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Monitoring the Natural Attenuation of Petroleum in Ground Water at the Former Naval Complex, Operable Unit A, Adak Island, Alaska, May and June 2003

Scientific Investigations Report 2005–5002

U.S. Department of the Interior
U.S. Geological Survey

Cover: Photograph of Geoprobe® Model 6610DT pushing a temporary borehole for sampling at the General Communications, Inc. (GCI) compound site, Adak Island, Alaska. (Photograph taken by R.S. Dinicola, U.S. Geological Survey, Tacoma, Washington, 2003.)

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By R.S. Dinicola, F.W. Simonds, and Rose Defawe

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U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
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Conversion Factors, Datums, Abbreviations, and Acronyms

Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Volume	
gallon (gal)	3.785	liter (L)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
	Flow rate	
foot per year (ft/yr)	0.3048	meter per year (m/yr)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32.$$

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD88).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD27).

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations

Abbreviations	Meaning
$CaCO_3$	calcium carbonate
g	gram
µm	micrometer
mL/min	milliliter per minute
mg/L	milligram per liter

Acronyms

Acronym	Meaning
ADEC	Alaska Department of Environmental Conservation
ANC	Acid-neutralizing capacity
AST	above ground storage tank
BRAC	Base Closure and Realignment Commission
BTEX	Benzene, toluene, ethylbenzene, xylene
DRO	diesel range organics
EPA	U.S. Environmental Protection Agency
FID	flame ionization detector
GC	gas chromatograph
GCI	General Communications, Inc.
GRO	gasoline range organics
JP	jet petroleum
MNA	monitored natural attenuation
NaCl	sodium chloride
NAP	natural attenuation parameter
NAPL	non-aqueous phase liquid
ORP	oxygen-reduction potential
OU	operable unit
PDS	polydimethylsiloxane
PVC	polyvinylchloride
ROD	Record of Decision
ROICC	Resident Officer in Charge of Construction
SAERA	State-Adak Environmental Restoration Agreement
SPME	solid phase microextraction
SWMU	solid waste management unit
TFB	Tank farm B
TS	Tanker shed
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UST	underground storage tank
VOC	volatile organic compound

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Monitoring the Natural Attenuation of Petroleum in Ground Water at the Former Naval Complex, Operable Unit A, Adak Island, Alaska, May and June 2003

By R.S. Dinicola, F.W. Simonds, and Rose Defawe

Executive Summary

During May and June 2003, the U.S. Geological Survey (USGS) installed monitoring wells and collected data to characterize the effectiveness of natural attenuation processes for remediating petroleum-contaminated ground water at Operable Unit A of the former Naval complex on Adak Island, Alaska. Evidence for petroleum biodegradation in ground water was evaluated at 10 sites, plans for future natural attenuation monitoring were suggested for those sites, and the natural attenuation monitoring strategy for all petroleum sites in the Downtown area of Adak Island was reviewed and refinements were suggested.

USGS personnel measured water levels and collected ground-water samples from about 100 temporary boreholes and 50 monitoring wells. Most samples were analyzed on-site for concentrations of selected petroleum compounds and natural attenuation parameters (NAPs) such as dissolved oxygen, ferrous iron, and carbon dioxide. The USGS evaluated the data onsite, selected new monitoring well locations, and installed, developed, and sampled 10 monitoring wells. This data collection approach facilitated accurate and rapid delineation of the downgradient margin of contaminant plumes, and the new wells generally were installed at downgradient locations where petroleum compounds were detected at concentrations less than the specified cleanup standards.

The review and suggestions for the natural attenuation monitoring strategy focused on how to better achieve monitoring objectives specified in the Record of Decision (ROD) for Adak Island petroleum sites. Specific refinements in the monitoring strategy were proposed with regard to the newly available sampling locations and the additional data collected during this investigation.

To achieve the monitoring objective of verifying that natural attenuation is occurring, monitoring plans for each monitored natural attenuation (MNA) site need to include sampling at least one strategically placed well at the downgradient margin of the contaminant plume, preferably where contaminant concentrations are detectable but less than the cleanup level. Wells installed during this investigation can be used for additional sampling at the 10 investigated sites. An ancillary benefit of sampling properly placed downgradient wells is that the new downgradient wells also can be used as sentinel monitoring wells for the MNA sites. Collection of NAP data and sampling background wells is no longer needed to achieve the monitoring objective of demonstrating the occurrence of natural attenuation. Collecting and analyzing contaminant concentration data from downgradient monitoring wells better demonstrates the overall effectiveness of MNA. In addition, the NAP data collected to date are adequate to demonstrate that biodegradation plays a significant role in natural attenuation. A preponderance of existing data demonstrates on-going petroleum biodegradation in the Downtown area of Adak Island, and a sound scientific basis exists for when to expect (and not expect) biodegradation to occur.

To achieve the objective of monitoring areas where chemical concentrations exceed specified cleanup levels, at least one natural attenuation well within or immediately downgradient from the contaminant source area at each site should be monitored. Most existing natural attenuation wells are in appropriate locations. Contaminant concentration data from those near source area wells are useful to clearly demonstrate natural attenuation (or in a few cases, the lack of natural attenuation) over distance, which is more important than demonstrating natural attenuation over time at a single well when protection of downgradient receptors is a primary remediation goal. Data from upgradient and downgradient wells also would be beneficial for any fate and transport modeling at MNA sites.

Achieving the ROD specified final monitoring objective of estimating the rate of natural attenuation to demonstrate achievement of cleanup levels within 75 years will be problematic. Demonstrating (predicting) achievement of cleanup levels within any timeframe in a technically defensible manner will be difficult to achieve using any type of short-term monitoring and evaluation, and will be particularly difficult to achieve through monitoring and evaluation of dissolved-phase petroleum only. The primary reason is the likelihood that the continuing source of dissolved-phase petroleum in ground water is residual non-aqueous phase liquid (NAPL) petroleum being held by capillary forces in the unsaturated zone and near the top of the saturated zone, and that the volumes of residual NAPL at the Adak Island petroleum sites are poorly known. A model that rigorously simulates NAPL dissolution could be developed to derive somewhat more precise estimates of time-to-cleanup. However, NAPL dissolution is a complex process, particularly in heterogeneous environments with fluctuating water tables. NAPL simulation models have extensive data requirements and the accuracy of their results often is uncertain.

Despite the difficulties in demonstrating (predicting) achievement of cleanup levels within any timeframe in a technically defensible manner, natural attenuation processes appear to have greatly limited the extent of ground-water contamination at most sites investigated and have limited the risk that petroleum contaminants pose to downgradient receptors. Clarification or refinement of the monitoring objective to demonstrate cleanup within 75 years would be a reasonable prelude to developing a monitoring and data evaluation strategy to meet the objective.

Abstract

During May and June 2003, the U.S. Geological Survey installed monitoring wells and collected data to characterize the effectiveness of natural attenuation processes for remediating petroleum-contaminated ground water at Operable Unit A of the former Naval complex on Adak Island, Alaska. In addition, the evidence for petroleum biodegradation in ground water was evaluated at selected petroleum sites, plans for future natural attenuation monitoring were suggested for the selected petroleum sites, and the natural attenuation monitoring strategy for the Downtown area of Adak Island was reviewed and refinements were suggested.

U.S. Geological Survey personnel measured water levels and collected ground-water samples from about 100 temporary boreholes and 50 monitoring wells. Most samples were analyzed on-site for concentrations of selected petroleum compounds and natural attenuation parameters such as dissolved oxygen, ferrous iron, and carbon dioxide. The U.S. Geological Survey evaluated the data on-site, selected new monitoring well locations, and installed, developed, and sampled 10 monitoring wells.

The review and suggestions for the natural attenuation monitoring strategy focused on how to better achieve monitoring objectives specified in the Record of Decision for Adak Island petroleum sites. To achieve the monitoring objective of verifying that natural attenuation is occurring, the monitoring plans for each monitored natural attenuation site need to include sampling of at least one strategically placed well at the downgradient margin of the contaminant plume margin, preferably where contaminant concentrations are detectable but less than the cleanup level. Collection of natural attenuation parameter data and sampling background wells is no longer needed to achieve the monitoring objective of demonstrating the occurrence of natural attenuation. To achieve the objective of monitoring locations where chemical concentrations exceed specified cleanup levels, at least one natural attenuation well within or immediately downgradient from the contaminant source area at each site needs to be monitored.

Achieving the Record of Decision-specified final monitoring objective of estimating the rate of natural attenuation to demonstrate achievement of cleanup levels within 75 years will be problematic. Demonstrating (predicting) achievement of cleanup levels within any timeframe in a technically defensible manner will be difficult to achieve using any type of short-term monitoring and evaluation, and will be particularly difficult to achieve through monitoring and evaluation of dissolved-phase petroleum only.

Overall, natural attenuation processes appear to have greatly limited the extent of ground-water contamination at most sites investigated and have limited the risk that petroleum contaminants pose to downgradient receptors. Clarification or refinement of the monitoring objective to demonstrate cleanup within 75 years would be a reasonable prelude to developing a monitoring and data evaluation strategy to meet the objective.

Introduction

The U.S. Navy is responsible for long-term monitoring of natural attenuation in ground water at petroleum-contaminated sites within the former Naval complex, Operable Unit A (OU A) at Adak Island, Alaska (fig. 1). The 1999 Record of Decision (ROD) (U.S. Navy and others, 2000) for Adak Island petroleum sites specified three objectives that ground-water monitoring in affected areas must satisfy:

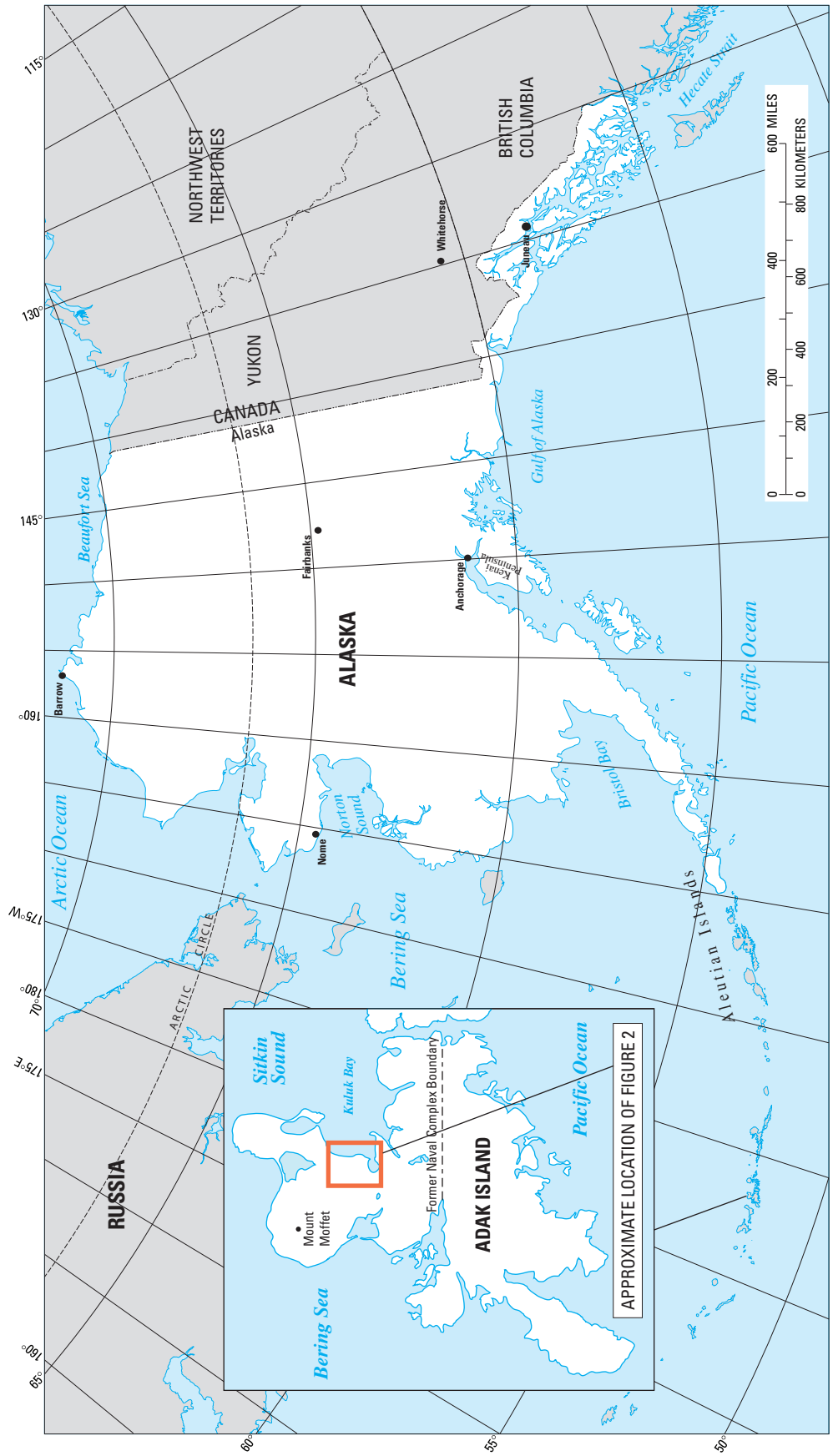
- To verify whether natural attenuation is occurring.
- To monitor locations where chemical concentrations exceed specified cleanup levels.
- To estimate the rate of natural attenuation to demonstrate achievement of cleanup levels within 75 years.

The U.S. Geological Survey (USGS) evaluated the Navy's monitoring program in 2002 to determine how well the program was meeting the objectives specified in the ROD. The Navy then asked the USGS to install new monitoring wells and collect data to better monitor the effectiveness of natural attenuation processes at the site.

Purpose and Scope

This report describes the implementation of suggestions made by the USGS in 2002 for refining the ground-water monitoring program at OU A, and proposes refinements to the natural attenuation monitoring strategy for the Downtown area of Adak Island. Specifically, this report describes:

- Installation of new monitoring wells positioned to better monitor the effectiveness of natural attenuation.
- Collection of new petroleum and natural attenuation parameter (NAP) data.
- Evaluation of the evidence for petroleum biodegradation.
- Evaluation of the natural attenuation monitoring strategy for the Downtown area.
- Suggestions for future natural attenuation monitoring.



Base map modified from U.S. Geological Survey Digital Line Graphs published at 1:2,000,000.
Canadian Land Inventory Level I Digital Data published at 1:2,000,000. Publication projection is Albers Equal Area.
Standard Parallels are 55° and 65°, central meridian -154° west, latitude of projection origin 50°.
Eastern Russian coastline from U.S. Geological Survey, Geologic Investigations Series I-2679, published at 1:7,500,000.
Projection is Albers Equal Area. Standard Parallels are 55° and 65°, central meridian 160° west.
Koryak Highlands coastline, 160°-175° modified from U.S. Geological Survey Open-File Report 96-727, published at 1:1,000,000.
Projection is Lambert Azimuthal Equal Area, central meridian 165° west.

Figure 1. Location of Adak Island in the Andreanof Group of the Aleutian Island chain, Alaska.

Site History

The former Naval complex (referred to as the former base) is in the Andreanof Group of the Aleutian Island chain of Alaska, about 1,300 mi west-southwest of Anchorage (fig. 1). The former base was an important military facility from 1942 to 1997 (U.S. Navy and others, 2000). Constructed as a defensive outpost in World War II, the former base supported as many as 100,000 troops and 100 ships. The airstrip was critical for the U.S. Air Force, which maintained control of the island until 1950 when the Navy took control of all facilities. By 1953, the island's population decreased to 176 military personnel, but increased steadily to about 5,600 military and civilian personnel by 1990. In 1995, the base was selected for closure by the Defense Base Closure and Realignment Commission (BRAC). The Navy has been involved in environmental restoration, cleanup, and closure activities since the military mission ended in March 1997, to allow for eventual lease and transfer of land and facilities to non-Federal organizations. Land transfer agreements and associated documentation are being negotiated under BRAC among the Navy, the U.S. Fish and Wildlife Service (USFWS), and the Aleut Corporation. Aleut Corporation currently operates most of the infrastructure on the northern half of the island, and the USFWS currently manages the southern part of the island as part of the Alaska Maritime National Wildlife Refuge system.

Environmental Restoration

Environmental restoration and cleanup activities related to petroleum contamination have focused on the developed portion of the island referred to as the "Downtown" area, which includes the air field, port facilities, and light industrial, administrative, commercial, and residential areas (fig. 2). The Downtown area comprises most of OU A, which is a non-contiguous area that includes all identified petroleum sites on Adak Island. Various petroleum products, primarily jet fuel (JP-5) and aviation gasoline (avgas) have leaked from former storage tanks and pipelines and have migrated to the shallow ground water. All known leaking tanks and pipelines have been removed or otherwise remediated, but both dissolved and undissolved (referred to as free product) petroleum compounds remain under the ground.

The State-Adak Environmental Restoration Agreement (SAERA) included 128 defined "petroleum sites" on the island. Monitored natural attenuation (MNA) was the selected remedy in the ROD (U.S. Navy and others, 2000) for 11 of the petroleum-contaminated sites at OU A (referred to as MNA sites). MNA also is a potential remedy for dissolved-phase ground-water contamination at 14 additional sites where recovery of free product was the original implemented remedy (referred to as free-product recovery sites). Selected remedies for other OU A petroleum sites were limited soil removal, limited ground-water monitoring, or no further action.

Previous USGS Evaluation of Monitored Natural Attenuation at Petroleum Sites

During 2002, the USGS evaluated the Navy's natural attenuation monitoring program to determine how well the program was meeting the objectives specified in the 1999 ROD (U.S. Navy and others, 2000), and made suggestions for refining the program. The USGS determined that existing data showed little direct evidence that natural attenuation was effective at most sites where MNA was the selected remedy. The downgradient extent of dissolved-phase contamination and the stability of contaminant plumes could not be determined using the small number of monitoring locations and because of recent increases in contaminant concentrations at the few locations that were monitored. Additional downgradient monitoring locations were proposed for at least eight of the petroleum sites evaluated. The USGS determined that existing data provided a reasonable amount of geochemical evidence to demonstrate that petroleum biodegradation was occurring at most MNA sites. It was suggested that the Navy may be able to reduce the frequency of sampling for NAPs such as nitrate, ferrous iron, and methane because the available data show reasonable evidence of on-going biodegradation, and because ample literature supports the ubiquitous occurrence of petroleum biodegradation.

The USGS determined that it would be difficult to achieve the monitoring objective of demonstrating achievement of cleanup levels within 75 years in a technically defensible manner using the current sampling and data analysis strategies. Current trend-analysis strategy relies on two unlikely assumptions:

1. That the change in dissolved-phase concentrations at a single monitoring well over time is directly proportional to the non-aqueous phase liquid (NAPL) dissolution rate, and

2. That a single monitoring well is near enough to the NAPL source so the measured dissolved-phase concentration is the maximum for a site.

No simple method was identified to predict achievement of cleanup levels throughout an entire MNA site. The USGS proposed that NAPs should be analyzed at existing "sentinel" wells (wells intended to detect on-going contaminant migration) and at proposed new wells installed at the downgradient margin of a plume to determine if the wells actually are on the same ground-water-flow path as the dissolved-petroleum plumes. Existing data indicated that it is appropriate to characterize background ground-water chemistry for much, but not all, of OU A as a similar water type. Additional data from uncontaminated background sites, and the collection and analysis of higher quality field data would greatly reduce the uncertainty in characterization of background geochemistry.

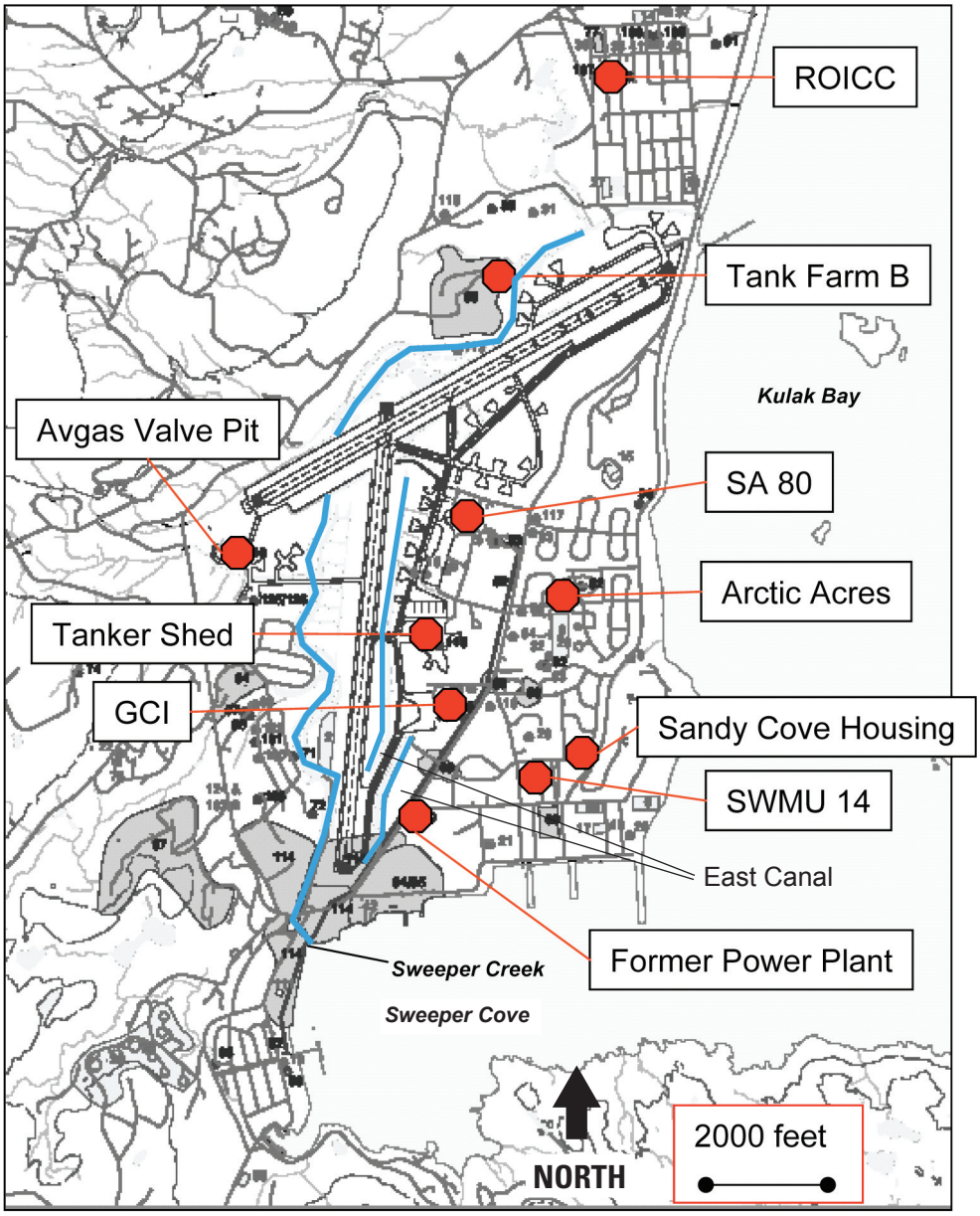


Figure 2. Petroleum sites investigated by the U.S. Geological Survey at the former Naval complex, Operable Unit A, Adak Island, Alaska, May and June 2003.

In addition to the evaluation of monitoring needs at specific petroleum sites, the Navy was interested in a review of their comprehensive strategy for monitoring natural attenuation throughout the Downtown area (fig. 2). The comprehensive strategy for the Downtown area, which includes most of the sites in the non-contiguous administrative unit OU A, was of particular interest. The Downtown area is the most developed part of the island and where the resident population is concentrated. It also has an accordingly high concentration of petroleum related infrastructure, and is nearly surrounded by potential surface-water receptors. One of the primary goals of remediating dissolved-phase petroleum contamination on Adak Island is the protection of lowland and marine surface water. Remediation for the protection of drinking water is a lesser concern because of an established (and currently greatly under-utilized) upland surface-water collection, treatment, and delivery system on the island. Ground water is not now and probably will never be used as a drinking-water source.

Acknowledgments

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Study Methods

This investigation focused on 10 specific petroleum sites in OU A (table 1 and fig. 2). During May and June 2003, USGS personnel measured water levels and collected ground-water samples from about 100 temporary boreholes and 50 existing monitoring wells. Most samples were analyzed using field test kits to determine NAP concentrations and an on-site gas chromatograph (GC) for concentrations of selected petroleum compounds. The USGS then evaluated the data on-site, selected new monitoring well locations, and installed, developed, and sampled 10 new monitoring wells. Data collection focused on delineating the downgradient margin of the contaminant plumes. New wells generally were installed downgradient from where petroleum compounds were positively detected at concentrations less than the specified cleanup standards.

Sampling and Analysis Strategy

Expense and logistics for transporting equipment and people to Adak Island are formidable due to its remoteness, so completion of the well installation and data collection in a single field mobilization was considered essential. An expedited site-assessment strategy was used to quickly characterize the sites of interest, and to install the needed monitoring wells at optimal locations during a single mobilization to the island. Prior to the field work, up-to-date conceptual models for each site were developed, data needs were defined, and data quality objectives were developed (R.S. Dinicola, U.S. Geological Survey, written commun., December 23, 2002). A detailed work plan was developed, which included the decision criteria for collecting additional samples and installing new wells (R.S. Dinicola, U.S. Geological Survey, written commun., May 2003). Direct-push equipment was used in the field to allow rapid ground-water sampling from multiple temporary boreholes. Real-time analysis of ground-water samples using field test kits and an on-site gas chromatograph (GC) facilitated interpretation and decision making regarding the installation of new monitoring wells using the same direct-push equipment.

Direct-push sampling equipment was well suited to the Downtown area of Adak Island because of the relatively shallow depth to the water table and the unconsolidated subsurface sediments. The sampling strategy allowed rapid and accurate quantification of petroleum and most NAP concentrations.

The primary focus of the characterization work at individual petroleum sites was the downgradient margin of the petroleum plumes, with the goal of installing new wells, which would allow long-term monitoring of the distal parts of the plumes. A specific sequence of field activities was used to characterize the downgradient margin of the petroleum plumes at each of the 10 petroleum sites:

1. Borehole and well sites were estimated where petroleum concentrations of concern were equal to compound-specific cleanup levels based on historical contaminant concentrations, NAP concentrations, and ground-water levels.

2. Direct-push equipment (Geoprobe® Model 6610DT, fig. 3) or a manual hammer was used to drive the screened portion of a ground-water sampling device below the water table. A Geoprobe® Screen Point 15 hidden-screen type with a 1-in. outside diameter and a 41-in. long wire-wound stainless steel screen was used for direct-push sampling. A 0.75-in. diameter steel pipe with a disposable drive point was used for manual sampling. Initially each device was driven to a depth where the top of the sampling interval was about 1 to 2 ft below the water table where the highest concentrations of petroleum compounds historically have been detected, with a sampling interval about 1 to 2 ft below the water table.

3. Water level in the sampling device was measured and converted to an altitude using a level referenced to a nearby existing well measuring-point altitude. The location (northing and easting) of the borehole was estimated by distance measurements from existing wells.

4. A ground-water sample was collected from the sampling device using a peristaltic pump. When feasible, the sample was analyzed immediately using various field kits and calibrated meters and sensors to determine field NAP parameters (dissolved oxygen, nitrate, sulfide, ferrous iron, carbon dioxide, pH, and specific conductance) (table 2, described in detail later in this section of the report). Petroleum concentration samples also were collected for analyses using a gas chromatograph at the nearby field laboratory. Samples with a geochemical signature indicative of petroleum contamination (elevated specific conductance, low dissolved-oxygen concentration, and elevated concentrations of ferrous iron and carbon dioxide relative to nearby uncontaminated wells) were analyzed for petroleum compounds.

5. An additional sampling device was installed nearby, about 5 ft deeper than the initial device, to determine if samples were from an appropriate depth. A new sample was then collected and analyzed for field parameters (and occasionally petroleum concentrations). If the field parameters and (or) petroleum concentrations indicated that petroleum probably was increasing with depth, additional sampling devices were driven to greater depths at 5-ft increments (if time allowed) until the interval of maximum petroleum concentrations was determined. Once the optimal sampling depth was determined for a site, sampling within a local area was confined to that optimal depth for all remaining boreholes.

Steps 2 through 5 were repeated at additional locations using an iterative procedure guided by real-time mapping and interpretation of the water level, petroleum, and NAP data. Additional boreholes were driven until the distribution of petroleum and NAP concentrations indicated that the downgradient "footprints" of the contaminant plume and the NAPs were known. Sampling devices were left in place overnight at a few locations to ensure that measured water levels were equilibrated with aquifer conditions. Once all desired data were obtained from a temporary borehole, the sampling device was removed, the hole was filled with grout, and the land surface was returned to its natural condition.

Best professional judgment of the field crew and the senior hydrogeologist was used to determine when the downgradient footprint of the plume was adequately characterized. In addition to detectable petroleum concentrations, the crew identified areas with dissolved-oxygen concentrations less than 1 mg/L, sulfide greater than 0.01 mg/L, nitrate less than 0.5 mg/L, ferrous iron greater than 0.5 mg/L, and relatively elevated carbon dioxide concentrations. Because the NAP footprints (such as ferrous iron) often extended beyond the plume of detectable petroleum concentrations, they added confidence that the ground-water-flow path of interest had been characterized.

Table 1. Petroleum sites investigated by the U.S. Geological Survey at the former Naval complex, Operable Unit A, Adak Island, Alaska, May and June 2003.

[Location of petroleum sites are shown in figure 2. **Acronyms:** GCI, General Communications, Inc.; ROICC, resident officer in charge of construction; SWMU, surface-water management area. **Primary contaminants of concern:** DRO, diesel range organics; GRO, gasoline range organics.]

Petroleum site name	Abbreviated petroleum site name	Primary contaminants of concern	Record of decision specified remedy
Former Power Plant Building T-1451	Former Power Plant	DRO	Monitored natural attenuation.
GCI Compound	GCI	GRO, benzene	Free product recovery.
Housing Area (Arctic Acres)	Arctic Acres	DRO	Monitored natural attenuation.
ROICC Contractor's Area (UST ROICC-7)	ROICC	Benzene	Limited ground-water monitoring.
Runway 5-23 Avgas Valve Pit	Avgas Valve Pit	GRO, benzene	Monitored natural attenuation.
SA 80, Steam Plant No. 4	SA 80	DRO	Free product recovery.
SWMU 14, Old Pesticide Storage and Disposal Area	SWMU 14	GRO, DRO	Monitored natural attenuation.
SWMU 61, Tank Farm B	Tank Farm B	GRO, benzene	Monitored natural attenuation.
SWMU 62, New Housing Fuel Leak (Sandy Cove Housing)	Sandy Cove Housing	DRO	Free product recovery.
Tanker Shed	Tanker Shed	DRO	Free product recovery.

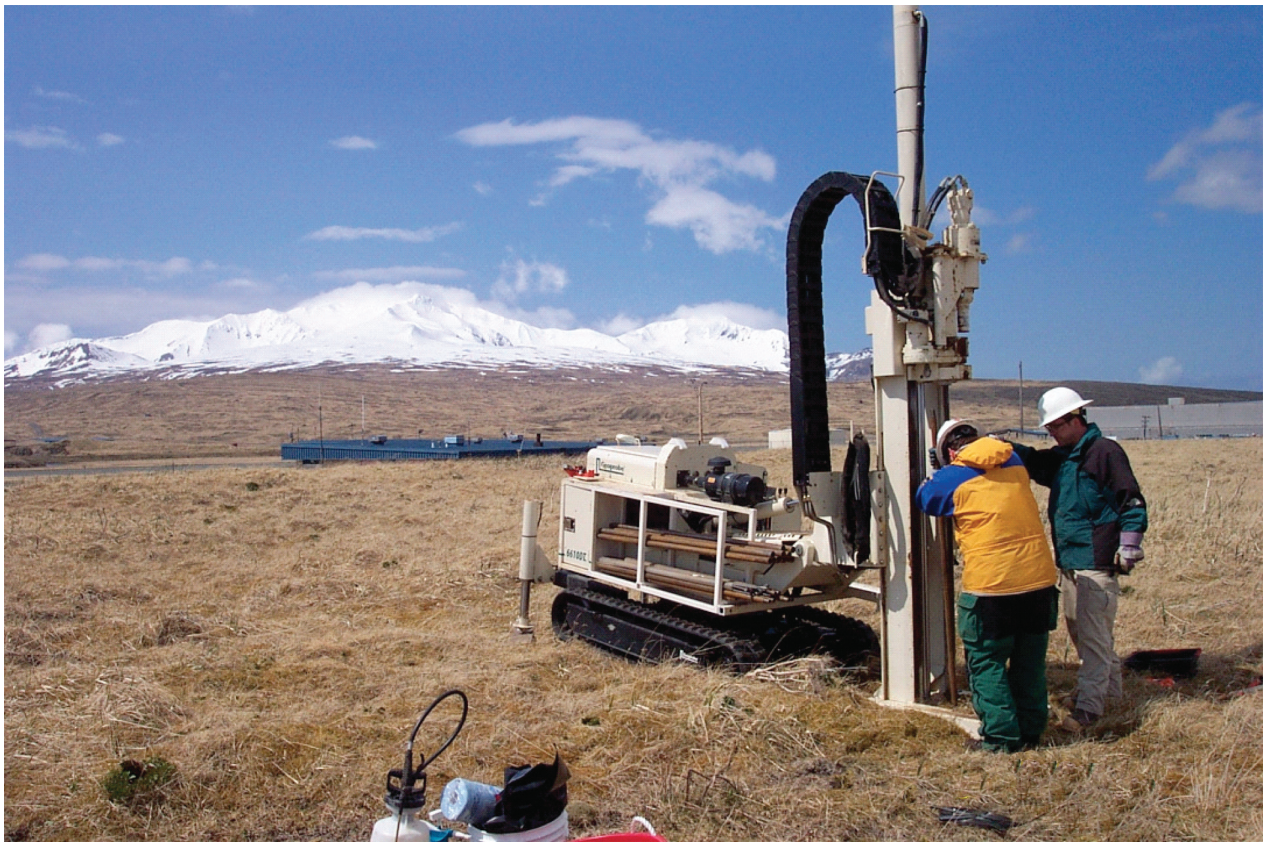

Figure 3. Geoprobe® Model 6610DT pushing a temporary borehole for sampling at the General Communications, Inc. (GCI) compound site, Operable Unit A, Adak Island, Alaska. (Photograph taken by R.S. Dinicola, U.S. Geological Survey, Tacoma, Washington, 2003.)

Monitoring Well Construction, Development, and Surveys

Permanent monitoring wells were installed where long-term data were needed to meet monitoring objectives. Monitoring wells were installed with direct-push equipment and were constructed of PVC with a 1½-in. inside diameter (fig. 4). Monitoring wells are 2.5- to 10-ft deep with 0.10 in. slotted PVC screens, the tops of which were from 0 to 3 ft above the current water table. New wells were screened at depths consistent with other monitoring wells in the vicinity. A filter pack composed of 20/40 mesh silica sand was installed to extend 0.5 to 2 ft above the top of the screen and 0.5 to 1 ft below the bottom of the screen. Each well had an end plug at the bottom. The annular space around each well above the sandpack was sealed with bentonite slurry. Well casings extended 2.5 to 3 ft above the land surface. Above-ground casings were protected with 6 in. steel riser pipe surrounded by a concrete surface-seal and set about 2 ft below land surface. The riser pipe was set directly in a bentonite plug at land surface when the water table was less than 5 ft below land surface. Riser pipes typically extended about 6 in. above the top of the well casing. The top of the casing and the top of the protective riser pipe were equipped with caps. The above-ground space between the well casing and the riser pipe was filled with coarse sand to within 6 in. of the top of the casing.

New monitoring wells were developed using a dual-head peristaltic pump. Well development did not begin until at least 24 hours after installation; development continued until the well water was visibly free of sediment. The new monitoring well at the Tank Farm B site was not completely developed and sampled before demobilizing from the island because the grout and concrete seal had not yet set in the saturated ground.

Altitudes, northings, and eastings of measuring points (the highest points of the PVC well casing) for the new monitoring wells were determined by completing a traverse survey from at least two existing monitoring wells using a level with a horizontal circle. Stadia or steel tapes were used to measure distances during the survey. The vertical datum for the new wells was NAVD88 and the horizontal datum was NAD27. Northings and eastings were for the Alaska State Plane, Zone 5 coordinate system.

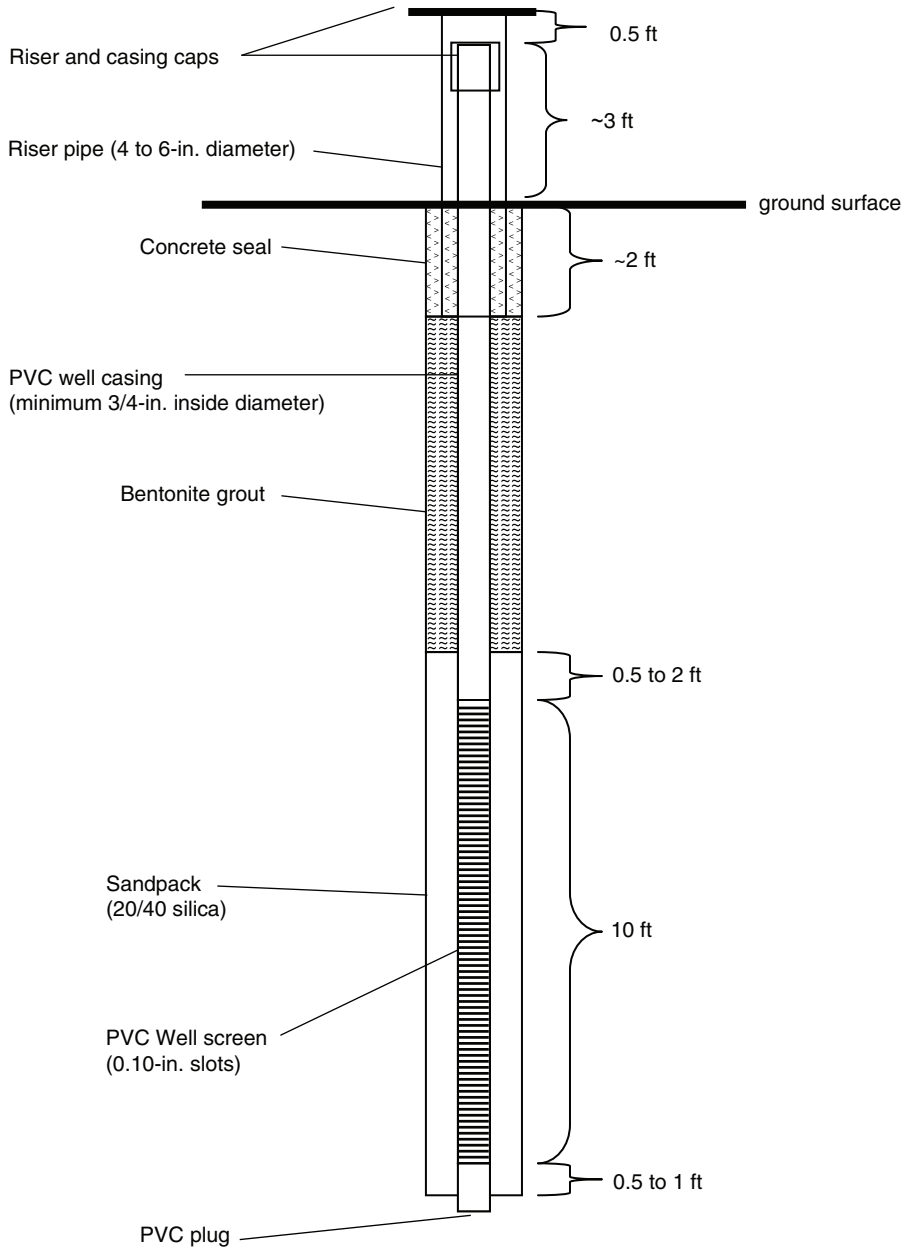

Figure 4. Typical monitoring well construction.

Ground-Water Level Measurements

Ground-water levels (and free product thickness when encountered) were measured in existing monitoring wells prior to sampling using an electronic oil/water interface probe. Water levels were measured in temporary boreholes prior to sampling using a graduated steel tape because the electronic device did not work properly in the small-diameter steel drill casing. A few subsequent water levels were measured at selected boreholes over a 24-hour period to confirm that the water levels were at equilibrium. All water levels checked had equilibrated within the first hour.

Ground-Water Sampling and Analyses

Ground-water samples from the temporary boreholes and existing monitoring wells were collected with a peristaltic pump equipped with single-use polyurethane tubing. Existing

monitoring wells were sampled at the mid-point between the current water level and the bottom of the screen. Each well was purged at low-flow rates (less than 500 mL/min) until stabilization criteria measured in a flow-through cell were met (±0.3 mg/L for dissolved oxygen, ±0.1 unit for pH, and ±3 percent for specific conductance). Samples for petroleum analyses were collected in 40-mL glass vials with septa lids and immediately transported for analysis to the field GC at the temporary field laboratory. Standard procedures for the collection and recording of purge-related water-quality data were followed as described in the USGS Techniques of Water-Resources Investigations (U.S. Geological Survey, variously dated).

Temporary boreholes were sampled at mid-screen depth after only a few minutes of purging. Complete purging was unnecessary in the new boreholes because there was no stagnant well-water to evacuate. Woven stainless steel screens with 0.145-mL pores were fitted over the end of the sampling tube to minimize turbidity in the sample.

Unfiltered samples were analyzed at the wellhead for selected NAP analytes. A summary of field measurement methods, ranges, detection limits, and accuracies is shown in table 2. Sulfide measurements from borehole samples were severely affected by the visibly high turbidity of the samples that interfered with the colorimetric tests, so sulfide data are not tabulated in this report; selected sulfide concentrations for samples that were not visibly turbid are discussed in the text. Sulfate was not included because no simple and reliable field test is available for that compound. Nitrite was not included because it historically has been undetectable or detected at very low concentrations throughout the Downtown area. Methane was not included because it would have required an excessive length of time to switch the column of the field GC for methane analyses from the column needed for petroleum analyses. Used field kit materials were collected in sealed polyethylene bottles and shipped off Adak Island for proper disposal.

Field Analyses of Petroleum Compounds

A temporary GC laboratory was set up to rapidly measure concentrations of the petroleum compounds of concern (diesel-range organics (DRO), gasoline-range organics (GRO), and benzene). A Shimadzu brand GC (model 17A) (fig. 5) was operated in a rented house where 110-volt AC power and heated space was available. The GC was equipped with a flame ionization detector and an Equity-1 capillary column (Supelco brand 28046-U), which was 30-m long, with a 0.25 mm inside diameter, and was coated with 0.25 µm of polydimethylsiloxane. Helium was the carrier gas at a flow rate of 1.2 mL/min. The GC injection port temperature was 250 ºC and the detector temperature was 325 ºC. For DRO analyses only, the oven temperature program was isothermal at 40 ºC. Benzene and GRO concentrations were calculated from the same chromatograms, and DRO concentrations were calculated from chromatograms created using separate samples.

Table 2. Summary of field measurement methods, ranges, detection limits, and accuracies used at the former Naval complex, Operable Unit A, Adak Island, Alaska, May and June 2003.

[**Measurement method:** GC-FID, gas chromatography with flame-ionization detector. **Abbreviations:** mg/L, milligram per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; %, percent; µg/L, microgram per liter. **Symbols:** ±, plus or minus; ~, approximately]

Field measurement	Measurement method	Range	Method detection limit or accuracy
Dissolved oxygen (High) (mg/L)	CHEMetrics K-7512	1 to 12	1
(Low)	K-7501	0 to 1	.025
Nitrate (mg/L)	K-6902	0.1 to 5	.1
Sulfide (mg/L)	K-9510	0.05 to 10	.05
Ferrous iron (mg/L)	K-6210	0.05 to 1	.05
Carbon dioxide (Low) (mg/L)	K-1910	10 to 100	10
(High) (mg/L)	K-1920	100 to 1,000	100
pH (units)	YSI 600XL	0 to 14	± .2
Specific conductance (µS/cm)	YSI 600XL	0 to 100	± .5 %
Dissolved oxygen (mg/L)	YSI 600XL	0 to 50	± .2
Benzene (µg/L)	GC-FID	unlimited	~ 2
Diesel-range organics (DRO) (mg/L)	GC-FID	unlimited	~ .1
Gasoline-range organics (GRO) (mg/L)	GC-FID	unlimited	~ .1

Figure 5. Portable gas-chromatograph (GC) in the temporary laboratory at Adak Island, Alaska. (Photograph taken by R.S. Dinicola, U.S. Geological Survey, Tacoma, Washington, 2003.)

Field GC methods for DRO, GRO, and benzene analyses approximated, but were not identical to, the established State of Alaska methods AK102 and AK101, and EPA method 8021B, respectively (Alaska Department of Environmental Conservation, 2002; U.S. Environmental Protection Agency, 2003). Solid phase microextraction (SPME) methods (Sigma-Aldrich Co., 1998) were used at the field site. These methods are different from the traditional liquid solvent extraction methods used in laboratory analyses, but they were selected for use in this study because they are easier and safer to use in a field laboratory. Subsequent identification and quantification of various compounds in the sample were essentially the same as that done in traditional laboratories.

Diesel Range Organics, Gasoline Range Organics, and Benzene Analyses

Samples analyzed for petroleum compounds were collected in amber glass 40-mL volatile organic compound (VOC) vials in the field, and a 1-cm long Teflon®-coated magnetic stir bar was added before the cap was replaced. All samples were temporarily stored at about 4 °C in a sample-dedicated refrigerator before they were analyzed. GRO and Benzene samples were analyzed within 24 hours of collection. Most DRO samples were analyzed within 7 days of collection, although 11 samples were analyzed within 16 days due to equipment problems, which created a temporary backlog.

For all analysis, the sample was brought to room temperature, and 2 mL of sample was removed from the vial. For GRO and benzene analysis only, 9 g of sodium chloride (NaCl) was added to the vial prior to removing the 2 mL of sample. All vials were shaken by hand for 10 seconds and placed on a magnetic stirrer. The septum of all vials was immediately pierced with the SPME needle and the sample water was exposed to a SPME fiber that can adsorb specific compounds based on the molecular weight of the analytes of interest to be extracted from the water sample (the 30-µm diameter polydimethylsiloxane (PDS) SPME fiber (Supelco, 57308-U) was selected for the analyses). The fiber was left immersed in the stirring water sample for 15 min ±30 sec. The fiber was retracted from the water sample and immediately inserted into the injection port of the GC. The extremely high temperature of the inlet port caused the compounds to desorb and flow with the carrier gas through the GC column. Specific petroleum compounds eluted from the column at known retention times, and the resulting concentration was calculated using calibration curves developed from the results of known calibration standards of DRO, GRO, and benzene. Chemicals used to make the calibration standards (BTEX standard, Product No. 31193; UST method Gasoline Range Organics standard, Product No. 30065-520; and UST method Diesel Fuel #2 composite, Product No. 30051-520) were obtained from Restek Corporation, Philadelphia, Pennsylvania. Analytical method detection limits for petroleum analyses are shown in table 2.

Quality Assurance and Quality Control of Petroleum Concentration Data

Quality assurance procedures for this investigation are described in a detailed work plan (R.S. Dinicola, U.S. Geological Survey, written commun., May 2003). The work plan describes procedures used for ground-water level measurements, ground-water sampling and analyses, field analyses of petroleum compounds, laboratory analytical procedures, and monitoring well construction, development, and surveying.

Field Blank

A single field blank was analyzed for GRO and benzene to determine if there was any contamination from the sampling equipment (no field blanks were analyzed for DRO). To prepare the field blank, de-ionized water was pumped through polyethylene tubing and previously used Masterflex® tubing cleaned with Liquinox®. The field blank was transported and stored with the sample bottles until analysis. Analysis was identical to that of the environmental samples. The field blank did have a positive detection for GRO at an estimated concentration of 24 µg/L, which was substantially less than the approximate method detection limit of 100 µg/L. Benzene was not detected in the field blank at an approximate method detection limit of 2 µg/L. The slight apparent GRO contamination in the field blank probably was due to carry-over from reusing the Masterflex® tubing in the peristaltic pump. Approximately 20 different pieces of the tubing were used during the investigation, so the magnitude of possible carry-over was variable. Tubing used for collection of the field blank previously had been used for collection of samples from boreholes with low estimated concentrations (less than 94 µg/L) of GRO.

Method Blanks

Method blanks were used to determine if there was contamination from the analytical procedure. Nitrogen purged volatile grade water (EM Science, 7732-18-5) was used to prepare method blanks in amber glass 40-mL VOC vials at the field laboratory. A Teflon®-coated magnetic stir bar, 1 cm in length was added before the cap was replaced. Analysis was identical to that of the environmental samples. One method blank was analyzed each for DRO, GRO, and benzene. Concentrations in all method blanks were less than the method detection limits (table 2).

Instrument Blanks

Instrument blanks were used to determine if there was carry-over contamination from the GC or SPME after highly concentrated samples were analyzed. These blanks were essentially an indication of the elution efficiency of the SPME fibers. One instrument blank was used for DRO and six instrument blanks were used for each benzene and GRO. Instrument blanks were done using an SPME fiber that previously was used for analysis of a contaminated sample. Previously used SPME fiber was inserted into the injection port of the GC without immersing it into any environmental sample water, and the analysis was done using the same GC settings as those used for sample analysis. All instrument blanks were less than the method detection limits (table 2).

Field Duplicates

Field duplicates were collected and analyzed to determine the variation in collection of field samples and analysis of the samples. Field duplicates were analyzed for DRO in 6 samples, for GRO in 11 samples, and for benzene in 6 samples. Two vials were filled sequentially with sample water in the same manner as other samples; the first vial is referred to as the environmental sample and the second is referred to as the duplicate. Field duplicates were stored and processed identically to environmental samples.

Overall, the duplicate analyses were reasonably comparable for all compounds. Concentrations of benzene were <5 µg/L in the environmental and the duplicate samples for 4 of the 6 duplicate pairs. Interference from other compounds in the samples did not allow positive detection of benzene at the target detection level of 2 µg/L. DRO was detected at <100 µg/L in the environmental and the duplicate samples for 2 of the 6 duplicate pairs. The average difference in DRO concentrations between environmental and duplicate samples in the 4 pairs with DRO concentrations greater than the detection limit was 13 percent; the largest difference was 29 percent and the smallest difference was 4 percent. Concentrations of GRO were detected at <100 µg/L in the environmental and the duplicate samples for 5 of the 11 duplicate pairs. The average difference between environmental and duplicate sample GRO concentrations in the 5 pairs that had GRO concentrations greater than the detection limit was 37 percent; the largest difference was 67 percent and the smallest difference was 5 percent. GRO was detected at 110 and <100 µg/L in the other duplicate sample. Benzene was detected at 854 and 823 µg/L in one duplicate pair, and at <5 and 13 µg/L in the other duplicate pair.

Inter-Laboratory Replicate Samples

Replicate samples were collected and analyzed to determine the accuracy of analytical field concentrations compared to analytical laboratory concentrations analyzed by standard laboratory methods. Eight replicate pairs were analyzed for DRO and four replicate pairs were analyzed for benzene and GRO. At the field location, four vials were filled sequentially with the same water sample. One of the vials was transported to the field laboratory and analyzed, and the other three vials were sent in a cooler with ice to Analytica Environmental Laboratories, Anchorage, Alaska, for analysis. GRO and benzene samples were analyzed in the field between 7 and 11 days after collection and were analyzed in the laboratory within 14 days. DRO samples were analyzed in the field between 12 to 26 days after sample collection and were analyzed in the laboratory within 7 days. Analytica Environmental Laboratories used EPA Method 8021B - aqueous (U.S. Environmental Protection Agency, 2003) to determine benzene concentrations, method ADEC AK101 (Alaska Department of Environmental Conservation, 2000) to determine GRO concentrations, and method ADEC AK102 (Alaska Department of Environmental Conservation, 2000) to determine DRO concentrations.

Replicate sample concentrations showed that field and laboratory analytical results were reasonably comparable for GRO and benzene analyses. GRO was not detected in either the field or laboratory at concentrations of <100 µg/L in the field and <50 µg/L in the laboratory. GRO was detected at <100 µg/L (field) and 65 µg/L (laboratory) in one pair, and at 178 µg/L (field) and 310 µg/L (laboratory) in the other pair. In three of the four sample pairs, benzene was not detected in either the field or the lab at concentrations of <5 µg/L in the field and <2 µg/L in the laboratory. Benzene was detected at 13 µg/L (field) and 3.3 µg/L (laboratory) in the other pair. In two of the four sample pairs, GRO was not detected at concentrations <100 µg/L in the field and <50 µg/L in the laboratory. GRO was detected at <100 µg/L (field) and 65 µg/L (laboratory) in one pair, and at 178 µg/L (field) and 310 µg/L (laboratory) in the other pair.

Replicate sample concentrations were more variable for DRO analyses. In one of the eight sample pairs, DRO was not detected in either the field or laboratory at concentrations of <100 µg/L. In another pair, DRO was detected at 230 µg/L (field) and <100 µg/L (laboratory). The average difference between DRO concentrations in the remaining six sample pairs that had DRO concentrations greater than the reporting limits was 52 percent. Laboratory-determined concentrations were greater than the field-determined concentrations in five of those sample pairs, which suggests that the field analyses may be biased low. Laboratory-determined concentration was about twice the field-determined concentration in three of the pairs, and was about four times the field-determined concentrations in one of the pairs. The low result in the field-determined DRO concentrations is probably a result of difficulties encountered in getting repeatable calibration results when analyzing samples spiked with known concentrations of DRO. Although the magnitude of the differences between field and laboratory DRO analyses were greater than anticipated, the data met the data-quality objectives and were useful as a screening-level tool to identify optimal locations for new monitoring wells.

Petroleum Biodegradation Processes and Geochemical Indicators

A large body of scientific research exists on the microbial transformation (biodegradation) of petroleum compounds in ground water (National Research Council, 2000). Following is a brief summary of that research relating to the types of petroleum compounds and the specific geochemical indicators of biodegradation that were observed at Adak. Geochemical indicators were relied on extensively during the USGS field investigation to determine ground-water-flow paths from contaminant source areas, and to properly locate new monitoring wells.

Biodegradation of petroleum hydrocarbons varies depending on the type of hydrocarbon. Gasoline and jet fuel (JP-5) were the most extensively used hydrocarbons on Adak Island. Gasoline is primarily composed of relatively volatile hydrocarbons containing 4 to 12 carbon atoms, including the “BTEX” compounds benzene, toluene, ethylbenzene, and xylene. JP-5 jet fuel is a kerosene-based fuel primarily

composed of relatively low-volatility hydrocarbons containing 11 to 13 carbon atoms with relatively insignificant (less than 1 percent by weight mass fraction) BTEX content.

Biodegradation of BTEX compounds to form the final end-product carbon dioxide is through a process that generally is well understood. The efficiency of the biodegradation is primarily a function of the availability of the various electron-acceptors that may be used in the reactions as well as the presence of the appropriate microorganisms and enzymes. Oxygen is by far the most favorable electron-acceptor, and BTEX degradation is relatively fast and efficient in aerobic ground water. When dissolved oxygen is depleted within a contaminant plume, nitrate is the next most favorable electron acceptor, followed by manganese, ferric iron, sulfate, and carbon dioxide. All these anaerobic biodegradation processes are slower than aerobic processes, and benzene degradation is particularly slow when carbon dioxide is the only available electron acceptor. Manganese is not often considered an important electron acceptor because it generally is not abundant in aquifer sediments. Biodegradation of the various longer chained hydrocarbons that make up JP-5 is less understood, although aerobic degradation generally is more rapid than anaerobic degradation.

Evidence for hydrocarbon degradation in ground water is most often evaluated by comparing the concentrations of various electron acceptors and end products in "background" ground water (located upgradient or in nearby uncontaminated areas) to concentrations of the same compounds within and downgradient from a hydrocarbon plume. Ground-water geochemistry in the Downtown area of Adak Island has been previously characterized (ICRC, 2003), so "background" data for comparison to data from within contaminant plumes were available in advance of the field investigation. Background ground water in the Downtown area has been characterized as generally aerobic (dissolved-oxygen concentrations of around 6 mg/L), with relatively low specific conductance (generally less than 200 µS/cm), low nitrate concentrations (1 mg/L), essentially no ferrous-iron (< 0.01 mg/L), sulfide (< 0.01 mg/L) or methane (< 0.001 mg/L), relatively little sulfate (6 mg/L) and alkalinity (about 34 mg/L as $CaCO_3$).

A universal indicator of hydrocarbon biodegradation is an accumulation of the end product carbon dioxide, which is often measured indirectly with a strong acid titration to determine alkalinity, but was measured more directly for this investigation using a strong base titration to determine carbon dioxide acidity. An indication of aerobic hydrocarbon degradation is depletion of dissolved oxygen within a plume. An indication of hydrocarbon degradation linked to nitrate reduction is the depletion of nitrate (relative to upgradient concentrations) and a possible accumulation of nitrite, although nitrite generally is short-lived in shallow ground water and was not analyzed for in this study. An indication of hydrocarbon degradation linked to iron reduction is the accumulation of ferrous iron. Ferrous iron is the soluble byproduct from iron reduction, and the oxidized ferric iron that serves as electron acceptors is primarily in a non-soluble state associated with aquifer sediments. An indication of hydrocarbon degradation linked to sulfate reduction is the depletion of sulfate and a possible accumulation of sulfide compound, although sulfide is generally short-lived in shallow ground water. Lastly, an indication of hydrocarbon degradation linked to carbon dioxide reduction is the accumulation of methane. That process, referred to as methanogenesis, is relatively inefficient and generally does not result in an observable depletion of carbon dioxide because of the abundance of carbon dioxide produced by the more efficient degradation processes.

One confounding circumstance for evaluating the indicators of hydrocarbon degradation is that they also are indicative of microbial transformation of non-petroleum organic compounds that may be naturally abundant in certain settings. In a wetland area where the water table is at or near the land surface, for example, the microbial degradation of abundant naturally occurring organic matter in saturated surface soils results in a geochemical signature that may be indistinguishable from the signature resulting from petroleum-hydrocarbon degradation. The perimeter of the Downtown area includes such areas.

Another confounding circumstance for evaluating the above indicators of hydrocarbon degradation is that conventional 10-ft long (or even 5-ft long) monitoring well screens often will span a thickness of aquifer in which different biodegradation processes may be occurring in thin vertical sections. The result can be a mixture of geochemical indicators in a single sample (such as aerobic conditions with abundant ferrous iron), or widely varying indicator concentrations between sampling rounds (such as wells changing between aerobic and anaerobic conditions depending on the season, or annual rainfall, or sampling depth). Low-flow sampling procedures are designed to minimize this problem, but they do not eliminate it. If sampling protocols call for sampling at the same depth below land surface each time, samples may be from the top of the water table during a dry year and from deeper below the water table in a wet year. If sampling protocols call for sampling at the same depth below the water table each time, samples may be from different parts of the aquifer year to year. Sampling at the same depth below land surface is the preferred method, but some confounding results may still be observed.

During this investigation, the most consistent geochemical indicators for petroleum degradation observed were anaerobic conditions (dissolved-oxygen concentrations less than 1 mg/L), and increased ferrous iron and carbon dioxide concentrations compared to nearby uncontaminated ground water. Although nitrate concentrations were measured reliably in the field, the concentrations often were less than detection limits in uncontaminated locations. Relatively high measurements of specific conductance were used during this investigation to help identify contaminant plumes, but this is not a unique indicator of biodegradation.

Monitoring for Natural Attenuation at Specific Petroleum Sites

Results of the field characterization work at each of the 10 selected petroleum sites are presented with a focus on improved monitoring for natural attenuation at OU A. For each site, brief background information is presented, followed by the presentation of the data collected, a discussion of the rationale used to locate new wells, an evaluation of the available evidence for petroleum biodegradation and attenuation, and suggestions for future monitoring locations. For most sites, additional sampling over time is needed for a more robust evaluation of the overall effectiveness of natural attenuation.

Selected data for each petroleum site are presented with the discussion of the individual sites. For clarity, field-determined petroleum concentrations are referred to as "field DRO," while laboratory-determined petroleum concentrations are referred to as "lab DRO." At times there were substantial differences between field and laboratory analyses, particularly for DRO concentrations. Petroleum concentrations often were substantially different in a borehole sample and in a monitoring well sample from the same location. Those differences are a result of the different analytical methods used in the field and laboratory, the different screen lengths of the borehole sampler (3.5 ft) and the monitoring wells (generally 10 ft), and heterogeneity in the plumes. Selected historical data obtained from the Navy are included when appropriate. Each site map accompanying the discussion shows only the selected data that were most useful for identifying the site's contaminant plumes in the field. An explanation of symbols used in common on the site maps is shown in figure 6.

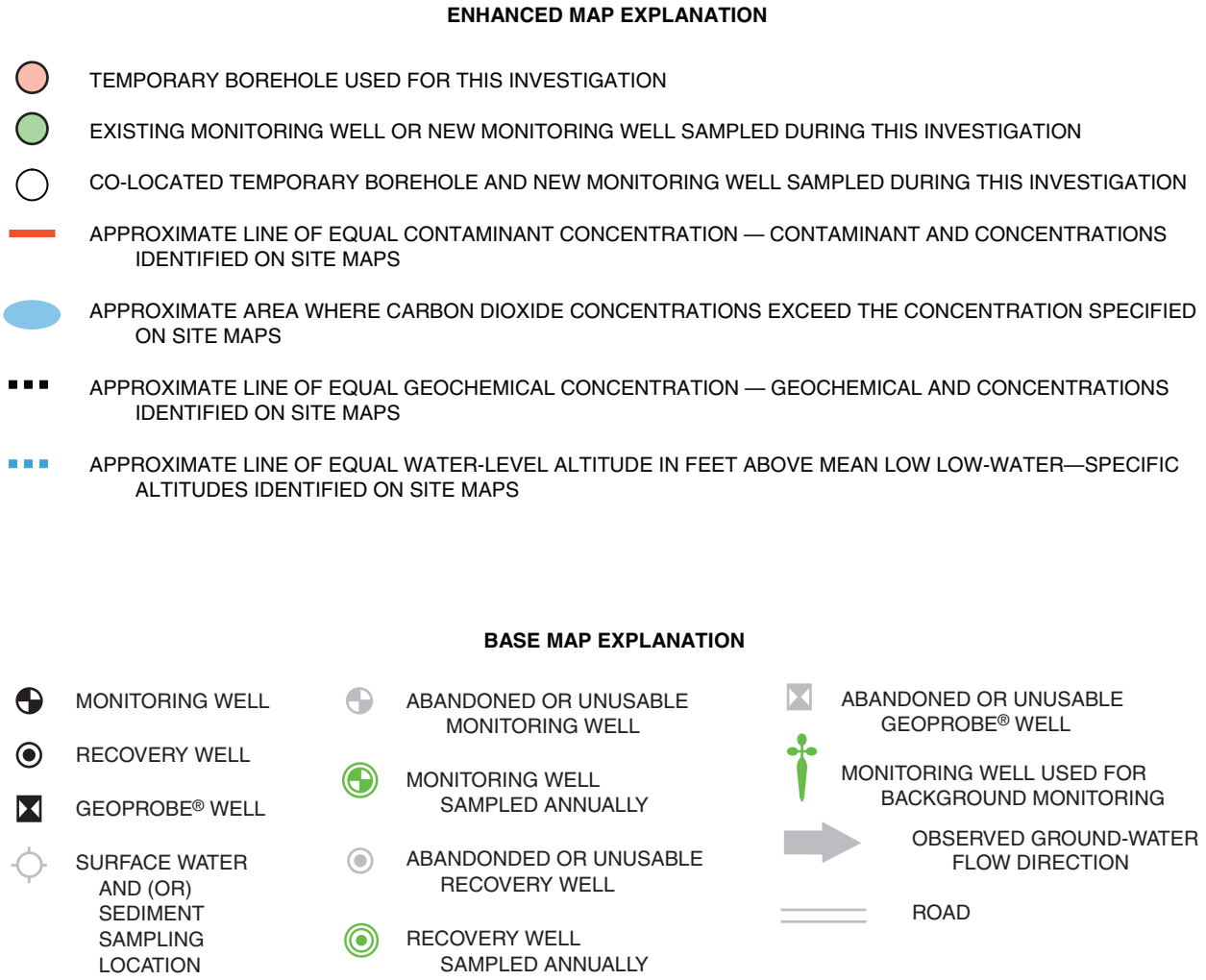

Figure 6. Explanation of symbols used on site maps.

Former Power Plant Building T-1451

Former Power Plant Building T-1451 (fig. 7) is in the southwest part of the Downtown area (fig. 2). Potential sources of petroleum contamination at the site include three former diesel-fuel above-ground storage tanks (ASTs) immediately east of the former power plant building, an AST for JP-5 jet fuel 50 ft south of the building, a north-south running diesel pipeline 100 ft east of the building, a JP-5 pipeline along the west side of Main Road, and an avgas pipeline along the east side of Main Road. None of the pipelines are still in service. The petroleum release history is not well known, and no free product has been detected at the site. In the past, an oil sheen had been detected in East Canal (about 500 ft west and downgradient of the site). A section of the canal was filled and routed through culverts in an attempt to prevent the sheen. Ground water entering East Canal near the site flows about 1,000 ft before it is pumped over a berm into Sweeper Creek (fig. 2). MNA is the ROD-specified remedy for ground-water contamination originating at the Former Power Plant, although additional possible contaminant sources west of Main Road are not administratively included in the site.

The Former Power Plant site is underlain primarily by sands and silty sands with some gravel. Near the former power plant, the water table is about 15 to 20 ft below land surface, and near East Canal it is about 5 ft below land surface. Ground-water flow direction across the site is to the west-southwest, and the previously estimated seepage velocity is 276 ft/yr (URS Greiner, Inc., 1999). Recent (2002) monitoring at the site included one monitoring well (01-118), although nearby well E-701 was sampled as a background well. Historical (1996-97) ground-water data were available for nine abandoned wells used for previous investigations.

Objectives at the site were to determine:

1. Downgradient extent of dissolved-phase DRO concentrations exceeding the 1,500 µg/L cleanup level that came from the suspected Former Power Plant source area and a suspected but unidentified source located west of Main Road, and

2. If concentrations of NAPs and DRO indicate biodegradation and attenuation of petroleum compounds within the DRO plume.

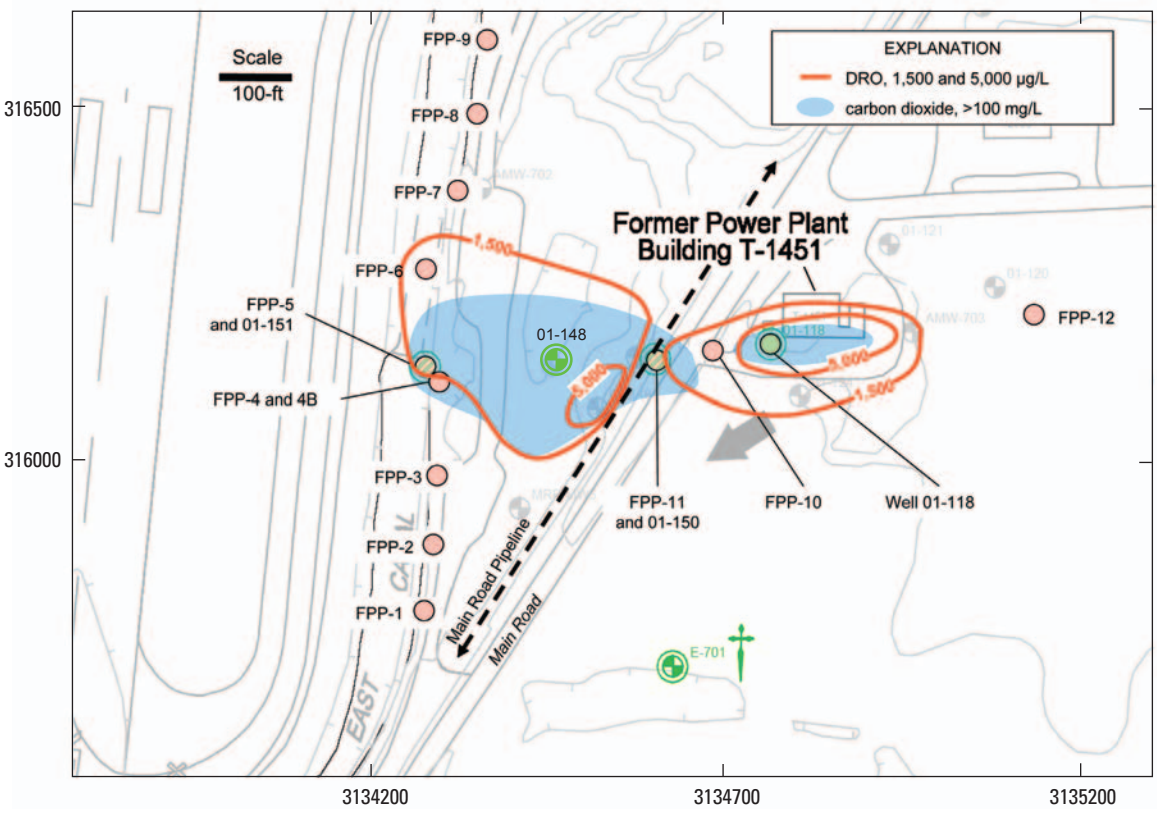

Figure 7. Diesel range organics (DRO) and carbon dioxide concentrations for the Former Power Plant Building T-1451 site, Operable Unit A, Adak Island, Alaska, May and June 2003.

The field investigation to determine the lateral and downgradient extent of the western plume with the unidentified source included pushing and sampling boreholes at nine locations spaced 100 to 150 ft apart in a north-south transect along the east bank of East Canal. The field investigation to determine the downgradient extent of the Former Power Plant plume itself included installing and sampling two boreholes spaced 75 ft apart immediately east and west of Main Road. Boreholes were installed along a ground-water-flow path downgradient from well 01-118, which was estimated from historical water-level data and confirmed by geochemical indicators. Water levels from boreholes (FPP-1 through FPP-9) along East Canal (table 3 and fig. 7) could not be interpreted directly to estimate flow direction because the water level in East Canal changed rapidly during sampling due to pumping from East Canal into Sweeper Creek 1,000 ft downstream (fig. 2). Borehole FPP-12, about 200 ft east of the site, was installed to determine background (upgradient) geochemistry conditions.

Sampling results (table 3) indicate that there may be two overlapping DRO plumes from different sources at the site. One plume begins under the Former Power Plant and DRO concentrations exceeding the cleanup level extend to just west of Main Road. A second plume begins immediately west of the first plume and extends to East Canal (fig. 7). The approximate upgradient extents of the plumes shown on figure 7 were augmented by 1996-97 DRO concentration data from abandoned wells at the site. The downgradient extent of the Former Power Plant plume initially was indicated in the field by a field-DRO concentration of 1,300 µg/L from borehole FPP-11, although the subsequent lab-DRO concentration in a split sample from FPP-11 was 2,300 µg/L.

Table 3. Selected diesel range organics, geochemical, and water-level data from boreholes and wells at the Former Power Plant Building T-1451 site, Operable Unit A, Adak Island, Alaska, May and June 2003.

[**Borehole or well No.** are shown in figure 7. **Sampling depths** are approximate feet below land surface of the mid-point of the sampling device or well screen. **Water-level altitudes** are in feet above or below (-) NAD27. **Diesel range organics:** Historical petroleum data collected by the Navy are in italics. **Abbreviations:** ft, foot; µg/L, microgram per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter. **Symbols:** <, actual value is less than value shown; –, not analyzed]

Borehole or well No.	Date sampled	Sampling depth (ft)	Water-level altitude (ft)	Diesel range organics (µg/L)		pH (units)	Specific conductance (µS/cm)	Carbon dioxide (mg/L)	Dissolved oxygen (mg/L)	Ferrous iron (mg/L)
				Field	Laboratory					
Boreholes										
FPP-1	05-19-03	4	0.97	–	–	6.2	218	20	4	0
-2	05-19-03	4	.91	–	–	6.1	336	25	4	.54
-3	05-19-03	4	.79	–	–	6.6	214	10	6	.06
-4	05-19-03	4	.85	630	–	6.3	365	80	<.025	1.1
-4B	05-19-03	10	–	630	–	6.5	401	150	<.025	1
-5	05-19-03	7	-.62	870	–	6.1	494	170	<.025	1.6
-6	05-19-03	8	1.45	1,400	–	6.3	618	35	.05	1.4
-7	05-19-03	8	2.94	320	–	6.6	261	35	<.025	1.3
-8	05-19-03	6	.89	<100	–	6.2	156	20	6	.15
-9	05-19-03	6	.73	–	–	6.6	261	15	2	.18
-10	05-22-03	23	3.42	2,900	–	6.1	251	70	<.025	.9
-11	05-22-03	20	3.09	1,300	2,300	6.1	482	170	<.025	1.5
-12	05-22-03	20	3.35	–	–	7.3	169	17	6	.1
Monitoring wells										
01-118	05-08-03	22.5	4.06	970	[1]*8,700*	5.7	450	200	0.05	50
-150	06-05-03	19	2.90	–	590	6.2	404	115	.9	4
-151	06-05-03	7.5	.95	–	2,000	6.6	405	120	<0.025	40

[1] The laboratory diesel range organics concentration listed for well 01-118 was from October 2002; the field diesel range organics value was inconsistent with all historical data from the well.

A new monitoring well (01-150) was installed at the FPP-11 location, and a lab-DRO concentration of 590 µg/L confirmed that the location was beyond the downgradient margin of the Former Power Plant plume. We believe that the concentration may be much greater because the accuracy of the 970 µg/L field-DRO concentration for well 01-118 is suspect. DRO concentrations at well 01-118 from 1996 to 2002 have ranged from 6,400 to 10,700 µg/L.

The western plume with the unidentified source is presumed to begin somewhere west of Main Road (fig. 7), and appears to extend westward to East Canal where the lab-DRO concentrations in new monitoring well 01-151 (2,000 µg/L) exceeded the 1,500 µg/L cleanup level. Petroleum sheen was observed in East Canal while sampling, and petroleum sheen was observed emerging from nearshore bed sediments between FPP-3 and FPP-7 when the sediments were stepped on. It was presumed that the East Canal area contamination originated somewhere west of Main Road and not at the Former Power Plant site because an additional contaminant source is the most likely explanation for detecting higher DRO concentrations detected along East Canal compared to well 01-150 location along Main Road. An alternative explanation is that an initial relatively large petroleum release at the Former Power Plant was followed in time by a smaller release at the same location. As previously mentioned, the water-level data from near East Canal were not reliable enough to determine the specific ground-water flow direction between Main Road and East Canal. Lateral limits of the DRO plume along East Canal (FPP-4 to FPP-7) were clearly indicated by anaerobic water with elevated specific conductance and DRO, carbon dioxide, and ferrous iron concentrations (table 3).

The USGS NAP data clearly indicated active biodegradation at the site. Upgradient shallow-ground water geochemistry (FPP-12) was typical for the Downtown area; aerobic with low specific conductance, and low concentrations of carbon dioxide and ferrous iron. Geochemistry within the plume indicated anaerobic ground water with substantially elevated specific conductance, and elevated concentrations of carbon dioxide and ferrous iron. Biodegradation end-product carbon dioxide concentrations within the most highly contaminated part of each plume were about 10 times higher than background concentrations. Historical (2001-02) NAP data from well 01-118 showed very low sulfate concentrations of about 0.2 mg/L, and relatively high methane concentrations of up to 10 mg/L indicating intense biodegradation within the core of the DRO plume have consumed all available electron acceptors to create methanogenic conditions.

Lab-DRO concentrations from the Former Power Plant plume suggest substantial attenuation along the flow path between well 01-118 and the new well 01-150, although those data are from different years; the absolute concentrations from field-DRO analyses were too uncertain at this site to definitively demonstrate attenuation. Historical (1996-2002) lab-DRO concentrations from well 01-118 ranged from 6,400 to 10,700 µg/L with no discernible trend over time, so those data alone do not demonstrate attenuation. DRO attenuation in the western plume is indicated by a decrease in DRO concentrations from 7,000 µg/L in 1997 in abandoned well 01-148 to 2,000 µg/L in new well 01-151 in 2003, and by the clear indication of biodegradation in the NAP data collected along the east shore of the canal. Differences in the timing of data collection, well construction details, and analytical techniques add some uncertainty to the absolute magnitude of attenuation.

Overall, data from this investigation indicate natural attenuation processes have effectively limited the downgradient extent of the 1,500 µg/L DRO plume from well 01-118 at the Former Power Plant to about 150 ft at Main Road. In the apparently separate western plume, natural attenuation processes do not appear to be wholly effective at preventing the discharge of ground water with DRO concentrations greater than 1,500 µg/L into East Canal, and a petroleum sheen was observed in the canal.

Suggestions for future monitoring at the Former Power Plant site include:

1. Sampling well 01-150 to monitor the stability of the downgradient margin of the Former Power Plant plume,

2. Sampling well 01-118 to monitor the contaminant source strength over time, and

3. Sampling well 01-151 to monitor the DRO concentration in ground water from the apparently separate western plume immediately before it discharges to East Canal.

GCI Compound

The GCI (General Communications, Inc.) Compound site, near the center of the Downtown area (fig. 8), was used as a gasoline station and motor pool facility in 1946. GRO and benzene are the primary contaminants of concern at this site. A 6,000 gal underground storage tank (UST) located 40 ft southeast of the building and associated pipelines were removed in 1995 along with approximately 3,000 gal of remaining liquid. A previously unknown supply/fill pipe separated from the tank during removal and about 2,000 gal of water and petroleum residue discharged into the excavation. About 90 percent of the liquid was recovered. No records of other releases from that UST are available. The ROD-specified remedy at the GCI site was free product recovery. Passive skimmers were used to recover free product near wells 04-201 and 04-202, and free product has not been observed in any GCI monitoring well since November 1997. MNA is being considered by the Navy as a follow-up remedy for dissolved-phase contamination in ground water at the site (remediation of dissolved-phase contamination was not addressed specifically in the ROD for sites with free product recovery remedies).

The GCI Compound is underlain primarily by sands and silty-sands with some gravel. A perched ground-water zone is present at a depth of about 5 ft below land surface adjacent to the former UST, and is present at a depth of 25 ft below land surface about 500 ft downgradient. Ground water from the GCI Compound flows in a semi-radial pattern in an arc extending from the south to the west. Recent (2002) water-quality monitoring included one well (04-701), although many additional wells are still at the site. Selected historical (1996-2002) ground-water data were available for most additional wells, including NAP data from 2002.

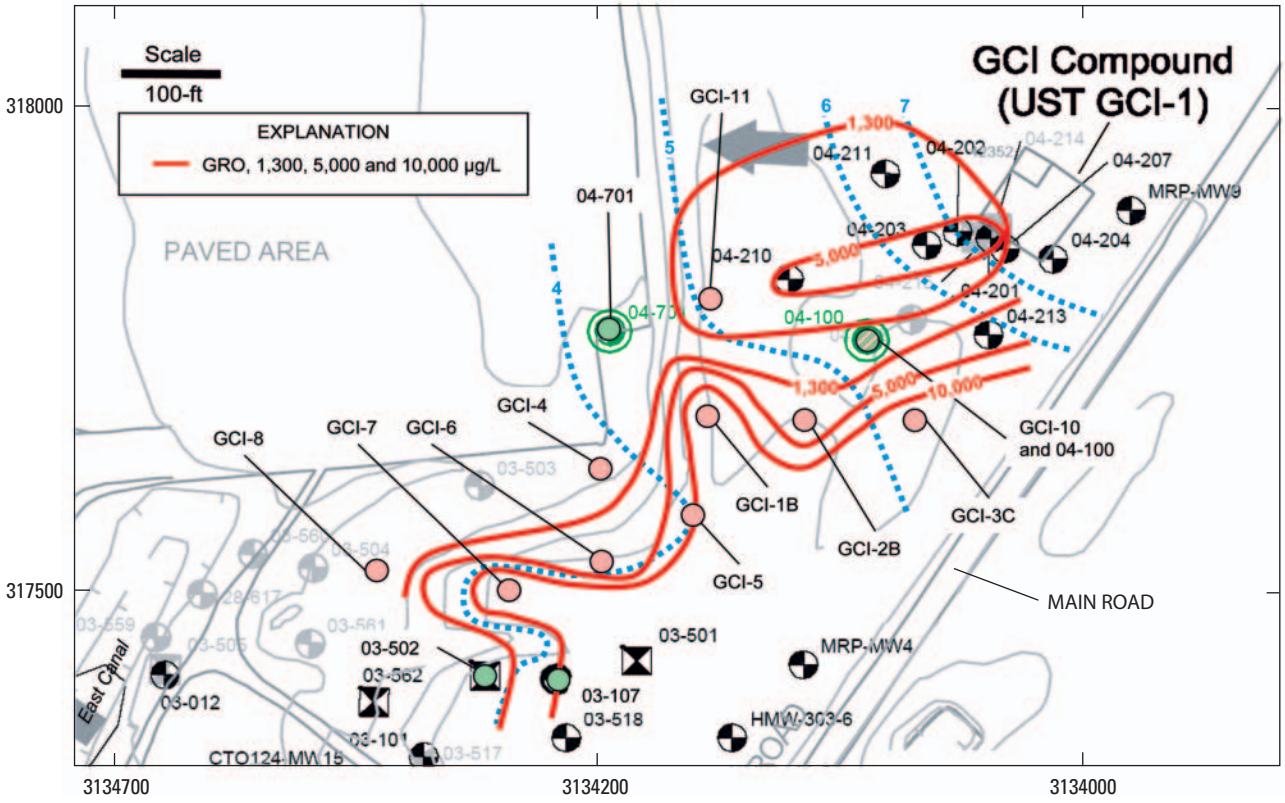

Figure 8. Gasoline range organics (GRO) concentrations and water levels for the GCI Compound site, Operable Unit A, Adak Island, Alaska, May and June 2003.

Objectives were to determine:

1. If well 04-701 is suitably placed to monitor the downgradient (western) extent of dissolved-phase benzene and GRO concentrations exceeding the 5 µg/L or 1,300 µg/L cleanup levels, respectively,
2. Extent of the contaminant plume towards the south and southwest, and
3. If concentrations of NAPs, benzene, and GRO indicate biodegradation and attenuation of petroleum compounds within the plume.

The field investigation began with an initial west to east transect of three boreholes (GCI-1A and -1B, GCI-2A and -2B, and GCI-3A and -3C) spaced 100 ft apart and about 300 ft south-southwest of the former UST. (A letter at the end of the borehole name indicates that different depths were sampled at the same location; A denotes the shallowest depth). The perched ground-water zone was detected at a depth of about 16 ft in the shallow boreholes (data not shown), but GRO concentrations were substantially lower than those detected in the deeper boreholes. GRO and benzene concentrations in the three deep boreholes (GCI-1B, GCI-2B, and GCI-3C, fig. 8 and table 4) greatly exceeded those at the GCI source area indicating a second overlapping GRO plume from an unidentified source for GRO somewhere south or southwest of the GCI Compound along Main Road. Additional boreholes (GCI-4 through GCI-8) were installed in an attempt to characterize the extent of area-wide GRO contamination, but that effort was terminated before the plume was fully characterized because it expanded well beyond the scope of the GCI site investigation. The investigation then refocused on the contaminant plume originating at the GCI Compound itself with two additional boreholes (GCI-10 and GCI-11), which were nearer the GCI source.

Table 4. Selected gasoline range organics, benzene, geochemical, and water-level data from boreholes and wells at the GCI Compound site, Operable Unit A, Adak Island, Alaska, May and June 2003.

[**Borehole or well No.** are shown in figure 8. **Sampling depths** are approximate feet below land surface of the mid-point of the sampling device or well screen. **Water-level altitudes** are in feet above or below (-) NAD27. **Gasoline range organics:** Historical petroleum data collected by the Navy are in italics. **Abbreviations:** ft, foot; µg/L, microgram per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter. **Symbols:** <, actual value is less than value shown; –, not analyzed]

Borehole or well No.	Date sampled	Date of historical petroleum data	Sampling depth (ft)	Water-level altitude (ft)	Gasoline range organics (µg/L)		Benzene (µg/L)		pH (units)	Specific conductance (µS/cm)	Carbon dioxide (mg/L)	Dissolved oxygen (mg/L)	Ferrous iron (mg/L)
					Field	Laboratory	Field	Laboratory					
Boreholes													
GCI-1B	05-14-03	–	25	4.88	30,000	–	3,400	–	–	–	–	–	–
-2B	05-14-03	–	25	4.34	3,000	–	0	–	6.4	161	27	0.6	30
-3C	05-23-03	–	25	5.53	–	28,000	–	6.6	5.8	262	100	<.025	14
-4	05-15-03	–	18	3.76	870	–	<2	–	5.6	143	35	.2	3.6
-5	05-15-03	–	28	4.00	10,000	–	270	–	5.7	285	70	.2	2.2
-6	05-15-03	–	28	3.84	3,400	–	32	–	5.8	200	70	<.025	1.5
-7	05-16-03	–	18	4.43	15,000	–	<2	–	5.7	342	180	.2	45
-8	05-16-03	–	18	3.06	370	–	<2	–	6.1	135	5	4.4	1.0
-10	05-23-03	–	24	–	–	3,800	–	5.8	6.2	348	130	<.025	3.3
-11	05-23-03	–	24	–	–	3,100	–	8.4	6.1	310	110	<.025	9.3
Monitoring wells													
03-107	05-16-03	–	28	4.60	10,000	–	30	–	6.0	266	160	<0.025	50
-502	05-16-03	–	24	3.38	2,900	–	2	–	5.8	249	100	<.025	15
04-100	06-06-03	–	26	5.25	–	850	–	1.4	6.4	306	70	.4	18
-202	05-14-03	08-01-02	22.5	7.00	–	*5,100*	–	*8.7*	–	–	–	–	–
-207	05-14-03	08-01-02	22.5	7.04	–	*1,700*	–	*2.3*	–	–	–	–	–
-210	05-14-03	08-01-02	28	5.29	–	*5,000*	–	*12*	–	–	–	–	–
-213	05-14-03	08-01-02	25	5.89	–	*4,000*	–	*3*	–	–	–	–	–
-701	05-15-03	–	13	4.67	<100	–	<2	–	5.6	192	65	.1	9.2

Lab-GRO concentrations in boreholes GCI-10 and GCI-11 (3,800 and 3,100 µg/L, table 4) were less than those observed by the Navy in August 2002 in pre-existing wells nearer the GCI compound source area. Those results indicate GRO concentrations within the GCI plume itself attenuate as the plume moves downgradient. Attenuation continues towards the west as indicated by the relatively low GRO concentrations detected in well 04-701 (<100 µg/L for this investigation and 99 µg/L in October 2002). NAP data from well 04-701 (anaerobic with relatively high ferrous iron and carbon dioxide concentrations) suggest that the well is on a contaminated flow path and that biodegradation occurs along that flow path. However, GRO concentrations increased substantially in many boreholes located south and southwest of borehole GCI-10, indicating an additional contaminant source in the area. A petroleum sheen (determined by GC analysis to be primarily GRO) was observed in discharging ground water at the head of East Canal a few hundred feet upstream from a previously identified DRO-related sheen located downstream of well 03-012; our field investigation could not determine if the sheen was related to the GRO plume characterized with data from boreholes GCI-1B through GCI-8.

The discontinuous distribution of GRO concentrations in the area south of the GCI plume was similar to that detected in a DRO plume associated with a separate petroleum site located immediately south of the GCI Compound site. Subsurface hydraulic heterogeneities in this part of the Downtown area may be the cause of the discontinuous distribution. A northeast to southwest trending break in topographic slope west of the GCI site probably is the surficial expression of foreset dunes that are thought to hinder and channelize ground-water flow in the area. The 10,000 µg/L GRO contour (fig. 8) appears to follow the top of the dunes, suggesting a hydraulic barrier is limiting contaminant migration farther to the west. The barrier may be related to the darker, reddish band evident in a similar dune (fig. 9)

Figure 9. Foreset dune about 500 ft north of the GCI Compound site (looking north-northwest), Operable Unit A, Adak Island, Alaska. (Photograph taken by R.S. Dinicola, U.S. Geological Survey, Tacoma, Washington, 2003.)

exposed about 500 ft north of the GCI Compound; the band is a low-permeability layer that slopes upward from east to west. Similar dunes likely mark the western edge of the topographic flat south of the GCI site, and the area east of the dunes has been back-filled by the military. A natural lagoon west of the dunes was filled to allow construction of the airfield runways.

Overall, the NAP data from the GCI site indicate active biodegradation beyond what was already indicated in background water for the site. Upgradient shallow ground-water geochemistry for the GCI site probably is not typical for uncontaminated background water because of upgradient petroleum contamination. The Navy detected petroleum compounds at concentrations less than the cleanup levels and indicator concentrations of NAPs in upgradient well MRP-MW9 in August 2002. NAP concentrations in that upgradient well were indicative of some petroleum biodegradation with no dissolved oxygen and moderately elevated concentrations of specific conductance (121 µS/cm), alkalinity (32 mg/L), ferrous iron (2.4 mg/L), and methane (0.8 mg/L). The Navy also sampled the GCI source area wells at that time and detected substantially higher concentrations of the NAPs, including specific conductance (336 µS/cm), alkalinity (85 mg/L), ferrous iron (25 mg/L), and methane (3 mg/L). The USGS measured similarly high specific conductance, carbon dioxide, and ferrous iron, concentrations in the anaerobic water in the nearest boreholes (GCI-10 and GCI-11) as well as most of the farther downgradient boreholes and wells (table 4). As mentioned previously, NAP data from well 04-701 suggest that the well is on a contaminated flow path, and that biodegradation is a contributor to the low GRO concentrations observed. Hydraulic heterogeneities in the area immediately east of 04-701 also may limit contaminant migration towards the well, although the steep slope to the east of the well is an excavated feature that may have disrupted the hydraulic-limiting structure in the pre-existing dune line.

GRO concentrations in the GCI plume indicate some attenuation along the flow path towards the southwest between the GCI Compound (considering the August 2002 data from well 04-202) and the new well 04-100. Attenuation also is evident along the downgradient part of the flow path to the west between well 04-210, borehole GCI-11, and well 04-701, but attenuation is limited along the beginning part of that flow path between wells 04-202 and 04-210. Attenuation is not apparent along the southward flow path between wells 04-202 and 04-213, probably because of an additional petroleum source between the wells. The GRO plume at the GCI site appears to be stable, although that cannot be confirmed with the available data. Historical (1996-2002) GRO and benzene concentrations in all GCI source-area wells have decreased consistently and substantially, indicating that petroleum concentrations throughout the site also have been attenuated over time. No such consistent trends have been observed at downgradient well 04-701, although contaminant concentrations there have always been much less than the specified cleanup levels.

Overall, data from this and previous investigations indicate natural attenuation processes are limiting the extent of the 1,300 µg/L GRO plume and the 5 µg/L benzene plume that originate at the GCI Compound site to less than 150 ft towards the southwest, and to less than 350 ft towards the west. Attenuation of the plumes to the south is confounded by an additional source of GRO, which appears to have created a plume that is more extensive than the GCI plume itself. The newly identified GRO plume south of the GCI site was not characterized well enough to ascertain the effectiveness of attenuation.

If MNA is selected as the remedy for this site, monitoring suggestions include:

1. Sampling well 04-100 to monitor the stability of the downgradient margin to the southwest,
2. Continued sampling of well 04-701 to monitor plume stability towards the west, and
3. Sampling well 04-202 near the source area to monitor contaminant source-strength area over time.

Housing Area (Arctic Acres)

The housing area known as Arctic Acres was constructed in 1975 in the Downtown area of Adak Island (fig. 2). Each housing unit was furnished with a pressurized steel pipe that supplied heating fuel from two 27,000-gal ASTs immediately west of well 03-890 (fig. 10). The release history of the site is partially known. In 1993, a pipeline test detected 10 leaks in a 150-ft length of pipe under Dolly Varden Drive. It was not known how long the pipe had been leaking, so the volume released is unknown. DRO-related compounds are the predominant contaminants and free product up to 1-ft thick historically has been observed in well 03-890. Monitored natural attenuation is the ROD-specified remedy for the site.

Arctic Acres housing area is underlain primarily by sands and silty-sands with some gravel. Ground water is 20-30 ft below land surface. Ground-water flow from the possible source areas had been presumed to be towards the west-southwest, but water-level data collected monthly by the Navy indicate that the flow direction may be variable or towards the east. Recent (2002) monitoring at the site included nine wells (all "03" prefix wells, AA-01, AA-02, AA-05 and AA-06). Selected historical (1996-2002) ground-water data were available for most wells, although the wells with "AA" prefixes were not installed until 2001.

Objectives at this site were to determine:

1. Direction of contaminant migration from the area of highest DRO concentrations (wells 03-890 and 03-421),
2. If existing wells are suitably located to monitor the extent of contamination and plume stability, and
3. If concentrations of DRO and NAPs indicate biodegradation and natural attenuation of petroleum compounds within the plume.

Data from existing wells and four temporary boreholes were used to meet the objectives.

Water-level data (table 5) collected for this and previous investigations indicates a ground-water flow divide near the center of the site, but the location of the divide appears to be variable. Eastward flow from a north-south line between wells 04-422 and 03-416 has been consistent, but the water table is nearly flat and flow directions have been variable in the area west of those wells. Instead of trying to determine flow directions from available water-level measurements (few of which represent winter conditions), the DRO and geochemistry data were interpreted to determine the predominant direction(s) of contaminant migration.

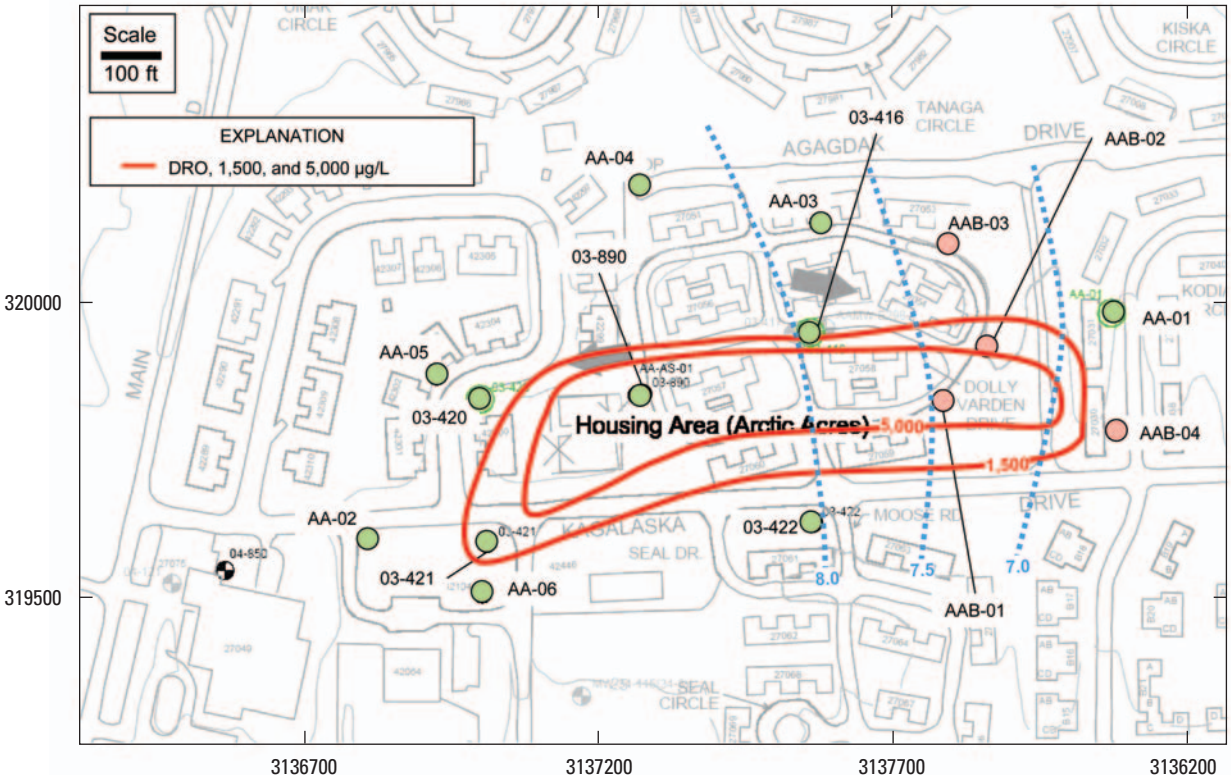

Figure 10. Diesel range organics (DRO) concentrations and water levels for the Housing Area (Arctic Acres) site, Operable Unit A, Adak Island, Alaska, May and June 2003.

Table 5. Selected diesel range organics, geochemical, and water-level data from boreholes and wells at the Housing Area (Arctic Acres) site, Operable Unit A, Adak Island, Alaska, May and June 2003.

[**Borehole or well No.** are shown in figure 10. **Sampling depths** are approximate feet below land surface of the mid-point of the sampling device or well screen. **Water-level altitudes** are in feet above or below (-) NAD27. **Abbreviations:** ft, foot; µg/L, microgram per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter. **Symbols:** <, actual value is less than value shown; –, not analyzed]

Borehole or well No.	Date sampled	Sampling depth (ft)	Water-level altitude (ft)	Diesel range organics (µg/L)		pH (units)	Specific conductance (µS/cm)	Carbon dioxide (mg/L)	Dissolved oxygen (mg/L)	Ferrous iron (mg/L)
				Field	Laboratory					
Boreholes										
AAB-01	05-21-03	22	7.47	7,700	18,000	5.9	614	400	<0.025	2.8
-02	05-21-03	22	7.43	4,200	4,400	6.2	425	240	<.025	2.4
-03	05-21-03	22	7.33	<100	–	6.2	242	60	.1	3.1
-04	05-21-03	22	6.66	460	920	6.0	340	45	<.025	1.4
Monitoring wells										
03-416	05-09-03	18	7.95	1,100	–	6.1	262	50	<0.025	17
-420	05-09-03	22	8.34	300	–	6.1	265	48	<.025	8.4
-421	05-09-03	22	8.44	3,500	–	6.1	305	50	<.025	9.6
-422	05-09-03	21	8.03	<100	–	6.1	231	70	.2	13
-890	05-09-03	23	7.89	–	[1]16,000	6.1	481	250	<.025	24
AA-01	05-09-03	22	6.86	570	–	6.2	189	34	<.025	10
-02	05-09-03	25	8.32	<100	–	6.0	286	70	6	<.05
-03	05-09-03	26	7.85	<100	–	6.1	214	37	<.025	7.9
-04	05-09-03	26	8.21	<100	–	5.7	119	15	6	<.05
-05	05-09-03	27	8.29	<100	–	5.6	198	40	4.5	<.05
-06	05-09-03	23	8.47	<100	–	5.8	208	40	5	<.05

[1] The laboratory diesel range organics concentration for well 03-890 was from October 2002; the diesel range organics value was not measured in the field because free product was in the well.

An area (or possibly two disconnected areas) with exceptionally high DRO concentrations is indicated by the distribution of DRO in wells and boreholes (fig. 10). The western part of the area is indicated by data from wells 03-890 and 03-421. About 0.5 ft of free product was detected floating on the water table at well 03-890 during this investigation, and free product and high DRO concentrations have been regularly detected by the Navy in that well since 1998. A field-DRO concentration of 3,500 µg/L was detected in well 03-421, and the USGS did not detect free product in that well. Less than 0.1 ft of free product was detected twice by the Navy during 2000 and questionably high DRO concentrations (26,000-81,000 µg/L) were reported during 2001 (typical concentrations at the well have ranged from 1,800 to 3,500 µg/L). The eastern part of the area with high DRO concentrations is represented by data from well 03-416 and boreholes AAB-01 and AAB-02. Historical DRO concentrations in 03-416 have ranged from 2,600 and 3,400 µg/L. The exceptionally high lab-DRO concentrations in the two boreholes extended the previously identified area of high DRO concentrations eastward.

From that area of high concentration, DRO appears to have migrated predominately towards the east, with less consistent migration towards the west. The lack of migration to the north is indicated by the geochemistry in well AA-04, which is representative of uncontaminated background conditions with a high dissolved-oxygen concentration (6 mg/L), low specific conductance (119 µS/cm), low carbon dioxide concentration (15 mg/L), and no detectable ferrous iron (<0.05 mg/L). Ground water in wells along the western margin of the site (AA-02, AA-05, and AA-06,) also was aerobic with no detectable ferrous iron, although DRO previously was reported for those wells at concentrations of 74-455 µg/L, and specific conductance and carbon dioxide concentrations were elevated (286, 198, and 208 µS/cm and 70, 40, and 40 mg/L, respectively) compared to background conditions. Those data indicate some DRO migration and biodegradation towards the west, but not enough to consume the dissolved oxygen replenished from ground-water recharge. Ground water in wells along the northern and eastern margins of the site (AA-03, AA-01, and 03-422) have historical DRO concentrations (151 and 1,190 µg/L) and elevated specific

conductance and carbon dioxide concentrations, but the wells are anaerobic with elevated ferrous iron concentrations. Those data indicate that petroleum migration was consistently towards the east-southeast with sufficient biodegradation to consume the dissolved oxygen replenished from ground-water recharge. Flow directions may have varied enough to disperse contamination under the center of the site, but the predominant flow path appears to have moved contaminants beyond the site towards the east.

Four boreholes were installed and sampled to confirm the assumed eastward contaminant migration direction. Three boreholes were spaced about 125 ft apart on a north-south transect about midway between wells 03-416 and AA-01. DRO concentrations were highest (18,000 µg/L) in borehole AAB-01 about due east of well 03-890. Field-DRO concentration of 7,700 µg/L was roughly estimated because the highest concentration standard used to develop calibration curves was about 3,000 µg/L. A fourth borehole (AAB-04) was installed about 125 ft south of well AA-01 to assure that the plume was not passing to the southeast of well AA-01. Field-DRO in borehole AAB-04 (460 µg/L) was less than the DRO measured in AA-01 (570 µg/L). It was concluded in the field that well AA-01 was reasonably located to monitor the distal part of the contaminant plume, although an optimal location may be about 75 ft south of that well. The subsequent lab-DRO concentration was 920 µg/L for borehole AAB-04, but a similar replicate was not analyzed for AA-01 for comparison. Because the observed DRO concentrations were less than the cleanup level at both downgradient locations, well AA-01 is reasonably located for monitoring the downgradient (eastern) margin of the contaminant plume.

Overall, the NAP data from the Arctic Acres housing area indicated active petroleum biodegradation. The USGS measured substantially elevated carbon dioxide and ferrous iron concentrations in the most contaminated wells, and moderately elevated concentrations in other wells with current or historical DRO contamination. The USGS also measured elevated sulfide concentrations (0.16-0.20 mg/L) in non-turbid samples from wells within the core of the plume (wells 03-890, 03-416, and 03-421), and the Navy has previously detected methane in multiple site wells.

DRO concentrations in the Arctic Acres housing area plume suggest attenuation of DRO concentrations along the flow path towards the east between wells 03-416 and AA-01, assuming the plume is stable. However, it is too soon to definitively determine the stability of the DRO plume at the Arctic Acres housing area because the distal parts of the plume have been monitored only since October 2001. At well AA-01 to the east, DRO concentrations were below the cleanup level during 2001-03 and too few data are available to determine changes over time. At well 03-420 to the west, DRO was not detected during 1999-2000, but had concentrations as high as 12,300 µg/L during 2001-02, and was only 300 µg/L during this investigation. That variability may reflect the variable ground-water flow directions near this well. The peak DRO concentration of 216 µg/L at AA-05 in 2001 suggests that the net direction of contaminant migration from 03-420 is to the east. Within the core of the plume (wells 03-890, 03-416, and 03-421), no consistent trend is evident in 1996-2003 DRO concentrations, although the 2001 concentrations were consistently greater than previously reported concentrations. Because at least one source of DRO was active until 1993 (the leaky piping), steady-state plume conditions may not yet have been attained. Overall, data from this and previous investigations clearly indicate active petroleum biodegradation at the Arctic Acres housing area, but it is too soon to determine the extent that natural attenuation processes are limiting the 1,500 µg/L DRO plume.

Minimal monitoring suggestions for the Arctic Acres housing area site include:

1. Sampling AA-01 to monitor the stability of the downgradient extent of contamination towards the east of the source area, and

2. Sampling well 03-890 to monitor the strength of the primary contaminant source and the presence of NAPL over time.

Potentially variable flow conditions at the site, combined with other known contamination “hot spots” such as well 03-421, may leave some uncertainty as to the overall performance of MNA with that minimal monitoring plan. For more certainty, sampling wells 03-420, AA-02, and AA-06 on an infrequent basis (perhaps every other year) would allow confirmation that contaminant transport towards the west remains insubstantial.

ROICC Contractor's Area (UST ROICC-7)

The Resident Officer In Charge of Construction (ROICC) Contractor's Area is north of the Downtown area in an unpopulated section about 0.5 mi west of Kuluk Bay (fig. 2). This area was used for equipment and supply storage for Navy contractors working on the island. Two specific sites with different remedies are in the vicinity. MNA was the ROD-specified remedy for the ROICC-8 site (near well 08-153), but the Navy proposed no further action at this site because of the lack of contamination greater than cleanup levels. Limited monitoring (which does not include NAP analyses) was the ROD-specified remedy for the ROICC-7 site (near wells 08-200 and 08-202), but MNA is being considered as an alternate remedy because 2000-02 contamination levels did not meet the limited-monitoring criteria.

The USGS focused its efforts at the ROICC-7 site near wells 08-200 and 08-202 (fig. 11). The release history related to the former UST ROICC-7 (near well 08-201) is unknown. Benzene is the primary contaminant of concern at the site, although benzene rarely has been detected in 08-201. Benzene (and GRO to a lesser extent) has been consistently detected at concentrations greater than cleanup levels in wells 08-200 and 08-202, north and upgradient from the former UST. Monitoring plans suggested for 2003 included continued sampling of the ROICC-8 site wells 08-153 and 08-160 for upgradient comparison to ROICC-7 wells, and sampling of wells 08-200 and 08-202 for the ROICC-7 benzene plume.

Like most of the Downtown area, the ROICC site is underlain primarily by sands and silty-sands with some gravel. However, ground water is at or within a few feet of land surface throughout the ROICC contractor's area and the surface-soils have an abundance of natural organics, including plant roots and soil humus. The shallow water table is atypical for the Downtown area and the abundance of available carbon-substrate likely leads to differences in background water chemistry. Historical data indicate ground-water flow to be predominantly towards the southeast, although there

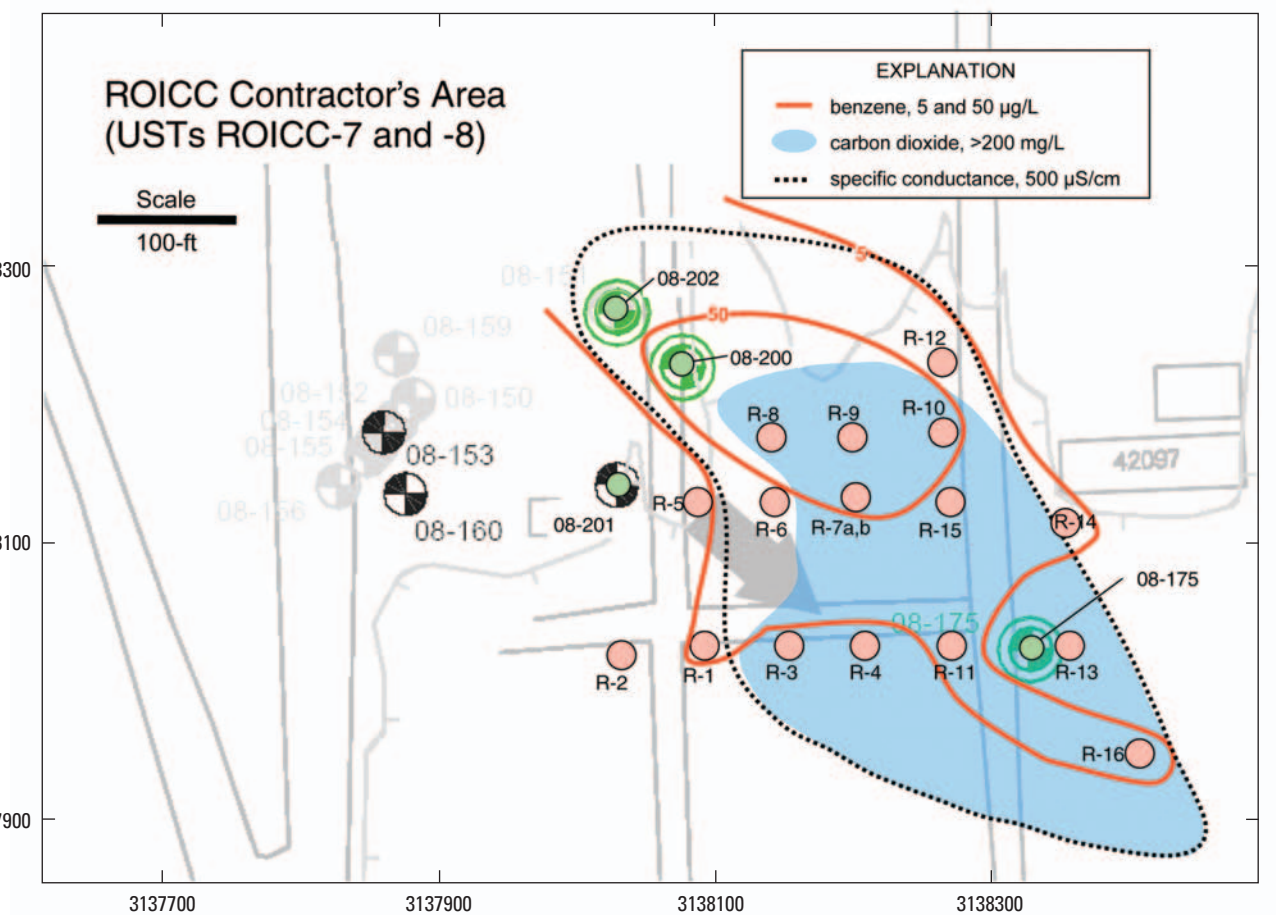

Figure 11. Benzene, carbon dioxide, and specific conductance concentrations for the ROICC Contractor's Area site, Operable Unit A, Adak Island, Alaska, May and June 2003.

has been seasonal flow towards the southwest. Recent (2002) monitoring at the site included three wells (08-200, 08-201, and 08-202). Historical (1999-2002) ground-water-level data were available for those wells, and data back to 1996 were available for the ROICC wells farther west.

Objectives at the ROICC site were to determine:

1. Direction of ground-water flow from the area of highest benzene concentrations near well 08-200,
2. Downgradient extent of benzene concentrations that exceeded the 5 µg/L cleanup level, and
3. If concentrations of NAPs indicate biodegradation of petroleum compounds within the plume.

Data from 17 hand-driven, shallow boreholes and 5 monitoring wells (table 6) were used to achieve the objectives. Water-level data from the boreholes are not comparable throughout the site because they were not all measured simultaneously,

Table 6. Selected gasoline range organics, benzene, geochemical, and water-level data from boreholes and wells at the ROICC Contractor's Area site, Operable Unit A, Adak Island, Alaska, May and June 2003.

[**Borehole or well No.** are shown in figure 11. **Sampling depths** are approximate feet below land surface of the mid-point of the sampling device or well screen. **Water-level altitudes** are in feet above or below (-) NAD27. **Gasoline range organics:** Historical petroleum data collected by the Navy are in italics. **Abbreviations:** ft, foot; µg/L, microgram per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter. **Symbols:** e, compound was detected but concentration was estimated; <, actual value is less than value shown; –, not analyzed]

Borehole or Well No.	Date sampled	Date of historical petroleum data	Sampling depth (ft)	Water-level altitude (ft)	Gasoline range organics (µg/L)		Benzene (µg/L)		pH (units)	Specific conductance (µS/cm)	Carbon dioxide (mg/L)	Dissolved oxygen (mg/L)	Ferrous iron (mg/L)
					Field	Laboratory	Field	Laboratory					
Boreholes													
R-1	05-15-03	–	2.8	10.37	<100	–	8	–	–	449	140	–	–
-2	05-15-03	–	2.5	10.58	<100	–	.9e	–	–	298	110	–	–
-3	05-15-03	–	2.8	10.39	<100	–	1.1e	–	–	877	250	–	–
-4	05-15-03	–	2.8	10.24	<100	–	1.4e	–	–	1,031	280	–	–
-5	05-15-03	–	2.8	10.47	<100	–	1.8e	–	–	449	140	–	–
-6	05-15-03	–	2.5	10.36	<100	–	13	–	–	599	140	–	–
-7a	05-15-03	–	2.8	10.28	<100	–	5.2	–	–	494	190	–	–
-7b	05-18-03	–	3.5	–	104	–	64	–	6.4	1,238	400	–	–
-8	05-17-03	–	2.8	–	94e	–	330	–	–	1,210	350	<0.025	–
-9	05-17-03	–	3.2	–	433	–	2,100	–	–	2,110	700	–	–
-10	05-17-03	–	2.2	–	86e	–	260	–	–	968	450	–	–
-11	05-17-03	–	3.2	–	<100	–	27	–	–	887	350	–	–
-12	05-17-03	–	3.5	–	<100	–	26	–	–	415	170	–	–
-13	05-18-03	–	3.7	–	<100	65	<2	<1	5.9	1,189	380	1.12	–
-14	05-18-03	–	3.7	–	<100	–	16	–	6.0	486	190	.72	–
-15	05-18-03	–	3.7	–	<100	<50	13	3.3	6.2	817	280	1.22	–
-16	05-18-03	–	3.7	–	<100	–	8.3	–	6.2	1,002	400	1.46	–
Monitoring wells													
08-153	05-14-03	10-11-02	7.5	10.99	–	*17.4e*	–	*<1*	–	–	–	–	–
-175	06-06-03	–	5.5	10.06	–	<50	–	<1	6.2	582	250	<0.025	85
-160	05-14-03	10-11-02	7.5	10.85	–	*12e*	–	*.6e*	–	–	–	–	–
-200	05-14-03	10-10-02	7.5	10.60	110	–	450	*250*	6.3	586	160	<.025	10
-201	05-14-03	10-10-02	7.5	10.67	–	–	–	*1.2*	6.3	289	36	<.025	11
-202	05-14-03	10-10-02	7.5	10.95	–	–	–	*18*	6.4	754	200	<.025	7.8

and they responded quickly to rainfall, which was frequent during the investigation. Because the boreholes were shallow (less than 4 ft deep), the ground-water yield was generally low and the unconfined water table was at or above the land surface, the samples obtained from the boreholes had a high potential for contamination with surface water flowing along the temporary well casing. To minimize pumping and the potential for contamination, only those NAPs that were most indicative of petroleum contamination at the ROICC site (specific conductance and carbon dioxide concentration) were sampled at most boreholes. Dissolved oxygen was not measured at most boreholes because it was difficult to obtain a non-aerated sample; some of the reported measurements may be non-representative of ambient ground-water conditions. Specific conductance of standing surface water at the site (approximately 200 µS/cm) was substantially less than the specific conductance of shallow ground water (generally greater than 500 µS/cm), so exceptionally low specific conductance measured in a ground-water sample indicated contamination by surface water. When such contamination was detected, samples were discarded, a new borehole was installed, and new samples were collected.

The contaminant plume at the ROICC site that migrated southeast from well 08-200 was clearly identified from the observed benzene, carbon dioxide, and specific conductance data (fig. 11). Field-determined benzene data were suitable for locating the relatively high concentration (2,100 µg/L) core of the contaminant plume. GRO concentrations were less than the cleanup level throughout the site. Field-determined benzene data were less suitable for determining the precise extent of the 5 µg/L benzene plume given how close that concentration is to the method detection limit of approximately 2 µg/L. Based on the field results, well 08-175 was installed at a downgradient location where benzene concentrations were expected to be somewhat greater than 5 µg/L but less than 30 µg/L, and where greatly elevated carbon dioxide concentrations indicated upgradient biodegradation. The new well could not be installed farther downgradient because the ground was too soft and saturated for Geoprobe® rig access.

The USGS NAP data indicated active biodegradation at the site primarily through elevated carbon dioxide concentrations. Boreholes were not installed north (upgradient) of the ROICC contractor's area, but samples from well 08-201 and borehole R-2 are suspected to represent uncontaminated shallow ground water in the vicinity. These samples were atypical for the Downtown area because they were anaerobic with elevated ferrous iron concentrations. These conditions probably resulted from microbial oxidation of naturally-occurring organic carbon in the rooting zone linked to oxygen and iron reduction. Geochemistry data within the plume indicated generally anaerobic ground water with substantially elevated specific conductance and carbon dioxide concentrations. The few reported aerobic samples probably were influenced by surface water flowing into the piezometer during sample collection. Historical (1999-2002) NAP data from contaminated wells at the site consistently had elevated concentrations of ferrous iron (4-11 mg/L) and methane (9-22 mg/L), sulfate concentrations less than 1 mg/L, and detectable sulfide (data not shown). These data indicate that intense biodegradation within the benzene plume has consumed most available electron acceptors, except carbon dioxide creating methanogenic conditions.

Field data suggest that the center of the benzene plume is approximately 100 ft downgradient (east-southeast) from well 08-200, and that concentrations decrease substantially in all directions from that location. Stability of the benzene plume at the ROICC site cannot be ascertained until additional data are collected from the new downgradient monitoring well. At wells 08-200 and 08-202, a downward temporal trend in benzene concentrations occurred during 1999-2002. Despite the field efforts to position the new well 08-175 within the contaminant plume, and despite the substantially elevated specific conductance and carbon dioxide concentration detected in the new well, benzene was not detected in well 08-175 in June 2003 in either the field or laboratory GC analyses. However, a petroleum odor was noted while sampling and the well is on the overall flow path from the site, so well 08-175 is in a reasonable location for monitoring possible future plume migration. Overall, data from this and previous investigations clearly indicate active benzene biodegradation at the ROICC site, but it is too soon to determine the extent to which natural attenuation processes are limiting the 5 µg/L benzene plume.

Monitoring suggestions for the ROICC site include:

1. Sampling well 08-175 to monitor the stability of the downgradient extent of contamination towards the southeast, and

2. Sampling well 08-200 to monitor contamination nearer the source area over time.

Additional sampling of well 08-201 is not essential because it is not on the contaminant flow path, and additional sampling of well 08-202 is not essential because it is upgradient from and less contaminated than well 08-200.

Runway 5-23 Avgas Valve Pit

Runway 5-23 Avgas Valve Pit (fig. 12) is west of Sweeper Creek near the end of the northernmost part of runway 5-23 (fig. 2). About 240 to 1,600 lb of GRO and benzene leaked from Avgas transfer equipment into the soil at the site prior to 1994. The extent of the contaminant plume and the potential discharge into an adjacent drainage ditch are the primary concerns at the site, and MNA is the ROD-specified remedy.

The Avgas Valve Pit site is underlain primarily by sands and silty-sands with some gravel. Historical data indicate that ground water flows eastward from the source area near well 14-100 at an estimated ground-water velocity of 97 ft/yr (URS Greiner, Inc., 1999). Depth to ground water at the site is relatively shallow (1–4 ft) for the Downtown area, so the abundance of available carbon substrate in the soil-rooting zone may lead to differences in background water chemistry. The only existing well at the site (14-100) has been monitored regularly since 1996. During 1996 (before abandonment), neither GRO nor benzene was detected in a second well at the site (abandoned well 14-101).

Objectives at the site were to determine:

1. Downgradient extent of benzene and GRO concentrations that exceed the 5 µg/L or 1,300 µg/L cleanup levels, respectively, and
2. If concentrations of NAPs indicate biodegradation of petroleum compounds within the plume.

Data were collected from six hand-driven boreholes spaced about 40 ft apart in an arc along the eastern and southern boundaries of the site at a distance of about 65 ft from existing well 14-100, and from a single upgradient borehole (AG-1) to the northwest of the site (fig. 12).

Field parameters and GRO concentrations (table 7) confirm the historical data and indicate that ground-water flow is from well 14-100 to the east-southeast towards the new well 14-110. Field-GRO concentrations decreased from 3,200 µg/L at well 14-100 to a maximum of 250 µg/L in the boreholes. Water levels in general indicated flow to the east-southeast, although head differences in the boreholes were relatively small compared to possible variation due to heavy rainfall or non-equilibrium water levels. One new monitoring well (14-110) was installed on the centerline of the plume

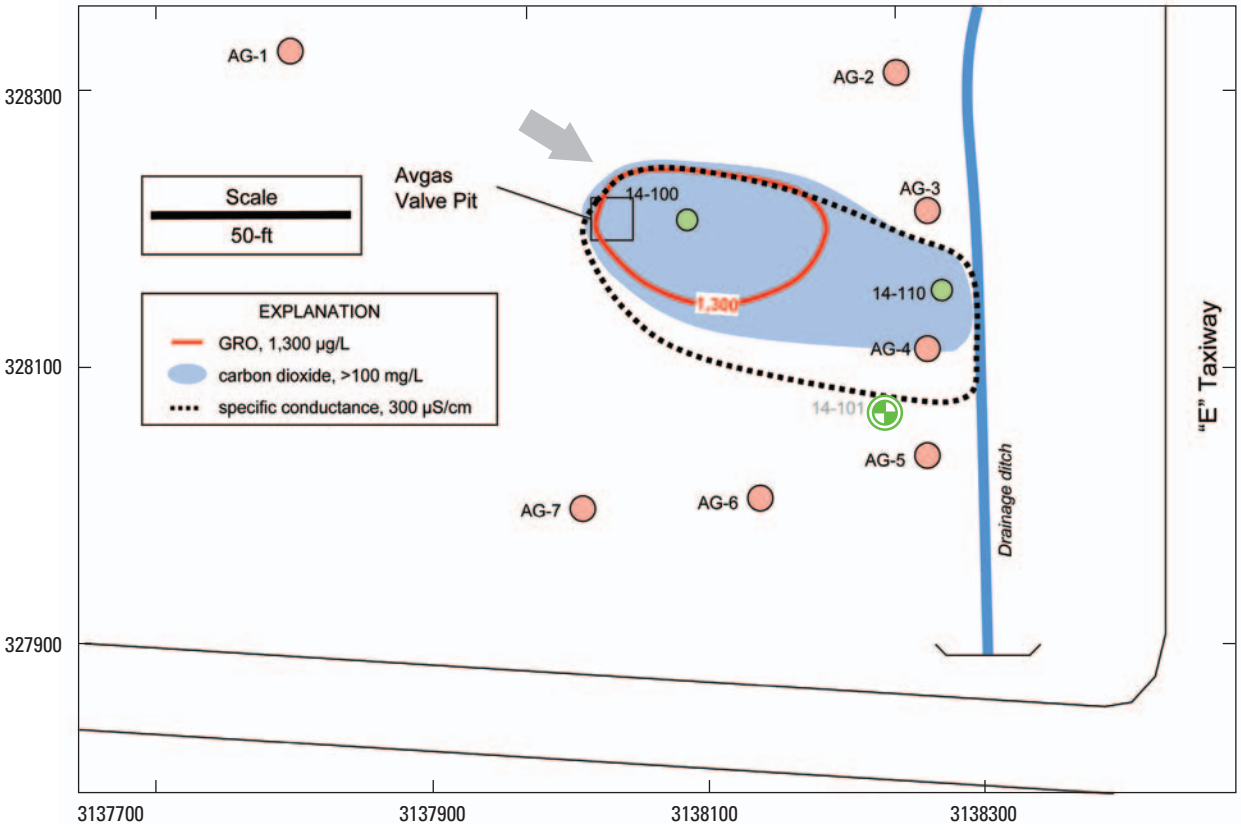

Figure 12. Gasoline range organics (GRO) and carbon dioxide concentrations and specific conductance for the Runway 5-23 Avgas Valve Pit site, Operable Unit A, Adak Island, Alaska, May and June 2003.

Table 7. Selected gasoline range organics, benzene, geochemical, and water-level data from boreholes and wells at the Runway 5-23 Avgas Valve Pit site, Operable Unit A, Adak Island, Alaska, May and June 2003.

[**Borehole or well No.** are shown in figure 12. **Sampling depths** are approximate feet below land surface of the mid-point of the sampling device or well screen. **Water-level altitudes** are in feet above or below (-) NAD27. **Abbreviations:** ft, foot; µg/L, microgram per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter. **Symbols:** <, actual value is less than value shown; –, not analyzed]

Borehole or well No.	Date sampled	Sampling depth (ft)	Water-level altitude (ft)	Gasoline range organics (µg/L)		Benzene (µg/L)		pH (units)	Specific conductance (µS/cm)	Carbon dioxide (mg/L)	Dissolved oxygen (mg/L)	Ferrous iron (mg/L)
				Field	Laboratory	Field	Laboratory					
Boreholes												
AG-1	05-12-03	2.5	12.48	<100	–	<2	–	6.3	217	60	<0.025	35
-2	05-12-03	2.5	11.73	<100	–	<2	–	6.0	235	42	<.025	25
-3	05-12-03	2.5	11.60	250	–	<2	–	6.2	156	18	<.025	30
-4	05-12-03	2.5	11.57	140	–	<2	–	6.3	413	100	<.025	35
-5	05-12-03	2.5	11.55	<100	–	<2	–	5.9	191	50	<.025	30
-6	05-12-03	2.5	11.48	<100	–	<2	–	6.1	137	–	–	–
-7	05-12-03	2.5	11.51	<100	–	<2	–	6.2	156	–	–	–
Monitoring wells												
14-100	05-12-03	6.5	11.80	3,200	–	–	–	5.8	409	160	<0.025	40
-110	06-06-03	6.5	10.85	–	180	–	1.2	6.1	360	150	<.025	45

to monitor GRO concentrations in ground water before it discharges to the surface-water drainage ditch 15 ft farther downgradient; the field-GRO concentrations in boreholes nearest the new well location were 140 µg/L (AG-4) and 250 µg/L (AG-3).

The USGS NAP data indicated active biodegradation at the site primarily through elevated carbon dioxide concentrations. Data from the upgradient borehole AG-1 indicated that ambient ground-water redox conditions were anaerobic with relatively high ferrous iron concentrations, similar to downgradient conditions. Those conditions probably are related to enhanced microbial activity due to the availability of natural sources of organic carbon under the shallow water table at the site. However, biodegradation of petroleum compounds was still indicated at the site by elevated carbon dioxide concentrations in contaminated wells. Background borehole AG-1 had 60 mg/L of carbon dioxide, while the contaminated wells and boreholes (with the exception of AG-3) had carbon dioxide concentrations ranging from 100 to 160 mg/L.

There appears to be an approximate order-of-magnitude attenuation of GRO along the relatively short distance between wells 14-100 and 14-110. Although the stability of the GRO plume at the site cannot be ascertained until additional data are collected from the new downgradient monitoring well, equilibrium conditions probably have been established over the 70 ft between the two wells. The leak occurred prior to 1996 and the estimated ground-water velocity at the site is 97-ft/yr, so ample time has passed for the plume to achieve equilibrium conditions. Historical GRO concentrations at well 14-100 have fluctuated inconsistently between 1,900 and 4,600 µg/L, and GRO never was detected in abandoned well 14-101. Overall, the data indicated active GRO biodegradation at the Avgas Valve Pit site, and that natural attenuation is preventing discharge of ground water with GRO concentrations exceeding 1,300 µg/L to the nearby drainage ditch. Because of the shallow water table, any contaminated ground water from the site would likely discharge to the drainage ditch; however, a borehole was not installed on the downgradient (east) side of the ditch to confirm that hypothesis.

Monitoring suggestions for the Avgas Valve Pit site include:

1. Sampling well 14-110 to monitor the stability of the downgradient contamination, and

2. Sampling well 14-100 to monitor the contaminant source strength over time.

Given the relatively small size of the site, sampling only well 14-110 would probably be suitable if contaminant discharge to surface water is the only concern.

SA 80, Steam Plant No. 4

SA 80, Steam Plant No. 4 (fig. 13) is northwest of the Arctic Acres housing area in the Downtown area of Adak Island (fig. 2). Steam Plant No. 4 was built in the late 1940's and was used to supply steam heat to various buildings, hangars, and barracks. The plant's boilers used jet petroleum (JP-5) from two 23,000 gal steel USTs located southeast of the main building. USTs were filled with jet petroleum from the Main Road pipeline. Whether or not a release occurred directly from either of the USTs during their use is unknown. A fill hose ruptured in 1991, releasing a reported 50-70 gal of JP-5. Trace amounts of fuel were released when the first UST was removed in 1993. The second UST failed a tightness test in 1993, and was removed in 1995 along with the associated piping to the steam building. No holes and little corrosion were observed in either UST during their removal, but the second tank and an adjacent utility vault did contain 4,000 gal of oily water. Field testing after tank removal indicated the presence of petroleum hydrocarbons in the soil. Sources for DRO contamination in ground water possibly are fuel spills related to overfilling, pipe releases, or direct leaks from the USTs. The ROD-specified remedy at the SA 80 site was free product recovery. Measurable free product had been observed in 6 of 15 wells at the site, and passive skimmers were used to recover free product in 5 wells. MNA is being considered as a follow-up remedy for contaminated ground water.

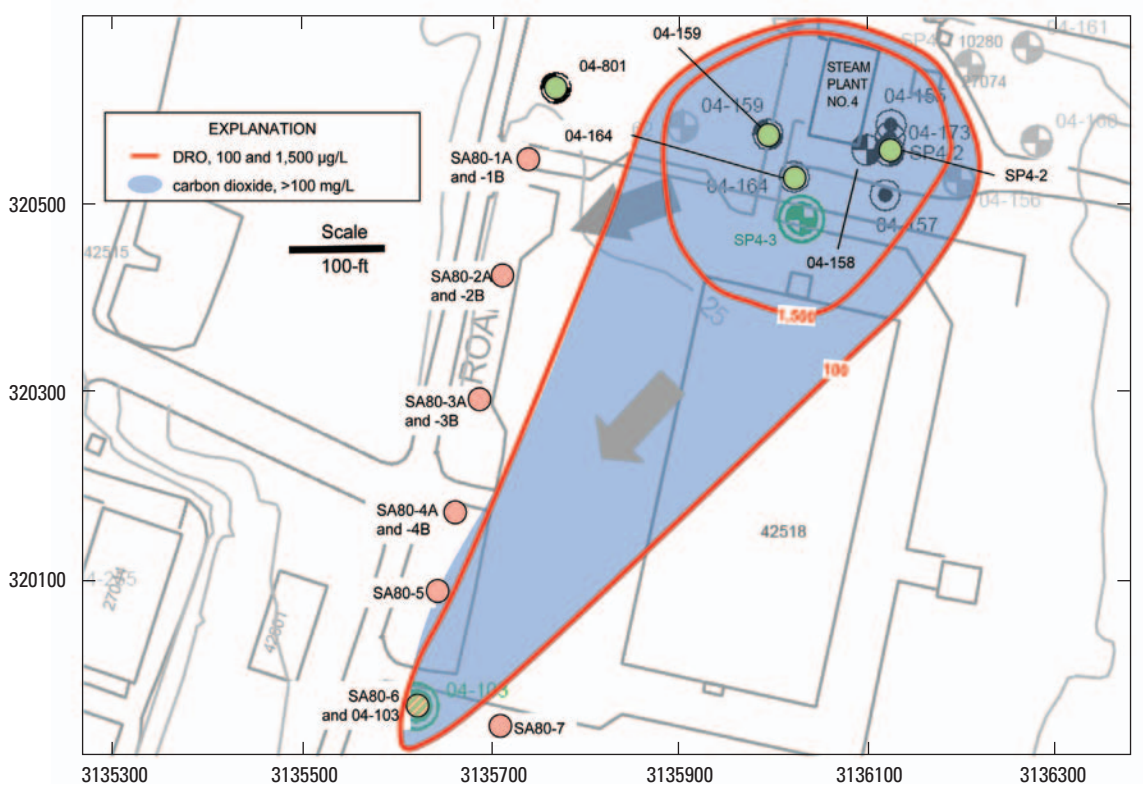

Figure 13. Diesel range organics (DRO) and carbon dioxide concentrations for the SA 80, Steam Plant No. 4 site, Operable Unit A, Adak Island, Alaska, May and June 2003.

The SA 80 site is underlain primarily by sands and silty-sands with some gravel. It has been inferred that ground water flows west-southwest from the site (fig. 13). Depth to ground water at the site is approximately 20 ft. Since 1998, well 04-801 has been regularly monitored for petroleum and NAP concentrations. Assorted historical contaminant concentrations data from multiple wells near the source area are available for selected times between 1996 and 2002, and NAP concentration data are available for 2002.

Objectives at the site were to determine:

1. Downgradient extent of dissolved-phase DRO concentrations that exceed the 1,500 µg/L cleanup levels, and
2. If concentrations of NAPs indicate biodegradation of petroleum compounds within the plume.

To meet the objectives, data were collected from 4 existing wells, 11 boreholes, and 1 new well at the site (table 8).

Table 8. Selected diesel range organics, geochemical, and water-level data from boreholes and wells at the SA 80, Steam Plant No. 4 site, Operable Unit A, Adak Island, Alaska, May and June 2003.

[**Borehole or well No.** are shown in figure 13. **Sampling depths** are approximate feet below land surface of the mid-point of the sampling device or well screen. **Water-level altitudes** are in feet above or below (-) NAD27. **Diesel range organics:** Historical petroleum data collected by the Navy are in italics. **Abbreviations:** ft, foot; µg/L, microgram per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter. **Symbols:** e, compound was detected but concentration was estimated; <, actual value is less than value shown; –, not analyzed]

Borehole or well No.	Date sampled	Date of historical petroleum data	Sampling depth (ft)	Water-level altitude (ft)	Diesel range organics (µg/L)		pH (units)	Specific conductance (µS/cm)	Carbon dioxide (mg/L)	Dissolved oxygen (mg/L)	Ferrous iron (mg/L)
					Field	Laboratory					
Boreholes											
SA 80-1A	05-19-03	–	20	7.18	–	–	5.8	239	21	7	0.4
-1B	05-19-03	–	30	7.02	–	–	6.3	191	22	8	.3
-2A	05-19-03	–	20	7.00	–	–	6.3	174	12	9	.1
-2B	05-19-03	–	30	6.88	–	–	6.1	163	26	9	–
-3A	05-19-03	–	20	6.89	–	–	5.9	201	18	8	.6
-3B	05-19-03	–	30	6.85	–	–	5.8	208	27	8	.8
-4A	05-19-03	–	20	6.69	<100	–	6.0	248	27	4	1.0
-4B	05-19-03	–	30	6.75	<100	–	5.9	263	50	.1	1.6
-5	05-19-03	–	30	6.53	<100	–	5.6	250	100	.15	1.7
-6	05-19-03	–	29	6.45	230	50e	5.9	272	150	<.025	1.8
-7	05-19-03	–	29	6.64	<100	–	6.2	239	26	3	1.5
Monitoring wells											
04-103	06-05-03	–	27	6.17	–	210	6.2	290	65	<0.025	18
-159	05-08-03	08-02-02	23	7.42	–	*3,300*	6.1	927	190	<.025	100
-164	05-08-03	08-02-02	22	7.44	–	*6,100*	5.9	818	180	<.025	70
-801	05-08-03	10-14-02	22	7.19	–	*80e*	5.4	341	40	3	<.05
SP4-2	05-08-03	08-02-02	8	–	–	*9,600*	5.8	939	250	<.025	400

Available NAP data from the presumed downgradient well 04-801 gave no indication of contamination (ground water was aerobic with little ferrous iron and low alkalinity).
An exposed bedrock ridge is about 500 ft west-northwest of SA 80, so it was presumed that ground-water flow from SA 80 was diverted towards the southwest. Thus, the current investigation focused on the area south of well 04-801. Building 42518 (south-southwest of SA 80) is surrounded by a thick apron of concrete that was impenetrable by the Geoprobe®, so the search for the downgradient DRO plume was done along the western margin of the apron.

DRO and NAP data (table 8) indicated that the contaminant plume flows southwest from Steam Plant No. 4 (fig. 13). Water levels somewhat suggested flow towards the west-southwest, but no boreholes could be installed under the concrete apron to obtain the widespread data needed to create a reliable flow map. Both shallow (20 ft) and deep (30 ft) boreholes (designated A and B, respectively on fig. 13) were installed at the first four locations (SA 80-1 through SA 80-4) to identify the depth of the plume. Anaerobic ground water and a slightly elevated carbon dioxide concentration at SA 80-4B were interpreted to indicate the lateral margin of the DRO plume. DRO was positively detected at SA 80-4B (as well as SA 80-5), but at concentrations too low (<100 µg/L) to quantify in the field. The centerline of the plume was identified at SA 80-6 from a DRO concentration of 230 µg/L and peak specific conductance and carbon dioxide concentration. The final borehole (SA 80-7) was interpreted to delimit the eastern boundary of the DRO plume.

The USGS NAP data indicated active biodegradation at the SA 80 site through elevated carbon dioxide concentrations throughout the contaminant plume, in addition to substantially elevated ferrous iron concentrations near the source area. Historical NAP data from near the source area (04-158, SP4-2, and SP4-3, data not shown) showed methane concentrations up to 100 mg/L and sulfide concentrations up to 0.3 mg/L, both indicators of substantial microbial activity and biodegradation. NAP data from boreholes SA 80-1 (A and B) through SA 80-3 (A and B) and well 04-801 are representative of uncontaminated background water at the site.

There appears to be nearly a two orders-of-magnitude attenuation of DRO (9,600 to 210 µg/L) along the flow path between SP4-2 and new well 04-103, although the stability of the DRO plume at the site cannot be ascertained until additional data are collected from the new downgradient monitoring well. Historical DRO concentrations from wells near the source showed no consistent trend between 1996 and 2002, although those data were likely affected by the starting and cessation of free product recovery from recovery wells at the site. Overall, the data indicated active DRO biodegradation at the SA 80 site, and as of 2003 natural attenuation is preventing DRO concentrations that exceed 1,500 µg/L from extending as far as 600 ft downgradient. DRO contamination in ground water is detectable somewhat farther downgradient from the source area when compared to other Downtown area petroleum sites. A plausible explanation for that observation is that the concrete apron surrounding Building 42518 does not allow recharge of oxygen rich water and subsequent aerobic biodegradation, so petroleum biodegradation outside of the source area is through one of the less efficient anaerobic processes.

If MNA is selected as a remedy for contaminated ground water at the SA 80 site, monitoring suggestions include:

1. Sampling well 04-103 to monitor the stability of the downgradient contamination, and

2. Sampling well SP4-3 or a similar source area well to monitor the contaminant source strength over time.

Well 04-801 also could be sampled if additional background water-chemistry data are desired, but the available data are strong indicators that the well is not on a contaminated flow path from Steam Plant No. 4.

SWMU 14, Old Pesticide Storage and Disposal Area

Solid Waste Management Unit (SWMU 14) (fig. 14) site is a vacant property in the southern part of the Downtown area near Sweeper Cove (fig. 2). From 1950 to about 1987, a motor vehicle gasoline filling station and a pesticide storage and disposal area were in a building near well MW14-5. No evidence of USTs has been detected at the site. The service station probably was supplied by pipe from an AST about 800 ft west of the building. The release history of the site is not known. GRO and DRO that presumably leaked from the AST or associated piping are the primary contaminants of concern at the site. MNA is the ROD-specified remedy at the SWMU 14 site.

SWMU 14 is underlain primarily by sands and silty-sands with some gravel. It has been inferred that ground water flows south from the site towards Sweeper Cove (about

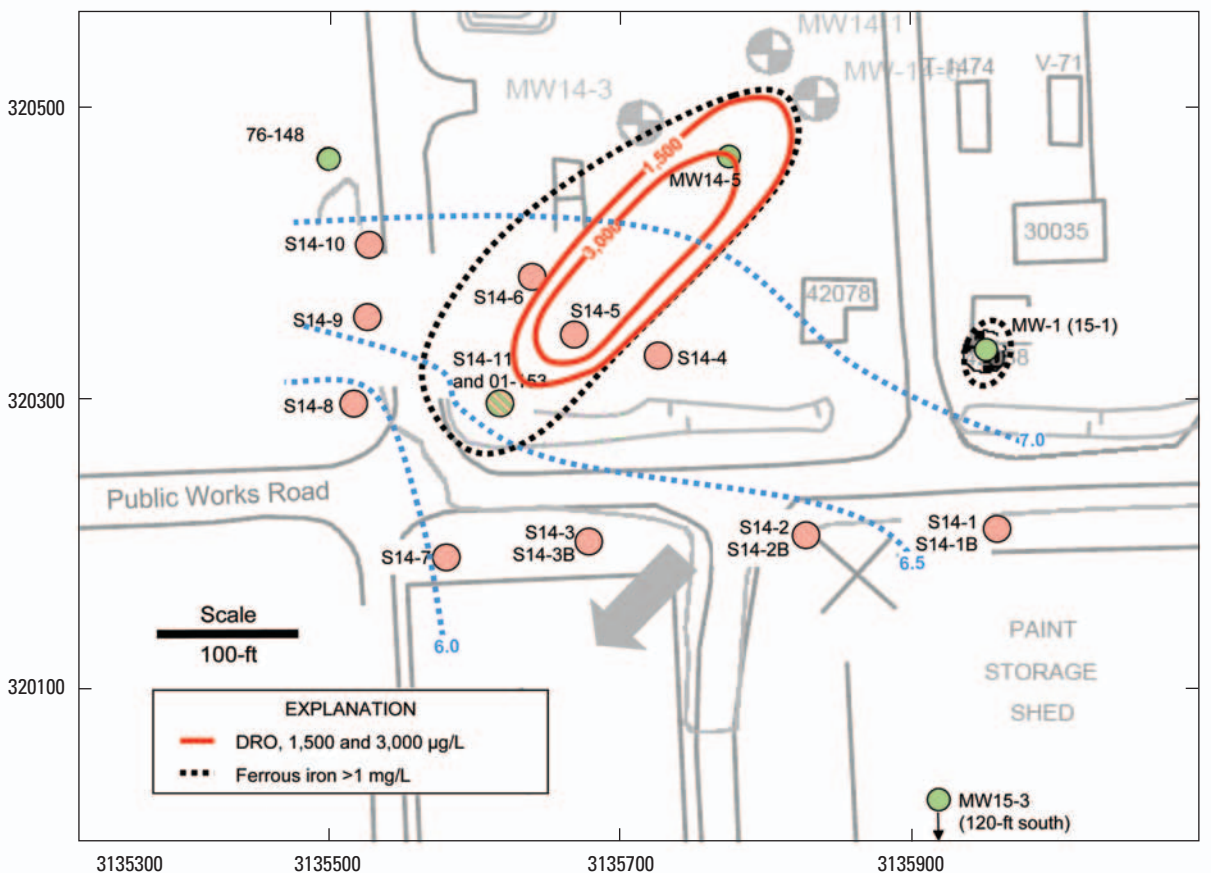

Figure 14. Diesel range organics (DRO) and ferrous iron concentrations, and water levels for the SWMU 14, Old Pesticide Storage and Disposal Area site, Operable Unit A, Adak Island, Alaska, May and June 2003.

1,200 ft due south). Depth to ground water at the site is about 15 ft. One well at the site (MW14-5) has been monitored regularly since 1998, including NAP data. A second well (MW14-423, not shown) 900 ft south-southwest of well MW14-5, has been monitored for petroleum and NAP concentrations regularly since 1999. Limited historical contaminant concentration data from abandoned upgradient wells also are available, but those concentrations are substantially less than those observed at well MW14-5.

Objectives at the site were to determine:

1. Downgradient extent beyond well MW14-5 of dissolved-phase DRO and GRO concentrations that exceed the 1,500 µg/L and 1,300 µg/L cleanup levels, respectively, and

2. If concentrations of NAPs indicate biodegradation of petroleum compounds within the contaminant plume.

To meet those objectives, data were collected from 4 existing wells, 14 boreholes, and 1 new well (01-153) at the site (table 9). The investigation started due south of the source

Table 9. Selected diesel range organics, gasoline range organics, geochemical, and water-level data from boreholes and wells at the SWMU 14, Old Pesticide Storage and Disposal Area site, Operable Unit A, Adak Island, Alaska, May and June 2003.

[**Borehole or well No.** are shown in figure 14. **Sampling depths** are approximate feet below land surface of the mid-point of the sampling device or well screen. **Water-level altitudes** are in feet above or below (-) NAD27. **Diesel and gasoline range organics:** Historical petroleum data collected by the Navy are in italics. **Abbreviations:** ft, foot; µg/L, microgram per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter. **Symbols:** e, compound was detected but concentration was estimated; <, actual value is less than value shown; –, not analyzed]

Borehole or well No.	Date sampled	Date of historical petroleum data	Sampling depth (ft)	Water-level altitude (ft)	Diesel range organics (µg/L)		Gasoline range organics (µg/L)		pH (units)	Specific conductance (µS/cm)	Carbon dioxide (mg/L)	Dissolved oxygen (mg/L)	Ferrous iron (mg/L)
					Field	Laboratory	Field	Laboratory					
Boreholes													
S14-1	05-17-03	–	14	6.81	–	–	<100	–	6.4	397	15	7	0.03
-1B	05-18-03	–	24	6.69	–	–	<100	–	6.8	301	11	.3	.71
-2	05-17-03	–	14	6.38	–	–	<100	–	6.7	430	16	7	.77
-2B	05-18-03	–	24	6.32	–	–	<100	–	6.2	174	20	.2	.34
-3	05-17-03	–	14	6.22	–	–	<100	–	6.6	579	15	7	.13
-3B	05-18-03	–	24	6.18	–	–	<100	–	6.0	309	30	6	.33
-4	05-18-03	–	18	6.70	–	–	<100	–	6.3	246	18	4.5	.33
-5	05-18-03	–	18	6.70	3,700	–	12,000	–	6.2	377	30	.05	1.5
-6	05-18-03	–	18	6.79	870	–	2,400	–	6.2	410	55	<.025	1.2
-7	05-18-03	–	18	6.06	–	–	<100	–	6.0	435	23	6	.34
-8	05-18-03	–	18	5.42	–	–	<100	–	6.5	217	18	10	.17
-9	05-19-03	–	18	6.77	–	–	<100	<50	5.5	368	20	7	.64
-10	05-19-03	–	18	6.95	–	–	<100	–	6.0	250	14	7	.18
-11	05-19-03	–	18	6.68	220	–	180	310	6.1	271	42	1.5	1.7
Monitoring wells													
MW-14-5	05-07-03	10-12-02	17	7.16	–	*3,000*	–	*12,000*	5.9	258	26	0.05	6
-1(15-1)	05-07-03	08-11-98	14	7.26	–	*450*	–	*<100*	6.0	340	30	5.4	3
-15-3	05-07-03	10-14-02	20	5.17	–	*<100*	–	*13e*	6.4	411	33	1.7	4
01-153	06-04-03	–	19	6.48	–	550	–	63e	6.3	313	45	.9	7.5
76-148	05-07-03	–	18	7.26	–	–	–	–	6.1	434	25	5.9	<.05

area near well MW14-5 along Public Works Road with boreholes S14-1 through S14-3. Both shallow (14 ft) and deep (24 ft) boreholes (deep boreholes designated B on fig. 14) were installed to identify the depth of the plume, but no contamination was detected and NAP data did not definitively indicate upgradient contamination. The investigation then moved closer to MW14-5 to clearly locate the contaminant plume and identify the southwest ground-water flow direction, and finally moved out farther to define the extent of contamination. Multiple buried utility lines are in the area, so boreholes could not be installed at all desired locations.

DRO, GRO, and ferrous iron data (table 9) indicated that the contaminant plume was flowing southwest from well MW14-5. Water-level altitudes consistently decreased towards the west in the boreholes along Public Works Road, also indicating that water from MW14-5 was not flowing due south. The centerline of the contaminant plume was identified at borehole S14-5, where both DRO and GRO concentrations exceeded the cleanup levels, and also at S14-11, where both DRO and GRO concentrations were less than the cleanup levels. New well 01-153 was installed to monitor the distal part of the contaminant plume near Public Works Road where DRO and GRO concentrations were 220 and 310 µg/L, respectively.

The USGS NAP data indicated some biodegradation at the SWMU 14 site, although carbon dioxide concentrations in contaminated wells were only marginally greater than those in cross-gradient uncontaminated wells. All contaminated wells were anaerobic, but deep uncontaminated boreholes in the area also were anaerobic. Ferrous iron concentrations exceeding 1 mg/L were a consistent indicator of enhanced microbial activity in contaminated wells. Historical NAP data from MW14-5 showed essentially no methane or sulfide, and ferrous iron concentrations of 1.8 to 3.6 mg/L. Data from well 76-148 best represents uncontaminated background water at the site because it is well off the contaminated flow path, and outside the built-up industrial area. Past intensive land-use activities in the areas south of Public Works Road and near well MW14-5 had a high potential for multiple small-scale releases of petroleum compounds.

Despite the suggestion of only moderate biodegradation, there appears to be nearly a two orders-of-magnitude attenuation of GRO along the flow path between MW14-5 and new well 01-153 (12,000 to 63e µg/L), and a one-order-of-magnitude attenuation of DRO (3,000 to 550 µg/L). Relative attenuation rates are consistent with the theory that GRO has more readily biodegradable compounds than does DRO. As with most other Adak sites, the stability of the contaminant plume at the site cannot be determined until additional data are collected from the new downgradient monitoring well (01-153). Historical GRO concentrations from MW14-5 appear to have consistently decreased from a peak of 32,000 µg/L during 1995, but DRO concentrations from MW14-5 showed no consistent trend between 1995 and 2002. Overall, the data indicate active biodegradation at the SWMU 14 site, and that natural attenuation as of 2003 is preventing GRO and DRO concentrations that exceed the cleanup levels from extending more than about 200 ft downgradient. Benzene was not detected (at a detection limit of 2 µg/L) in the laboratory analyses of samples collected from the new well 01-153 or from borehole S14-11 (data not shown).

Monitoring suggestions include:

1. Sampling well 01-153 to monitor the stability of the downgradient contamination, and

2. Sampling well MW14-5 to monitor the contaminant source strength over time.

Downgradient well MW14-423 (not shown) is far beyond the current extent of contamination from the SWMU 14 site, so continued monitoring of that well would not be useful for MNA monitoring.

SWMU 61, Tank Farm B

SWMU 61, Tank Farm B (fig. 15) is on the hillside west of Sweeper Creek in the northwest part of the Downtown area (fig. 2). The site was a former bulk fuel storage facility and had multiple ASTs and associated pipelines. The release history and specific source of contamination is unknown. GRO and benzene are the contaminants of concern with an estimated mass of 1,300 to 4,000 lb in the soil at the site. Monitoring wells TFB-MW4A and B (a pair of existing wells adjacent to one another where the "B" well is the deeper of the two) are downgradient from two former storage tanks. MNA is the ROD-specified remedy at the site.

The geology of the Tank Farm B site is not typical for Downtown area sites. The upland portion of the Tank Farm B site is underlain primarily by dense lahar deposits consisting of poorly sorted, cobble and boulder gravel in a matrix of silt and fine sand. The lowland portion of the site is underlain by lagoonal deposits consisting of a mix of sand, silt, peat, and clay. Upland deposits are of highly variable permeability and water-bearing capacity, while the lowland deposits are porous and permeable. It has been inferred that ground water flows northeast from the TFB-MW4 wells beneath the well-defined swale, and then across the lagoonal deposits to Sweeper Creek. Depth to ground water in the TFB-MW4 and 14-210 wells is 2 to 4 ft, and the water table is a few inches below the spongy land surface in the lowland area between

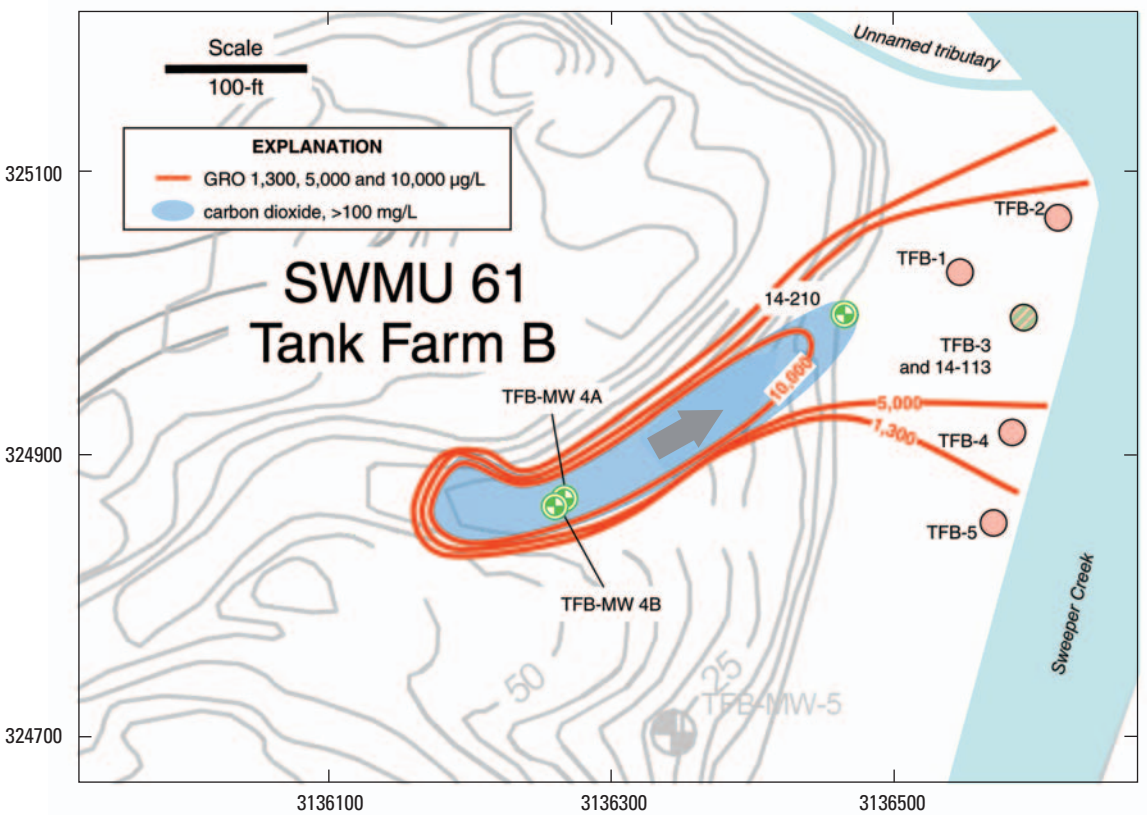

Figure 15. Gasoline range organics (GRO) and carbon dioxide concentrations for the SWMU 61, Tank Farm B site, Operable Unit A, Adak Island, Alaska, May and June 2003.

well 14-210 and North Sweeper Creek. TFB-MW4 wells have been monitored regularly for petroleum compounds since 1996, and the TFB-MW4 wells and well 14-210 have been monitored for petroleum compounds and NAPs since 1999. Abandoned well TFB-MW5 was sampled once for petroleum compounds in 1996, and none were detected.

Objectives at the site were to determine:

1. Downgradient extent of dissolved-phase benzene and GRO concentrations that exceed the 5 µg/L or 1,300 µg/L cleanup levels, respectively, and
2. If concentrations of NAPs indicate biodegradation of petroleum compounds within the plume.

Five hand-driven boreholes and three monitoring wells were sampled at the site to meet these objectives. Four boreholes spaced about 60 ft apart were installed along the west bank of Sweeper Creek in a transect starting near an unnamed tributary flowing into Sweeper Creek and continuing south about 240 ft. A fifth borehole was installed about midway from existing well 14-210 and Sweeper Creek along the flow path centerline, which was determined from surveyed water-level information.

Benzene and GRO data (table 10) indicate that the contaminant plume flows east across the lowlands and into Sweeper Creek. Field-GRO concentrations ranging from 260 to 9,700 µg/L were detected in boreholes along the bank of Sweeper Creek. The centerline of the contaminant

Table 10. Selected gasoline range organics, benzene, geochemical, and water-level data from boreholes and wells at the SWMU 61, Tank Farm B site, Operable Unit A, Adak Island, Alaska, May and June 2003.

[**Borehole or well No.** are shown in figure 15. **Sampling depths** are approximate feet below land surface of the mid-point of the sampling device or well screen. **Water-level altitudes** are in feet above or below (-) NAD27. **Gasoline range organics:** Historical petroleum data collected by the Navy are in italics. **Abbreviations:** ft, foot; µg/L, microgram per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter. **Symbols:** <, actual value is less than value shown; –, not analyzed]

Borehole or well No.	Date sampled	Date of historical petroleum data	Sampling depth (ft)	Water-level altitude (ft)	Gasoline range organics (µg/L)		Benzene (µg/L)		pH (units)	Specific conductance (µS/cm)	Carbon dioxide (mg/L)	Dissolved oxygen (mg/L)	Ferrous iron (mg/L)
					Field	Laboratory	Field	Laboratory					
Boreholes													
TFB-1	05-13-03	–	3	7.19	9,600	–	<2	–	–	260	55	<0.025	20
-2	05-13-03	–	3	6.24	6,000	–	<2	–	–	300	70	<.025	35
-3	05-13-03	–	4	6.28	9,700	–	850	–	–	310	45	<.025	30
-4	05-13-03	–	4	6.46	2,700	–	<2	–	–	307	40	<.025	12
-5	05-13-03	–	4	6.54	260	–	7	–	–	220	45	.2	.6
Monitoring wells													
14-113	06-07-03	–	3	6.00	–	2,000	–	15	–	–	–	–	–
-210	05-13-03	–	7.9	8.81	8,100	–	<2	–	6.4	212	100	<0.025	60
TFB-MW-4A	05-13-03	–	6	33.83	<100		<2		5.9	334	140	.2	35
-4B	05-13-03	10-07-02	15	33.48	–	*29,000*	–	*50*	6.0	329	45	<.025	15

plume was identified at borehole TFB-3 where GRO and benzene concentrations substantially exceeded cleanup levels. GRO also exceeded the cleanup levels in the two boreholes immediately north and south of TFB-3, along the bank of Sweeper Creek. A new well (14-113) was installed to monitor discharge of the contaminant plume immediately before it enters Sweeper Creek.

USGS data and historical NAP data indicated some biodegradation of petroleum in the upland portion of the site, but indicated little biodegradation in the lowland portion. Ground water in all boreholes and wells was anaerobic with relatively high ferrous iron concentrations and specific conductance. No wells were available to sample background conditions for the uplands, and the direct-push rig could not penetrate the sediments to obtain a sample for this investigation. Carbon dioxide did appear to be elevated (140 mg/L) in the shallowest upland well TFB-MW4A, although that well historically has had often detectable, but low, GRO concentrations of less than 100 µg/L. The deeper well, TFB-MW4B, historically has had GRO concentrations up to 57,000 µg/L, but substantially less carbon dioxide (45 mg/L) was detected in May 2003. In contrast, six rounds of historical NAP data from the well pair indicate that both wells have similar alkalinity concentrations, with an average of 124 mg/L as $CaCO_3$ in the deep well and an average of 112 mg/L in the shallow well. Historical methane concentrations ranged from 3 to 9.4 mg/L for the shallow well and 1.7 to 2.3 mg/L for the deep well. Overall, these data suggest that biodegradation may be at least partly responsible for the lower petroleum concentrations detected in the shallowest upland well. In the lowlands, however, carbon dioxide and other NAP concentrations showed little variability and gave no clear indication of active petroleum biodegradation. Ambient conditions for the saturated and organic-rich flood plain were expected to be anaerobic, so anaerobic and iron-rich water at the contaminated boreholes is not distinctly indicative of petroleum biodegradation.

Consistent with the results regarding biodegradation, attenuation of GRO concentrations was apparent in the upland portion of the site, but not apparent in the lowland portion. October 2002 data show an approximately one order-of-magnitude attenuation of GRO along the upland flow path between TFB-MW4B and 14-210 (29,000-2,300 µg/L). For this investigation, a higher field-GRO concentration of 8,100 µg/L was detected at 14-210 in May 2003, but the upland well TFB-MW4B would not yield enough water to collect a sample for field or lab analysis. May 2003 data indicated essentially no attenuation along the lowland flow path between well 14-210 and boreholes TFB-1 and TFB-3. Like most other Adak sites, the stability of the contaminant plume at the site cannot be determined until additional data are collected from the new downgradient monitoring well. October 2002 GRO concentrations from monitoring wells at Tank Farm B were the lowest observed to date, but there was no clear decreasing trend before that date. Overall, the data indicated that, despite some active biodegradation at the upland portion of the Tank Farm B site, as of 2003 natural attenuation is not preventing benzene and GRO concentrations that exceed the cleanup levels from discharging to Sweeper Creek.

Monitoring suggestions include:

1. Sampling well 14-113 to monitor the contaminant concentrations in ground water near Sweeper Creek, and

2. Sampling well TFB-MW4B to monitor concentrations near the contaminant source over time.

Intermediate well 14-210 also could be sampled to add duration to the historical dataset, but the contaminant concentrations from well 14-113 would be more indicative of what may be reaching surface water. Bed-sediment porewater under Sweeper Creek could be sampled using diffusion samplers, or a similar technology, to directly measure petroleum concentrations discharging to surface water, if that is considered a critical issue.

SWMU 62, New Housing Fuel Leak (Sandy Cove Housing)

Solid Waste Management Unit (SWMU) 62 includes several base housing areas in the Downtown area constructed for military and civilian personnel and their families (fig. 2). At least four distinct petroleum plumes have been identified in the Sandy Cove housing area of SWMU 62, but this investigation was focused only on the southernmost plume (fig. 16) suspected to originate near housing unit 134 (labeled as building 42234 in fig. 16). The housing unit is served by a JP-5 fuel oil furnace and hot water heater. Two 30,000 gal ASTs on raised earth pads are just south of Raven Street and about 300 ft east of the contamination plume of interest. Fuel is distributed from the ASTs to individual housing units via main distribution lines, lateral lines, and 0.5 in. copper pipes. The Navy did visual inspections and inventory record reviews in 1988, after occupants reported hydrocarbon odors. Contaminated soil was detected and removed from the crawl space below unit 134 in 1988, and free product was first detected in monitoring wells in 1989. The ROD-specified remedy at the Sandy Cove housing area of SWMU 62 was free product recovery. Between 1989 and 1990, 1,563 gal of free product was removed from the area. DRO is the petroleum contaminant of concern at the site, although chlorinated solvents also have been detected at concentrations exceeding cleanup levels in well MW-134-10. The investigation did not focus on the chlorinated solvents, but samples from the

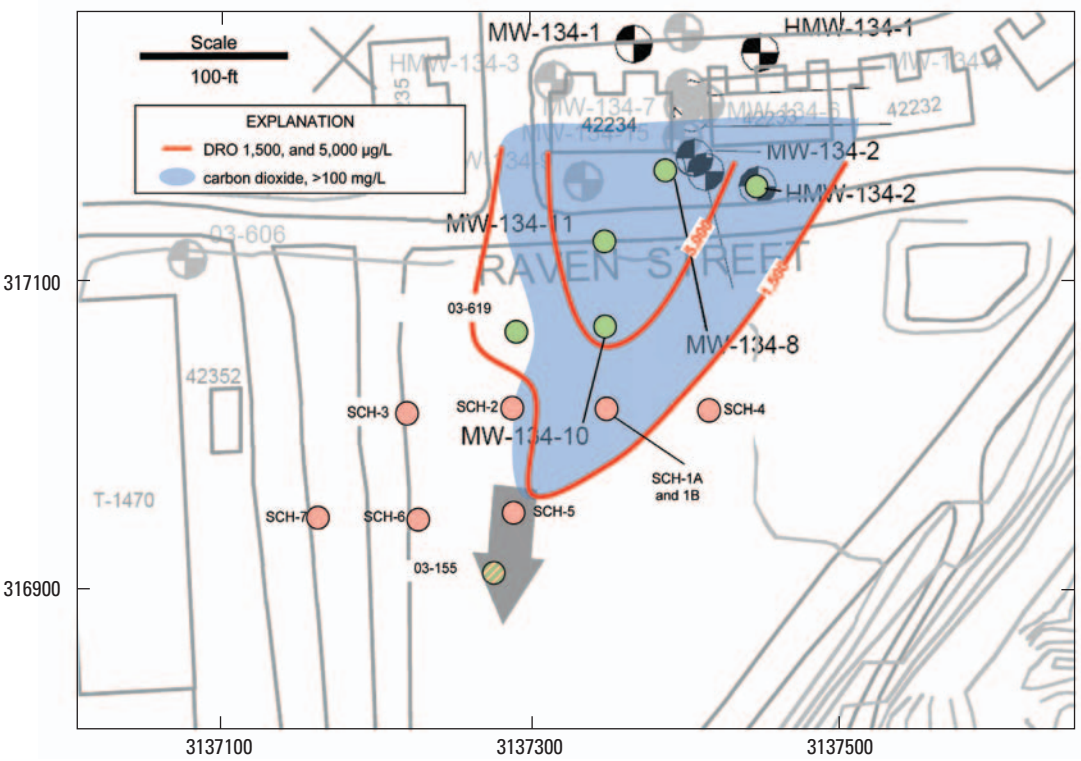

Figure 16. Diesel range organics (DRO) and carbon dioxide concentrations for the SWMU 62, New Housing Fuel Leak (Sandy Cove Housing) site, Operable Unit A, Adak Island, Alaska, May and June 2003.

newly installed monitoring well were analyzed for solvents using EPA method SW8260B (U.S. Environmental Protection Agency, 2003). MNA is being considered as a follow-up remedy for contaminated ground water.

The Sandy Cove housing area is underlain primarily by sands and silty-sands with some gravel. It has been inferred that ground water flows south-southwest from the site towards Sweeper Cove (about 1,700 ft downgradient). Depth to ground water at the site is about 15 to 20 ft. Abundant historical contaminant concentration data are available dating from 1989, and one well (03-619) has been monitored regularly since 1998.

Objectives at this site were to determine:

1. Downgradient extent of DRO concentrations that exceed the 1,500 µg/L cleanup level, and,
2. If NAP data indicate biodegradation of petroleum compounds within the contamination plume.

To meet the objectives, data were collected from five existing wells, eight boreholes, and one new well (03-155) (table 11). An initial east-west transect of four boreholes spaced about 75 ft apart was installed 75 ft south of existing well 03-619. Both shallow (17 ft) and deep (22 ft) boreholes (designated A and B, respectively on fig. 16) were installed at the first

Table 11. Selected diesel range organics, geochemical, and water-level data from boreholes and wells at the SWMU 62, New Housing Fuel Leak (Sandy Cove Housing) site, Operable Unit A, Adak Island, Alaska, May and June 2003.

[**Borehole or well No.** are shown in figure 16. **Sampling depths** are approximate feet below land surface of the mid-point of the sampling device or well screen. **Water-level altitudes** are in feet above or below (-) NAD27. **Diesel range organics:** Historical petroleum data collected by the Navy are in italics. **Abbreviations:** ft, foot; µg/L, microgram per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter. **Symbols:** e, compound was detected but concentration was estimated; <, actual value is less than value shown; –, not analyzed]

Borehole or well No.	Date sampled	Date of historical petroleum data	Sampling depth (ft)	Water-level altitude (ft)	Diesel range organics (µg/L)		pH (units)	Specific conductance (µS/cm)	Carbon dioxide (mg/L)	Dissolved oxygen (mg/L)	Ferrous iron (mg/L)
					Field	Laboratory					
Boreholes											
SCH-1A	05-22-03	–	17	8.49	730	3,200	5.9	497	170	0.05	1.6
-1B	05-22-03	–	22	8.55	80e	–	5.6	267	80	.2	.9
-2	05-22-03	–	18	8.44	180	–	6.1	470	100	.9	1.7
-3	05-22-03	–	18	8.34	–	–	6.4	218	16	5	.22
-4	05-22-03	–	18	8.61	<100	–	5.7	261	45	1.5	.7
-5	05-22-03	–	19	8.19	860	490	6.3	289	32	1.5	1.3
-6	05-22-03	–	19	8.26	<100	–	5.8	211	45	3	.8
-7	05-22-03	–	19	8.20	–	–	6.6	175	11	8	<.05
Monitoring wells											
03-155	06-04-03	–	17	8.04	–	1,200	6.0	287	100	3.5	35
-619	05-10-03	09-02-01	15	8.48	–	*2,600*	5.3	297	60	.4	3.0
HMW-134-2	05-10-03	09-02-01	17	8.67	–	*2,870*	6.1	363	170	<.025	22
MW-134-8	05-10-03	–	18	8.66	–	–	5.9	291	120	<.025	15
-134-10	05-10-03	09-02-01	17	8.55	–	*5,030*	5.9	404	200	<.025	30
-134-11	05-10-03	09-02-01	17	8.59	–	*7,450*	6.0	439	210	<.025	18

location (SCH-1) to identify the depth of the plume. To assure that the distal part of the plume was sampled, a second transect of boreholes was installed 100 ft farther south of the first transect.

Water-level, DRO, and carbon dioxide data (table 11) indicate that the contaminant plume flows south-southwest from the highest concentration source area well near the east side of unit 134. The centerline and depth of the contaminant plume was first identified by high DRO, carbon dioxide, and ferrous iron concentrations at the shallow borehole SCH-1A. The plume extent was tracked farther downgradient to borehole SCH-5 in the second transect, with a field-DRO concentration of 860 µg/L. DRO concentrations less than 100 µg/L in boreholes SCH-4 and SCH-6 defined the lateral extent of the plume. New well 03-155 was installed about 40 ft downgradient from SCH-5 to monitor the distal part of the DRO plume along the most contaminated flow path. Subsequent lab-DRO concentration in well 03-155 (1,200 µg/L) was below the cleanup level. Trichloroethene was the only chlorinated solvent detected in the well at a concentration of 2 µg/L. At borehole SCH-5 (interpreted from field data to be on the centerline of the flow path immediately upgradient from 03-155), the relatively low lab-DRO (490 µg/L) and carbon dioxide concentrations, combined with the relatively high dissolved-oxygen concentration suggest that the borehole was screened on the fringe of the contaminant plume, while the monitoring well is screened across the core of the plume.

The USGS NAP data indicate biodegradation at the Sandy Cove housing area by a ten-fold increase above background levels in carbon dioxide concentrations in the most contaminated wells. Ferrous iron concentrations also were elevated in petroleum contaminated samples. Data from boreholes SCH-3 and SCH-7 appear to best represent uncontaminated background water at the site because the water from those sites was aerobic, with ferrous iron concentrations of 0.22 mg/L or less, and carbon dioxide concentrations of 11 and 16 mg/L, respectively. Two of the contaminated samples from well 03-155 and borehole SCH-5 had dissolved-oxygen concentrations greater than 1 mg/L, but the elevated ferrous iron concentrations in those same samples suggest that they are a mix of aerobic and anaerobic water from different depths penetrated by the screens.

There appears to be an approximately six-fold attenuation of lab-DRO along the flow path between MW134-11 and new well 03-155 (7,450 to 1,200 µg/L). Overall attenuation is approximate because the upgradient concentration is from 2001, but a three-fold attenuation of lab-DRO (3,200 to 1,200 µg/L) between SCH-1A and 03-155 was observed in 2003. As with most other Downtown area sites, the stability of the contaminant plume at the site cannot be ascertained until additional data are collected from the new downgradient monitoring well. Historical DRO concentrations from wells near the source area showed no consistent trend between 1996 and 2002, although those data were likely affected by the start and end of free product recovery from wells at the site. Overall, the data indicate active biodegradation at the Sandy Cove housing area, and that as of 2003 natural attenuation is preventing DRO concentrations that exceed the cleanup levels from extending more than about 200 ft downgradient.

If MNA is selected as a remedy for this site, monitoring suggestions include:

1. Sampling well 03-155 to monitor the stability of the downgradient contamination, and

2. Sampling well MW134-11 to monitor the contaminant source strength over time.

Existing well 03-619 appears to be on the west side of the contaminant plume and could be sampled to monitor the lateral extent of DRO, but the new well 03-155 appears to be more directly on the contaminant flow path.

Tanker Shed

The Tanker Shed site (fig. 17) is near an airport runway in the Downtown area of Adak Island (fig. 2). This site was used for maintenance on tanker trucks that transported fuel and heating oil around the base. The Tanker Shed facility included a 6,000 gal UST, and a 12 ft by 60 ft recessed pit with catch basin (sump), which was used as a vehicle wash rack. Used oil generated from truck maintenance and waste fluids from an oil/water separator system associated with the vehicle wash rack was stored in the UST. The Tanker Shed is believed to have been constructed during the 1960s, but the UST was functional only from 1985 to 1995. When the UST was removed in 1995, the 6,000 gal, double-walled, fiberglass tank was reported to be in good condition. No record of releases or spills exist for the Tanker Shed site; however, oil stains, strong petroleum hydrocarbon odor, and heavy sheen on ground water in the tank excavation indicate that an unknown quantity of fuel and oil was released. The probable source of contamination was overfill or pipe leakage. DRO is the petroleum contaminant of concern at the site. Since 1996, free product has been detected in 12 monitoring wells around the Tanker Shed, so the ROD-specified remedy was free product recovery. Over 200 gal of free product were removed between 1997 and 1998. MNA is being considered as a follow-up remedy for contaminated ground water.

The Tanker Shed site is underlain primarily by sands and silty-sands with some gravel. It has been inferred that ground water flows west towards East Canal (approximately 800 ft downgradient). Depth to ground water at the site is about 8 to 10 ft. Abundant historical contaminant concentration data, as far back as 1996, are available for the site, and well 04-601 has been monitored regularly as a sentinel well since 1998.

Objectives at the site were to determine:

1. If the downgradient well TS-01 is on the centerline of the contaminant plume flow path and is suitably located to monitor the extent of contamination and plume stability, and

2. If NAP data indicate biodegradation of petroleum compounds within the plume.

To meet these objectives, data were collected from six existing wells and four boreholes (table 12). Two boreholes (TSB-1A and TSB-1B) were nested to determine the depth distribution of contaminants before they passed under the taxiway west of the site. Two other boreholes (TSB-2 and TSB-3) were placed north and south of the first pair to delimit the lateral extent of the contaminant plume.

DRO concentrations (table 12) indicate that well TS-01 is reasonably located on the contaminant flow path to monitor the distal part of the contaminant plume at the site. Data from the nested pair of boreholes (TSB-1A and TSB-1B) 80 ft north

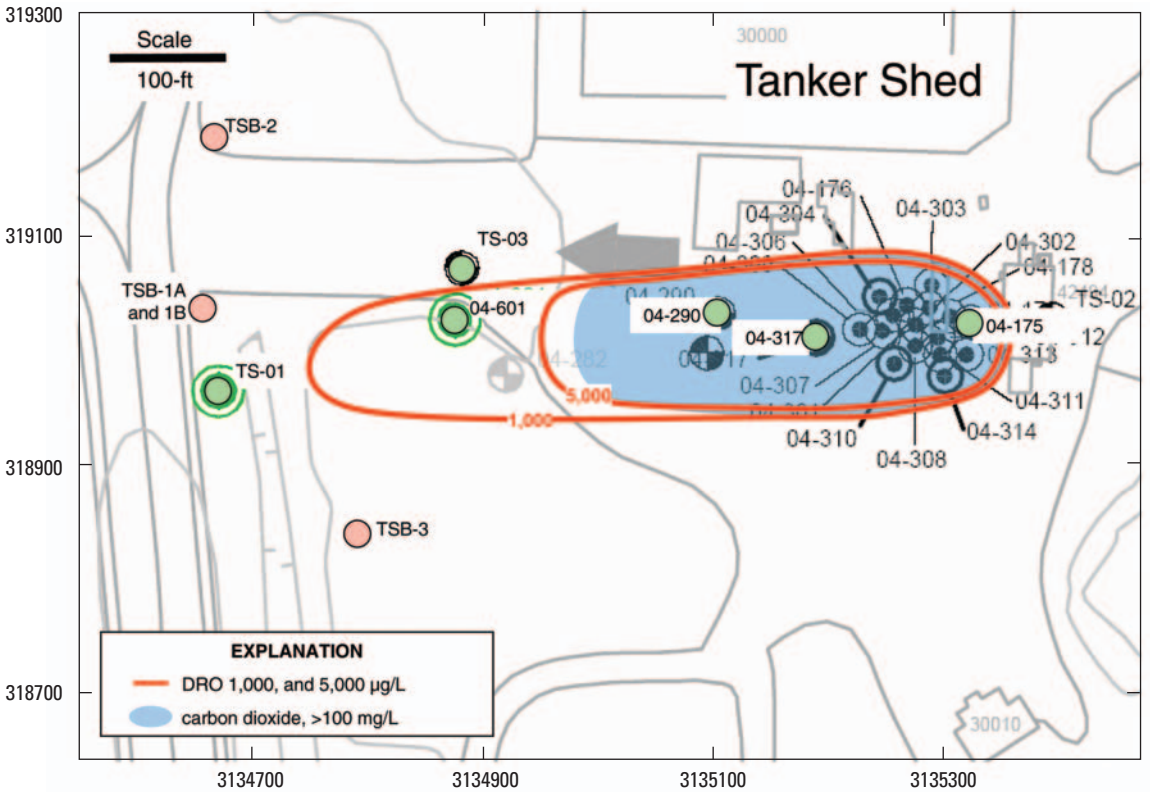

Figure 17. Diesel range organics (DRO) and carbon dioxide concentrations for the Tanker Shed site, Operable Unit A, Adak Island, Alaska, May and June 2003.

Table 12. Selected diesel range organics, geochemical, and water-level data from boreholes and wells at the Tanker Shed site, Operable Unit A, Adak Island, Alaska, May and June 2003.

[**Borehole or well No.** are shown in figure 17. **Sampling depths** are approximate feet below land surface of the mid-point of the sampling device or well screen. **Water-level altitudes** are in feet above or below (-) NAD27. **Diesel range organics:** Historical petroleum data collected by the Navy are in italics. **Abbreviations:** ft, foot; µg/L, microgram per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter. **Symbols:** e, compound was detected but concentration was estimated; <, actual value is less than value shown; –, not analyzed]

Borehole or well No.	Date sampled	Date of historical petroleum data	Sampling depth (ft)	Water-level altitude (ft)	Diesel range organics (µg/L)		pH (units)	Specific conductance (µS/cm)	Carbon dioxide (mg/L)	Dissolved oxygen (mg/L)	Ferrous iron (mg/L)
					Field	Laboratory					
Boreholes											
TSB-1A	05-21-03	–	10	2.24	<100	50e	5.8	192	35	0.5	15
-1B	05-21-03	–	18	2.31	–	–	5.6	206	19	6	.8
-2	05-21-03	–	10	2.46	–	–	5.6	93	10	7	.4
-3	05-21-03	–	10	2.67	–	–	5.9	143	23	1.5	7.0
Monitoring wells											
TS-01	05-21-03	10-08-01	7	2.31	–	*240*	6.1	492	30	0.8	0.14
-03	05-21-03	10-08-01	11	4.53	–	*153*	5.9	175	35	7	.09
04-175	05-21-03	10-07-01	9	4.99	–	*12,400*	6.0	369	135	<.025	1.5
-290	05-21-03	10-07-01	9	4.24	–	*9,220*	6.0	453	180	<.025	2.0
-317	05-21-03	10-08-01	9	4.53	–	*9,220*	6.0	380	180	<.025	2.1
-601	05-21-03	10-14-02	11	3.36	–	*2,600*	5.5	265	35	3	.96

of well TS-01 indicate that the contaminant plume was at the water table rather than at depth; the deep borehole was aerobic and uncontaminated, and the shallow borehole was anaerobic with only a trace of DRO (50e µg/L). In October 2001, the DRO concentration in well TS-01 was 240 µg/L. Water-level data from existing wells and boreholes also indicate that well TS-01 is directly on the contaminated flow path.

The USGS NAP data indicated biodegradation at the Tanker Shed by a ten- to twenty-fold increase in carbon dioxide concentrations above background levels in the most contaminated wells. Ferrous iron concentrations also were elevated in petroleum contaminated samples. Data from boreholes TSB-2 and TSB-3 appear to best represent uncontaminated background water at the site, which is aerobic with carbon dioxide concentrations of 10 to 23 mg/L. All of the contaminated samples had carbon dioxide concentrations exceeding 30 mg/L. Historical (1998-2002) NAP data suggest that ground water has switched between aerobic and anaerobic conditions at well 04-601, although the alkalinity concentrations have consistently been 71 to 74 mg/L as $CaCO_3$. The apparent varying historical NAP data at 04-601, as well as the elevated ferrous iron concentrations observed in the aerobic May 2003 sample, suggest that the 10 ft well screen spans both the contaminated, anaerobic upper part of the aquifer, and the uncontaminated and aerobic deeper part of the aquifer that was characterized by nested boreholes TSB-1A and TSB-1B.

There appears to be an approximately fifty-fold attenuation of DRO along the flow path between 04-175 and well TS-01 (12,400–240 µg/L). As with most other Adak Island sites, the stability of the contaminant plume at the site cannot be ascertained until additional data are collected from the new downgradient monitoring well. Historical DRO concentrations from wells near the source area showed no consistent trend between 1996 and 2002, although those data likely were affected by the start and end of free product recovery from wells at the site. Overall, the data indicated active biodegradation at the Tanker Shed site, and that, as of 2003, natural attenuation is preventing DRO concentrations that exceed the cleanup levels from extending more than about 400 ft downgradient from well 04-290 near the source area.

If MNA is selected as a remedy for this site, monitoring suggestions include:

1. Sampling well TS-01 to monitor the stability of the downgradient contamination, and

2. Sampling either well 04-290 or 04-317 to monitor contaminant concentrations near the source over time.

Existing sentinel well 04-601 also could be sampled to monitor intermediate concentrations in the DRO contaminant plume, or it could be sampled in the future to document shrinking of the dissolved-phase plume when concentrations become non-detectable at TS-01. As of 2003, data from TS-01 was optimal for delimiting the downgradient extent where concentrations were less than the 1,500 µg/L cleanup level.

Monitoring Strategy for Natural Attenuation of Petroleum Throughout the Downtown Area

A summary of the proposed monitoring locations for the investigated petroleum sites is presented in table 13. The proposals were based in large part on the overall monitoring strategy for natural attenuation throughout the Downtown area.

The 1999 ROD specified three objectives that ground-water monitoring in affected areas must satisfy:

- To verify whether natural attenuation is occurring.
- To monitor locations where chemical concentrations exceed specified cleanup levels.
- To estimate the rate of natural attenuation to demonstrate achievement of cleanup levels within 75 years.

Table 13. Wells proposed for monitoring natural attenuation at investigated petroleum sites, Operable Unit A, Adak Island, Alaska.

[Locations of petroleum sites are shown in figure 2. **Site** is abbreviated site name; see table 1 for full site name. **Well No.** in bold indicates proposed future monitoring well. **Abbreviations:** MNA, monitored natural attenuation; NAPL, non-aqueous phase liquid.]

Site	Well No.	2002 sampling status	2004 and proposed future monitoring status
Former Power Plant	**01-118**	Sampled for MNA	Sample to monitor source strength over time for MNA.
	01-150	Not available	Sample to monitor plume stability for MNA.
	01-151	Not available	Sample to monitor discharge to East Canal.
	E-701	Sampled for background/sentinel	Discontinue sampling.
GCI	**04-100**	Not available	Sample to monitor plume stability (towards southwest) for MNA.
	04-202	Not sampled	Sample to monitor source strength over time for MNA.
	04-701	Sampled-sentinel	Sample to monitor plume stability (towards west) for MNA.
Arctic Acres	03-420	Sampled for MNA	Sample infrequently to confirm no westward contaminant migration.
	03-421	Sampled for MNA	Discontinue sampling.
	03-422	Sampled for MNA	Discontinue sampling.
	03-890	Sampled for MNA	Sample to monitor source-strength and NAPL over time for MNA.
	AA-01	Sampled for MNA	Sample to monitor plume stability (towards east) for MNA.
	AA-02	Sampled for MNA	Sample infrequently to confirm no westward contaminant migration.
	AA-05	Sampled for MNA	Discontinue sampling.
	AA-06	Sampled for MNA	Sample infrequently to confirm no westward contaminant migration.
ROICC	08-153	Sampled for MNA	Discontinue sampling.
	08-160	Sampled for MNA	Discontinue sampling.
	08-175	Not available	Sample to monitor plume stability for MNA.
	08-200	Sampled for limited monitoring	Sample to monitor source strength over time for MNA.
	08-201	Sampled for limited monitoring	Discontinue sampling.
	08-202	Sampled for limited monitoring	Discontinue sampling.
Avgas Valve Pit	**14-100**	Sampled for MNA	Sample to monitor source strength over time for MNA.
	14-110	Not available	Sample to monitor plume stability for MNA.
SA 80	**04-103**	Not available	Sample to monitor plume stability for MNA.
	04-801	Sampled for sentinel monitoring	Discontinue sampling.
	SP4-3	Not sampled	Sample to monitor source strength over time for MNA.
SWMU 14	**01-153**	Not available	Sample to monitor plume stability for MNA.
	MW14-5	Sampled for MNA	Sample to monitor source strength over time for MNA.
	MW14-423	Sampled for sentinel monitoring	Discontinue sampling.
Tank Farm B	**14-113**	Not available	Sample to monitor plume stability near Sweeper Creek.
	14-210	Sampled for sentinel monitoring	Discontinue sampling.
	TFB-MW-4A	Sampled for MNA	Discontinue sampling.
	TFB-MW-4B	Sampled for MNA	Sample to monitor source strength over time for MNA.
Sandy Cove Housing	**03-155**	Not available	Sample to monitor plume stability for MNA.
	03-619	Sampled for sentinel monitoring	Discontinue sampling.
	MW134-11	Not sampled	Sample to monitor source strength over time for MNA.
Tanker Shed	**04-290** or **04-317**	Not sampled	Sample to monitor source strength over time for MNA.
	04-601	Sampled for sentinel monitoring	Sample in future years to monitor shrinking plume.
	TS-01	Not sampled	Sample to monitor plume stability for MNA.

The U.S. Navy developed a comprehensive monitoring plan to achieve these objectives (URS Greiner Inc., 2001a), and they update that plan annually based on annual findings. Their overall monitoring strategy for MNA sites includes three types of sampling—natural attenuation, sentinel, and background. The goal of natural attenuation sampling is to verify that natural attenuation is occurring. Natural attenuation sampling is done at wells within the dissolved-phase petroleum plumes, and usually includes one well per MNA site. Samples from those wells are analyzed for petroleum chemicals of concern to monitor concentrations within the plumes and to assess the rate of degradation. Samples also are analyzed for NAPs to assess biodegradation. Degradation rates are estimated (when possible) based on a statistical determination of significant concentration trends over time at individual wells. The goal of sentinel sampling is to monitor the protectiveness of the remedy. Sentinel sampling is done at wells outside of dissolved-phase petroleum plumes and upgradient from the nearest receptor (generally surface water), and samples are analyzed for petroleum chemicals of concern. The goal of background sampling is to collect NAP data from uncontaminated ground water for demonstration of contaminant degradation by comparison to NAP data from within dissolved-phase petroleum plumes. The 2001 monitoring plan (URS Greiner, Inc., 2001a) proposed evaluating the MNA data using a peer-reviewed computer model (approved by EPA and the Alaska Department of Environmental Conservation) that simulates natural attenuation of hydrocarbons in ground water. The specific objective of such modeling is unclear, although it may be used to demonstrate achievement of cleanup levels within 75 years.

Overall, the rationale behind that existing strategy is reasonable, but three years of monitoring data (1999-2002) suggest that the strategy needs some refinement because it does not appear that the monitoring objectives will be achieved in the specified 5-year evaluation period. This conclusion was reached in a USGS evaluation of the data (R.S. Dinicola, U.S. Geological Survey, written commun., December 23, 2002). A primary objective of this investigation was to install new wells at selected sites to better meet monitoring objectives. Because of the new sampling locations and the additional data collected while installing the new wells, specific refinements in the monitoring strategy are proposed. The sampling plan based on the proposed revisions should be considered as the minimum sampling effort needed to meet the first two monitoring objectives at the sites (a discussion concerning the third objective follows). A number of published regulatory agency and Department of Defense guidance documents recommend much more extensive monitoring at MNA sites, particularly with regard to the lateral and vertical extents of all contaminant plumes. However, the methods used to position the new monitoring wells during this investigation have addressed many of the concerns discussed in the guidance documents (at least in the near term). Ground-water flow directions over time may shift and contaminant plumes may migrate in different directions. A minimal monitoring program may not detect such changes.

The most direct approach for verifying that natural attenuation is effective is to monitor petroleum concentrations at the downgradient margin of contaminant plumes to demonstrate that the plumes are not expanding or that they are getting smaller. Regardless of the efficiencies of the individual attenuation mechanisms at work (biodegradation, dispersion, dilution, volatilization, and sorption), a stable or shrinking contaminant plume demonstrates that natural attenuation is effectively containing the migration of contamination. Thus, the monitoring plans for each MNA site should include sampling at least one strategically placed well at the downgradient margin of the contaminant plume, preferably where contaminant concentrations are detectable, but less than the cleanup level. Monitoring wells placed in such locations are now available for sampling at the 10 sites investigated.

An ancillary benefit of properly located downgradient wells is that they also are optimal for improved sentinel sampling. Although the theory of locating sentinel wells in uncontaminated downgradient locations is sound, the real-world difficulties of locating such wells precisely on contaminant flow paths are substantial, as was illustrated by the field work completed for this investigation. It was often challenging to find the contaminant plume over distances of a few hundred feet, and that challenge is much more difficult when trying to locate sentinel wells many hundreds of feet downgradient. Whether or not an uncontaminated and aerobic sentinel well in the Downtown area of Adak Island is actually downgradient from a contaminant source will always be uncertain. The area is too large to install the required density of sentinel wells near all potential surface-water receptors to substantially reduce the uncertainty that a plume will be missed. Similarly, if a far downgradient sentinel well does become contaminated, the source of the contamination will be uncertain. As detected at the Former Power Plant and GCI sites, there may be petroleum contamination in the Downtown area very near to but not associated with a specific MNA site. Installing sentinel wells at the distal parts of known plumes where contaminant concentrations are low and geochemical indicators of petroleum contamination and biodegradation are definitive is a more certain approach for sentinel monitoring. Thus, it would be beneficial to use the downgradient natural attenuation wells as sentinel monitoring wells for the MNA sites, and not include less accurately located sentinel wells in the MNA monitoring program. Four non-useful sentinel wells were identified at the sites investigated: 04-801 at the SA 80 site, MW14-423 at the SWMU 14 site, 03-619 at the Sandy Cove housing area, and 04-601 at the Tanker Shed site. Well 04-701 at the GCI site was proposed as one possibly useful sentinel well for future sampling.

In addition to the downgradient sentinel wells, continued monitoring is appropriate for at least one natural attenuation well within or immediately downgradient from the contaminant source area at each site. Continued monitoring at most existing natural attenuation wells is suggested because they are already suitably located. Contaminant concentration data from those near-source-area wells are useful for clearly demonstrating natural attenuation (or in a few cases, the lack of attenuation) over distance when their contaminant concentrations are compared to downgradient wells. Demonstration of attenuation over distance is more important than demonstrating natural attenuation over time at a single well when protection of downgradient receptors is a primary remediation goal. Data from upgradient and downgradient wells also would be beneficial for any fate and transport modeling at MNA sites, as was suggested in the comprehensive monitoring plan. Although "off-the-shelf" contaminant degradation values often have been used for similar modeling exercises, the use of observed field attenuation rates calculated from observed data adds credibility to those modeling efforts.

Benefits from continued "background" sampling for MNA seem to have become marginal. This conclusion is based on the preponderance of existing NAP data demonstrating on-going petroleum biodegradation in the Downtown area of Adak Island, and the sound scientific basis for when to expect (and not to expect) biodegradation to occur. At most sites sampled for this investigation, the aerobic and uncontaminated background water characteristic of the shallow aquifer became anaerobic in contaminant plumes, along with increased ferrous iron and carbon dioxide concentrations. Even at the few sites that have naturally anaerobic and iron-rich ground-water (such as the ROICC and Avgas Valve Pit sites), elevated carbon dioxide concentrations within contaminant plumes clearly indicated petroleum biodegradation. A consistent relation between carbon dioxide concentrations and petroleum concentrations was observed at all sites except Tank Farm B (figs. 18 and 19). That relation indicates that, in general, the more dissolved-phase petroleum available, the more biodegradation occurs. At the lone site where biodegradation appeared to be inconsequential (the flood plain area at Tank Farm B), the contaminant concentration data alone clearly demonstrate the ineffective attenuation processes. Even there, the NAP data were somewhat superfluous. And despite some earlier data quality issues, the 1999-2002 NAP data from Downtown area sites lead to the same conclusions; petroleum biodegradation has been demonstrated to be nearly ubiquitous.

Continued collection of NAP data is not suggested to achieve the ROD monitoring objective of verifying the occurrence of natural attenuation. The overall effectiveness of MNA is better demonstrated through contaminant concentration data from downgradient monitoring wells. In addition, the NAP data collected to date are adequate to demonstrate that biodegradation plays a significant role in that attenuation (figs. 18 and 19).

A benefit of NAP data collection at intensively monitored MNA sites is the potential for detecting small-scale expansion of methanogenic layers within a contaminant plume that can lead to subtle (a few meters) plume expansion over a few decades (Bekins and others, 2001; Cozzarelli and others, 2001). As available electron-acceptors (iron in particular) are consumed in narrow preferred-flow pathways within a plume, the switch to slower petroleum degradation linked to methanogenesis can result in petroleum plume expansion. However, this phenomena has only been detected through analysis of porewater samples from aquifer cores, and it probably cannot be detected using plume-scale monitoring well data. Thus, realization of those benefits for continued NAP data collection at Adak Island MNA sites would require a substantially enhanced monitoring program, and the risk of not being able to immediately identify relatively subtle plume expansion at most Adak Island sites is minimal. A second potential benefit for continued NAP data collection at the MNA sites is to facilitate predictive modeling of petroleum attenuation over time; however the existing data are probably sufficient to complete the type of predictive modeling proposed in the comprehensive monitoring plan.

Predictive modeling of contaminant plume behavior was proposed to achieve the third ROD specified monitoring objective "to estimate the rate of natural attenuation to demonstrate achievement of cleanup levels within 75 years." The comprehensive monitoring plan (URS Greiner, Inc., 2001a) describes another strategy for meeting that objective that relies primarily on a statistical trend analysis on 5 years of petroleum concentration data from individual within-plume wells. Demonstrating (predicting) achievement of cleanup levels will be difficult to achieve within any timeframe in a technically defensible manner using any type of short-term monitoring and evaluation, and will be particularly difficult to achieve through monitoring and evaluation of dissolved-phase petroleum only.

The majority of petroleum contamination at MNA sites resulted from past spills or leaks of pure-phase petroleum into the ground. Thus, the continuing source of dissolved petroleum in ground water probably is residual NAPL petroleum held by capillary forces in the unsaturated zone or near the top of the saturated zone. Volumes of residual NAPL at Adak Island MNA sites are not well known, but the presence of NAPL is clearly indicated by the many within-plume wells that show no clear decreasing trends in petroleum concentrations. If that residual NAPL is the predominant continuing source of dissolved-phase contaminants, time required to achieve cleanup levels is primarily controlled by the volume of residual NAPL remaining, and by the rate at which the NAPL dissolves into ground water. NAPL itself is essentially not susceptible to biodegradation (U.S. Environmental Protection Agency, 1995). Many of the NAPL-related compounds are amenable to biodegradation, but they must first dissolve into water before biodegradation can occur. Thus, the dissolution rate of residual NAPL (rather than the biodegradation rate of dissolved petroleum compounds) primarily controls the time it takes to achieve cleanup levels throughout an MNA site.

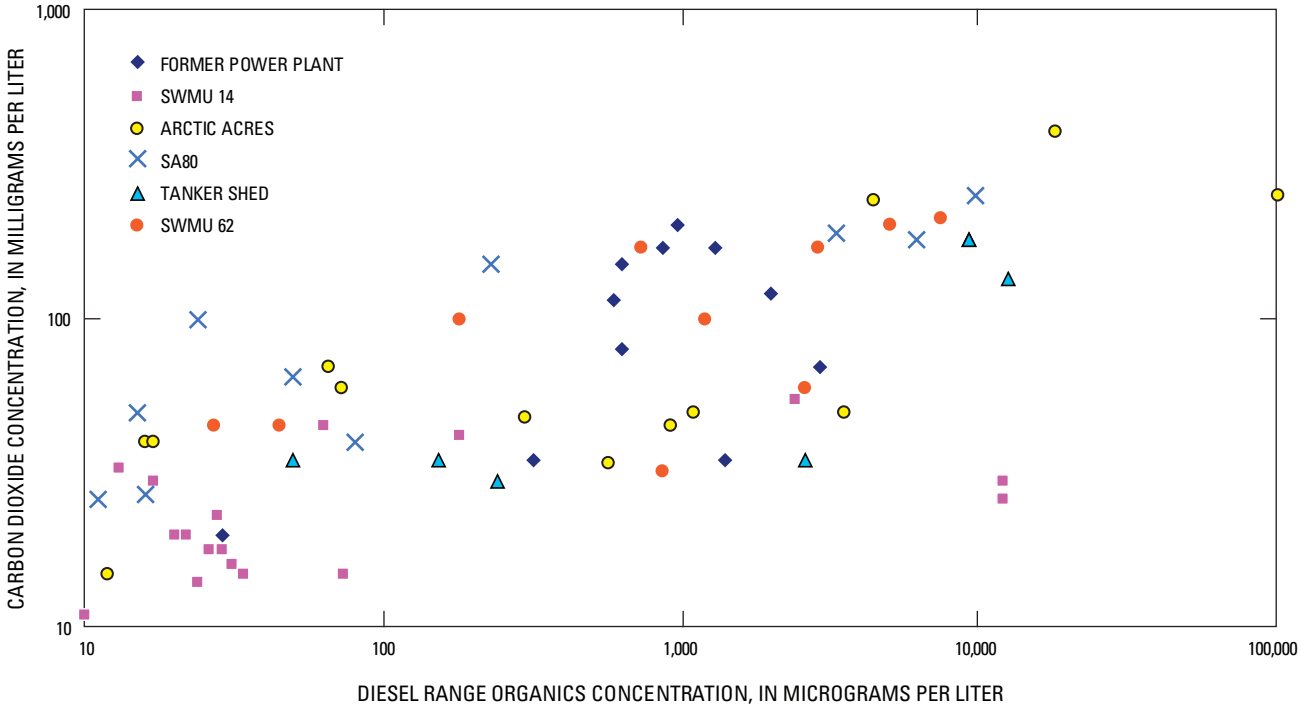

Figure 18. Relation between diesel range organics (DRO) and carbon dioxide concentrations from all petroleum sites where DRO was a contaminant of concern, Operable Unit A, Adak Island, Alaska.

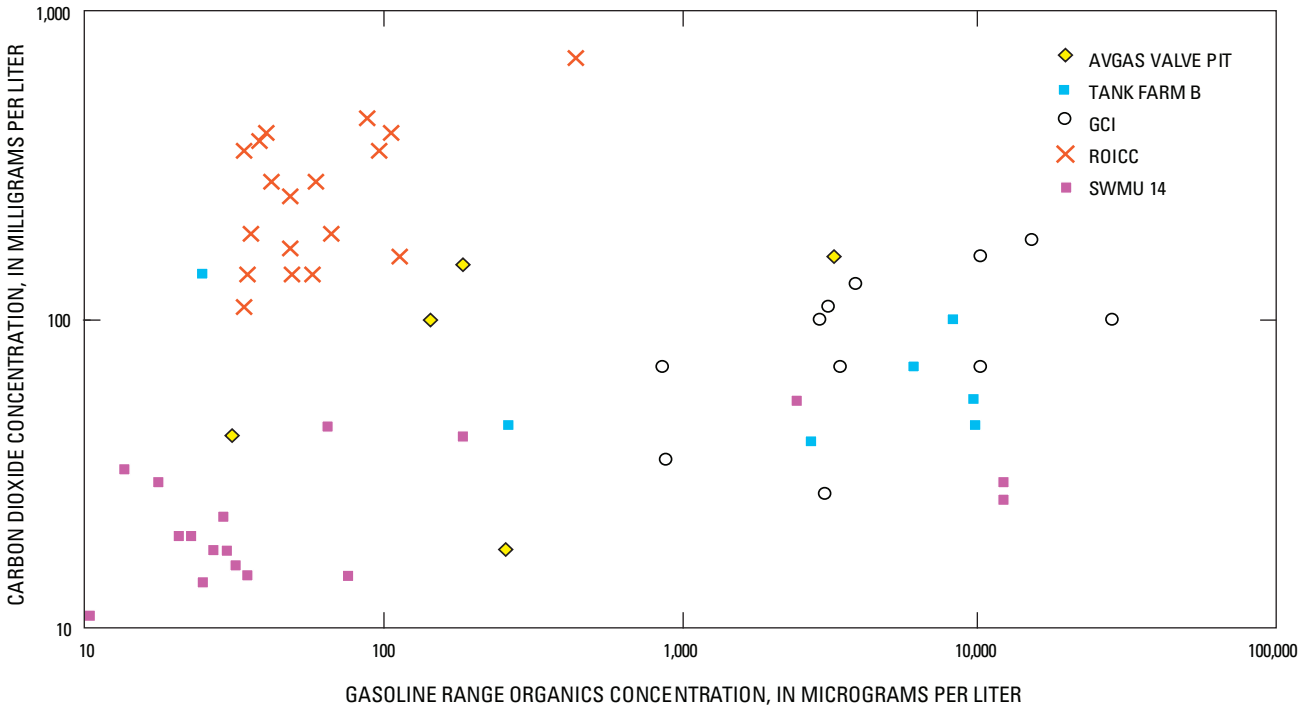

Figure 19. Relation between gasoline range organics (GRO) and carbon dioxide concentrations from all sites investigated where GRO was a contaminant of concern, Operable Unit A, Adak Island, Alaska.

The trend-analysis strategy for predicting cleanup times relies on the assumptions that the change in dissolved-phase concentrations over time at a monitoring location is directly proportional to the NAPL dissolution rate, and that the monitoring location is located close enough to the NAPL source that the observed dissolved-phase concentration is the maximum concentration that is dissolving from the NAPL source. Those assumptions are not likely true. Laboratory and modeling studies conducted by many researchers (Borden and Kao, 1992; Geller and Hunt, 1993; Huntley and Beckett, 2002; Powers and others, 1991) have shown that when NAPL is present, nearby dissolved-phase contaminant concentrations are initially high, followed by a rapid decline primarily due to volatilization, followed by a slow asymptotic decline over a long period. In that case, a trend calculated from concentration data collected during the rapid decline would not be representative of the following slower decline. Also, given that most MNA sites have only one monitoring well within the dissolved-phase contaminant plume, the probability is low that those lone wells at each site are directly adjacent to the residual NAPL source. And finally, as the NAPL weathers over time, the more soluble petroleum compounds (such as benzene) will be depleted in the remaining NAPL and the residual less soluble compounds will dissolve at a slower rate.

Unfortunately, no simple method exists to demonstrate (predict) achievement of cleanup levels in all ground water under an MNA site within 75 years. BIOSCREEN modeling results presented in Appendix C of the Final Focused Feasibility Study for Petroleum Sites (URS Greiner, Inc., 1999) present time-to-cleanup estimates for MNA sites that probably are more realistic than those that can be derived from dissolved petroleum data alone. The BIOSCREEN model considers both attenuation of dissolved-phase petroleum through biodegradation, and attenuation of the source through dissolution of the remaining NAPL. However, the estimates of how much NAPL remained are highly uncertain. BIOSCREEN modeling applications were not evaluated in detail for this report, but in general, the results appear realistic.

BIOSCREEN modeling results indicate that within 80 years:

1. Contaminant concentrations at nearly all MNA source areas are predicted to remain above specified cleanup levels, but

2. Dissolved-phase contaminant concentrations are predicted to be below cleanup levels except at distances of only a few feet to a few tens of feet from the sources.

An alternative approach for more precise time-to-cleanup estimates would be to more rigorously simulate NAPL dissolution. The BIOSCREEN model uses a simplified and unverified theory (a caveat listed in the model documentation) to simulate NAPL dissolution—it assumes that dissolution can be approximated as a first-order decay process. A modeling toolkit that is similar to BIOSCREEN with regard to dissolved-phase processes, but more rigorous with regard to NAPL dissolution would be one option (Huntley and Beckett, 2002). However, NAPL dissolution is a complex process, particularly in heterogeneous environments with fluctuating water tables. As a result, NAPL simulation models have extensive data requirements and the accuracy of their results often are uncertain. Published research from the well-studied crude-oil spill site at Bemidji, Minnesota, illustrates the intensity of monitoring required and the sophistication of modeling needed to realistically attempt to predict petroleum fate and transport far into the future (Bekins and others, 2001; Cozzarelli and others, 2001; Dillard and others, 1997).

Overall, demonstrating (predicting) achievement of cleanup levels within any timeframe in a technically defensible manner will be difficult to meet using any type of short-term ground-water monitoring data. Natural attenuation processes appear to have greatly limited the extent of ground-water contamination at most sites investigated, and therefore have limited the risk that petroleum contaminants pose. However, relatively small areas where contaminants remain at concentrations exceeding cleanup levels will likely persist for many decades, but how many decades is a difficult question to answer. Clarification or refinement of the monitoring objective to demonstrate cleanup within 75 years would be a reasonable prelude to developing a monitoring and data evaluation strategy to meet the objective.

Conclusions

The expedited site-assessment strategy used for this investigation allowed us to quickly and effectively characterize ground-water conditions at the sites of interest. The extent of petroleum contamination and natural attenuation parameter evidence for petroleum biodegradation in ground water were determined on-site using field analyses of selected petroleum compounds, specific conductance, dissolved oxygen, ferrous iron, and carbon dioxide, and 10 new monitoring wells were optimally positioned and installed. Specific refinements in the natural attenuation monitoring strategy were proposed with regard to the newly available sampling locations and the additional data collected during this investigation.

The monitoring objective of verifying that natural attenuation is occurring can be achieved at the 10 investigated sites by including in the sampling plans the new wells installed at the downgradient margin of the contaminant plumes. An ancillary benefit of sampling the new wells is that they also can serve as sentinel monitoring wells for the monitored natural attenuation sites. Continued collection of natural attenuation parameter data and sampling background wells is no longer essential to achieve the monitoring objective of demonstrating the occurrence of natural attenuation.

Collecting and analyzing contaminant concentration data from downgradient monitoring wells better demonstrates the overall effectiveness of monitored natural attenuation. In addition, the natural attenuation parameter data collected to date are adequate to demonstrate that biodegradation plays a significant role in natural attenuation. A preponderance of existing data demonstrates on-going petroleum biodegradation in the Downtown area of Adak Island, and a sound scientific basis exists for when to expect (and not expect) biodegradation to occur.

The objective of monitoring locations where chemical concentrations exceed specified cleanup levels can be achieved by monitoring at least one natural attenuation well within or immediately downgradient from the contaminant source area at each site, and most existing natural attenuation wells are in appropriate locations. Contaminant concentration data from the near source-area wells are useful to clearly demonstrate natural attenuation over a distance, and that demonstration is more important than demonstrating natural attenuation over time at a single well when protection of downgradient receptors is a primary remediation goal. Achieving the monitoring objective of estimating the rate of natural attenuation to demonstrate achievement of cleanup levels within 75 years will be problematic. Demonstrating (predicting) achievement of cleanup levels within any timeframe in a technically defensible manner will be difficult to achieve using any type of short-term monitoring and evaluation, and will be particularly difficult to achieve through monitoring and evaluation of dissolved-phase petroleum only. Despite the difficulties in achieving that final objective in a technically defensible manner, natural attenuation processes appear to have greatly limited the extent of ground-water contamination at most sites investigated and have limited the risk that petroleum contaminants pose to downgradient receptors.

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