Natural Attenuation of Chlorinated-Hydrocarbon Contamination at Fort Wainwright, Alaska

A Hydrogeochemical and Microbiological Investigation Workplan

By Kathleen A. McCarthy, Michael R. Lilly, Joan F. Braddock, and Larry D. Hinzman

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U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Thomas J. Casadevall, Acting Director

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CONVERSION FACTORS, VERTICAL DATUM, AND SYMBOLS

Multiply	by	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot per day (ft/d)	0.3048	meter per day
pound per square inch (lb/in^2)	6,895	pascal
square foot per day (ft^2/d)	0.0929	square meter per day
degree Celsius (°C)	°F = 1.8 x °C + 32	degree Fahrenheit (°F)

Vertical Datum:

In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929), a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929. For all recent and current hydrologic investigations in the Fort Wainwright and Fairbanks areas, the USGS uses the U.S. Coast and Geodetic Survey (1966) data.

Horizontal Datum:

The horizontal datum for all locations in this report is the North American Datum of 1927. The U.S. Army typically uses local coordinate systems for each installation. These coordinates were converted to state-plane coordinates and latitude and longitude.

Abbreviations, Acronyms, and Symbols used in this report:

A	substrate added
A*	radioactivity added
AEC	U.S. Army Environmental Center
ASTM	American Society for Testing and Materials
a	thermal coefficient, 1.28×10^{-3}
atm	atmosphere
BH	Bushnell-Haas
BTEX	benzene, toluene, ethylbenzene, xylenes
b	thermal coefficient, 2.37×10^{-4}
$C_{hydrogen}$	sample hydrogen concentration
C_w	concentration dissolved in ground water
COE	U.S. Army Corps of Engineers, Alaska District
CRREL	Cold Regions Research and Engineering Laboratory
c	thermal coefficient, 9.06×10^{-8}
DCE	dichloroethylene
DCA	dichloroethane
DMM	digital voltage multi-meter
DODEC	Department of Defense Environmental Clean-up Program
DPW	Department of Public Works
DRO	diesel-range organics
dpm	disintegrations per minute
FID	flame ionization detector
ft	foot
ft/d	foot per day
GC	gas chromatograph
GRO	gasoline-range organics
g	gram
g/L	gram per liter
$H_{hydrogen}$	dimensionless distribution coefficient for hydrogen between the gaseous and dissolved phases
$H_{methane}$	dimensionless distribution coefficient for methane between the gaseous and dissolved phases
IDW	investigation-derived waste
lb/in^2	pound per square inch
K	degree Kelvin
MPN	most probable number
mg/L	milligram per liter
mi	mile
mL	milliliter
mL/min	milliliter per minute

mmol/L	millimole per liter
N	normal
NWQL	National Water Quality Laboratory
n	mole
nmol/L	nanomole per liter
Ω	ohm
OU5	Operable Unit 5
P	partial pressure of gas
PEA	phenylethylamine
ppm	parts per million
R	universal gas constant (0.08206 L-atm/mole-K)
ROD	Record of Decision
R_Ω	resistance
r	average mineralization rate
r*	average rate of $^{14}CO_2$ production
S_n	*in situ* substrate concentration
T	temperature
TCA	trichloroethane
TCE	trichloroethylene
TDR	time-domain reflectometer
TV	2,5-diphenyl-3 [α-naphthyl] tetrazolium chloride
UHP	ultra-high purity
USARAK	U.S. Army Alaska
USGS	U.S. Geological Survey
UAF	University of Alaska Fairbanks
μg	microgram
μg/L	microgram per liter
μL	microliter
μm	micrometer
μS/cm	microsiemen per centimeter
V	volume

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ABSTRACT

Natural attenuation processes include biological degradation, by which microorganisms break down contaminants into simpler product compounds; adsorption of contaminants to soil particles, which decreases the mass of contaminants dissolved in ground water; and dispersion, which decreases dissolved contaminant concentrations through dilution. The primary objectives of this study are to (1) assess the degree to which such natural processes are attenuating chlorinated-hydrocarbon contamination in ground water, and (2) evaluate the effects of ground-water/surface-water interactions on natural-attenuation processes in the area of the former East and West Quartermasters Fueling Systems for Fort Wainwright, Alaska. The study will include investigations of the hydrologic, geochemical, and microbiological processes occurring at this site that influence the transport and fate of chlorinated hydrocarbons in ground water. To accomplish these objectives, a data-collection program has been initiated that includes measurements of water-table elevations and the stage of the Chena River; measurements of vertical temperature profiles within the subsurface; characterization of moisture distribution and movement in the unsaturated zone; collection of ground-water samples for determination of both organic and inorganic chemical constituents; and collection of ground-water samples for enumeration of microorganisms and determination of their potential to mineralize contaminants.

We will use results from the data-collection program described above to refine our conceptual model of hydrology and contaminant attenuation at this site. Measurements of water-table elevations and river stage will help us to understand the magnitude and direction of ground-water flow and how changes in the stage of the Chena River affect ground-water flow. Because ambient ground water and surface water typically have different temperature characteristics, temperature monitoring will likely provide further insight into ground-water/surface-water interactions in the subsurface. Characterization of the unsaturated zone will improve our understanding of interactions among ground water, the unsaturated zone, and the atmosphere. The interactions likely of importance to this study include the migration of water, dissolved contaminants, nutrients, and gases (oxygen, carbon dioxide, and methane) between the saturated and unsaturated zones. We will use the results of ground-water chemical analyses to determine the spatial and temporal distribution of (1) chlorinated-hydrocarbon contaminants and their degradation products, (2) oxidation-reduction indicators, (3) nutrients, and (4) major ground-water ions. These water-quality data will provide insight into ground-water flow directions, interactions between ground water and surface

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water, attenuation of contaminant concentrations caused by dispersion, and intrinsic microbiological processes. Microbiological analyses will indicate whether microorganisms at the site are capable of degrading the contaminants of interest, and will allow us to estimate their potential to attenuate existing contamination. Physical and chemical data interpreted as part of the analysis of ground water and surface water mixing will improve our understanding of the relationship between water quality and contaminant source mixing.

INTRODUCTION

Ground water in the area of the former East and West Quartermasters Fueling Systems for Fort Wainwright, Alaska, presently part of Operable Unit 5 (OU5) (fig. 1), has been contaminated with both petroleum and chlorinated hydrocarbons. The U.S. Army Alaska (USARAK) is investigating the distribution and fate of these contaminants, and is evaluating potential remedial actions for the site. Identifying the natural attenuation mechanisms occurring at a particular site and understanding the overall capacity of the hydrologic system to naturally attenuate contamination are of critical importance for the selection of a technically sound and efficient remediation plan.
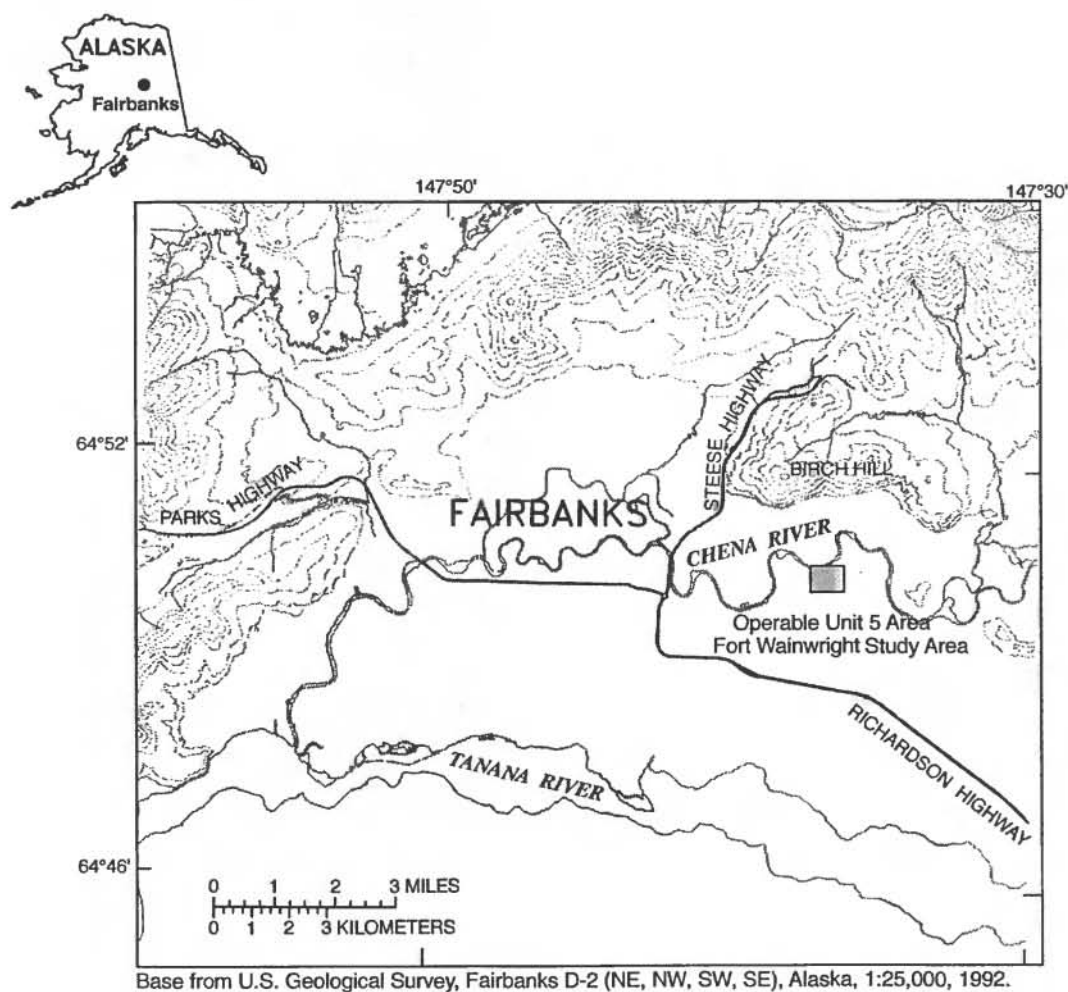

Base from U.S. Geological Survey, Fairbanks D-2 (NE, NW, SW, SE), Alaska, 1:25,000, 1992.

Figure 1. Study area location on Fort Wainwright, Alaska.

Many natural processes can attenuate contamination in ground water, and natural attenuation is rapidly gaining acceptance as a valid remedial alternative at contamination sites (McCarty and Wilson, 1992; McAllister and Chiang, 1994; Bradley and others, 1996; Chapelle and others, 1996; Klecka and others, 1995). Processes contributing to natural attenuation in ground-water systems can be physical, such as dilution by dispersion and by adsorption; chemical, as a result of reactions with aquifer materials; or biological, such as degradation by indigenous microorganisms. Natural biological degradation is often considered to be the most important mechanism of natural attenuation of organic contaminants (National Research Council, 1993).

Objectives and Scope of Work

The primary objectives of this study are to (1) assess the degree to which natural processes, particularly biodegradation and dispersion, are attenuating chlorinated-hydrocarbon contamination of ground water, and (2) evaluate the effects of ground-water/surface-water interactions and how they relate to natural-attenuation processes at Fort Wainwright.

The study draws on information available from a number of previous and ongoing investigations in the vicinity of the site (Harding Lawson Associates, 1995; CH2M Hill, 1993; EMCON Alaska, Inc., 1994, 1995). A general understanding of the site was developed from this available information. The conceptual model will be refined through focused investigations of the hydrologic, geochemical, and microbiological processes occurring at the site that influence the transport and fate of ground-water contaminants. We will measure water-table elevations and the stage of the Chena River, measure vertical temperature profiles within the subsurface, characterize the spatial and temporal distribution of moisture in the unsaturated zone, collect ground-water samples for analyses of both organic and inorganic chemical constituents, and enumerate indigenous contaminant-degrading microorganisms and measure their potential to mineralize target contaminants.

Project Location and Background

The study will focus on Fort Wainwright OU5 because ground water at this site is contaminated with chlorinated hydrocarbons, and because the site is located adjacent to the Chena River. These factors will allow us to study the natural attenuation of chlorinated hydrocarbons, as well as investigate the effects of ground-water/surface-water interactions on natural-attenuation processes in a near-stream environment.

We have compiled hydrologic and water-quality information available from a number of previous and ongoing investigations in the vicinity of the site. Available sources of hydrologic information include the Army Cold Regions Research and Engineering Laboratory (CRREL)—through the triangulation site project (Taras, 1995); and the U.S. Geological Survey (USGS)—through fort-wide ground-water level monitoring, an ongoing aquifer characterization program (Nakanishi and Lilly, 1998), sub-regional ground-water modeling, and a number of studies at other contaminated sites along the Chena River (Claar and Lilly, 1995; Kriegler and Lilly, 1995; Glass and others, 1996; Jackson and Lilly, 1996; Lilly and others, 1996). Information from these sources has provided us with a general understanding of the ground-water flow system and with estimates for aquifer parameters, such as horizontal and vertical hydraulic conductivity and specific yield.

Water-quality information available from a number of sources has provided us with a general understanding of the spatial distribution of contaminants at the site. For example, Harding Lawson Associates (1995) compiled data collected by themselves, by CH2M Hill (1993), and by others (EMCON Alaska, Inc., 1994 and 1995, as examples) and identified plumes of the chlorinated hydrocarbons 1,1,1-trichloroethane (1,1,1- TCA); trichloroethylene (TCE); cis-1,2-dichloroethylene (cis-1,2-DCE); and 1,2-dichloroethane (1,2-DCA), as well as plumes of petroleum hydrocarbons such as gasoline-range organics (GRO)—including benzene—and diesel-range organics (DRO). During 1994, Harding Lawson Associates analyzed ground-water samples for chlorinated hydrocarbons and BTEX compounds (benzene, toluene, ethylbenzene, and xylenes) from 27 small-diameter wells in the East Quartermasters Fueling System area, and both Harding Lawson Associates (1995) and CH2M Hill (1993) documented a decrease in chlorinated hydrocarbon concentration with depth. These available water-quality data form a substantial foundation from which the current study will be developed.

SITE CONCEPTUAL MODEL

Our current conceptualization of the hydrologic system at the study site—based on the previous and ongoing investigations cited earlier—was used in the design of the current study, especially to identify gaps in the existing data and guide further data-collection efforts. The earlier studies have shown that during the winter, ground water in the vicinity of the study site flows into the Chena River from the southeast. Typical ground-water levels during a period of low stage in the Chena and Tanana Rivers are shown on figure 2. During periods of rapidly rising river levels in the Chena—such as during spring thaw and periods of high rainfall (fig. 3)—ground-water flow directions are reversed and water flows from the Chena River into the ground-water system. In contrast to the Chena, the Tanana River stage primarily rises during mid-summer, when glacial melt and high-elevation snowmelt is at a maximum (Glass and others, 1996). Stage changes in the Chena River are typically more transient than those in the Tanana River (fig. 4). A simulation of a 1995 storm hydrograph (fig. 5) illustrates how ground-water flux directions are reversed as the Chena River stage changes. Once the hydrograph starts to decline, ground-water levels near the river bank decline, but ground-water levels continue to rise at greater distances away from the bank (fig. 6). The information shown in figures 5 and 6 is from Nakanishi and Lilly (1998).

One important effect of flow reversals in the ground-water system is to increase the length of ground-water and solute flow paths (as water moves back and forth), which slows the net northwestward migration of dissolved ground-water contaminants south of the Chena River. We also hypothesize that in a zone of such flow reversals, contaminant attenuation may be augmented by increased dispersion and enhanced biodegradation resulting from increased residence time, elevated water temperature resulting from mixing with surface water, and increased fluxes of nutrients and dissolved gases (fig. 7).

In a hydrologic setting similar to that near the Chena River, Squillace and others (1996) found that ground-water/surface-water mass interaction caused by surface-water stage changes extended into the aquifer on the order of 10's to 100's of feet from the river. We hypothesize that stage changes in the Chena River and resulting ground-water/surface-water interactions create a similar zone, roughly parallel to the river, which mitigates the effects of ground-water contamination on the river.

In addition to inducing horizontal movement of water and solutes, cyclic fluctuations in the water table resulting from the changing stage of the river serve to redistribute dissolved contaminants vertically and smear contaminants near the water table over a relatively large vertical distance. This smearing may considerably increase the total volume of soil that comes into contact with the contaminants. Exposure of contaminants to the unsaturated zone is therefore increased, and natural attenuation processes such as vertical dispersion, volatilization, and aerobic biodegradation are likely enhanced considerably. Such cyclic fluctuations of the water table affect most of the Fort Wainwright area.

Numerical ground-water modeling efforts associated with concurrent USGS studies will further analyze ground-water velocities and flow paths under the highly transient conditions resulting from the interactions between ground-water and the Chena River. Results from these simulations will be used to refine our conceptualization of the study site and guide the current study.

PROJECT APPROACH

Our approach will be a rigorous field investigation based on measurements of water-table elevations, water chemistry, indigenous microorganisms, soil moisture, and subsurface thermal conditions. A considerable number of monitoring wells were installed in the study area as part of previous investigations. The locations of those wells were selected to determine the source and extent of contamination at the site. Additional sampling points have been installed as part of the current study to investigate the hydrologic and geochemical effects of ground-water/surface-water interactions, and to measure solute concentration gradients. These new sampling points include (1) a two-dimensional array to the west of the contaminated area, (2) an array in the part of the contaminated area nearest the river, and (3) an array near the source area, aligned perpendicular to the primary direction of ground-water flow.

Geohydrologic Assessment

It is critical to identify the effects of ground-water flow (magnitude and direction) on the dynamics of dissolved contaminants. Ground-water flow reversals, caused by the alternating high and low river stages discussed previously, can influence contaminant concentrations through several mechanisms (fig. 7). Although the predominant ground-water flow direction is toward the river, the direction is reversed during short periods of high stage on the Chena River. This reversal leads to bank recharge of ground water. This bank recharge likely delays contaminant movement toward the river, and provides an influx of nutrients and oxygen to the aquifer. Additionally, both the rise and fall of the Chena River cause a rapid response (typically within 24 hours) in ground-water levels at a distance of several miles. This response likely aids in contaminant degradation by smearing contaminants vertically (thus increasing volatilization and gas exchange in the contaminated zone), and by increasing the volume of soil exposed to contaminants (thus increasing the effects of adsorption). Cyclic changes in water elevation and the magnitude and direction of ground-water flow also contribute to attenuation of contaminant concentrations by increasing dispersion and thus decreasing contaminant concentrations by dilution. To understand and begin to quantify these phenomena, it is essential to determine the extent to which river water penetrates the aquifer.
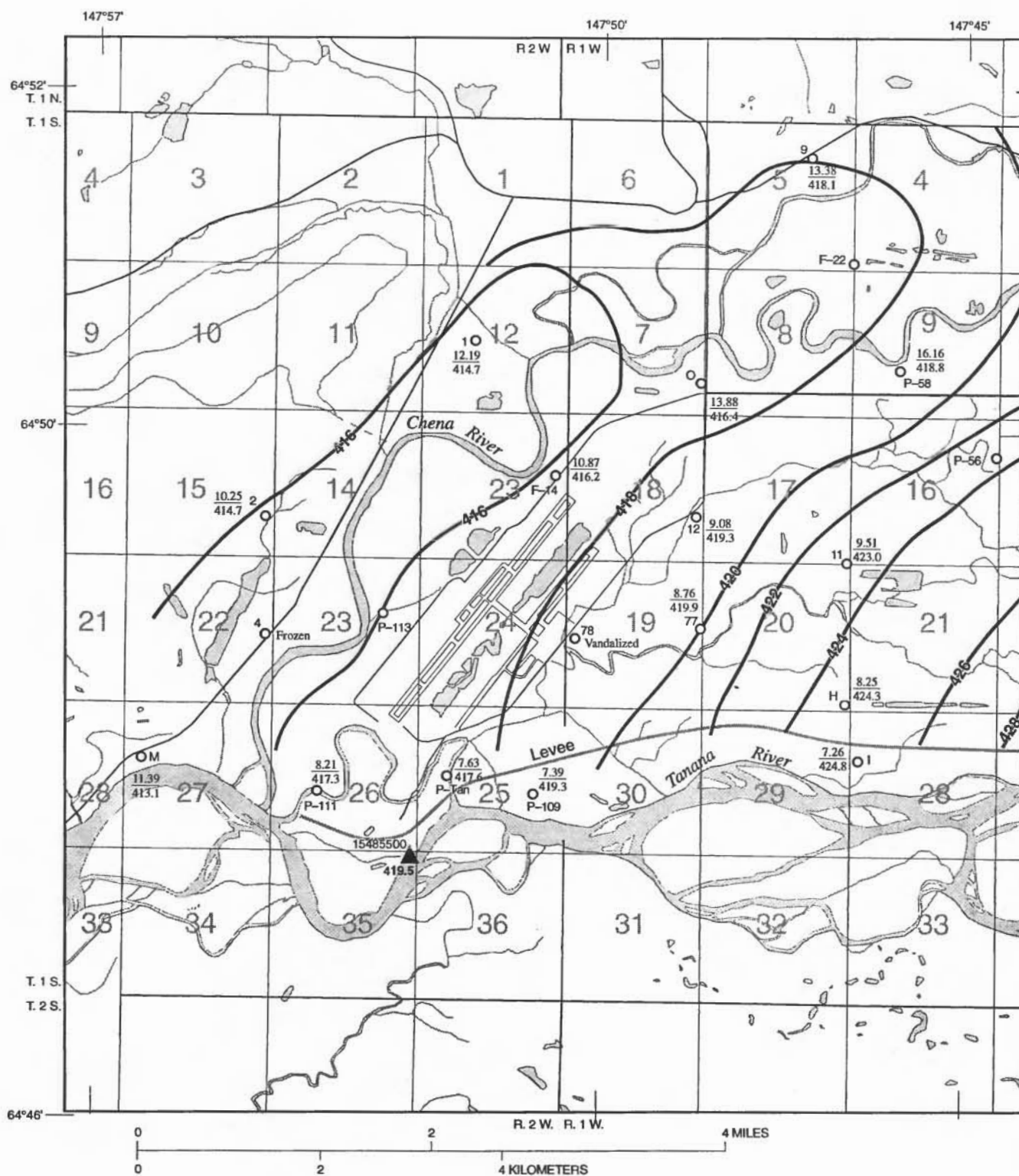
Figure 2. Water-table map for the Fairbanks and Fort Wainwright areas, showing ground-water levels during a period of low stage in the Chena and Tanana Rivers near Fairbanks, Alaska (from Glass and others, 1996).

Map showing water-table contours, stream-gaging stations, and water-level monitoring wells in the Chena River and Tanana River area. Map boundaries: 147°40' and 147°30' longitude; 64°52', 64°50', 64°47'30", 64°46' latitude. Township/Range labels: R. 1 W., R. 1 E., T. 1 N., T. 1 S., T. 2 S. Labeled features include Chena River, Tanana River, Lakloey Hill, and Levee.
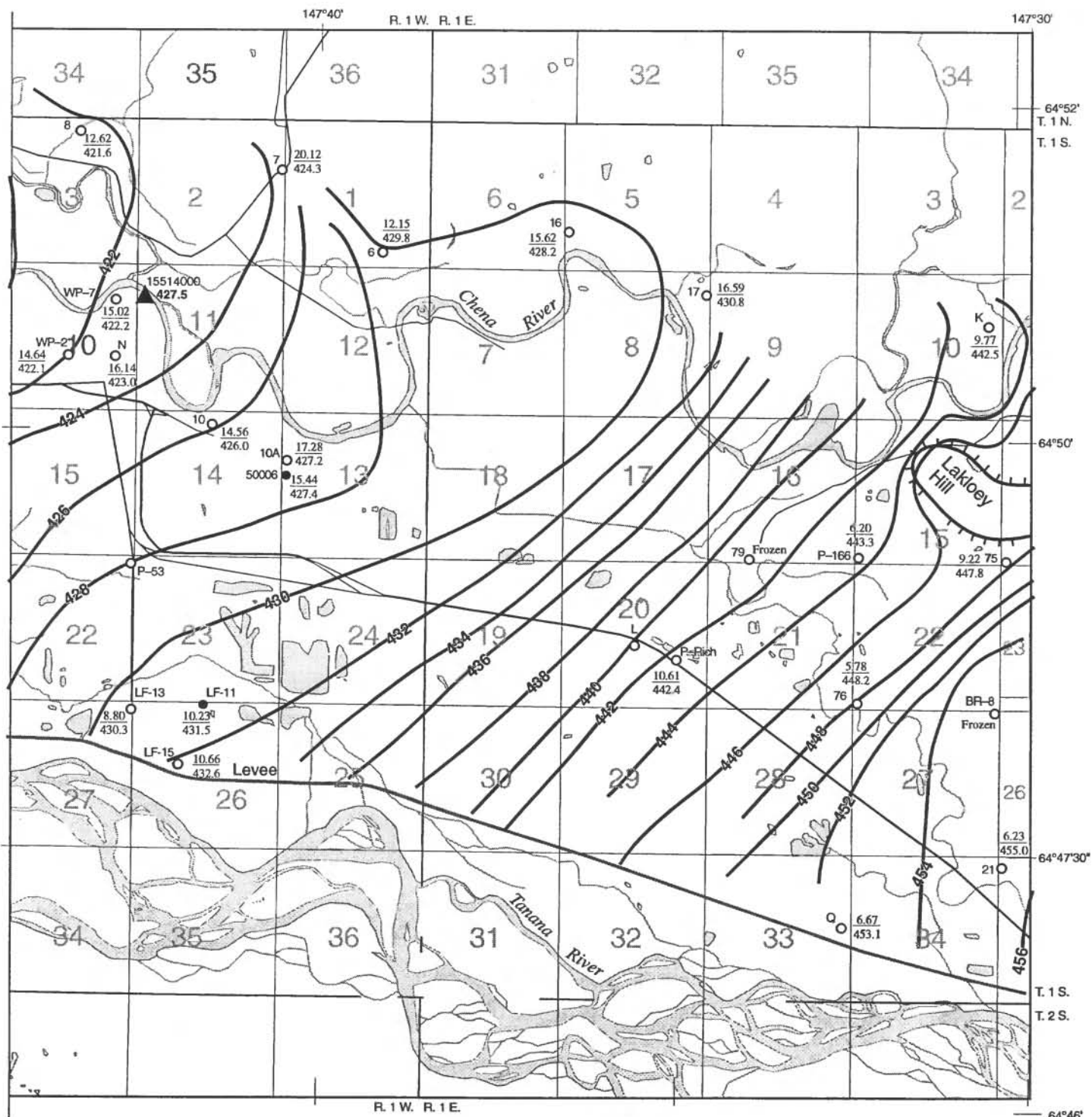
EXPLANATION

—438— Water-table contour—Shows altitude of water table. Contour is 2 feet. Datum is sea level

▲ 15485500 / 419.5 Stream-gaging station and number—Number with decimal is Stage, in feet above sea level

○ LF-13 Water-level monitoring well and field identifier

● LF-11 Water-level monitoring well equipped with a continuous recorder and field identifier

10.66 / 432.6 Top number is water level, in feet below land surface; negative if water level was above land surface. Bottom number is water level, in feet above sea level

CHENA RIVER
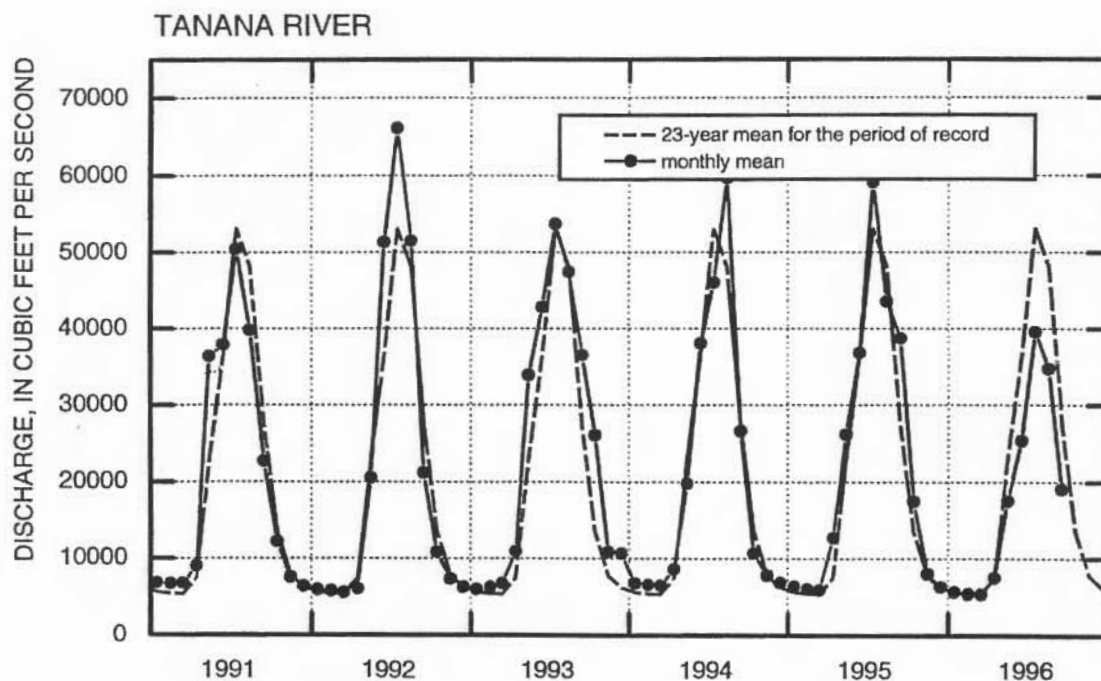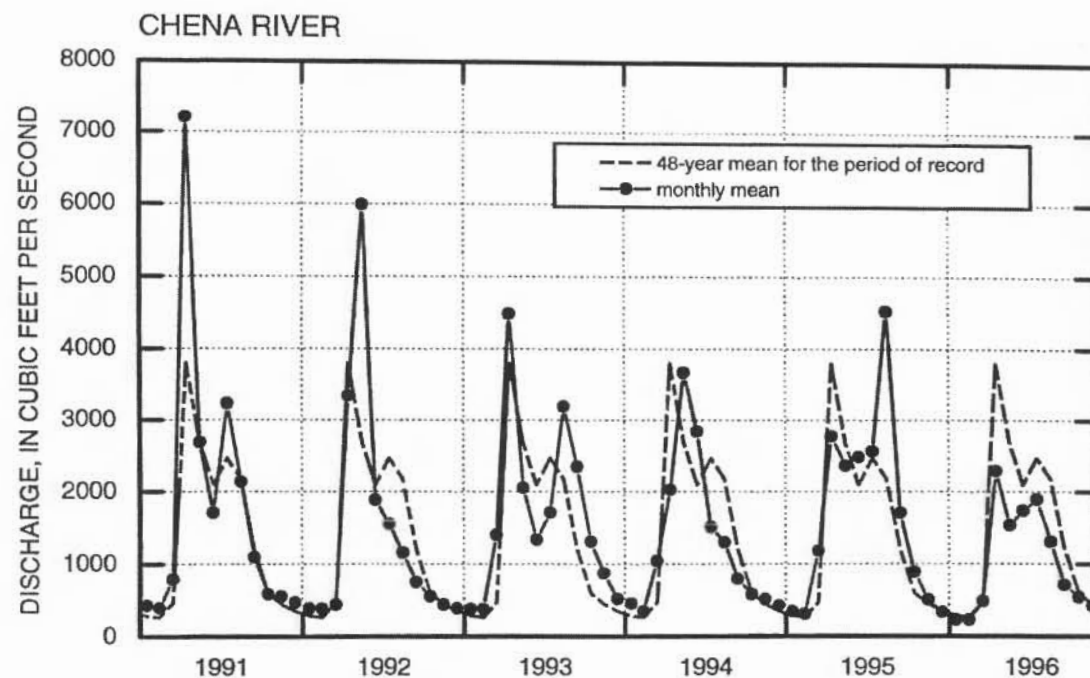
TANANA RIVER

Figure 3. Monthly mean discharges for the study period and mean monthly discharges for the period of record for the Chena and Tanana Rivers. Period-of-record statistics are for water years (October to September).
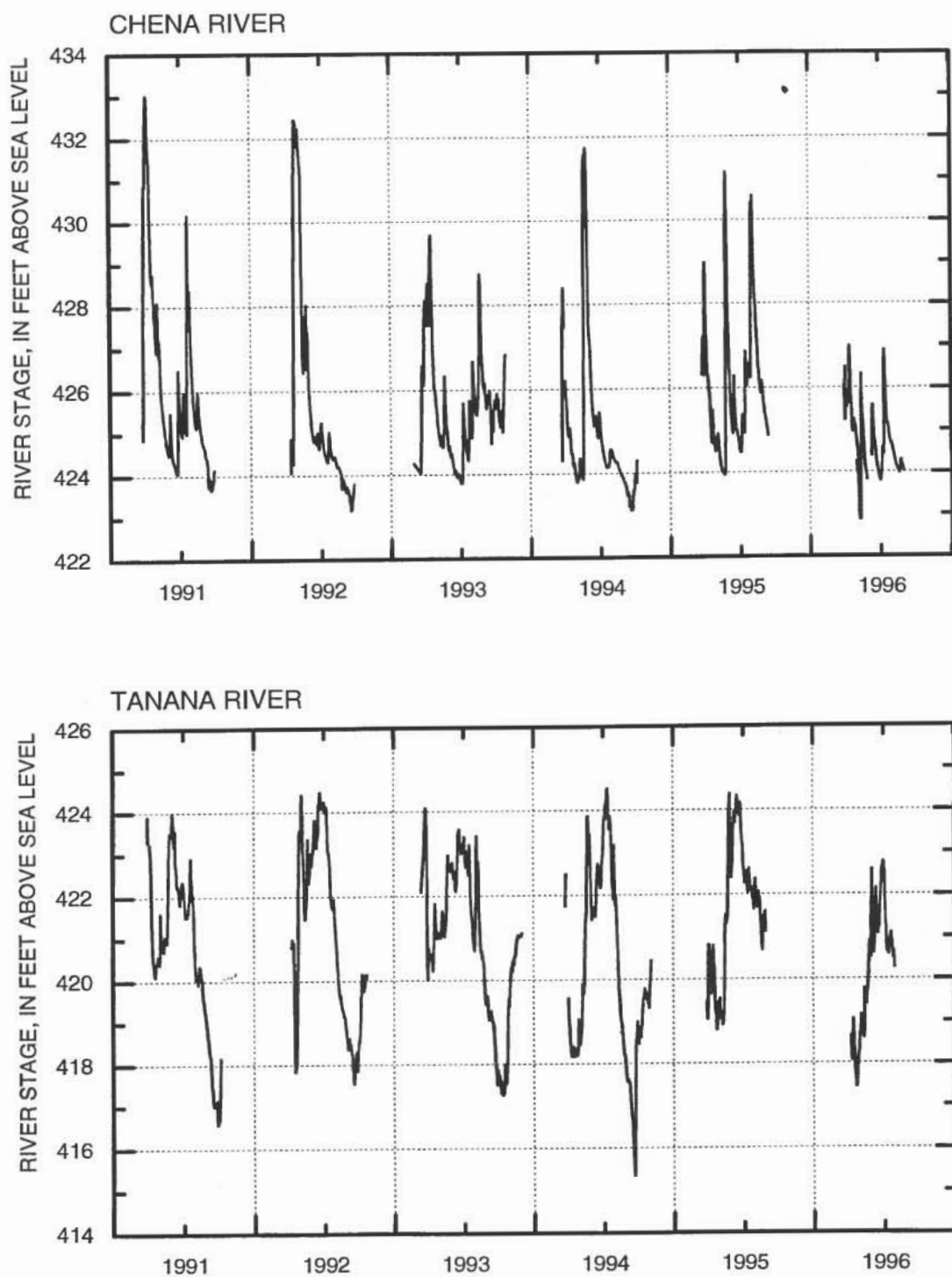
Figure 4. River stage of the Chena River at Fairbanks gaging station and the Tanana River at Fairbanks gaging station for calendar years 1991 to 1996.
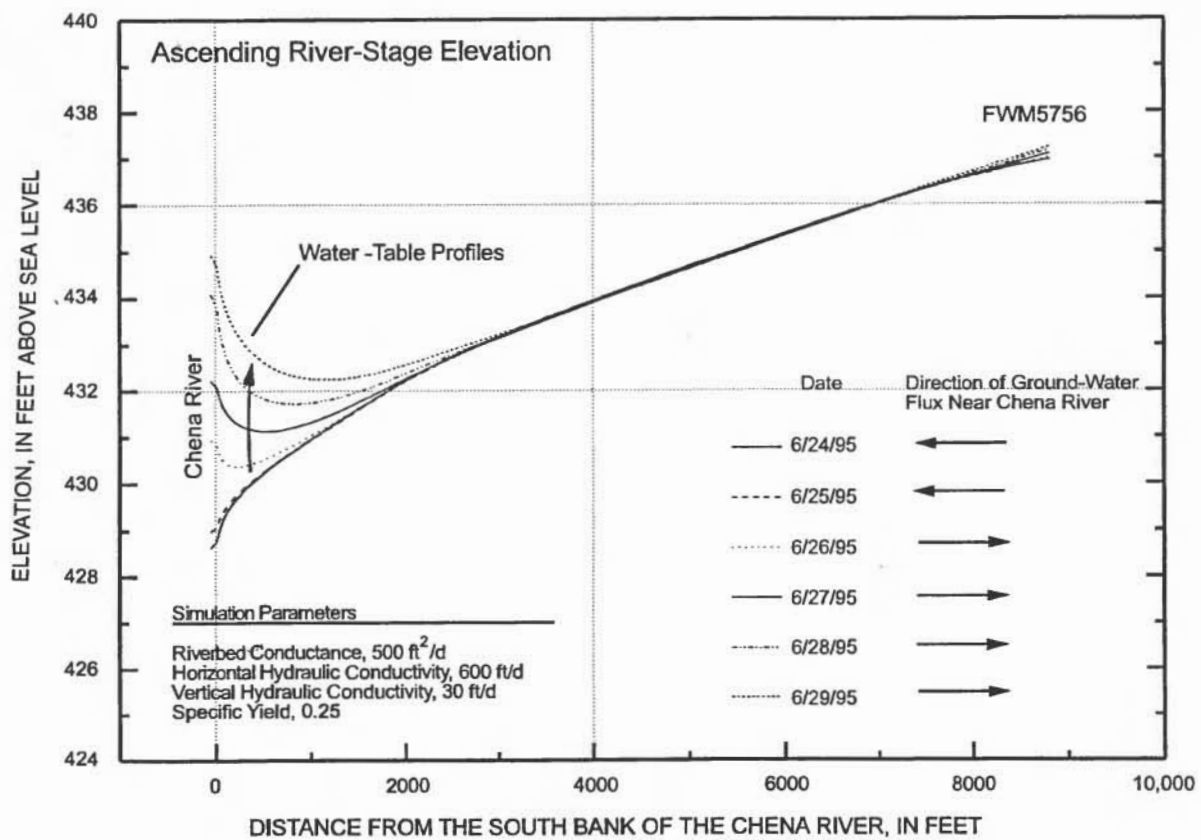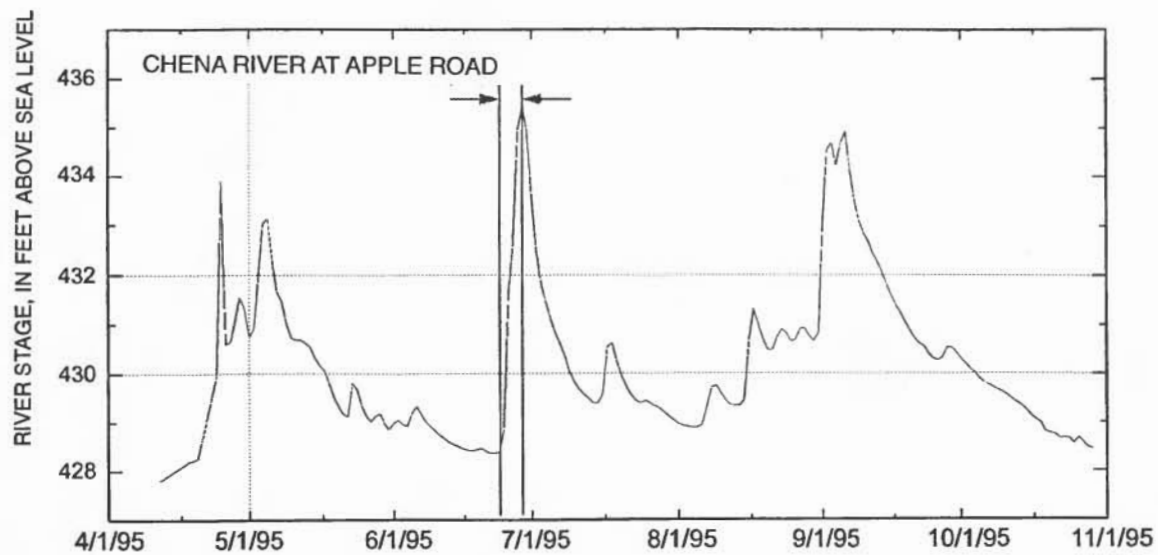
Figure 5. Simulated water-table profiles for June 24 to 29, 1995.
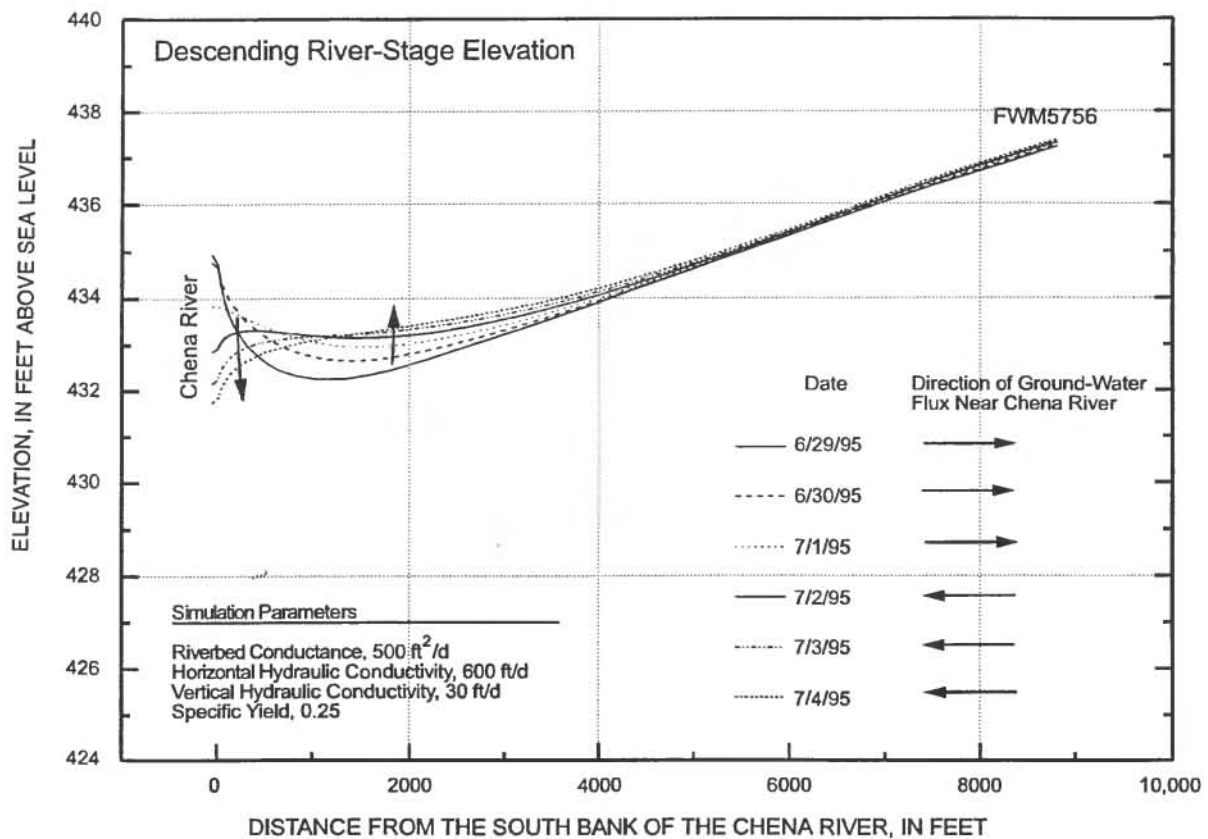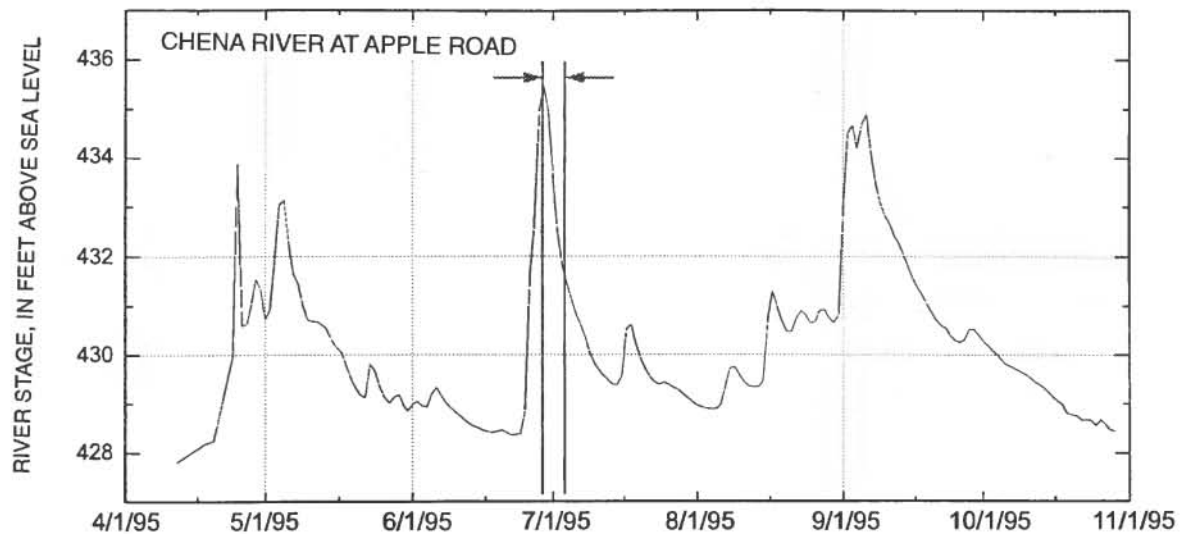
Figure 6. Simulated water-table profiles for June 29 to July 4, 1995.
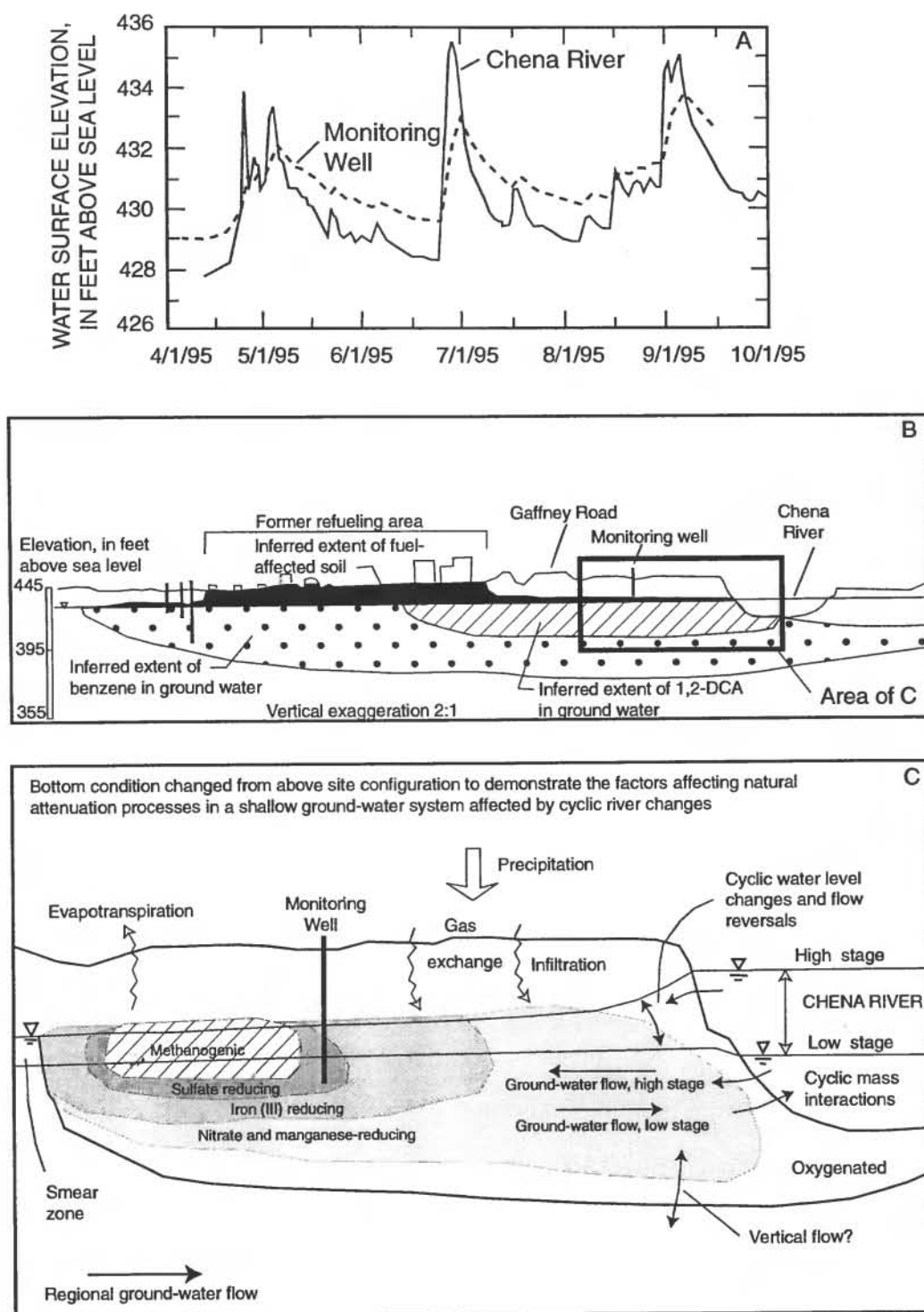
Figure 7. Operable Unit 5: Former West Quartermasters Fueling System Area. Cross sections illustrating factors affecting natural attenuation. (A) Hydrographs of surface-water stage fluctuations and resulting ground-water elevation changes. (B) Conceptual model of site conditions from figure 2. (C) Schematic representation of processes affecting natural attenuation.

Determination of Magnitude and Direction of Ground-Water Flow

Ground-water flow directions across the study site will be monitored continuously by pressure transducers, which will be installed in at least four wells. The water levels in these wells will also be measured manually, approximately monthly, to verify transducer measurements. The water levels will be measured in reference to a measurement point on the top of the well (see section "Ground-Water Level Measurements") and the well measuring points will be tied into a vertical and horizontal survey that will be completed in the summer of 1997.

Vertical surveys will be repeated in the summer of 1998 or as needed, to evaluate well movement caused by effects such as frost jacking. Hydrologic properties, such as hydraulic conductivity, are expected to vary across the site and affect measurements and interpretations sensitive to the site-specific scale of the project. Results from previous and ongoing concurrent aquifer studies performed at a larger scale will initially be used to describe the site (table 1). However, the scaling of geohydrologic parameters will be taken into account when data indicate the necessity and when supporting field data are available to make finer scale interpretations. As new information becomes available, both analytical and numerical methods will be used to refine our characterization of the hydrologic properties of the study area.

Table 1. Estimated values of geohydrologic parameters
[Values from Nakanishi and Lilly (1998)]

Parameter	Estimated value
Riverbed conductance (R_c)	350 ft^2/d
Alluvium	
Vertical hydraulic conductivity (K_v)	20 ft/d
Horizontal hydraulic conductivity (K_h)	400 ft/d
Anisotropy (K_v/K_h)	1:20
Specific yield (S_y)	[a]0.25
Specific storage (S_s)	[a]1×10^{-6}
Bedrock	
Vertical hydraulic conductivity (K_v)	[a]0.005 ft/d
Horizontal hydraulic conductivity (K_h)	[a]0.10 ft/d
Specific storage (S_s)	[a]1×10^{-7}

[a]Value assumed rather than estimated by calibration

Assessment of Ground-Water/Surface-Water Interactions

As discussed previously, mixing of water from different sources—ground-water flow into the river, river-water flow into the subsurface (bank recharge), or infiltration of heavy rainfall or snow-melt to ground water—will likely have a significant effect on rates of contaminant degradation and dilution. It is unclear, however, to what depth below the water table or to what distance away from the river mixing will extend. The degree of mixing will probably be influenced by density differences among the different waters. The temperature of river water varies, ranging from 0°C to as high as 15°C (1989, Chena River at Fairbanks gaging station), depending on the season. Conversely, ground water is typically between 2°C and 10°C (Kriegler and Lilly, 1995), and its temperature changes slowly relative to surface water. Because water reaches its maximum density at 4°C, river water will be more or less dense than the ground water, depending on the season. Therefore, the amount of mixing will not only depend on river stage fluctuations, but will likely exhibit a seasonal pattern. The density of water will be calculated from temperature measurements. Although density is affected to some degree by solute concentration, in most ground waters this effect is negligible compared with the effect of temperature differences. Nonetheless, for confirmation, we will periodically calculate the impact of solutes on density from measured concentrations.

Characterization of the Unsaturated Zone

To understand how biodegradation is affected by a fluctuating water table, it is important to characterize hydrologic processes occurring in the unsaturated zone just above the water table. To accomplish this, we have installed an array of suction lysimeters (fig. 8) to complement a nested array of piezometers that span the expected range of water-table depths. These piezometers and lysimeters will be used to collect samples from discrete depths and will thus allow measurement of vertical gradients in microbial populations, dissolved gas concentrations, and nutrient levels in the vicinity of the water table. In addition, we installed thermistor strings, C-Index probes, and time-domain reflectometer (TDR) probes vertically through the unsaturated zone and into the saturated zone. These instruments (described in a later section) will provide data on water movement in the unsaturated zone, including rainfall and snowmelt infiltration rates. The C-Index probes will also provide information on water chemistry through indirect measurements of electrical conductivity. These electrical conductivity measurements will be validated through analyses of water samples collected from lysimeters and piezometers.

General unsaturated-zone characteristics, such as soil type and bulk density, were recorded during instrumentation installation. The soil profile was clearly layered, indicating a considerable degree of anisotropy. Because alluvium occurs at this site to great depths, this layered, anisotropic pattern likely extends into the saturated zone.

Geochemical Assessment

Geochemical analyses will provide information on the origin of and flow paths followed by ground water. This information will be used to refine a conceptual model of contaminant transport at the site, and will help in identifying and quantifying recharge zones. Because geochemical properties of ground water are directly related to processes such as biodegradation, chemical reactions, and sorption, understanding the geochemistry of the ground-water system will also be used to increase our understanding of the natural-attenuation processes active at OU5 and, hence, to improve and expand our conceptual model.

Pit 1, Northern Pit, Closest to Chena River

TDR Probes
▲ C-Index
+ Temp, thermistors
= Suction Lysimeter
—— Piezometer Screen Depths
▬▬ Pressure Transducer Piezometer

Ground-Surface for FWM6191, FWM6192 = 446.5

FWM6191, 12 to 22.5 Screen Depth
FWM6192, 38.5 to 49 Screen Depth
Chena River at Apple Road
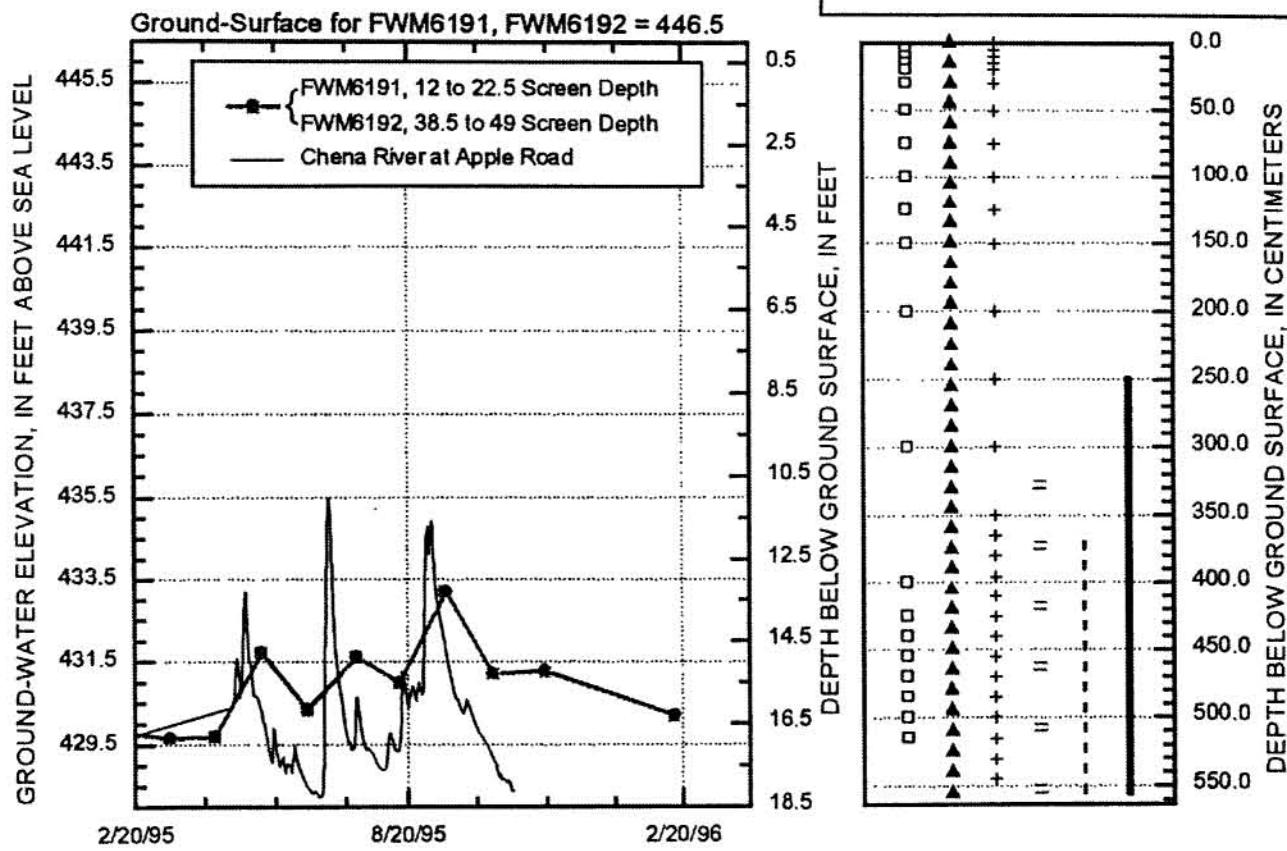
Pit 2, Southern Pit, farthest from Chena River

TDR Probes
▲ C-Index
+ Temp, thermistors
= Suction Lysimeter
—— Piezometer Screen Depths
▬▬ Pressure Transducer Piezometer

Ground-Surface for FWM6191, FWM6192 = 446.5

FWM6191, 12 to 22.5 Screen Depth
FWM6192, 38.5 to 49 Screen Depth
Chena River at Apple Road
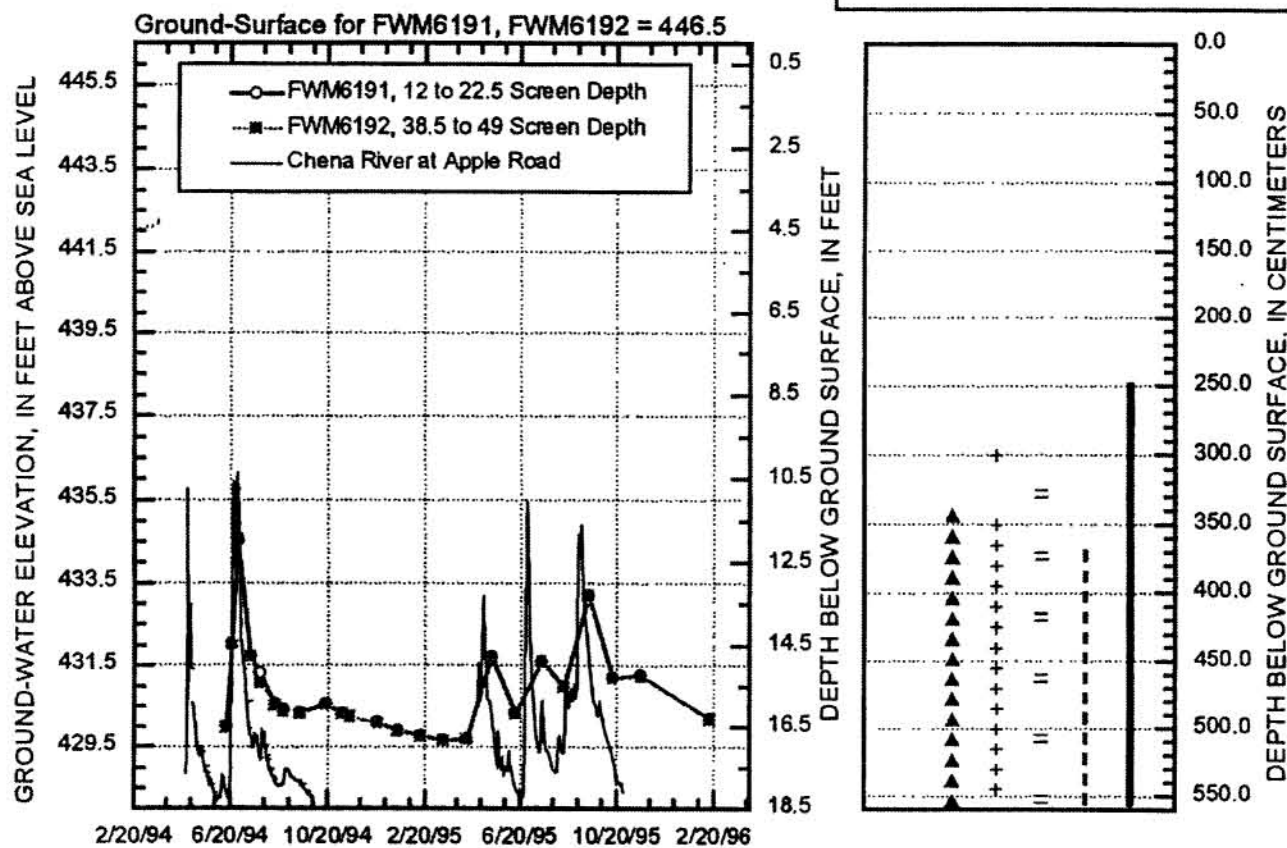
Figure 8. Schematic detail of instrumentation installed in tests pits 1 and 2.

Assessment of Spatial and Temporal Distribution of Contaminants

The distribution of various contaminants provides insight into the degree to which they are being transformed by degradation, diluted by dispersion, and (or) retarded by sorption and thus, how quickly and how far contaminants are migrating. We will sample and analyze ground water to determine the concentrations of dissolved chlorinated hydrocarbons and expected degradation products of these compounds (fig. 9). Results of analyses will be used to map the spatial distribution of contaminants and degradation products within the study area and determine how their distribution changes with time.

PCA = Tetrachloroethane
1,1,1-TCA = 1,1,1-Trichloroethane
1,1-DCA = 1,1-Dichloroethane
Cis-1,2-DCE = Cis-1,2-Dichloroethene
CA = Chloroethane
PCE = Tetrachloroethylene
TCE = Trichloroethylene
Trans-1,2-DCE = Trans-1,2-Dichloroethene
VC = Vinyl chloride
1,1-DCE = 1,1-Dichloroethene

Dashed lines are minor pathways
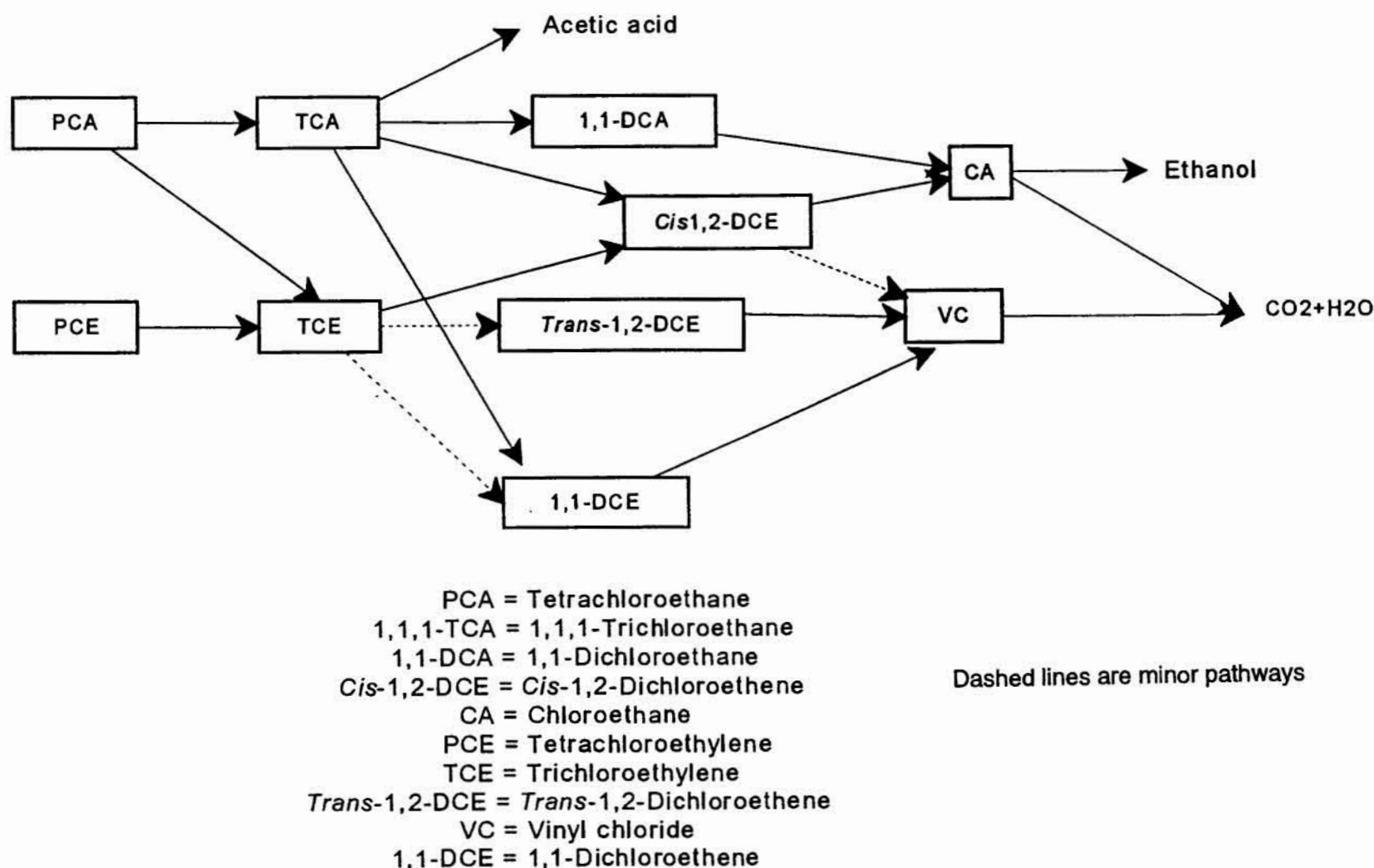
Figure 9. Transformation pathways and products of selected chlorinated hydrocarbons (modified from Davis and Olsen, 1990).

Spatial and Temporal Characterization of Ground-Water Chemistry

The various mechanisms of natural attenuation in ground water are related to the geochemical nature of the environment in which contamination exists. In addition, the geochemistry of ground water typically provides insight into the timing and extent of exchange between surface water and the ground-water system. Therefore, in addition to assessing the presence of contamination in ground water, we will measure pH, specific conductance, alkalinity, dissolved oxygen, and temperature, and will sample and analyze for a number of inorganic constituents including nutrients, major dissolved ions, and indicators of oxidation-reduction conditions.

Microbiological Assessment

Degradation of organic contaminants by microorganisms is one of the major mechanisms of removal of these compounds from the environment, and natural attenuation is therefore highly dependent on these microbial processes (National Research Council, 1993; McAllister and Chiang, 1994). Because no one measurement can be used to establish that biodegradation is occurring (National Research Council, 1993), documentation of natural attenuation requires several measurements that, taken together, support the assertion that biodegradation is occurring. The strategy recommended by the National Research Council (1993) and used in this study requires (1) documentation of loss of target contaminants from the site, (2) laboratory analyses showing that microorganisms from the site have the potential to catalyze the appropriate transformations under conditions at the site, and (3) evidence that biodegradation is occurring in the field. Loss of contaminants in this study will be documented through organic chemistry analyses of ground water. The potential of the indigenous microbial population to biodegrade chlorinated hydrocarbons under site conditions will be evaluated using the laboratory assays described below. Geochemical analyses—especially those relating to oxidation-reduction potential—as well as measurements of dissolved hydrogen and methane, will be used to provide evidence of *in situ* microbial activity. In addition to examining factors supporting natural attenuation in general, we will address how site-specific factors (e.g., proximity to the Chena River) influence microbial populations and activity.

Enumeration of Contaminant-Degrading Microorganisms

We will use miniaturized most-probable-number (MPN) enumerations to document the presence of microorganisms that can metabolize contaminants present in the ground-water system at OU5. Specific populations enumerated will include total heterotrophs, gasoline degraders, toluene degraders, and TCE degraders. Population enumeration results will be evaluated with respect to contaminant levels in the wells tested.

Determination of Microbial Mineralization Potentials

Mineralization potentials will be determined for microbial populations present in ground water at OU5. Laboratory assays will be conducted under temperatures approximating those in the field and at atmospheric and in situ oxygen levels. Specific laboratory mineralization potentials will be measured for toluene and TCE.

PROJECT DATES, ORGANIZATION, AND RESPONSIBILITY

This project began in September 1996, and is scheduled for completion in September 1998. Interim reports explaining the progress and status of the project will be submitted periodically at project meetings with the U.S. Army Corps of Engineers (COE), USARAK, and U. S. Army Environmental Center (AEC).

Larry D. Hinzman, UAF, Principal Investigator.—Responsible for project management; installation of hydrologic instrumentation; hydrologic data collection, analyses, and interpretation; writing of reports and scientific journal articles.

Joan F. Braddock, UAF, Co-Principal Investigator.—Responsible for microbiological data collection, analyses, and interpretation; writing of reports and scientific journal articles.

Michael R. Lilly, Arctic Region Supercomputing Center—UAF, Co-Principal Investigator.—Responsible for project management; installation of hydrologic instrumentation; hydrologic data collection, analyses, and interpretation; project coordination with COE, USARAK, and AEC.

Kathleen A. McCarthy, USGS, Co-Principal Investigator.—Responsible for interpretation of geochemical data; reports coordination; writing of reports and scientific journal articles.

Stanley A. Leake, USGS, Hydrologist.—Responsible for assisting in the interpretation of ground-water/surface-water interactions and the application of analytical or numerical methods to interpretation of ground-water flow modeling.

Sharon A. Richmond, UAF/USGS, Graduate Student.—Jointly responsible for collection and analyses of microbiological data; collection and analyses of ground-water samples for measurement of dissolved methane and hydrogen gases; interpretation of all data relevant to microbial transformations of chlorinated-hydrocarbon contaminants. Will assist in writing reports and journal articles.

Nada I. Raad, UAF, Graduate Student.—Jointly responsible for field data collection and interpretation. Will assist in writing reports and journal articles.

Matthew A. Wegner, UAF, Graduate Student.—Jointly responsible for field data collection; primarily responsible for investigations related to ground-water/surface-water interactions. Will assist in writing reports and journal articles.

FIELD PROCEDURES, DATA COLLECTION, AND ANALYSES

The procedures for installing instrumentation and monitoring wells, collecting and analyzing data, and documenting field work are described in the following sections.

Installation and Instrumentation of Test Pits

Two test pits were excavated west of, and adjacent to, the contaminated study site, along a line perpendicular to the Chena River (fig. 10). The purpose of the test pits is to provide background geochemistry data and allow use of measurement equipment that could not be installed in auger-drilled borings. The selection of the test pit locations was based on the extent of existing contamination, existing roadways, buried utilities, overhead utilities, and buried antenna systems in the area. These test pits were instrumented with clustered piezometers, lysimeters, thermistors, C-Index probes, and TDR probes (fig. 8; table 2).

Lysimeters

Suction lysimeters were constructed in the laboratory to enable collection of samples in both test pits from the zone above the water table. The lysimeters were constructed using 1 Bar, High flow 653X02-B1M3 Round Bottom, neck top, 2-inch porous cups (Soilmoisture Equipment Corp.; Goleta, CA). These cups were attached to 24-inch sections of 2-inch inside-diameter PVC pipe.

Table 2. Instrumentation in test pits

Probe Types:
1, Time domain reflectometer (TDR) probes (unfrozen moisture content)
2, C-Index probes (relative electrical conductivity)
3, Thermistors (temperature)
4, Discrete suction lysimeter sampling points (5-cm cup lengths)
5, Discrete piezometer-screen sampling points (1-inch PVC, 5-cm screen lengths)
6, Single 10-foot piezometer screen for continuous water-level measurements with pressure transducer

TEST PIT 1 Depth below land surface (centimeters)						TEST PIT 2 Depth below land surface (centimeters)				
Probe type						Probe type				
1	2	3	4	5	6	2	3	4	5	6
8	0	0	409	370	250	335	300	190	370	250
15	15	5	414	375	555	350	350	196	375	555
41	30	15	439	385		365	365	262	385	
66	45	35	444	390		380	380	267	390	
91	60	55	470	400		395	395	292	400	
122	75	80	475	405		410	410	297	405	
152	90	105	500	415		425	425	323	415	
203	105	130	505	420		440	440	328	420	
300	120	180	531	430		455	455	353	430	
340	135	230	536	435		470	470	358	435	
405	150	280		445		485	485	384	445	
425	165	330		450		500	500	388	450	
440	180	345		460		515	515	414	460	
457	195	360		465		530	530	419	465	
470	210	375		475		545	545		475	
485	225	390		480					480	
495	240	405		490					490	
506	255	420		495					495	
	270	435		505					505	
	285	450		510					520	
	300	465		520					525	
	315	480		525					535	
	330	495							540	
	345	510							550	
	360	525							555	
	375									
	390									
	405									
	420									
	435									
	450									
	465									
	480									

Figure 10. General location of test pits 1 and 2, Fort Wainwright.

One end of each pipe section was heated in hot cooking oil to the point of becoming pliable, at which point a porous cup was forced into the pipe. The pipe was then allowed to cool around the porous cup. After the pipe was cool, it was cleaned using hot water and dish-washing soap. A new porous cup was then glued into the pipe section using epoxy. Two sections of polyethylene tubing were then inserted into a rubber stopper. One tubing section ended near the top (open end) of the pipe section, and will be used to apply air pressure to remove water samples. The other tubing section continued to the bottom of the porous cup, and will serve to remove the water samples. Both tubing sections were run through a rubber stopper with two holes, and the tubing sections were sealed once the proper tubing lengths were verified. The rubber stopper was inserted tightly into the open end of the pipe section by heating the pipe slightly with a hot air gun. The rubber stopper was coated with silicone sealant prior to insertion. A total of 12 lysimeters were installed: five in test pit 1 and seven in test pit 2.

Thermistors

Thermistor theory.—Thermistor probes are used to measure temperature. The thermistor has a resistance that varies inversely with temperature: if the temperature increases, the resistance of the thermistor decreases. The relationship between the temperature and resistance can be expressed by the following theoretical equation (Omega, 1992):

$$T^{-1} = a + b\,(\log_e R_\Omega) + c\,(\log_e R_\Omega)^3 \tag{1}$$

where T is temperature (K), R_Ω is resistance (Ω), a is 1.28×10^{-3}, b is 2.37×10^{-4}, c is 9.06×10^{-8} and $\log_e$ is the natural logarithm. The values for thermal coefficients a, b, and c were determined by regression analyses in our laboratory.

By measuring the temperature and associated resistance of the probe in an ice-bath, we can calculate the appropriate offset for this equation to accurately describe the response of the thermistor to changes in temperature. Most of the temperature measurements at the study site will be close to 0°C, so this method is particularly useful. We can then use this equation to calculate subsurface temperature based on the measured resistance.

Thermistor construction.—The following steps describe the procedure for constructing thermistor probes:

- Lay 25-pair telephone cable in a location where it can be stretched to its full length. (The type of cable used depends on the number of probes per thermistor string and the length of cable required per probe.)
- Designate one end of the cable as the top and the other as the bottom.
- Starting at the bottom, measure the appropriate distances between the thermistor probes and mark the locations on the cable with a permanent marker.
- Strip approximately 6 inches of insulation off the top end of the cable to expose the bundle of wires.
- Starting at the position where each thermistor is to be located and extending toward the bottom of the string, make 0.5-inch lengthwise incisions on the cable for each thermistor.
- Select two wires for each thermistor location, and cut these wires near the bottom of each incision. Bend the wires such that they protrude approximately 0.5 inch from the bundle at the location where the thermistor is to be located. (At each thermistor location, carefully check field log book and the top of the cable where the bundle of wires are exposed to assure that the wires selected have not been previously used for another thermistor location.)
- After each pair of wires is cut, record their colors and the intended depth of the associated probe in the field book. (Record the primary wire color first, followed by the color of the stripe, or secondary color.) Label the ends of the wire pairs (at the top end of the cable) with the depth of the associated probe.
- Strip slightly less than 0.5 inch of insulation off each end of the wires.
- Cut pieces of shrink tubing (about half the length of the exposed wires) and fit loosely over the exposed wire ends where the probe will be located.

- Bend each wire pair such that they are slightly apart, forming an angle with one another of approximately 30 to 45 degrees.
- On each thermistor, bend the two exposed wires in the same manner as above, then tightly twist one thermistor wire around one of the exposed wires on the cable. Repeat with the other thermistor and cable wires. There may be some excess loose wire from both sets, which will be snipped off later.
- After cleaning the tip on a wet sponge, use a hot soldering iron to solder the wires together. Keep the iron close to the thermistor for as little time as possible so as not to damage the thermistor with the heat from the soldering iron.
- Gently pull on the wires to make sure that a good connection has been formed.
- Snip off the loose ends of the wires.
- Straighten the wires so that the shrink tubing can be pulled up over the top of the connection. (A heat gun can be used to shrink the tubing, which increases the strength of the connection.)
- Test each thermistor by attaching a digital voltage multi-meter (DMM) to the two free wires at the top of the string corresponding to that thermistor. Set the DMM to read electrical resistance with the appropriate number of significant figures and check the resistance of the wires. Verify that the resistance decreases in response to being warmed by the touch of your fingers. (Note that the thermistor may still be hot from the heat gun and the resistance may still be decreasing when the circuit is first tested.) A decrease in resistance with the addition of heat indicates that the thermistor is functioning. If this is not the case, there may be a break in the circuit, the thermistor may be defective, the DMM may be set up incorrectly, or the incorrect wires may have been used. Verify that the thermistors all have similar resistance values.
- Cut a piece of shrink tubing to fit over the entire thermistor probe, and place the tubing over the probe flush against the cable. The tubing should be slightly longer than the probe so as not to expose the tip of the thermistor.
- To waterproof each thermistor probe, fill both ends of the shrink tubing with silicone; assure that all of the incision is filled with silicone so that no water can enter the cable.
- Allow the silicone to harden overnight.
- After the silicone hardens, use a heat gun to shrink the tubing.
- To further waterproof and strengthen the probes, apply a heavy-duty waterproofing tape over the probe and incision. Tightly wrap each probe and associated cable incision area with the tape. Apply the tape so as to completely cover the probe and surrounding area and provide support to the probe so that it is difficult to move.

Thermistor calibration.—The following steps describe the procedure for calibration of thermistor strings:

- Select the thermistor string to be calibrated.
- Prepare an ice bath by filling a cooler with crushed or small-cube ice and then fill remaining volume with water.
- Prepare a log book for the calibration and record the time, date, name of the person performing the calibration, intended depth of each probe, wire color used for each probe, temperature of the water bath, and resistance of the probe at that temperature.

- Immerse all of the thermistor string except for the wires at the top of the string into the water/ice bath. Agitate the water bath slightly to make sure the water has not thermally stratified.
- Let the thermistor string equilibrate with the bath for approximately 30 minutes.
- Using a high precision thermometer, measure the temperature of the water bath and record in the log book.
- Using a digital volt/ohm meter, measure the resistance of each thermistor probe by attaching the leads to the two wires that correspond to that probe. Record each resistance in the log book.
- Using the temperature and associated resistance measured during the calibration procedure, calculate the appropriate linear offset for equation 1.

C-Index Probes

The basic theory underlying C-Index probes is the measurement of electric potential. An electric potential is generated by running the string of probes parallel to a metal ground spike; the difference in concentration of metals creates an electric cell. The ion concentration of the soil water in the vicinity of the probe and ground spike determines the relative strength of the electric potential. By measuring the electric potential, a relative measure of the soil water ion concentration can be determined—this is referred to as the C-Index (Outcalt and others, 1989). The principles of the C-Index are based on the equation for an electrolytic cell without transference. Using a complex equation (Outcalt and others, 1990), electric potential is converted into the C-Index, which can then be used to compare relative ion concentrations in the soil water.

Time-Domain Reflectometery Probes

Time-domain reflectometery theory.—TDR probes are used to measure the unfrozen moisture content of soils. The probes work much like radar, sending electromagnetic wave pulses through the soil and timing the return of the reflected wave form. It is the dielectric constant of the bulk soil that determines the propagation velocity of electromagnetic waves through the soil. Because the dielectric constant of liquid water is much greater than that of air, ice, or soil, changes in the dielectric properties of unsaturated soils—and thus in the speed of a waveform traveling through the soil—are governed primarily by changes in the unfrozen-water content. Once the relationship between moisture content and wave-propagation velocity is defined for a particular soil through calibration, an empirical third-order equation (Stein and Kane, 1983; Kane, 1986; Hinzman and others, 1990) can be used to calculate the unfrozen water content of that soil based on the time required for a wave form to be reflected through a known distance in the soil.

Our TDR instrumentation was calibrated in the laboratory. Pairs of 12-inch steel probes were buried in the ground at a desired depth, 1 inch apart. Cables were then run from the probes to the surface where they can be connected to the TDR.

The algorithm used by Campbell Scientific, Inc. to convert dielectric constant to percent moisture content performs well for unfrozen soils. As the region of primary importance in understanding the interaction of surface water and ground water is that just above the water table, measurement of the unfrozen soil moisture content in the frozen soil near the surface is not particularly important for this study. If, during the course of the study, it becomes apparent that we do need to measure the unfrozen soil moisture content in the near-surface frozen soils, we can obtain these data by storing every measurement point along the entire wave form for each trace.

Installation of Monitoring Wells

Monitoring wells will be installed with standard augering techniques as described in American Society of Testing and Material (ASTM) Standards D5092-90 (ASTM, 1997a) and D1452-80 (ASTM, 1997b).

Hydrologic Data Collection and Analyses

The procedures for the collection and analyses of hydrologic data are described in the following sections.

Ground-Water Level Measurements

Water levels are measured at Fort Wainwright on a monthly basis. All wells are measured within a three-day period during the winter and within a one- or two-day period in the summer. The measurement dates are coordinated with USGS and CRREL so that all measurements are made at approximately the same time each month. The procedure for conducting these measurements is discussed in the following paragraphs.

The field crew wears rubber gloves while performing all measurements. A piezometer is opened/unlocked and a clean electric tape (e-tape) is turned on and set to a sensitivity of 3 or 4 on a scale of 10. All wells are marked on the outer rim to indicate the measurement points. The e-tape is lowered into the well until a beep is heard, indicating that the indicator is submerged in water, or until the bottom of a dry well is reached. The depth to water is determined by reading the value off the e-tape cable at the measuring point. It is important to measure depths accurately and consistently; readings are therefore consistently recorded at the initial sound of the beep. Measurements are repeated until consecutive readings are within 0.01 ft. All measurements are recorded in a field book and (or) on a field measurement and sampling form (see appendix, fig. A-1) along with the sequential stop number, date, time, crew members and site identification. After completing the measurement, the well is closed and locked.

Water levels at some wells may be measured with a weighted steel measuring tape and chalk. The methods for measuring water levels will follow ASTM Standard D4750-87 (ASTM, 1997c). Chalk is applied to the lower 2-3 feet of the steel tape. The steel tape is then lowered into the well until the lower section of the weighted tape is under water and part of the chalked section is wet. The tape is held to the measuring point for the well and a hold reading is recorded. The tape is then withdrawn back to surface and the wetted limit indicated on the tape by the chalk, the cut mark, is recorded. This cut measurement is then subtracted from the hold measurement to give the depth to water below the reference mark.

After each water level is measured, including individual measurements within piezometer nests, the part of the e-tape or steel tape exposed to ground water will be decontaminated as follows:
- Immerse and swirl in a container of tap water.
- Immerse and swirl in a solution of detergent and distilled water.
- Rinse in distilled water.
- Rinse in a container of methanol.
- Rinse in deionized water and dry with a paper towel.

- Dispose of the paper towel in a plastic garbage bag.
- Change the water and methanol at the end of each monthly measurement, or more frequently, as necessary.

Field equipment and supplies.—The equipment and supplies required to measure water levels include:
- Field book
- Location map
- E-tape
- Tools:
    -- flathead screwdriver
    -- channel locks
    -- hammer
    -- flush-mount well-cover wrench
    -- crescent wrench
- 15-20-foot length of tubing that will fit down a well (optional; may be used to free e- tape if caught down a well)
- Steel tape, for calibration of e-tape
- Keys to open wells
- Decontamination kit:
    -- rinse 1: tap water
    -- rinse 2: detergent/distilled water mixture
    -- rinse 3: deionized water
    -- rinse 4: methanol
    -- rinse 5: deionized water
    -- paper towels
    -- trash bags
    -- rubber gloves
    -- waste water container
    -- waste methanol container
    -- extra methanol container

Unsaturated-Zone Characterization

Water chemistry.—Water samples for chemical analyses will be collected from lysimeters as necessary, to augment water-chemistry data collected from monitoring wells. To obtain a water sample from a lysimeter, a vacuum is applied to the lysimeter with a hand pump, and the evacuated lysimeter is then left undisturbed for 1-24 hours, depending on the degree of wetness of the soil. The water sample is then removed from the lysimeter by applying a positive air pressure to the shorter lysimeter tubing and forcing the water sample out of the lysimeter via the longer tubing.

The C-Index probes will be used to determine relative ion concentrations in the unsaturated zone soil water. C-Index probe readings will be recorded every hour on a CR-10 data logger (Campbell Scientific, Inc., Logan, UT). The frequency of measurement may be increased during intense rain storms or to track particular time periods more closely.

Temperature.—Thermistors will be used to measure temperature profiles in the unsaturated zone. The thermistor readings will be recorded every hour on a CR-10 data logger (Campbell Scientific, Inc., Logan, UT). The frequency of measurement may be increased during intense rain storms or to track particular time periods more closely.

Soil-moisture content.—The unfrozen moisture content of the unsaturated zone will be measured using TDR probes connected to a model 1502B TDR (Tektronix, Inc., Beaverton, OR). The TDR measurements will be recorded every 3 hours on a CR-10 data logger (Campbell Scientific, Inc., Logan, UT). The frequency of measurement will be increased during intense rain storms or to track particular time periods more closely.

Data Validation, Reduction, and Reporting

Data that are automatically collected will be stored on CR-10 data loggers (Campbell Scientific, Inc., Logan, UT). The data from the data loggers will be retrieved approximately once per month throughout the year. The data will be transferred to an IBM-compatible personal computer for data reduction and compilation. Data will then be plotted to determine if they are reasonable. Some data, such as radiation data, follow diurnal patterns that can be easily checked. Other data, such as ground-water levels, will be compared to periodic manual measurements for verification. All reduced and compiled data will be plotted and checked by a second person. After review, data will be archived in established USGS databases or in the National Snow and Ice Data Center in Boulder, Colorado.

Geochemical Data Collection and Analyses

Concentrations of target petroleum and chlorinated hydrocarbons, major inorganic ions, pH, alkalinity, dissolved oxygen, specific conductance, and water temperature will be measured in ground water. Measurements in addition to target contaminant concentrations are necessary to characterize the subsurface geochemistry and will provide supporting data for assessments of surface-water/ground-water interactions and natural-attenuation processes. These data will also be used to guide and constrain our conceptual model of the system. To understand the relative importance of adsorption of organics onto the soil matrix, we will also measure the organic carbon fraction of the soil.

Ground water will be collected from a number of wells in OU5 periodically. The choice of wells to be sampled will be based on our updated knowledge of the distribution of the contaminants.

Sample Collection

To minimize cross contamination among wells, sampling will generally proceed from the least to the most contaminated sites.

Sampling equipment.—The following equipment and materials will be used for sample collection and processing:
- Field log books and field sampling forms
- Waterproof writing instruments
- Gloves and protective eye wear

- Trash bags and paper towels
- Coolers for sample storage and shipping
- Tubing for purging wells
- Hydrolab, Hach Kits and spectrophotometer
- Thermometer, dissolved oxygen and specific conductance probes, and pH meter
- Sample containers and labels
- Disposable Teflon bailers
- Deionized water
- Hydrochloric acid
- Containers for collection of purge water
- Peristaltic pump (2)

Sampling procedure.—Samples will be collected and processed according to specific protocols described by Koterba and others (1995) and outlined in the catalog and memoranda of the USGS National Water Quality Laboratory (NWQL). These protocols vary depending on the target analyte(s) for a particular sample, but in general, the following procedures will be observed at each data-collection site in the field:

- Record the following data in field log books and (or) on field sampling forms (see appendix, fig. A-1):
    - -- Names of sampling crew
    - -- Date and time of sampling
    - -- Weather conditions
    - -- Name of person collecting the sample
    - -- Location, identification number and depth of well sampled
    - -- Instruments used, including identification numbers
    - -- Results of all field measurements
    - -- Number and type of samples collected
    - -- Unexpected problems and course of action
    - -- Observations of contamination, such as odors or sheens
    - -- Date, time, and results of all calibration and repairs to field instruments
- Measure the water level in the well to a precision of ±0.01 ft.

- To remove stagnant water, purge the well by pumping until pH, conductance, dissolved oxygen and temperature stabilize over approximately three consecutive well volumes of water pumped. (Stabilization criteria are pH, ±0.05 units; conductance, ±5 percent for conductance ≤100 microsiemens per centimeter (µS/cm) and ±3 percent for conductance >100 µS/cm; dissolved oxygen, ±0.3 milligrams per liter (mg/L); temperature, ±0.2°C).

- Carefully collect, containerize, and deliver purge water to the Fort Wainwright storage area. When results of chemical analyses are available, send data for each container to the Fort Wainwright Department of Public Works (DPW) facility and the DPW Office of Environmental Affairs. (Based on these results, the purge water will be disposed of using an appropriate method).

- Label purge-water containers with the investigators name, date, and well number, and apply a label to the container that clearly states non-regulated waste.

- Protect purge-water containers against freeze rupture by storing them in a warm warehouse following cold-weather sampling.

- After purging, re-measure the water level.

- Label sample containers with time, date, well identification number, sample preservation method (if any), intended laboratory analysis code for the sample.

- Use a 0.45-micrometer (μm) disposable filter to filter those samples requiring filtration.

- Before filling sample containers, rinse all containers and lids with the liquid to be sampled.

- Collect samples for analysis of organic compounds with disposable Teflon bailers.

- Lower the bailer slowly into the well to minimize disturbance of the water and avoid contact with equipment, clothing, etc.

- Lift the bailer slowly and transfer the contents to the labeled containers with a minimum of disturbance and agitation to avoid loss of volatile compounds.

- Minimize head space in containers for organic analyses by filling the containers until a positive meniscus is present.

- Preserve samples for organic analyses by adding two drops of hydrochloric acid to lower the pH to less than 2 standard units.

- Seal sample containers quickly and tightly.

- To minimize biodegradation and volatilization, immediately place samples in a cooler with ice that is maintained at 4°C (maximum temperature) through delivery to the receiving laboratory.

- Fill out and ship laboratory submittal forms (see appendix, fig. A-2) with each sample.

- After sampling, collect tubing, gloves, and bailers in trash bags for disposal; repackage other equipment used during sampling for decontamination in the laboratory.

Data Analyses

Field analyses.—Dissolved oxygen, pH, water temperature, and conductance will be measured in the field using a flow-through meter (Hydrolab Monitor with Scout II data logger, Hydrolab Corporation, Austin, TX). Dissolved oxygen concentrations will occasionally be verified using the azide modification of the wet chemistry Winkler method (American Public Health Association and others, 1989). Alkalinity will be measured in the field using a Hach digital titrator with the end point being determined by field pH measurements. Ferrous iron, total iron, and sulfide concentrations will be measured by colorimetric field assays (Hach Company, Loveland, CO).

Laboratory analyses.—Laboratory analyses will be performed at the USGS NWQL following methods described by Faires (1993), Fishman (1993), Fishman and others (1994), and Rose and Schroeder (1995).

Quality Control

Quality control in the field.—Quality control measures in the field will include collection and processing of sample blanks and duplicates. The number of quality control samples will vary, depending on the total number of environmental samples: field duplicates, approximately 10 percent of environmental samples; equipment blanks, approximately 5 percent of environmental sam-

ples; trip blanks, approximately 1 percent of environmental samples collected for organic analyses (Koterba and others, 1995).

Quality control in the laboratory.—Quality-control procedures used in the laboratory, including sample surrogates, standards, matrix spikes, duplicates, reagent blanks, reference samples, and blanks are described by Pritt and Raese (1995).

Microbiological Data Collection and Analyses

The procedures for collecting and analyzing samples for the microbiological assessment are described in the following sections.

Sample Collection

Ground-water samples for microbiological analyses will be collected concomitantly with samples for chemical analyses. Samples will be collected from purged wells using sterile Teflon bailers, and will be aseptically transferred to 250- or 500-milliliter (mL) polypropylene wide-mouth bottles that have been sterilized by autoclaving (15 minutes at 121°C and 15 lb/in^2). Samples for zero-headspace mineralization assays will be collected directly into vials (20 or 40 mL) and capped with lids containing silicone-covered septa (I-Chem vials, I-Chem Research, Hayward, CA). The samples will be placed immediately on ice in coolers until return to the laboratory where they will be maintained at 4°C until processing. Microbial population and activity analyses will be initiated within 24 hours of sample collection.

Microbial Population Estimates

An MPN technique will be used to assay four populations of microorganisms: total heterotrophs, gasoline degraders, toluene degraders, and TCE degraders. We have previously used MPN techniques for documenting microbial populations at other contaminated sites and have well-established procedures for assaying petroleum-hydrocarbon degraders and heterotrophs (Brown and Braddock, 1990; Lindstrom and others, 1991; Braddock and others, 1995) and for specific contaminants (Catterall and others, 1995; method adapted from Bochner and Savageau, 1977). The MPN enumeration procedure is a statistical method that helps assure the attainment of quality data through its design. Based on the results of a number of replicate inoculations, the statistically most probable number of microbes (selected for by the medium) per unit volume is calculated. If the numbers fall below or above the dilution series selected, the final numbers will be reported as either less than or greater than the table value. Since the technique is based on the culture of environmental microorganisms in the lab, it is a relative, rather than absolute, measure of the population of interest.

Enumeration of total heterotrophs.—The procedure for enumerating total heterotrophic microorganisms is outlined in the following sections.

Medium preparation:
- Prepare enough R2A broth (Atlas, 1993; p. 174) to provide approximately 5 mL per plate (one plate can be used for either two samples or duplicates of one sample).

- Filter the R2A medium through a 0.45-μm cellulose acetate filter (Millipore Corp., Bedford, MA) prior to volumetric measurement and autoclaving. This removes anything that did not dissolve in the medium and prevents precipitate formation during autoclaving.
- Using a graduated cylinder, add 200 mL of the filtered R2A medium to a clean, dry 500-mL Wheaton bottle (Wheaton, Millville, NJ).
- Using a clean graduated cylinder, add 300 mL of distilled water to the 200 mL of filtered R2A. This yields 2/5 strength R2A medium.
- Shake the bottle well and autoclave for 15 minutes at 121°C and 15 lb/in^2. Allow the medium to sit at room temperature for at least 48 hours prior to use. Discard if turbidity develops.

Heterotroph plate preparation:
- Using sterile technique, transfer the prepared R2A medium into a sterile petri dish. NOTE: Do not overfill the petri dish. Replace the lid. The petri dish is used in the sterile transfer of R2A medium to the 96-well plate. NOTE: The R2A medium is a heterotrophic medium that will allow the growth of many environmental organisms; good sterile technique is extremely important. Periodically replace the petri dish with a fresh, sterile one.
- Using an eight-channel pipettor and sterile pipette tips, transfer 100 microliters (μL) of R2A medium to each well of a 96-well plate.
- Store medium in a humid environment at room temperature for 48-72 hours. Discard any plates with visible turbidity NOTE: Do not prepare plates more than one week in advance of the planned sampling to avoid loss of medium to evaporation.

Serial dilutions:
- Use sterile 24-well plates for diluting samples; wells should be large enough to hold 2.5 mL. Sterile Ringer solution (Collins and others, 1989; p. 78) is used as the diluent.
- Prepare Ringer solution and autoclave for 15 minutes at 121°C and 15 lb/in^2. Orient a 24-well plate on the bench top so that there are six columns and four rows.
- Using an automatic pipettor with sterile tips, transfer 2.25 mL of sterile Ringer solution to each well except the wells in row one/column one, row one/column three and row one/column five. Empty wells will hold undiluted sample.
- Store the filled 24-well plates in a humid environment. NOTE: Do not make plates more than three days in advance of the planned sampling to minimize evaporation of diluent.
- Remove samples from refrigerator. Immediately prior to removing an aliquot for analysis, shake sample container with wide-arc arm movement 50 times.
- Using a pipettor and sterile tips, aseptically transfer approximately 2.5 mL of a water sample into the first empty well (row one/column one). Aspirate well contents three times to mix and aseptically transfer 0.25 mL from the first well to the second well (column one/row two). This is a 10^{-1} dilution. Discard pipette tip after each transfer of the dilution series.
- With a fresh tip, mix well contents as above and transfer a 0.25-mL aliquot from the 10^{-1} dilution well to the third well (column one/row three). This is a 10^{-2} dilution. Repeat this process of mixing and transferring until a 0.25-mL aliquot has been transferred from the

well in column two/row three (10^{-6}) to the well in column two/row four (10^{-7}). With this procedure, each 24-well plate contains enough wells to dilute three samples to a final dilution of 10^{-7}.

- The same dilution series may be used for heterotrophic, gasoline-degrader and toluene-degrader MPN determinations. However, for replication, a separate dilution series should be prepared from a separate sample container to avoid pseudoreplication.

Transfer of sample from the dilution plate to the heterotroph plate:
- Each sterile 96-well plate can hold two 6-tube MPN assays. Orient the plate so there are 12 columns and eight rows. Columns 1-6 hold one MPN assay (designated Sample A) and columns 7-12 hold a second assay (Sample B). These may be either different samples or replicates of the same sample.
- Using an eight-channel pipettor and sterile tips, aspirate samples (as described above) to mix and aseptically transfer a 100-µL aliquot from the Sample-A low dilutions (10^{-4} to 10^{-7}) to columns 4-6 in the heterotroph plate. Repeat this process to transfer Sample-A higher dilutions (10^{-1} to 10^{-3}) to columns 1-3 in the heterotroph plate. Replace pipette tips with sterile tips between samples. Take care to avoid placing tips that have contacted a higher dilution into wells containing a lower dilution. NOTE: With an eight-channel pipettor, two pipette tips fit into each well of the 24 well dilution plate; confirm that the two tips are positioned in each well before withdrawing an aliquot. For the 96 well heterotroph plate, a single tip fits in each well.
- Repeat the process described in the previous step for Sample B.
- Place three plates per bag in Whirl-Pak bags (Millipore Corp., Bedford, MA), seal, and incubate at room temperature.

Reading the plates:
- Score plates after 3 weeks and 5 weeks of incubation.
- Score each well plus or minus for turbidity.
- Use an uninoculated control plate, prepared at the same time the samples are prepared, as a reference.
- Determine the final MPN for the six-tube assay by an MPN algorithm (Koch, 1994).

Quality control:
- In all cases, assay the samples in triplicate so as to provide a mean and standard error.
- Randomly collect duplicate samples from 10 percent of monitoring wells and assay as described above.

Enumeration of gasoline and toluene degraders.— The procedure for enumerating gasoline-degrading and toluene-degrading microorganisms is outlined in the following sections.

Medium and plate preparation:
- Prepare enough modified Bushnell-Haas (BH) broth to yield approximately 5 mL per plate (Atlas, 1993; $FeCl_3$ concentration is reduced from 0.05 grams/liter (g/L) to 0.005 g/L to

prevent precipitation of phosphate buffers). One plate contains enough wells for two assays.

- Filter BH broth through a 0.45-μm cellulose acetate filter (Millipore Corp., Bedford, MA) prior to volumetric measurement.

- Using a graduated cylinder, add 400 mL of filtered BH broth to a clean, dry 500-mL Wheaton bottle (Wheaton, Millville, NJ).

- Measure 100 mL of distilled water and transfer to a separate clean, dry 500-mL Wheaton bottle (Wheaton, Millville, NJ). Dissolve 0.025 gram (g) 2,5-diphenyl-3 [α–naphthyl] tetrazolium chloride (TV) in this bottle.

- Add TV solution to BH broth in the 500-mL bottles. This yields 4/5 strength BH-TV medium. Shake well and autoclave for 15 minutes at 121°C and 15 lb/in^2.

- Fill sterile 96-well plates with TV-BH medium following the same protocol as for filling heterotroph-enumeration plates.

- Store in a humid environment at room temperature for 48-72 hours. Discard any plates with visible turbidity NOTE: Do not prepare plates more than one week in advance of the planned sampling to avoid loss of medium to evaporation.

- Transfer diluted sample from dilution plate to prepared BH-TV plates as previously described in heterotroph enumeration section.

Addition of carbon sources:
- Using separate sterile Luer-Lock syringes and autoclaved Acrodiscs (Gelman ®Acrodisc CR PTFE 0.2 μm, Ann Arbor, MI), filter-sterilize each carbon source (gasoline or toluene) into a separate, autoclaved I-Chem vial. Seal each vial with a sterile, silicone-lined septum.

- Using a sterile 3-mL syringe fitted with a 26-gauge 0.5-inch needle, withdraw approximately 3 mL of air while flaming the needle tip (to sterilize the air). Sterilize the surface of the I-Chem septum vial with methanol. Inject the sterilized air into the I-Chem vial and withdraw a syringe full of the carbon source.

- Add one drop (approximately 1 μL) of gasoline or toluene to each well in the BH-TV plate. Designate each plate as gasoline or toluene. Do not mix carbon sources on a single plate.

- After addition of carbon source, place three plates per bag in Whirl-Pak bags (Millipore Corp., Bedford, MA).

- Incubate at room temperature.

Reading the plates:
- Read plates after 3 and 5 weeks of incubation.

- Score each well as plus or minus for purple color development (microbial oxidation of supplied carbon source).

- Use an uninoculated control plate, prepared at the same time the samples are prepared, as a reference.

- Determine the final MPN for the six-tube assay by an MPN algorithm (Koch, 1994).

Quality control:

- In all cases, assay the samples in triplicate so as to provide a mean and standard error.

- Randomly collect duplicate samples from 10 percent of monitoring wells and assay as described above.

Enumeration of TCE degraders.— TCE degraders will be estimated by a three-tube MPN procedure using 40-mL sealed glass serum vials. Each sample will be serially diluted in sterile 125-mL polypropylene containers containing 90-mL Ringer solution (Collins and others, 1989). For initial samplings, the final dilution series will range from 10^0 to 10^4. The specific dilution series may be modified as appropriate for the Fort Wainwright samples. Twenty mL of each dilution will be added to each of three 40-mL glass serum vials. Five mL of BH medium (Atlas, 1993) will then be added to each serum vial to provide mineral nutrients, and 300 µL of toluene will be added as a co-substrate. The vials will then be sealed with butyl rubber stoppers (Bellco, Vineland, NJ) and 300 µL of TCE added through the stopper with a syringe. Headspace analyses of loss of TCE will be used as an indicator of TCE degradation following incubation of the serum vials. Killed (auto-claved) samples will be run in parallel to control for abiotic loss of TCE. Loss of TCE two times that of the control will be scored as positive for TCE degradation. The final MPN will be estimated from an MPN algorithm (Koch, 1994).

Toluene Mineralization Potentials

Radiorespirometry will be used to assay toluene-mineralization potentials of microorganisms in ground water at temperatures approximating those in the field (Brown and others, 1991; Fan and Scow, 1993). Radiolabelled toluene ([U-^{14}C]-toluene) will be used as a representative aromatic hydrocarbon. Ground water will be added to 40-mL vials fitted with Teflon-lined septa, either with headspace (aerobic incubations) or without headspace to retain naturally occurring oxygen levels. Replicate vials of the diluted ground water will be injected with 50 µL of a 2-g/L solution (in ace-tone) of radiolabelled substrate—about 50,000 disintegrations per minute (dpm). The resulting ini-tial concentration of added substrate will thus be 100 micrograms (µg) per vial. At the end of the incubation period, microbial activity will be stopped by adding 1 mL 10 normal (N) sodium hydroxide (NaOH). The samples will later be re- acidified with 1.5 mL hydrochloric acid (HCl), after which the radiolabelled carbon dioxide ($^{14}CO_2$) will be stripped into a CO_2-sorbing scintilla-tion cocktail and counted in a liquid scintillation counter. An in-line solvent trap will trap volatile organic products which will then be counted. Radiorespirometry will be used to calculate average laboratory mineralization rates for substrate by the formula:

$$r = r * \frac{(S_n + A)}{A *} \qquad (2)$$

where r is the average mineralization rate, $r*$ is the average rate of $^{14}CO_2$ production, S_n is the *in situ* substrate concentration, A is the added substrate concentration, and $A*$ is the total radioactivity added. Ten percent of samples will be replicated for quality assurance. For each sample, abiotic (killed) control samples will be run to control for any possible abiotic evolution of CO_2. CO_2-cap-turing efficiency is periodically monitored for our stripping line by using samples containing $^{14}CO_2$-bicarbonate. Previous results indicate that the purging system recovers greater than 99 per-cent of $^{14}CO_2$ from radiolabelled bicarbonate (Braddock and others, 1995). Potential carryover in

the system will be monitored by running a set of water blanks through the stripping line at the beginning and end of each day of analyses.

Mineralization-potential laboratory protocol.—The procedure for determining toluene mineralization potentials is outlined in the following sections.

Note: Only authorized users and designated supervised users are allowed to handle radioisotopes. (For details, see radioisotope manual at University of Alaska Fairbanks, Irving 104).

Preparing scintillation cocktail:
- Prepare scintillation cocktail on the day of use.
- Using a repipettor filled with the CytoScint cocktail (ICN Aurora, Costa Mesa, CA), dispense 7.5 mL into each scintillation vial.
- Add 2.5 mL of phenylethylamine (PEA) to the vial containing 7.5 mL of CytoScint. Shake the vials to mix the cocktail. The cocktail is then ready to use.

Spiking vials:
- Using a designated gas-tight syringe (Hamilton; Reno, NV), remove 100 µL of radiolabelled substrate, ensuring that no air bubbles are present in the syringe.
- Inject 50 µL of the substrate into a sample vial. Inject the remaining 50 µL of substrate into another sample vial.
- Repeat this process until all of the sample vials have been spiked with the radioactive substrate.

Killing vials:
- After an established incubation period (to be determined by a series of time-course experiments), use a 10-mL Luer-Lock disposable syringe with 22-gauge 1.5 inch needle to inject 1 mL of 10 N NaOH into each vial to stop activity and fix respired CO_2 in solution.
- Store vials until processing on the radiorespirometry line.
- Run killed vials as controls for each experiment (time 0).

Analysis of samples:
- Using a 10-mL Luer-Lock disposable syringe with 22-gauge 1.5 inch needle, inject 1.5-mL concentrated HCl into six sample vials, shake the vials approximately 10 times, and allow them to sit undisturbed for 5 minutes.
- Fill six scintillation vials with 10 mL of the 25 percent PEA-75 percent CytoScint cocktail mixture.
- On the stripping line apparatus, find the long needle from the nitrogen source tubing and the short needle from the tubing leading to the Harvey trap. Place an I-Chem vial in each clamp (6 total) located beneath the needle attachments.
- Place a scintillation vial filled with cocktail in the clamps located below the Teflon stoppers (with pipette tips). Remove cap from scintillation vial. Place the Teflon stopper (with the pipette tips) into the scintillation vial filled with cocktail.

- Insert the long needle (nitrogen source) into the sample vial so that the needle tip is approximately 0.5 inch above the water line. Insert the short needle fully. Insert the long needle farther so that the tip of the needle is below the water level.

- Allow nitrogen to bubble through the line for 15 minutes, then remove the Teflon stopper from the scintillation vial and replace the cap. Remove needle from the sample vial.

- Place scintillation vials in a scintillation vial rack and place rack in the scintillation counter.

- Rinse the pipette tips of the Teflon stopper by dipping in deionized water several times, wiping dry with a Kimwipe, and re-rinsing with acetone.

- Ensure that needles are not clogged with septum pieces; unclog if necessary.

Analysis of blanks:
- Run blanks between approximately every 48-60 samples and at the end of the day.
- Fill six clean I-Chem vials with 10 mL of water.
- Fill six scintillation vials with 25 percent PEA-75 percent CytoScint cocktail.
- Follow the instructions above for analyzing samples.

Using scintillation counter:
- Analyze the samples with a Beckman model LS6000 scintillation counter (Beckman Instruments, Inc., Fullerton, CA).
- Count samples for 5 minutes with the disintegrations per minute calculated for single label with H-Number Plus correction.

Clean up:
- Run blanks at the beginning and end of each day.
- After running final blanks, rinse pipette tips with deionized water and acetone.
- Unclog needles if necessary and rinse in deionized water.

Measurement of Dissolved Gases

Active microorganisms have a considerable effect on the concentrations of dissolved gases in ground-water systems. To better understand these *in situ* conditions, we will measure concentrations of dissolved hydrogen and methane in ground water. The following sections describe the procedure for sample collection and analyses of dissolved gases, and are adapted from the laboratory protocol of F. H. Chapelle (U.S. Geological Survey, written commun., 1996).

Hydrogen sample collection.—
- Place the intake hose of a peristaltic pump down the sampling well.
- Position the intake at the depth of the screened interval.
- Attach a 250-mL glass water-sampling bulb (Supelco, Inc., Bellefonte, PA) to the outflow end of the hose.
- Turn on the pump and adjust the flow rate to about 500-700 mL/min. (Use the same flow rate for all sampling wells.)

- Briefly hold the outlet end of the sampling bulb in the upright position and inject 20 mL of ultra-high purity (UHP) nitrogen gas.
- Allow the nitrogen bubble to equilibrate with the flowing ground water for approximately 10 minutes.
- After the equilibration period, remove 3-5 mL of the gas bubble using a 10-mL glass syringe with attached mini-inert valve.
- Close the valve to seal the sample.
- Wait an additional 5 minutes and remove another 3-5 mL from the nitrogen bubble using a separate syringe with valve.
- Close the valve and seal the sample.
- Analyze both samples on the hydrogen detector. If the hydrogen concentrations of the duplicate samples are not within 5 percent, it may be necessary to take a third gas sample in the same manner.

Hydrogen analytical method.—Concentrations of dissolved hydrogen will be determined using the bubble strip method coupled with gas chromatography (GC). For GC analysis, the gaseous sample is injected into a stream of nitrogen carrier gas, and is transported by the carrier through a separation column (stainless steel, 1/8-inch, 100/120 Carbosieve S-11, Supelco, Inc., Bellefonte, PA). This column separates components primarily through size exclusion. The separated components elute from the column at different times and pass through a heated bed of mercuric oxide where the reduced gases (primarily hydrogen and carbon monoxide) are oxidized and mercury vapor is released. The concentration of mercury vapor is directly proportional to the concentrations of reduced gases in the sample and is detected by means of an ultraviolet photometer.

The concentration of hydrogen dissolved in ground water is estimated from the headspace (sample) concentration as follows:

- Prepare a calibration curve for hydrogen using a 100 parts-per-million (ppm) Scotty II standard gas mixture (can mix 210). Convert ppm (by volume) units to molar units by using the Ideal Gas Law:

$$PV = nRT \tag{3}$$

rearranged to:

$$\frac{n}{V} = \frac{P}{RT} \tag{4}$$

where n is the quantity of gas in moles, V is the volume the gas occupies in liters, P is the partial pressure of the gas in atmospheres (atm), T is the temperature in degrees Kelvin, and R is the universal gas constant (0.08206 L-atm/mole-K). Thus, the concentration of a pure gas at atmospheric pressure and room temperature (298 K) is 40.9 millimoles/L (mmol/L), and the hydrogen concentration of a 100-ppm hydrogen standard is 4090 nanomoles/L (nmol/L).

- Calculate the linear regression which describes the calibration curve.
- Load the sample collected from the sampling bulb into the sample loop, close the sample loop outlet valve, and pressurize the loop.

- Inject the sample.
- Calculate the dissolved hydrogen concentration from the sample hydrogen concentration using the following relationship:

$$C_w = \frac{C_{hydrogen}}{H_{hydrogen}} \tag{5}$$

where C_w is the hydrogen concentration dissolved in ground water in nmol/L, $C_{hydrogen}$ is the sample hydrogen concentration in nmol/L, and $H_{hydrogen}$ is the dimensionless distribution coefficient for hydrogen between the gaseous and dissolved phases.

- Identify the predominant terminal-electron-accepting process from the characteristic hydrogen-concentration ranges (table 3).

Table 3. Characteristic hydrogen-concentration ranges of terminal-electron-accepting processes (Chapelle and others, 1995).

Predominant terminal-electron-accepting process	Sample hydrogen concentration (nmol/L)
Nitrate reduction	< 0.1
Iron reduction	0.1 to 0.8
Sulfate reduction	1 to 4
Methanogenesis	6 to 25

Methane sample collection.—Samples for determination of dissolved methane concentrations will be collected in triplicate, concomitantly with hydrogen samples:
- Prior to sampling, purge serum vials with methane-free nitrogen and stopper with butyl rubber stoppers (Bellco, Vineland, NJ).
- Seal vials with aluminum crimp caps.
- Insert the needle of a gas-tight syringe (Hamilton, Reno, NV) fitted with a Teflon syringe valve (Supelco, Inc., Bellefonte, PA) through the septum of the sampling bulb, withdraw a 10-mL aliquot, and close the syringe valve. (It is critical that no bubbles are present in the bulb at the time of sampling.)
- Remove the syringe needle and discard.
- Attach a 0.45-μm syringe filter to the syringe valve and replace the discarded needle with a fresh, sterile one.
- Insert the needle of the syringe containing the ground-water sample into the vial and inject the sample.

Ground-water samples collected in this manner can be stored for 3 weeks at ambient temperature before beginning headspace analyses.

Methane analytical method.—Gaseous methane samples will be transferred from the collection syringe to 40-mL serum bottles fitted with Teflon or butyl-rubber septa and sealed with alu-

minum crimp caps. (Serum bottles will be flushed with UHP nitrogen for 3 minutes prior to sample transfer.)

A Shimadzu GC-14A gas chromatograph (Shimadzu Scientific Instruments, Columbia, MD) equipped with a 5-foot Porapak N stainless steel column (Alltech Associates, Inc., Deerfield, IL) and flame ionization detector (FID), and using UHP hydrogen as carrier gas, will be used for methane analyses. The steps in the methane analyses are:

- Ignite FID 45 minutes prior to analyses to allow for baseline stabilization.
- Prepare a methane calibration curve using a 100-ppm Scotty II standard gas mixture.
- Calculate the linear regression that describes the calibration curve.
- Load the sample from the sampling bulb into the sample loop, close the sample loop outlet valve, pressurize the loop.
- Inject the sample.
- Analyze a known standard every 10 samples to monitor baseline drift.
- Calculate dissolved methane concentration from the headspace methane concentration using equation 3, but using the dimensionless distribution coefficient for methane rather than hydrogen.

Field Documentation

All field procedures will be carefully documented, as described in the following sections.

Equipment Calibration

- Calibrate flow-through meters (Hydrolab Monitor with Scout II data logger, Hydrolab Corporation, Austin, TX) daily according to the manufacturers recommended procedure.
- Calibrate electronic tapes used to measure water levels bimonthly with a steel tape.
- Record all calibration results in the log book.

Log Books

During all field activities, log books will be used to keep detailed records. All pages of each log book will be sequentially numbered. Information recorded in log books will include:

- Site location; procedure/measurement performed; method used; date and time; names of those involved; all measurement results.
- Date, time, battery voltage, and serial numbers of memory modules installed in or removed from data loggers.
- Current field conditions, such as general weather, air temperature, stream stage, and other relevant ambient or antecedent conditions which may impact environmental variables or measurement of those variables.
- Conditions measured on data logger or chart record.

DELIVERABLES

The primary products from this work will be a technical report. This report will be supplemented with oral presentations and submissions to scientific and engineering journals, as warranted. In addition, we will respond to informal requests for information as needed.

DEVIATIONS FROM WORKPLAN

We expect to follow the workplan closely, but in scientific and engineering work involving the development and application of innovative ideas and techniques, flexibility is necessary to respond appropriately to the unexpected. Significant deviations from the workplan will be addressed in interim reports.

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APPENDIX

U.S. GEOLOGICAL SURVEY, WRD, GROUND-WATER QUALITY FIELD NOTES

Proj. Name, No. _____ Date _____ Time _____

Loc. Well No. _____

Composite Samples? ☐ YES ☐ NO
If YES, indicate:

Site I.D. [ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ]

Dates _____

Times _____

Sampled by _____

SMS Cntrl. No. _____

Record No. _____ Sample Purpose (71999) : _____

* VOLUME FACTORS		
Dia. (in.)	Cas. Vol. Factor F	

WELL DATA ☐ Well ☐ Open Hole ☐ Spring

Altitude, ft (72000) ___.___

Static water level, * ft (72019) ___.___

Casing vol. (gal.) ___.___

Depth top sample interval (72015) ___.___

Dia. inside (in.) ___.___

Purge vol. (gal.) ___.___

Depth bottom sample interval (72016) ___.___

Screened/ open interval Top : ___.___

Bottom : ___.___

Allowable draw-down (ft.) ___.___

* Casing Vol. (gal.) = 0.0408 X Dia. (in.)² X Height (ft)
Height = H = Well Depth - Static Water Level = ___.___

OR Cas. Vol. = H X F
F = Casing volume factor

Dia. (in.)	F
1.0	0.04
1.5	0.09
2.0	0.16
3.0	0.37
4.0	0.65
4.5	0.83
5.0	1.02
6.0	1.47
8.0	2.61
10.0	4.08
12.0	5.88
24.0	23.5
36.0	52.9

SAMPLING DATA

Location _____ Date well last sampled _____

Minutes pumped before sampling (72004) _____ static water level when well last sampled ___.___

Sampler type (84164) _____ Sampling condition (72006) _____

PUMPS:
4010 = thief
4020 = bailer
4025 = double-valve bailer
4100 = flowing well

4030 = suction pump
4040 = submersible
4050 = squeeze

4060 = gas recip.
4070 = gas lift
4080 = peristaltic
4090 = jet
8010.0 = other

0.10 = site was being pumped
0.11 = site recently pumped

4. = flowing
8. = pumping
30. = seeping
31. = nearby well pumping

SAMPLES COLLECTED

Nutrients ☐ TOC ☐
Major Ions ☐ DOC ☐
SOC ☐ Filt. ___ mL
BOD ☐ ___ ☐
COD ☐ ___ ☐

Sampler ID _____

Sampler material : Stainless Steel Brass PVC Teflon Other _____

Aquifer Name: _____

GW Color _____ Clarity _____

Sample extracted and processed under ☐ oxygenated ☐ nonoxygenated conditions

Sample contact with : ☐ atmosphere ☐ oxygen ☐ nitrogen ☐ other

ORGANICS TR. ELEMENTS

Pesticide ☐ Unfiltered ☐
VOC ☐ Filtered ☐
BNA ☐ ___ ☐
Radiochemical ☐
Isotope ☐
☐
☐

Weather: Clear Partly Cloudy Cloudy Light Medium Heavy Snow Rain Calm Light Breeze Very Gusty Windy Very Cold Warm Hot Other

FIELD MEASUREMENTS

Q. Inst. (00059) ___ GPM

Eh (00090) ___ m volts

LABORATORY SCHEDULES
Lab Schedules Req. (or copy of lab request form attached ☐)

Temp. Water (00010) ___ °C

Alkalinity ( ) ___ mg/L

Temp. Air (00020) ___ °C

Bicarbonate ( ) ___ mg/L

pH (00400) ___ units

Carbonate ( ) ___ mg/L

Sp. Cond. (00095) ___ µS/cm 25°C

Hydroxide ( ) ___ mg/L

Dis. Oxy. (00300) ___ mg/L

E. Coli (31633) ___ col./100 mL; Rmk ___

DO Sat. (00301) ___ %

FC (31625) ___ col./100 mL; Rmk ___

Lab Codes Add (A) Delete (D):

Bar. Press. (00025) ___ mm Hg

FS (31673) ___ col./100 mL; Rmk ___
Other:

Remarks _____

Checked by _____ Date _____

Appendix A-1. Field measurement and sampling form.

TEMPERATURE		AMPULE LOT NUMBERS:	
Lab Thermometer ☐ Checked w/ASTM within ± 0.5°C; Date _____		nitric acid _____	mercuric chloride _____
Down-Hole Sensor ☐ Describe		nitric acid/potassium dichromate _____	

pH
Mtr W-no. _____   METER Make/Model _____

electrode no.				electrode type		

pH Buffer	pH Buffer Temp °C	Initial Reading	Adj. Reading	millivolts (redox meas)	Remarks
____.__					
____.__					
____.__					
____.__					

☐ unfiltered sample   ☐ filtered sample

Temp correction factors for buffers applied? ☐ YES ☐ NO

stirrer used? ☐ YES ☐ NO
If yes, ☐ magnetic stirrer ☐ manually stirred

pH subsample from or pH measurement location :   Churn   flow through chamber   single point at _____ depth   vertical avg of _____ points

Sample Temp = _____ °C   FIELD pH = _____   USE _____

SPECIFIC CONDUCTANCE
Mtr W-no. _____   METER Make/Model _____

probe no.				

standard value	Temp std °C	Initial Reading	Adj. Reading	Remarks

correction factor applied?
☐ YES ☐ NO
☐ auto temp compensated meter
☐ manual temp compensated meter
corr. factor = _____

SC subsample from or SC measurement location :   Churn   flow through chamber   single point at _____ depth   vertical avg of _____ points

FIELD CONDUCTANCE = _____   USE _____

DISSOLVED OXYGEN   W-no. _____   METER Make/Model _____

D.O. measurement location or D.O. subsample from :   Churn   BOD bottle   flow through chamber   single point at _____ depth   vertical avg of _____ points

Calibration :
☐ Air Calibration in Water   ☐ Air Calibration Chamber in Air
☐ Air-Saturation Deionized Water   ☐ Calibration by Winkler Titration (attach Supplementary Winkler page)

D.O. Zero Check (using zero D.O. solution) ☐ YES ☐ NO
Thermister Check ☐ YES ☐ NO

BAR. PRESS _____ mm Hg;   (mm = in. X 25.4)
Salinity Corr. Factor _____   H₂O Temp. _____ °C

Chart D.O. Sat. _____ mg/L   stirrer used? ☐ YES ☐ NO If yes, ☐ magnetic stirrer ☐ manually stirred

Meter D.O. Sat. _____ mg/L; Adjusted to _____ (if corr. factor applicable)   GROUND WATER D.O. = _____

QUALITY ASSURANCE SAMPLES
Were quality assurance samples collected?
☐ YES ☐ NO If YES indicate type(s) :

	Organic-free	DI	water from sampling site
Replicate	☐	☐	☐
Spike	☐	☐	☐
Field Blank	☐	☐	Supplementary page w/additional
Trip Blank	☐	☐	QA sample info attached ☐

Other ☐ Indicate Type(s) : _____

Calibration Notes and Remarks
_____
_____
_____
_____
_____
_____
_____
_____

Appendix A-1. Field measurement and sampling form (continued).

ALKALINITY

pH	Δ pH	Vol acid DC or mL	ΔVol acid DC or mL	$\frac{\Delta\ pH}{\Delta\ Vol\ acid}$

Date _____ Time _____

CALCULATIONS :

$$CO_3^{-2} = A \times \frac{F_1}{mL\ sample} \times CF \quad *$$

$$HCO_3^{-1} = [\,B - 2(A)\,] \times \frac{F_2}{mL\ sample} \times CF; \quad *$$

$$\begin{array}{l}\text{ALKALINITY} \\ \text{as CaCO}_3 = B \times \dfrac{F_3}{mL\ sample} \times CF \quad *\end{array}$$

A = DC or mLs acid from initial
pH to endpoint near 8.3 = _____

B = DC or mLs acid from initial
pH to endpoint near 4.5 = _____

*
APPLY CORRECTION FACTOR (CF) IF ACID USED FOR
BURETTE TITRATION HAS NONSTANDARD NORMALITY--
CF = corr. factor = H_2SO_4 normality/0.01639

(IMPORTANT : CF NOT APPLICABLE FOR THE DIGITAL TITRATION FACTORS
SHOWN; use only with nonstandard normality BURETTE titration)

ALKALINITY (_____) _____ mg/L as $CaCO_3$

BICARBONATE (_____) _____ mg/L as HCO_3^{-1}

CARBONATE (_____) _____ mg/L as CO_3^{-2}

NOTE:
ATTACH OUTPUT COPY
IF ALKALINITY VALUES
ARE CALCULATED USING
A COMPUTER PROGRAM

FACTORS — DIGITAL COUNT TITRATION (DC)

	Using 0.1600 normal	Using 1.60 normal
F_1	12.0	120
F_2	12.2	122
F_3	10.0	100

FACTORS — BURETTE TITRATION (mL) *

Using ml of 0.01639 normal H_2SO_4

F_1	983.5
F_2	1000
F_3	820.2

OBSERVATIONS/CALCULATIONS : _____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

Acid: 1.60 N   0.1600 N   0.01639N   OTHER _____

Acid Lot No. : _____

Sample Volume : _____ mL

☐ Filtered   ☐ Unfiltered

Sample stirred : ☐ magnetically ☐ manually

pH: Start _____ End _____

DC (Digital Counts) or
Vol. titrated at End Point near pH 8.3 : _____

Digital Counts or
Vol. titrated at End Point near pH 4.5 : _____

☐ Incremental Equivalence   ☐ Fixed End Point   ☐ Gran Titration

Appendix A-1. Field measurement and sampling form (continued).

Miscellaneous Section (Notes/Calculations/Well Purge Log & Etc.)
WELL PURGE LOG

Time	Water Level b/w MP LS	Draw Down feet 72040	Well Yield When Sampling gpm 00059	cfs	pH 00400	T °C 00010	SC 00095	DO 00300

E. COLI (31633)

Time collected : _____
Time In @ 35°C : _____   Date : _____
Time In @ 44.5°C : _____
Time out : _____   Date : _____

Vol (mL)	Count	Used in calculation?	Remarks *
Blank			
Blank			

* Remarks   1 = Less than   2 = Greater than
            0 = Est ct   K = non Ideal ct

Incub. Time 2 hrs @ 35°C followed by :
filt. size _____   20-24 hrs @ 44.5°C
Ideal count 20-80 col.
E. COLI COUNT /100 mL _____ ; Rmk _____

FECAL STREPTOCOCCI (31673)

Time collected : _____
Time in : _____   Date : _____
Time out : _____   Date : _____

Vol (mL)	Count	Used in calculation?	Remarks *
Blank			
Blank			

* Remarks   1 = Less than   2 = Greater than
            0 = Est ct   K = non Ideal ct

Incub. Time 46-50 hrs   filt. size _____
Ideal count 20-100 col.   Incub. Temp 35°C

FS COUNT / 100 mL _____ ; Rmk _____

FECAL COLIFORM (31625)

Time collected : _____
Time in : _____   Date : _____
Time out : _____   Date : _____

Vol (mL)	Count	Used in calculation?	Remarks *
Blank			
Blank			

* Remarks   1 = Less than   2 = Greater than
            0 = Est ct   K = non Ideal ct

Incub. Time 22-26 hrs   filt. size _____
Ideal count 20-60 col.   Incub. Temp 44.5°C

FC COUNT / 100 mL _____ ; Rmk _____

CALCULATIONS

Appendix A-1. Field measurement and sampling form (continued).

U.S. GEOLOGICAL SURVEY - NATIONAL WATER-QUALITY LABORATORY
ANALYTICAL SERVICES REQUEST FORM

SMS CONTROL NO	NWIS RECORD NO	LABORATORY ID	LAB USE ONLY	SAMPLE SET

* | | | | | | | | | | | | | | | | | | | | |

STATION NAME   STATION ID OR UNIQUE NO.

FIELD OFFICE   *PHONE NO.   *PROJECT CHIEF   FIELD SAMPLE ID   SITE TYPE

* | | | * | | | | | | | | * | | | | | | | | |
STATE   DISTRICT/USER   CNTY   PROJECT ACCOUNT

*BEGIN DATE: |1|9| | | | | | | | | | | | | |
 END DATE: |1|9| | | | | | | | | | | | | |
              YEAR   MONTH   DAY   TIME

SCHEDULES, FIELD, AND LABORATORY CODES

SCHEDULE 1: _____   **SAMPLE MEDIUM: _____   **SAMPLE TYPE: _____
SCHEDULE 2: _____   GEOLOGIC UNIT: _____   **HYDRO EVENT: _____
SCHEDULE 3: _____   **ANALYSIS STATUS: _____
SCHEDULE 4: _____   **ANALYSIS SOURCE: _____
SCHEDULE 5: _____   **HYDRO CONDITION: _____

	A/D		A/D		A/D		A/D
CODE:		CODE:		CODE:		CODE:	
CODE:		CODE:		CODE:		CODE:	
CODE:		CODE:		CODE:		CODE:	
CODE:		CODE:		CODE:		CODE:	

FIELD VALUES

LAB/P CODE|VALUE|RMK	LAB/P CODE|VALUE|RMK	LAB/P CODE|VALUE|RMK
_21/00095				_51/00400				___2/39086			
1171/00452				1170/00453				

+COMMENTS (Limit to 138 characters) _____

_____

LOGIN COMMENTS: _____

SHIPPED BY: _____   PHONE NO.: _____   DATE: | | |

BOTTLE TYPES (PLEASE FILL IN NO. OF TYPES SENT)

__ FA	__ RU·	__ FU	__ FAM	__ RAM	__ RCC	__ FCC	__ FAB	__ CU
__ RA	__ RAH	__ CN-	__ RCB	__ TOC	__ DOC	__ SOC	__ COD	__ VOA
__ CHY	__ O&G	__ GCC	__ RCA	__ FCA	__ PHENOL		_____ OTHER	

CUSTOM/SPECIAL SAMPLE APPROVED BY: _____   APPROVAL NO. _____
PROGRAM/PROJECT: __ NPDES   __ NAWQA   __ DRINKING WATER   FILL IN OTHER _____
POSSIBLE HAZARDS _____

Revised 11/94   +Comments to be stored by the laboratory   *Mandatory for acceptance for laboratory analysis
                                                                    **Mandatory for storage in WATSTORE/NWIS

Appendix A-2. Laboratory submittal form.