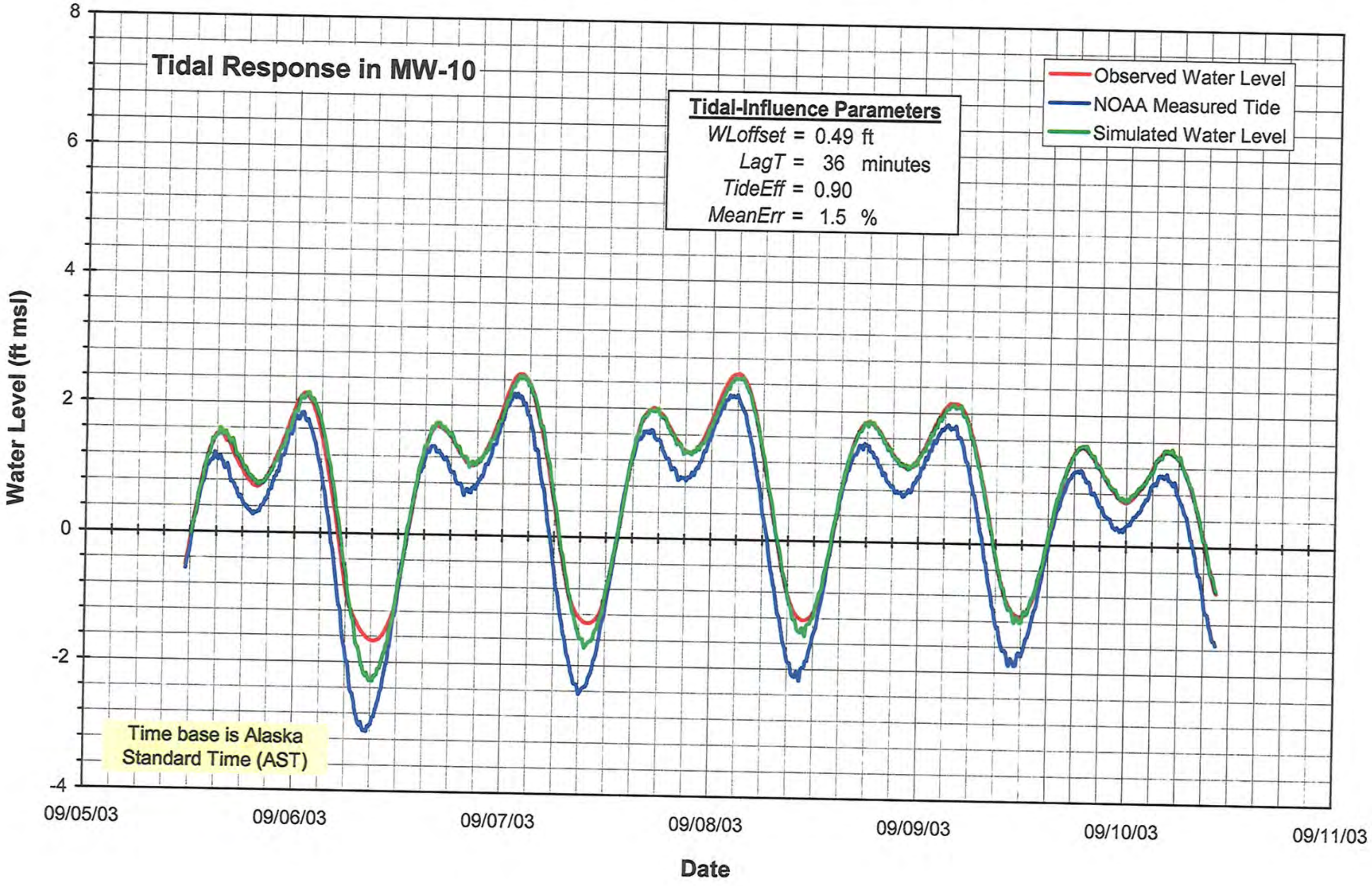


Figure 1-7
Observed and Simulated Tidal Influence in MW-11

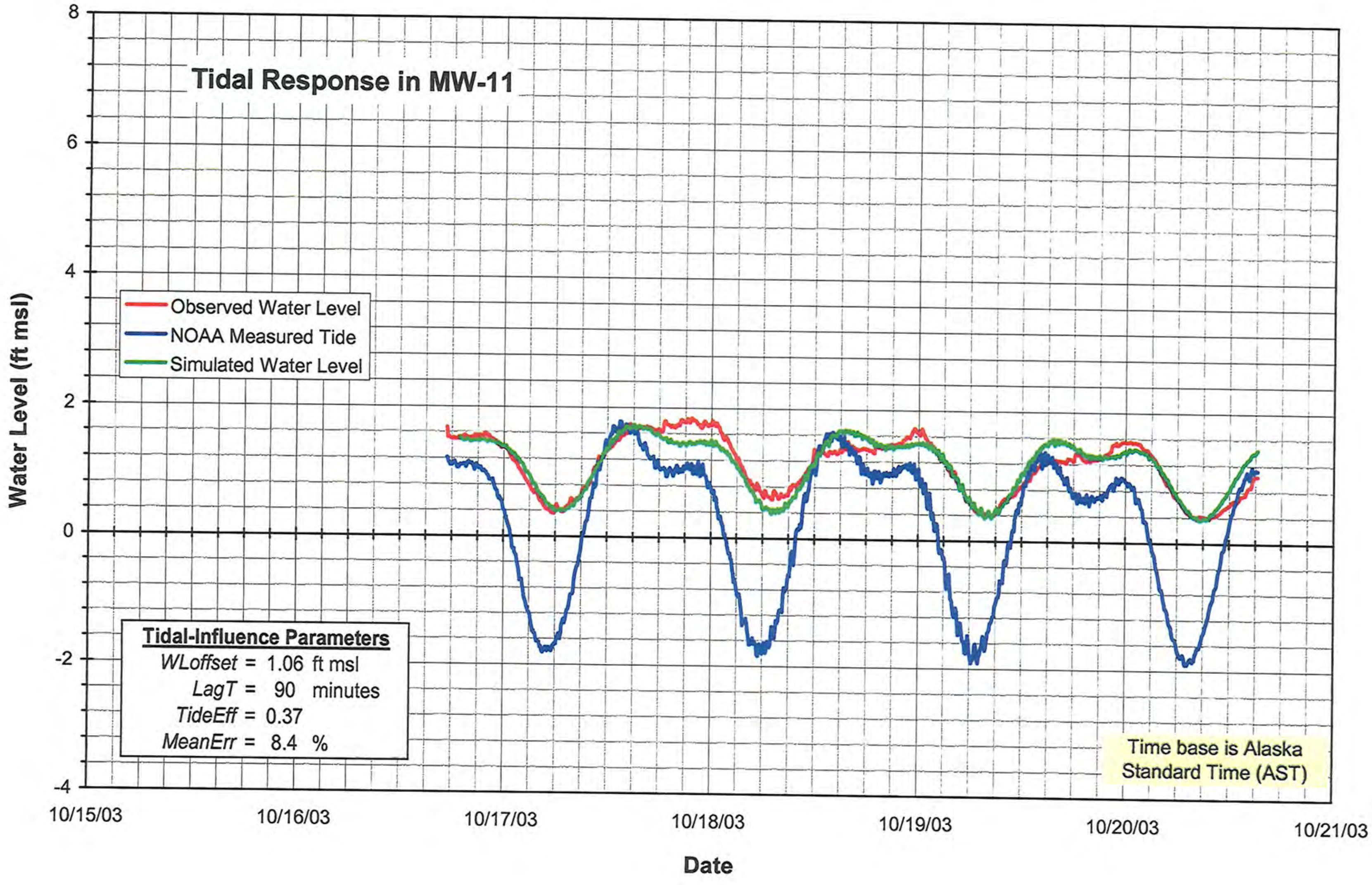


Figure 1-8
Observed and Simulated Tidal Influence in MW-12

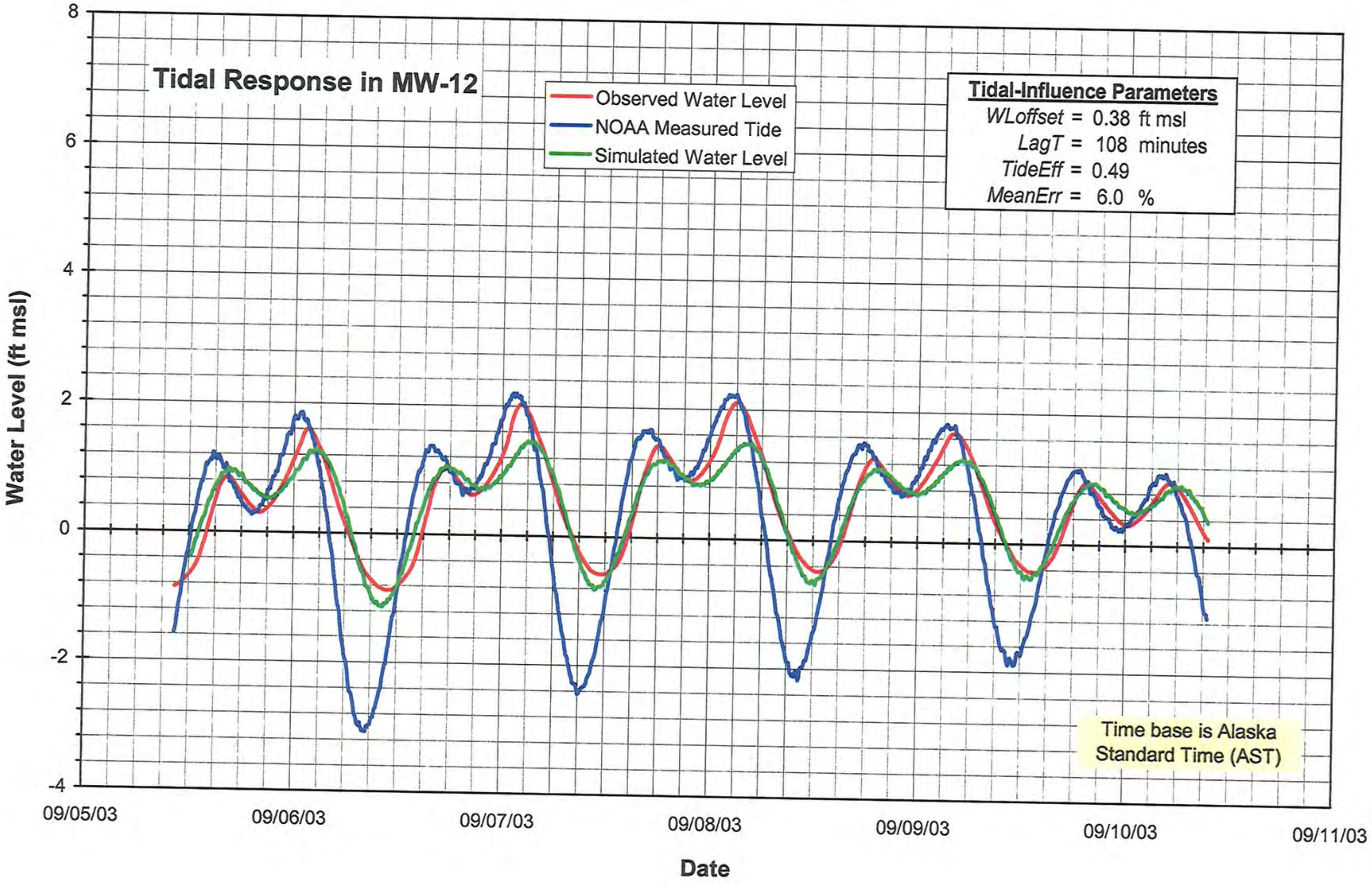


Figure 1-9
Observed and Simulated Tidal Influence in MW-13

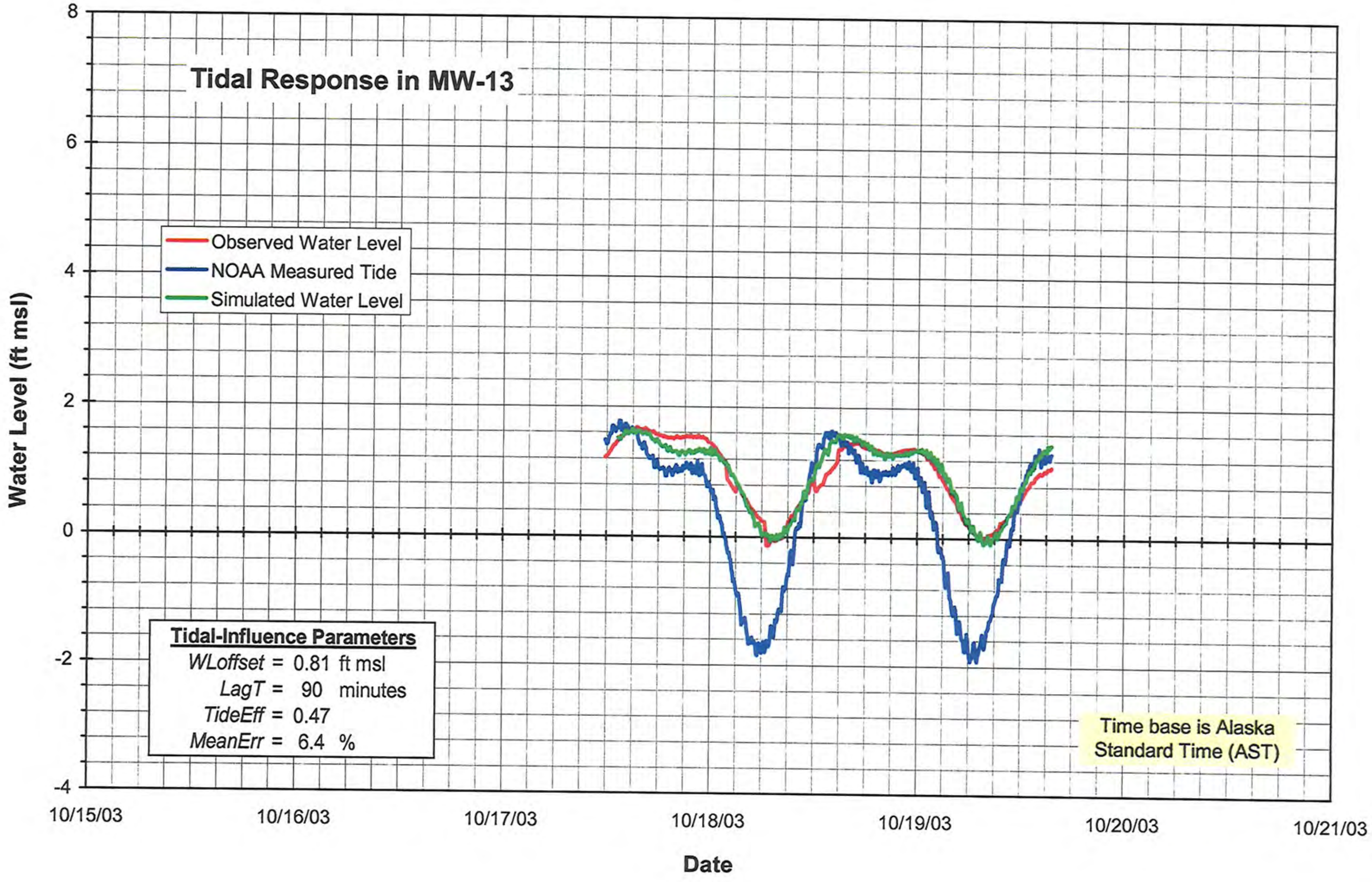


Figure 1-10
Observed and Simulated Tidal Influence in MW-14

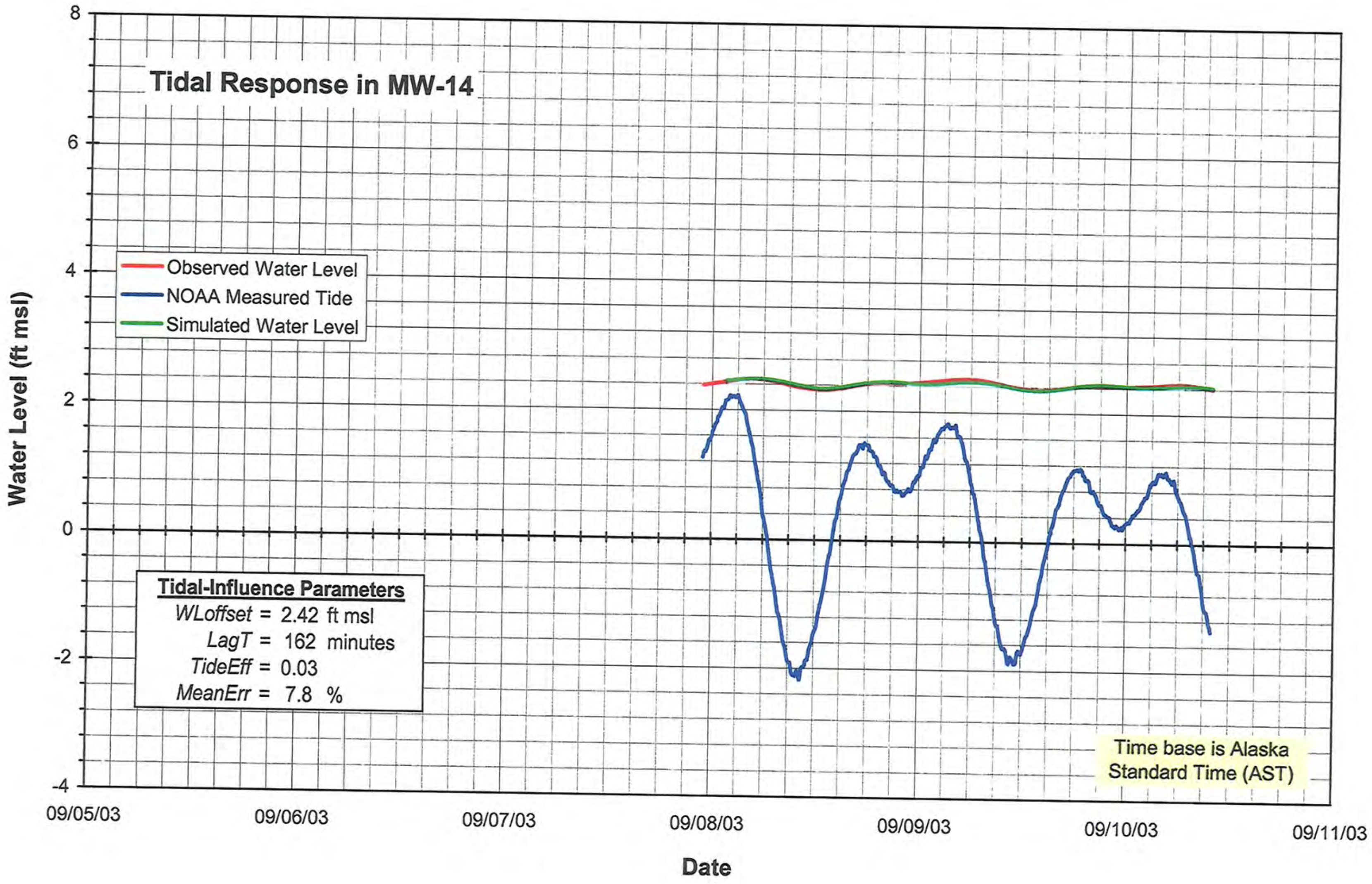


Figure 1-11
Observed and Simulated Tidal Influence in MW-15

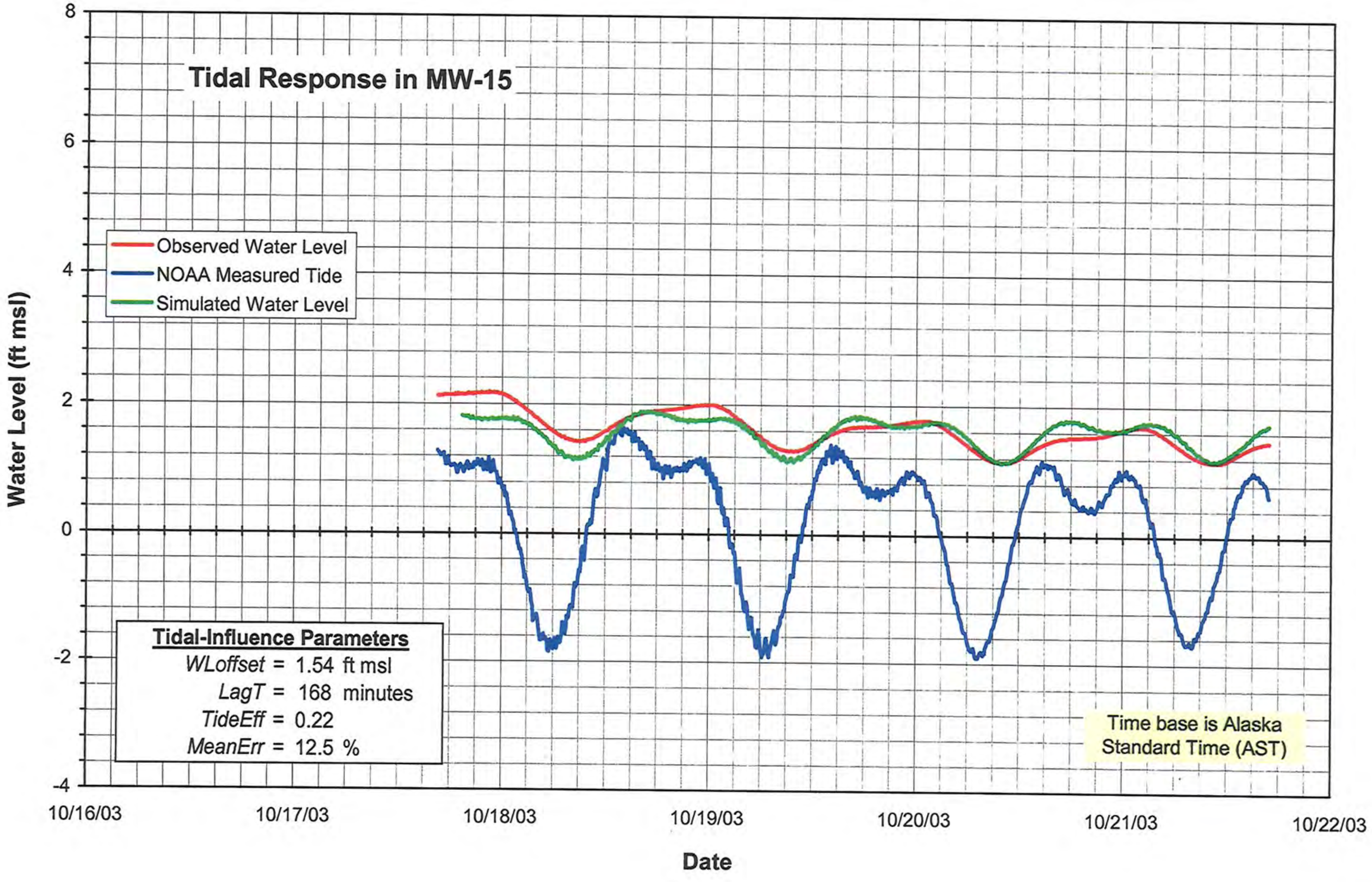
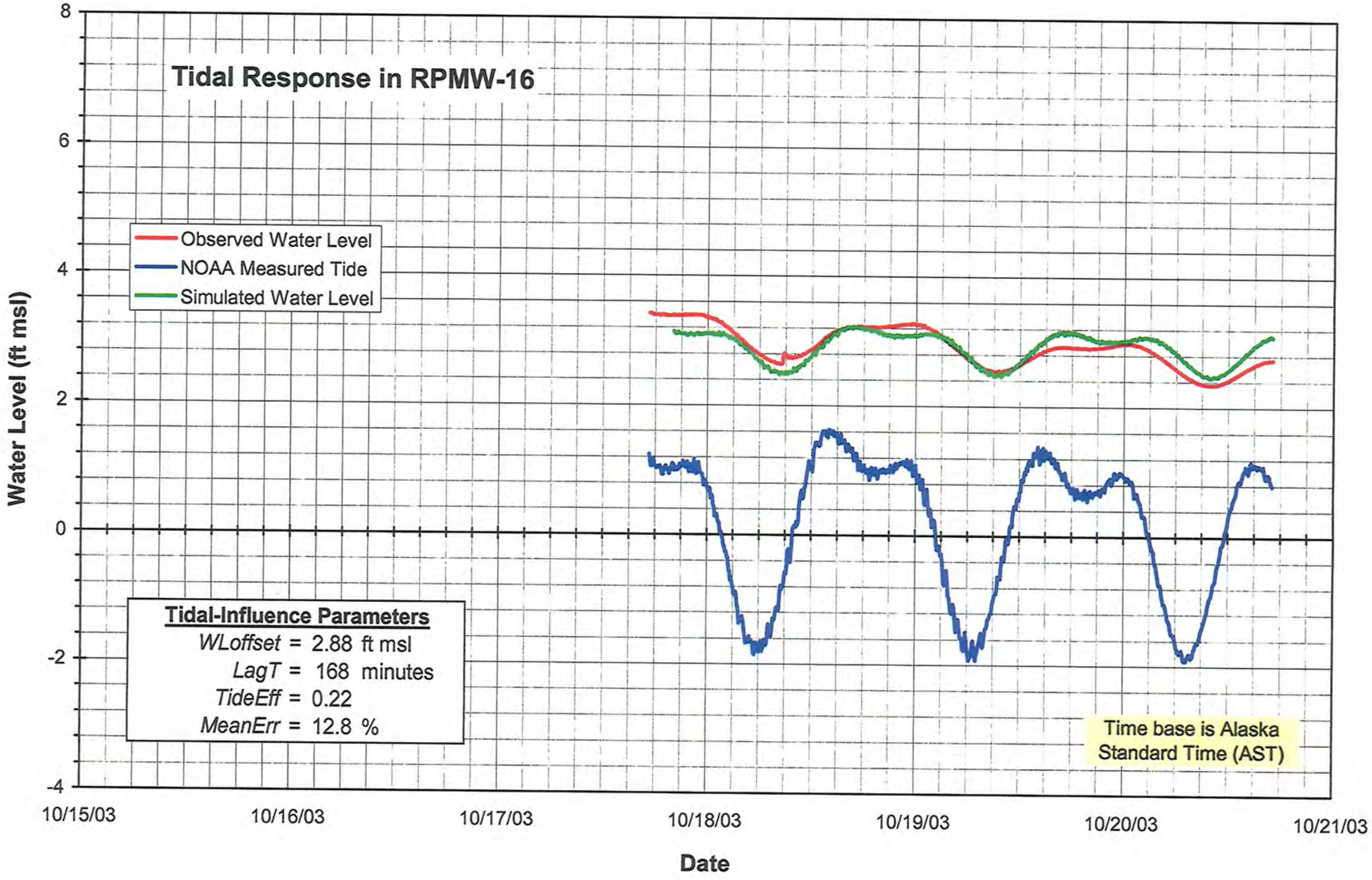


Figure 1-12
Observed and Simulated Tidal Influence in RPMW-16



2.0 SLUG TEST DETAILS AND FIGURES

The following discussions rely on figures which display (a) the raw transducer data (converted from pressure to head), and (b) the processed displacements. The wells are discussed in ascending order, with RPMW-16 last.

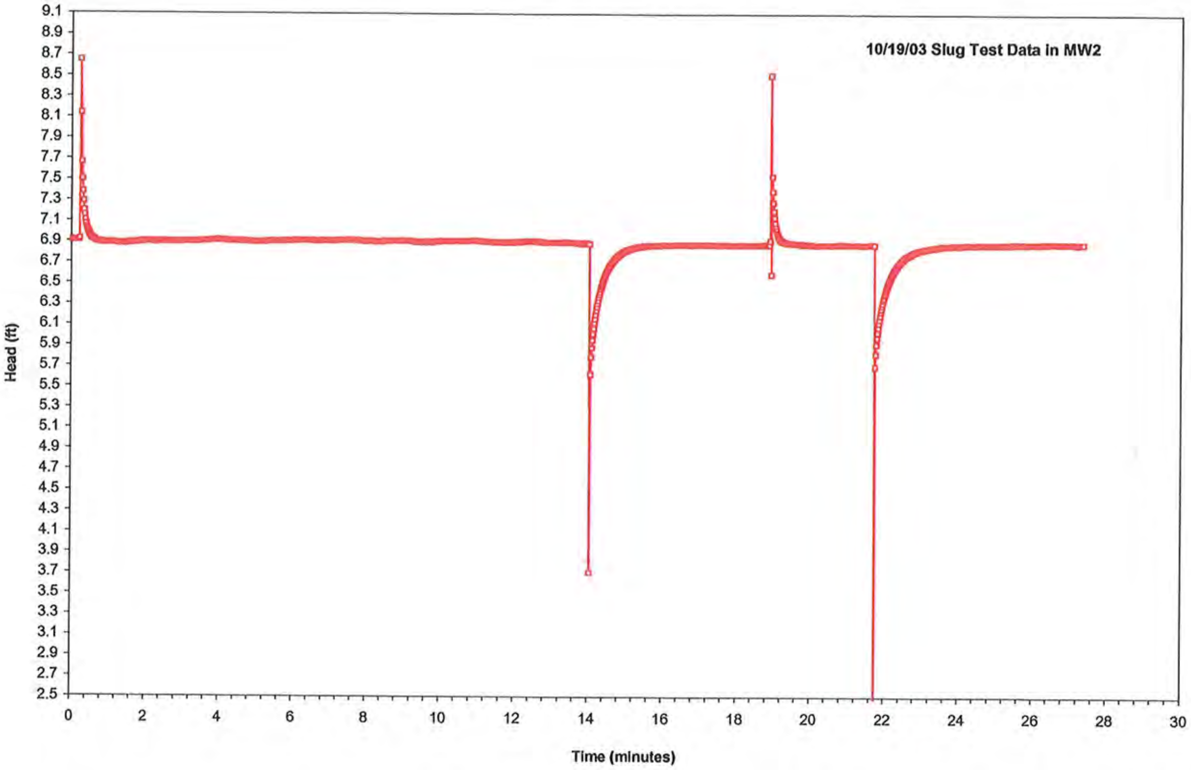
2.1 MW-2

The raw heads from MW-2 (Figure 2-1a) show no drift in baseline head over time and reproducible displacement curves. Initial displacements for the rising-head tests are much more negative than predicted from the slug and well-bore dimensions, indicating that rapid withdrawal of the slug produced a brief period of suction. The second falling-head test oscillates over the first several seconds, perhaps related to the slug falling through the water column and then bouncing off the stainless steel body of the transducer.

The processed displacements versus time (Figure 2-1b) highlight the differences between the falling-head and rising-head tests. The falling-head tests return to the pre-test water level much more quickly, likely reflecting the influence of the loose gray sandy gravel noted in the upper part of the borehole (USAED 1999) relative to the dense slightly gravelly sand noted below 10 feet below ground surface. The slow recovery for the rising-head tests may reflect the thinner initial saturated thickness near the well, and may also be influenced by the filter pack around the well screen.

Applying the Bouwer-Rice analysis to visually best-fit straight lines through the later data yields surprisingly consistent estimates of K_h for all four tests (Figure 2-2). The arithmetic average is 4.9 ft/day, somewhat low for gravelly sand, and may reflect the effects of silt that could have washed into the open well during the tidal monitoring that preceded these tests. Although the well was redeveloped a day before slug testing, there may have been some residual fines in the filter pack.

Figure 2-1
Slug-Test Raw Data and Displacements Measured in MW-2



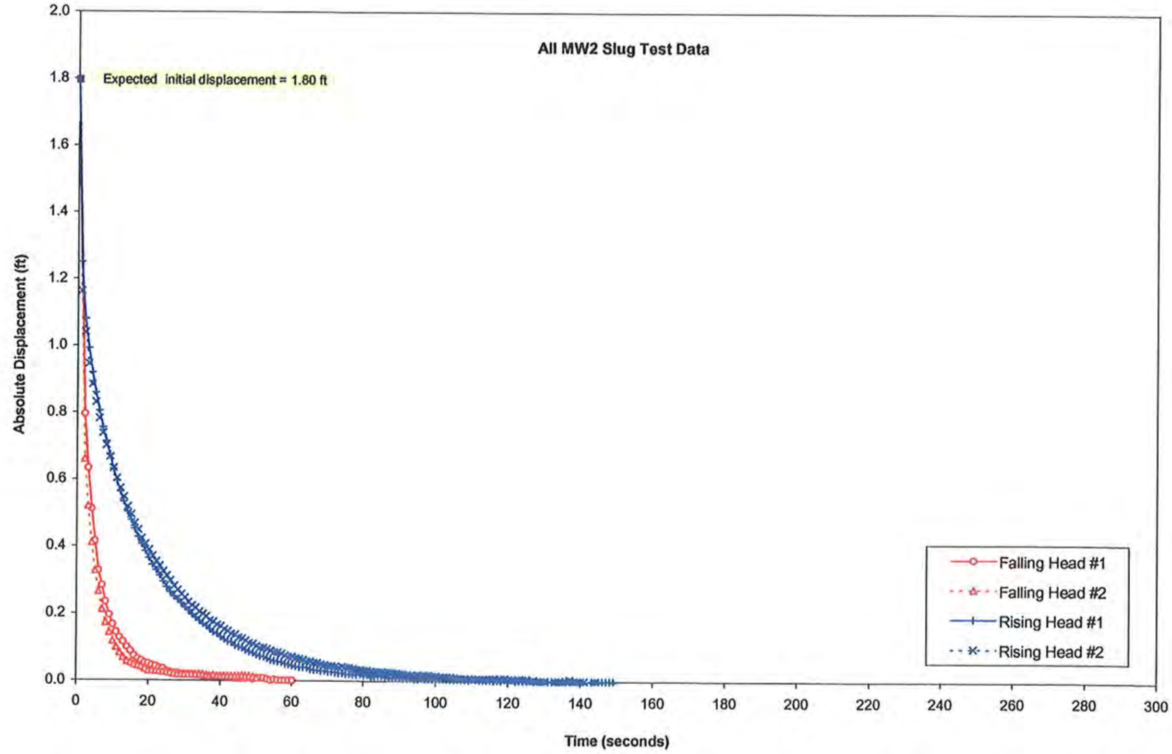
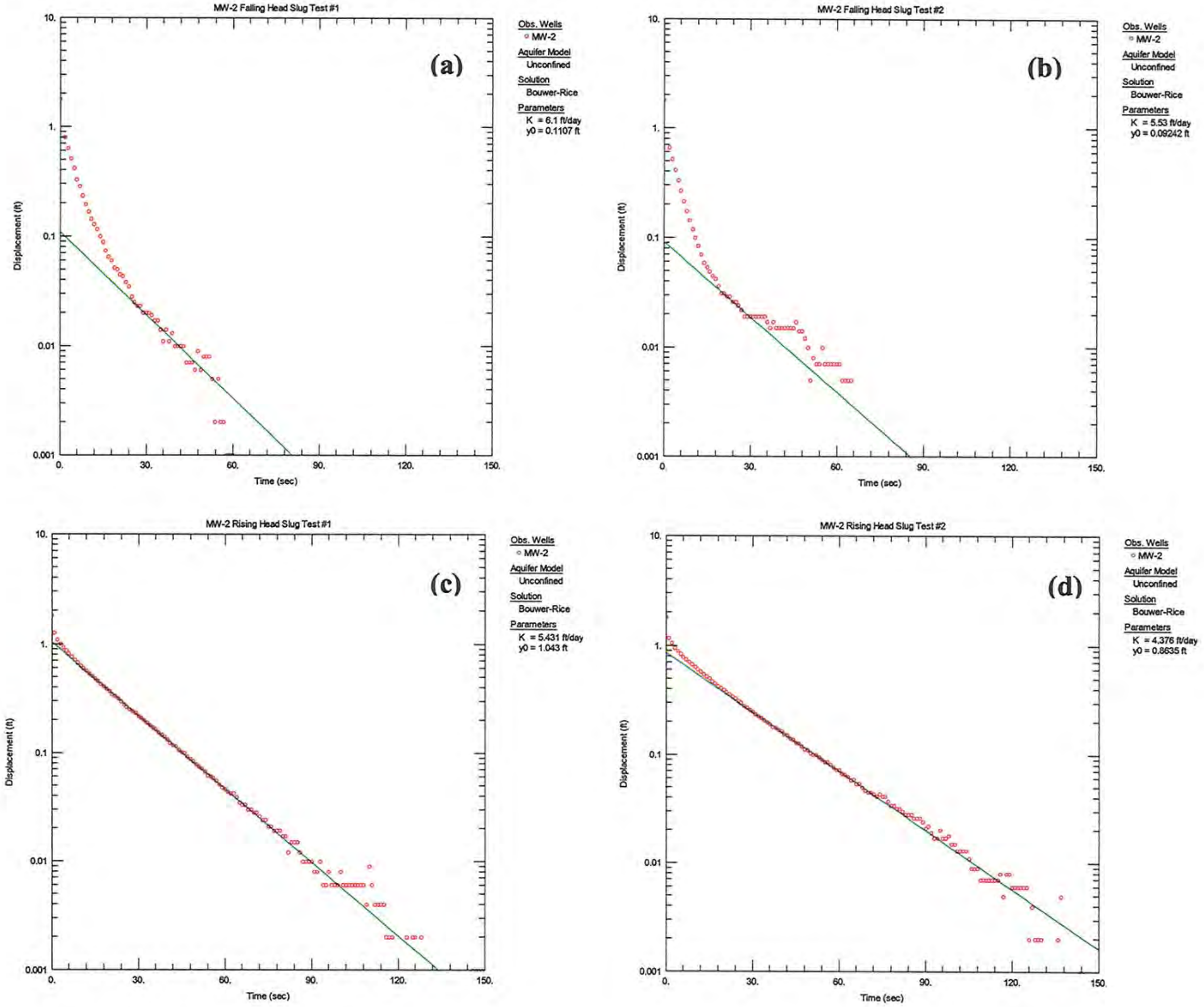


Figure 2-2
Bouwer-Rice Analysis of MW-2 Slug Tests



2.2 MW-8

The raw heads from MW-8 (Figure 2-3a) show negligible drift, and the recovery curves are smooth. Initial displacements are similar to the theoretical value of 1.80 feet (Table 3-4 in the main body of this report), lacking any artifacts relating to insertion or withdrawal of the slug. The processed displacements (Figure 2-3b) show the same dichotomy as seen from MW-2, with much more rapid recovery for the falling-head test. The borehole log (USAED 1999) indicates that this well is screened in medium-dense gravelly sand. Although the lithology is uniform, the lower four feet of the well resides in moderately to heavily contaminated material, with greatly reduced hydraulic conductivity.

Results of the Bouwer-Rice analysis (Figure 2-4) are quite different for the two tests. Unlike at MW-2, the falling-head test exhibited only a rapid return to baseline, without any late-stage slow equilibration, providing an estimated K_h of 23 ft/day. In contrast, the rising-head test returned to baseline much more slowly, resulting in an estimated K_h of 6.6 ft/day. This latter value is most representative of the saturated zone here, and provides an indication of the effect of extensive contamination by Bunker C.

Figure 2-3
Slug-Test Raw Data and Displacements Measured in MW-8

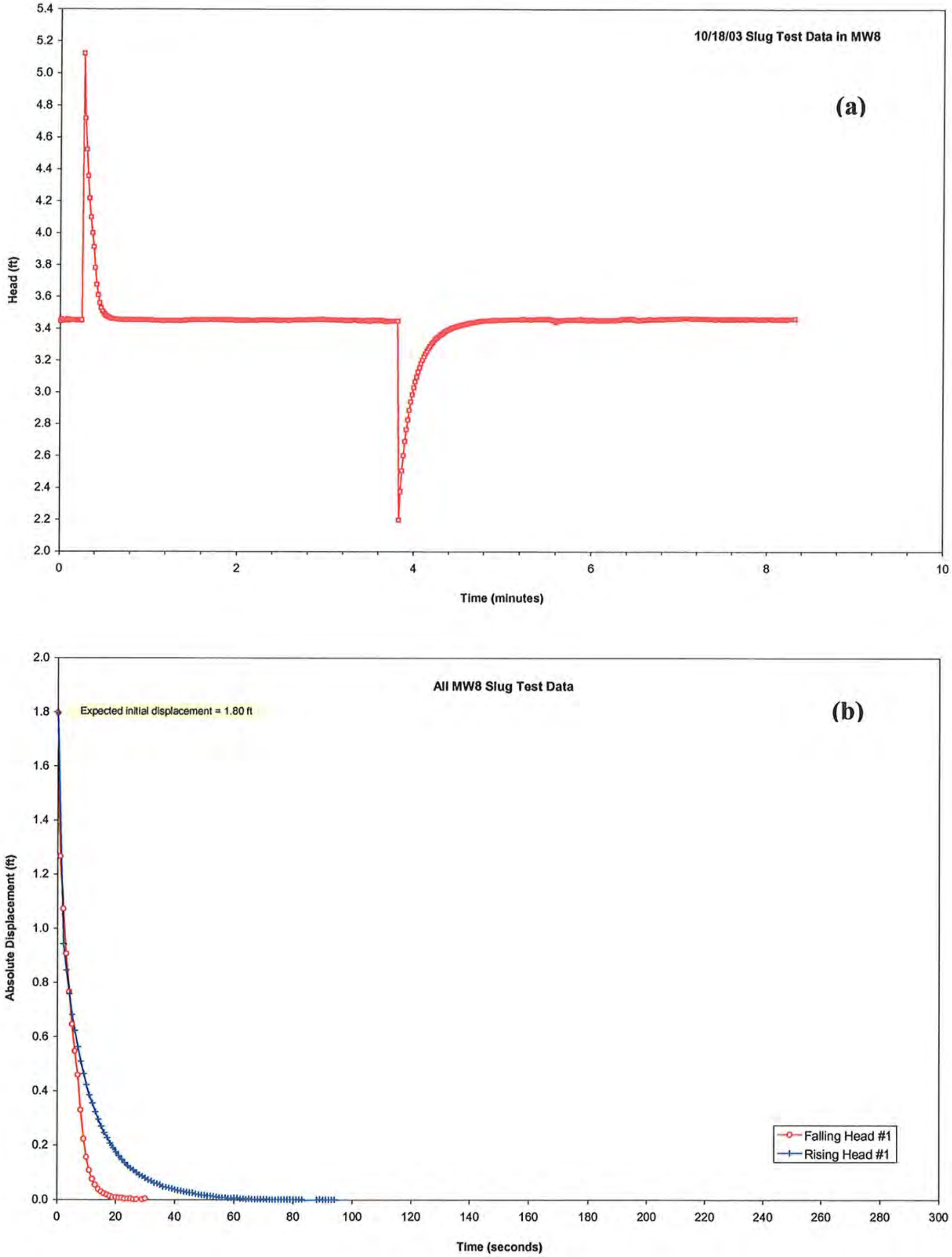
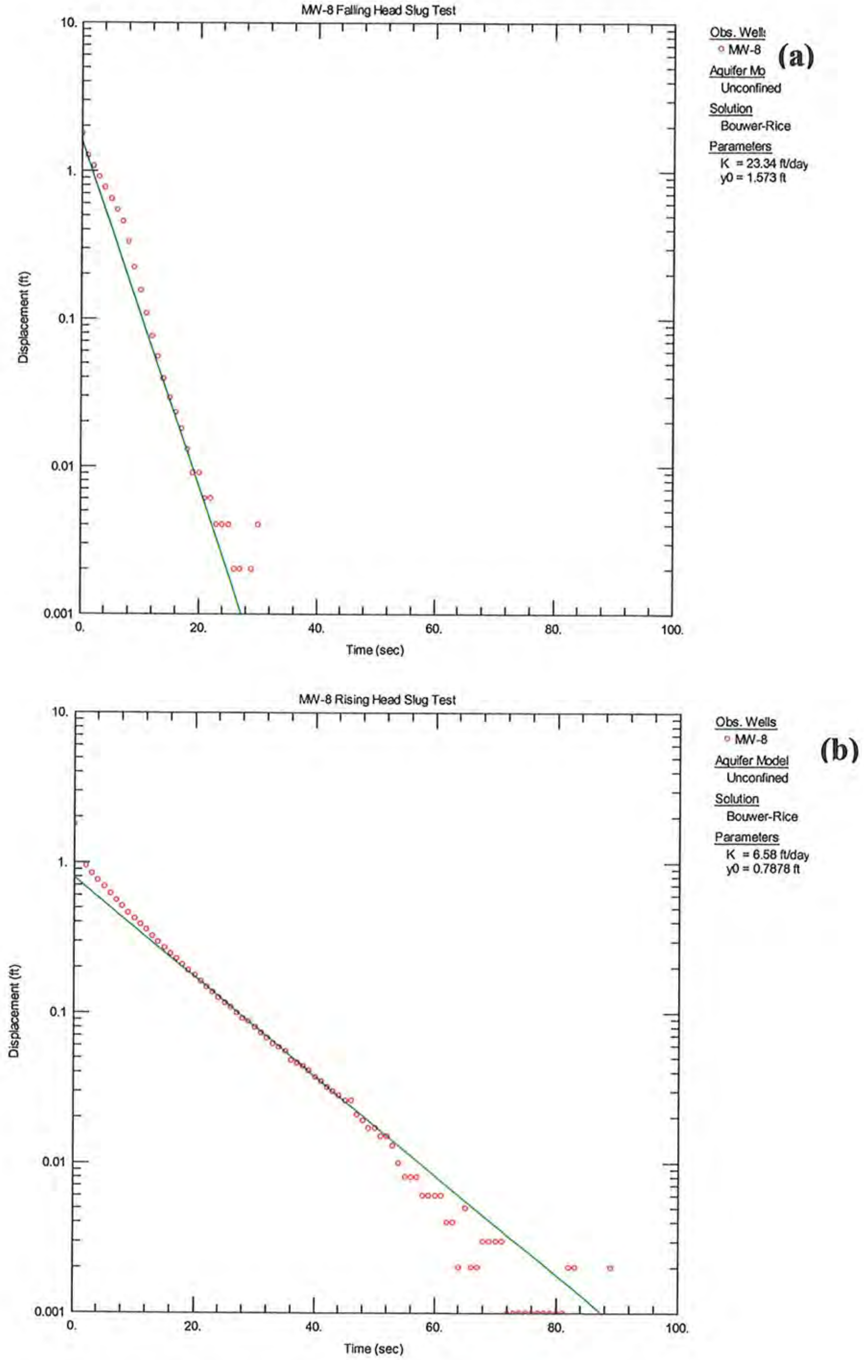


Figure 2-4
Bouwer-Rice Analysis of MW-8 Slug Tests



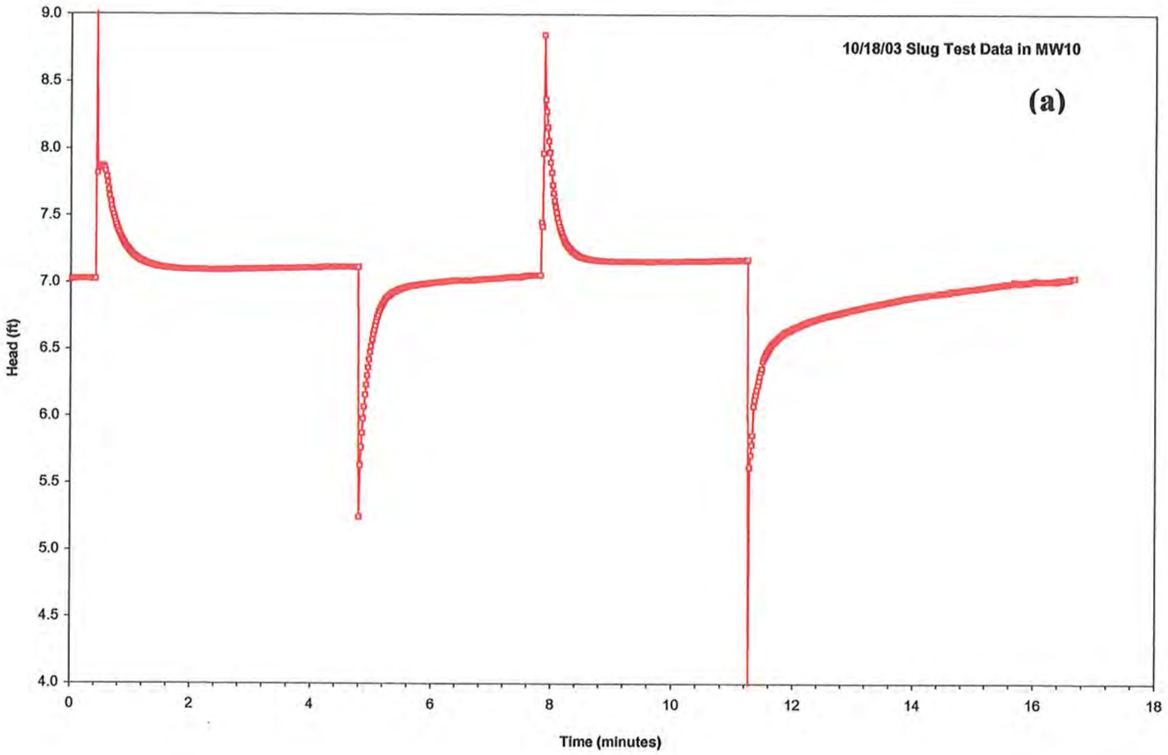
2.3 MW-10

The raw heads from MW-10 (Figure 2-5a) exhibit several problematic characteristics. Baseline heads between tests slowly rise with time, reflecting a strong tidal influence. The test period was about an hour before high tide, when water level in Iliuliuk Bay was increasing at approximately 0.4 ft/hr (0.007 ft/min). Because the tidal efficiency of MW-10 was found to be 0.90 (Table 3-3 in the main body of this report), a similar rate of increase in the well is expected. The second problematic feature is that the slug tests exhibit some hysteresis, with final water levels not quite returning to the pre-test baseline trends even though the rate of change matches the baseline rate of change. This may reflect some jostling of the downhole transducer as the slug was dropped and lifted. The ragged and erratic shape of the initial displacements provides further evidence of transducer disturbance. The cleanest tests appear to be the Rising Head #1 and Falling Head #2. Rising Head #2 exhibited a large suction effect when the slug was withdrawn, and had a prolonged slow return to baseline.

The processed displacements versus time (Figure 2-5b) have been corrected to account for the sloping baseline, and early data affected by transducer disturbances have been eliminated. The good-quality tests (Rising Head #1 and Falling Head #2) exhibit nearly identical displacement curves, and are bracketed by the problematic tests. Nevertheless, the Bouwer-Rice analysis of all four tests (Figure 2-6) produced clustered K_h estimates, ranging from 16 to 25 ft/day. On log-linear plots, the late data (later than about 30 seconds) define similar slopes, and hence K_h values. The early data, where still present, define much steeper slopes, and hence higher K_h values, probably reflecting the properties of the filter pack around the well screen.

The average of the rising head tests, 23 ft/day, should be most representative of the saturated zone near MW-10. The borehole log (USAED 1999) indicates that the aquifer here is composed of loose sub-angular to angular sandy gravel.

Figure 2-5
Slug-Test Raw Data and Displacements Measured in MW-10



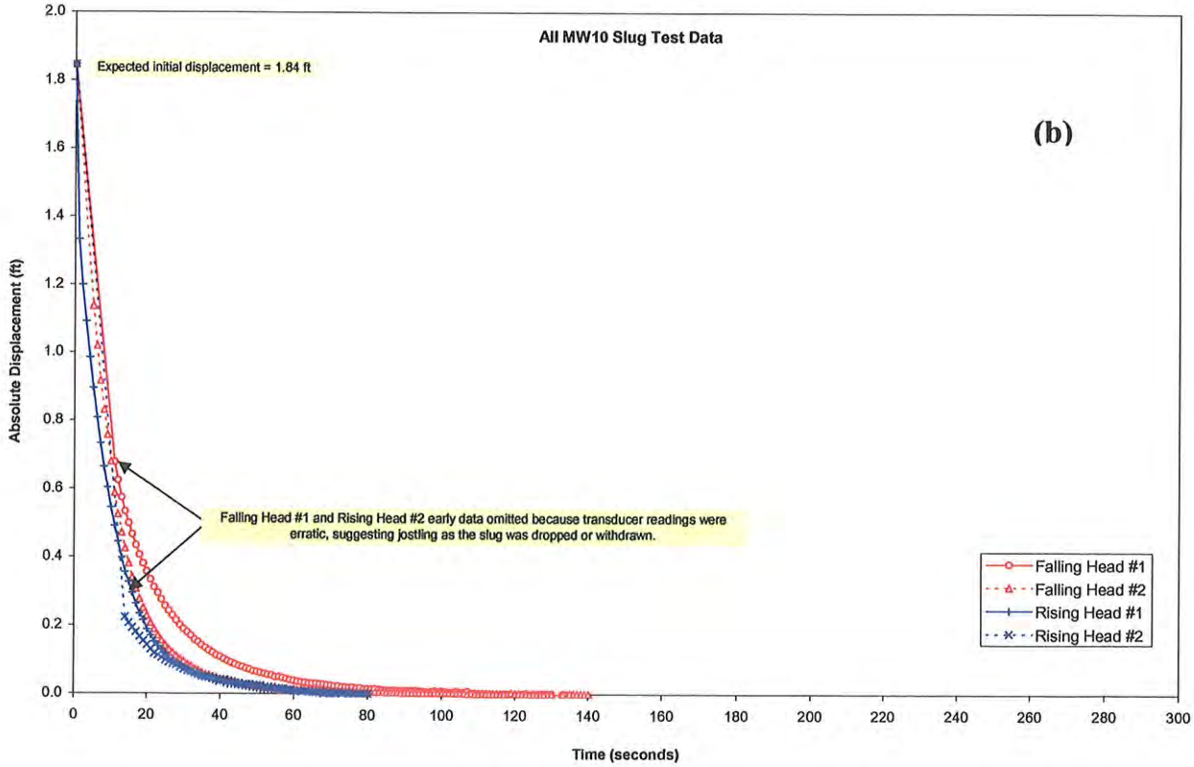
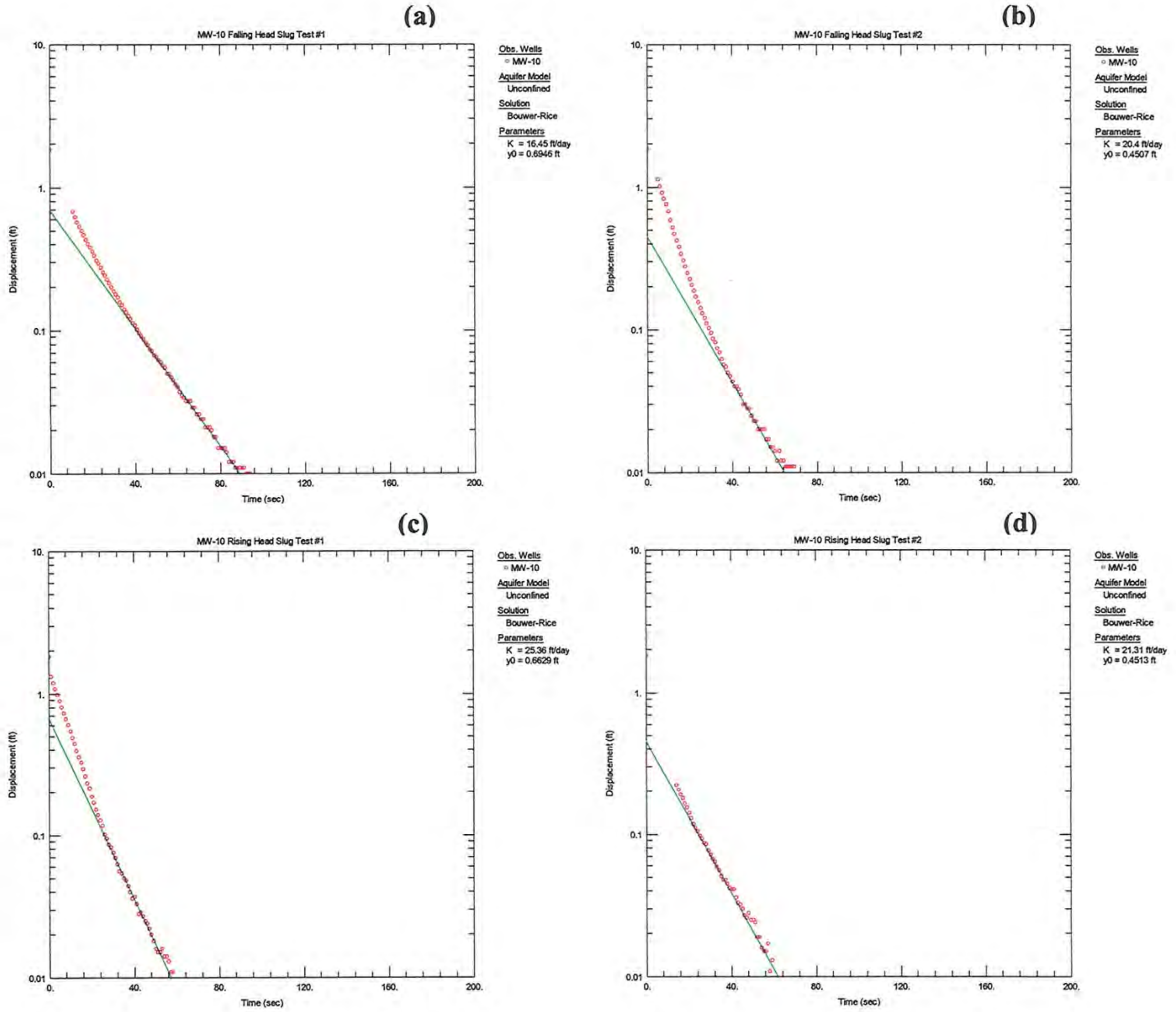


Figure 2-6
Bouwer-Rice Analysis of MW-10 Slug Tests



2.4 MW-12

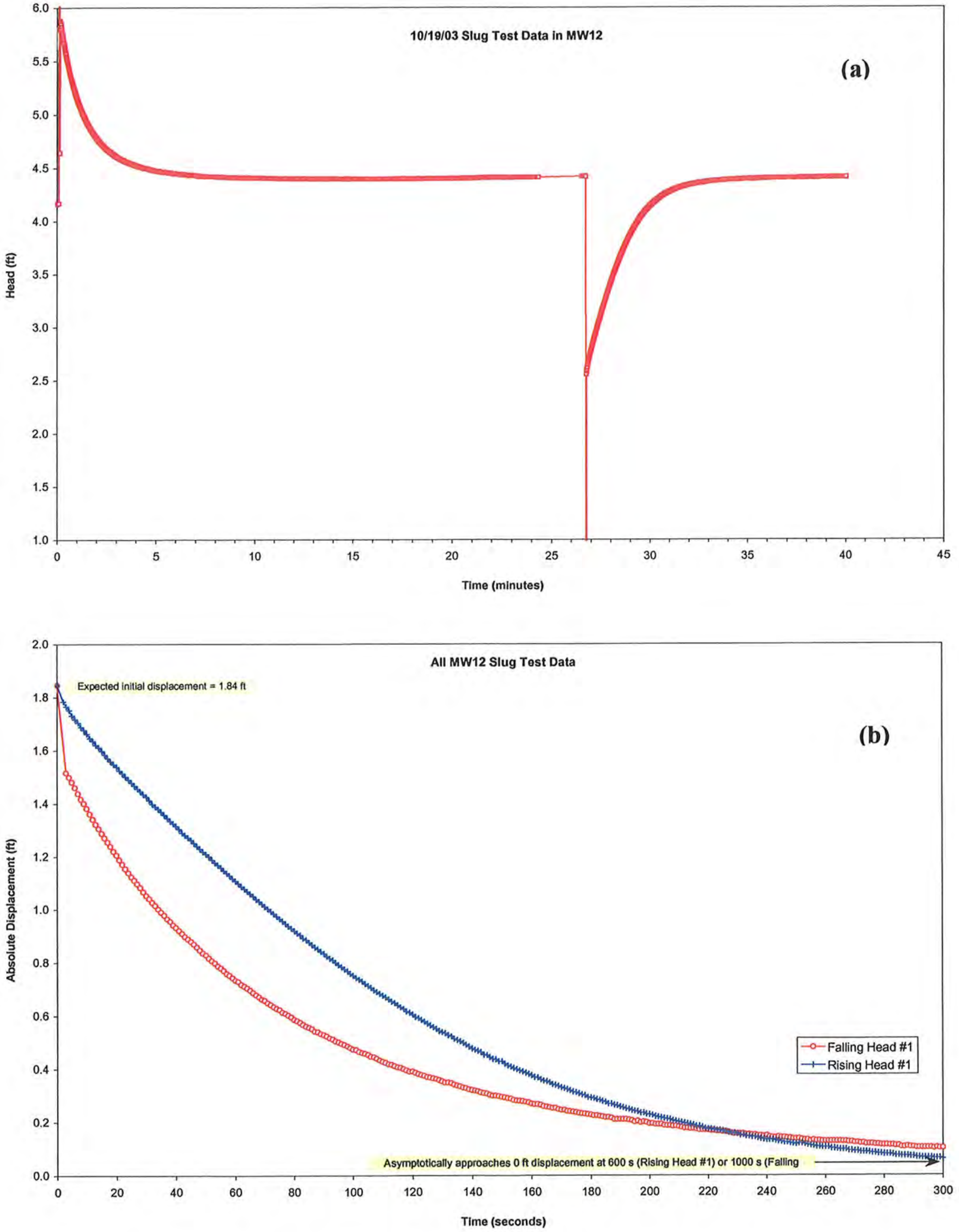
The raw heads for MW-12 (Figure 2-7a) show that this well is very slow to respond to perturbations, with each test requiring more than 10 minutes to return to baseline. Because of the slow response, only one falling-head test and one rising-head test were conducted. Baseline appears to have remained constant throughout the 40-minute testing period, but initial displacements were erratic. For the falling-head test, the initial baseline was at about 4.2 feet, whereas the final baseline was at 4.4 feet. The rising-head test also returned to the 4.4 ft baseline, indicating an absence of hysteresis. Initial displacements for both tests are erratic; the falling-head test showed a wide oscillation for the first three seconds, and the rising-head test showed a large suction effect for the first two seconds.

The processed displacements versus time (Figure 2-7b) are plotted for 300 seconds, for consistency with the slug tests in the other wells, but require up to 1000 seconds to return to the baseline (0 feet displacement). In addition to this very slow recovery, the falling-head test is anomalous because the extrapolated initial displacement falls short of the expected initial displacement by about 0.15 feet, an amount that closely matches the observed baseline shift. This is most readily explained by a one-time hysteresis effect.

Estimates of K_h by the Bouwer-Rice method (Figure 2-8) range from 1.5 to 4.1 ft/day, with higher values derived from the early part of the falling-head test and late part of the rising head test, and lower values from the other parts of the tests. In these log-linear plots, the falling-head test shows the usual concave upward pattern, but with the steep portion lasting for nearly 120 seconds, too long for filter pack effects. One interpretation is that the nearby aquifer is more conductive than more distant parts. This idea is not supported by the rising-head test, which shows the opposite pattern, concave downward, with slower than expected initial equilibration compared to later observations.

The boring log for MW-12 (USAED 1999) indicates that the well is screened in loose sandy silt, but that 6 feet of medium-dense slightly sandy gravel occurs less than a foot below the bottom of the screen. Early data should predominantly reflect the properties of the silt, with increasing contributions from the underlying gravel at later times. The average of early data from the two tests is 3.2 ft/day.

Figure 2-7
Slug-Test Raw Data and Displacements Measured in MW-12



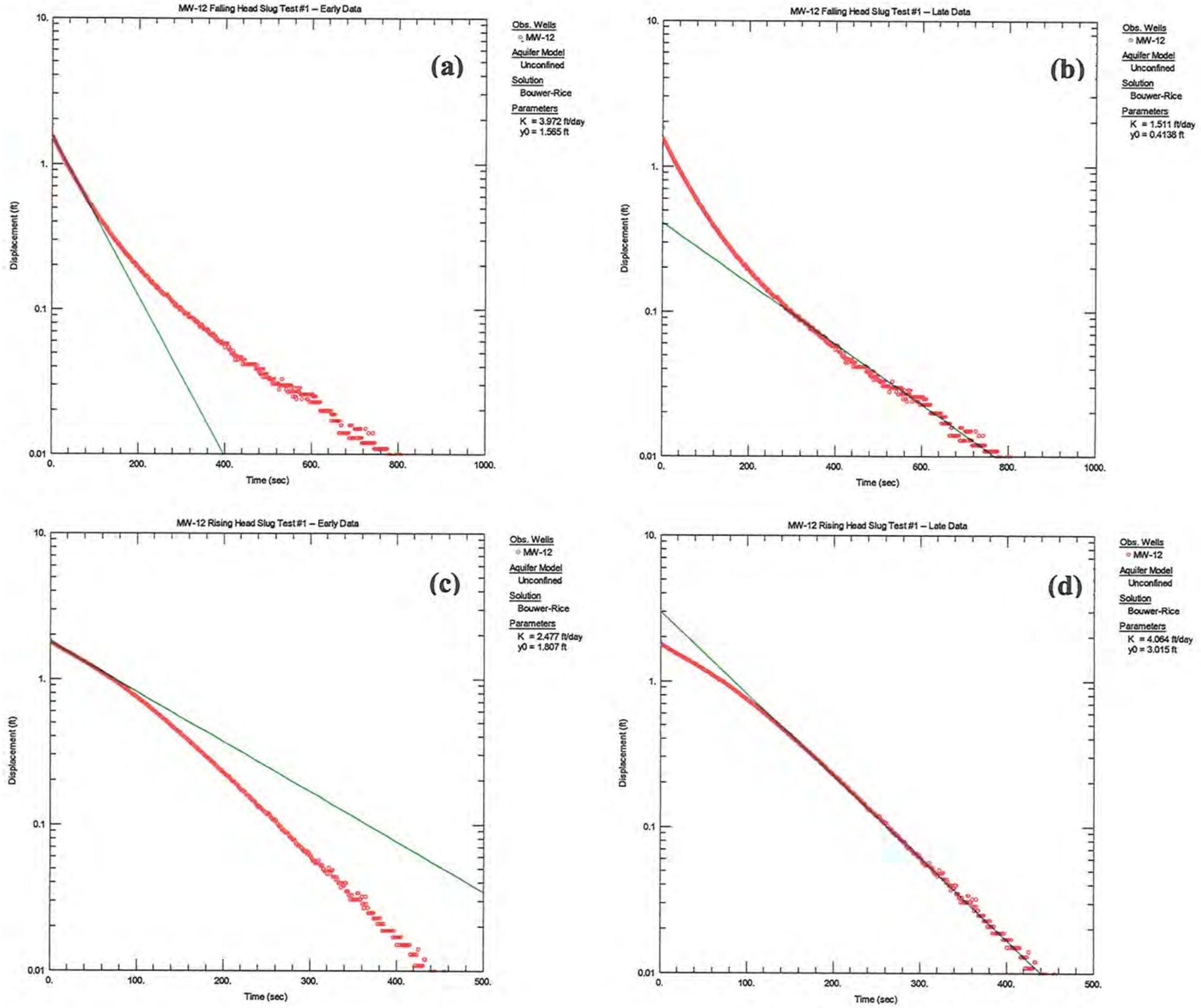
10/19/03 Slug Test Data in MW12

All MW12 Slug Test Data

Expected initial displacement = 1.84 ft

Asymptotically approaches 0 ft displacement at 600 s (Rising Head #1) or 1000 s (Falling

Figure 2-8
Bouwer-Rice Analysis of MW-12 Slug Tests

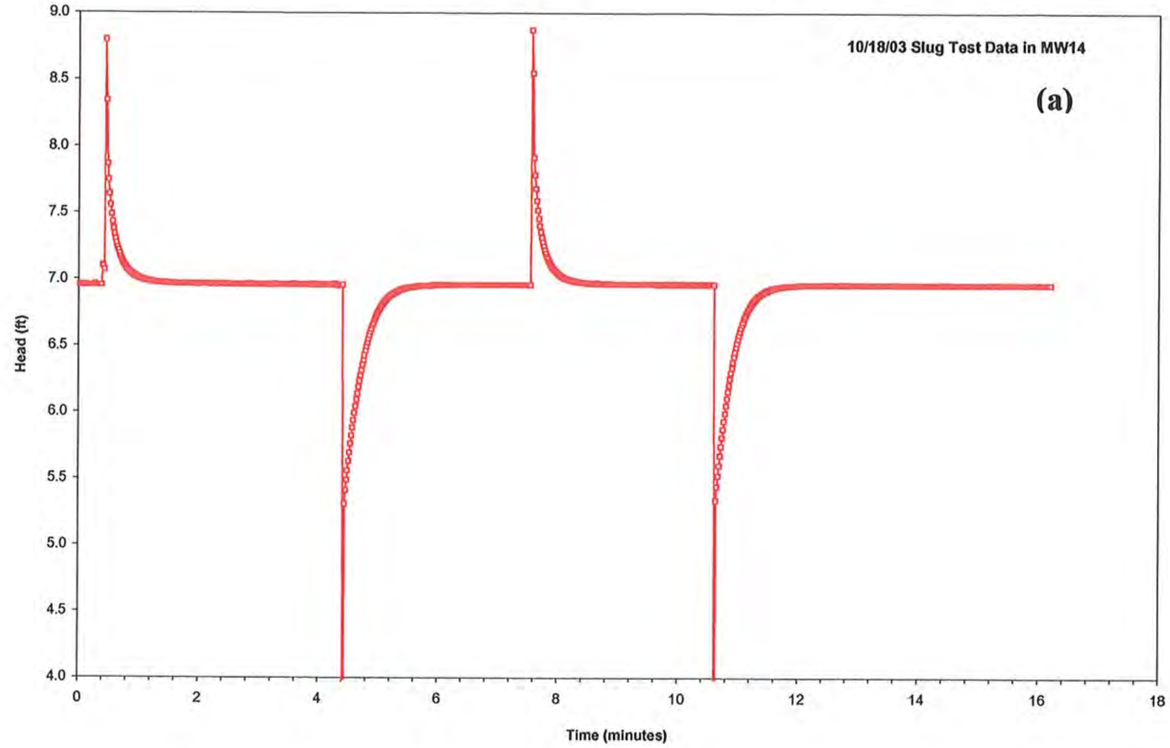


2.5 MW-14

The raw heads for MW-14 (Figure 2-9a) exhibit few irregularities. Baseline is constant, and each test shows smooth and similar recoveries. Initial displacements for the falling-head tests are similar to the expected value of 1.84 feet, but those for the rising-head tests are somewhat larger because of suction effects as the slug was withdrawn. For the first falling-head test, the slug must have been lowered several inches into the water column before being released, producing the 2 second step in the initial displacement. This was compensated for during data processing.

Processed displacements (Figure 2-9b) show nearly coincident curves for the falling-head tests and for the rising-head tests. The two sets of curves are similar in shape, but the rising-head curves are offset by about 30 seconds to later times relative to the falling-head curves. Estimated K_h values from the Bouwer-Rice analyses for times later than 20 seconds are very consistent for all tests, averaging 28 ft/day with a range of 27 to 28 ft/day. The falling-head tests exhibit the usual rapid early recovery, but the rising-head tests show slower than expected early recovery rates. From the boring log (USAED 1999), there is a gravelly silt from 6 to 10 feet below ground surface, bracketing the static water level of 8.41 feet below ground surface during the test period, which may be responsible for the asymmetry of the early recovery rates. Below the silt is 5 feet of loose gravelly sand.

Figure 2-9
Slug-Test Raw Data and Displacements Measured in MW-14



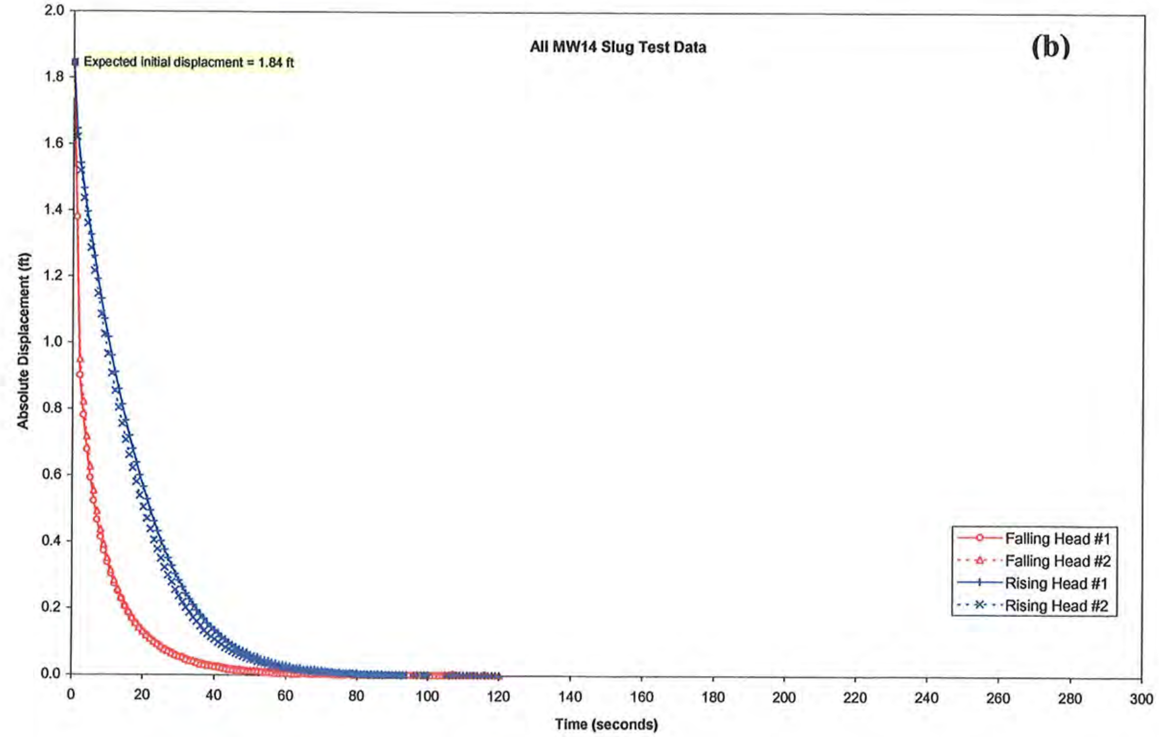
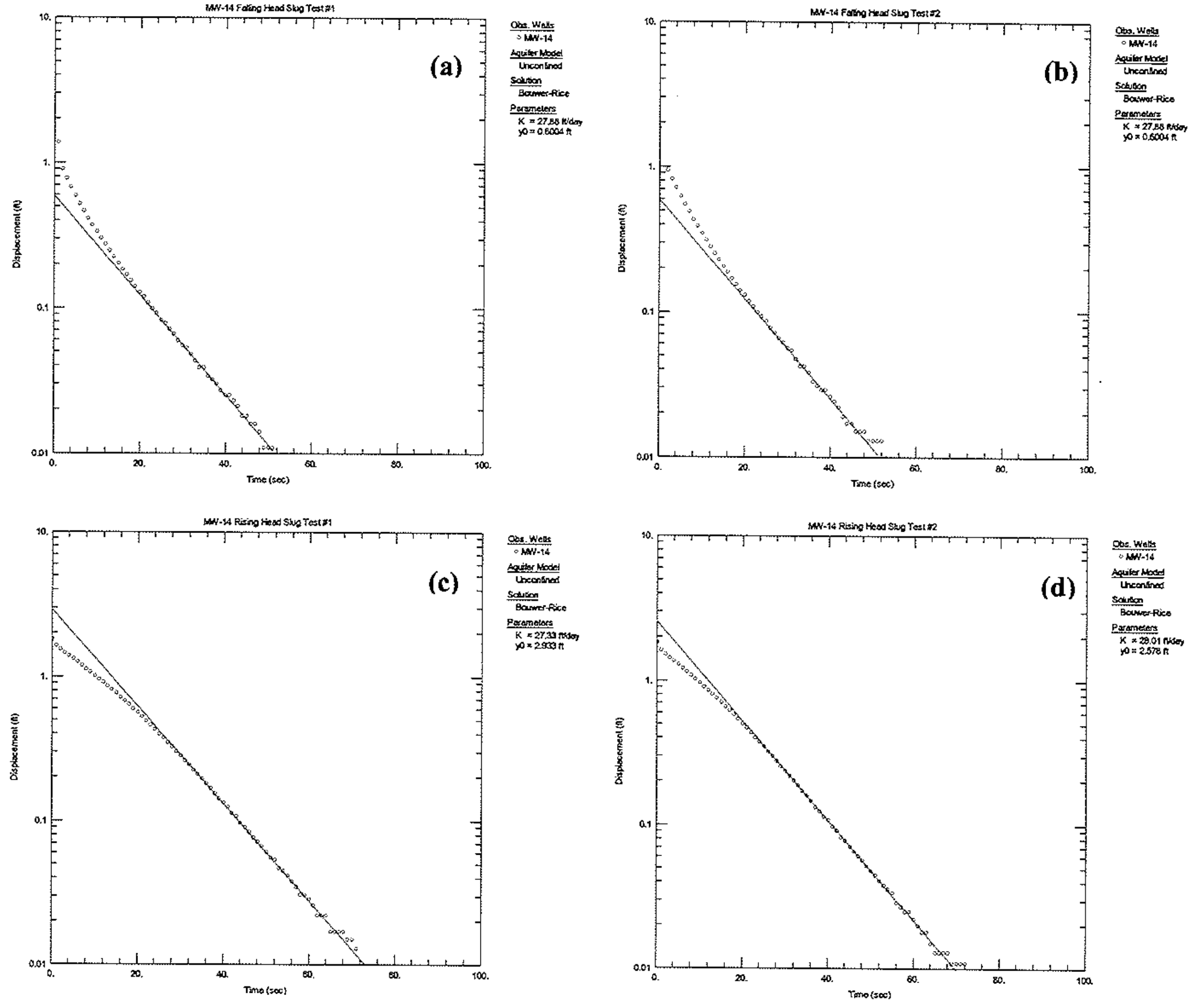


Figure 2-10
Bouwer-Rice Analysis of MW-14 Slug Tests



2.6 MW-15

The raw heads for MW-15 (Figure 2-11a) exhibit a constant baseline, with each test showing smooth and similar recoveries. Most initial displacements are similar to the expected value of 1.84 feet, but that for the first rising head test is slightly larger at 2.3 feet, reflecting some suction as the slug was withdrawn. Processed heads (Figure 2-11b) show excellent agreement, with nearly coincident curves for the two falling-head and for the two rising-head tests, and only a slight difference between the two types of test.

Bouwer-Rice analyses of displacements after 30 seconds yield consistent results near 4.9 ft/day for the falling-head tests and near 8.3 ft/day for the rising-head tests. Earlier data show very rapid recovery rates, interpreted as arising from the sand filter packs around the screens. The boring log for this well (USAED 1999) records a silt zone, just above the static water level, that is a likely explanation for the slow falling-head response. The saturated portion of the screen, completed in medium-dense gravelly sand, would be best represented by the rising-head value (8.3 ft/day).

Figure 2-11
Slug-Test Raw Data and Displacements Measured in MW-15

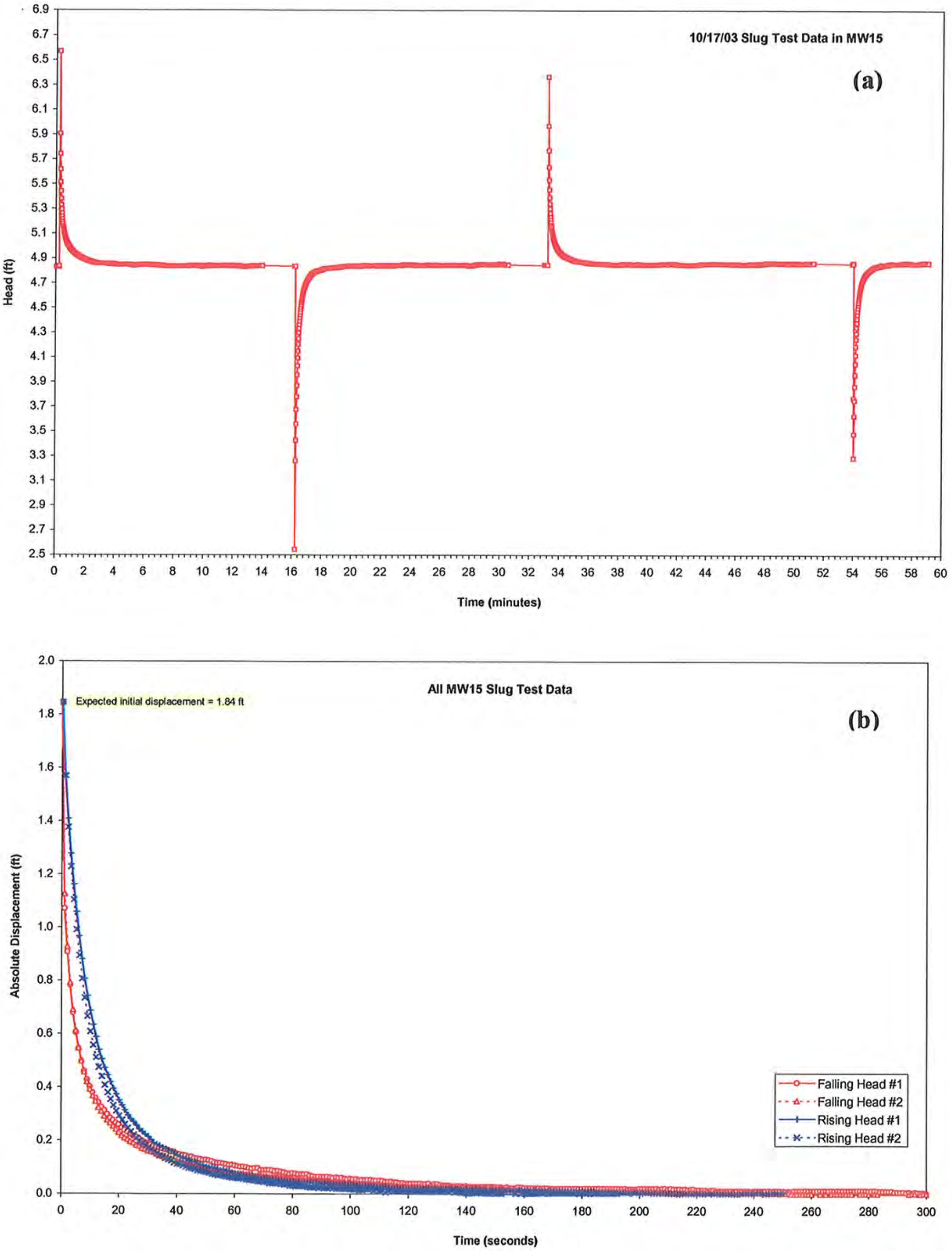
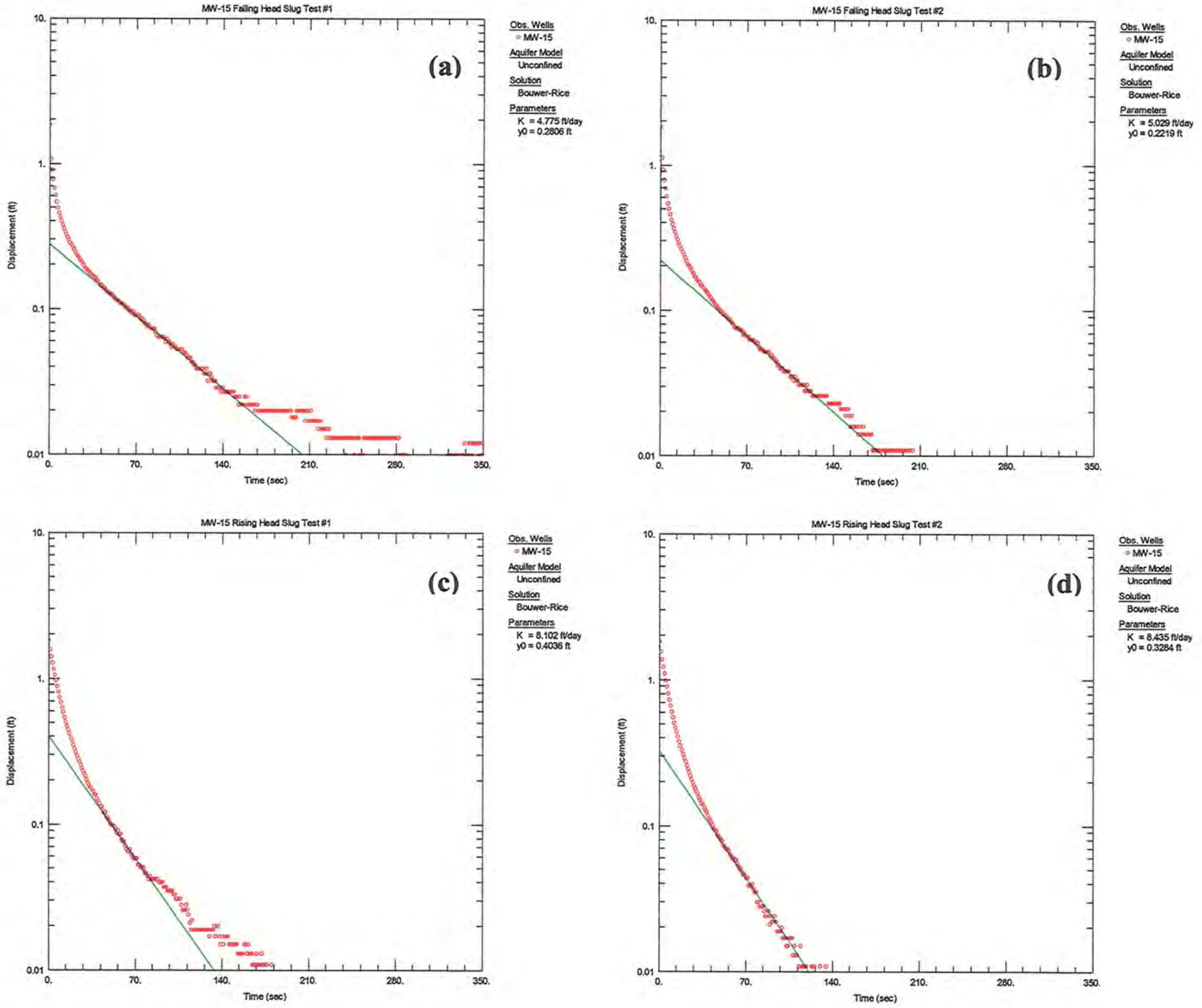


Figure 2-12
Bouwer-Rice Analysis of MW-15 Slug Tests



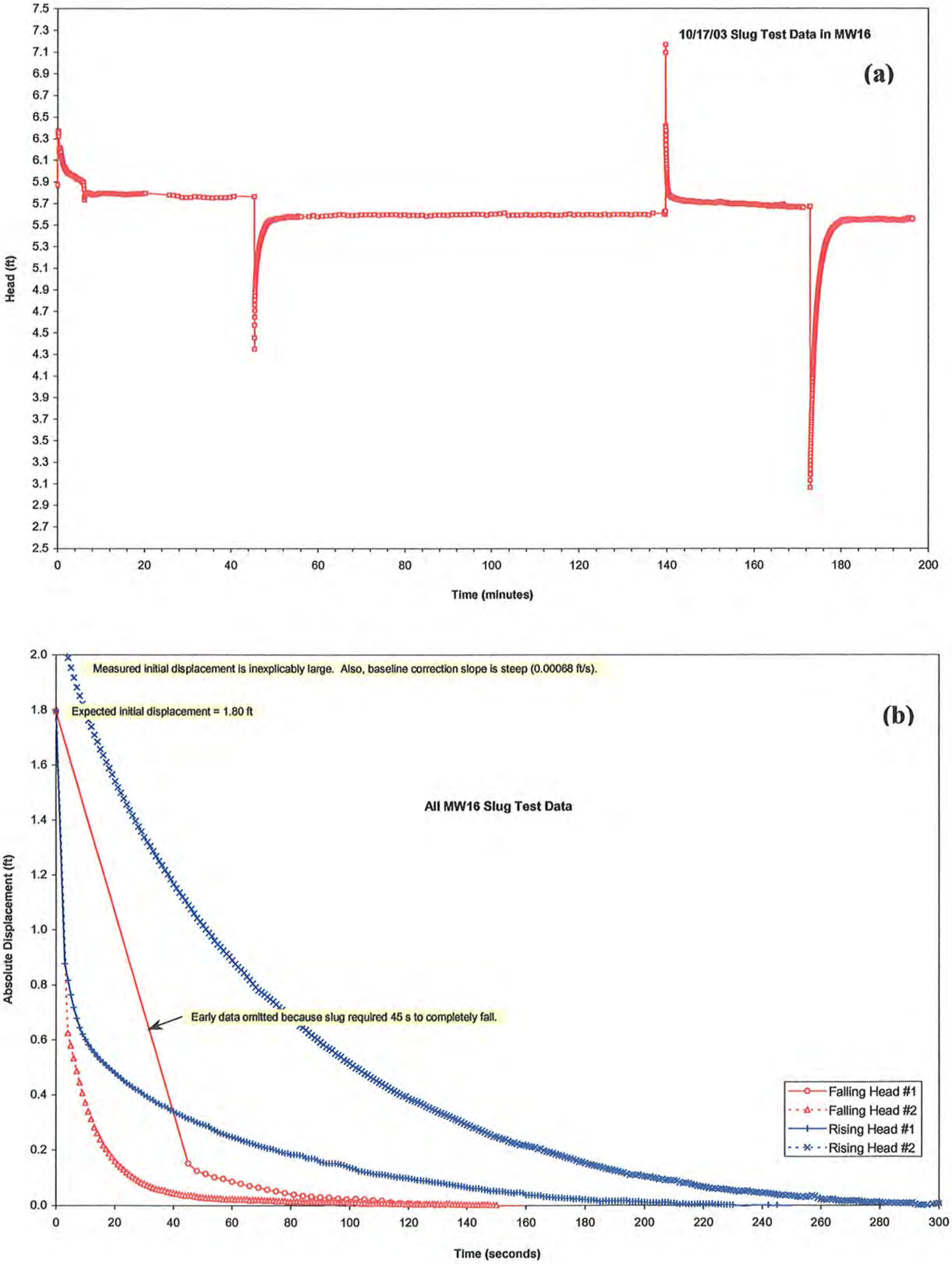
2.7 RPMW-16

RPMW-16, the first well to be slug-tested, utilized a range of data-collection rates and equilibration periods, as is shown by the plot of raw heads versus time (Figure 2-13a). These data showed that complete recovery required only several minutes, so there was no need to change the recording interval part way through each test. Rather, the recording interval could be left at 1 second without producing an ungainly data file. Hydraulically, the raw data show a nearly constant baseline for the first 140 minutes followed by a declining trend for the next 55 minutes, reflecting tidal influences (slack water followed by the ebbing tide). The small step downward at 8 minutes may reflect departure of a vehicle that had been parked nearby. The initial displacement for the first falling-head test is erratic because the slug continued to move slowly downward in the well for 45 seconds. The initial displacement for the final rising-head test is inexplicably large at 2.19 feet (compared to the expected value of 1.80 feet). The remaining tests have reasonable initial displacements but show substantial hysteresis. Although it appears that heads never recovered fully during the 95-minute equilibration period following the first rising-head test, it is likely that recovery occurred but was masked by the start of the ebb tide.

Processed displacements (Figure 2-13b) show little consistency among the four tests. The K_h estimates from the Bouwer-Rice analyses (Figure 2-14) range from 1.4 to 3.5 ft/day; the two rising-head tests have essentially the same slope, and average 1.5 ft/day. Because of the anomalously large displacement for the second rising-head test and other difficulties with the falling-head tests, the K_h estimate of 1.6 ft/day from the first rising-head test is the most representative value.

The aquifer matrix in the saturated interval of RPMW-16 is sandy gravel according to the boring log (Chevron 2001), and probably densely compacted because of the low hydraulic conductivity there. The substantial hysteresis in the slug tests may imply a nearby but unseen silt zone.

Figure 2-13
Slug-Test Raw Data and Displacements Measured in RPMW-16



10/17/03 Slug Test Data in MW16

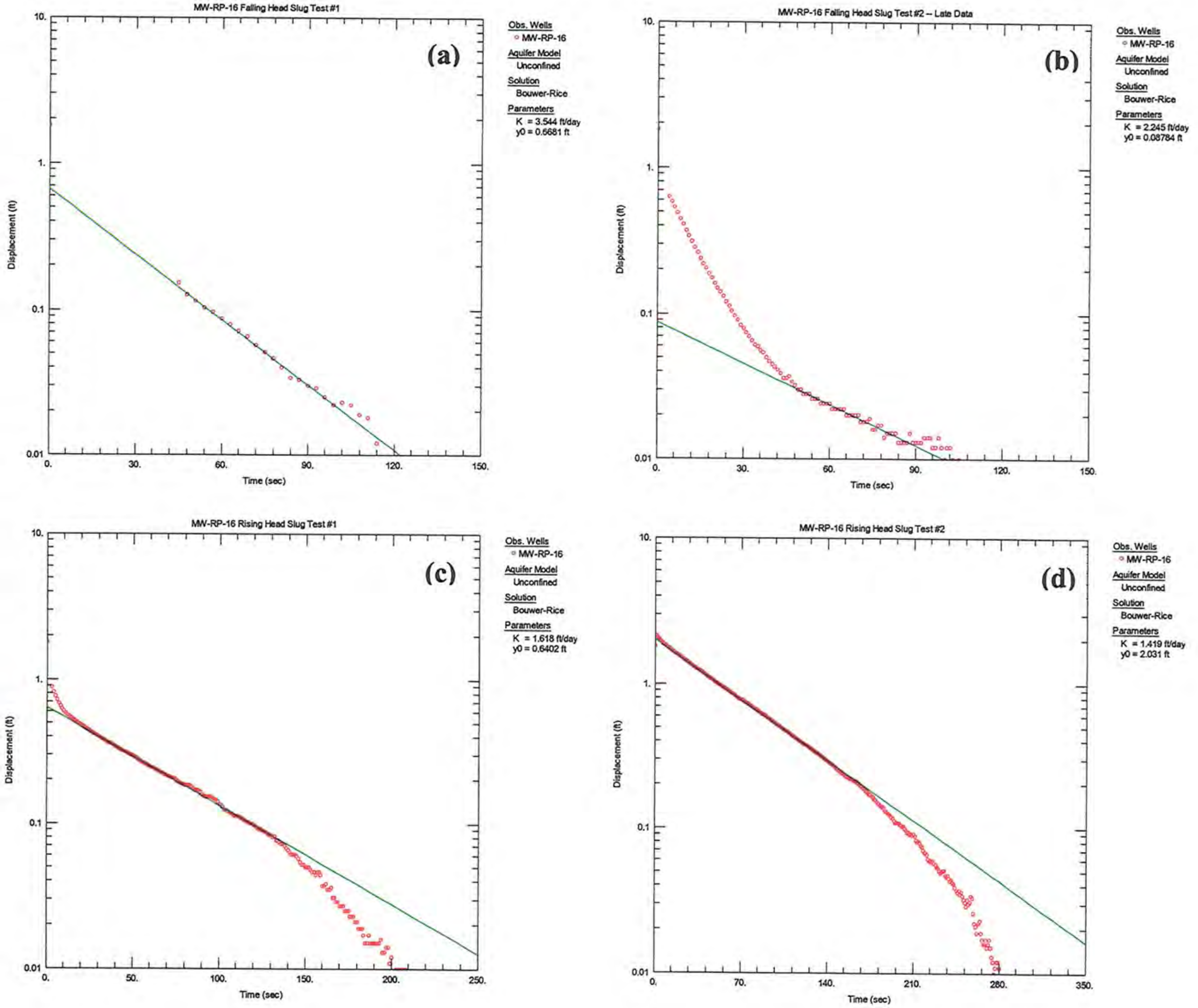
All MW16 Slug Test Data

Measured initial displacement is inexplicably large. Also, baseline correction slope is steep (0.00068 ft/s).

Expected initial displacement = 1.80 ft

Early data omitted because slug required 45 s to completely fall.

Figure 2-14
Bouwer-Rice Analysis of RPMW-16 Slug Tests



3.0 REFERENCES

Chevron. 2001. *Phase I/II Site Characterization: Data Evaluation Report, Rocky Point Management Area #1*. Prepared by Foster Wheeler Environmental Corp. for Chevron USA, Delta Western, and USACE.

USAED. 1999 (August). *1998 SI/RI/IRA Report, Amaknak and Unalaska Islands, Alaska.* Prepared by Jacobs Engineering Group Inc.

Appendix B

APPENDIX B

Field Notes

"Rite in the Rain"®
ALL-WEATHER WRITING PAPER

FIELD

All-Weather Maxi-Spiral
No. 353-MX

Characterization of
Groundwater Flow
Pre-WWII Tank Farm
Amaknak Is., AK

10/6/03 to

David Ward
Jacobs Engineering
4300 B St.
Anchorage, AK 99503
907-563-3322

Property of Jacobs Engineering, 4300 B Str., Anchorage, AK 99503 907-563-3322

Table of Contents

Page	Description
3	Wiring and Bench Testing the Conductivity Probe
5	Miscellaneous Information for Dutch Harbor
7+23	Field Log for Characterization for Groundwater Modeling 10/15-$\overset{23}{22}$/03
16	Field map from 10/15 and 10/16/03.
24	Mike Utley's Field Notes from 10/21/03.

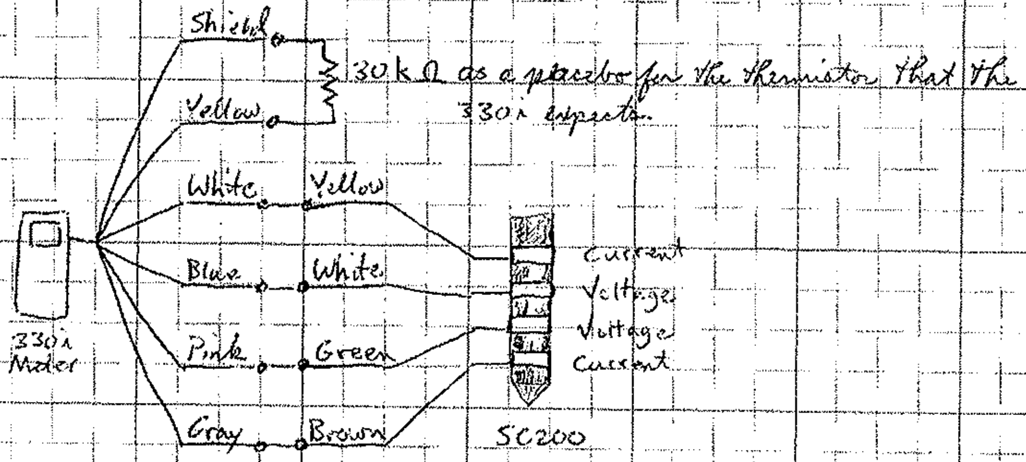
Wiring and Bench Testing the Conductivity Probe

D. Ward

10/6/03

Conductivity Probe: Geoprobe SC200   Meter: Geotech 330i

Wiring:



Testing:

1. Calibrated the native probe for the 330i in the supplied 0.1 M KCl solution. 1322 µS/cm (calibation value @ cell constant = 0.473).
2. Tap water w/native probe = 169.6 µS/cm at 23.4°C

3. Geoprobe SC200 in tapwater, using a cell constant of 0.473

   2.53 mS/cm (wired as above) Apparent cell constant would be 0.032
   17.42 mS/cm (Blue → Green, Pink → White) App. cell const. is 0.0046
   This second configuration is much too sensitive, so cable was hard-wired as above.

   $$\text{App. cell const.} = \frac{169.6\,\mu S/cm}{\text{Obs. value }(\mu S/cm)} \cdot \overset{\text{meter const.}}{0.473}$$

4. Meter cell constant can range from 0.25 to 2.5, or be set to 0.1 or 0.01.

   Cell const. @ 0.01 ⇒ 53.8 µS/cm for t.w. $\text{App. cell const.} = \frac{169.6}{53.8} \cdot 0.01 = 0.0315$

   Empirical cell const.: Adj. until display reads 1696 µS/cm (divide by 10 for true conductivity) ⇒ 0.320 gives 1695 µS/cm

contd →

Cont'd from ③

5. Drift: Significant. Within 5 minutes, cell constant was up to 0.323. I also noticed some $FeOOH$ in suspension around the tip of the probe. Local oxidation and precipitation? Water chemistry is probably changing; so the original cell const. is probably best (0.315).

Miscellaneous Information for Dutch Harbor

Combination for all locks: 1423

Calibration gas: AK Airlines airbill 60393771 $62.17 at the cargo desk

Jessica – 751-3397, 569-8481 (home), 229-8239 (cell)
Jennifer – 751-3459

Credit card for shipping samples: Mastercard 5405 1070 0236 7327
exp 5/05 Betty Lewis

Imakmak cell phone: 907-~~[illegible]~~591-6817

Field Office fax machine: Panasonic KX-FL501
Toner: KX-FA76 (replaced 10/20/02)
Drum: KX-FA77

Field Log - Dave Ward + Mike Utley

10/15/03 17:10 Prep of 4 transducers

- Adj clock on Pocket PC to watch. Result = ~10s fast. (Watch was synchronized to NIST last night)
- Renamed 010628 to 010627 to match ~~label~~ property label on actual transducer.
- Transducers have a property number as do the cables attach. Original names match the cable numbers; 01062$\overset{7}{8}$ is un-renamed to 010628. (Entry in Pocket PC is changed from 010628 back to 01062$\overset{8}{\cancel{7}}$.
- Set all transducers to start @ 1800 ADT. Test name = TEST#1

18:20 Looking for wells - MW-2 + MW-4 - not a trace. Beneath gravel in parking area

- MW-16 - found, but ~50' closer to Starbuck Bay
- MW-15 - easily found. There is a storm drain near MW-16. Some water flowing in (maybe 1 gpm)

+ stormdrain outfall on adjacent beach. Flow maybe 10gpm. (20gpm?)

19:00 Transducer in ~~#~~MW-16

- Photos 17 (well vault), 18 (view to NE), 19 (v. to NW)
- Bailed well vault
- Static water level @ 8.41' @ 19:02
- Installed transducer 010628 @ ~19:15 (19:10?)

19:25 Transducer in MW-15

- Water Level 9.86' at 19:28
- Transducer 010631 @ 19:32 (about)
- Photos 20 21 (coiling transducer cable), 22 (v. to SE)

19:40 Transducer in MW-11

- ~~Water level~~
- ~~Transducer~~
- Photo 23 (~~inside of standpipe showing Bunker C contam~~)

Not installed ~~at~~ at @ this time. We didn't bring the interface probe, and there is lots of Bunker C here.

Storm Drain + Utilidor near Bldg 551

- Photo 23
- Standing water, but not much flowing into the drain.

cont'd on p.8

cont'd from p. 7

10/15/03 cont'd Looking for wells near Bldg 551
- MW13 Not found. May be under a large puddle
- MW5 Not found. May be under a puddle or under debris adjacent to Bldg 551
- MW-4 Still partially obstructed by a junker car, which could probably be moved.

10/16/03 Call to Dave Gregory at OC re: Ettelidor as-builts
- Dave had to leave town for at least a couple of days.
- Call/visit on Monday.

Francis Cagle 581-1260 Public Works. 1 mi S on Broadway from stop sign at SYL. Big brown box building. Says to come on over.
- Visited for about 30 min, obtained drawings

~ 11:15 Transducer Prep.
- 010632 (# on cable) Changed batteries
- "Frayed Cable" (no prop. name) Changed batteries
- Set "Test #1" on both to start at 12:00 noon, 6 min interval

12:00 13:30 · Scanned for MW-4 w/ magnetometer. Dug 2 test pits, but found nothing.
· Near this area is a large drain to a bunker
· Photos: 24 (overview of TPs), 25 (TPs closer up, looking E still)
26 (closeup of both, v. to NE)
27 well vault next to corner 28 Well plug in gravel
29 Storm drain

Conclusion: MW-4 has been destroyed.

MW-5 Not to be found. Either under puddle or under junk, or both
Photos 30, 31 v. to NE

MW-2 Found by using ties: 64' from door to "Rapp Hydema", 6" from building "corner" near Carquest. See map. ← Tom is proprietor
WL = 10.19' at 14:46 No well box; bare PVC w/ plug only
Transducer = "Frayed Cable" (SN 5419)
Photo 32 view to SE

cont'd on p. 8

cont'd from p. 8

10/16/03 cont'd MW-13 Survey Tie: 27.5' S of Bldg 551, aligned w/ 2nd bay of windows from E. Benny (Delta Western Fuel Dock) moved pallets so that we could get access. Found it easily w/ magnetometer, right where it ~~#~~ was supposed to be. Too much water and oil (used motor oil recently spilled) to do anything today.

MW-~~#~~6 WL = 12.97 @ 16:38 Transducer ID = ?? 010624, I think. SN 8002 DOW 10/17/03
Photo 33 showing excavated ~~was~~ well vault.

MW-8 moved car that was on top of well by using a strap found in field trailer + gently pulling w/ field vehicle.
WL = 10.44 @ 17:56 Trace of product.
Transducer = 010622

MW-11 Oil level = 13.34 ft at 18:17 WL = 19.38 ft
Transducer = 010625

10/17/03 Transducer prep. Test #1 6 min interval starting at 10.00 this morning
- "4INCHCAP" Has 4" cap on cable. (SN 5397)
- "008138" Serial # is engraved on outside. Property tags came off; they were 010629 ~~o~~ on cable, 010623 on probe.

MW-13 Product Level = 10.91 ft at 12:30. Meas. relative to highest point on casing.
WL = 10.80 at 12:37
Installed transducer "4INCHCAP" at 12:50. Lubed PVC slip joint with Bostik "Never Seez" from Shipe Supply. It contains Barium Oleate, Copper, Molybdenum Disulfide, Petroleum Grease, Graphite, Zinc Oxide. No VOCs.

MW-16 Slug Test Static WL = 8.78 ft @ 12:41 Test #1 stopped.
Test "MW-6RHT" ~~Log scale~~ 1.5 in x 36 in slug.
Transducer will only do linear tests. Started at 3 s interval. Called "Test #1" because I forgot to rename it.
Slug dropped at 14:52:20. Test #1 started a minute or so earlier. Slug ~~dropped about~~ lowered about 9.7 ft, then dropped as far as it would go. It fell freely 2 to 2.5 ft, hung briefly when the line snarled on grass, then

Transducer SN 8014 Init. Head = 2.541 ft

cont'd p. 10

cont'd from p.9

10/17/03 cont'd Slug test at MW-16 cont'd

settled another 6" to 1 ft within a few seconds. Within the next couple of minutes, it settled another 18 inches or so, probably as it fell past the transducer.

equil. in ~500s

15:12 "Test #1" Stopped. Initial head was 2.504, jumping to ~2.8 psi.

Final head had dropped to ~2.5, then started to climb

~15:19 Started MW16FH1B w/ 1 min intervals. (15:17:38) Slow drift from 2.504 to 2.435.

"Hail storm moving through - nearly 0.1" precip."

~15:27 Test stopped

Rising Head test — Initial head ~ 2.49 psi

Pi = 2.498 psi

15:37 MW16RH1a @ 1 s intervals started and slug pulled from well.

Equil in ~500s again

15:50 Test #1 @ 1 min intervals

~17:05 Stopped

Pf = 2.428 psi

17:12 Started & dropped slug 15 Δ "Data showed test was complete after 7 min."

17:45 Rising head. Slug pulled and transducer started 15 Δ.

18:07 Stopped.

18:07 Started 6 min Δ again

Diesel odor on slug + rope at conclusion of MW-2 test. ← Didn't mean MW-16 here? Almost certainly DBW 11/6/03

Trans S/N 3005

Equil in about 450s.

MW-15 Slug Test (concurrent w/ MW-16, partly). 4 in well

Static water level = 10.73 ft Transducer = 2.093 psi

Slug (4") dropped at ~16:28 Test #1 started a few seconds earlier

Falling head stabilized at 2.096 after 12 min.

Rising head test: slug pulled at 16:45. Transducer started a few seconds earlier.

Falling head: slug dropped at 17:23 ~~Stopped at ~18:08.~~

~17:30 Stopped.

~17:32 Started 6 min monitoring.

Cont'd p.11

cont'd from p.9

10/18/03 Plan: Slug Tests in MW-6, MW-10, MW-8, MW-14
Product samples from Bldg 551
Building 551 and Utilidor recon.

10/27/03 DBW) No. All readings ~ 0.226 after it was installed (10/16 16:45). ⇒ No tidal influence here.

10/27/03 DBW Name = 010624 (SN 2002) →

MW-6 Slug Test 9:45 - 10:35 4 in well
Static WL = 12.14 ft
Transducer: No readings since installation! This one may be broken. Installed new transducer (# ~~[illegible]~~ ?). "Zero" was 0.13 psi.
P. was 0.45 psi. Δ = 0.32 psi or about 0.65 ft.
Dropped slug into well, but it would not pass the transducer and displace any water ⇒ can't do a slug test here.
Started 6 min monitoring at 10:30

all readings ≈ 0, but it was reading every 6 min.

10/27/03 DBW Name = 010622

MW-8 Slug Test 10:40 - 11:15 2 in well
Static WL = 11.77 ft Probe partially coated in Bunker C, but not enough to be worth using interface probe
Transducer (#8136) reading okay, ~1.45 psi ⇒ 3 ft of water
Performed falling and rising head tests (1 each). Equilibration was rapid (~70 s) ~~[illegible]~~; pressure change ~~[illegible]~~

MW-10 Slug Test 13:35 - 14:00 4 in well
Static WL = 9.11 ft
Used transducer #5351. Equilibration time was ~5 min, so ran a pair of Falling Head - Rising head couplets back to back, all in the same data file.

MW-14 Slug Test 14:05 - 14:25 4 in well
Gained access via Powerhouse operator
Static WL = 8.41 ft.
Used transducer #5351. 2 pair of falling head - rising head couplets all in one data file again

Recon of Utilidor access at the former LF
Photos 37, 38, 39. Utilidor is only as tall as the opening (30-36" (not measured)). Only 1-2" of mud on floor.

cont'd p.12

cont'd from p. 11

10/18/03 cont'd

Recon of Building 551 and barracks buildings to west (549 and 547)

- Ventilation openings every 20 to 40 ft provide a glimpse of conditions and geometry.
- Building 551:

  Geometry: ~~for~~ "floor" of "crawl" space is 4 to 5 ft below ground level, composed of dirt with scattered debris. Damp in some areas, dry elsewhere. No standing water.

  Product: free product is visible through an opening in the middle of the south east wall. Extent of oozing product to NE cannot be seen.

  Access: There is a two ft square opening on the NW side of the building and there is an opening w/ plywood across it on the SE wall, 20 ft east of product location. We will pry the plywood loose and assess access possibilities, replacing it when we are finished.

  Photos:

  42 Utility room at SE corner of building
  43 SE corner of building, showing openings to two utility rooms.
  44 Mike w/ old hardhat. (It's a good thing he has a tough head!)
  45,46 Access opening on NW side of building
  47 View through opening where free product is.

- Barracks (Bldgs 549 and 547)

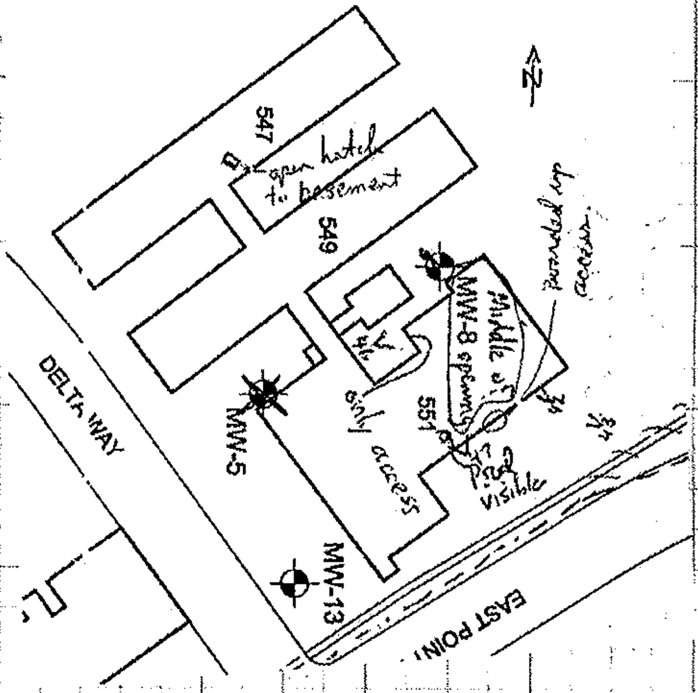
  Geometry: "crawl space" is more like a basement, partially finished with flooring and storage areas. Bottom is estimated to be 5 to 6 ft below ground level. Appeared dry where visible (SW ends of buildings, open hatch in middle of 547)

  Elevation of ground floor of barracks and mess hall (551) is uniform (all buildings built to same elevation).

cont'd from p. 12

Buildings 551, 549 and 547 Recon Notes

10/18/03



10/15/03 cont'd

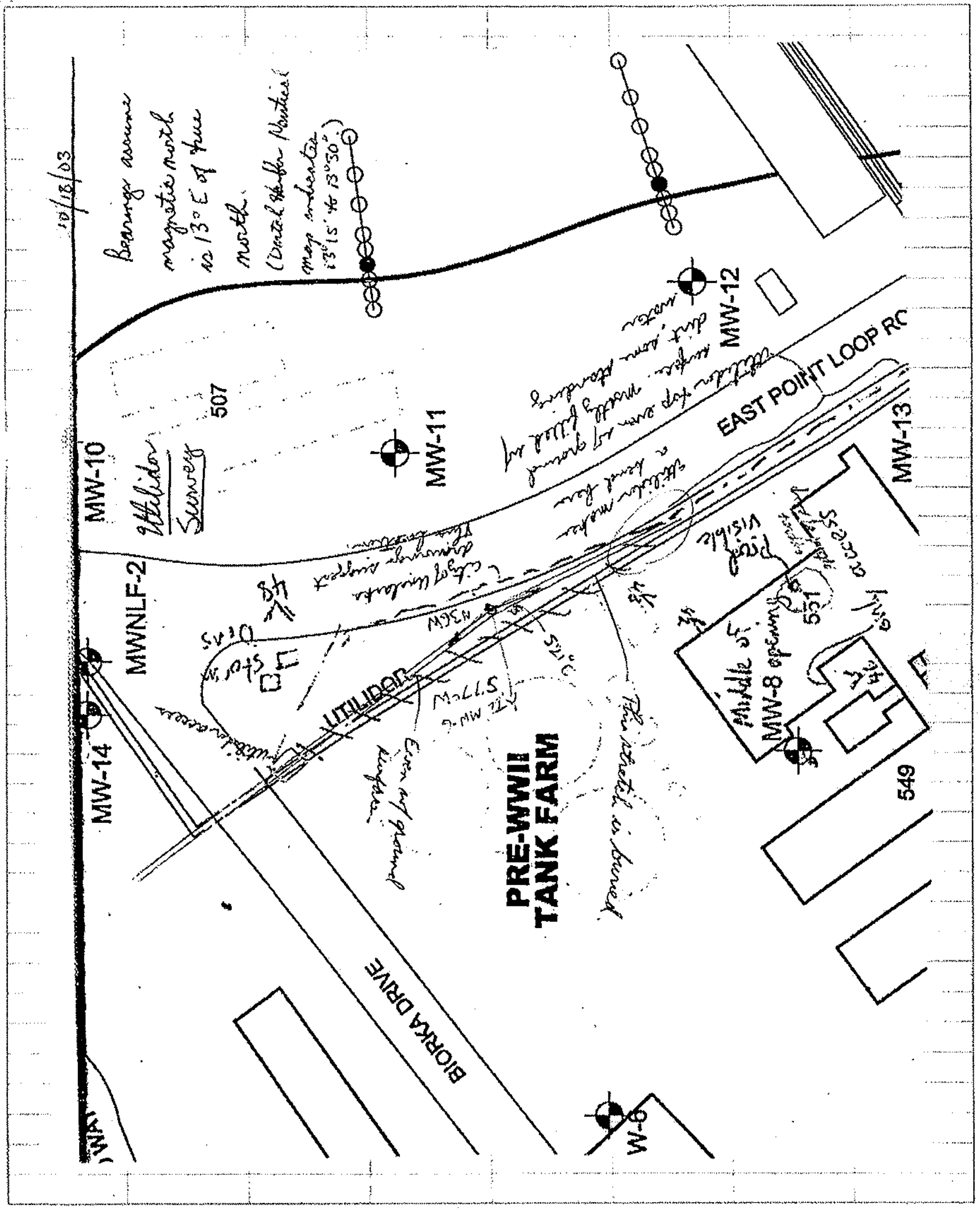
Recon of Utilidor
- Map on next pages

- Engineering maps from Francis Engle (City of Unalaska) for proposed Storm Drain system show the utilidor in great detail, but they appear to be based on limited field observations (Francis said test pits are planned, though). In particular, these drawings show the utilidor making a jog around the tank farm site, running under the edge of East Point Loop.

- Field recon suggests:
  (1) Utilidor runs straight from exposure on hill NW of Biorka Dr to East Point Loop (N36W or S36E)
  (2) Utilidor then bends, running straight next to East Point Loop (N21W or S21E)
  At this bend, the bearing to MW-6 is S77W.

Cont'd p. 14

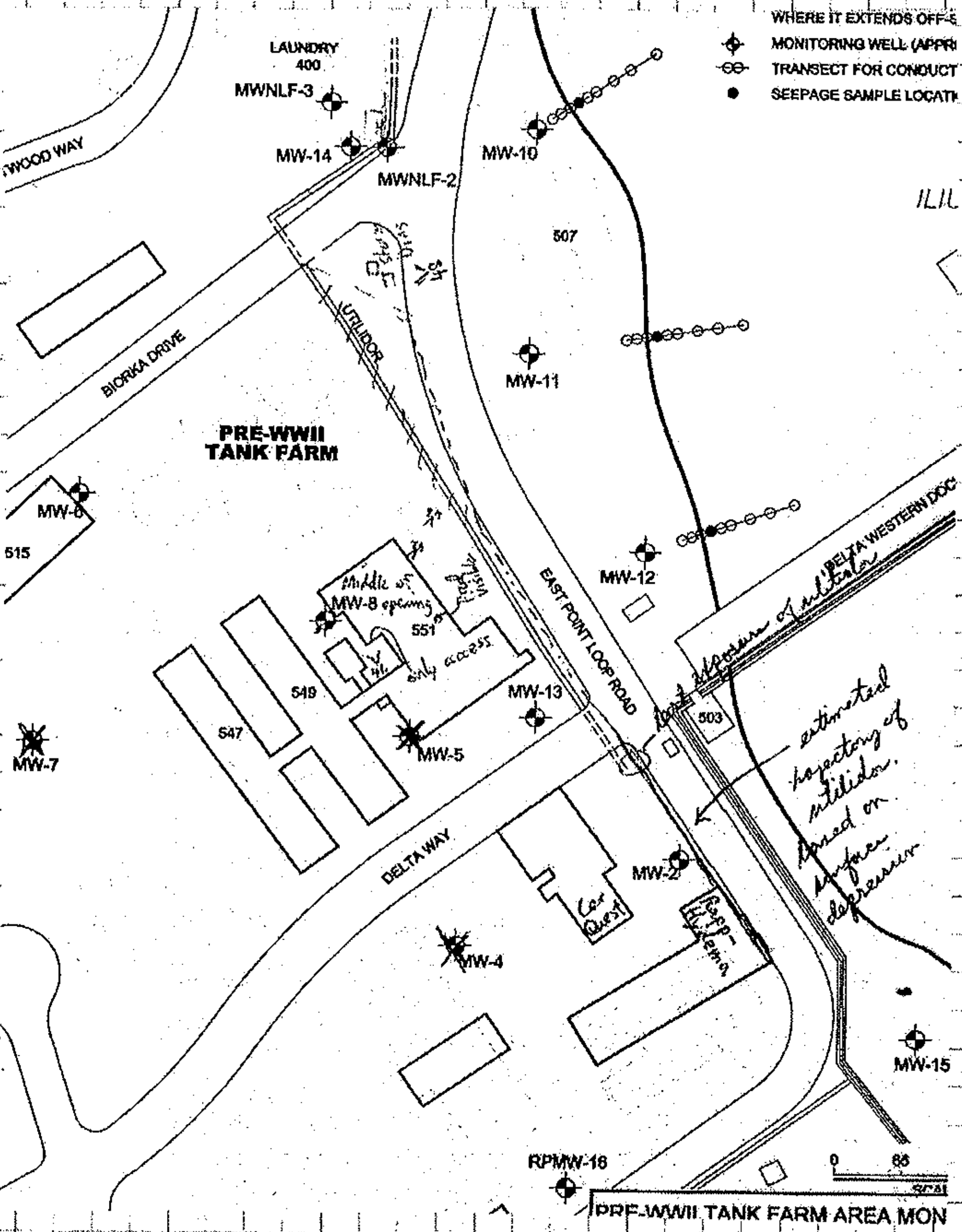
cont'd from p. 12



cont'd on p. 15.

Cont'd from p. 14

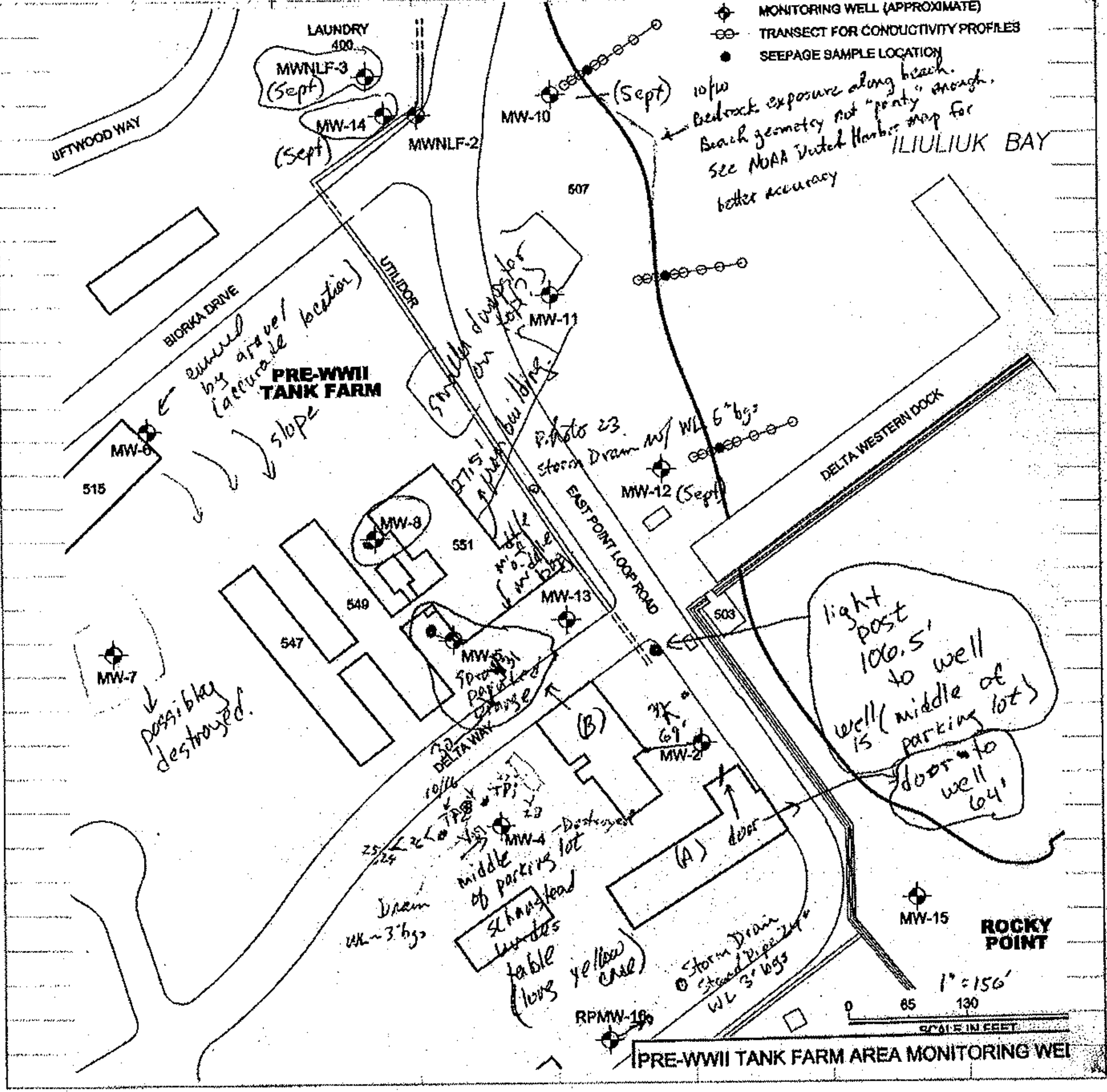
10/18/03 cont'd ~~Ut~~ Utilidor Recon cont'd.



Utilidor appears to run past MW-2, but is ~~can~~ ~~so~~ caved in SE of Delta Way

Cont'd on p. 17

~~Fiel~~
Field Map from 10/15 and 10/16/03



PRE-WWII TANK FARM AREA MONITORING WEI

cont'd from p.15

Field Log (cont'd)

10/17/03 Tasks planned today:

① Product samples from Bldg 551, MW-13, MW-11 (and MW-12?)
② Slug tests at MW-2 (may need development because of seds washing in), MW-12, and MW-13.
③ Recon of beach (shoreline) geometry

QRae 4-gas meter calibrated 10:02

~~At the pt~~ Arrived at site 10:20. Heavy snow until about 10:40.

P approximately 5.6 psi

MW-2 Recheck – No data from transducer because date not properly set.
- Rainwater had been puddling and draining into open well
- Dug moat, made dike, bailed moat, then bailed well. Added 2" extension (a 2" coupling) to keep water out └ 4 gal. still quite silty
- P stable at 2.69 psi, so started tidal monitoring again

Product Sample from Bldg 551
- access from SE end. Roy of [illegible] moved cover from stairs. Cleared enough debris away for safe access
- entered in level C w/ hardhat, respirator, Tyvek suit and gloves
- Collected sample from pool seen yesterday on NE side of crawl space (see map p.13) ~ 13:30
- Seep area is extensive in that part of building and used to be more extensive
- Most product is highly weathered, and is now the consistency of asphalt patch material for roofs
- Most is crusted over and dusty, but there are a few open pools (very sticky!)
- Extent of seep to the NW only estimated; I did not venture there
- Care was taken not to disturb any pipe insulation.

Slug Test at MW-12 14:57 – 16:30 No precip since this morning
- Transducer 5351. Internal date appears to be in error, reading 6/3/05 or thereabouts – Static WL = 10.67 ft – No product
- P_0 = 1.30 psi. Slug dropped ~15:12
- Well vault filled with mud from recent tractor work in the area; some mud appears to have gone down the well ⇒ this may explain any slowness to equilibrate.
- Run 2 pairs of FH-RH complete, but transducers stopped communicating after the first pair.

cont'd on p.18

⑱

Cont'd from p.17

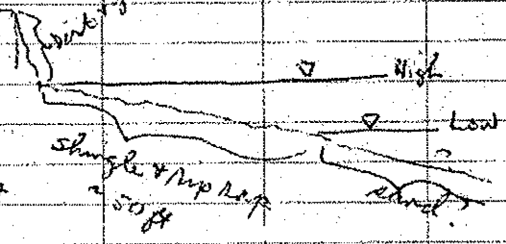
~~Slug Test~~ and Product Sample in MW-13 16:35 – 15:30 16:45 PID=24 ppm

- Static PL = 10.14 ft Static WL = 12.37 at 17:37
- No standing water now but deposited oil shows that water had completely filled the well vault during rains of the past few days
- Transducer cable end must have been submerged at these times
- Transducer data was read. Transducer # 5397
- Free product sampled by bailer at ~17:05. Viscous, but flowed easily enough that it filled the bailer.
- Decided not to do slug test because of thickness of product

Slug Test at MW-2 18:05–18:45
- Static WL = 10.82 ft
- Slug dropped at 18:10 1sΔ Transducer # ~~5397~~ 5419 (Frayed cable)
  ft = 2.996
- ~~Rising~~ Falling head equilibrated in ~30 s; ~~falling~~ rising head required ~500 s.
- Ran a pair of FH-RH couplets.

10/20/03 Today's Goals
- ✓ ① Sample product in MW-11
- ② Visit OC re as-builts for utilidor
- ✓ ③ Conductivity probing on beach
- ✓ ④ Field-check shoreline geometry
- ✓ ⑤ Buy Dutch Harbor nautical chart

7:00 ADT Beach at low tide
- Low tide at 0658 AST* of 0.15 ft MLLW
- ~50 ft of shingle and rip rap exposed
- Rip rap appears to end not far past the low tide line.



* our visit was 1 hr before actual low tide
- Difference in shoreline between MSL (2.15 ft MLLW) and high tide is small, and will not be important at the scale of the forthcoming groundwater model.

(CND11-1)

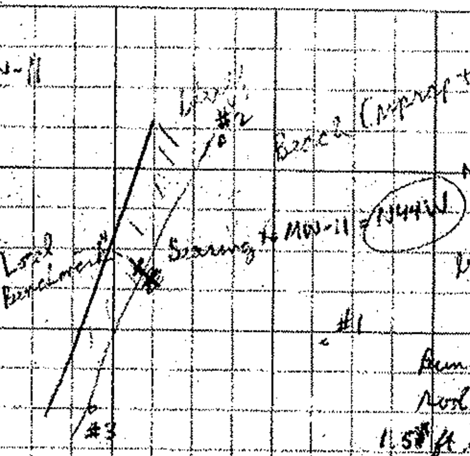
10:55 Cond. Probing Station #1 - E of MW-11

Depth	Meter Reading
1.0 ~~0.5~~ ft	26.1 mS/cm
1.5 ~~1.0~~ ft	15 → 63.5
2.0 ~~1.5~~ ft	35 → 54.4
2.5 ~~2.0~~ ft	31.3
3.0 ft	57.4
3.5 ft	62.0
4.0 ft	73.6
4.5	77.3
5.0	55.5
Refusal	

Bearing to local "Benchmark" = S81W
Distance = 14.0 ft
Plunge of probe rod string S52E 70°

Probe in seawater ⇒ 306 mS/cm on meter.

Station #1 on beach near water edge at start. Tide crosses msl (2.15 ft mllw) at 12:27 ADT; tide at 10:55 was 1.16 ft mllw, so elev. of Station #1 ~ -0.5 ft msl. DBW 1/15/04



Not possible from the site map, S75°W looks reasonable DBW 1/14/04

Bunker C on rod to about 1.5 ft below surface

Probe was deflected by rocks, bent first rod 5 to 10° and bent probe slightly

Station #2

Depth	Meter Reading
1.0 ~~0.5~~ ft	856 µS/cm
1.5 ~~1.0~~	~9.2 mS/cm
2.0 ~~1.5~~	17.51 mS/cm
2.5	19.62 mS/cm
3.0	13.6 → ~34
3.5	37.2
4.0	50.0
4.5	66.6

~~Bearing~~ Dist to local BM = 10'5"
Bearing " " " = S67W
Plunge = N37W 73°

Station #2 is slightly above the normal high tide line of 3.5 to 4 ft mllw (12 to 18 ft mid), so has a likely elevation of +2 ft msl. DBW 1/15/04

Station #3

Depth	Meter
1.0	475 µS/cm
1.5	240 µS/cm
2.0	159.5 µS/cm
Refusal	

Dist to BM = 32'10"
Bearing to BM N17°W
Plunge <10°, bearing NR

Actual Cond. = $\frac{\text{meter cond.}}{10}$ DBW 1/20/04

cont'd p.20

cont'd from p. 19

10/20/05 cont'd

16:15 MW-11 Stopped, downloaded transducer (#8121)
Static PL = 14.61 ft.
Static WL = 22.86 ft ← Not real. Bailer came up w/ essentially no product. Actual product thickness probably 2" or less (top of weights on bailer not oil coated.) (Bailer was completely full of water.)

18:30 Finished collecting product sample.

18:13 MW-16 Pulled transducer #8014, stopped test. Diesel in well? (sheen, odor). Static WL not measured

10/21/05 Today's tasks
1. Cond. probing along beach
2. Water sample(s) along beach
3 Pull remaining transducers - MW-2, MW-6, MW-8, MW-15
~~4~~

9:57 Cond Probing near MW-10

	Station #1	N54E from level B.M.	51'8"	in 18" water	
10:30	#2	N43E	56'5"	in 18" water	
10:40	#3	N24E	37'11"	at water edge	10" plunge

See Mike Utley's field notes this date. A copy is on p. 24.

depth	Meter	
1.0 ft	37.8 mS/cm	
1.5 ft	[illegible]	
2.0	40.3	
2.5	73.3	
3.0	91.8	
3.5	59.6	
4.0	60.3	
4.5	66.2	
5.0	50.9	
5.5	29.1	
5.75	23.7	Refusal

Actual = $\frac{\text{meter}}{10}$ DBW 1/20/04

Predicted tide at 10:40 is 0.9 ft mllw or -1.25 ft msl ⇒ Station 3 at ~-4.0 ft msl. Stations 1+2 at -2.7 ft msl. DBW 1/15/04

10/28 Could this be due to changing lithology (i.e., finer grained sand compared to overlying gravel) rather than decreasing salinity?

cont'd p. 21

cont'd from p.20

Top of shingle beach, just below gravel berm. Probably at high tide line.
⇒ Elev. ±1.5 ft mll
DBW 1/15/04

11:05 Station #4 114.2° W from Local BM, 7'10"

Depth	Meter
1.0 ft	1380 µS/cm
1.5	7.8 mS/cm
2.0	14.3 mS/cm
2.5	11.91 mS/cm
3.0	6.15 mS/cm
3.5	49.0 mS/cm
4.0	42.5 mS/cm
4.5 ~~43.3~~	43.3 mS/cm
5.0	56.6 mS/cm
5.5	36.2 mS/cm
6.0	33.9 mS/cm
6.5	23.8 mS/cm
6.7	36.8 mS/cm Refusal

6

Actual = $\frac{\text{meter}}{10}$ DBW 1/20/04

11 TU
6.5 DO
7.16 T°C
1.3% Sal
14 g/L
336 mV ORP
5.8 pH
2.3 S/cm

11:45 Snowstorm

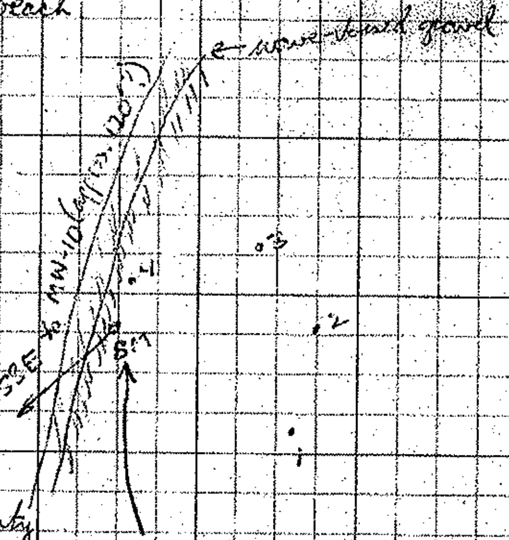
13:00 ~~Set~~ Installed PVC screen. Top open flush w/ beach ← station #4 again, in same hole as probe. WL = 2.81 TD = 3.42

13:30 Purged ~2 L @ 400 ml/min

Param	Value #1	Value #2
Turbidity (NTU)	11	13
DO mg/L	6.3	7.6
T °C	7.16	7.4
% salinity	1.3	1.3
TDS (g/L)	14	14
ORP (mV)	336	353
pH	5.8	6.13
Cond (S/cm)	2.33	2.15

↑ S/m? DBW 1/14/04 S/m ÷ 10 = mS/cm

mS/cm? m/m reasonable, given salinity of 1.3% DBW 1/21/04



N53°53'33.3"
W166°52'13.4"
15 ft accuracy

MW-10 GPS N53°53'33.1"
W166°32'13.7"
17.2 ft accuracy

← drifting rapidly ~0.1" every 2 or 3 min.

cont'd on p.22

cont'd from p. 21
10/21/05 cont'd

15:30 Water Sample from Station #2 (see p. 19) ~~near~~ on beach near MW-11.
- Installed PVC screen in same hole as made by cond. probe yesterday
- TOS flush w/ beach, almost (stickup 1-2")
- WL = 1.45 ft TD = 3.92 ft
- Sheen (coagulated looking) - Purging at 600 ml/min

Field Params	Values	Value (15:50)	Value (1600)
Turbidity (NTU)	>1000	461	163*
DO (mg/L)	10.1	10.4	10.5
T °C	7.04	7.10	7.2
% salinity	0.9	0.9	0.9
TDS (g/L)	10	10	10
ORP (mV)	321	332	335
pH	6.7	6.8	6.5
cond (S/m)	1.60	1.66	1.66

← Turbidity due to orange floc (probably FeOOH) ⇒ upgr. is probably a reducing zone w/ high dissolved Fe^{2+}

* Still pretty cloudy in appearance.

16:47 MW-6 WL <12.75 ft
- pulled transducer #2:38
- All readings in data file ~0453, so pulled transducer up part way and verified responsiveness
- Water in well vault essentially even w/ top of casing.

17:00 MW-8 WL = 11.54 ft.
- pulled transducer #8136

17:25 MW-2 WL = 11.12 ft.
- Pulled transducer # 5419 (Frayed cable)

17:50 MW-15 WL = 11.36 ft
- Pulled transducer #3051

10/22/03 Shipment to Anchorage

1 Red cooler – Slide hammer
1 Blue cooler – Mike's stuff
1 Green cooler (Dave's stuff)
3 short FedEx tubes
1 longer " "
1 Bl. toolbox
1 Hoist
1 Gastec Pump
1 QRae
1 TTT black case (PID)
1 Cond. meter
1 Hi Lift Jack
1 Rubbermaid Roughneck (Transducers)
Slate (zink)

10/23/03 Met with Dave Gregory at OC offices, obtained good photocopies of the relevant parts of 2 "as-built" drawings of the utilidor.

(24)

Mike Ettley's Field Notes from 10/21/03 – Conductivity Probing Near MW-10

cloudy
35-45
light rain

10/21 Aurkrank GW

0800 Site prep / tailgate.
0930 MW10 for conductivity, GW sampling (possibly MW11).
1000 MW10 Cond
1' – 43.6
1.5 – 45.6 (Rock) (Refusal) DBW 10/28/03

Location 2
1' 56.6
1.5' 45.6
2.0' 57.0 (Refusal) DBW 10/28/03

1300 GW sampling
flow rate = 15 s black line on probe container
~ 100 mls
~ 400 mls/min
Purge ~ 1 gallon

02MW10
10/21/03
VOC
PAH
metals
MS/D
dup
(1054)

1410 GW sampling MW11 Station 2
flow rate = 10 s as above
~ 100 mls in 10 s
~ 600 mls / min

02MW11 10/21/03
VOC (8021)
PAH, metals @ (1457)

Appendix C

APPENDIX C

Historical Boring and Test Pit Logs

Test pit logs from the *1996 Amaknak Interim Removal Action/Investigation Report,* Appendix C, prepared by Jacobs Engineering Group Inc. for the USAED, August 1998.

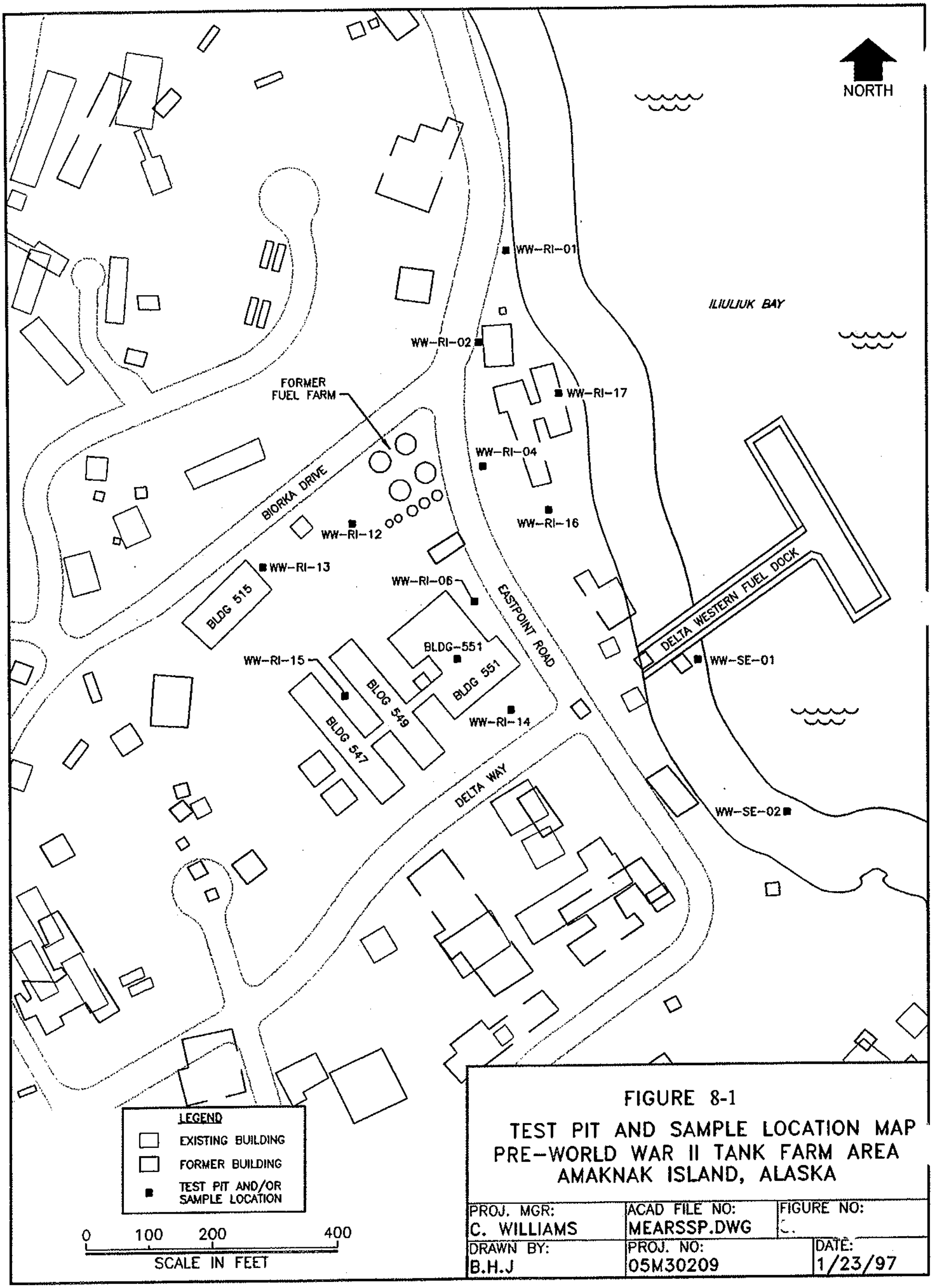


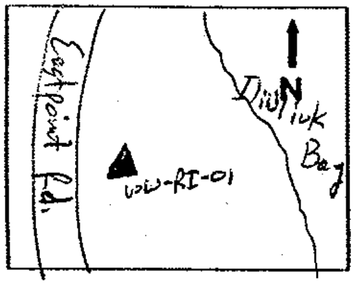
FIGURE 8-1

TEST PIT AND SAMPLE LOCATION MAP
PRE-WORLD WAR II TANK FARM AREA
AMAKNAK ISLAND, ALASKA

PROJ. MGR: C. WILLIAMS	ACAD FILE NO: MEARSSP.DWG	FIGURE NO: C.
DRAWN BY: B.H.J	PROJ. NO: 05M30209	DATE: 1/23/97

Lithologic Borehole Log
Project # 05m30207

Sheet 1 of 1



Site ID ww II TF
Northing 9656.35
Elevation 10.51'
Date Started 21 Aug 96
Drilling Contr. WCC
Drill Method Backhoe
Sample Type Grab
Hammer Wt. NA

Location ID ww-RI-01
Easting 8584.82
T.D. 11.0'
Date Completed 21 Aug 96
Driller NA
Rig Type
Geo/Eng. E. Gorove
Backfilled Date 21 Aug 96

Weather Conditions
overcast, drizzel,
winds 5-10 mph, temp ~58°F

Names of Persons Present
E. Gorove
B. Sy
S. Virg-In

Depth in Feet	Sampled Interval	Sample Number	Percent Recovery	HNU or OVM Reading	Blows Per 6"	Sampling Method	Water Content	USCS Code	Color	Graphic Log
0			NA		NA	GRAB				
				0.0						
5										
				0.0						
10				5.0						
	10.5-11.0	ww-RI-01						SP		▨
15										
20										
25										
30										

Interval **Description**

0.0 - 10.5' Clayey cobbles with some sand, redish brown, Cobbles: up to 3', avg. 6", angular to subrounded. Sand: f.g. - m.g. Clay: med. stiff, well graded, damp.

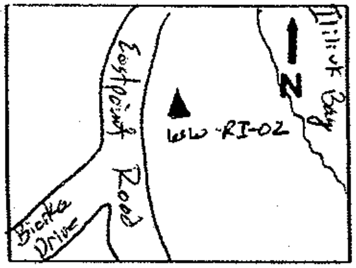
10.5-11.0' Sand, dark gray. Sand: m.g. - c.g., subangular to angular. Poorly graded, wet.
Groundwater @ 11.0'

11.0' TD

well point installed

Lithologic Borehole Log
Project # 05m30207

Sheet 1 of 1



Site ID	WWII TF	**Location ID**	WW-RI-02
Northing	9583.38	**Easting**	8568.03
Elevation	11.67'	**T.D.**	12.0'
Date Started	21 Aug 96	**Date Completed**	21 Aug 96
Drilling Contr.	WCC	**Driller**	NA
Drill Method	Backhoe	**Rig Type**	
Sample Type	Grab	**Geo/Eng.**	E. Gorove
Hammer Wt.	NA	**Backfilled Date**	21 Aug 96

Weather Conditions

overcast, drizzel, winds 5-10 mph, temp ≈ 50°F

Names of Persons Present

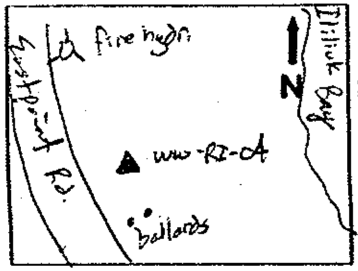
E. Gorove
B. Sy
S. Virg-In

Depth In Feet	Sampled Interval	Sample Number	Percent Recovery	HNU or OVM Reading	Blows Per 6"	Sampling Method	Water Content	USCS Code	Color	Graphic Log	Interval	Description
0			NA		NA	Grab					0.0-12.0'	Cobbles and boulders with some gravel and trace silt and clay, tannish brown, Cobbles & boulders: up to 4', avg. 10", angular to sub-angular. Gravel: 1/2" to 3", avg. 1", angular. well graded, oil contaminated >10' bgs. Groundwater with product blebs globules @ 11.5' bgs.
5				0.0								
				0.0								
				20.0								
10	10.0'	WW-RI-02										
											12.0' TD	
15												
20												
25												
30												

Lithologic Borehole Log

Project # 05W30207

Sheet 1 of 1



Site ID Pre WWII TF
Northing 9356.09
Elevation 14.01
Date Started 21 Aug 96
Drilling Contr. WCC
Drill Method Backhoe
Sample Type Grab
Hammer Wt. NA

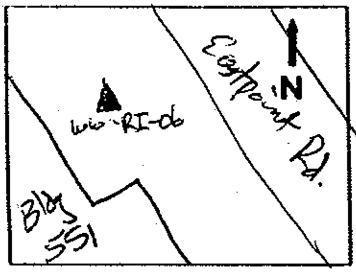
Location ID ww-RI-04
Easting 8594.77
T.D. 14.0'
Date Completed 22 Aug 96
Driller NA
Rig Type
Geo/Eng. E. Gorove
Backfilled Date 22 Aug 96

Weather Conditions
Ptly cloudy, temp ~45°F, winds 10 mph
Names of Persons Present
E. Gorove
S. Virg-In

Depth in Feet	Sampled Interval	Sample Number	Percent Recovery	HNU or OVM Reading	Blows Per 6"	Sampling Method	Water Content	USCS Code	Color	Graphic Log	Interval	Description
0			NA		NA	Grab					0.0 - 11.0'	Silty gravel with some cobbles and boulders, med. brown. Gravel: 1/2" to 4", avg. is 2", angular to subrounded. Cobbles/boulders: up to 24", avg. is 14", angular to subangular, well graded, dry to damp.
				0.0				GM				
5												
				0.0								
				0.0								
10												
				220.0								
	11.0'	ww-RI-04						GP			11.0-14.0'	Sandy gravel, black. Sand: c.g., angular. Gravel: 1/4" to 4", avg. is 1/4", subrounded to rounded. Oil saturated, poorly graded.
											14.0' TD	Groundwater not encountered
15												
20												
25												
30												

Lithologic Borehole Log
Project # 05UM30207

Sheet 1 of ___



Site ID Pre WWII TF
Northing 9152.25
Elevation 13.76
Date Started 22 Aug 96
Drilling Contr. WCC
Drill Method Backhoe
Sample Type Grab
Hammer Wt. NA

Location ID ww-RI-06
Easting 8577.73
T.D. 14.0'
Date Completed 22 Aug 96
Driller NA
Rig Type
Geo/Eng. E. Gorove
Backfilled Date 22 Aug 96

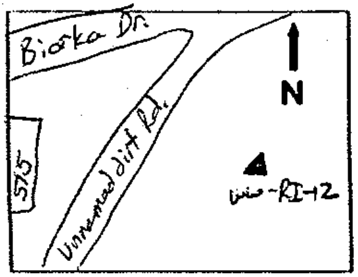
Weather Conditions
Ptly cloudy, temp ~45°F, winds 10 mph

Names of Persons Present
E. Gorove
S. Virg-In

Depth in Feet	Sampled Interval	Sample Number	Percent Recovery	HNU or OVM Reading	Blows Per 6"	Sampling Method	Water Content	USCS Code	Color	Graphic Log	Interval	Description
0			NA	0.0	NA	Grab		OL			0.0-3.5'	Gravely silt, orangish brown. Gravel: 1/4"-2", avg. is 1", subangular to subrounded, Silt: topsoil. Misc. debris 2.5-3.5' bgs. Damp,
5	4.0'	ww-RI-06		12.0				GW-gp			3.5-14.0'	Sandy gravel, black, Sand: m.g. - c.g., subangular to subrounded, Gravel: 1/2" - 4", avg. is 3/4", rounded to subrounded, Oil saturated 4.0 - 14.0' bgs, mod. graded.
10												
											14.0'	TD
15												well point installed
20												
25												
30												

Lithologic Borehole Log
Project # 05M30207

Sheet 1 of 1



Site ID Pre WW II TF
Northing 9262.25
Elevation 15.53
Date Started 22 Aug 96
Drilling Contr. WCC
Drill Method Backhoe
Sample Type Grab
Hammer Wt. NA

Location ID ww-RI-12
Easting 8324.31
T.D. 13.0'
Date Completed 22 Aug 96
Driller NA
Rig Type
Geo/Eng. E. Gorove
Backfilled Date 23 Aug 96

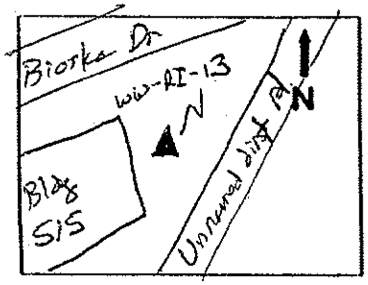
Weather Conditions
Ptly cloudy, temp. ~45°F, winds 10mph

Names of Persons Present
E. Gorove
B. Sy
S. Ving-In

Depth In Feet	Sampled Interval	Sample Number	Percent Recovery	HNU or OVM Reading	Blows Per 6"	Sampling Method	Water Content	USCS Code	Color	Graphic Log	Interval	Description
0			NA		NA	Grab					0.0-3.0'	Silty sandy cobbles, med. brown. Cobbles: 4" to 3', avg. is 6", angular to rounded. Well graded, dry to damp.
				0.0								
5				6.0 ppm 2.0 ppm				Pt		▤	3.0-9.5'	Silt (peat), dark brown to black. oil stained 4.0-9.5' bgs, vegetation @ 7.0' bgs, damp.
	7.0-8.0	ww-RI-12										
10				5-6.0 ppm							9.5-13.0'	Sandy cobbles with some gravel, dark gray. Sand: f.g.-c.g., angular. Cobbles: 6"-16", avg. is 8", angular to subrounded, some oil staining throughout intvl. and fuel odor. Well graded, damp.
	13.0	ww-RI-12									13.0' TD	Groundwater not encountered
15												
20												
25												
30												

Lithologic Borehole Log
Project # 05W30207

Sheet 1 of 1



Site ID Pre WWII TF
Northing 9229.10
Elevation 22.46
Date Started 23 Aug 96
Drilling Contr. WCC
Drill Method Backhoe
Sample Type Grab
Hammer Wt. NA

Location ID ww-RI-13
Easting 8216.57
T.D. 11.0'
Date Completed 23 Aug 96
Driller NA
Rig Type
Geo/Eng. E. Gorove
Backfilled Date 23 Aug 96

Weather Conditions
Clear, temp ~40°F, winds 5-10 mph

Names of Persons Present
E. Gorove
B. Sy
S. Ving-In

Depth in Feet	Sampled Interval	Sample Number	Percent Recovery	HNU or OVM Reading	Blows Per 6"	Sampling Method	Water Content	USCS Code	Color	Graphic Log
0			NA		NA	Grab				
5				0.0				OL		▨
10	11.0	ww-RI-13								▨
15										
20										
25										
30										

Interval Description

0.0-3.0' Silty gravelly cobbles, lt. brown.
Gravel: 1/4"-3", avg. 2", angular.
Cobbles: 4"-24", avg. is 10", angular
to subrounded, well graded, dry to damp

3.0-11.0 Silt, brownish orange, loose,
damp. Intvl. 10.0-11.0 is black
with sewage odor & vegetation.

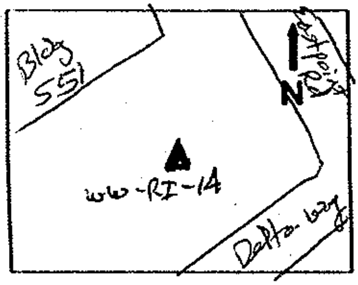
11.0 TD

Groundwater not encountered

WP\FORMS\BORE-LOG

Lithologic Bore. a Log
Project # 05UW30207

Sheet 1 of 1



Site ID	PrewwII TF	Location ID	ww-RI-14
Northing	8999.49	Easting	8650.21
Elevation	14.12	T.D.	13.5'
Date Started	23 Aug 96	Date Completed	23 Aug 96
Drilling Contr.	WCC	Driller	NA
Drill Method	Backhoe	Rig Type	
Sample Type	Grab	Geo/Eng.	E. Gorove
Hammer Wt.	NA	Backfilled Date	23 Aug 96

Weather Conditions
Clear, temp. ~65°F, winds 5-10mph

Names of Persons Present
E. Gorove
B. Sy
S. Viitg - In

Depth in Feet	Sampled Interval	Sample Number	Percent Recovery	HNU or OVM Reading	Blows Per 6"	Sampling Method	Water Content	USCS Code	Color	Graphic Log
0	NC	NC	NA		NA	NC		GM		
				0.0 0-1 ppm				Pt		
5										
10								GM		
15										
20										
25										
30										

Interval **Description**

<u>0.0-2.5' Silty gravel</u> with some sand, gray. Gravel: ½"-3", avg. is 2", rounded to subrounded, Sand: f.g.-c.g., subangular to subrounded. Intvl. is compacted road base. 1" lens of stained soil @ 2.5' bgs. Well graded, dry to damp.

<u>2.5-3.5' Silt</u>, orangish brown with trace sand. Compacted peat / topsoil, damp.

<u>3.5-13.5' Silty gravel</u>, dark brown. Gravel: 1"-2", avg. is 1", rounded to subrounded. Silt content decreases with depth. Poorly graded, damp. Oil saturated intvl. >12.0' bgs.

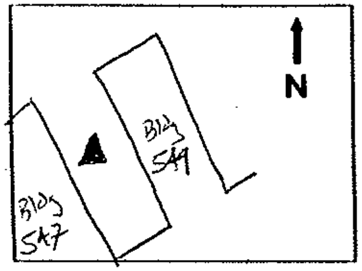
<u>13.5' TD</u>

Groundwater not encountered

MP\FORMS\BORE-LOG

Lithologic Borehole Log
Project # 05M30207

Sheet 1 of 1



Site ID Pre WW II TF
Northing 9031.40
Elevation 13.79'
Date Started 23 Aug 96
Drilling Contr. WCC
Drill Method Backhoe
Sample Type Grab
Hammer Wt. NA

Location ID WW-RI-15
Easting 8371.34
T.D. 13.0'
Date Completed 23 Aug 96
Driller NA
Rig Type
Geo/Eng. E. Gorove
Backfilled Date 23 Aug 96

Weather Conditions
Clear, temp ~ 70°F, winds 5-10 mph

Names of Persons Present
E. Gorove
S. Virg-In

Depth in Feet	Sampled Interval	Sample Number	Percent Recovery	HNU or OVM Reading	Blows Per 6"	Sampling Method	Water Content	USCS Code	Color	Graphic Log
0			NA		NA	Grab		GM		
				0.0 1.0-2.0						
5								GM		
				2 ppm				GM		
				0.0						
10								GP		
	12.0	ww-RI-15		5.0 ppm						
15										
20										
25										
30										

Interval Description

0.0-3.0' Silty gravel, med.-dk. brown. Gravel: 1"-4", avg. is 1", subrounded. Roots 0.0-2.0', poorly graded, damp

3.0-4.5' Gravel with some silt, grayish brown. Gravel: 1"-2", avg. is 1", rounded to subrounded. Minor oil staining & fuel odor. Damp, poorly graded.

4.5-9.0' Silty gravel, med.-dk. brown. Gravel: 1"-4", avg. is 1", subrounded. Poorly graded, damp

9.0-13.0' Sandy gravel, gray. Sand: m.g., subrounded. Gravel: 1"-3", avg. is 2", rounded to subrounded. Oil stained 11.0-13.0' (smear zone). Poorly graded, damp to moist.

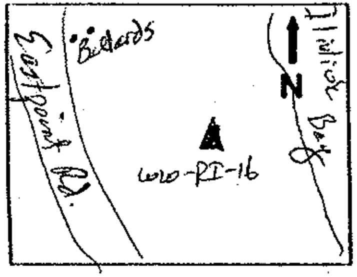
Groundwater @ 13.0' bgs to 12.5' bgs

13.0' TD

Well point installed

Lithologic Borehole Log
Project #05M30207

Sheet 1 of 1



Site ID	Pre WWII TF	Location ID	wo-RI-16
Northing	9270.50	Easting	869.09
Elevation	12.78	T.D.	15.0'
Date Started	24 Aug 96	Date Completed	24 Aug 96
Drilling Contr.	WCC	Driller	NA
Drill Method	225 Excavator	Rig Type	
Sample Type	Grab	Geo/Eng.	E. Gosnve
Hammer Wt.	NA	Backfilled Date	24 Aug 96

Weather Conditions
Ptly. cloudy, temp ~45°F

Names of Persons Present
B. Sy
E. Gosnve
K. Beaty

Depth In Feet	Sampled Interval	Sample Number	Percent Recovery	HNU or OVM Reading	Blows Per 6"	Sampling Method	Water Content	USCS Code	Color	Graphic Log
0			NA		NA	Grab				
								GM		
5				3.0 ppm						
10	10.0	wo-RI-16						GW		
	12.5-13.5'	wo-RI-16								
15										
20										
25										
30										

Interval **Description**

0.0-2.5' Silty cobbles, lt. brown. Cobbles: 6"-30", subangular to subrounded. Vegetation/roots to 1.5' bgs. well graded, dry to damp.

2.5-4.0' Silty gravel, Dark brown to black, Gravel: rounded to subrounded beach deposits. Fuel odor/staining on west side of excavation.

4.0-15.0' Sandy gravel and cobbles, lt. to dark brown. Sand: m.g.-c.g., angular to subrounded. Cobbles; 6"-36", avg. is 8", angular to subangular. oil saturated >12.5' bgs. 010 bldg. column present at depth. Well graded, damp.

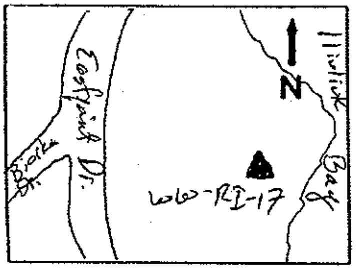
Groundwater encountered @ 15' bgs and rose to 13.5' bgs

15.0' TD

VP\FORMS\BORE-LOG

Lithologic Borehole Log
Project # 05M30207.

Sheet 1 of 1



Site ID Pre WW II TF
Northing 9504.49
Elevation 13.00
Date Started 24 Aug 96
Drilling Contr. WCC
Drill Method Excavator - Cat 225
Sample Type Grab
Hammer Wt. NA

Location ID ww-RI-17
Easting 8681.18
T.D. 11.5'
Date Completed 24 Aug 96
Driller NA
Rig Type
Geo/Eng. E. Garove
Backfilled Date 24 Aug 96

Weather Conditions
Ptly cloudy, temp ~ 45°F

Names of Persons Present
E. Garove
B. Sy
K. Beaty

Depth in Feet	Sampled Interval	Sample Number	Percent Recovery	HNU or OVM Reading	Blows Per 6"	Sampling Method	Water Content	USCS Code	Color	Graphic Log
0			NA	NC	NA	Grab		GM		
5								GM		
10	10.0	ww-RI-17								
15										
20										
25										
30										

Interval **Description**

0.0-3.5' Silty gravel with some cobbles, med. brown. Gravel: 1"-4", avg. is 2", angular to subrounded. Cobbles: to 16", avg. 12", well graded, dry.

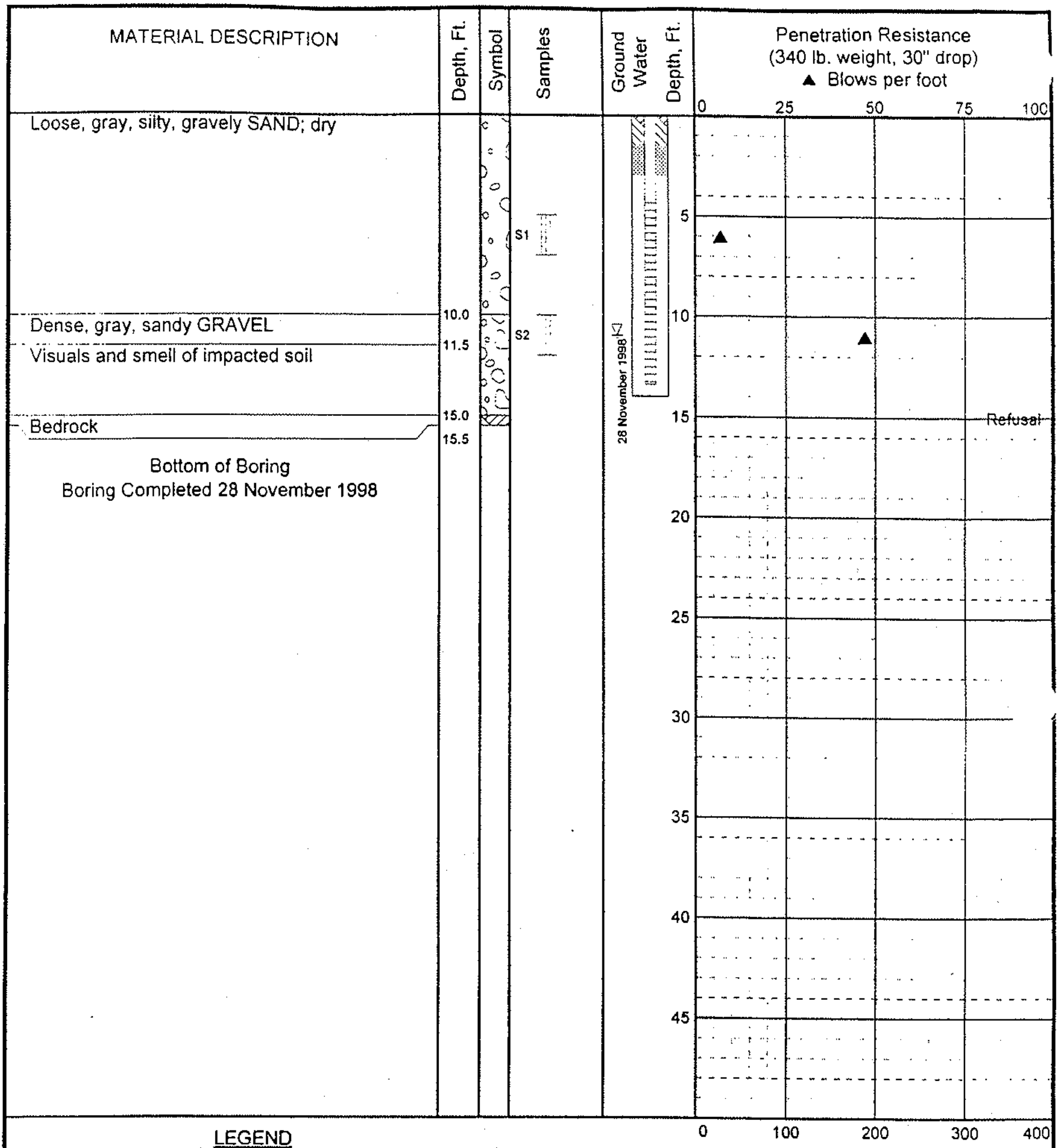
3.5-5.0' Silty gravel, gray. Gravel: 2"-4", avg. is 3", well rounded to subrounded. Poorly graded, damp.

5.0-11.5' Sandy cobbles, dark brown. Sand: m.g. - c.g.; subangular to subrounded. Cobbles: 4"-16", avg. is 10", angular. well graded, damp from 5.0'-10.0', moist to wet from 10.0-11.0', saturated from 11.0-11.5'.

Groundwater @ 11.0' bgs

11.5' TD

Boring logs and cross sections from the *1998 SI/RI/IRA Report, Amaknak and Unalaska Islands, Alaska*, Appendix D, prepared by Jacobs Engineering Group Inc. for the USAED, August1999.



LEGEND

*	Sample Not Recovered	▨	Surface Seal
⌶	2" O.D. Split Spoon Sample	▩	Solid Casing and Annular Sealant
⌶	3" O.D. Split Spoon Sample	☐	Well Screen and Filter Sand
		▨	Cuttings Backfill
		▽	Ground Water Level ATD
		▼	Static Ground Water Level

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.
4. USC letter symbol based on visual classification.

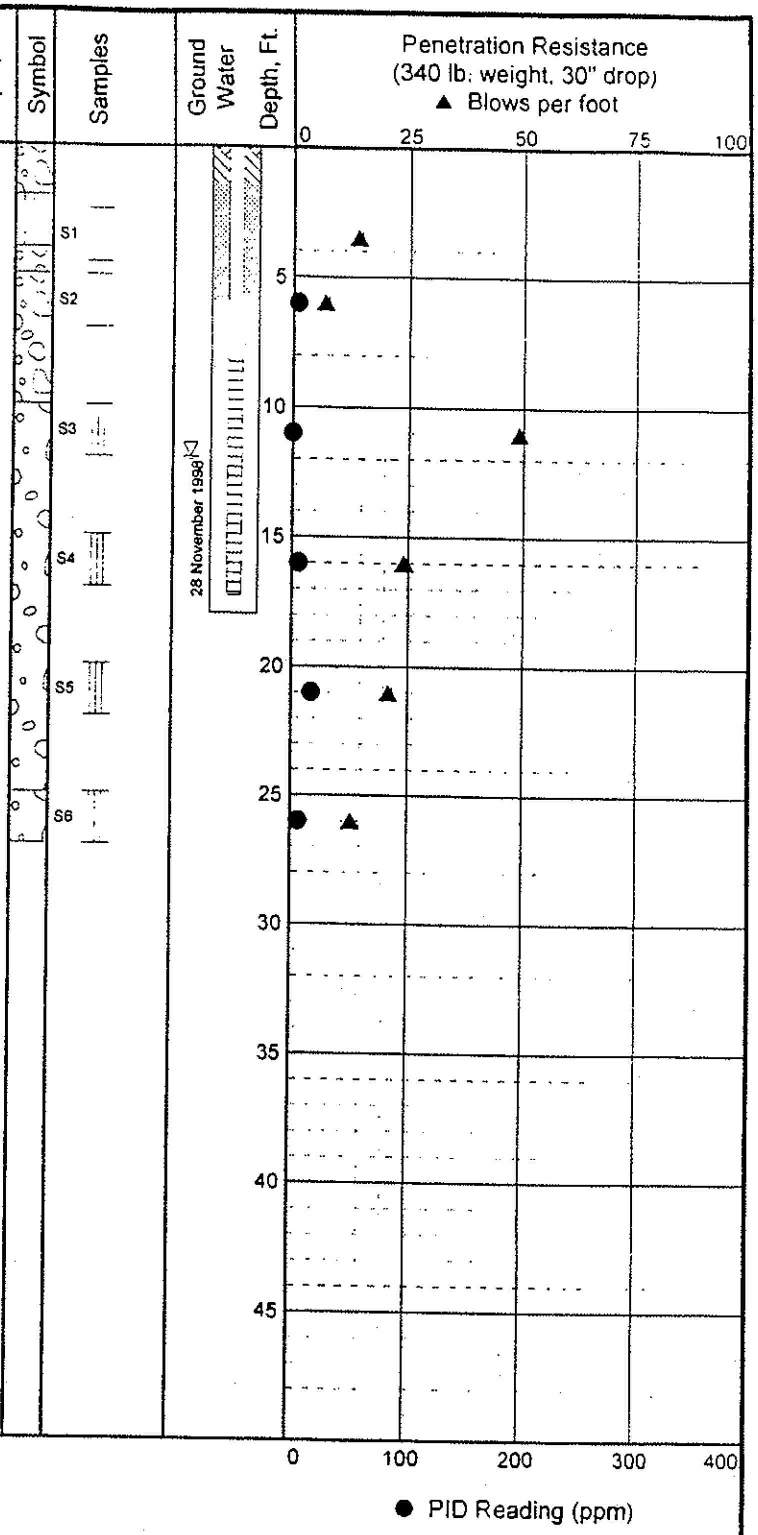
LOG OF BORING NO. B1
Pre-WWII Tank Farm
1998 Report SI/RI/IRA
Amaknak and Unalaska Islands, Alaska

PROJ MGR.: L. Phyfe	FILE NO: Y-6007-12		FIGURE NO.: 1
DRAWN BY: S&W, Inc.	REVIEW BY: D.K.C.	PROJ NO.: 05M30211	DATE: 12 January, 1999

JACOBS BORING LOG PWWII2.GPJ SHAN WIL GDT 1/15/99

MATERIAL DESCRIPTION	Depth, Ft.
GRAVEL fill	
Stiff, brown, organic SILT	2.0
Medium dense, gray GRAVEL	4.0
Loose, gray, sandy GRAVEL	5.0
Very dense, gray/brown, slightly gravelly SAND; slightly moist	10.0
Medium dense, angular, gravelly SAND	25.0
	27.0

Bottom of Boring
Boring Completed 28 November 1998



LEGEND

- * Sample Not Recovered
- 2" O.D. Split Spoon Sample
- 3" O.D. Split Spoon Sample
- ▨ Surface Seal
- ▨ Solid Casing and Annular Sealant
- ☐ Well Screen and Filter Sand
- ▨ Cuttings Backfill
- ▽ Ground Water Level ATD
- ▼ Static Ground Water Level

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.
4. USC letter symbol based on visual classification.

JACOBS BORING LOG PWWII2.GPJ SHAN WIL.GDT 2/1/99

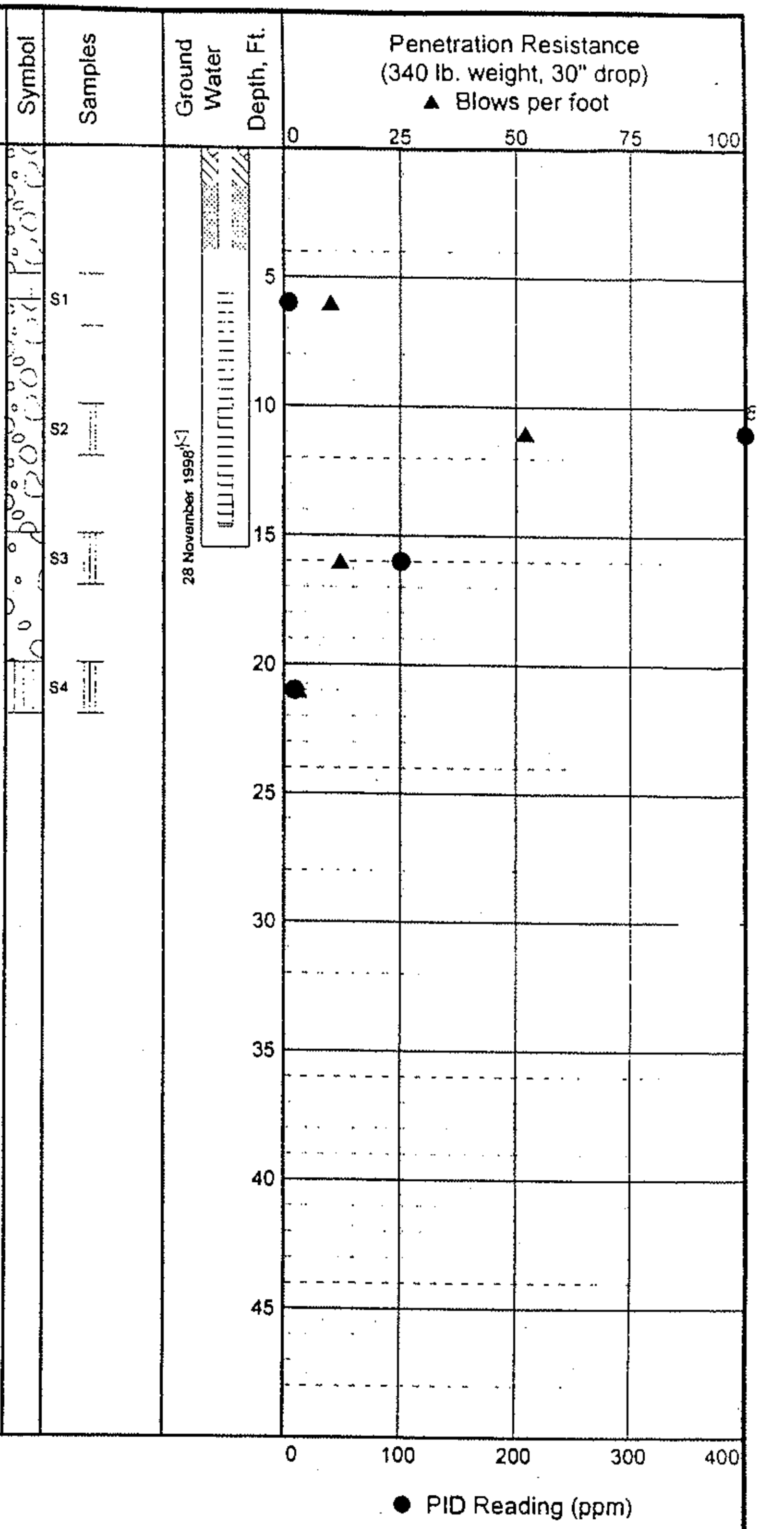
LOG OF BORING NO. B2
Pre-WWII Tank Farm
1998 Report SI/RI/IRA
Amaknak and Unalaska Islands, Alaska

PROJ MGR.:	FILE NO:	FIGURE NO.:
L. Phyfe	Y-6007-12	2

DRAWN BY:	REVIEW BY:	PROJ NO.:	DATE:
S&W, Inc.	D.K.C.	05M30211	1 February, 1999

MATERIAL DESCRIPTION	Depth, Ft.	Samples
Medium dense, brown, sandy GRAVEL; dry		
Medium dense, gray, organic, sandy SILT	5.0	
Medium dense, gray/brown, sandy GRAVEL	6.0	S1
Moist; diesel smell	11.0	S2
Medium dense, gray, gravelly SAND; wet	15.0	
Diesel smell, brown, impacted	16.5	S3
Soft, black/brown, sandy SILT; moist; rust staining.	20.0	S4
	22.0	

Bottom of Boring
Boring Completed 28 November 1998



LEGEND

* Sample Not Recovered
⌶ 2" O.D. Split Spoon Sample
⌶ 3" O.D. Split Spoon Sample
▨ Surface Seal
▨ Solid Casing and Annular Sealant
▭ Well Screen and Filter Sand
▨ Cuttings Backfill
▽ Ground Water Level ATD
▼ Static Ground Water Level

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.
4. USC letter symbol based on visual classification.

LOG OF BORING NO. B3
Pre-WWII Tank Farm
1998 Report SI/RI/IRA
Amaknak and Unalaska Islands, Alaska

PROJ MGR.:	FILE NO:	FIGURE NO.:
L. Phyfe	Y-6007-12	3

DRAWN BY:	REVIEW BY:	PROJ NO.:	DATE.
S&W, Inc.	D.K.C.	05M30211	1 February, 1999

MATERIAL DESCRIPTION

Medium dense, gray, angular sandy GRAVEL

Medium dense, brown, organic, silty, sandy GRAVEL; dry; found wood

Medium dense, gray, angular GRAVEL

Medium dense, gray, silty, sandy GRAVEL

Medium dense, brown organic silty PEAT; dry

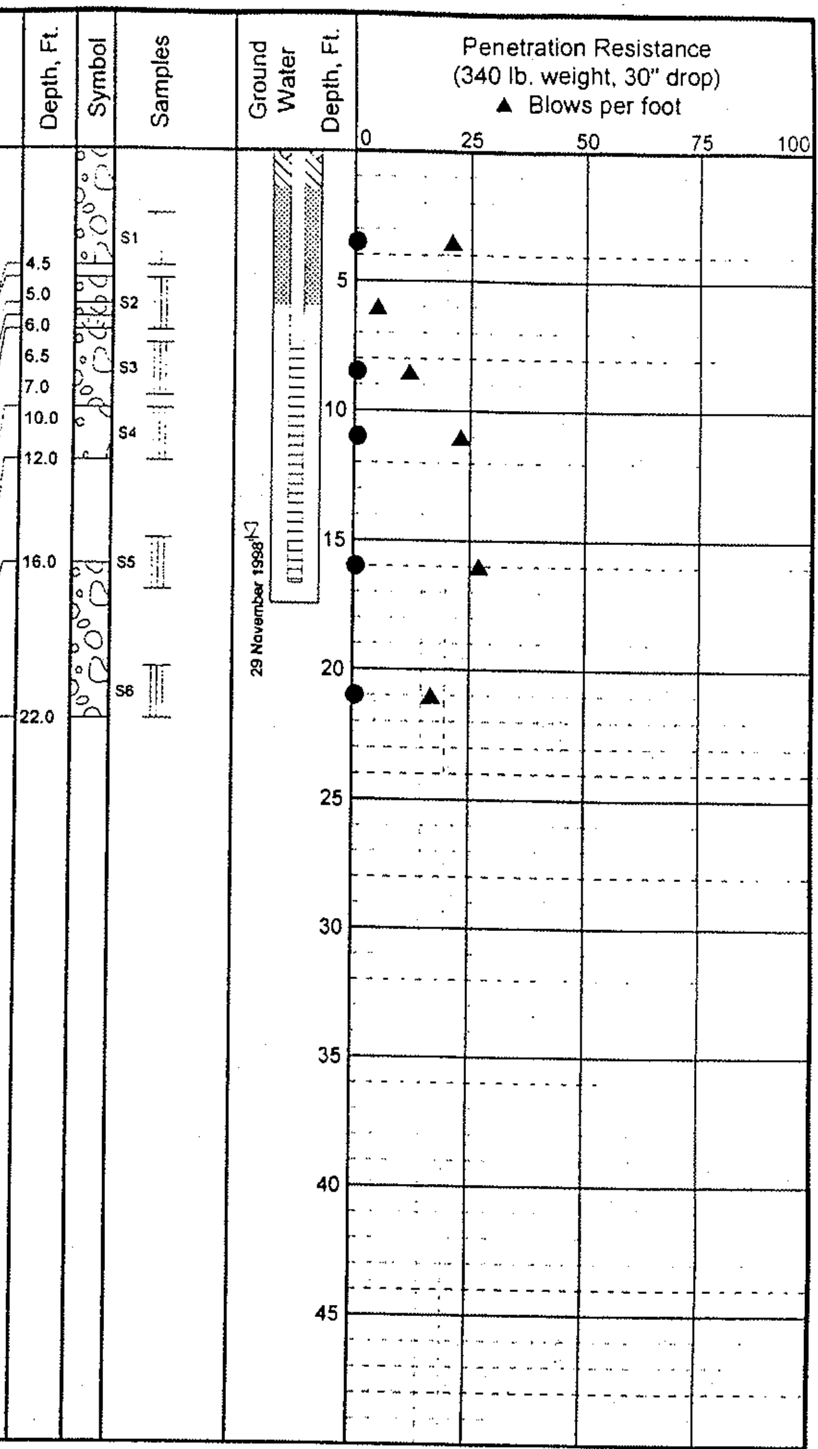
Medium dense, sandy, round to angular GRAVEL; heavilly impacted with brown residue.

Medium dense, brown SAND; intermitant layers of gray, angular gravel; moist; no visual evidence.

Medium dense, brown SAND

Medium dense, gray, silty, sandy GRAVEL; wet

Bottom of Boring
Boring Completed 29 November 1998



LEGEND

*	Sample Not Recovered	▨	Surface Seal
⌶	2" O.D. Split Spoon Sample	▨	Solid Casing and Annular Sealant
⌶	3" O.D. Split Spoon Sample	☐	Well Screen and Filter Sand
		▨	Cuttings Backfill
		▽	Ground Water Level ATD
		▼	Static Ground Water Level

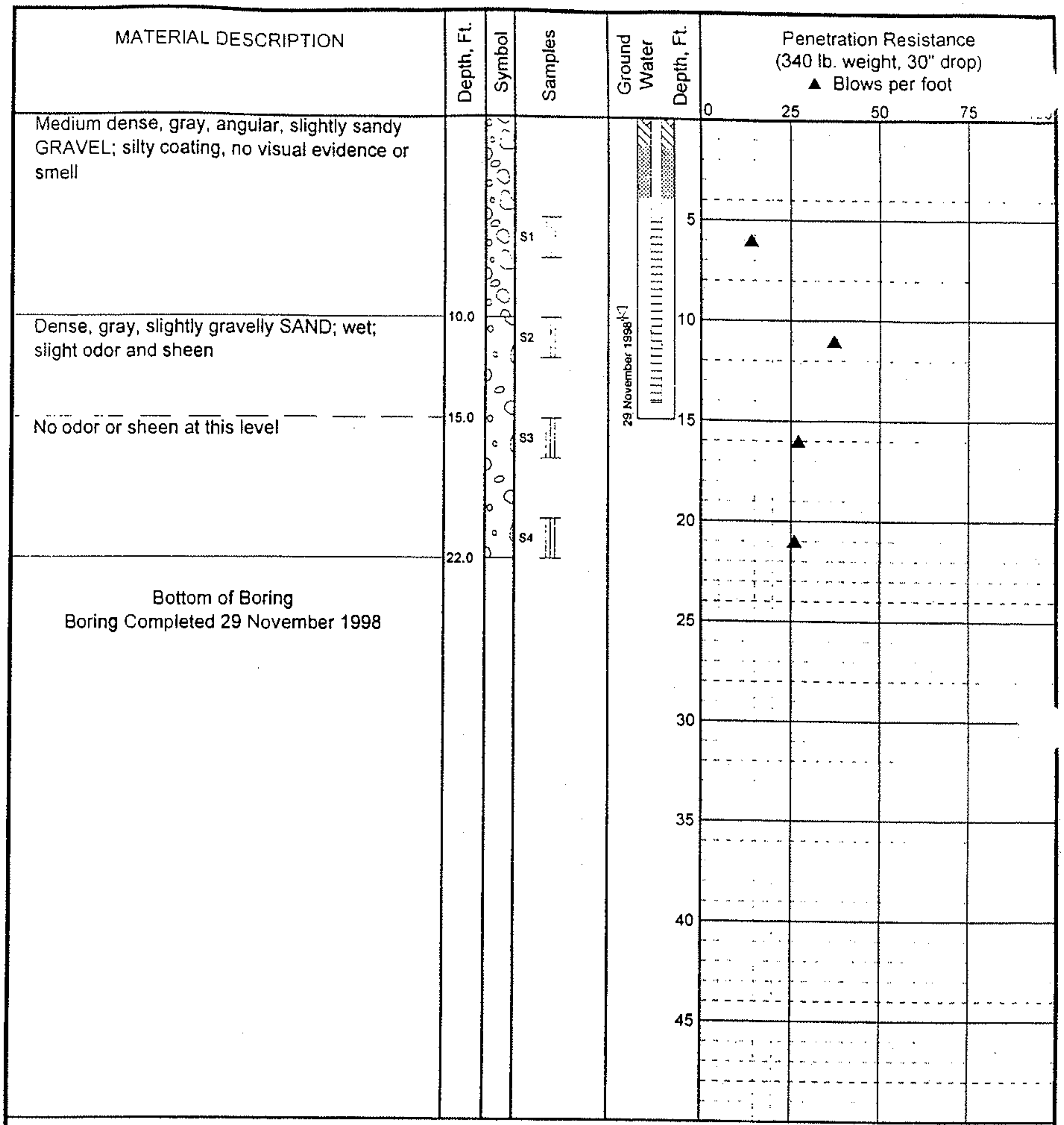
NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.
4. USC letter symbol based on visual classification.

LOG OF BORING NO. B4
Pre-WWII Tank Farm
1998 Report SI/RI/IRA
Amaknak and Unalaska Islands, Alaska

PROJ MGR.:	FILE NO:	FIGURE NO.:
L. Phyfe	Y-6007-12	4

DRAWN BY:	REVIEW BY:	PROJ NO.:	DATE:
S&W, Inc.	D.K.C.	05M30211	12 January, 1999



Medium dense, gray, angular, slightly sandy GRAVEL; silty coating, no visual evidence or smell

Dense, gray, slightly gravelly SAND; wet; slight odor and sheen

No odor or sheen at this level

Bottom of Boring
Boring Completed 29 November 1998

LEGEND

•	Sample Not Recovered	▨	Surface Seal
⋮	2" O.D. Split Spoon Sample	▨	Solid Casing and Annular Sealant
⋮	3" O.D. Split Spoon Sample	☰	Well Screen and Filter Sand
		▨	Cuttings Backfill
		∇	Ground Water Level ATD
		▼	Static Ground Water Level

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.
4. USC letter symbol based on visual classification.

LOG OF BORING NO. B5
Pre-WWII Tank Farm
1998 Report SI/RI/IRA
Amaknak and Unalaska Islands, Alaska

PROJ MGR.: L. Phyfe		FILE NO: Y-6007-12	FIGURE NO.: 5
DRAWN BY: S&W, Inc.	REVIEW BY: D.K.C.	PROJ NO.: 05M30211	DATE: 12 January, 1999

MATERIAL DESCRIPTION

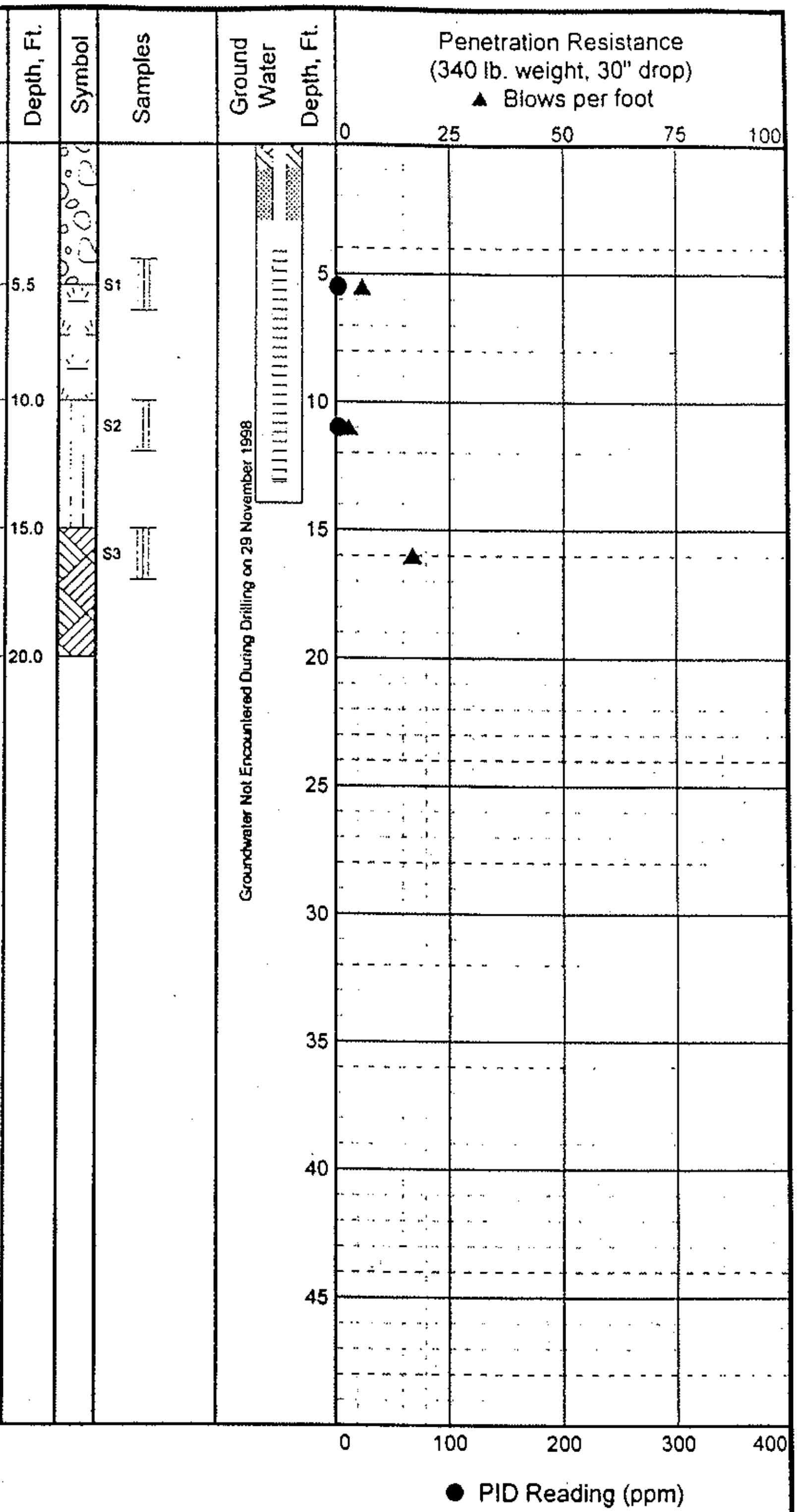
Loose, gray, silty, sandy GRAVEL

Loose, black PEAT; heavy organic smell

Very loose, brown, silty SAND; with organics, possible ash.

Medium dense, gray-green, weathered BEDROCK; volcanic with white veins

Bottom of Boring
Boring Completed 29 November 1998



Groundwater Not Encountered During Drilling on 29 November 1998

LEGEND

*	Sample Not Recovered	▨	Surface Seal
⌶	2" O.D. Split Spoon Sample	▨	Solid Casing and Annular Sealant
⌶	3" O.D. Split Spoon Sample	☐	Well Screen and Filter Sand
		▨	Cuttings Backfill
		∇	Ground Water Level ATD
		▼	Static Ground Water Level

NOTES

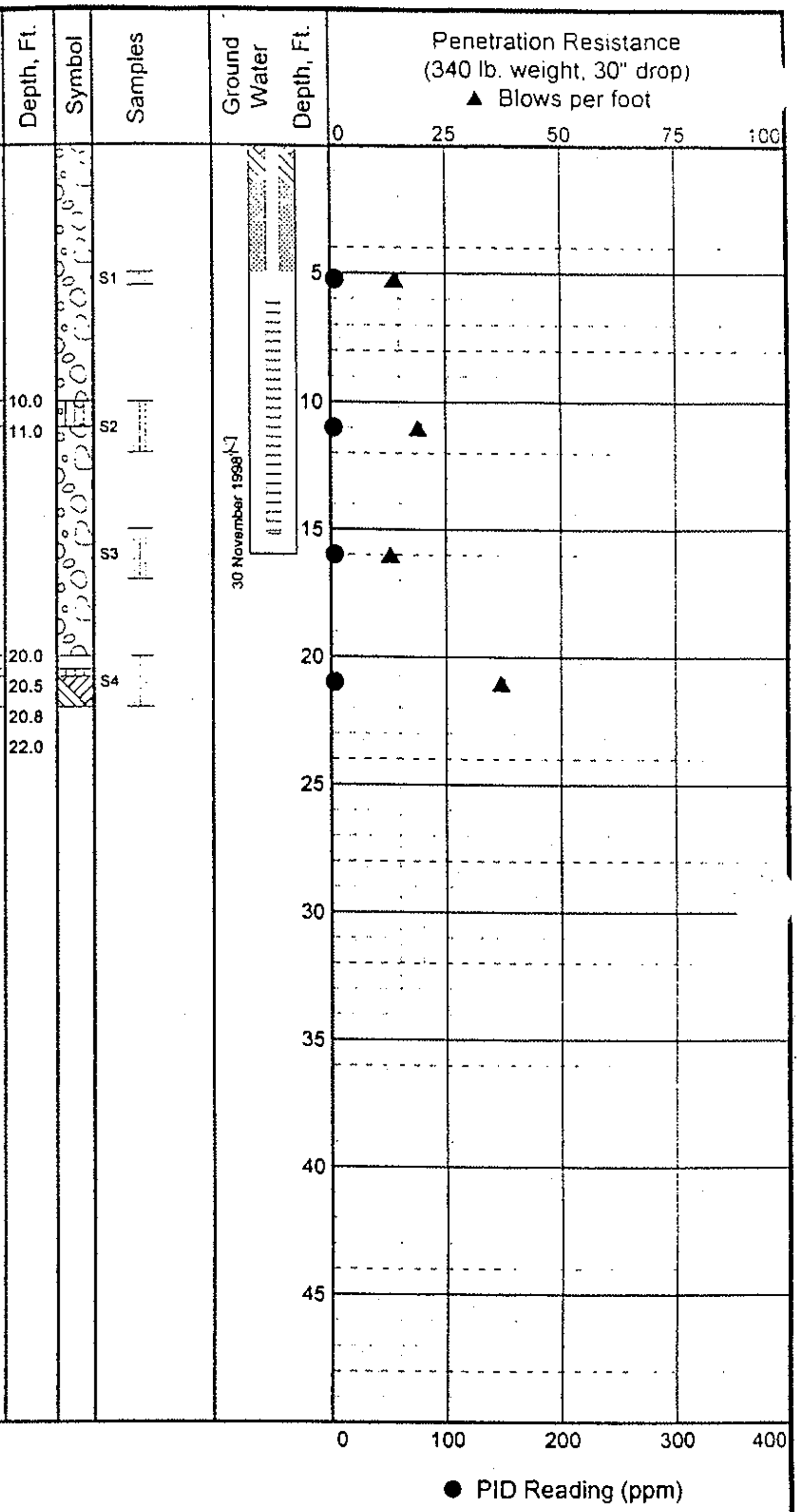
1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.
4. USC letter symbol based on visual classification.

LOG OF BORING NO. B6
Pre-WWII Tank Farm
1998 Report SI/RI/IRA
Amaknak and Unalaska Islands, Alaska

PROJ MGR.:	FILE NO:	FIGURE NO.:
L. Phyfe	Y-6007-12	6

DRAWN BY:	REVIEW BY:	PROJ NO.:	DATE:
S&W, Inc.	D.K.C.	05M30211	12 January, 1999

MATERIAL DESCRIPTION	Depth, Ft.
Medium dense, gray, sandy GRAVEL; with small pieces of wood	
Stiff, gray, gravelly SILT	10.0
Medium dense, brown, sandy GRAVEL; moist to wet	11.0
Dense, black SAND	20.0
Hard, black/brown SILT	20.5
Hard, fractured, weathered BEDROCK	20.8
Bottom of Boring Boring Completed 30 November 1998	22.0



LEGEND

*	Sample Not Recovered	▧	Surface Seal
⌶	2" O.D. Split Spoon Sample	▩	Solid Casing and Annular Sealant
⌶	3" O.D. Split Spoon Sample	▭	Well Screen and Filter Sand
		▨	Cuttings Backfill
		▽	Ground Water Level ATD
		▼	Static Ground Water Level

NOTES

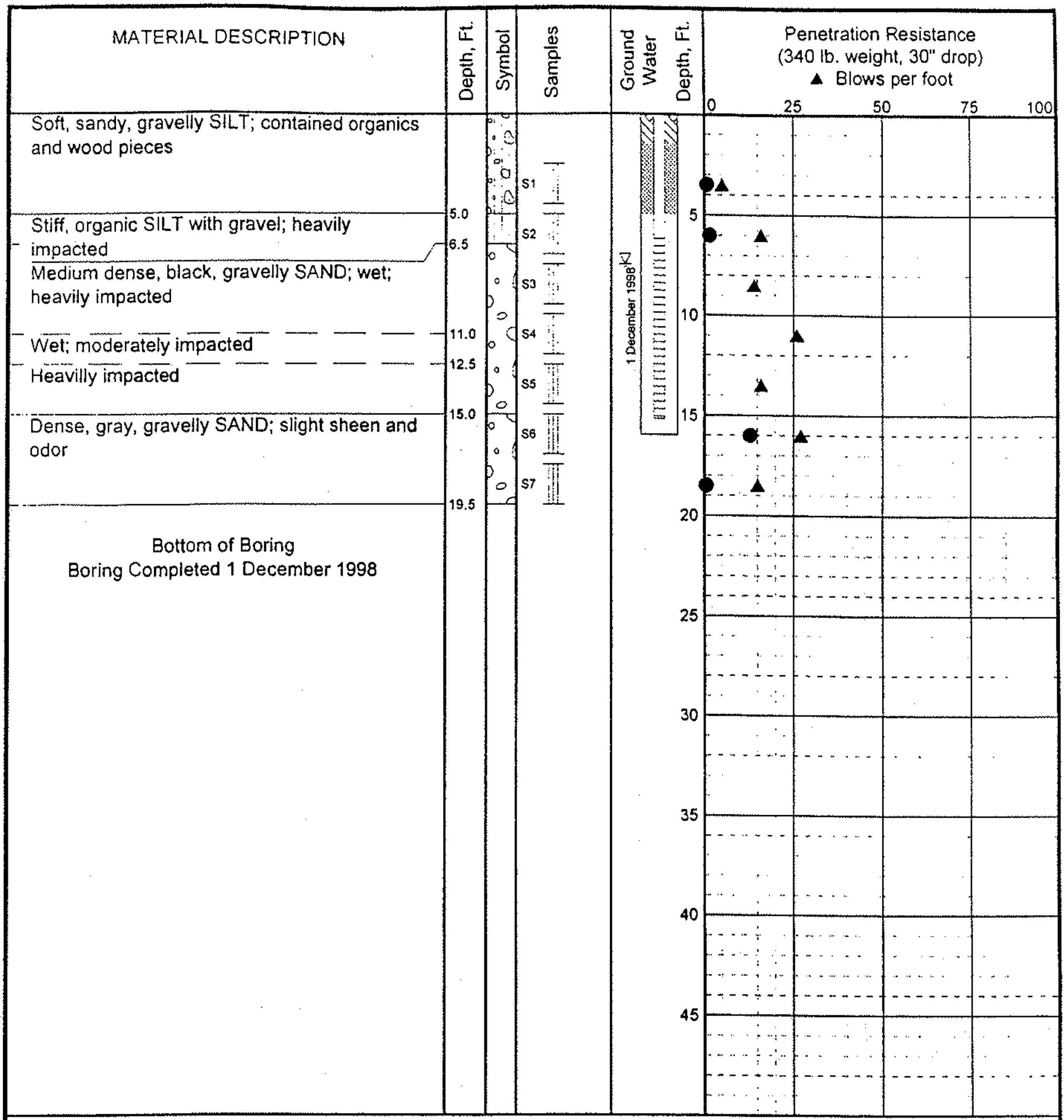
1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.
4. USC letter symbol based on visual classification.

LOG OF BORING NO. B7
Pre-WWII Tank Farm
1998 Report SI/RI/IRA
Amaknak and Unalaska Islands, Alaska

PROJ MGR.:	FILE NO:	FIGURE NO:
L. Phyfe	Y-6007-12	7

DRAWN BY:	REVIEW BY:	PROJ NO.:	DATE:
S&W, Inc.	D.K.C.	05M30211	1 February, 1999

JACOBS BORING LOG PWWII2.GPJ SHAN_WIL.GDT 2/1/99



Depth, Ft.	MATERIAL DESCRIPTION
	Soft, sandy, gravelly SILT; contained organics and wood pieces
5.0	Stiff, organic SILT with gravel; heavily impacted
6.5	Medium dense, black, gravelly SAND; wet; heavily impacted
11.0	Wet; moderately impacted
12.5	Heavilly impacted
15.0	Dense, gray, gravelly SAND; slight sheen and odor
19.5	

Bottom of Boring
Boring Completed 1 December 1998

LEGEND

*	Sample Not Recovered	▨	Surface Seal
⌶	2" O.D. Split Spoon Sample	▨	Solid Casing and Annular Sealant
⌶	3" O.D. Split Spoon Sample	☰	Well Screen and Filter Sand
		▨	Cuttings Backfill
		▽	Ground Water Level ATD
		▼	Static Ground Water Level

NOTES

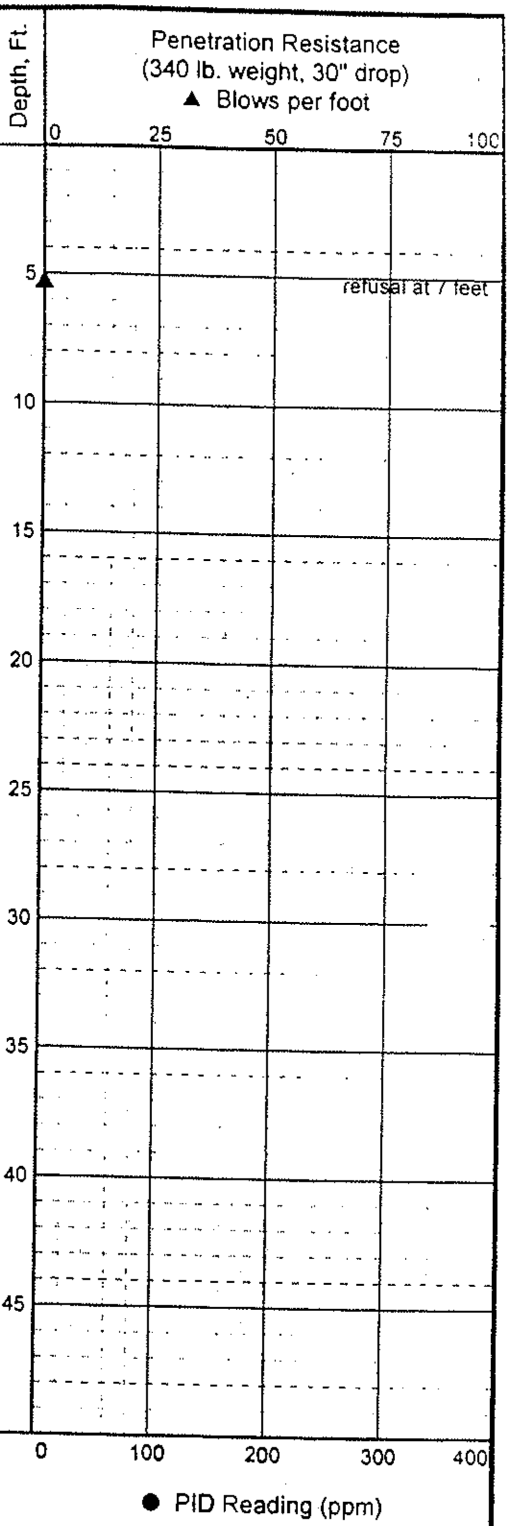
1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.
4. USC letter symbol based on visual classification.

LOG OF BORING NO. B8
Pre-WWII Tank Farm
1998 Report SI/RI/IRA
Amaknak and Unalaska Islands, Alaska

PROJ MGR.:	FILE NO:	FIGURE NO.:
L. Phyfe	Y-6007-12	8

DRAWN BY:	REVIEW BY:	PROJ NO.:	DATE:
S&W, Inc.	D.K.C.	05M30211	12 January, 1999

MATERIAL DESCRIPTION	Depth, Ft.	Symbol	Samples	Ground Water
Brown, slightly organic SILT; wet	7.0		S1	Groundwater Not Encountered During Drilling on 1 December 1998
Bottom of Boring Boring Completed 1 December 1998				



LEGEND

*	Sample Not Recovered	▨	Surface Seal
⌶	2" O.D. Split Spoon Sample	▩	Solid Casing and Annular Sealant
⌶	3" O.D. Split Spoon Sample	▤	Well Screen and Filter Sand
		▨	Cuttings Backfill
		▽	Ground Water Level ATD
		▼	Static Ground Water Level

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.
4. USC letter symbol based on visual classification.

LOG OF BORING NO. B9
Pre-WWII Tank Farm
1998 Report SI/RI/IRA
Amaknak and Unalaska Islands, Alaska

PROJ MGR.:	FILE NO:	FIGURE NO.:	
L. Phyfe	Y-6007-12	9	
DRAWN BY: S&W, Inc.	REVIEW BY: D.K.C.	PROJ NO.: 05M30211	DATE: 12 January, 1999

MATERIAL DESCRIPTION

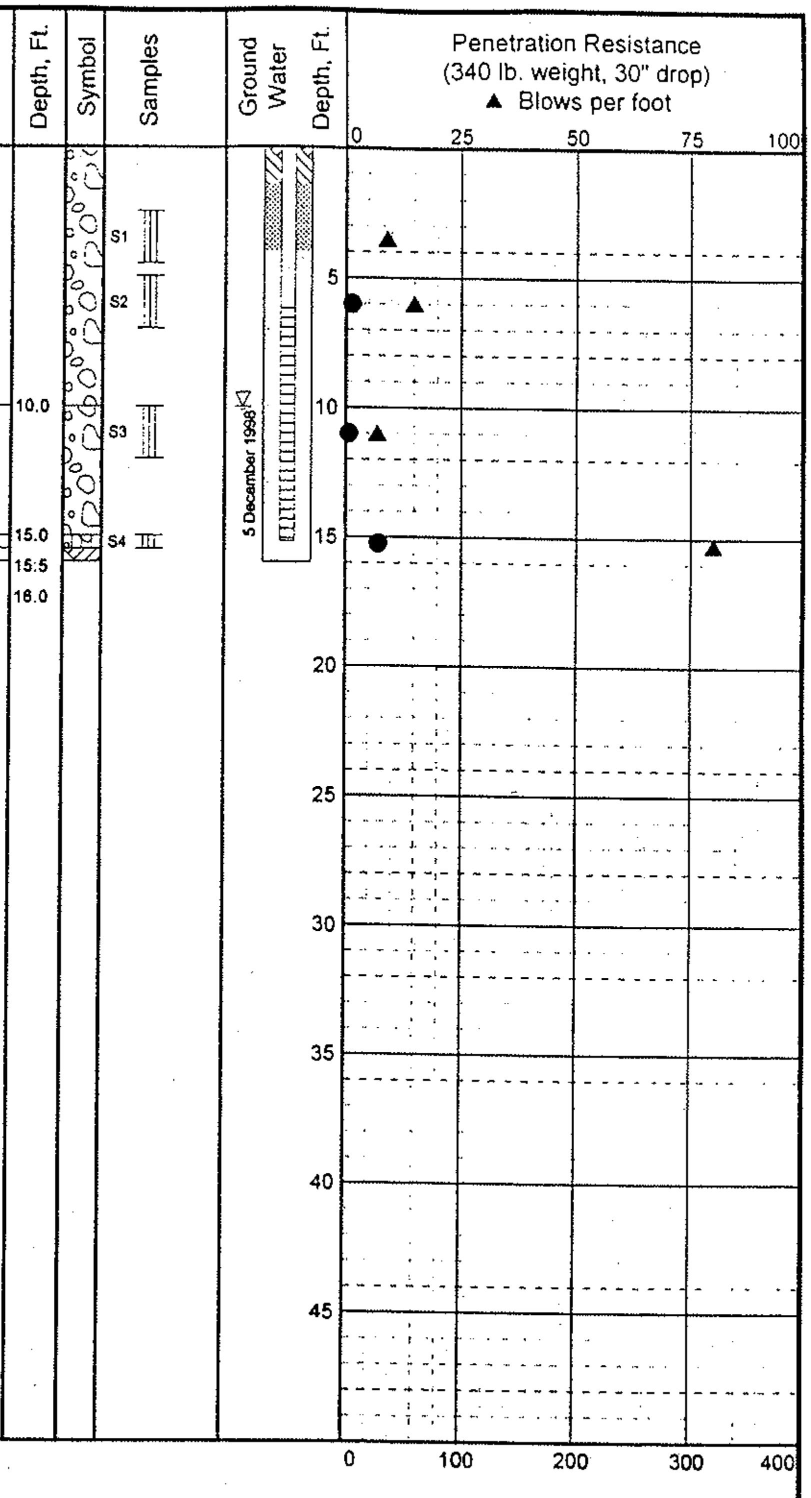
Loose, brown to black, sandy GRAVEL; dry, subangular

Loose, gray/green, slightly sandy GRAVEL; angular

Very dense, black, slightly gravelly SILT; oily sheen and slight odor.

Very dense, green, weathered, volcanic BEDROCK

Bottom of Boring
Boring Completed 5 December 1998



LEGEND

*	Sample Not Recovered	⊠	Surface Seal
⌶	2" O.D. Split Spoon Sample	▩	Solid Casing and Annular Sealant
⌶	3" O.D. Split Spoon Sample	⊟	Well Screen and Filter Sand
		▨	Cuttings Backfill
		▽	Ground Water Level ATD
		▼	Static Ground Water Level

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.
4. USC letter symbol based on visual classification.

LOG OF BORING NO. B10
Pre-WWII Tank Farm
1998 Report SI/RI/IRA
Amaknak and Unalaska Islands, Alaska

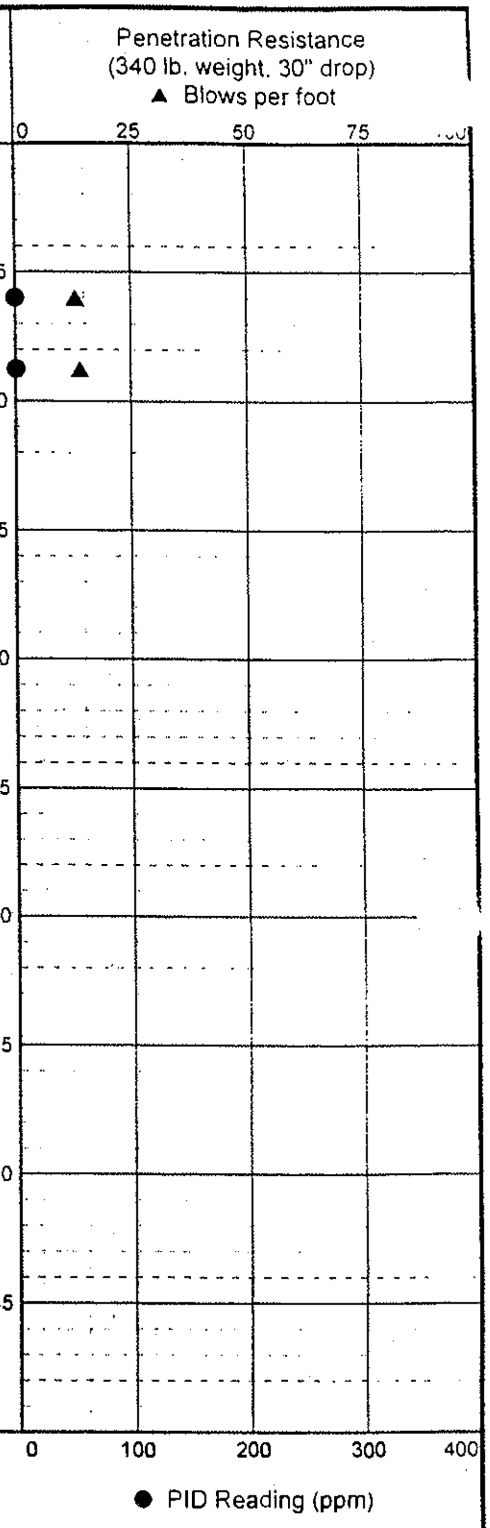
PROJ MGR.:	FILE NO:	FIGURE NO.:
L. Phyfe	Y-6007-12	10

DRAWN BY:	REVIEW BY:	PROJ NO.:	DATE:
S&W, Inc.	D.K.C.	05M30211	12 January, 1999

MATERIAL DESCRIPTION	Depth, Ft.	Samples
Medium dense, black to brown, sandy GRAVEL		
Medium dense, brown, slightly organic, gravelly SAND	5.0	S1
Medium dense, gray/black, angular gravels, with brown, silty GRAVEL	8.0	S2
	10.0	

Bottom of Boring
Boring Completed 5 December 1998

Groundwater Not Encountered During Drilling on 5 December 1998



LEGEND

- * Sample Not Recovered
- 2" O.D. Split Spoon Sample
- 3" O.D. Split Spoon Sample

- Surface Seal
- Solid Casing and Annular Sealant
- Well Screen and Filter Sand
- Cuttings Backfill
- ∇ Ground Water Level ATD
- ▼ Static Ground Water Level

NOTES

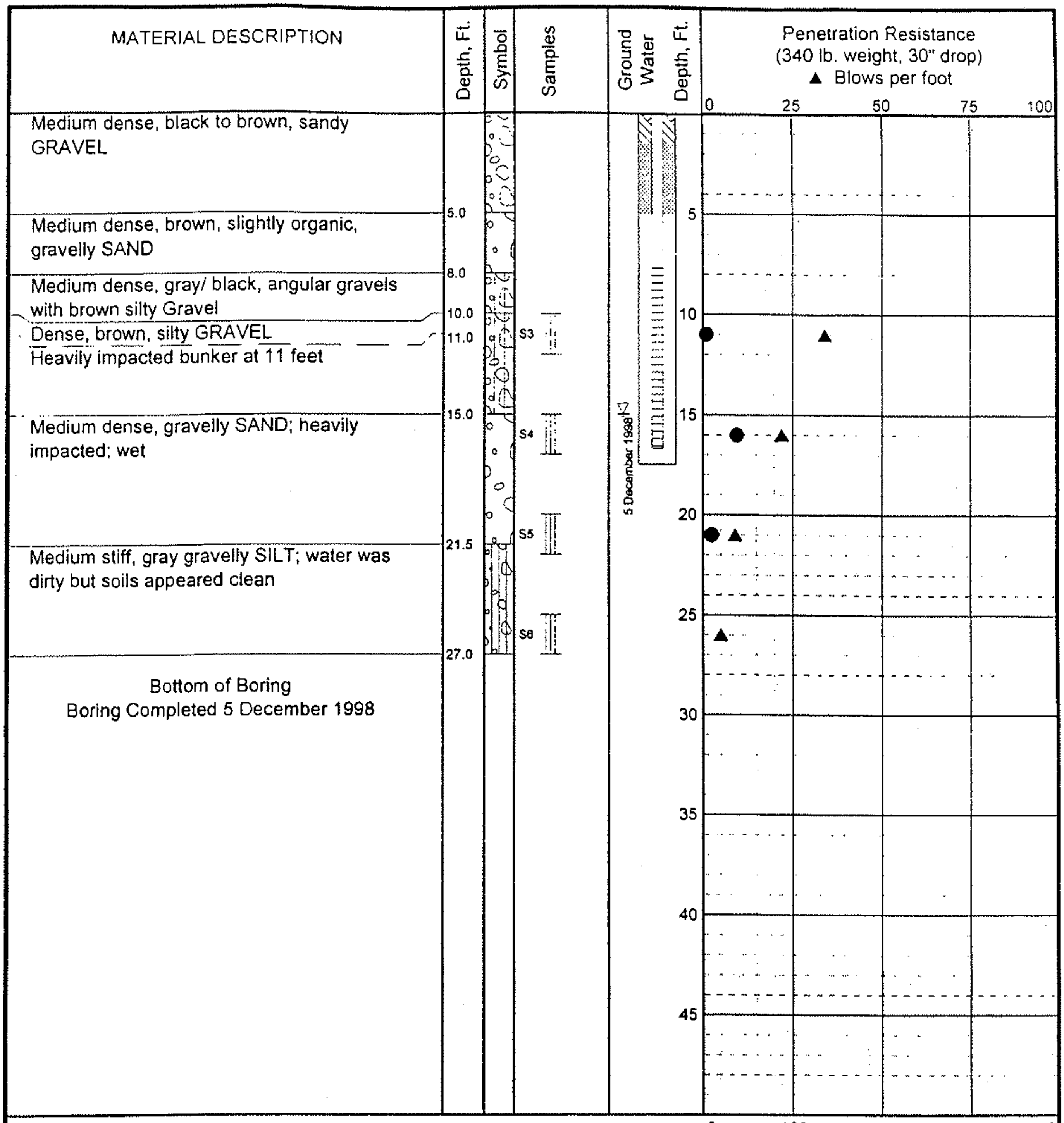
1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.
4. USC letter symbol based on visual classification.

LOG OF BORING NO. B11
Pre-WWII Tank Farm
1998 Report SI/RI/IRA
Amaknak and Unalaska Islands, Alaska

PROJ MGR.:	FILE NO:	FIGURE NO.:
L. Phyfe	Y-6007-12	11

DRAWN BY:	REVIEW BY:	PROJ NO.:	DATE:
S&W, Inc.	D.K.C.	05M30211	1 February, 1999

JACOBS BORING LOG PWWII2.GPJ SHAN WIL.GDT 2/1/99



MATERIAL DESCRIPTION	Depth, Ft.	Samples
Medium dense, black to brown, sandy GRAVEL		
Medium dense, brown, slightly organic, gravelly SAND	5.0	
Medium dense, gray/ black, angular gravels with brown silty Gravel	8.0	
Dense, brown, silty GRAVEL	10.0	
Heavily impacted bunker at 11 feet	11.0	S3
Medium dense, gravelly SAND; heavily impacted; wet	15.0	S4
Medium stiff, gray gravelly SILT; water was dirty but soils appeared clean	21.5	S5 S6
Bottom of Boring Boring Completed 5 December 1998	27.0	

LEGEND

- * Sample Not Recovered
- 2" O.D. Split Spoon Sample
- 3" O.D. Split Spoon Sample
- ▨ Surface Seal
- ▨ Solid Casing and Annular Sealant
- ☐ Well Screen and Filter Sand
- ▨ Cuttings Backfill
- ▽ Ground Water Level ATD
- ▼ Static Ground Water Level

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.
4. USC letter symbol based on visual classification.

LOG OF BORING NO. B11a
Pre-WWII Tank Farm
1998 Report SI/RI/IRA
Amaknak and Unalaska Islands, Alaska

PROJ MGR.:	FILE NO:	FIGURE NO.:
L. Phyfe	Y-6007-12	11a

DRAWN BY:	REVIEW BY:	PROJ NO.:	DATE:
S&W, Inc.	D.K.C.	05M30211	1 February. 1999

MATERIAL DESCRIPTION

Very loose, brown, gravelly SAND

Very loose, brown, slightly organic, sandy SILT

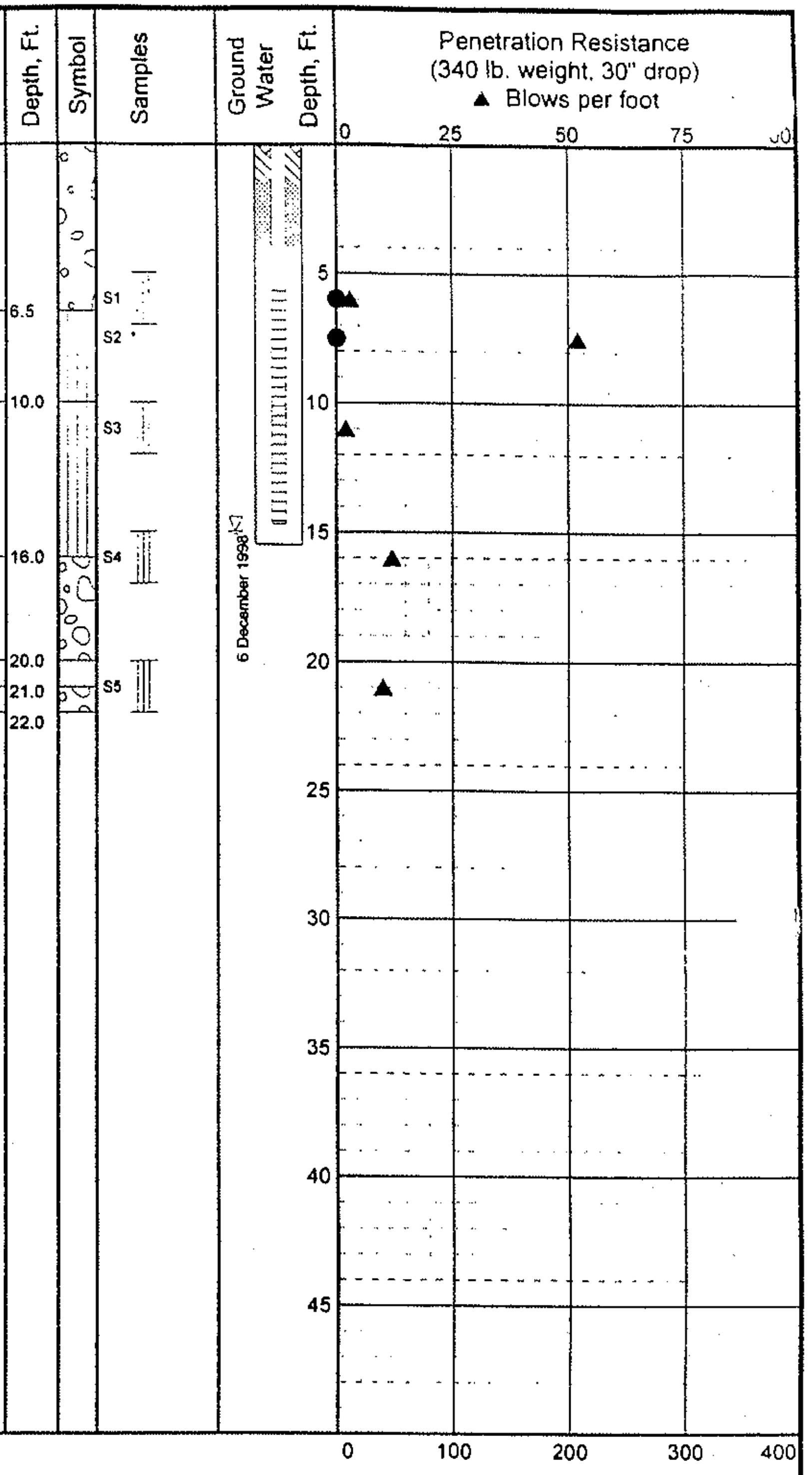
Very soft, brown, sandy SILT; with occasional large rocks/ cobbles, moist

Medium dense, gray, slightly sandy GRAVEL

Loose, gray SAND

Loose, gray, slightly sandy GRAVEL

Bottom of Boring
Boring Completed 5 December 1998



● PID Reading (ppm)

LEGEND

- * Sample Not Recovered
- 2" O.D. Split Spoon Sample
- 3" O.D. Split Spoon Sample
- ▨ Surface Seal
- ▨ Solid Casing and Annular Sealant
- ▨ Well Screen and Filter Sand
- ▨ Cuttings Backfill
- ▽ Ground Water Level ATD
- ▼ Static Ground Water Level

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.
4. USC letter symbol based on visual classification.

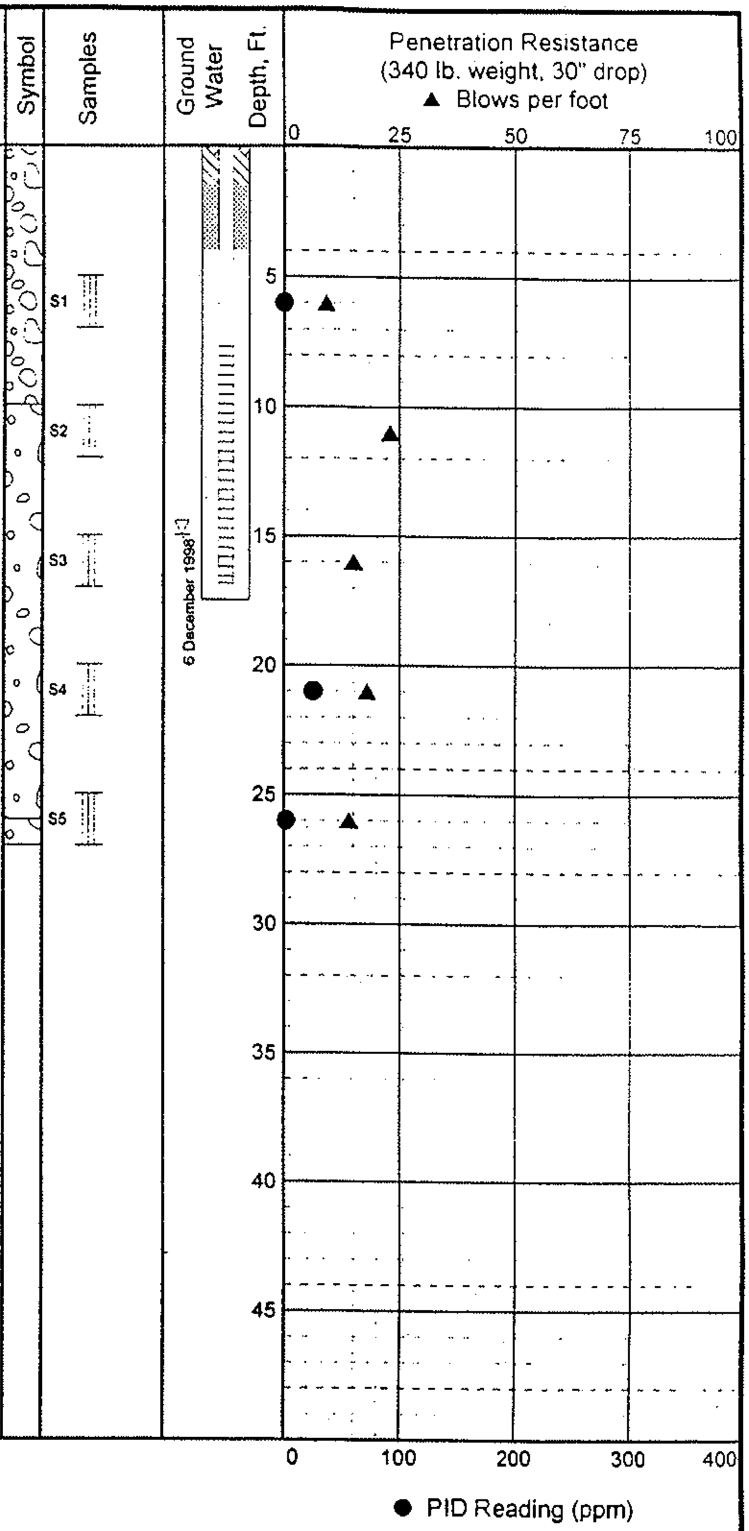
LOG OF BORING NO. B12
Pre-WWII Tank Farm
1998 Report SI/RI/IRA
Amaknak and Unalaska Islands, Alaska

PROJ MGR.: L. Phyfe	FILE NO: Y-6007-12		FIGURE NO.: 12
DRAWN BY: S&W, Inc.	REVIEW BY: D.K.C.	PROJ NO.: 05M30211	DATE: 1 February, 1999

JACOBS BORING LOG PWWII2.GPJ SHAN WIL.GDT 2/1/99

MATERIAL DESCRIPTION	Depth, Ft.
Loose, gray, sandy GRAVEL; with wood and silty organics	
Medium dense, gray, gravelly SAND	10.0
Heavily impacted with bunker at 11 feet	11.0
Impacted heavily to 16 feet	16.0
Slightly impacted	21.0
Medium dense, gray, silty, gravelly SAND; appeared not impacted	26.0
	27.0

Bottom of Boring
Boring Completed 6 December 1998



LEGEND

- • Sample Not Recovered
- 2" O.D. Split Spoon Sample
- 3" O.D. Split Spoon Sample

▨ Surface Seal
▨ Solid Casing and Annular Sealant
▤ Well Screen and Filter Sand
▨ Cuttings Backfill
▽ Ground Water Level ATD
▼ Static Ground Water Level

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.
4. USC letter symbol based on visual classification.

LOG OF BORING NO. B13
Pre-WWII Tank Farm
1998 Report SI/RI/IRA
Amaknak and Unalaska Islands, Alaska

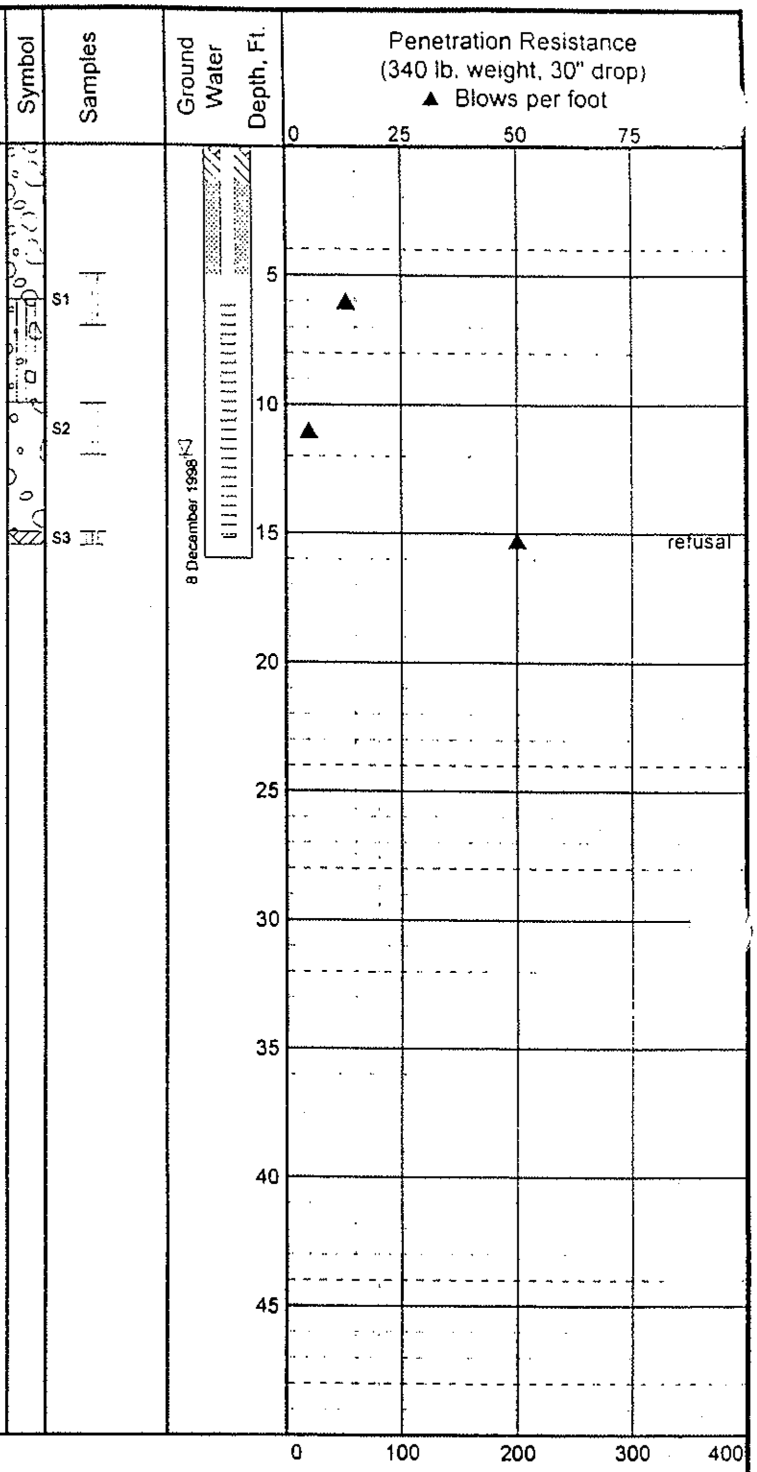
PROJ MGR.:	FILE NO:	FIGURE NO.:
L. Phyfe	Y-6007-12	13

DRAWN BY:	REVIEW BY:	PROJ NO.:	DATE:
S&W, Inc.	D.K.C.	05M30211	1 February, 1999

JACOBS BORING LOG PWWII2.GPJ SHAN WIL.GDT 2/1/99

MATERIAL DESCRIPTION	Depth, Ft.
Medium dense, sandy GRAVEL; also contained wood, concrete, and organics	
Medium stiff, brown, gravelly SILT	6.0
Loose, brown, silty, gravelly SAND	10.0
Heavily impacted wood	11.5
Brown/ white, volcanic BEDROCK, with white veins	15.0
	15.5

Bottom of Boring
Boring Completed 8 December 1998



● PID Reading (ppm)

LEGEND

- • Sample Not Recovered
- ⌶ 2" O.D. Split Spoon Sample
- ⌶ 3" O.D. Split Spoon Sample
- ▨ Surface Seal
- ▨ Solid Casing and Annular Sealant
- ▭ Well Screen and Filter Sand
- ▨ Cuttings Backfill
- ▽ Ground Water Level ATD
- ▼ Static Ground Water Level

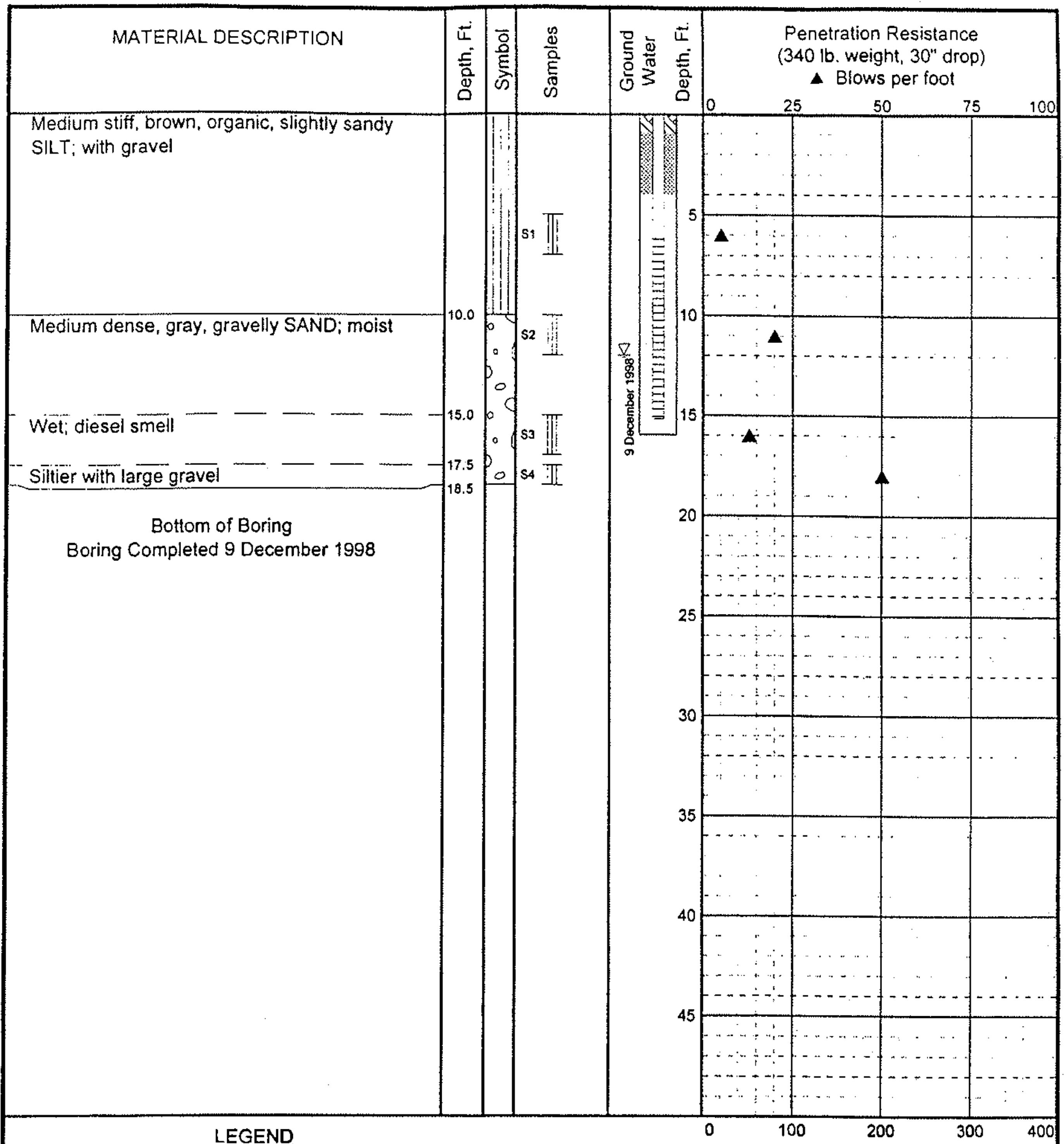
NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.
4. USC letter symbol based on visual classification.

LOG OF BORING NO. B14
Pre-WWII Tank Farm
1998 Report SI/RI/IRA
Amaknak and Unalaska Islands, Alaska

PROJ MGR.:	FILE NO:	FIGURE NO.:
L. Phyfe	Y-6007-12	14

DRAWN BY:	REVIEW BY:	PROJ NO.:	DATE:
S&W, Inc.	D.K.C.	05M30211	1 February, 1999



LEGEND

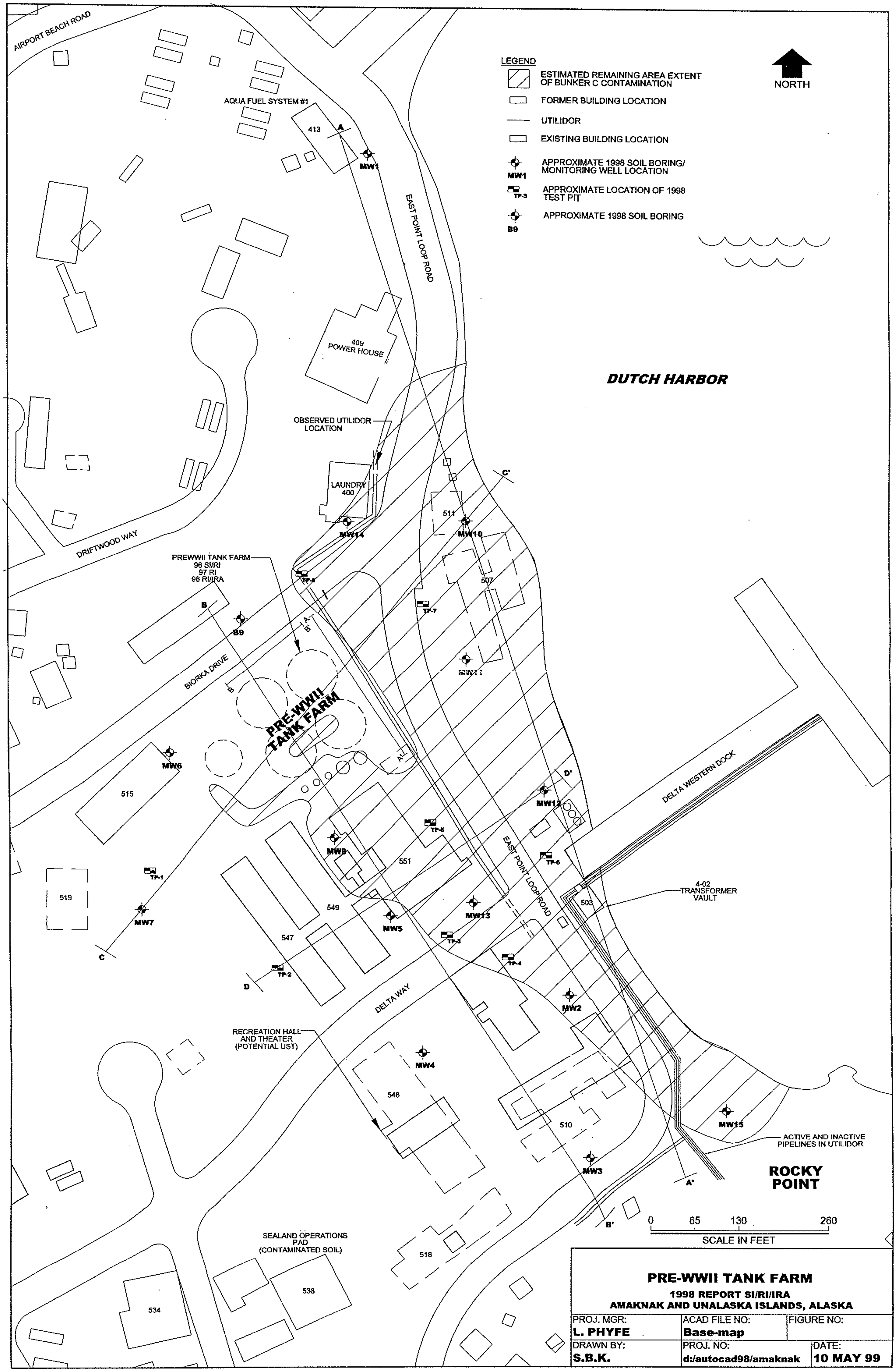
•	Sample Not Recovered	⊠	Surface Seal
⫶	2" O.D. Split Spoon Sample	▩	Solid Casing and Annular Sealant
⫼	3" O.D. Split Spoon Sample	☐	Well Screen and Filter Sand
		⊠	Cuttings Backfill
		▽	Ground Water Level ATD
		▼	Static Ground Water Level

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.
4. USC letter symbol based on visual classification.

LOG OF BORING NO. B15
Pre-WWII Tank Farm
1998 Report SI/RI/IRA
Amaknak and Unalaska Islands, Alaska

PROJ MGR.: L. Phyfe		FILE NO: Y-6007-12	FIGURE NO.: 15
DRAWN BY: S&W, Inc.	REVIEW BY: D.K.C.	PROJ NO.: 05M30211	DATE: 12 January, 1999

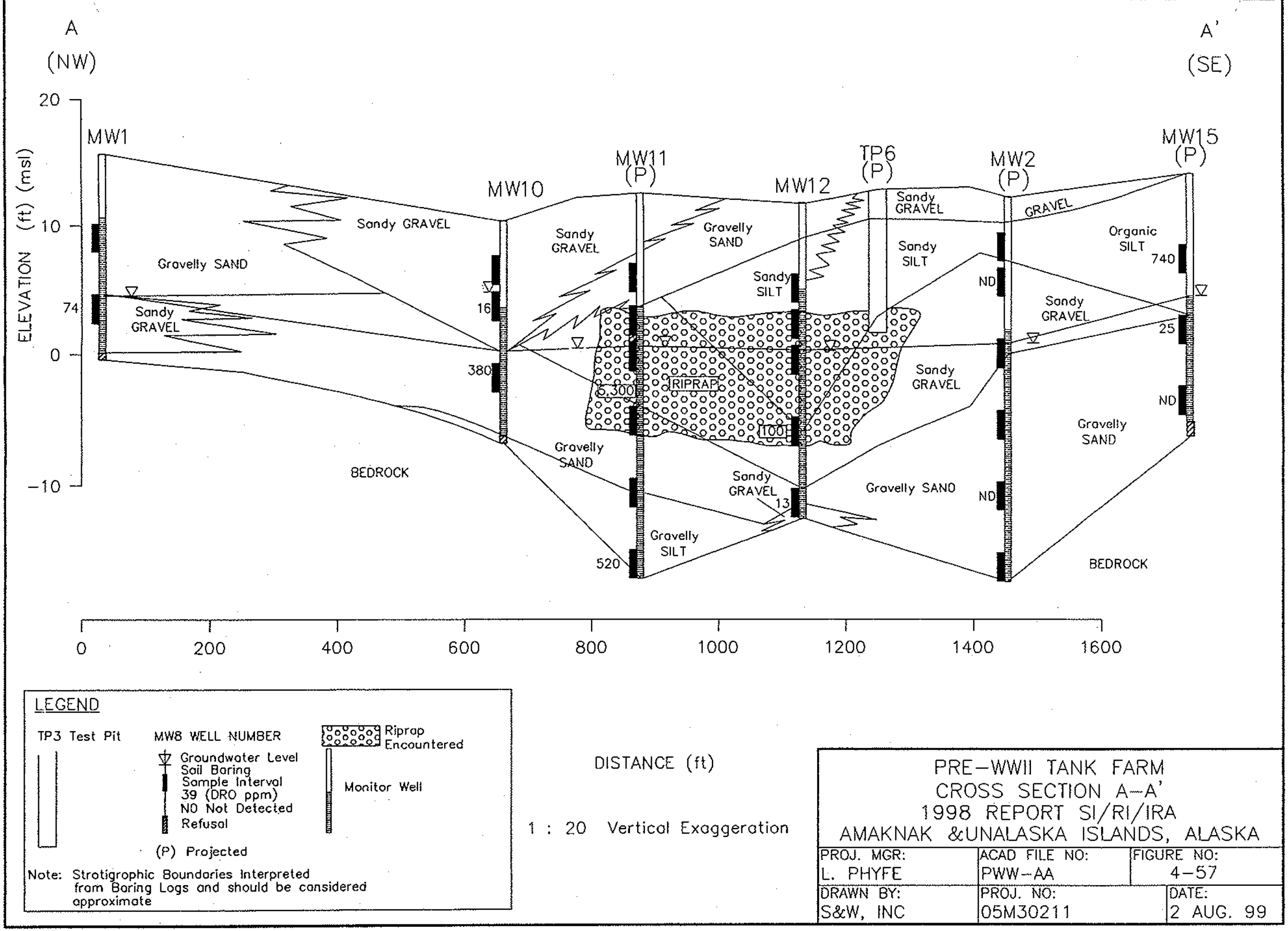


PRE-WWII TANK FARM

1998 REPORT SI/RI/IRA

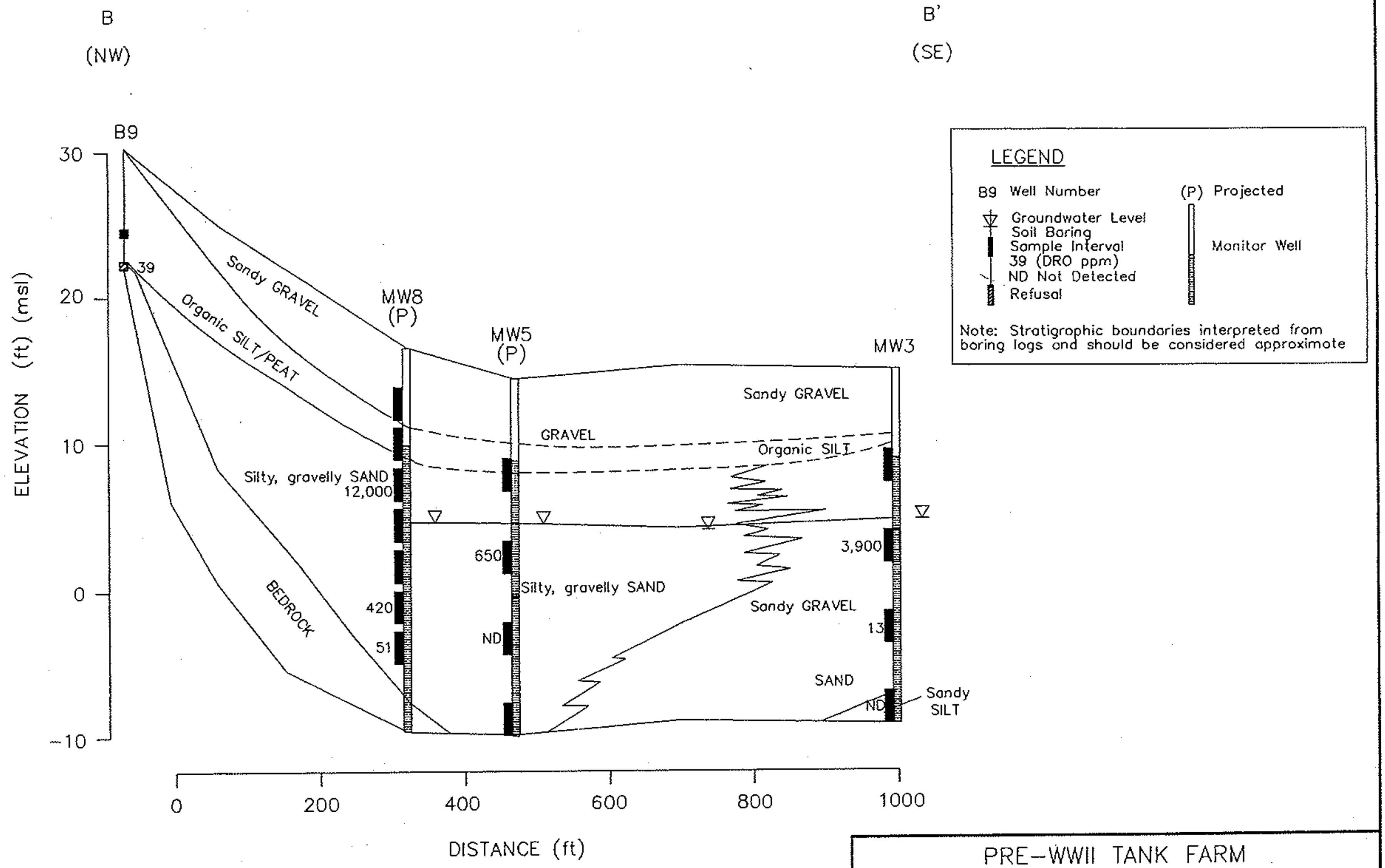
AMAKNAK AND UNALASKA ISLANDS, ALASKA

PROJ. MGR: **L. PHYFE**	ACAD FILE NO: **Base-map**	FIGURE NO:
DRAWN BY: **S.B.K.**	PROJ. NO: **d:/autocad98/amaknak**	DATE: **10 MAY 99**



PRE-WWII TANK FARM
CROSS SECTION A-A'
1998 REPORT SI/RI/IRA
AMAKNAK &UNALASKA ISLANDS, ALASKA

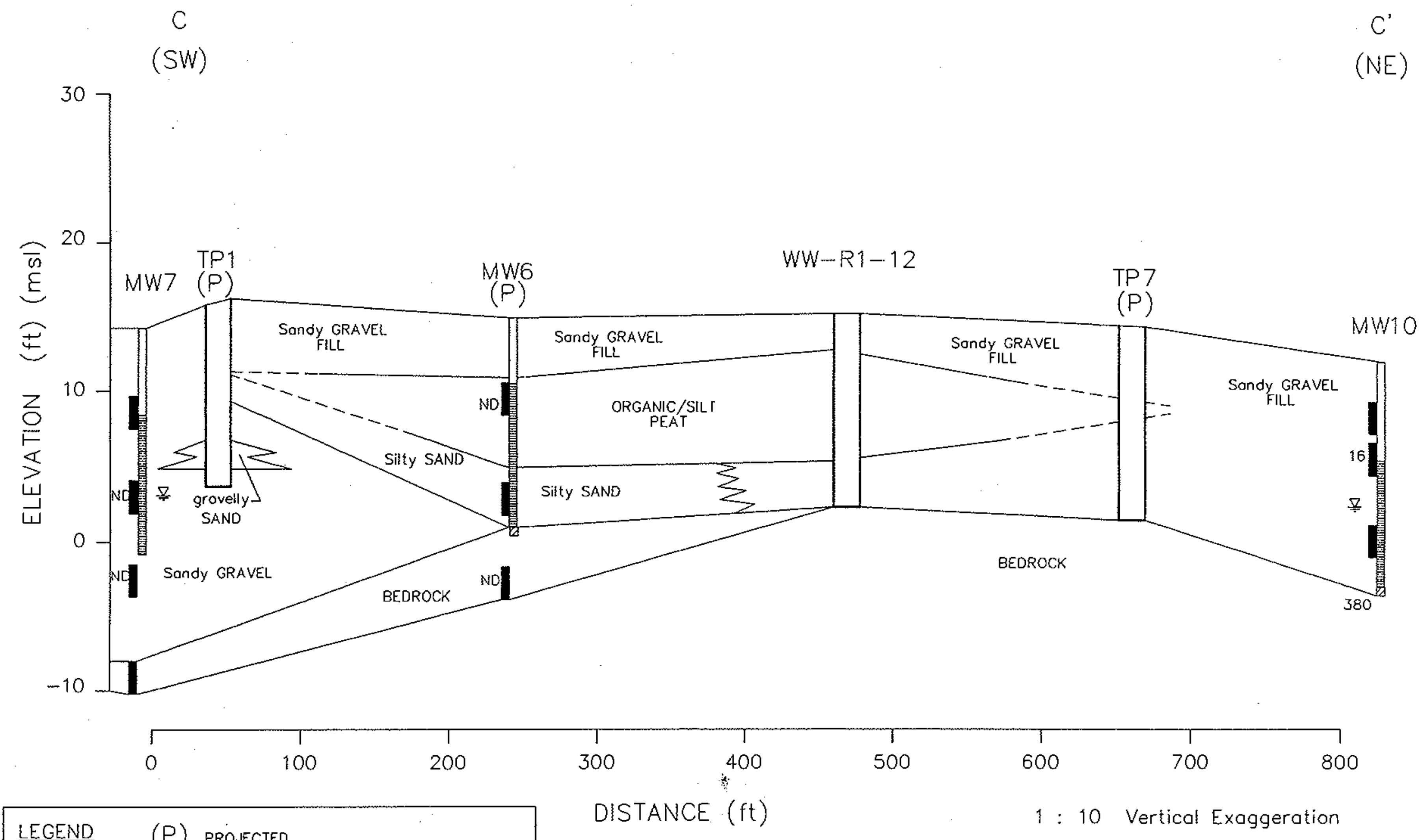
PROJ. MGR: L. PHYFE	ACAD FILE NO: PWW-AA	FIGURE NO: 4-57
DRAWN BY: S&W, INC	PROJ. NO: 05M30211	DATE: 2 AUG. 99

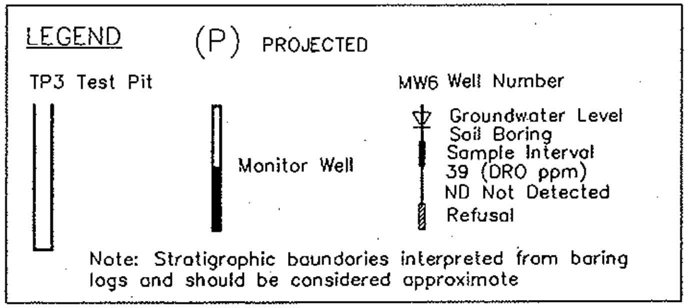


1:20 VERTICAL EXAGGERATION

PRE-WWII TANK FARM
CROSS SECTION B-B
1998 REPORT SI/RI/IRA
AMAKNAK & UNALASKA ISLANDS, ALASKA

PROJ. MGR: L. PHYFE	ACAD FILE NAME: PWW-BB	FIGURE NO: 4-58
DRAWN BY: S.B.K.	LOCATION: d:autocad/amaknak/comp.RI	DATE: 2 AUG. 99

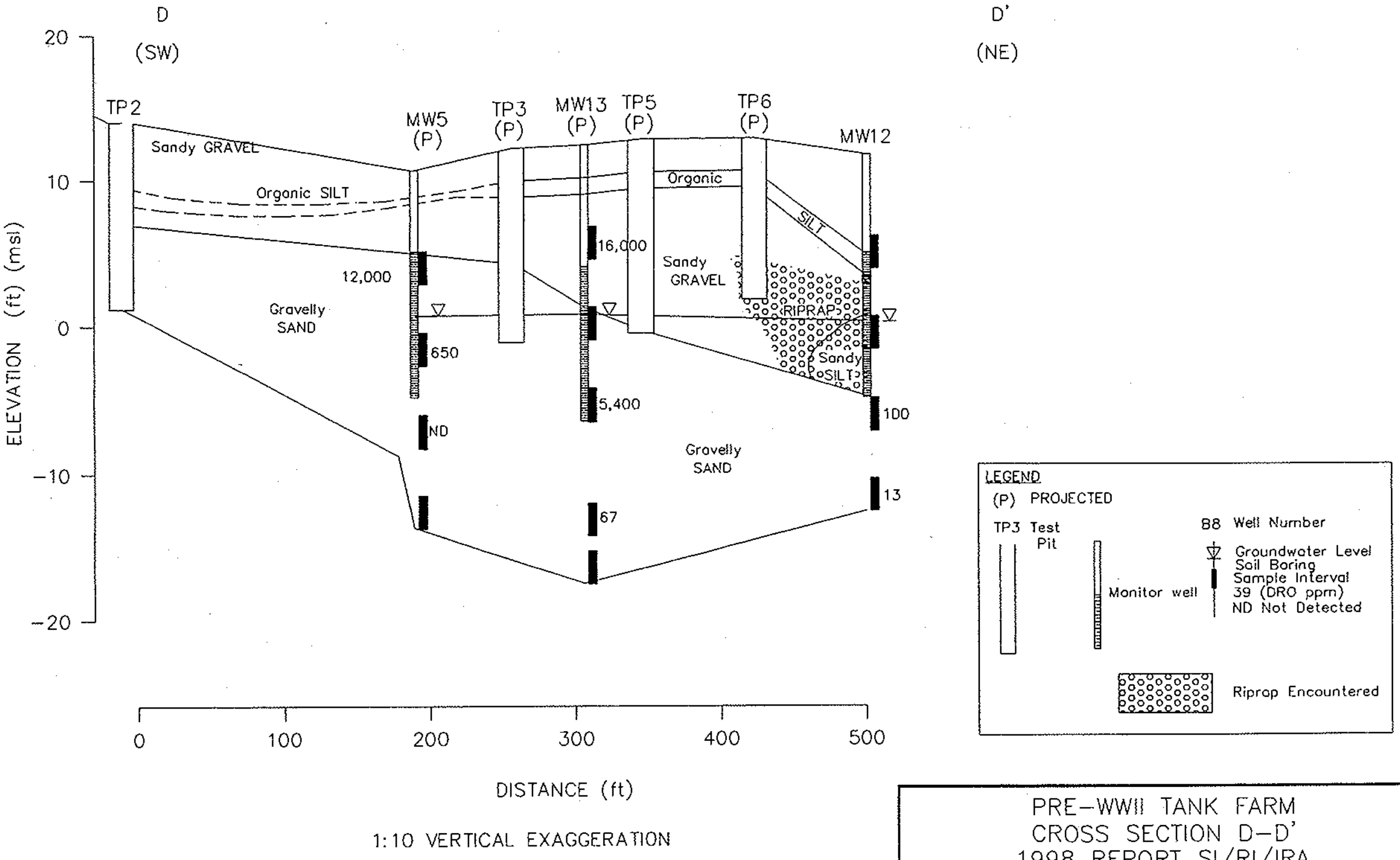




Note: Stratigraphic boundaries interpreted from boring logs and should be considered approximote

PRE-WWII TANKK FARM
CROSS SECTION C-C'
1998 REPORT SI/RI/IRA
AMAKNAK & UNALASKA ISLANDS, ALASKA

PROJ. MGR: L. PHYFE	ACAD FILE NAME: PWW-CC	FIGURE NO: 4-59
DRAWN BY: S.B.K.	LOCATION: d:/autocad/amaknak/islandwide	DATE: 2 AUG. 99



Note: Strotigraphic boundaries interpreted from boring logs and should be considered approximate

PRE-WWII TANK FARM
CROSS SECTION D-D'
1998 REPORT SI/RI/IRA
AMAKNAK & UNALASKA ISLANDS, ALASKA

PROJ. MGR: L. PHYFE	ACAD FILE NO: PWW-DD	FIGURE NO: 4-60
DRAWN BY: S&W INC.	PROJ. NO: 05M30211	DATE: 2 AUG. 99

Boring logs from the *2000 Islandwide SI/IRA/RI Report, Amaknak/Unalaska Islands, Alaska, prepared by Jacobs Engineering Group Inc. for the USAED, August 2001..*

ALASKA DISTRICT
CORPS OF ENGINEERS
ENGINEERING SERVICES

Soils and Geology Section

EXPLORATION LOG

Project: *Amaknak/Unalaska Islands, Alaska 2000 Islandwide Former Naval Laundry Facility*

Page 1 of 1

Date: *9 Nov 2000*

Drilling Agency: ☐ Alaska District ☒ Other *Denali Drilling*

Elevation Datum: ☒ MSL ☐ other

Location: Northing: Easting:

Top of Hole Elevation:

Hole Number, Field: Permanent: *NLF-MW1*

Driller: *Ryan Kaston/Orville Emes*

Inspector: *Bruce McDonald*

Type of Hole: ☐ other ☐ Test Pit ☐ Auger Hole ☒ Monitoring Well ☐ Piezometer

Depth to Groundwater: *NE*

Depth Drilled: *12.0 ft*

Total Depth: *12.0 ft*

Hammer Weight: *300 lbs*

Split Spoon I.D.: *3.0 in*

Size and Type of Bit: *4.25 in Hollow Stem Auger*

Type of Equipment: *Mobile B-61*

Type of Samples: *Split Spoon*

Depth (ft)	Lithology	Sample	Frozen ASTM D 4083	Frost Class. TM 5-822-5	Blow Count	Symbol	Classification ASTM: D 2487 or D 2488	Grain Size %Gravel	Grain Size %Sand	Grain Size %Fines	Max Size (in)	PID (ppm)	% Water	Description and Remarks
	▩	S-1			2 7 11	GP-GM	**Poorly graded GRAVEL with Silt and Sand**					**0.0**		**Brown/gray, medium dense, silty, sandy gravel. Fill material.**
2	▩													
	▩	S-2			3 4 3	GP-GM	**Poorly graded GRAVEL with Silt and Sand**					**0.0**		**Brown/gray, medium dense, silty, sandy gravel. Fill material.**
4	◌													
	◌	S-3			4 6 10	GP-GM	**Poorly graded GRAVEL with Silt and Sand**					**0.0**		**Brown, medium dense, silty, sandy grave organic silt zones. Collected AM-A510616 and AM-A510617.**
6	◌													
	◌	S-4			6 7 10	GP-GM	**Poorly graded GRAVEL with Silt and Sand**					**0.0**		**Dark brown, medium dense, silty, sandy gravel with organics.**
8	◌													
10	◌													
	⁙	S-5			11 12 14	SP-SM	**Poorly graded SAND with Silt**					**0.0**		**Brown, medium dense, silty sand. Collected AM-A510618, AM-A510619, and AM-A510620.**
12														**Bottom of Hole 12.0 ft Groundwater Not Encounted PID = Photo Ionization Detector Possible refusal on bedrock.**
14														
16														
18														

NPA Form 19-E
May 94 Prev. Ed. Obsolete

Project: *Amaknak/Unalaska Islands, Alaska 2000 Islandwide*

Hole Number: *NLF-MW1*

ALASKA DISTRICT
CORPS OF ENGINEERS
ENGINEERING SERVICES

Soils and Geology Section

EXPLORATION LOG

Project: *Amaknak/Unalaska Islands, Alaska 2000 Islandwide Former Naval Laundry Facility*

Page 1 of 1

Date: *9 Nov 2000*

Drilling Agency: ☐ Alaska District ☒ Other *Denali Drilling*

Elevation Datum: ☒ MSL ☐ other

Location: Northing:
Easting:

Top of Hole Elevation:

Hole Number, Field: Permanent: *NLF-MW2*

Driller: *Ryan Kaston/Orville Emes*

Inspector: *Bruce McDonald*

Type of Hole: ☐ other ______
☐ Test Pit ☐ Auger Hole ☒ Monitoring Well ☐ Piezometer

Depth to Groundwater: *9.50 ft*

Depth Drilled: *13.0 ft*

Total Depth: *13.0 ft*

Hammer Weight: *300 lbs*

Split Spoon I.D: *3.0 in*

Size and Type of Bit: *4.25 in Hollow Stem Auger*

Type of Equipment: *Mobile B-61*

Type of Samples: *Split Spoon*

Depth (ft)	Lithology	Sample	Frozen ASTM D 4083	Frost Class. TM 5-822-5	Blow Count	Symbol	Classification ASTM: D 2487 or D 2488	Grain Size %Gravel	Grain Size %Sand	Grain Size %Fines	Max Size (in)	PID (ppm)	% Water	Description and Remarks
		S-1			2 2 1	GP-GM	Poorly graded GRAVEL with Silt and Sand					0.0		Gray/brown, loose, silty, sandy gravel. Fill material.
2		S-2			6 6 9	GP-GM	Poorly graded GRAVEL with Silt and Sand	65	20	15		0.0		Brown, medium dense, silty, sandy gravel. Collected AM-A510607, AM-A510608, and AM-A510609.
4		S-3			6 4 4	GP-GM	Poorly graded GRAVEL with Silt and Sand	65	20	15		0.0		Brown, loose, silty, sandy gravel with trace small roots.
6 8		S-4			7 12 14	GP-GM	Poorly graded GRAVEL with Silt and Sand	65	20	15		0.0		Brown to gray, medium to very dense, slightly silty, sandy gravel. Odor/visible product. Collected AM-A510610, AM-A510611, AM-A510612, and AM-A510613.
10		S-5			27 29 33	GP-GM	Poorly graded GRAVEL with Silt and Sand	75	20	5		30.0	▼	Brown to gray, medium to very dense, slightly silty, sandy gravel. Odor/visible product. Collected AM-A510614 and AM-A510615.
12		S-6			29 50/3"	GP-GM	Poorly graded GRAVEL with Silt and Sand	75	20	5		38.9		Brown to gray, medium to very dense, slightly silty, sandy gravel. Odor/visible product.
14 16 18														Bottom of Hole 13.0 ft PID = Photo Ionization Detector Possible refusal on bedrock.

EXPLORATION LOG ISWIDE.GPJ ACE_ANC.GDT 2/16/01

NPA Form 19-E
May 94 Prev. Ed. Obsolete

Project: *Amaknak/Unalaska Islands, Alaska 2000 Islandwide*

Hole Number: *NLF-MW2*

ALASKA DISTRICT
CORPS OF ENGINEERS
ENGINEERING SERVICES

Soils and Geology Section

EXPLORATION LOG

Project: *Amaknak/Unalaska Islands, Alaska 2000 Islandwide*
Former Naval Laundry Facility

Page 1 of 1

Date: *7 Nov 2000*

Drilling Agency: ☐ Alaska District ☒ Other *Denali Drilling*

Elevation Datum: ☒ MSL ☐ other

Location: Northing:
Easting:

Top of Hole Elevation:

Hole Number, Field: Permanent: *NLF-MW3*

Driller: *Ryan Kaston/Orville Emes*

Inspector: *Bruce McDonald*

Type of Hole: ☐ other ______
☐ Test Pit ☐ Auger Hole ☒ Monitoring Well ☐ Piezometer

Depth to Groundwater: *8.00 ft*

Depth Drilled: *11.5 ft*

Total Depth: *11.5 ft*

Hammer Weight: *300 lbs*

Split Spoon I.D.: *3.0 in*

Size and Type of Bit: *4.25 in Hollow Stem Auger*

Type of Equipment: *Mobile B-61*

Type of Samples: *Split Spoon*

Depth (ft)	Lithology	Sample	Frozen ASTM D 4083	Frost Class. TM 5-822-5	Blow Count	Symbol	Classification ASTM: D 2487 or D 2488	Grain Size %Gravel	Grain Size %Sand	Grain Size %Fines	Max Size (in)	PID (ppm)	% Water	Description and Remarks
														Concrete Slab
		S-1			7 9 11	GP-GM	**Poorly graded GRAVEL with Silt and Sand**					0.0		**Brown/gray, medium dense, slightly silty, sandy gravel. Fill material.**
2														
		S-2			3 11 11	GP-GM	**Poorly graded GRAVEL with Silt and Sand**					0.0		**Brown/gray, medium dense, slightly silty, sandy gravel. Fill material.**
4														
		S-3			6 10 11	GP-GM	**Poorly graded GRAVEL with Silt and Sand**	65	20	15		0.0		**Brown, medium dense, silty, sandy gravel. Collected AM-A510601 and AM-A510602.**
6														
8		S-4			2 3 1	GP-GM	**Poorly graded GRAVEL with Silt and Sand**	65	20	15		0.0	▼	**Brown, medium dense, silty, sandy gravel. Collected AM-A510604 and AM-A510605.**
10		S-5			3 3 50/1"	GP-GM	**Poorly graded GRAVEL with Silt and Sand**	65	20	15		0.0		**Brown, medium dense, silty, sandy gravel.**
12														**Bottom of Hole 11.5 ft** **PID = Photo Ionization Detector** **Possible refusal on bedrock.**
14														
16														
18														

NPA Form 19-E
May 94 Prev. Ed. Obsolete

Project: *Amaknak/Unalaska Islands, Alaska 2000 Islandwide*

Hole Number: *NLF-MW3*

ALASKA DISTRICT
CORPS OF ENGINEERS
ENGINEERING SERVICES

Soils and Geology Section
EXPLORATION LOG

Project: *Amaknak and Unalaska Islands, Alaska*
Pre-WWII Tank Farm

Page 1 of 2
Date: *2 Sep 2000*

Drilling Agency: ☐ Alaska District ☒ Other *Discovery Drilling*

Elevation Datum: ☒ MSL ☐ other

Location: Northing: Easting:

Top of Hole Elevation:

Hole Number, Field: Permanent: *MW-11Replacement*

Driller: *Gary Cormer/Tim Beckner*

Inspector: *Bruce McDonald*

Type of Hole: ☐ other ______ ☐ Test Pit ☐ Auger Hole ☒ Monitoring Well ☐ Piezometer

Depth to Groundwater: *11.50 ft*

Depth Drilled: *20.0 ft*

Total Depth: *20.0 ft*

Hammer Weight: *300 lbs*

Split Spoon I.D.: *3.0 in*

Size and Type of Bit: *4.25 in Hollow stem auger*

Type of Equipment: *CME75*

Type of Samples: *Split Spoon*

Depth (ft)	Lithology	Sample	Frozen ASTM D 4083	Frost Class. TM 5-822-5	Blow Count	Symbol	Classification ASTM: D 2487 or D 2488	Grain Size			Max Size (in)	PID (ppm)	% Water	Description and Remarks
								%Gravel	%Sand	%Fines				
2		S-1			14 26 27 35	GP-GM	Poorly graded GRAVEL with Silt and Sand	60	30	10		3.0		Brown to gray, medium dense to very dense, slightly silty, sandy gravel (fill). Grains are angular to subrounded. Occasional metal debris.
4		S-2			26 70 103 20	GP-GM	Poorly graded GRAVEL with Silt and Sand	60	30	10		1.2		Brown to gray, medium dense to very dense, slightly silty, sandy gravel (fill). Grains are angular to subrounded. Occasional metal debris.
6		S-3			11 14 13 7	GP-GM	Poorly graded GRAVEL with Silt and Sand	60	30	10		1.4		Brown to gray, medium dense to very dense, slightly silty, sandy gravel (fill). Grains are angular to subrounded. Occasional metal debris.
8		S-4			40 138	GP-GM	Poorly graded GRAVEL with Silt and Sand	60	30	10		3.4		Brown to gray, medium dense to very dense, slightly silty, sandy gravel (fill). Grains are angular to subrounded. Occasional metal debris.
10 12		S-5			9 8 5 5	GP-GM	Poorly graded GRAVEL with Silt and Sand	50	40	10		60.2		Dark gray to black, medium dense, slightly silty sandy gravel. Grains are angular to subrounded. Product is visible.
14		S-6			7 9 14 12	GP-GM	Poorly graded GRAVEL with Silt and Sand	50	40	10		97.3		Dark gray to black, medium dense, slightly silty, sandy gravel. Grains are angular to subrounded. Product is visible.
16		S-7			10 12 10 10	GP	Poorly graded GRAVEL with Sand	80	20	0		91.3		Dark gray to black, medium dense, sandy gravel. Grains are angular to subrounded. Product is visible.
18		S-8			5 6 8 9	GP	Poorly graded GRAVEL with Sand	80	20	0		59.7		Dark gray to black, medium dense, sandy gravel. Grains are angular to subrounded. Product is visible.

EXPLORATION LOG .GPJ ACE_ANC.GDT 2/16/01

ALASKA DISTRICT
CORPS OF ENGINEERS
ENGINEERING SERVICES

Soils and Geology Section

EXPLORATION LOG

Project: *Amaknak and Unalaska Islands, Alaska*
Pre-WWII Tank Farm

Page 2 of 2

Date: *2 Sep 2000*

Drilling Agency: ☐ Alaska District ☒ Other *Discovery Drilling*

Elevation Datum: ☒ MSL ☐ other

Location: Northing:
Easting:

Top of Hole Elevation:

Hole Number, Field: Permanent: *MW-11Replacement*

Driller: *Gary Cormer/Tim Beckner*

Inspector: *Bruce McDonald*

Type of Hole: ☐ other
☐ Test Pit ☐ Auger Hole ☒ Monitoring Well ☐ Piezometer

Depth to Groundwater: *11.50 ft*

Depth Drilled: *20.0 ft*

Total Depth: *20.0 ft*

Hammer Weight: *300 lbs*

Split Spoon I.D: *3.0 in*

Size and Type of Bit: *4.25 in Hollow stem auger*

Type of Equipment: *CME75*

Type of Samples: *Split Spoon*

Depth (ft)	Lithology	Sample	Frozen ASTM D 4083	Frost Class. TM 5-822-5	Blow Count	Symbol	Classification ASTM: D 2487 or D 2488	Grain Size %Gravel	Grain Size %Sand	Grain Size %Fines	Max Size (in)	PID (ppm)	% Water	Description and Remarks
														Bottom of Hole 20.0 ft **PID = Photo Ionization Detector**
22														
24														
26														
28														
30														
32														
34														
36														
38														

NPA Form 19-E
May 94 Prev. Ed. Obsolete

Project: *Amaknak and Unalaska Islands, Alaska*

Hole Number: *MW-11Replaceme*

Boring logs from the *Groundwater Monitoring Program, 2004 Annual Report, Pre-WWII Tank Farm, Amaknak Island, Alaska*, prepared by Jacobs Engineering Group Inc. for the USAED, February 2005 (draft).

JACOBS
EXPLORATION LOG

Project: **Amaknak Pre-WWII Tank Farm**

MW-3R

Client: **US Army Corp of Engineers, Alaska District**

Elevation Datum:

Location: Northing: **1,189,737.54 ft** Easting: **5,316,075.65 ft**

Surface Elevation: **12.18 ft**

Date Completed: **24 Aug 2004**

Driller: **Gary Cormier**

Inspector: **Frank Marley**

Type of Hole: ☐ other ______

☐ Test Pit ☐ Auger Hole ☒ Monitoring Well ☐ Piezometer

Depth to Groundwater: **13.00 ft**

Depth Drilled: **20.60 ft**

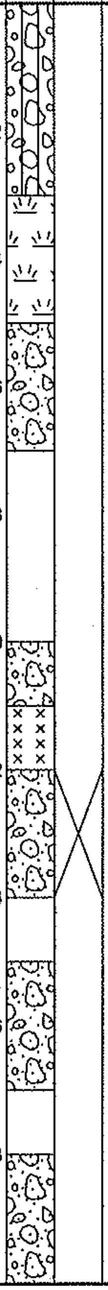
Total Depth: **20.60 ft**

Hammer Weight:

Split Spoon Size: **2.5 in ID x 2.0 ft**

Drill Type and Size:

Type of Equipment: **CME75 Hollow Stem Auger**



Depth (ft)	Lithology	Analytical Sample	Blow Count	Symbol	Classification ASTM: D 2487 or D 2488	Gravel (%)	Sand (%)	Fines (%)	PID (ppm)	Product & Fe Alteration	Description and Remarks
				GM					0.0		Gray, sandy, silty, gravel. Moist.
2											
				PT						none	Dark brown peat. Moist.
4											
			8	GM		55	30	15	10.0	none	Brownish-gray, silty sandy gravel. Moist.
			5								
6											
			5								
			6								
				GM							
8											
10			14	GM		55	30	15	104.0	slight	Brownish-gray, silty, sandy gravel. Moist.
			12								
			15	SP-SM		20	50	30		strong	Dark gray, gravelly, silty sand. Moist to wet.
			15								
12			3	GM		60	25	15	316.0	strong	Dark gray, silty, sandy gravel. Wet. Sheen.
			10							▼	Analytical Sample AM-A562001 and AM-A-62002 (duplicate) collected and analyzed for GRO, DRO/RRO, VOCs, and PAHs.
			15								
			13								
14											
				GM							
			20	GM		60	25	15		strong	Dark gray, silty sandy gravel. Wet.
			14								
16			14								
			19								
				GM							
18			16	GM						strong	Dark gray, silty sandy gravel. Saturated.
			14								
			12								
			11								

JACOBS

EXPLORATION LOG

Project:	Amaknak Pre-WWII Tank Farm
	MW-3R
Client:	US Army Corp of Engineers, Alaska District
Elevation Datum:	
Location:	Northing: 1,189,737.54 ft Easting: 5,316,075.65 ft
Surface Elevation:	12.18 ft
Date Completed:	24 Aug 2004
Driller:	Gary Cormier
Inspector:	Frank Marley
Type of Hole:	☐ other ☐ Test Pit ☐ Auger Hole ☒ Monitoring Well ☐ Piezometer
Depth to Groundwater:	13.00 ft
Depth Drilled:	20.60 ft
Total Depth:	20.60 ft
Hammer Weight:	
Split Spoon Size:	2.5 in ID x 2.0 ft
Drill Type and Size:	
Type of Equipment:	CME75 Hollow Stem Auger

Depth (ft)	Lithology	Analytical Sample	Blow Count	Symbol	Classification ASTM: D 2487 or D 2488	Gravel (%)	Sand (%)	Fines (%)	PID (ppm)	Product & Fe Alteration	Description and Remarks
22											
24											
26											
28											
30											
32											
34											
36											
38											

KODIAK BORING LOG A K PRE-WWII TANK FARM 2004.GPJ CHINIAK.GDT 1/20/05

JE JACOBS

EXPLORATION LOG

Project: Amaknak Pre-WWII Tank Farm

MW-4R

Client: US Army Corp of Engineers, Alaska District

Elevation Datum:

Location: Northing: 1,189,881.36 ft
Easting: 5,315,777.70 ft

Surface Elevation: 11.72 ft

Date Completed: 24 Aug 2004

Driller: Gary Cormier

Inspector: Frank Marley

Type of Hole: ☐ other ________

☐ Test Pit ☐ Auger Hole ☒ Monitoring Well ☐ Piezometer

Depth to Groundwater: 15.00 ft

Depth Drilled: 20.20 ft

Total Depth: 20.20 ft

Hammer Weight:

Split Spoon Size: 2.5 in ID x 2.0 ft

Drill Type and Size:

Type of Equipment: CME75 Hollow Stem Auger

Depth (ft)	Lithology	Analytical Sample	Blow Count	Symbol	Classification ASTM: D 2487 or D 2488	Gravel (%)	Sand (%)	Fines (%)	PID (ppm)	Product & Fe Alteration	Description and Remarks
				GM					0.0		Brownish-gray, silty, sandy gravel. Moist. Observed from drill cuttings.
2											
4											
			4 3	PT					0.0		No recovery due to a rock in the split spoon. Very soft (pe
6											
				PT							Dark brown organic peat mixed with gravel. Observed from drill cuttings.
8											
10			2 6	GM		50	15	35	0.0	none	Brownish-gray, sandy, silty, gravel. Moist.
			10 9	SP		45	55			none	Brown, gravelly sand. Moist.
12											
14											
			3 6 6 6	GM		45	35	20	0.0	▼ none	Brown, silty, sandy gravel. Saturated.
16											
18											

JE JACOBS

EXPLORATION LOG

Project: Amaknak Pre-WWII Tank Farm		MW-4R
Client: US Army Corp of Engineers, Alaska District	Elevation Datum:	
Location: Northing: 1,189,881.36 ft Easting: 5,315,777.70 ft	Surface Elevation: 11.72 ft	

Date Completed: 24 Aug 2004	Driller: Gary Cormier	Inspector: Frank Marley

Type of Hole: ☐ other ______________
☐ Test Pit ☐ Auger Hole ☒ Monitoring Well ☐ Piezometer

Depth to Groundwater: 15.00 ft	Depth Drilled: 20.20 ft	Total Depth: 20.20 ft	
Hammer Weight:	Split Spoon Size: 2.5 in ID x 2.0 ft	Drill Type and Size:	Type of Equipment: CME75 Hollow Stem Auger

Depth (ft)	Lithology	Analytical Sample	Blow Count	Symbol	Classification ASTM: D 2487 or D 2488	Gravel (%)	Sand (%)	Fines (%)	PID (ppm)	Product & Fe Alteration	Description and Remarks
22											
24											
26											
28											
30											
32											
34											
36											
38											

KODIAK BORING LOG JAK PRE-WWII TANK FARM 2004.GPJ CHINIAK.GDT 12/22/04

JE JACOBS

EXPLORATION LOG

Project: Amaknak Pre-WWII Tank Farm

MW-7R

Client: US Army Corp of Engineers, Alaska District

Elevation Datum:

Location: Northing: 1,190,098.62 ft
Easting: 5,315,268.51 ft

Surface Elevation: 13.78 ft

Date Completed: 24 Aug 2004

Driller: Gary Cormier

Inspector: Frank Marley

Type of Hole: ☐ other

☐ Test Pit ☐ Auger Hole ☒ Monitoring Well ☐ Piezometer

Depth to Groundwater: 15.60 ft

Depth Drilled: 19.00 ft

Total Depth: 19.00 ft

Hammer Weight:

Split Spoon Size: 2.5 in ID x 2.0 ft

Drill Type and Size:

Type of Equipment: CME75 Hollow Stem Auger

Depth (ft)	Lithology	Analytical Sample	Blow Count	Symbol	Classification ASTM: D 2487 or D 2488	Gravel (%)	Sand (%)	Fines (%)	PID (ppm)	Product & Fe Alteration	Description and Remarks
				GP-GM					0.0		Brown grey sandy gravel with large cobbles. Moist. Observations made from drill cuttings.
2											
4											
			2	GM		60	25	15	0.0	none	Brownish-gray, silty, sandy gravel. Moist.
			2	PT						none	Black, organic peat. Moist to wet.
6			1								
			1								
8											
			1								
10				PT					0.0	none	Reddish-brown peat. Moist to wet.
12											
14											
			0	PT				10	0.0	none ▼	Brownish-black peat with some silt. Wet.
			1								
16			5								
			8	Rx						none	Gray, weathered bedrock.
18											

Page: Page 1 of 1

Project: Amaknak Pre-WWII Tank Farm

MW-7R

JE JACOBS

EXPLORATION LOG

Project: **Amaknak Pre-WWII Tank Farm**

MW-16

Client: **US Army Corp of Engineers, Alaska District**

Elevation Datum:

Location: Northing: **1,190,511.85 ft** Easting: **5,315,609.36 ft**

Surface Elevation: **15.99 ft**

Date Completed: **24 Aug 2004**

Driller: **Gary Cormier**

Inspector: **Frank Marley**

Type of Hole: ☐ other ______ ☐ Test Pit ☐ Auger Hole ☒ Monitoring Well ☐ Piezometer

Depth to Groundwater: **17.00 ft**

Depth Drilled: **20.00 ft**

Total Depth: **20.00 ft**

Hammer Weight:

Split Spoon Size: **2.5 in ID x 2.0 ft**

Drill Type and Size:

Type of Equipment: **CME75 Hollow Stem Auger**

Depth (ft)	Lithology	Analytical Sample	Blow Count	Symbol	Classification ASTM: D 2487 or D 2488	Gravel (%)	Sand (%)	Fines (%)	PID (ppm)	Hydrocarbon Odor	Description and Remarks
									0.0		No cuttings observed.
2											
4											
			4 1 2 4	GM		50	30	20	0.0	none	Dark brown, silty, sandy gravel. Moist.
6											
8											
10									34.9		
			15 9 10 10	GM		65	25	10		strong	Brownish gray, silty, sandy gravel with fractured rock. Moist to wet with visible bunker oil.
12											
14											
		☒	3 7 12 33	GM		70	20	10	67.8	strong	Brownish gray, silty, sandy gravel with fractured rock. Moist to wet with visible bunker oil. Analytical - sample AM-A562003 collected and analyzed for GRO, DRO/RRO, VOCs, and PAHs.
16											
				Rx						▼	Bedrock. Final blow count advanced 2 inches.
18											

Page: **Page 1 of 1**

Project: **Amaknak Pre-WWII Tank Farm**

MW-16

KODIAK BORING LOG …AK PRE-WWII TANK FARM 2004.GPJ CHINIAK.GDT 12/22/04

Appendix D

APPENDIX D

Responses to Comments on the Draft Report

REVIEW COMMENTS | **PROJECT: Pre WWII Tank Farm, Amaknak/Unalaska Islands FUDS**
DOCUMENT: draft Groundwater Modeling Report dated April 2004

AK DEPT OF ENVIRONMENTAL CONSERVATION

DATE: June 10, 2004
REVIEWER: J. Halverson (DEC)
PHONE: (907) 269-7545

Action taken on comment by: Jacobs Engineering Group Inc.

Item No.	Drawing Sheet No., Spec. Para.	COMMENTS	REVIEW CONFERENCE A - comment accepted W - comment withdrawn (if neither, explain)	CONTRACTOR RESPONSE	USAED RESPONSE ACCEPTANCE (A - agree) (D - disagree)
1	General	The report documents discrepancies between some of the field data and the input values necessary to calibrate the model (i.e., water level elevation data, hydraulic conductivity, slug test results, tidal efficiency). The conclusions/recommendations should include verifying the monitoring well survey data and other field data, as appropriate. If incorrect elevation or other data were used, the report should be updated with the correct data.	A	Section 7.0 will be renamed "Summary and Recommendations," and will be expanded to include recommendations for refining the groundwater flow model. Re-surveying all existing monitoring wells, and installing additional monitoring wells near the locations of the destroyed MW-4 and MW-7 wells were implemented during the 2004 field season. The latest results will be incorporated in the final groundwater modeling report. Additional subsurface investigation is needed to define the extent of contamination.	
2	General	The report should include a summary and depiction (figures, cross sections) of observed NAPL occurrence and thickness based on prior soil boring logs, test pit logs, observations during excavation work/removal actions, and the groundwater monitoring events (1991 E&E, 1996-2004 Jacobs Eng.). This should be described in respect to the model calibration, sensitivity analysis and uncertainty analysis.	A	The requested information (borehole and test pit logs and cross sections from previous reports) will be provided in an additional appendix, and will be discussed in Section 3 in the final Report. New cross sections will be developed after the USAED further defines the extent of contamination at the site.	
3	3.2.1, pg. 3-2	Several TOC elevations are estimated, as noted in Table 3-1. Is there an estimate of the range elevations within which the TOC elevation falls? MW-6 the main upgradient control for all of the water table maps has an estimated TOC elevation. Contours could change significantly if this TOC were surveyed and found to be different.	A	Coordinates and surface and TOC elevations were resurveyed during the 2004 field season for all existing and new wells (except MW-12, for which coordinates and surface elevation only were obtained because the well was inaccessible and could not be opened during the survey). These data will be incorporated in the final report, removing the uncertainties associated with estimated TOC	

REVIEW COMMENTS

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				elevations at all wells except MW-12 and the destroyed wells (MW-3, MW-4, and MW-7).	
4	3.2.1, pg. 3-3	The last paragraph states that water levels in three monitoring wells were only measured once during the year and lists the wells as MW-6, MW-6 and MW-13. It appears MW-5 should listed.	A	The parenthetical statement will be changed to read "(MW-5, MW-6, and MW-13)."	
5	3.2.2.1, pg. 3-5	Please show location of Building 409 (powerhouse) on appropriate figures when it is used in text to describe site.	A	The southwest corner of Building 409 appears in Figures 3-2 through 3-8 but is not labeled. A label will be added to these figures.	
6	3.2.2.1, pg. 3-6	Question marks should be added to watertable contours that lack well control.	A	To indicate uncertainty in water table contours lacking nearby control, affected contour lines in Figures 3-2 through 3-8 will be displayed as dotted, and the difference in line styles will be described in the legend.	
7	3.6, Table 3-7	Please clarify whether the "-" symbol under some of the samples means they were not analyzed using that particular method (add a footnote).	A	The hyphen indicates that the parameter was not analyzed in that particular sample. A footnote will be added to the table for clarification.	
8	3.3, pg. 3-13	As a check on hydraulic parameters determined using slug tests, the aquifer transmissibility could be calculated based on the tidal information gathered according to the stage-ratio method or time-lag method described in Ferris, J.G. 1963, Cyclic Water-Level Fluctuations as a Basis for Determining Aquifer Transmissibility: US Geol. Survey Water Supply Paper 1536-I, p. 305–318.	A	This will be pursued, with results summarized in a new subsection and table in Section 3.4.	

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9	3.3.2, pg. 3-15	Is the density of the Bunker C/diesel product mixture taken at a temperature of 15 degrees Celsius appropriate? Groundwater temperatures were measured at 5 to 8 degrees Celsius (p. 3-40).	W	The laboratory was unable to perform density measurements at temperatures representative of groundwater temperatures. Therefore, practical corrections were applied using equation 3.3 (p. 3-40). Errors resulting from these corrections are insignificant compared uncertainties regarding viscosity, hydraulic conductivity, water table configuration, and extent of remaining oil contamination on site.	
10	3.5.2, pg. 3-26	Are there variations in lithology that may be used as part of the explanation for the variation in conductivity? Are any consistent units present in MW-11 or MW-10 that might be projected into these areas, particularly fine-grained units? Boring logs should be attached as an appendix.	A	A transition from clean sand to pure clay would probably be accompanied by a conductivity increase of about 2 mS/cm, possibly explaining between 25 and 50 percent of the observed variation. However, the boring log for MW-10 records only sandy gravel except for a thin layer of gravelly silt at the bedrock interface. Similarly, the boring log for MW-11 records only gravelly sand between 15 and 21.5 ft bgs. Thus, there is no subsurface evidence for a clay-rich layer at the depths of the observed increases in conductivity. Because stratigraphic units at the site are laterally discontinuous, the presence of a clay-rich horizon beneath the shoreline cannot be completely ruled out. Boring logs will be included as an appendix in the final Report.	
11	3.6, pg. 3-31	First paragraph describes "DZMW12 near MW12", should this be "DZMW11 near MW11"? A brief description of sampling protocol should be	A	It should be "DZMW11 near MW11" as noted. The text will be corrected. The sampling description will be expanded.	

REVIEW COMMENTS	PROJECT: Pre WWII Tank Farm, Amaknak/Unalaska Islands FUDS DOCUMENT: draft Groundwater Modeling Report dated April 2004	
AK DEPT OF ENVIRONMENTAL CONSERVATION	**DATE: June 10, 2004** **REVIEWER: J. Halverson (DEC)** **PHONE:** (907) 269-7545	**Action taken on comment by: Jacobs Engineering Group Inc.**

Item No.	Drawing Sheet No., Spec. Para.	COMMENTS	REVIEW CONFERENCE A - comment accepted W - comment withdrawn (if neither, explain)	CONTRACTOR RESPONSE	USAED RESPONSE ACCEPTANCE (A - agree) (D - disagree)
		included to describe how DZMW11 was sampled while free product was present.		DZMW11 was purged at 600 mL/min for approximately 20 minutes until the parameters (except turbidity) were stabilized per standard EPA protocol. Parameters were measured using a Horiba U-22. A coagulated brown sheen was evident in the purge water bucket, but no sheen was noted in the fraction collected for analysis. Suspended material was eliminated by immediate filtration through a 0.4 micron filter before transfer to an acidified sample bottle. This additional information will be provided in the text.	
		The text indicates that low level PAHs may be indicative of contamination in the seawater rather than from groundwater discharge, however, low level PAHs have been documented over time in the groundwater.		The text will be amended to note that although low level PAHs have been documented in groundwater elsewhere on the site, the high proportions of seawater in these samples (on the order of 0.5 to 0.7), reflected by their high conductivities, suggests that a maritime industrial origin for the PAHs is also possible.	
12	4.2 & 4.3, pg. 4-4	If the bedrock subcrops near the surface or outcrops at the surface and forms an embayment (as described on p. 3-5), the model boundaries could be moved to these areas and the boundaries of the model could then be depicted as no-flow boundaries. This assumes that bedrock is not hydraulically conductive as indicated by the model having a no-flow boundary at its base.	A	The model is configured in essentially as suggested. As described in Section 4.4.1, all cells to the east of the coastline are configured as inactive, with discharge to the intertidal zone controlled by constant-head cells in layers 8 through 10. Cells beneath the bedrock surface are also configured as inactive (Section 4.2). Thus, where bedrock outcrops/subcrops on the shoreline south of MW-10, the constant-head cells are inactivated, converting the boundary there to a no-flow boundary.	

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Action taken on comment by: Jacobs Engineering Group Inc.

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				For clarity, explanations will be added to Figures 4-3, 4-4, and 4-5 describing the initially inactive cells (no shading).	
13	4.2, pg. 4-4	It would help to have a figure showing the depth to bedrock across so the reader can see how significant changes in sediment thickness are in relation to a model that depicts the model bottom as being flat lying. This could easily be created based on the bedrock topography map.	A	Across most of the model domain, the surface topography is nearly flat, at an elevation of 12 to 14 feet above mean sea level. A sediment thickness map would thus have the same contours as bedrock but with values shifted by 12 to 14 feet and presented as positive instead of negative values. Only along the northwestern part of the area, at the base of the Biorka Drive hill, does the ground surface slope upward, altering the relationship between bedrock topography and sediment thickness. Although a thickness map would be useful here, surface contours have not been mapped. Additional discussion of these ideas will be added to Section 4.3, but the current figure provides adequate visualization.	
		Please explain the rationale for using 15 layers each being 1.67 feet thick.		The model is explicitly three-dimensional, with transmissivity based on cell thickness and hydraulic conductivity. The use of fifteen layers, each 1.67 ft thick, is a tradeoff between vertical precision and model size. Although it is likely that a model with fewer layers would have produced the same results, the 15-layer model provides adequate resolution for depiction of bedrock, and allows explicit modeling of variations in vertical as well as horizontal hydraulic conductivity. The model was easily manipulated and offered the possibility of modeling	

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				thin flow barriers such as the utilidor.	
14	4.5, pg. 4-10	The text should describe in more detail how the zones were delineated.	A	Initially, polygonal zones were created around each monitoring well with slug-test or tidal-response data, with the polygon boundaries drawn as perpendicular bisectors of the lines connecting pairs of monitoring wells. The calibration process involved adjusting the polygon boundaries and hydraulic properties to obtain the best possible match with the target water levels. The process is described at length in Section 4.6.	
		It should describe how sensitive the model was to changes in hydraulic conductivity in the Default Zone.		The Default zone serves primarily to conduct water from the western portion of the model to the tank farm, MW-2, and RPMW-16 zones. All water entering the model is modeled as recharge, and enters at a specified rate that is independent of head or hydraulic conductivity. The hydraulic gradient across the Default zone is inversely proportional to the hydraulic conductivity there, but heads along the downgradient margins of the Default zone are controlled by the downgradient hydraulic properties, not be Default zone properties. Thus, increasing the hydraulic conductivity across the Default zone will flatten the hydraulic gradient rather than increasing the amount of water delivered to downgradient zones. This discussion will be added to Section 4.5.	
		It states that a low conductivity zone was needed along the shoreline to reproduce the steep watertable gradient in that area, however, the gradient information is suspect due to uncertainty over the		After incorporation of the 2004 survey data, which used mean sea level as the vertical datum, water table gradients no longer steepen near the shoreline,	

REVIEW COMMENTS

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Item No.	Drawing Sheet No., Spec. Para.	COMMENTS	REVIEW CONFERENCE A - comment accepted W - comment withdrawn (if neither, explain)	CONTRACTOR RESPONSE	USAED RESPONSE ACCEPTANCE (A - agree) (D - disagree)
		reference datum. A sensitivity analysis should be included.		eliminating the need for the low-conductivity zone. Because of the shortcomings of the model, a formal sensitivity analysis seems unlikely to provide further useful insights into model behavior. Instead, the schematic model through MW-11 was developed to examine the ability of any model to simulate key calibration targets to variations in hydraulic parameters. The reader is referred to Section 4.7 as a substitute for formal sensitivity analysis.	
15	4.6.1, pg.	Particle tracks depicted in Figure 4-6 indicate that the TFSlice Model Section A-A (page 5-3) may be more representative of cross-gradient conditions than down gradient conditions. If this is the case, how would this impact interpretation of the current MOFAT simulations, and would it be important to simulate a TFSlice section that runs more parallel to the presented particle paths (for example, a section that runs roughly through MW-8, MW-3, and the shoreline)?	A	After revising the groundwater flow model based on the newly surveyed TOC elevations, the model depicts groundwater in the eastern portion of the tank farm site as discharging to the east, past MW-11. This flow path remains the most important trajectory to simulate with the TFSlice model because it provides the closest observed approach of Bunker C contamination to the shoreline.	
16	4.8, pg. 4 -22	Item #9 lists major uncertainties associated with the groundwater flow modeling. The report should include more description of the potential impacts these have on the results, conclusions and recommendations. Additional recommendations should be included on how to reduce or address these uncertainties.	A	As stated in the response to General Comment #1, Section 7.0 will be renamed "Summary and Recommendations," and will be expanded to include recommendations for refining the groundwater flow model. The discussion of modeling results in Section 7.0 will be edited and expanded to more explicitly	

REVIEW COMMENTS	PROJECT: **Pre WWII Tank Farm, Amaknak/Unalaska Islands FUDS** DOCUMENT: **draft Groundwater Modeling Report dated April 2004**	
AK DEPT OF ENVIRONMENTAL CONSERVATION	**DATE: June 10, 2004** **REVIEWER: J. Halverson (DEC)** **PHONE:** (907) 269-7545	**Action taken on comment by: Jacobs Engineering Group Inc.**

Item No.	**Drawing Sheet No., Spec. Para.**	**COMMENTS**	**REVIEW CONFERENCE** A - comment accepted W - comment withdrawn (if neither, explain)	**CONTRACTOR RESPONSE**	**USAED RESPONSE ACCEPTANCE** (A - agree) (D - disagree)
				address the influence of the principal uncertainties (i.e., water table configuration, recharge, hydraulic conductivity, and LNAPL transport).	
17	5.3.3, pg. 5-14	Text suggests that "if oil viscosity is 3000 cSt or more, then other factors must have promoted oil migration". This is an important statement since the ambient conditions do indicate that simulated viscosity for the oil should be 6,071 cSt or greater. This statement appears to nullify the entire LNAPL model results since these factors have not been defined and appear to have a significant impact on the rate of product transport. More discussion should be provided to address this issue.	A	This limitation of the LNAPL model precludes quantitative interpretation of the model results. Section 5.4 (Implications of LNAPL Flow Modeling) generally draws qualitative conclusions about the physical mechanisms affecting oil migration while pointing out the seemingly disparate site information (insufficient hydraulic conductivity, viscosity that is too high, presence of oil in MW-11). Discussion beyond that presented in Section 5.4 and Section 7.0 of factors affecting oil viscosity or migration rate would be unsupported by facts and observations. Speculatively, the most likely factors leading to increased oil mobility would be the presence of coarse gravels with very high hydraulic conductivity, initially elevated temperature leading to initially very low viscosity (less than 500 cSt), or a low viscosity because of blending with a lighter fuel oil. The final two sentences in ¶1 on p.5-14 ("Given the … oil migration.") are interpretative rather than descriptive. They will be deleted, and the ideas will be discussed in Section 5.4.	
18	5.3.3, pg. 5-14	Noted uncertainties in the groundwater flow model coupled with uncertainties with the LNAPL flow	A	This comment appears to refer to Section 7.0, p.7-2, where the phrase "conditions will not worsen"	

REVIEW COMMENTS

PROJECT: Pre WWII Tank Farm, Amaknak/Unalaska Islands FUDS

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Action taken on comment by: Jacobs Engineering Group Inc.

Item No.	Drawing Sheet No., Spec. Para.	COMMENTS	REVIEW CONFERENCE A - comment accepted W - comment withdrawn (if neither, explain)	CONTRACTOR RESPONSE	USAED RESPONSE ACCEPTANCE (A - agree) (D - disagree)
		model do not provide sufficient grounds for a no further action scenario at this time. The statement "conditions will not worsen" is not strongly supported by this document. In addition, the rate at which the site will "slowly improve" is not well defined. Due to complex site conditions and insufficient data to constrain modeling scenarios, it appears to be inappropriate to rely heavily on a deterministic basis for site action.		appears. The wording here will be changed to "… the groundwater flow modeling, LNAPL flow modeling, and natural attenuation evaluation collectively suggest that conditions may not worsen, but would slowly improve on only a decadal time scale." Additionally, Section 7.0 will be edited to lend more weight to the possibility that the oil migration front may not yet have arrived at Iliuliuk Bay, and to more clearly acknowledge that additional work (to characterize in detail the distribution of oil in the subsurface and to reconcile the disparate indicators of hydraulic conductivity) is needed before modeling can quantitatively support decisions for site action. Estimated timeframes for potential remedial actions will be provided in more general terms, such as "several decades," "up to a decade," and "several years."	
19	General	It does not appear that the MOFAT simulations offer a sufficiently small range of possible transport events to determine whether product discharges have or will occur into the Bay. Some recommendation(s) should be included in the report that serve to either further refine the simulated transport estimates or better define site conditions to narrow simulation scenarios	A	See the response to Comment No. 1.	
20		Well logs and stratigraphic cross-sections should be included to help in understanding the hydrogeologic	A	See the response to Comment No. 2.	

REVIEW COMMENTS

PROJECT: Pre WWII Tank Farm, Amaknak/Unalaska Islands FUDS
DOCUMENT: draft Groundwater Modeling Report dated April 2004

AK DEPT OF ENVIRONMENTAL CONSERVATION	**DATE: June 10, 2004** **REVIEWER: J. Halverson (DEC)** **PHONE: (907) 269-7545**	**Action taken on comment by: Jacobs Engineering Group Inc.**

Item No.	Drawing Sheet No., Spec. Para.	COMMENTS	REVIEW CONFERENCE A - comment accepted W - comment withdrawn (if neither, explain)	CONTRACTOR RESPONSE	USAED RESPONSE ACCEPTANCE (A - agree) (D - disagree)
		system.			