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A Tracer Test to Estimate Hydraulic Conductivities and Dispersivities of Sediments in the Shallow Aquifer at the East Gate Disposal Yard, Fort Lewis, Washington

Water-Resources Investigations Report 99-4244

Prepared in cooperation with
Department of the Army
Fort Lewis Public Works
Environmental and Natural Resources Division

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By E.A. Prych

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1999

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

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
1201 Pacific Avenue – Suite 600
Tacoma, Washington 98402

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To Obtain
acre	0.4047	hectare
inch (in)	25.4	millimeter
foot (ft)	0.3048	meter
gallon (gal)	3.785	liter
mile (mi)	1.609	kilometer

Temperature: To convert temperature given in this report in degrees Celsius (°C) to degrees Fahrenheit (°F), use the following equation: $°F = 9/5°C+32$.

Sea Level: 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.

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ABSTRACT

Knowledge of the hydraulic characteristics of the unconsolidated glacial sediments that make up the shallow aquifer at Fort Lewis, a U.S. Army facility in western Washington, is necessary for use in the numerical models of ground-water flow and solute transport that are being used by the U.S. Geological Survey and others to design and evaluate alternatives for the remediation of subsurface contamination at and downgradient of the East Gate Disposal Yard near the Logistics Center at the fort. Data from a tracer test, which utilized an existing pump-and-treat system at the disposal yard, were used to estimate hydraulic conductivities and longitudinal dispersivities in horizontal and vertical directions. During the tests, the outflow from the pump-and-treat plant was dosed with potassium bromide before being returned to the ground-water system through two 100-foot-long horizontal recharge galleries and a 110-foot-deep recharge well. Specific electrical conductance was monitored in 16 observations wells, and a few samples were collected from most of the wells for determining bromide concentrations.

The water table at the test site was less than 10 feet (ft) below land surface, and ground-water-flow directions, as inferred from water levels, were generally northwesterly, but flow patterns were complex. This complexity, which probably is caused in part by the heterogeneity of the sediments, is reason for those working to remediate contamination at the Logistics Center to be cautious when planning remediation and when drawing conclusions from observed distributions of contaminant concentrations.

Differences between water levels and between centroids and variances of the temporal distributions of excess (observed minus ambient) specific conductance at pairs of locations were used to estimate hydraulic conductivities and longitudinal dispersivities. Although the equations used for estimating hydraulic conductivities and dispersivities are based on assumptions of rectilinear or radial flow, which were assumed to be reasonable at the scale of distances between observation locations, deviations from these idealized flows and other assumptions can introduce errors of unknown magnitude; therefore, the estimated values should be used with caution.

Analyses of data from five pairs of horizontally separated locations near the water table yielded estimates of horizontal hydraulic conductivity between 69 and 3,100 feet per day (ft/d), and estimates of horizontal longitudinal dispersivity that ranged from 6.9 to 28 ft. Data from a pair of wells screens at about 80 ft below land surface yielded values of horizontal hydraulic conductivity between 2,300 and 3,800 ft/d. The largest estimated values of horizontal hydraulic conductivity are larger than those obtained for the East-Gate area by earlier investigators from calibration of a ground-water flow model (80 to 260 ft/d) and from aquifer tests (16 to 330 ft/d), probably because the values from the tracer test are biased toward thin (probably less than 10 ft) highly permeable units of the aquifer, while the values from the earlier studies are averages over a large fraction or entire thickness of the approximately 100-foot-thick aquifer. Analyses of data from four pairs of vertically separated locations yielded vertical hydraulic conductivities between 8 and 590 ft/d and vertical longitudinal dispersivities that ranged from 1.8 to 12 ft for the upper 40 ft of sediments below land surface.

INTRODUCTION

From about 1946 to 1971 the U.S. Army dumped or buried waste trichloroethylene (TCE) and other materials in the East Gate Disposal Yard near the Logistics Center on Fort Lewis, Washington (Woodward Clyde, 1998). As a result, a plume of TCE-contaminated ground water in the shallow water-table aquifer (about 100 ft thick) now extends from the disposal yard, beneath the Logistics Center, to near American Lake and the community of Tillicum, which are located about 2 miles (mi) northwest of the disposal yard (fig. 1). In 1995 two pump-and-treat systems, one near and downgradient of the East Gate Disposal Yard and another near U.S. Interstate 5 and upgradient of the boundary between Fort Lewis and Tillicum, were installed in the shallow aquifer to intercept the transport of contaminants by ground water out of the disposal yard and from Fort Lewis to neighboring areas, respectively. In addition to concerns about the plume in the shallow aquifer, there are also concerns about the movement of contaminants from the shallow to a deeper aquifer.

Cantrell and others (1998) estimated that if no other remediation work is done at the site, it may be necessary to operate the pump-and-treat systems for 76 to 160 years or more to clean up the ground-water system. Consequently, the Army is investigating methods to accelerate the removal of TCE and other volatile organic compounds (VOC's) from the subsurface and the attenuation of VOC concentrations in ground water. The design and evaluation of many of the methods use numerical models of ground-water flow and transport, which in turn require knowledge of the hydraulic conductivities and dispersivities of the subsurface materials. An existing three-layer model that was developed and used by the U.S. Army Corps of Engineers (1998) and that was modified by H. H. Bauer of the U.S. Geological Survey (Sue C. Kahle, U. S. Geological Survey, written commun., October 5,1998) simulates the entire shallow aquifer as a single layer. The model uses hydraulic conductivities of the upper layer that were obtained (1) by analyses of traditional aquifer tests in which changes in ground-water levels are observed after the start or cessation of pumping from a well and (2) by calibrating the numerical model so that model-simulated water levels agree with those observed. Because transport probably is not uniform over the depth of this aquifer as a result of preferred movement within layers of coarse-grained sediments with relatively high permeability and as a result of a nonuniform vertical distribution of the contaminant source, the existing modified model is being further modified by subdividing the model layer that represents the upper aquifer into multiple layers of different hydraulic characteristics. Knowledge of the hydraulic characteristics of the individual layers within the upper aquifer is necessary for making this modification as well as for assisting in the interpretation of observed distributions of contaminant concentrations and for the designing remediation systems.

Purpose, Method, and Scope

This report describes and presents the results of a tracer test performed in and near the East Gate Disposal Yard and pump-and-treat system to estimate hydraulic conductivities and dispersivities of parts of the shallow (less than 100 ft) subsurface sediments. As part of the test, the outflow from the treatment plant was dosed continuously over a 3-day period with a tracer, potassium bromide (KBr), before the treated water was reinjected into the ground though two recharge galleries and a recharge well. In addition, the water discharged into the well was dosed with sodium chloride (NaCl). Before, during, and for about 6 weeks after the addition of the tracers, in-situ specific electrical conductance of the water (referred to in the remainder of this report as specific conductance or conductance) in 16 wells was monitored, and a few water samples were collected from most of these wells for determinations of specific conductance, and bromide and chloride concentrations. Differences between water levels, between centroids (average arrival times), and between variances (spreading) of the temporal distributions of specific conductance above ambient levels at selected pairs of locations were used to infer local ground-water flow directions and to estimate hydraulic conductivities and longitudinal dispersivities in the horizontal and vertical directions. Because most of the horizontal tracer movement probably was within layers with high values of permeability, the estimates of horizontal hydraulic conductivity and dispersivity probably were biased toward these layers.

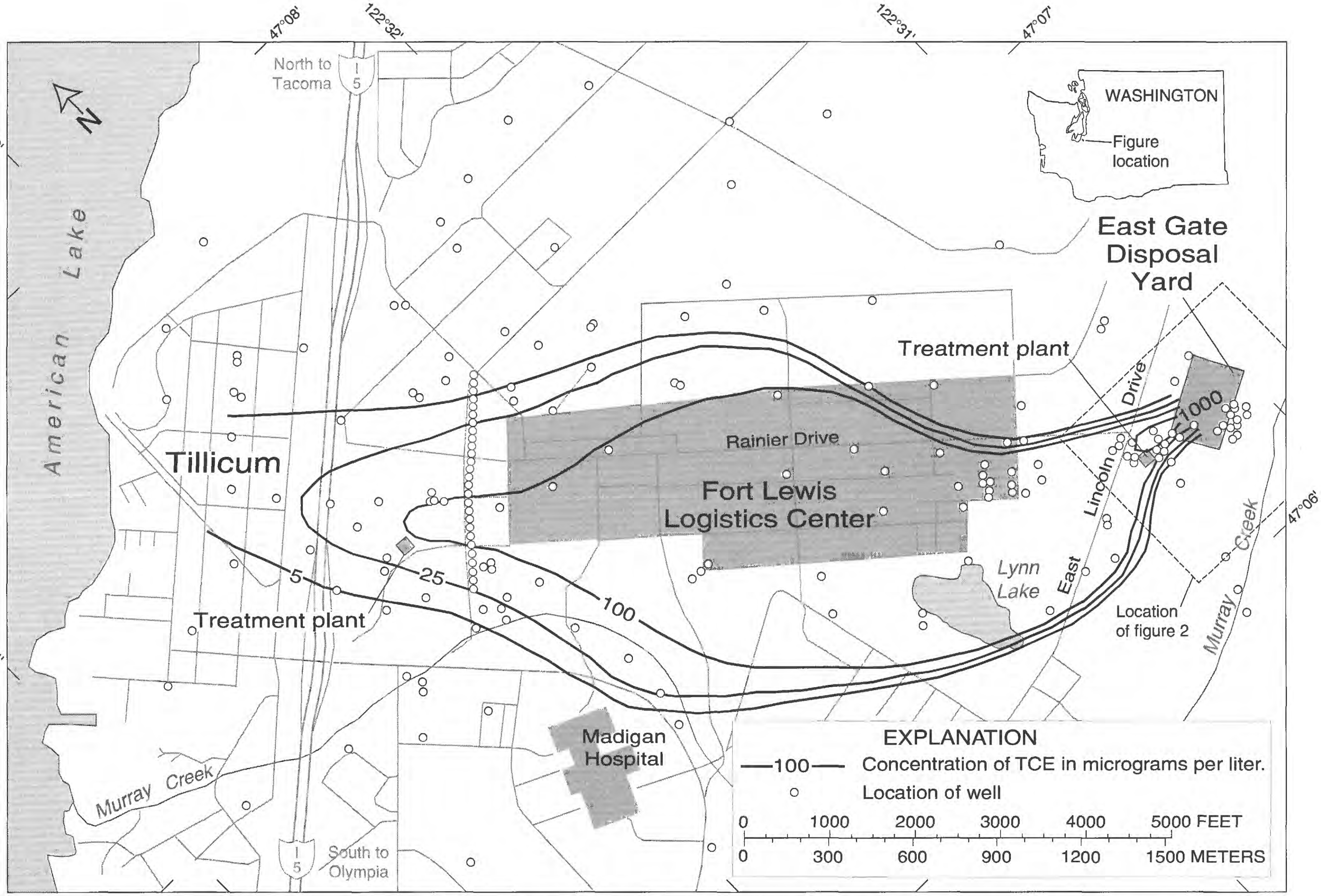

Figure 1. Location of the East Gate Disposal Yard near the Logistics Center of Fort Lewis, Washington, and the plume of dissolved trichloroethylene (TCE) in ground water (TCE isoconcentrations from Woodward-Clyde, 1997).

Acknowledgment

The work described in this report was part of a larger study funded by the Department of the Army through Military Inter-departmental Purchase Request 8EUSGS4012, which was administered by Mr. Dennis Korycinski, Installation Restoration Program Manager, Fort Lewis Public Works, Environmental and Natural Resources Division.

Description Of The Area

Fort Lewis is located in the Puget Sound lowlands of western Washington about 10 mi southwest of the city of Tacoma. The East Gate Disposal Yard occupies about 13 acres near the southeast end of the Logistics Center, which in turn is located near the northeast corner of Fort Lewis (fig. 1).

Physical Setting

The Logistics Center sits on a gently rolling uplands plain about 280 ft above sea level. This plain is underlain by over 1,000 ft of unconsolidated glacial and inter-glacial sediments (Jones, 1996). The area where the tracer test was conducted is vegetated mostly with Douglas fir, black cottonwood, red alder and wild cherry trees, Scotch broom and other hardwood shrubs, and grasses. The roads in the area of the tracer test and in the East Gate Disposal Yard are unpaved, and there are no streams; however, most roads and many industrial and parking areas elsewhere in the Logistics Center are paved, and nearby Murray Creek flows through marshy areas south and west of the Logistics Center (fig.1). Mean annual precipitation at Fort Lewis is about 40 inches per year (in/yr), and evapotranspiration is about half of that. Precipitation in Tacoma during March 1998, when a large part of the test was conducted, was 4.52 inches (National Oceanic and Atmospheric Administration, 1998).

Geohydrology

The upper 100 ft or so of sediments, where nearly all the data were gathered during the tracer test and where most of the TCE plume is located, is commonly referred to as the upper aquifer (Shannon & Wilson, 1986). It consists of a widespread deposit of glacial outwash gravels about 20 ft thick near the surface that is underlain by a complex distribution of layers and lenses of till, glacial outwash sands and gravels, and scattered deposits of non-glacial sediments near the bottom. In most places, a confining layer of mostly fine-grained material (silts and clays, primarily of interglacial origin) underlies the upper aquifer and separates it from a lower aquifer that consists mostly of older glacial sediments.

In the area of the tracer test the water table is less than about 10 ft below land surface, and parts of the surficial outwash gravels are saturated. The general direction of ground-water flow in the upper aquifer, as inferred from a water-level contour map (U.S. Army Corps of Engineers, 1998, fig. 5) and the TCE plume (fig. 1), is from the southeast to the northwest (from the East Gate Disposal Yard to American Lake); however, the complex distribution of fine- and coarse-grained layers and lenses within the upper aquifer may cause local ground-water flow patterns to be complex. Lithologic logs from wells less than 100 ft apart can be quite different, suggesting that there can be a large amount of uncertainty in the spacial geometry of individual units as inferred from lithologic information from wells (see, for example, U.S. Army Corps of Engineers, 1993, figs. 1-4 to 1-9).

Horizontal hydraulic conductivities of the sediments in the upper aquifer obtained by model calibration ranged from 80 to 260 ft/d in the East Gate area and from 40 to 380 ft/d in the entire Logistics Center (Michael M. Easterly, U.S. Army Corps of Engineers, Seattle, Wash., written commun., September 19, 1997). Values obtained from aquifer tests during which water was pumped from extraction or recharge wells of the East Gate pump-and-treat system (see the following section for a description of this system) range from 16 to 330 ft/d, and the ratio of horizontal to vertical hydraulic conductivity ranged from 12 to 259 (U.S. Army Corps of Engineers, 1993, tables 4-2 and 4-4). The horizontal hydraulic conductivities in the numerical model are vertical averages over the approximately 100-ft thickness of the upper aquifer and horizontal averages over areas with horizontal dimensions of several model cells (one to several hundreds of feet), while horizontal hydraulic conductivies from the aquifer tests probably approximate vertical averages over intervals equal to or larger than the thicknesses of the screened intervals of the pumped wells (from 10 to 30 ft) and horizontal averages over the area of influence of the pumped well (radii up to a few hundred feet).

The East Gate Pump-and Treat System

The East Gate pump-and-treat system consists of six extraction wells, a treatment facility, and a recharge system composed of two recharge galleries (numbers 5 and 6) and two recharge wells (LR-1 and 2 on figs. 2 and 3). All extraction and recharge wells and galleries are in the upper aquifer. Four of the extraction wells (LX-17, 18, 19 and 21) are located about 200 to 500 ft downgradient (northwest) of the disposal yard, and the other two (LX-16 and RW-1) are located about 2,000 ft farther downgradient. The deepest of the extraction wells (LX-19) is screened from 53 to 83 ft below land surface, and the shallowest (LX-18) is screened from 31 to 41 ft below land surface. The treatment facility contains a VOC stripping tower, sumps, pumps, meters, and control systems. Outflow from the stripping tower flows into a sump, from which it is pumped to the recharge galleries and wells. The recharge area is upgradient of and near the southeast edge of the disposal yard (figs. 2 and 4). Each recharge gallery consists of a 100-ft-long horizontal perforated pipe on a bed of gravel or coarse sand buried about 5 ft below land surface. The two recharge wells have 10-inch-diameter, 30-ft-long screens whose tops are 78 ft (LR-1) and 68 ft (LR-2) below land surface. The pipe feeding each gallery and well has a valve and totalizing flow meter for adjusting and measuring discharge.

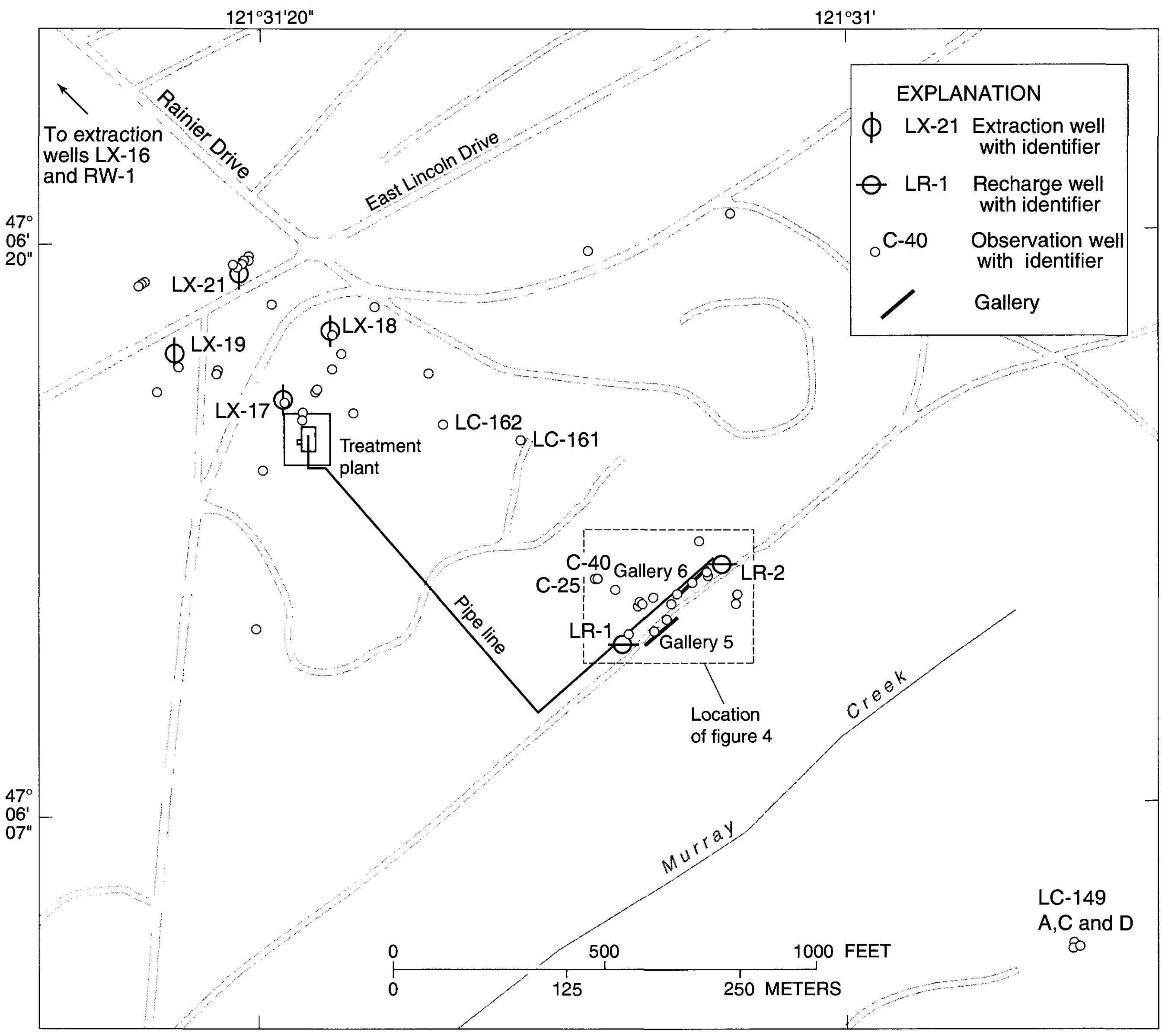

Figure 2. East Gate pump-and-treat system and nearby observation wells, Fort Lewis, Washington.

METHODS

The tracer test was conducted in the vicinity of the recharge area of the East Gate pump-and-treat system and utilized the recharge galleries and one of the two recharge wells to introduce tracers into the ground water. During the test, the metered discharges into galleries 5 and 6 were 270 and 330 gallons per minute (gpm), respectively, and the metered discharge into well LR-1 was 180 gpm. No water was being discharged into well LR-2 during the test. Although none of the flow meters were calibrated as part of this study, the sum of the metered discharges into the two galleries and one recharge well equals 780 gpm, which is nearly the same as the metered discharge through the treatment plant, 790 gpm.

Injection of Tracers

About 530 gallons of a KBr solution at about 80 percent saturation was prepared in a trailer-mounted plastic tank and pumped into the outflow pipe of the stripping tower (fig. 3) for 3 days at a rate of 0.12 gpm. Dosing with KBr started at 10:20 a.m. on March 3, 1998, and ended at 10:20 a.m. on March 6. The dosing rate of the solution was monitored with a flow meter and was checked volumetrically a few times per day. Dosing with the KBr solution increased the specific conductance of the water from about 125 microsiemens per centimeter (µS/cm) to about 200 µS/cm, and increased the bromide concentration from less than 0.05 milligrams per liter (mg/L) to about 40 mg/L.

In addition to the KBr solution, about 200 gallons of NaCl solution at about 70 percent saturation was prepared in another plastic tank on the bed of a truck and was fed by gravity into recharge well LR-01. The purpose of the NaCl tracer was to enable distinguishing between KBr tracer that entered the ground water through the shallow galleries and that which entered through the recharge well. The dosing rate of the NaCl solution was controlled with a valve, monitored with a flow meter, and checked volumetrically. In the experimental design the NaCl solution was to be added over the same time period as the KBr; however, repeated formation of gas bubbles in the NaCl feed line resulted in a sporadic and lower-than-planned dosing rate during most of the 3 days that KBr was added. The bubbles stopped appearing near the end of the 3-day period, and the NaCl was added to the well for two additional days (without the addition of KBr at the treatment plant) until 10:30 a.m. on March 8 at a rate of about 0.036 gpm. Although it was not possible to measure the specific conductance or chloride concentration in the water after dosing with NaCl, the calculated approximate increase in chloride concentration was from about 2.5 mg/L to 30 mg/L when dosing at the desired rate; and the approximate increase in specific conductance was from about 200 µS/cm to 290 µS/cm or from 125 µS/cm to 215 µS/cm, depending on whether or not the outflow from the treatment plant was being dosed with KBr.

Monitoring

The movement of tracers through the ground-water system was monitored by two methods. One by routinely measuring in-situ vertical profiles of specific electrical conductance within the screened intervals of 16 observation wells (including the inactive recharge well, LR-2) at a frequency that varied from a few times per day at the beginning of the test to once every few days at the end of the test for a period of about 6 weeks, and the other by occasionally pumping samples from the wells during this period and analyzing the samples for specific conductance, and for bromide and chloride concentrations. The observation wells were located within about 50 to 700 ft of the recharge galleries and recharge well (fig. 4). The screened intervals of the wells varied from 5 to 15 ft below land surface (well A15) to 139 to 149 ft (well LC-26D), but most were less than 50 ft deep (table 1). Six of the wells (A15, A30, A45, B15, C25, and C40; numbers in these identifiers are approximate well depths in feet below land surface) were installed for this test using an auger; the others already existed. The casings and screens of most wells were either 2 or 4 inches in diameter (table 1).

Specific conductance of the treated water before and after dosing with KBr (effluent of the stripping tower, and inflow to recharge well LR-1 before dosing with NaCl, respectively) was also monitored. Water temperatures always were measured along with specific conductance. Water levels in the wells were measured twice during the test. Data on the ambient values of specific conductance, and bromide and chloride concentrations were collected about 1 week before the start of the test (February 25, 26, and 27) and a few hours before the test (March 3).

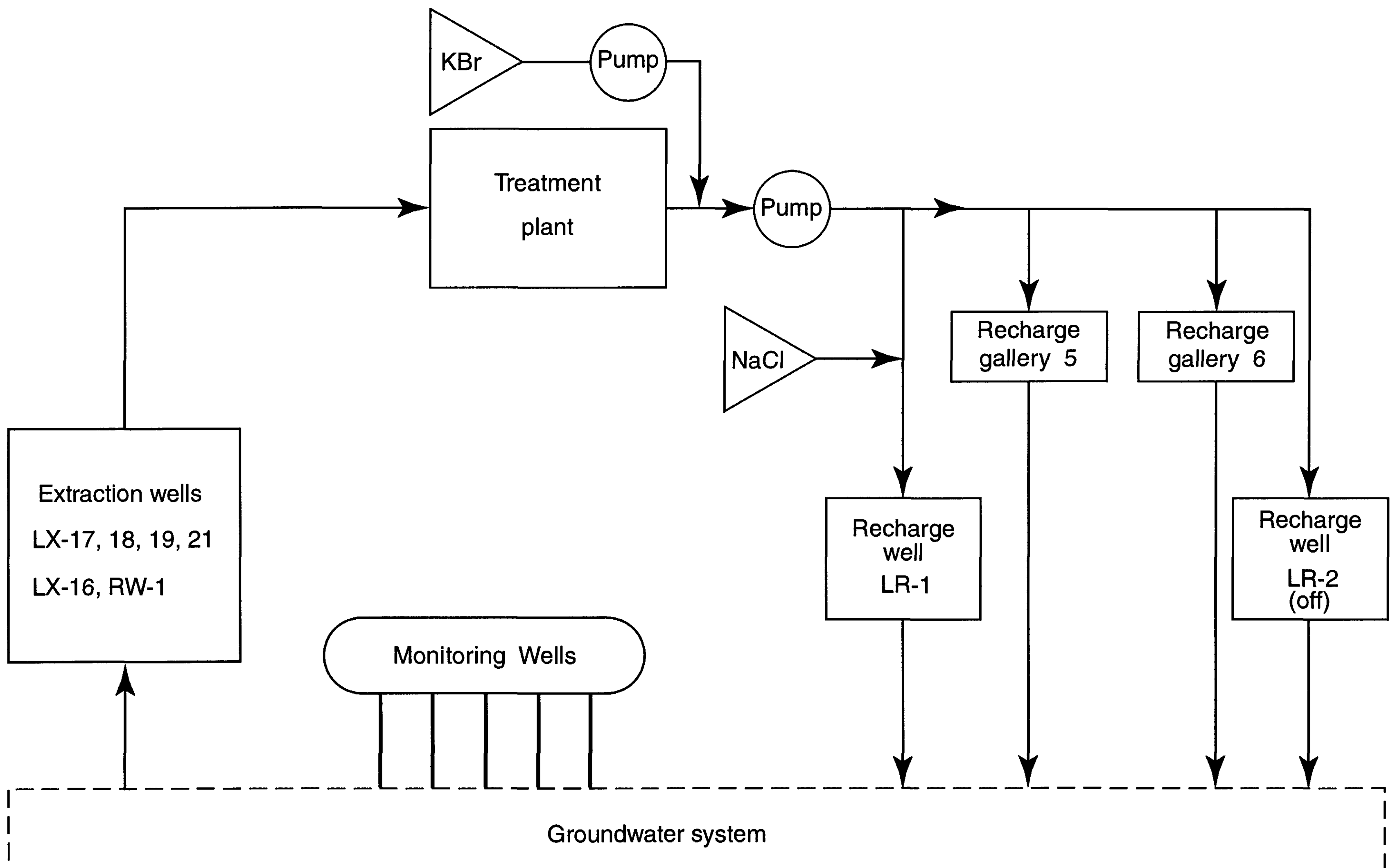

Figure 3. Schematic diagram of East Gate pump-and-treat and tracer-test systems, Fort Lewis, Washington.

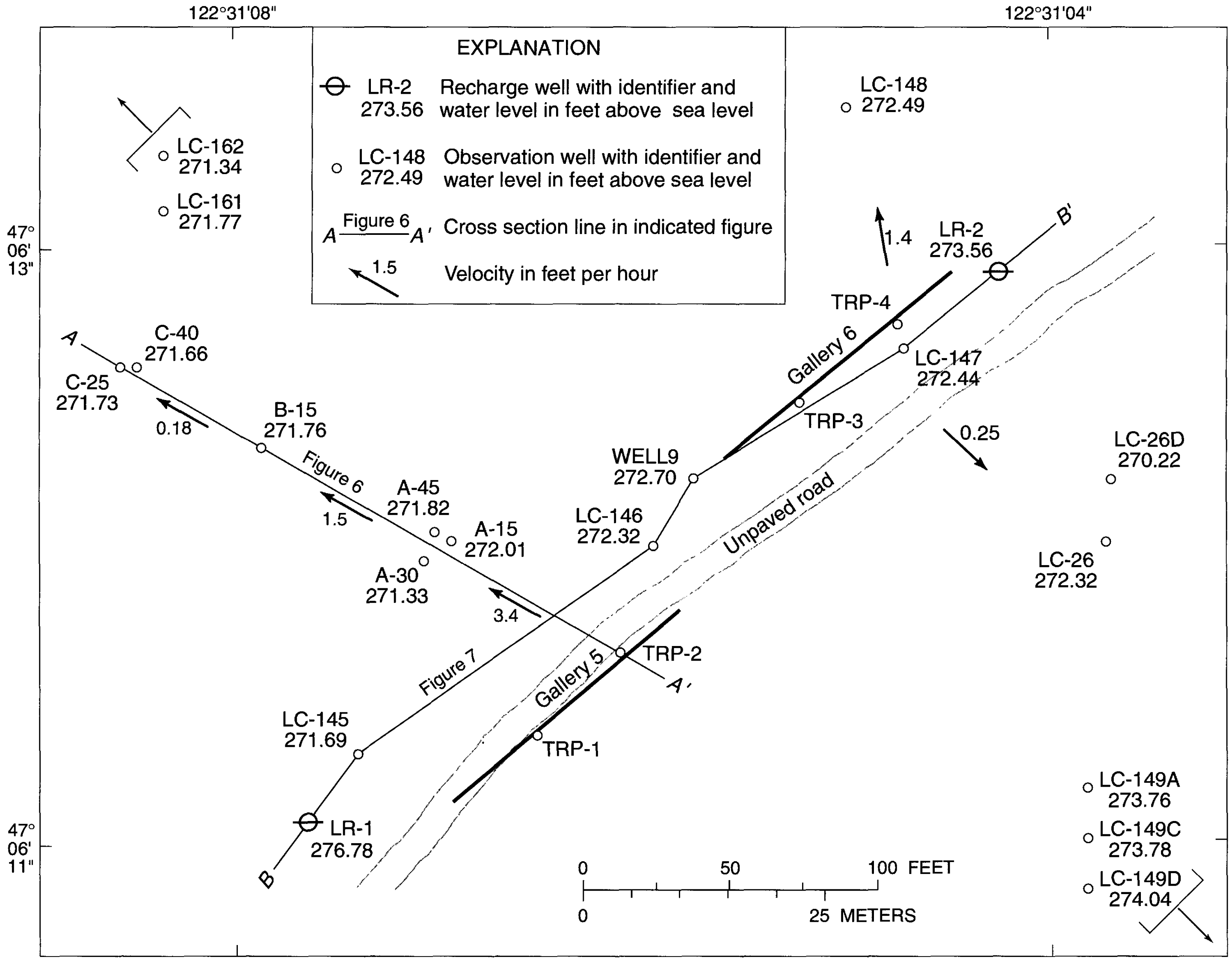

Figure 4. Locations of wells in tracer-test and pump-and-treat recharge area at East Gate Disposal Yard, Fort Lewis, Washington, with observed ground-water levels, and inferred ground-water flow directions and estimated velocities . Water levels are averages of observations on March 4 and 23, 1998.

Table 1. Characteristics and observed water levels in wells

[Elevations are in feet above sea level; --, no data]

Well identifier		Elevation of indicated point					Screen length, in feet	Nominal screen diameter, in inches
Date	Time	Water level	Top steel casing	Top plastic coating	Land surface	Top of screen		
A15			279.07	278.90	276.62	272.6	10.0	2
03-04-1998	1104	272.05						
03-23-1998	1047	271.97						
A30			279.17	279.00	277.05	262.0	15.0	2
03-04-1998	1103	271.78						
03-23-1998	1050	271.68						
A45			278.94	278.83	276.63	247.6	15.0	2
03-04-1998	1102	271.85						
03-23-1998	1049	271.78						
B15			281.01	280.88	278.19	273.2	10.0	2
03-04-1998	1100	271.78						
03-23-1998	1052	271.71						
C25			280.10	279.94	277.67	272.7	20.0	2
03-04-1998	1012	271.76						
03-23-1998	1053	271.70						
C40			280.02	279.89	277.53	253.5	15.0	2
03-04-1998	1052	271.69						
03-23-1998	1056	271.62						
LC-26			277.20	277.00	275.80	264.3	25.0	2
03-04-1998	1122	272.35						
03-23-1998	1043	272.28						
LC-26D			278.00	277.00	276.90	137.4	10.0	4
03-04-1998	1119	270.25						
03-23-1998	1044	270.39						
LC-145			282.30	281.72	279.92	249.9	19.6	2
03-04-1998	1108	271.74						
03-23-1998	1029	271.64						
LC-146			280.03	279.57	277.59	248.1	19.6	2
03-04-1998	1110	272.34						
03-23-1998	1032	272.30						
LC-147			280.00	279.60	277.68	248.7	20.0	2
03-04-1998	1114	272.44						
03-23-1998	1034	272.43						
LC-148			282.15	281.73	279.81	250.8	20.0	2
03-04-1998	1118	272.50						
03-23-1998	1039	272.48						

Table 1. Characteristics and observed water levels in wells—Continued

Well identifier		Elevation of indicated point					Screen length, in feet	Nominal screen diameter, in inches
Date	Time	Water level	Top steel casing	Top plastic coating	Land surface	Top of screen		
LC-161			283.48	282.62	280.36	256.9	10.0	4
03-04-1998	1048	271.80						
03-23-1998	1104	271.74						
LC-162			280.40	279.43	277.32	254.9	10.0	4
03-04-1998	1045	271.37						
03-23-1998	1107	271.30						
LC-149A			308.23	307.67	305.87	275.9	9.5	4
03-04-1998	--	--						
03-26-1998	1007	273.76						
LC-149C			308.39	307.86	306.12	268.1	10.0	4
03-04-1998		--	--					
03-26-1998	1010	273.78						
LC-149D			309.03	308.19	305.89	245.9	10.0	4
03-04-1998	--	--						
03-26 1998	1014	274.04						
WELL-9			280.27	279.65	278.05	265.0	15.0	4
03-04-1998	1112	272.73						
03-23-1998	1033	272.67						
LR-1			284.28	284.02	281.53	203.7	32.0	10
03-04-1998	1106	276.76						
03-23-1998	1026	276.79						
LR-2			280.62	280.43	277.96	210.0	32.0	10
03-04-1998	1116	273.62						
03-23-1998	1038	273.49						
TRP1			279.59	279.26	--	--	[1]5.3	--
02-09-1998	1257	Dry						
TRP2			279.90	278.25	--	--	[1]3.9	--
02-09-1998	1259	Dry						
TRP3			278.23	278.28	--	--	[1]4.4	--
02-09-1998	1304	Dry						
TRP4			278.60	278.77	--	--	[1]5.1	--
02-09-1998	1307	Dry						

[1]Number is well depth, in feet below land surface

On the February dates, conductance profiles were measured, and water samples were collected from most of the 16 observation wells in the test area and three other wells (LC-149A, C, and D, fig. 2) located upgradient from the test area. On March 3, a few hours before the start of the test, conductance profiles were measured in the 16 observation wells.

A vertical profile of specific conductance in a well was obtained by lowering a probe into the well and manually recording the data at 1- to 3-foot intervals within the screened interval of the well. A water sample was obtained by lowering a submersible electric pump to the center of the screened interval of the well, purging the well by pumping a volume of water equal to about three times the volume in the screened interval of the well, and then collecting the sample. An exception to this procedure was for well LR-2, the inactive recharge well. Because this well has a 10-inch-diameter screen that is 30 ft long, it was impractical to pump, store, transport, and dispose of three screen volumes (about 350 gallons) from this well. Only about 20 gallons of water was pumped from this well before taking a sample on each of 3 days. The specific conductance of a sample was measured within a few minutes of the time it was collected.

About one month after the end of the test the samples were filtered through a 0.45-micron filter and sent to the U.S. Geological Survey Field Support Unit in Ocala, Florida, for bromide and chloride analyses. Aliquots of selected samples were sent to the U.S. Geological Survey National Water Quality Laboratory in Arvada, Colorado, for quality assurance. Concentrations determined by the two laboratories agreed well (table 2), as did specific conductances determined in the field and in the laboratories (not shown).

The passive method of obtaining vertical profiles of specific conductance is only appropriate if the ambient flow of water through the well screen is sufficient to purge the screened interval in a much shorter time than is needed for changes in conductance or concentrations in the ground water. Given the relatively high permeability of most of the sediments in the study area, this requirement is probably met.

Analyses of Specific Electrical Conductance Data

To put the specific conductance data into a form useful for estimating hydraulic conductivities and dispersivities, each observed vertical profile was vertically averaged, and the average, maximum, and minimum values (table A1, in Appendix) were plotted as functions of time (fig. 5). The centroid (average time of arrival) and variance (a measure of longitudinal spreading) of the temporal distributions of excess vertically averaged conductance (conductance above the ambient level) were calculated (table 3) for use in computations of ground-water flow velocities, hydraulic conductivities, and dispersivities as described in the following subsections. The vertical conductance profiles themselves were not used because a vertical profile in a well could differ from the vertical profile in the ground water because of vertical flow in the well caused by differences in ground-water head over the screened interval (see, for example, Church and Granato, 1996). (If there are differences in ground-water head within the screened interval of a well, then ground water from zones with the greatest head would flow into the well, flow vertically within the well to zones where ground-water head is smallest, and flow back into the ground-water system there. Therefore, the conductance of water in a well probably is more representative of the ground water in the zones with the largest heads rather than an average over the entire screened interval. On the other hand, when water is pumped from a well for a length of time at a rate large enough to lower the water level in the well sufficiently below the minimum ground-water head within the screened interval, then more of the pumped water would come from zones with the larger hydraulic conductivity than from zones with the smaller hydraulic conductivity.) Because water samples for determinations of bromide and chloride concentrations were collected only a few times during the test, these data were insufficient for defining the temporal distribution of tracer at each well (fig. 5). However, the bromide and chloride data were used to assist in interpreting and verifying the conductance data.

Table 2. Concentrations of bromide and chloride, and specific electrical conductances of water samples

[Unless otherwise indicated, sample analyzed by laboratory at U.S. Geological Water Quality Services Unit (WQSU), Ocalla, Florida; *, Replicate of preceeding sample in table analyzed at WQSU laboratory; **, Replicate of preceeding sample in table analyzed by U.S. Geological Survey National Water Quality Laboratory, Arvada, Calif.; ***, outflow from treatment tower of East Gate pump-and-treat plant without dosing with potassium bromide; <, less than]

Site identifier	Date	Time	Specific electrical conductance, in microsiemens per centimeter	Concentration of indicated constituent, in milligrams per liter	
				Bromide	Chloride
A15	02-26-1998	0907	133	<.05	2.6
	03-04-1998	0925	174	14	2.7
	03-05-1998	1436	186	35	2.7
	03-07-1998	0923	156	24	2.7
	03-11-1998	0940	140	0.4	2.8
A30	02-26-1998	0925	117	<.05	2.5
	03-04-1998	0937	121	0.9	2.5
A45	02-26-1998	0944	117	<.05	2.4
B15	02-26-1998	1015	128	<.05	2.5
	*			.03	2.3
	03-04-1998	1736	145	13	2.4
	03-05-1998	1449	161	25	2.4
	03-07-1998	0908	164	28	2.4
C25	02-26-1998	1145	150	<.05	2.8
	03-08-1998	1115	167	12	2.9
	03-16-1998	1023	143	4.5	2.7
C40	02-26-1998	1140	143	<.05	2.8
	03-10-1998	0908	150	6.2	2.7
Well-9	02-26-1998	1629	122	<.05	2.9
	03-04-1998	1000	178	35	2.4
LC-145	02-26-1998	1403	112	<.05	2.4
	03-08-1998	1057	112	1.0	2.5
	03-18-1998	0952	121	5.5	2.4
LC-146	02-26-1998	1425	122	<.05	2.4
	03-04-1998	1013	167	27	2.4
	**			27.5	2.3
	03-04-1998	1710	168	30	2.4
LC-147	02-26-1998	1440	106	<.05	2.5
	03-18-1998	1156	110	1.8	2.6

Table 2. Concentrations of bromide and chloride, and specific electrical conductances of water samples—Continued

Site identifier	Date	Time	Specific electrical conductance, in microsiemens per centimeter	Concentration of indicated constituent, in milligrams per liter: Bromide	Chloride
LC-148	02-26-1998	1456	117	<.05	2.4
	03-04-1998	1715	132	7.8	2.4
	03-05-1998	1423	134	12	2.4
	03-06-1998	0920	140	15	2.4
	*			15	2.4
	**			16.3	2.4
LC-149A	02-25-1998	1625	105	<.05	2.1
LC-149C	02-25-1998	1659	116	<.05	2.4
LC-149D	02-25-1998	1640	112	<.05	2.3
LC-161	02-27-1998	1552	128	<.05	2.3
	03-10-1998	0848	132	<.05	2.4
LC-162	02-27-1998	1625	239	<.05	2.9
LC-26	02-26-1998	1437	111	<.05	2.5
	03-09-1998	0923	110	1.9	2.4
LR-1[1]	03-05-1998	0635	192	38	6.3
	03-06-1998	0730	[2]200	40	2.8
LR-2	02-26-1998	1657	104	<.05	5.5
	*			<.05	5.5
	**			.04	5.5
	**			.04	5.6
	03-07-1998	1000	144	10	6.4
LR-2	*			10	6.3
	**			10.7	6.2
	03-16-1998	0939	136	2.8	5.0
EGAT***	04-14-1998	0758	119	0.1	2.5

1. Sample from well LR-1 without dosing with sodium chloride (NaCl).

2. Specific conductance of sample taken at 0655.

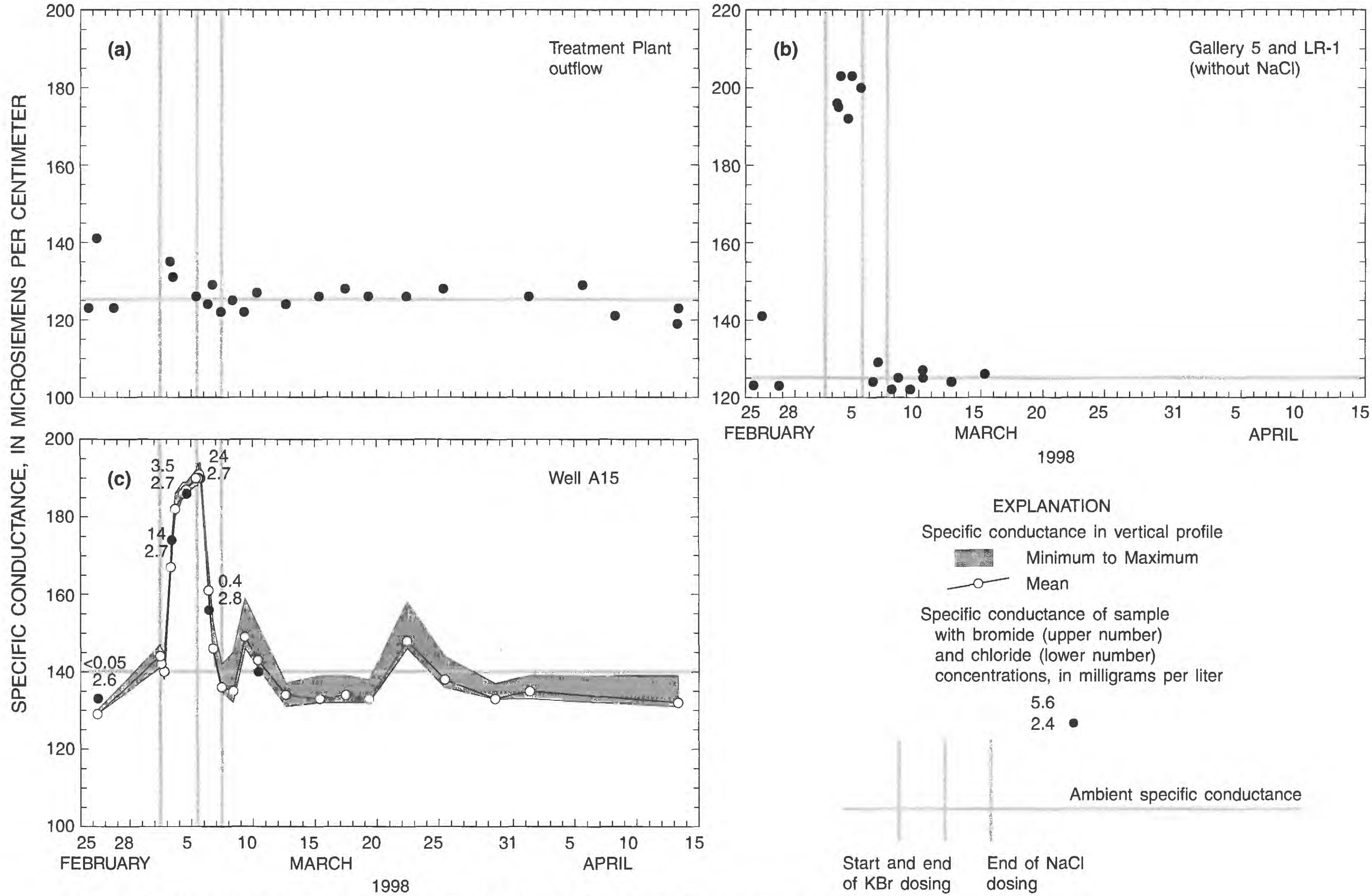

Figure 5. Specific electrical conductances, and bromide and chloride concentrations in wells as functions of time.

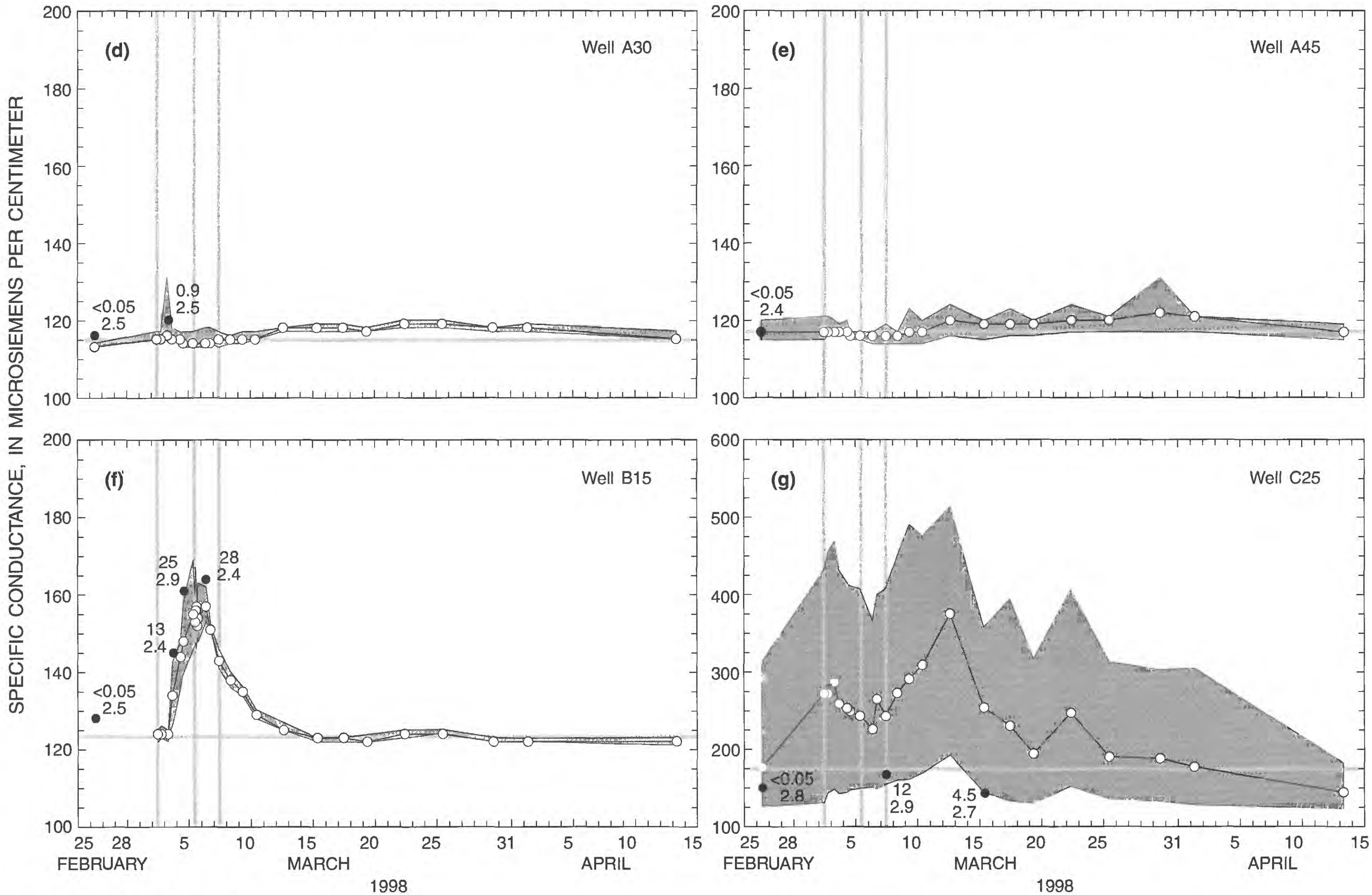

Figure 5. Continued

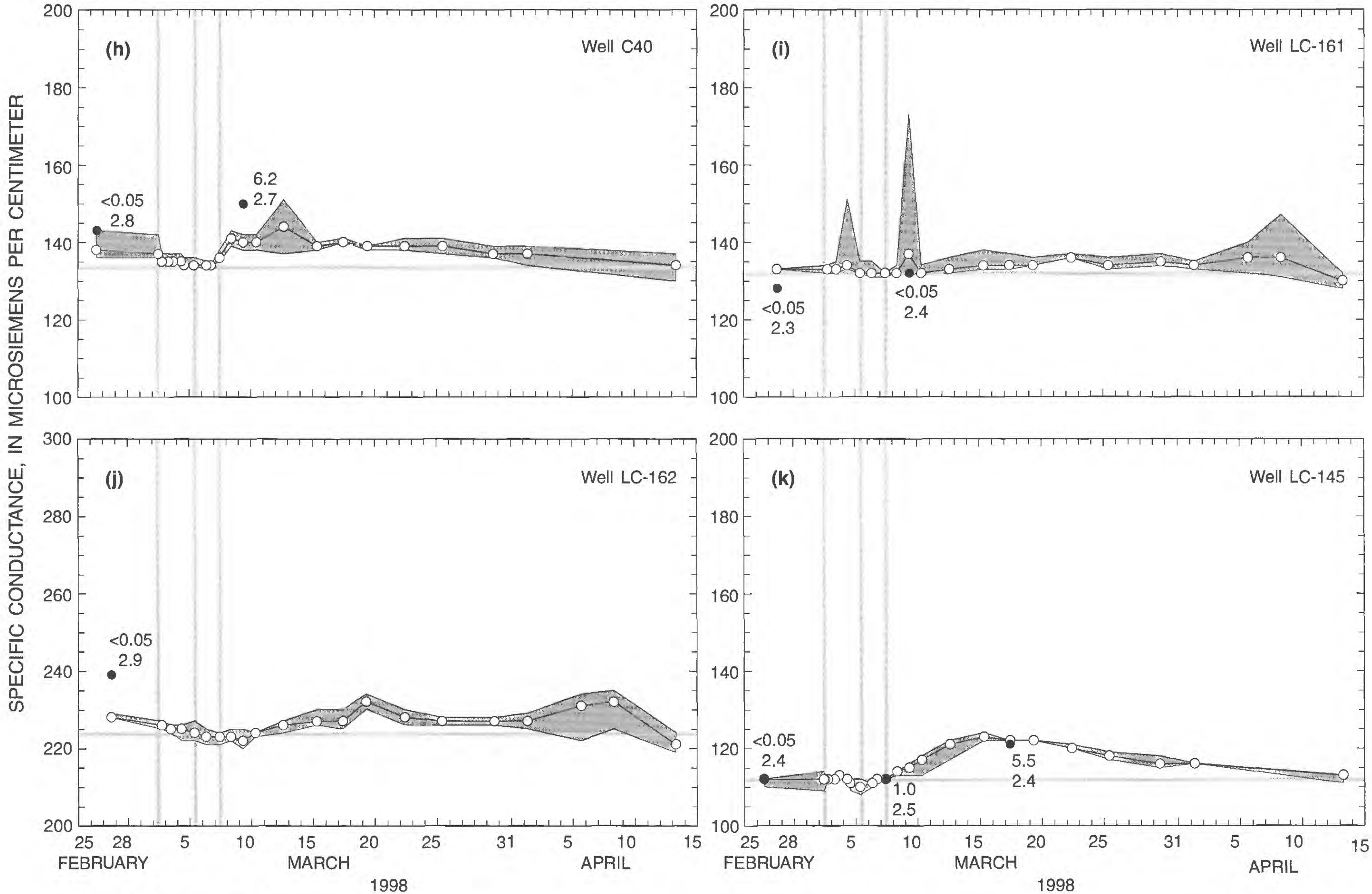

Figure 5. Continued

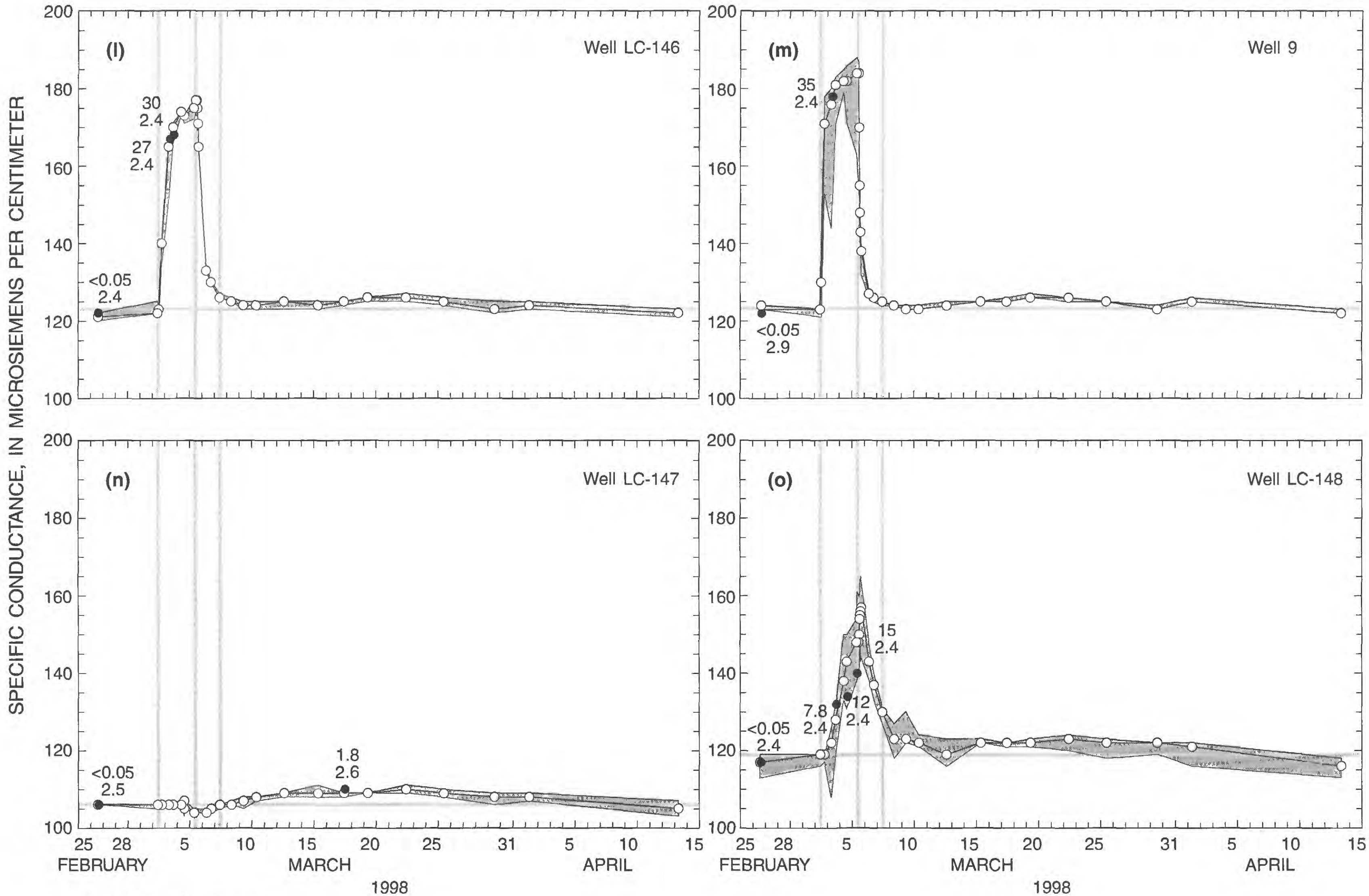

Figure 5. Continued

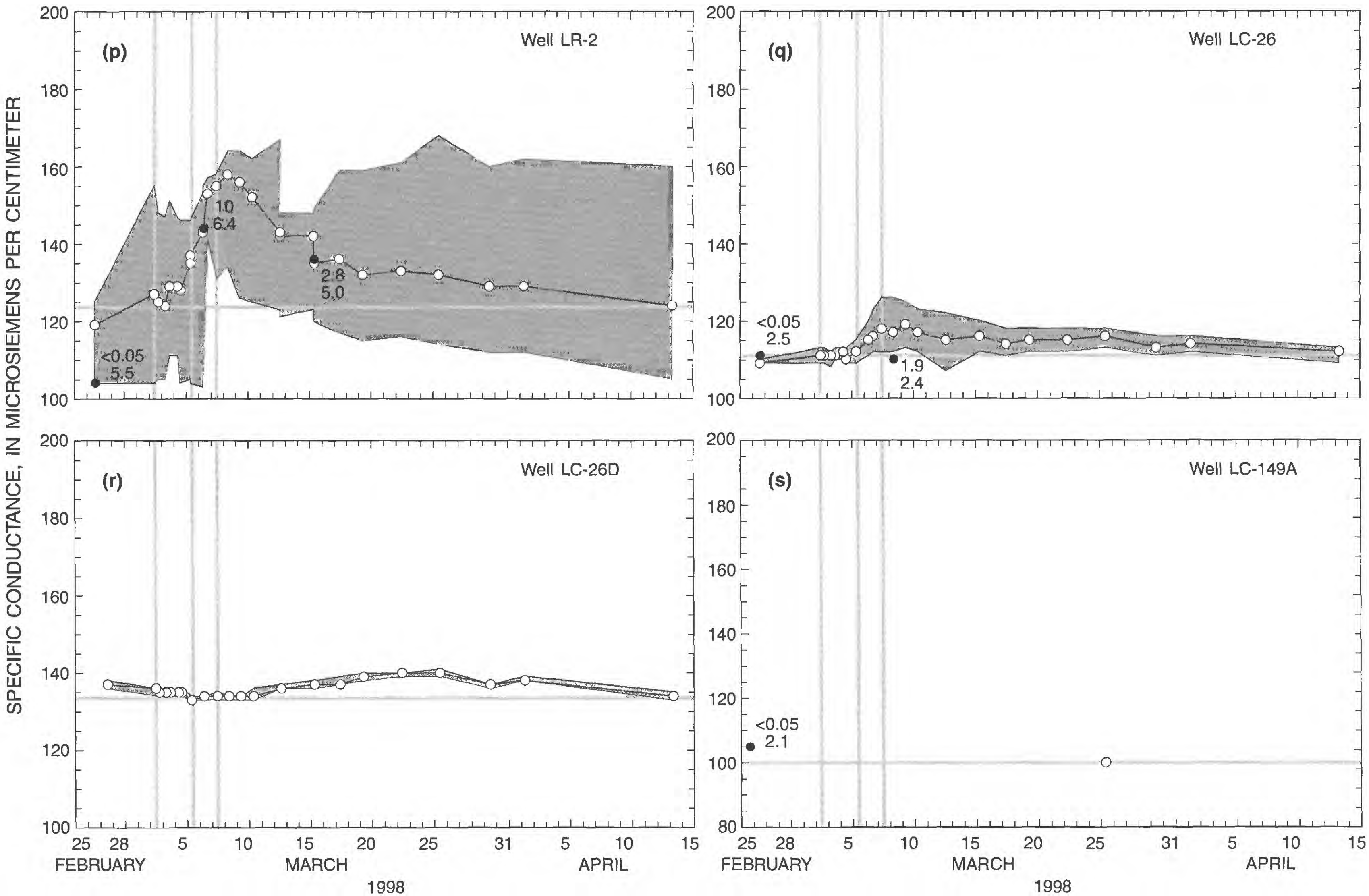

Figure 5. Continued

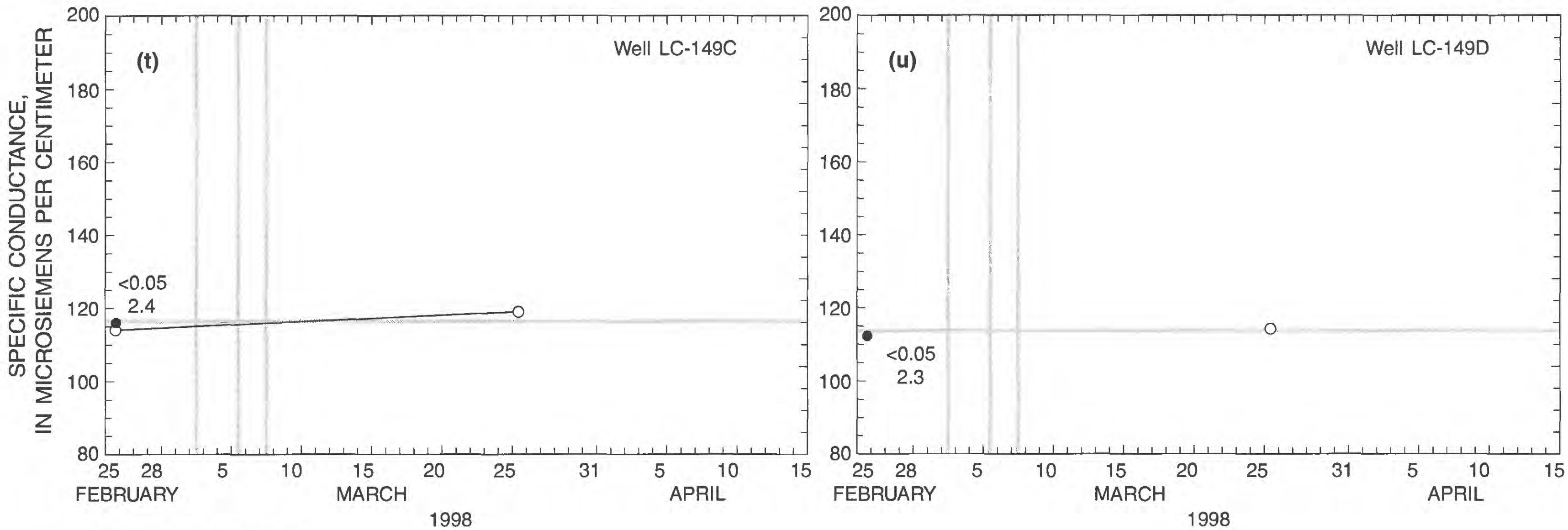

Figure 5. Continued

Table 3. Computed centroids and standard deviations of temporal distributions of observed vertically averaged values of specific electrical conductance in excess of ambient values

[--, value not determined]

Site identifier	Ambient specific electrical conductance in microsiemens per centimeter	Estimate when specific electrical conductance returns to ambient value: Month-day in 1998	Estimate when specific electrical conductance returns to ambient value: Time	Centroid: Month-day in 1998	Centroid: Time	Centroid: Hours since 03-01-1998, 0000	Standard deviation (square root of variance), in hours
Gallery 5 and 6	125	03-06	1020	03-04	2250	94.8	20.8
A15	140	03-08	0230	03-05	1913	115.2	22.7
A30	116	04-14	0848	03-26	0537	605.6	189.9
A45	117	04-14	0851	03-27	2219	646.3	191.6
B15	124	03-15	0000	03-07	1714	161.2	46.9
C25	--	--	--	--	--	--	--
C40	134	04-10	0000	03-21	0050	480.3	199.7
WELL-9	123	03-10	0732	03-05	0710	103.2	23.0
LC-145	112	04-14	0818	03-22	2159	527.8	143.2
LC-146	123	03-10	0728	03-05	2005	116.1	26.1
LC-147	106	04-09	0800	03-22	2241	526.7	172.1
LC-148	119	03-13	1332	03-07	0137	145.6	40.7
LC-149A	100	--	--	--	--	--	--
LC-149C	116	--	--	--	--	--	--
LC-149D	114	--	--	--	--	--	--
LC-161	132	--	--	--	--	--	--
LC-162	224	--	--	--	--	--	--
LC-26	111	04-14	0836	03-21	2005	500.1	247.2
LC-26D	134	04-14	0840	03-26	1652	616.9	177.7
LR-1	--	03-08	1030	03-05	1200	[1]108	--
LR-2	124	04-14	0827	03-16	2212	382.2	216.0
LR-2	124	03-25	0827	03-12	1231	276.5	106.3

[1]Assumed value.

Hydraulic Conductivity

Hydraulic conductivity is a measure of the capability of a porous medium to transmit water. The conductivity is a function of the viscosity and specific weight of the water and of the size, shape, and connectivity of the pores in the media through which the water flows. In sedimentary geologic formations, the geometry of the pores is a function of the size, shape, and packing of the sediment particles. In formations with horizontal bedding, the effective gross hydraulic conductivity of a geologic unit usually is larger in the horizontal than in the vertical direction because of layers with different particle sizes within the unit and the orientations of individual particles.

Hydraulic conductivity, K, can be computed by applying variations of Darcy's law between pairs of observation wells (see, for example, Freeze and Cherry, 1979). Two expressions are derived here, one for steady uniform rectilinear flow and another for steady axially symmetric radial flow away from a recharge well. For uniform rectilinear flow with uniform K,

$$\nu = \frac{-K\left(\frac{\Delta h}{L}\right)}{n} , \qquad (1)$$

where ν is the so-called average linear velocity (Freeze and Cherry, 1979, p. 71); n is the effective porosity; Δh is the difference between water levels (hydraulic heads) at two locations separated by a distance L parallel to the flow direction. The velocity, v, can be approximated by

$$v = \frac{L}{\Delta t} , \qquad (2)$$

where Δt is the average travel time between the two locations. The Δt can be estimated as the difference between the computed centroids of the temporal distributions tracer concentration or excess specific conductance. Substituting equation 2 into equation 1 and solving for K yields

$$K = \frac{-nL^2}{\Delta t \Delta h} , \qquad (3)$$

In areas of primarily horizontal flow, equation 3 can be used to estimate the horizontal hydraulic conductivity K_h of the material between the wells. For this case the observation wells must be screened at about the same depth in the same geohydrologic unit, and L is the horizontal distance between the wells. In areas of primarily vertical flow, equation 3 can be used to estimate vertical hydraulic conductivity, K_v. In this case the horizontal distance between the observation wells must be small, and L is the vertical distance between the midpoints of the screened intervals of the wells. If two wells are separated both horizontally and vertically, or if flow is not primarily vertical or horizontal and the hydraulic conductivity is not isotropic, equation 3 is not suitable for estimating hydraulic conductivity.

An expression similar to equation (3) for horizontal radial flow away from a recharge well is also needed. The discharge per unit thickness, q, away from a well in a radial direction, r, is given by the differential equation:

$$q = -K_h 2\pi r \frac{dh}{dr} ,$$

which, when integrated, gives

$$q = -2\pi K_h \frac{\Delta h}{\ln\left(\frac{r_2}{r_1}\right)} , \qquad (4)$$

where Δh is the difference between heads at radii r_2 and r_1. The equation for travel time is

$$dt = \frac{dr}{v} = \frac{dr}{\left[\frac{q}{(2\pi r n)}\right]} . \qquad (5)$$

Substituting equation 4 into this equation, integrating, and solving for K_h yields

$$K_h = -n(r_2^2 + r_1^2)\frac{\left[\ln\left(\frac{r_2}{r_1}\right)\right]}{(2\Delta t \Delta h)} .$$

Longitudinal Dispersivity

Longitudinal dispersion is the mixing of dissolved material in the direction of flow by the combined effects of differences in flow velocity along different flow paths and cross-wise mixing between the flow paths (see, for example, Fetter, 1993). A mathematical analysis of this process reveals that transport per unit area by longitudinal dispersion can be computed as the product of a longitudinal hydrodynamic dispersion coefficient and the longitudinal gradient of the concentration averaged over an area perpendicular to the flow velocity. The value of this dispersion coefficient increases with the variation in velocity within the area and the dimensions of the area, and it decreases with the intensity of crosswise mixing within the area. Consequently, the value of the dispersion coefficient is dependent on the area over which it is defined. For example, the longitudinal dispersion coefficient in the horizontal direction for a combined sequence of coarse- and fine-grained geologic units with horizontal bedding would be much larger than the dispersion coefficient for any of the individual units because the variation in flow velocity within the sequence would be larger than the variation within any of the individual units, and the thickness of the sequence would be larger than the thickness of an individual unit. Dispersion coefficients for directions perpendicular to the flow velocity, often referred to as transverse dispersion coefficients, are the result of different processes and normally are smaller than the longitudinal dispersion coefficient.

In order for the concept of a longitudinal dispersion coefficient to be valid (flux by longitudinal dispersion equals the product of a dispersion coefficient and longitudinal concentration gradient), sufficient time must elapse after the introduction of a material into the flow system for each parcel of material to migrate across the entire area for which the dispersion coefficient is defined. For times shorter than this, the apparent dispersion coefficient will be less than the ultimate value.

Dispersivity is a coefficient with units of length that relates a hydrodynamic dispersion coefficient to ground-water velocity (Freeze and Cherry, 1979, p. 389-399). For the longitudinal dispersion coefficient, one can write

$$D_L = a_L v \quad , \qquad (6)$$

where D_L is the longitudinal hydrodynamic dispersion coefficient, and a_L is the longitudinal dispersivity. Often, to obtain the total longitudinal dispersion coefficient, a term to account for molecular diffusion is added to D_L; however, in most cases, including the present investigation, this term is many factors of 10 less than D_L and is neglected.

The longitudinal dispersion coefficient and the dispersivity can be calculated from the rate of longitudinal spreading of a tracer. If a tracer is being transported in a uniform steady rectilinear velocity field, the dispersion coefficient may be computed as

$$D_L = \frac{1}{2}\left(\frac{d\sigma_L^2}{dt}\right) \quad , \qquad (7)$$

where $\frac{d\sigma_L^2}{dt}$ is the time rate of change in the variance of the longitudinal (spatial, in the direction of flow) distribution of concentration of the tracer (see, for example, Fischer and others, 1979, p.41). (Here, D_L is defined such that the dispersive flux per unit gross area is equal to the product nD_L times the concentration gradient, while some investigators define D_L such that the flux is equal to D_L times the concentration gradient. In the latter case, the values of the dispersion coefficient and dispersivity would be n times the values obtained in the present study.)

In this as in most investigations, the available data consist of temporal rather than the needed spatial distributions of tracer. To obtain σ_L^2 for use in equation 7, the variance of the temporal distribution, σ_t^2, is multiplied by the square of the velocity, v^2. When the time derivative in equation 7 is replaced by the difference between values at two observation locations divided by the travel time between the locations and equation 2 is used for the velocity, equation 7 becomes

$$D_L = \frac{L^2 \Delta\sigma_t^2}{2(\Delta t)^3} \quad . \qquad (8)$$

Substituting equations 8 and 2 into equation 6 and solving for the dispersivity yields

$$\alpha_L = \frac{L\Delta\sigma_t^2}{2(\Delta t)^2} \quad . \tag{9}$$

GROUND-WATER FLOW DIRECTIONS

In this section observed ground-water levels are presented and used to infer directions of ground-water flow in the test area. This section also presents and describes observed temporal and spatial distributions of specific conductance, and bromide and chloride concentrations and relates them to the flow directions inferred from water levels.

Ground-Water Levels and Flow Directions

Water levels in wells within the test area were measured twice during the tests, once near the beginning of the test on March 4, 1998, and again on March 23, 1998. All measured water levels, except in upgradient wells LC-149A, C, and D, were less than 10 ft below land surface. Water levels declined slightly in the period between the two measurements and on March 23 were 0.01 to 0.10 ft lower than on March 4 in all wells except the recharge well (LR-1), where the water level was 0.03 ft higher (table 1). Although there are two shallow wells (4 to 5 ft deep) in each of the galleries (wells TRP1 through TRP4 on figure 4), water levels were below the bottoms of these wells. Consequently, water levels directly beneath the galleries are unknown. The water levels that form the basis for the discussions in the following paragraphs and those that appear on the accompanying figures are averages of the March 4 and 23 measurements. However, the interpretations of the data would not have changed if one or the other of these data sets were used instead of the average.

Directions of ground-water flow can be inferred from water levels because flow is in the general direction of decreasing water level, and average linear velocities can be estimated using equation 2 (figs. 4, 6, and 7, and table 4). The available data indicate that the flow field is complex, probably partly because of the heterogeneity of the sediment deposits and partly because of the withdrawal and recharge from the pump-and-treat system. Estimated velocities in the horizontal direction ranged from 0.18 to 3.4 feet per hour and decreased along section *AA'* with distance from recharge gallery 5 (figs. 4 and 6). Most of the velocities in the vertical direction, which ranged from 0.083 to 2.0 feet per hour, were of the same order of magnitude as in the horizontal direction, probably because all of the former were beneath the recharge gallery. Although the data are not sufficient to completely define the flow field in the test area, some generalizations can be made. The data are sufficient to allow one to infer that near the water table there was a horizontal component of flow in the northwesterly direction along section *AA'* (figs. 4 and 6). This is consistent with previously inferred flow directions in the upper aquifer beneath the East Gate Disposal Yard and most of the Logistics Center (U.S. Army Corps of Engineers, 1998, fig. 5) and with the concept that ground water flows from the recharge to the extraction area of the pump-and-treat system. At a depth of about 80 ft below land surface, which is still within the upper aquifer, there was a horizontal component of flow from the active to the inactive recharge well (LR-1 to LR-2, fig. 7), as would be expected. However, at a depth of about 40 ft below land surface, at the elevation of the midpoints of the screened intervals in wells LC-145, LC-146, LC-147, and LC-148, the apparent horizontal component of flow was in the opposite direction (fig. 7). One possible reason for the different flow direction at 40-ft depth could be the slightly larger flow into gallery no. 6 (330 gpm) than into gallery no. 5 (270 gpm); other reasons include a spatial pattern or an anisotropy in the hydraulic conductivity.

One would expect that the vertical component of ground-water flow near the recharge galleries would be downwards near the water table, and near the recharge well would be upwards at depths slightly less than the center of the screened interval of this well. Flow directions near the water table, as inferred from water levels, are indeed down between WELL-9 and well LC-146, between A15 and A30, and between C25 and C40 (figs. 6 and 7). Because water levels in wells LR-1 and LR-2 are higher than in wells LC-145, LC-146, LC-147, and LC-148, the direction of the vertical component of flow between about 40 ft and 80 ft below land surface is most likely upward. The vertical component of flow between wells A30 and A45 is upward also.

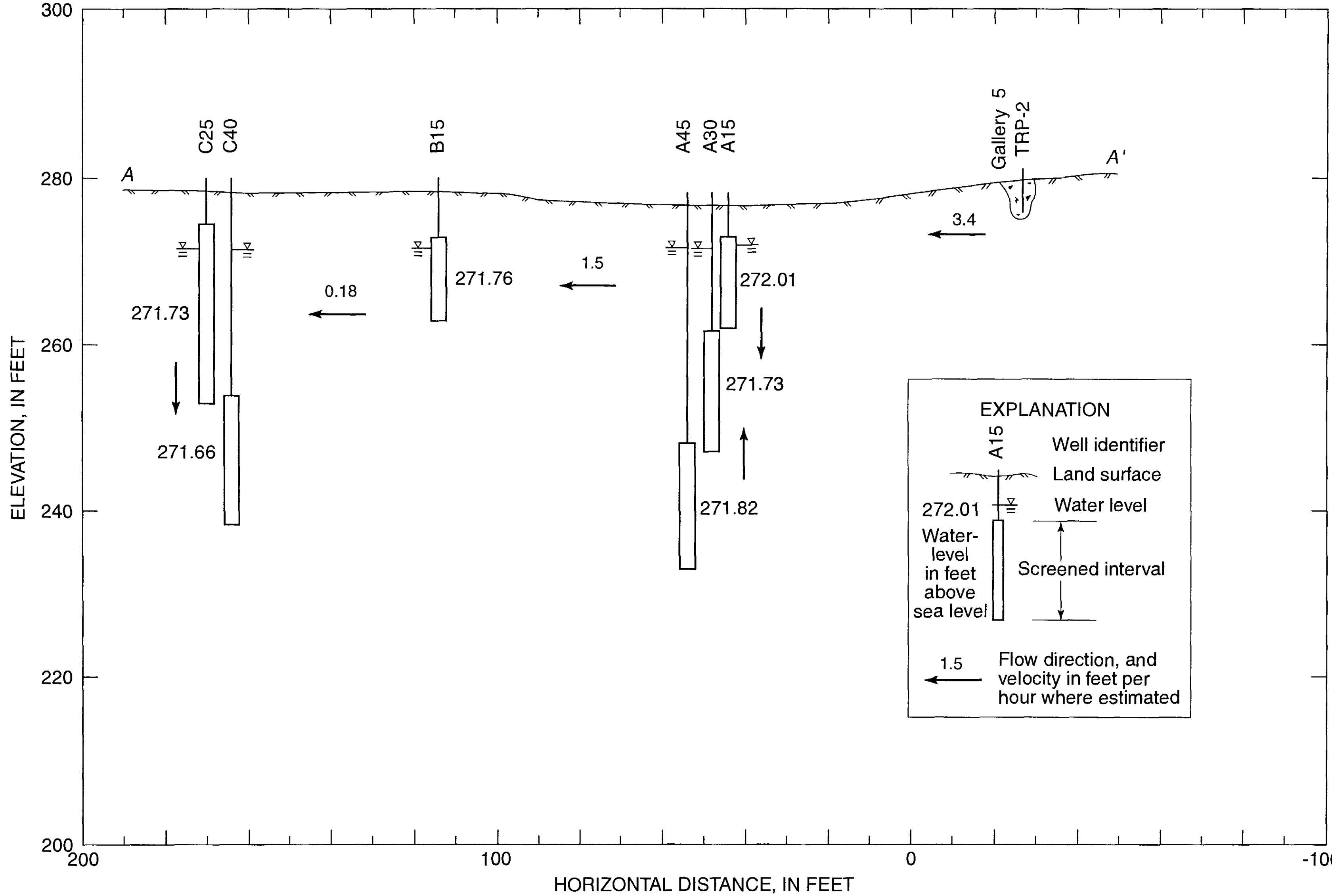

Figure 6. Section along a line through wells C25 and TRP-2 showing elevations of well screens, observed water levels, and inferred ground-water flow directions and estimated velocities, Fort Lewis, Washington. Water levels are averages of observations on March 4 and 23, 1998.

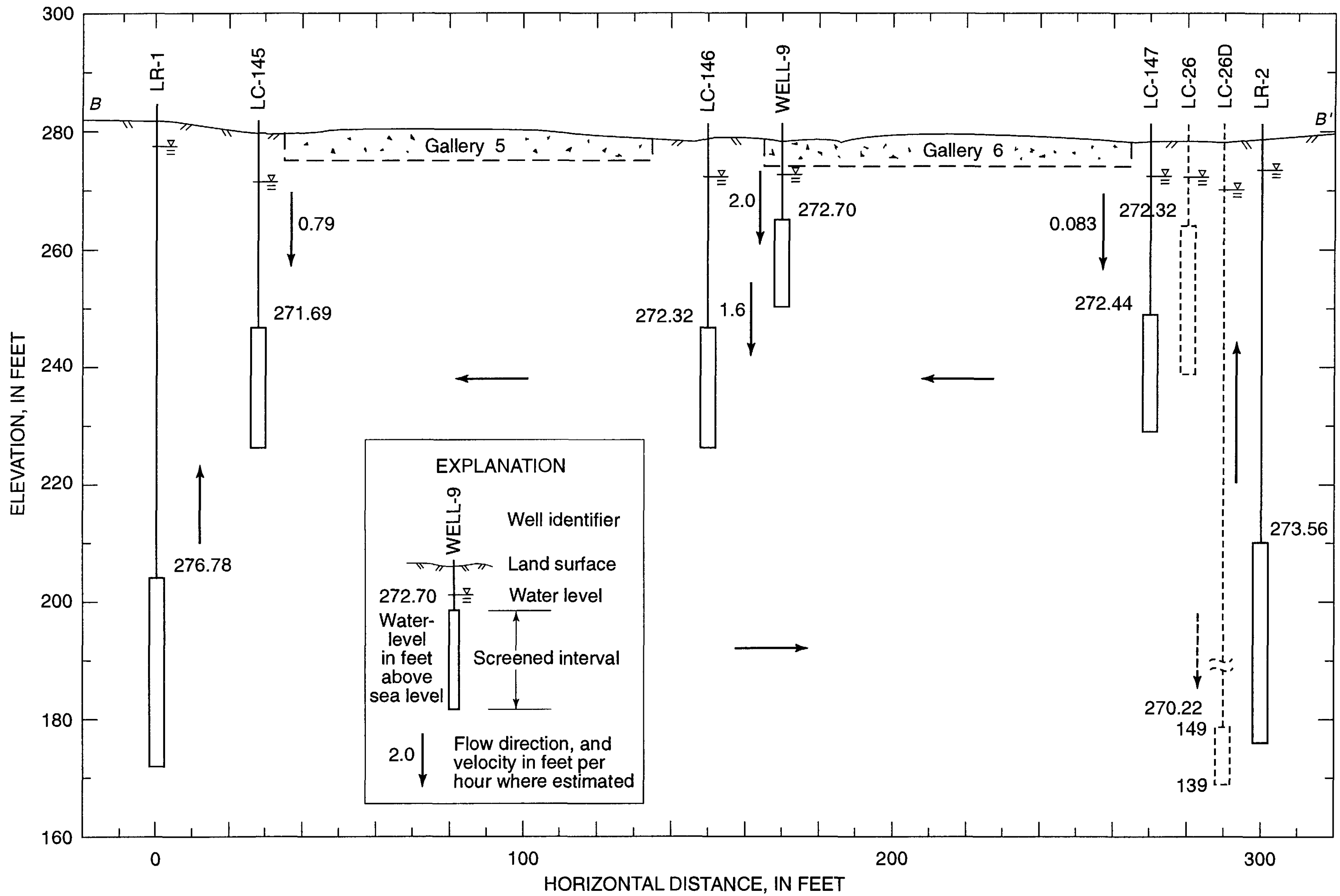

Figure 7. Section along a line through wells LR-1 and LR-2 showing elevations of well screens, observed water levels, and inferred ground-water flow directions and estimated velocities, Fort Lewis, Washington. Water levels are averages of observations on March 4 and 23, 1998.

Table 4. Estimated values of hydraulic conductivities and longitudinal dispersivities, and data used to compute them

[1 and 2, up-gradient and down-gradient sites, respectively; h and v, horizontal and vertical directions, respectively; horizontal coordinates, except for sites LR-1 and LR-2, are northwest from a line through wells LR-1 and LR-2 and parallel to line through wells A15 and C25, for LR-1 and LR-2 coordinates are radial distance from center of well LR-1; vertical coordinates are elevations above sea level; ground-water head is average of observations on March 4 and April 23, 1998; Centroid is measured from 0000 hours on March 1, 1998; <, less than; >, greater than; --, value not determined]

Identifier of indicated site		Direction	Hydraulic conductivity, in feet per day	Longitudinal dispersivity, in feet	Coordinate of indicated site, in feet		Ground-water head at indicated site, in feet		Centroid at indicated site, in hours		Ground-water velocity, in feet per hour	Standard deviation at indicated site, in hours	
1	2				1	2	1	2	1	2		1	2
Gallery 5	A15	h	>840	6.9	-24	45	[1]<274	272.01	94.8	115.2	3.4	20.8	22.7
Gallery 5	A15	h	<2,400	--	-24	45	[2]>272.70	272.01	94.8	115.2	3.4	--	--
A15	B15	h	3,100	28	45	115	272.01	271.76	115.2	161.2	1.5	22.7	46.9
B15	C25	h	2,300	--	115	170	271.76	271.73	161.2	[3]480.3	0.18	46.9	--
B15	C40	h	540	9.1	115	164	271.76	271.66	161.2	480.3	0.18	46.9	199.7
Gallery 6	LC-148	h	>260	16	8	76	[1]<275	272.49	94.8	145.6	1.4	20.8	40.7
Gallery 6	LC-148	h	<3,100	--	8	76	[2]>272.70	272.49	94.8	145.6	1.4	--	--
Gallery 6	LC-26	h	>69	19	8	-94	[1]<275	272.32	94.8	500.1	0.25	20.8	247.2
Gallery 6	LC-26	h	<490	--	8	-94	[2]>272.70	272.32	94.8	500.1	0.25	--	--
LR-1	LR-2	h	3,800	--	0.5	300	276.78	273.56	[4]108	276.6	--	--	106.3
LR-1	LR-2	h	2,300	--	0.5	300	276.78	273.56	[4]108	382.2	--	--	216.0
Gallery 5	LC-145	v	>8	1.8	274	240	[1]<274	271.69	94.8	527.8	0.79	20.8	143.2
Gallery 5	LC-145	v	<19	--	274	240	[2]>272.70	271.69	94.8	527.8	0.79	--	--
Gallery 6	WELL-9	v	>110	12	275	258	[1]<275	272.70	94.8	103.2	2.0	20.8	23.0
WELL-9	LC-146	v	590	9.1	258	238	[2]272.70	272.32	103.2	116.1	1.6	23.0	26.1
Gallery 6	LC-147	v	>8	2.8	275	239	[1]<275	272.44	94.8	526.7	0.083	20.8	172.1
Gallery 6	LC-147	v	<80	--	275	239	[2]>272.70	272.44	94.8	526.7	0.083	--	--

[1]Approximate elevation at bottom of gallery.
[2]Water level in WELL-9.
[3]Centroid is from data at well C40.
[4]Estimated.

The complexity of the inferred flow patterns in the test area would make the design and evaluation of most remediation methods and the interpretations of observed contaminant distributions difficult. Those doing these tasks should be cautious and aware of the complex patterns of ground-water movement that are possible in this environment.

Bromide and Chloride Concentrations

Bromide, but not chloride, concentrations in samples collected from most wells during the test were higher than ambient concentrations in samples collected about one week before the test, indicating that most of the observed increases in electrical conductance in water in wells during the test (see the subsection "Specific Electrical Conductance") were the result of the KBr tracer in the water from the recharge galleries. (See also the plot of specific conductance as a function of bromide concentration on fig. A1 of the Appendix.) The ambient concentrations of bromide in samples from all 15 sampled observation wells in the test area and the three upgradient wells were less than 0.05 mg/L (table 2 and fig. 5, samples collected on February 25, 26, or 27). The bromide concentration was 0.9 mg/L or more in at least one sample from all but one of the 13 observation wells that were sampled during the test (table 2 and fig. 5, samples collected on or after March 4). The largest concentration (35 mg/L) was in a sample from well A15, which is nearly equal to the observed concentration in recharge water, as represented by the samples from well LR-1 (38 and 40 mg/L, table 2). No samples were taken during the test from wells A45 or LC-162, and the one sample taken from well LC-161 during the test may have been taken before the tracer reached this well.

Ambient chloride concentrations in samples from all wells (with the exception of LR-2) ranged from 2.1 to 2.9 mg/L. Concentrations in the samples collected during the test from all wells but LR-2 were no more than 0.2 mg/L greater than the ambient concentrations, and concentrations in samples from seven of the wells were the same or lower than ambient levels (table 2 and fig. 5).

Chloride concentrations in samples from well LR-2 suggest that some of the water in this well was injected at well LR-1—as would be expected because both wells are screened at nearly the same elevations (fig. 7). However, anomalies in the chloride concentrations in samples from this well preclude drawing definite conclusions. Although the bromide concentration in the sample collected from well LR-2 one week before the test was about the same as the concentrations in samples from the other observation wells (<0.05 mg/L), the chloride concentration was 5.5 mg/L, which is about twice that in samples from the other wells (table 2). On March 7, when the bromide concentration increased to 10 mg/L, the chloride concentration was 6.4 mg/L, about 1 mg/L larger than before the test (table 2 and fig. 5; note that the concentrations in the samples collected from well LR-2 on February 26 and March 7 were verified by analyses of replicate aliquots of the sample at two laboratories). On March 16, when the bromide concentration decreased to 2.8 mg/L, the chloride concentration decreased to 5.0 mg/L, which is 0.5 mg/L or 9 percent smaller than before the test. The reasons for the anomalies in the chloride concentrations in the samples from well LR-2 are unknown, but are suspected to be a result of inadequate purging of this well before sample collection (see the "Monitoring" subsection in the "Methods" section).

Specific Electrical Conductance

The effect of the KBr tracer on the specific conductance of the ground water and the usefulness of electrical conductance for monitoring the movement of the tracer are evident in the graphs of vertically averaged conductance as functions of time (fig. 5). In each sample collected the bromide but not the chloride concentration was elevated whenever the electrical conductance that was measured in situ was elevated (fig. 5). The specific electrical conductances of samples from most wells are about the same as the vertically averaged specific conductances measured in situ (see data for wells A15, LC-145, LC-146, LC-147 and WELL-9 on figs. 5c, k, l, m and n, respectively). However, sample conductances differ from the vertically averaged in-situ values for some wells, and some even lie outside the range of values in the in-situ vertical profile (see data for wells B15, C25, C40 and LC-26 on figs. 5f, g, h, and r, respectively). As stated earlier, the average of a vertical profile of a characteristic of water in a well and the characteristic of a sample taken from the well can differ because of vertical flow within the well induced by differences in hydraulic heads within the well's screened interval and differences in horizontal hydraulic conductivity within the screened interval.

The ambient values of specific conductance varied among the wells, with time, and with depth within the screened intervals of some wells. Although most ambient values were between about 105 and 125 μS/cm, the entire range was from about 100 μS/cm at well LC-149A to greater than 200 μS/cm at LC-162 and greater than 400 μS/cm at well C25. Some of the variation in ambient specific conductance among wells is probably natural, but the larger conductances probably are a result of local dissolution of materials buried in the disposal yard. For example, on March 26 the values of vertically averaged in-situ specific conductance at wells LC-149A, C, and D, which are within a circle of 20 ft radius and are screened at increasing depths between 30 and 80 ft below land surface, were 100, 119, and 114 μS/cm, respectively (figs. 5s, t and u, and Appendix A). (Values of specific conductance of samples collected from these wells on February 25 had a similar but slightly smaller variation, 105, 116, and 112 μS/cm, table 2.) The differences between the vertically averaged value for well LC-149A and the other two wells are much greater than the observed variation with depth within any of these wells, even though these wells are upgradient of any suspected contamination. On the other hand, reported concentrations of TCE in samples from well LC-162 have been as large as 1,000 μg/L (Woodward-Clyde, 1998, table 2-3B), suggesting that the elevated ambient specific conductance of the water in this well may be the result of local contamination. Also, the large values of specific conductance observed at some levels in well C25 probably can be attributed to a local contaminant source because an oily substance was encountered when drilling the hole to install this well.

Differences between values of specific conductance measured in-situ 1 week before, a few hours before, and at the end of the test are an indication of the temporal variations in ambient electrical conductance. At most locations observed temporal changes in ambient specific conductance are of the order of the estimated accuracy of the measurements (a few microsiemens per centimeter) (wells A45, LC-145, LC-146, LC-147, and WELL 9 on figs. 5e, k, l, n, and m). However, at a few locations the apparent variation was as large as 10 μS/cm (well A15, fig. 5c).

The movement of tracer from recharge gallery 5 to the northwest is evident from the observed electrical conductance at wells A15 and B15, which are screened at the water table, and to a lesser extent at well C40, in which the top of the screen is about 18 ft below the water table. Presence of the tracer based on the specific conductance at well C25, which is screened at the water table and is adjacent to C40, is difficult to discern because of the large variation in the ambient conductance, as described previously. However, the bromide concentration in the sample collected from well C25 on March 16 (4.5 mg/L) indicates the presence of the tracer at that location. The conductance at wells LC-161 or LC-162 (figs. 5i and j), which are the farthest downgradient observation wells, hints at the presence of tracer; however, the changes in conductance are small and there are no bromide data for verification.

Even though wells LC-26 and LC-26D are upgradient (with respect to the regional flow system) of the recharge galleries and recharge well, the recharge of the water through the galleries and well apparently reverses the gradient locally, and some of the recharged water moved from the galleries to LC-26 and perhaps to the deeper well LC-26D. The presence of tracer at LC-26 is indicated by an increase in specific conductance of about 10 μS/cm, which is confirmed by a bromide concentration of 1.9 mg/L in a sample collected on March 9 (fig. 5q and table 2). No bromide data are available to verify that the increase in conductivity at LC-26D (fig. 5r) was caused by arrival of the tracer.

Data from wells with screens that are entirely below the water table suggest there is large spatial variability in the downward movement of the tracer. At wells A30 and A45, which are adjacent to A15 but screened 0 to 15 ft and 15 to 30 ft deeper than well A15, respectively (table 1), observed values of specific conductance increased no more than about 5 μS/cm above background (figs. 5d and e). The magnitudes of these increases are near the magnitudes of the variations in ambient conductance and the estimated magnitude of the error in the determinations of specific conductance. However, a bromide concentration of 0.9 mg/L in the sample from well A30 (fig. 5d and table 2) indicates that the tracer was present in this well. No sample was collected from well A45; however, the fact that the water level in well A45 is about 0.1 ft higher than in A30 indicates that tracer could not be moving downward from well A30 to A45 at this location. Wells LC-145, LC-146, and LC-147 are all located on a line near and approximately parallel to the two galleries, and all are screened at similar depths from about 30 to 50 ft below land surface (figs. 4 and 7). Well LC-148 also is screened at about the same depth but is about 75 ft northwest of the line, and WELL-9 is on the line but is screened at a shallower depth (13 to 28 ft below land surface). Specific conductance in WELL-9, and in nearby well LC-146, increased by 50 µS/cm within two days after the start of the test and decreased to ambient levels by March 10, 5 days later (figs. 5m and l). In well LC-148 conductivity also increased substantially, by about 35 µS/cm, and returned to near ambient levels by March 10. On the other hand, conductance in wells LC-145 and LC147 increased by only about 15 and 5 µS/cm, respectively, and did not appear to return to ambient levels until after April 2.

ESTIMATED HYDRAULIC CONDUCTIVITIES AND DISPERSIVITIES

Although the complexity of the ground-water-flow in the test area probably prohibits the application of equations 3, 5, and 9 at the scale of the test site, it will be assumed that the flow patterns at the scale of distances between observation locations are approximately rectilinear or radial and these equations will be used to estimate hydraulic conductivities and dispersivities from the observed specific conductances. The centroids and variances of the temporal distributions of excess specific conductance at selected locations were computed by numerical integration (table 3) and used with observed or estimated water levels in the equations to obtain the estimates (table 4). In some cases two values of hydraulic conductivity were estimated between a pair of locations because of an uncertainty in the water level or the centroid at one of the locations. A value of 0.3 was assumed for porosity. The estimated hydraulic conductivities are directly proportional to the assumed value of porosity (equations 3 and 5), but the estimated dispersivities are independent of porosity (equation 9).

Horizontal Hydraulic Conductivity

Estimated values of horizontal hydraulic conductivity of the sediments in the upper part of the upper aquifer, as computed with data from five pairs of locations, were between 69 and 3,100 ft/d (table 4). The lowest estimated horizontal hydraulic conductivities are between gallery 6 and well LC-26 (69 to 490 ft/d). The values for this pair of locations may be low because the top of the screen in LC-26 is below the water table and the time of arrival of the tracer at this well could have been delayed because ground water would have had to flow vertically as well as horizontally to reach this well. However, the top of the screen in well LC-148 also is below the water table but the hydraulic conductivies computed between gallery 6 and this well (260 to 3,100 ft/d) are more than three times those between gallery 6 and well LC-26.

The estimated horizontal hydraulic conductivity at a depth of about 80 ft below land surface, as obtained with data from the two recharge wells (LR-1 and LR-2), is 2,300 ft/day or 3,800 ft/day, depending on which value of the centroid at LR -2 is used (table 3). The uncertainty in the centroid is a result of the uncertainty in the time at which the specific conductance returned to the ambient value. These values of hydraulic conductivity are near or greater than the largest values estimated for shallower sediments near the water table.

Vertical Hydraulic Conductivity

Estimated values of vertical hydraulic conductivity, as computed with data from four pairs of locations, were between 8 and 590 ft/day (table 4), which, as would be expected, are considerably less than the estimated hydraulic conductivities in the horizontal direction. The ratio of estimated horizontal to vertical hydraulic conductivity appears to be of the order of 10 or 100. Although the ratio is difficult to quantify because of the large range in the estimates for each direction and because many of the values are only lower or upper limits, the magnitudes of the ratios appear to be similar to those found from aquifer tests (12 to 259). Values of vertical hydraulic conductivities were not obtained from model calibration because the upper aquifer was simulated as a single layer.

Horizontal and Vertical Longitudinal Dispersivities

Estimated values of longitudinal dispersivity in the horizontal direction range from 6.9 to 28 ft. In the vertical direction the values are smaller, 1.8 to 12 ft. The values in the horizontal direction are within the broad range of values found by others in field tests of similar scale in granular materials (Gelhar and others, 1985). Although Gelhar and others (1985) also summarize values of dispersivity in the vertical direction, those values are dispersivity in the vertical direction resulting from flow in the horizontal direction (transverse dispersivity). The vertical dispersivities estimated in the current study are for flow in the vertical direction (longitudinal dispersivity).

Estimated longitudinal dispersivity is larger in the horizontal direction than in the vertical direction probably because of the nearly horizontal layering of the sediments in the study area. As discussed earlier, longitudinal dispersion normally is the result of variations of flow velocity in directions perpendicular to the velocity. When the layering is nearly horizontal, horizontal velocities could vary appreciably within the vertical as a result of vertical variations in texture of the sediments, whereas vertical velocities would tend to be more uniform within horizontal planes because of the relative uniformity of texture within bedding planes.

Discussion and Applicability of Estimates

The largest values of horizontal hydraulic conductivity estimated from the tracer tests are larger than previous estimates for the East Gate area based on numerical model calibration (80 to 260 ft/day) or aquifer tests (16 to 330 ft/day), (see "Geohydrology" subsection of "Introduction"). The probable reason for the differences is that the values from the tracer test are biased toward highly conductive layers (probably less than about 10 ft in thickness) that occupy only part of the total aquifer thickness (about 100 ft), while the values from model calibration and aquifer tests are averages over the entire thickness, or a large fraction of the thickness, of the upper aquifer. The significance of these differences is that if a vertical sequence of geohydrologic layers of varying hydraulic conductivities in an aquifer is represented in a numerical model by a single layer with a vertically averaged hydraulic conductivity, the model would tend to underestimate the shortest travel times between locations if the locations are connected by lenses or layers of material with a high hydraulic conductivity (a preferred pathway), even though the simulated ground-water heads agree well with observations. However, the relatively high values of hydraulic conductivity obtained from the tracer test can only be incorporated into a model if individual layers within the aquifer are explicitly represented.

The values of horizontal longitudinal dispersivity obtained in this study probably are also representative mostly of flow through thin, highly permeable layers. Although the estimated values of dispersivity may have been increased a small amount by tracer migrating into and out of adjacent layers of less permeable material, the magnitude of this increase also is unknown. On the other hand, if the time scales of the test were too short for parcels of tracer to migrate across all zones within the layer with different flow velocities, the estimated dispersivity for the layer would be too small (see the discussion of longitudinal dispersion in the "Dispersivity" subsection of the "Methods" section). The values estimated from the tracer test probably are appropriate only for coarse-grained units in numerical models in which these layers are represented individually and explicitly. If these units are grouped with other units of different hydraulic conductivity into one model layer, then the dispersivity of this larger model layer would need to be larger than that obtained from the current study because of the greater variation in flow velocity among the units within the layer and the greater thickness of the layer.

A number of factors affect the accuracies of the estimated hydraulic conductivities and dispersivities. These include (1) the assumption that the flow between observation locations was rectilinear or radial as was assumed in the derivation of equations 3, 5, and 9; (2) the assumption that the values of vertically averaged specific conductance measured over the screened interval inside the wells were equal to the vertically averaged values in the aquifer outside the well, and (3) the accuracy of the procedure used to obtain the centroids and variances of the distributions of specific conductance, which depends, among other things, on the accuracy of the estimated values of ambient conductance and the estimated tail of the distributions. This report makes no attempt to quantify the errors associated with the above assumptions and estimates.

Factors that can affect the applicability of the estimates are not knowing (1) the accuracy of the estimates, and (2) the thicknesses and lithologies of the layers for which the estimates were obtained. The latter factor is the result of a lack of detailed knowledge of the lithology of the screened intervals of the wells or the entire test area. However, as stated earlier, the estimated values probably are representative of layers of larger than average hydraulic conductivity less than about 10 ft thick.

SUMMARY AND CONCLUSIONS

From about 1946 to 1971 the U.S. Army disposed of trichloroethylene (TCE) and other wastes at its East Gate Disposal Yard near the Logistics Center of Fort Lewis in western Washington. As a result, a plume of TCE dissolved in ground water now extends downgradient (northwest) from the disposal yard. Two pump-and-treat systems, one close to the disposal yard and another near the fort boundary, were put in operation in 1995 to prevent migration of TCE from the disposal yard and from the fort to neighboring areas; however, additional remediation may be necessary. The upper aquifer in the area consists of about 100 ft of a complex distribution of layers and lenses of mostly glacial outwash gravels, outwash sands, and glacial till. The water table at the disposal yard is about 10 ft below land surface. Knowledge of the hydraulic characteristics of these sediments is necessary for use in numerical ground-water flow and transport models that are being used to design and evaluate alternatives for remediation of subsurface contamination at the site.

A tracer test that utilized the pump-and-treat system at the disposal yard was conducted to obtain data for estimating hydraulic conductivities and longitudinal dispersivities in the horizontal and vertical directions. During the test, the outflow from the treatment plant was dosed for three days with potassium bromide before being returned to the aquifer through two horizontal 100-ft-long recharge galleries and a well screened from about 80 to 110 ft below land surface. Vertical profiles of specific electrical conductance over the screened intervals of 16 observation wells were monitored for about 6 weeks, and a few samples were collected from most wells for determinations of specific conductance and bromide concentration. Mean arrival time and longitudinal spreading of the tracer were computed as the centroid and variance, respectively, of the temporal distribution of vertically averaged excess (observed minus ambient) specific conductance at each observation well. Differences between centroids, variances, and water levels at pairs of locations were used to estimate hydraulic conductivities and longitudinal dispersivities of the subsurface material between the wells.

Observed specific conductances, bromide concentrations, and water levels in the observation wells indicate that the general flow direction at the study site is to the northwest, which is consistent with the flow direction for the entire Logistics Center. However, flow patterns at the scale of the test site (tens to hundreds of feet) are complex and probably are controlled by the local distribution of fine- and coarse-grained units and the locations and rates of pumping and recharge to the ground-water system. Because of this complexity, the design of remediation schemes and the interpretation of observed distributions of contaminant concentrations in ground water should be done with caution.

Analyses of data from five pairs of horizontally-separated locations near the water table provided estimates of horizontal hydraulic conductivity that were between 69 and 3,100 ft/day. Data from two wells screened from about 70 to 100 ft below the water table yielded values of 2,300 and 3,800 ft/day. The largest estimated hydraulic conductivities are larger than those obtained for the East Gate area by other investigators from calibration of a numerical ground-water flow model (80 to 260 ft/day) and from aquifer tests (16 to 330 ft/day), probably because the largest values from the tracer test are representative of thin (probably less than 10 ft) lenses or layers of highly conductive material, while the values from the earlier investigations are averages of the entire thickness, or a large fraction of the 100-ft thickness, of the aquifer.

Analyses of data from four pairs of vertically separated locations yielded estimates of vertical hydraulic conductivity between 8 and 590 ft/day for the subsurface sediments less than about 30 ft below the water table. The ratio of horizontal to vertical hydraulic conductivity was of the order of 10 or 100.

Estimated values of longitudinal dispersivity ranged from 6.8 to 28 ft in the horizontal direction and 1.8 to 12 ft in the vertical direction. The values in the horizontal direction are probably representative of the flow through thin layers or lenses of highly permeable units and are probably less than would be representative of flow through the entire thickness of the aquifer.

The above hydraulic conductivities and dispersivities were estimated using equations based on the assumption of rectilinear or radial ground-water flow between observation locations. Although the flow pattern at the test site was found to be complex, the assumptions are believed to be sufficiently valid at the scales of the distances between pairs of observation locations to yield reasonable estimates. However, because deviations from the assumptions can introduce errors of unknown magnitude, the estimated values should be used with caution.

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APPENDIX

Supplemental Information

Table A1. Summary of specific electrical conductance and temperature data

[--, indicates no data]

Date	Time	Specific electrical conductance (microsiemens per centimeter) Vertical profile Minimum	Mean	Maximum	Sample	Temperature (degrees Celsius) Vertical profile Minimum	Mean	Maximum	Sample
				Well A15					
02-26-1998	0822	129	129	130	--	9.7	9.7	9.7	--
02-26-1998	0907	--	--	--	133	--	--	--	9.5
03-03-1998	0950	141	144	147	--	9.3	9.6	9.7	--
03-03-1998	1200	141	142	146	--	9.5	9.6	9.7	--
03-03-1998	1758	138	140	145	--	9.4	9.6	9.7	--
03-04-1998	0638	166	167	170	--	9.5	9.7	9.7	--
03-04-1998	0925	--	--	--	174	--	--	--	8.9
03-04-1998	1545	180	182	186	--	9.5	9.7	9.7	--
03-05-1998	0712	185	186	189	--	9.6	9.6	9.7	--
03-05-1998	1306	186	187	189	--	9.5	9.7	9.7	--
03-05-1998	1436	--	--	--	186	--	--	--	9.6
03-06-1998	0806	188	190	192	--	9.2	9.6	9.7	--
03-06-1998	1148	188	190	194	--	9.7	9.7	9.8	--
03-06-1998	1251	189	190	193	--	9.5	9.6	9.7	--
03-06-1998	1346	189	190	192	--	9.6	9.7	9.7	--
03-06-1998	1438	190	191	194	--	9.7	9.7	9.8	--
03-06-1998	1546	189	190	194	--	9.5	9.7	9.7	--
03-06-1998	1714	189	190	194	--	9.5	9.7	9.8	--
03-07-1998	0822	159	161	167	--	9.3	9.6	9.6	--
03-07-1998	0923	--	--	--	156	--	--	--	9.5
03-07-1998	1716	145	146	153	--	9.5	9.7	9.7	--
03-08-1998	1010	135	136	142	--	9.6	9.7	9.7	--
03-09-1998	0845	132	135	145	--	9.6	9.7	9.7	--
03-10-1998	0755	146	149	159	--	9.3	9.5	9.6	--
03-11-1998	0847	141	143	152	--	9.7	9.7	9.7	--
03-11-1998	0940	--	--	--	140	--	--	--	10.1
03-13-1998	1453	131	134	137	--	9.8	9.9	10.0	--
03-16-1998	0812	132	133	139	--	9.6	9.8	9.9	--
03-18-1998	1046	132	134	139	--	9.9	9.9	10.0	--
03-20-1998	0822	132	133	138	--	9.6	9.8	9.9	--
03-23-1998	1008	146	148	158	--	10.0	10.0	10.0	--
03-26-1998	1124	136	138	144	--	9.9	10.0	10.1	--
03-30-1998	1337	133	133	137	--	10.0	10.1	10.1	--
04-02-1998	0838	133	135	139	--	9.6	9.8	9.9	--
04-14-1998	0846	131	132	139	--	9.4	9.8	10.0	--

Table A1. Summary of specific electrical conductance and temperature data—Continued

		Specific electrical conductance (microsiemens per centimeter)				Temperature (degrees Celsius)			
		Vertical profile				Vertical profile			
Date	Time	Minimum	Mean	Maximum	Sample	Minimum	Mean	Maximum	Sample
				Well A30					
02-26-1998	0847	114	114	115	--	10.1	10.2	10.2	--
02-26-1998	0925	--	--	--	117	--	--	--	10.0
03-03-1998	0954	116	116	118	--	9.9	10.1	10.2	--
03-03-1998	1802	116	116	118	--	10.0	10.2	10.2	--
03-04-1998	0640	116	117	132	--	10.1	10.2	10.2	--
03-04-1998	0937	--	--	--	121	--	--	--	9.1
03-04-1998	1546	116	116	119	--	10.1	10.2	10.3	--
03-05-1998	0715	116	116	118	--	10.0	10.2	10.2	--
03-05-1998	1309	114	115	118	--	10.0	10.2	10.3	--
03-06-1998	0808	114	115	118	--	10.0	10.2	10.2	--
03-07-1998	0828	114	115	119	--	10.0	10.2	10.3	--
03-07-1998	1720	115	115	119	--	10.1	10.2	10.2	--
03-08-1998	1012	114	116	118	--	10.1	10.2	10.2	--
03-09-1998	0846	115	116	117	--	10.1	10.2	10.2	--
03-10-1998	0758	115	116	118	--	10.0	10.2	10.2	--
03-11-1998	0850	116	116	118	--	10.1	10.3	10.3	--
03-13-1998	1456	118	119	119	--	10.2	10.2	10.3	--
03-16-1998	0814	118	119	120	--	10.1	10.2	10.2	--
03-18-1998	1048	118	119	120	--	10.1	10.2	10.3	--
03-20-1998	0828	118	118	119	--	10.1	10.2	10.3	--
03-23-1998	1010	119	120	121	--	10.1	10.2	10.3	--
03-26-1998	1126	119	120	121	--	10.1	10.2	10.3	--
03-30-1998	1341	118	119	119	--	10.2	10.2	10.3	--
04-02-1998	0840	118	119	120	--	10.1	10.2	10.2	--
04-14-1998	0848	116	116	118	--	10.1	10.2	10.2	--
				Well A45					
02-26-1998	0840	115	117	120	--	10.1	10.1	10.1	--
02-26-1998	0944	--	--	--	117	--	--	--	10.2
03-03-1998	0958	115	117	121	--	10.1	10.2	10.2	--
03-03-1998	1804	116	117	121	--	10.2	10.2	10.2	--
03-04-1998	0642	116	117	120	--	10.2	10.2	10.2	--
03-04-1998	1548	116	117	119	--	10.2	10.2	10.2	--
03-05-1998	0716	116	117	120	--	10.2	10.2	10.2	--
03-05-1998	1312	115	116	117	--	10.1	10.2	10.2	--
03-06-1998	0810	115	116	117	--	10.2	10.2	10.2	--
03-07-1998	0830	114	116	117	--	10.2	10.2	10.2	--
03-08-1998	1014	114	116	119	--	10.2	10.2	10.2	--
03-09-1998	0848	114	116	117	--	10.2	10.2	10.2	--
03-10-1998	0800	114	117	123	--	10.2	10.2	10.2	--

Table A1. Summary of specific electrical conductance and temperature data—Continued

Date	Time	Specific electrical conductance (microsiemens per centimeter) Vertical profile Minimum	Mean	Maximum	Sample	Temperature (degrees Celsius) Vertical profile Minimum	Mean	Maximum	Sample
				Well A45--Continued					
03-11-1998	0856	114	117	120	--	10.2	10.2	10.2	--
03-13-1998	1500	116	120	124	--	10.2	10.3	10.3	--
03-16-1998	0815	115	119	120	--	10.1	10.2	10.2	--
03-18-1998	1051	116	119	123	--	10.2	10.2	10.2	--
03-20-1998	0833	116	119	120	--	10.1	10.2	10.2	--
03-23-1998	1012	117	120	124	--	10.2	10.2	10.2	--
03-26-1998	1127	117	120	121	--	10.2	10.2	10.3	--
03-30-1998	1345	117	122	131	--	10.2	10.2	10.2	--
04-02-1998	0842	117	121	121	--	10.2	10.2	10.2	--
04-14-1998	0851	115	117	119	--	10.1	10.2	10.2	--
				Well B15					
02-26-1998	1015	--	--	--	128	--	--	--	9.8
03-03-1998	1053	122	124	125	--	9.8	10.0	10.1	--
03-03-1998	1806	123	124	126	--	9.9	10.0	10.1	--
03-04-1998	0645	122	124	125	--	10.0	10.0	10.1	--
03-04-1998	1551	126	134	143	--	10.0	10.0	10.1	--
03-04-1998	1736	--	--	--	145	--	--	--	9.8
03-05-1998	0722	136	144	148	--	10.0	10.0	10.1	--
03-05-1998	1314	139	148	158	--	9.9	10.0	10.1	--
03-05-1998	1449	--	--	--	161	--	--	--	9.9
03-06-1998	0812	146	155	169	--	9.8	10.0	10.1	--
03-06-1998	1150	147	153	160	--	9.9	10.0	10.1	--
03-06-1998	1255	148	156	167	--	9.9	10.0	10.1	--
03-06-1998	1351	146	156	166	--	10.0	10.0	10.1	--
03-06-1998	1440	146	157	163	--	9.8	9.9	10.0	--
03-06-1998	1551	149	152	158	--	10.0	10.1	10.1	--
03-06-1998	1717	148	154	163	--	9.8	10.0	10.1	--
03-07-1998	0835	153	157	162	--	9.8	9.9	10.0	--
03-07-1998	0908	--	--	--	164	--	--	--	9.8
03-07-1998	1721	151	151	152	--	10.0	10.0	10.1	--
03-08-1998	1017	141	143	146	--	9.9	10.0	10.1	--
03-09-1998	0850	136	138	140	--	9.9	10.0	10.0	--
03-10-1998	0802	134	135	136	--	9.8	9.9	10.0	--
03-11-1998	1021	128	129	130	--	10.0	10.1	10.1	--
03-13-1998	1505	125	125	125	--	10.2	10.2	10.3	--
03-16-1998	0818	122	123	123	--	9.8	10.0	10.0	--
03-18-1998	1054	122	123	123	--	10.1	10.1	10.1	--
03-20-1998	0838	122	122	122	--	9.9	10.0	10.1	--
03-23-1998	0938	123	124	125	--	10.0	10.1	10.1	--

Table A1. Summary of specific electrical conductance and temperature data—Continued

Date	Time	Specific electrical conductance (microsiemens per centimeter) Vertical profile Minimum	Mean	Maximum	Sample	Temperature (degrees Celsius) Vertical profile Minimum	Mean	Maximum	Sample
				Well B15--Continued					
03-26-1998	1130	124	124	125	--	10.1	10.1	10.1	--
03-30-1998	1349	122	122	123	--	10.1	10.1	10.2	--
04-02-1998	0844	122	122	123	--	10.0	10.1	10.1	--
04-14-1998	0852	121	122	123	--	9.8	10.0	10.1	--
				Well C25					
02-26-1998	1031	126	176	314	--	8.3	9.4	9.9	--
02-26-1998	1145	--	--	--	150	--	--	--	9.7
03-03-1998	1100	131	272	432	--	8.0	9.1	9.9	--
03-03-1998	1809	143	272	455	--	8.1	9.1	9.8	--
03-04-1998	0647	148	287	469	--	8.0	9.1	9.8	--
03-04-1998	1555	142	259	432	--	8.2	9.1	9.8	--
03-05-1998	0725	144	253	416	--	8.0	9.1	9.8	--
03-05-1998	1317	147	249	411	--	8.3	9.2	9.8	--
03-06-1998	0816	149	232	408	--	8.2	9.1	9.8	--
03-07-1998	0838	151	226	367	--	8.1	9.1	9.8	--
03-07-1998	1723	149	265	400	--	8.2	9.2	9.8	--
03-08-1998	1018	155	243	408	--	8.3	9.2	9.8	--
03-08-1998	1115	--	--	--	167	--	--	--	9.9
03-09-1998	0854	160	273	452	--	8.0	9.0	9.8	--
03-10-1998	0805	161	291	490	--	7.9	9.0	9.8	--
03-11-1998	1005	169	309	476	--	8.1	9.2	9.8	--
03-13-1998	1512	192	375	513	--	8.3	9.1	9.7	--
03-16-1998	0821	144	254	358	--	8.2	9.2	9.8	--
03-16-1998	1020	--	--	--	143	--	--	--	9.8
03-18-1998	1058	133	230	394	--	8.3	9.2	9.9	--
03-20-1998	0844	130	194	317	--	8.3	9.4	9.9	--
03-23-1998	0938	152	247	406	--	8.3	9.2	9.8	--
03-26-1998	1132	136	190	313	--	8.6	9.4	9.8	--
03-30-1998	1353	133	188	303	--	8.7	9.4	9.9	--
04-02-1998	0846	128	177	305	--	8.6	9.4	9.9	--
04-14-1998	0855	123	144	182	--	9.0	9.6	9.9	--
				Well C40					
02-26-1998	1038	136	138	143	--	9.9	10.0	10.0	--
02-26-1998	1140	--	--	--	143	--	--	--	9.8
03-03-1998	1106	136	137	142	--	8.0	9.8	10.0	--
03-03-1998	1812	135	135	137	--	9.8	9.9	10.0	--
03-04-1998	0649	134	135	137	--	9.7	9.9	10.0	--

Table A1. Summary of specific electrical conductance and temperature data—Continued

		Specific electrical conductance (microsiemens per centimeter)				Temperature (degrees Celsius)			
		Vertical profile				Vertical profile			
Date	Time	Minimum	Mean	Maximum	Sample	Minimum	Mean	Maximum	Sample
				Well C40--Continued					
03-04-1998	1556	135	135	137	--	9.7	9.9	10.0	--
03-05-1998	0727	134	135	137	--	9.6	9.9	10.0	--
03-05-1998	1320	134	134	136	--	9.7	9.9	10.0	--
03-06-1998	0818	134	134	136	--	9.7	9.9	10.0	--
03-07-1998	0841	133	134	135	--	9.8	9.9	10.0	--
03-07-1998	1725	134	134	134	--	9.7	9.9	10.0	--
03-08-1998	1020	135	136	138	--	9.8	9.9	10.0	--
03-09-1998	0858	139	141	143	--	9.7	9.9	10.0	--
03-10-1998	0808	138	140	142	--	9.7	9.9	10.0	--
03-10-1998	0908	--	--	--	150	--	--	--	9.8
03-11-1998	1010	138	140	142	--	9.8	9.9	10.0	--
03-13-1998	1518	137	144	151	--	9.9	10.0	10.0	
03-16-1998	0824	138	139	140	--	9.6	9.9	10.0	--
03-18-1998	1103	140	140	141	--	9.8	9.9	10.0	--
03-20-1998	0948	138	139	139	--	9.8	9.9	10.0	--
03-23-1998	0936	138	139	141	--	9.7	9.9	10.0	--
03-26-1998	1134	137	139	141	--	9.7	9.9	10.0	--
03-30-1998	1359	136	137	139	--	9.7	9.9	10.0	--
04-02-1998	0849	134	137	139	--	9.6	9.9	10.0	--
04-14-1998	0858	130	134	137	--	9.8	9.9	10.0	--
				Well 9					
02-26-1998	1543	123	124	124	--	10.1	10.1	10.1	--
02-26-1998	1629	--	--	--	122	--	--	--	10.1
03-03-1998	0927	123	123	123	--	9.9	10.1	10.1	--
03-03-1998	1155	121	130	144	--	9.9	10.1	10.1	--
03-03-1998	1737	153	171	178	--	10.0	10.1	10.2	--
03-04-1998	0655	144	176	181	--	10.0	10.1	10.1	--
03-04-1998	1000	--	--	--	178	--	--	--	9.4
03-04-1998	1525	171	181	183	--	10.0	10.1	10.1	--
03-05-1998	0652	179	182	185	--	9.9	10.0	10.1	--
03-05-1998	1245	171	182	186	--	10.0	10.1	10.1	--
03-06-1998	0744	163	184	188	--	10.0	10.1	10.1	--
03-06-1998	1141	173	184	187	--	9.9	10.0	10.1	--
03-06-1998	1240	169	170	172	--	10.0	10.1	10.1	--
03-06-1998	1336	150	155	158	--	10.0	10.1	10.1	--
03-06-1998	1433	141	148	150	--	10.0	10.1	10.1	--
03-06-1998	1537	137	143	145	--	10.0	10.1	10.1	--
03-06-1998	1705	132	138	140	--	10.0	10.1	10.1	--
03-07-1998	0749	126	127	128	--	9.8	10.0	10.1	--

Table A1. Summary of specific electrical conductance and temperature data—Continued

		Specific electrical conductance (microsiemens per centimeter)				Temperature (degrees Celsius)			
		Vertical profile				Vertical profile			
Date	Time	Minimum	Mean	Maximum	Sample	Minimum	Mean	Maximum	Sample
				Well 9--Continued					
03-07-1998	1701	125	126	127	--	10.1	10.1	10.1	--
03-08-1998	0950	124	125	125	--	10.0	10.1	10.1	--
03-09-1998	0811	124	124	124	--	10.0	10.1	10.1	--
03-10-1998	0732	123	123	124	--	10.1	10.2	10.2	--
03-11-1998	0804	123	123	124	--	10.1	10.2	10.2	--
03-13-1998	1412	124	124	125	--	10.3	10.3	10.5	--
03-16-1998	0748	125	125	125	--	10.1	10.2	10.2	--
03-18-1998	0959	125	125	126	--	10.1	10.2	10.2	--
03-20-1998	0748	126	126	127	--	9.9	10.1	10.2	--
03-23-1998	0952	125	126	126	--	10.2	10.3	10.3	--
03-26-1998	1039	125	125	125	--	10.1	10.2	10.2	--
03-30-1998	1308	123	123	124	--	10.0	10.2	10.2	--
04-02-1998	0816	125	125	126	--	9.8	10.1	10.1	--
04-14-1998	0822	122	122	123	--	10.0	10.1	10.1	--
				Well LC-145					
02-26-1998	1343	110	112	112	--	10.2	10.2	10.2	--
02-26-1998	1403	--	--	--	112	--	--	--	10.2
03-03-1998	0916	109	112	114	--	9.9	10.1	10.2	--
03-03-1998	1148	112	112	112	--	10.0	10.1	10.2	--
03-03-1998	1732	112	112	112	--	10.1	10.2	10.2	--
03-04-1998	0635	112	112	112	--	10.1	10.2	10.2	--
03-04-1998	1518	113	113	113	--	10.2	10.2	10.3	--
03-05-1998	0646	112	112	113	--	10.1	10.1	10.2	--
03-05-1998	1239	109	111	112	--	10.2	10.3	10.4	--
03-06-1998	0736	108	110	112	--	9.8	10.1	10.2	--
03-07-1998	0742	110	111	111	--	10.0	10.2	10.2	--
03-07-1998	1655	111	112	112	--	10.2	10.2	10.2	--
03-08-1998	0945	112	112	112	--	10.2	10.2	10.2	--
03-08-1998	1057	--	--	--	112	--	--	--	10.2
03-09-1998	0800	113	114	114	--	10.2	10.2	10.3	--
03-10-1998	0725	113	115	116	--	10.2	10.2	10.2	--
03-11-1998	0750	113	117	118	--	10.2	10.2	10.3	--
03-13-1998	1400	117	121	122	--	10.2	10.3	10.4	--
03-16-1998	0741	122	123	124	--	10.1	10.2	10.2	--
03-18-1998	0950	122	122	122	--	10.1	10.2	10.2	--
03-18-1998	1135	--	--	--	121	--	--	--	10.5
03-20-1998	0736	122	122	122	--	10.0	10.1	10.2	--
03-23-1998	0946	120	120	121	--	10.2	10.2	10.2	--
03-26-1998	1030	117	118	119	--	10.1	10.2	10.2	--

Table A1. Summary of specific electrical conductance and temperature data—Continued

Date	Time	Specific electrical conductance (microsiemens per centimeter) Vertical profile Minimum	Mean	Maximum	Sample	Temperature (degrees Celsius) Vertical profile Minimum	Mean	Maximum	Sample
				Well LC-145--Continued					
03-30-1998	1256	115	116	118	--	10.1	10.2	10.2	--
04-02-1998	0812	116	116	116	--	10.0	10.2	10.2	--
04-14-1998	0818	111	113	113	--	10.0	10.1	10.1	--
				Well LC-146					
02-26-1998	1349	120	121	122	--	10.1	10.1	10.1	--
02-26-1998	1425	--	--	--	122	--	--	--	10.1
03-03-1998	0923	122	122	124	--	9.9	10.1	10.1	--
03-03-1998	1151	122	123	124	--	10.0	10.2	10.2	--
03-03-1998	1735	134	140	141	--	10.1	10.2	10.2	--
03-04-1998	0654	149	165	167	--	9.8	10.1	10.1	--
03-04-1998	1013	--	--	--	167	--	--	--	9.5
03-04-1998	1521	166	170	171	--	10.1	10.2	10.2	--
03-04-1998	1710	--	--	--	168	--	--	--	10.1
03-05-1998	0650	173	174	174	--	10.0	10.1	10.1	--
03-05-1998	1242	171	173	173	--	10.1	10.2	10.2	--
03-06-1998	0740	172	175	177	--	10.0	10.2	10.2	--
03-06-1998	1138	174	177	178	--	10.1	10.2	10.2	--
03-06-1998	1235	176	177	178	--	10.2	10.2	10.3	--
03-06-1998	1330	173	177	178	--	9.9	10.1	10.2	--
03-06-1998	1430	169	175	176	--	10.2	10.2	10.3	--
03-06-1998	1533	170	171	172	--	10.1	10.2	10.2	--
03-06-1998	1700	163	165	166	--	10.0	10.1	10.1	--
03-07-1998	0748	133	133	135	--	10.1	10.2	10.2	--
03-07-1998	1659	130	130	131	--	10.1	10.2	10.2	--
03-08-1998	0948	126	126	127	--	10.2	10.2	10.2	--
03-09-1998	0806	125	125	126	--	10.1	10.2	10.2	--
03-10-1998	0728	123	124	125	--	10.1	10.1	10.2	--
03-11-1998	0758	123	124	125	--	10.2	10.2	10.2	--
03-13-1998	1406	123	124	125	--	10.2	10.2	10.3	--
03-16-1998	0745	123	124	125	--	9.9	10.1	10.1	--
03-18-1998	0955	124	125	125	--	10.0	10.1	10.2	--
03-20-1998	0740	125	126	126	--	10.0	10.2	10.2	--
03-23-1998	0950	125	126	127	--	10.2	10.2	10.2	--
03-26-1998	1036	124	125	126	--	10.1	10.1	10.2	--
03-30-1998	1302	122	123	125	--	10.1	10.2	10.2	--
04-02-1998	0814	123	124	125	--	10.1	10.2	10.2	--
04-14-1998	0821	121	122	123	--	10.0	10.1	10.1	--

Table A1. Summary of specific electrical conductance and temperature data—Continued

Date	Time	Specific electrical conductance (microsiemens per centimeter)				Temperature (degrees Celsius)			
		Vertical profile				Vertical profile			
		Minimum	Mean	Maximum	Sample	Minimum	Mean	Maximum	Sample
				Well LC-147					
02-26-1998	1355	106	106	106	--	10.2	10.2	10.2	--
02-26-1998	1440	--	--	--	106	--	--	--	10.3
03-03-1998	0933	105	106	106	--	10.0	10.2	10.2	--
03-03-1998	1740	106	106	106	--	10.2	10.2	10.3	--
03-04-1998	0658	106	106	106	--	10.1	10.2	10.2	--
03-04-1998	1528	106	106	106	--	10.2	10.2	10.2	--
03-05-1998	0655	106	106	106	--	10.0	10.2	10.2	--
03-05-1998	1247	106	107	107	--	10.2	10.2	10.2	--
03-05-1998	1248	103	105	105	--	10.2	10.2	10.2	--
03-06-1998	0746	104	104	105	--	10.1	10.2	10.2	--
03-07-1998	0752	104	104	105	--	10.2	10.2	10.3	--
03-07-1998	1704	104	105	106	--	10.2	10.2	10.2	--
03-08-1998	0952	105	106	106	--	10.2	10.2	10.2	--
03-09-1998	0814	106	106	107	--	10.2	10.2	10.3	--
03-10-1998	0734	105	107	108	--	10.1	10.2	10.2	--
03-11-1998	0810	107	108	108	--	10.2	10.3	10.3	--
03-13-1998	1418	108	109	109	--	10.2	10.3	10.3	--
03-16-1998	0750	108	109	111	--	10.0	10.2	10.2	--
03-18-1998	1003	108	109	109	--	10.2	10.2	10.2	--
03-18-1998	1156	--	--	--	110	--	--	--	10.7
03-20-1998	0752	109	109	109	--	10.0	10.2	10.2	--
03-23-1998	0954	109	110	111	--	10.2	10.3	10.3	--
03-26-1998	1044	108	109	110	--	10.1	10.2	10.2	--
03-30-1998	1248	106	108	109	--	10.2	10.2	10.3	--
04-02-1998	0820	107	108	109	--	10.1	10.1	10.2	--
04-14-1998	0827	103	105	107	--	10.0	10.1	10.2	--
				Well LC-148					
02-26-1998	1301	113	117	119	--	10.1	10.2	10.2	--
02-26-1998	1456	--	--	--	117	--	--	--	10.1
03-03-1998	0945	116	119	119	--	10.0	10.1	10.2	--
03-03-1998	1755	117	119	119	--	10.1	10.2	10.2	--
03-04-1998	0704	108	122	126	--	10.0	10.1	10.2	--
03-04-1998	1534	119	128	132	--	10.1	10.2	10.2	--
03-04-1998	1715	--	--	--	132	--	--	--	10.1
03-05-1998	0702	133	138	146	--	10.0	10.1	10.2	--
03-05-1998	1255	131	143	150	--	10.1	10.2	10.2	--
03-05-1998	1423	--	--	--	134	--	--	--	10.3
03-06-1998	0750	138	148	154	--	10.0	10.2	10.2	--

Table A1. Summary of specific electrical conductance and temperature data—Continued

Date	Time	Specific electrical conductance (microsiemens per centimeter) Vertical profile Minimum	Mean	Maximum	Sample	Temperature (degrees Celsius) Vertical profile Minimum	Mean	Maximum	Sample
				Well LC-148—Continued					
03-06-1998	0920	--	--	--	140	--	--	--	10.0
03-06-1998	1144	140	148	161	--	10.0	10.1	10.1	--
03-06-1998	1245	141	150	160	--	10.1	10.2	10.2	--
03-06-1998	1342	143	154	161	--	10.1	10.2	10.2	--
03-06-1998	1436	150	155	163	--	10.1	10.2	10.2	--
03-06-1998	1543	143	156	165	--	10.1	10.2	10.3	--
03-06-1998	1708	144	157	164	--	10.1	10.2	10.2	--
03-07-1998	0802	138	143	148	--	10.1	10.2	10.2	--
03-07-1998	1710	133	137	140	--	10.2	10.2	10.2	--
03-08-1998	0958	127	130	131	--	10.1	10.2	10.2	--
03-09-1998	0828	118	123	127	--	10.1	10.2	10.2	--
03-10-1998	0742	122	123	130	--	10.1	10.2	10.2	--
03-11-1998	0822	121	122	124	--	10.1	10.2	10.2	--
03-13-1998	1332	116	119	123	--	10.2	10.3	10.3	--
03-16-1998	0758	122	122	123	--	10.1	10.1	10.2	--
03-18-1998	1027	121	122	122	--	10.1	10.2	10.2	--
03-20-1998	0802	121	122	123	--	10.0	10.1	10.2	--
03-23-1998	0958	120	123	124	--	10.2	10.2	10.2	--
03-26-1998	1114	118	122	123	--	10.1	10.2	10.2	--
03-30-1998	1320	119	122	122	--	10.1	10.2	10.2	--
04-02-1998	0826	116	121	122	--	10.0	10.1	10.1	--
04-14-1998	0832	113	116	118	--	10.0	10.1	10.1	--
				Well LC-149A					
02-25-1998	1625	--	--	--	105	--	--	--	9.6
03-26-1998	0955	99	100	100	--	9.5	9.5	9.5	--
				Well LC-149C					
02-25-1998	1612	112	114	116	--	9.3	9.3	9.4	--
02-25-1998	1659	--	--	--	116	--	--	--	9.4
03-26-1998	0959	116	119	121	--	9.4	9.5	9.5	--
				Well LC-149D					
02-25-1998	1640	--	--	--	112	--	--	--	9.2
03-26-1998	1002	113	114	115	--	9.4	9.4	9.5	--

Table A1. Summary of specific electrical conductance and temperature data—Continued

Date	Time	Specific electrical conductance (microsiemens per centimeter)				Temperature (degrees Celsius)			
		Vertical profile				Vertical profile			
		Minimum	Mean	Maximum	Sample	Minimum	Mean	Maximum	Sample
				Well LC-161					
02-27-1998	1507	133	133	133	--	9.9	9.9	9.9	--
02-27-1998	1552	--	--	--	128	--	--	--	10.6
03-03-1998	1718	132	133	134	--	9.7	9.9	9.9	--
03-04-1998	1032	132	133	135	--	9.7	9.9	10.0	--
03-05-1998	0736	133	134	151	--	9.6	9.8	10.0	--
03-06-1998	0851	132	132	135	--	9.9	10.0	10.1	--
03-07-1998	0723	131	132	135	--	9.6	9.9	9.9	--
03-08-1998	0928	131	132	132	--	9.9	9.9	9.9	--
03-09-1998	0744	132	132	134	--	9.8	9.9	9.9	--
03-10-1998	0702	132	137	173	--	9.8	9.9	10.0	--
03-10-1998	0848	--	--	--	132	--	--	--	9.9
03-11-1998	0729	132	132	134	--	9.8	9.8	9.9	--
03-13-1998	1341	132	133	136	--	9.8	9.8	10.3	--
03-16-1998	0725	133	134	138	--	9.7	9.7	9.9	--
03-18-1998	0936	133	134	137	--	9.8	9.9	9.9	--
03-20-1998	0718	134	134	136	--	9.4	9.7	9.8	--
03-23-1998	0924	136	136	137	--	9.8	9.8	9.9	--
03-26-1998	0927	133	134	136	--	9.8	9.8	9.8	--
03-30-1998	1532	134	135	137	--	9.8	9.8	10.0	--
04-02-1998	0758	133	134	135	--	9.6	9.7	9.7	--
04-06-1998	1636	132	136	140	--	9.8	9.9	10.1	--
04-09-1998	0758	131	136	147	--	9.6	9.8	9.8	
04-14-1998	0804	128	130	132	--	9.1	9.4	9.5	--
				Well LC-162					
02-27-1998	1520	228	228	229	--	9.7	9.8	9.9	--
02-27-1998	1625	--	--	--	239	--	--	--	10.1
03-03-1998	1723	225	226	227	--	9.6	9.8	9.9	--
03-04-1998	1035	224	225	226	--	9.7	9.9	10.0	--
03-05-1998	0740	222	225	226	--	9.6	9.8	9.9	--
03-06-1998	0855	222	224	227	--	9.6	9.8	9.9	--
03-07-1998	0729	221	223	225	--	9.5	9.8	9.9	--
03-08-1998	0932	221	223	224	--	9.8	9.9	10.0	--
03-09-1998	0749	222	223	225	--	9.7	9.8	9.9	--
03-10-1998	0715	220	222	225	--	10.0	10.0	10.2	--
03-11-1998	0737	223	224	224	--	9.7	9.8	10.0	--
03-13-1998	1347	224	226	227	--	9.8	9.8	9.9	--
03-16-1998	0728	226	227	230	--	9.4	9.6	9.8	--
03-18-1998	0941	225	227	230	--	9.8	9.8	9.9	--
03-20-1998	0725	230	232	234	--	9.4	9.7	9.8	--

Table A1. Summary of specific electrical conductance and temperature data—Continued

		Specific electrical conductance (microsiemens per centimeter)				Temperature (degrees Celsius)			
		Vertical profile				Vertical profile			
Date	Time	Minimum	Mean	Maximum	Sample	Minimum	Mean	Maximum	Sample
				Well LC-162					
03-23-1998	0928	226	228	230	--	9.7	9.8	9.9	--
03-26-1998	0943	226	227	228	--	9.6	9.7	9.8	--
03-30-1998	1538	226	227	228	--	9.7	9.8	9.9	--
04-02-1998	0802	225	227	229	--	9.4	9.6	9.8	--
04-06-1998	1641	222	231	234	--	9.9	9.9	9.9	--
04-09-1998	0806	225	232	235	--	9.4	9.7	9.9	--
04-14-1998	0808	219	221	224	--	9.3	9.5	9.6	--
				Well LC-26					
02-26-1998	1355	109	109	110	--	9.9	10.0	10.0	--
02-26-1998	1437	--	--	--	111	--	--	--	10.0
03-03-1998	1118	109	111	113	--	9.6	9.9	10.0	--
03-03-1998	1746	109	111	113	--	9.8	9.9	10.0	--
03-04-1998	0708	108	111	112	--	9.5	9.9	10.0	--
03-04-1998	1528	110	111	113	--	9.8	9.9	10.0	--
03-05-1998	0706	110	112	113	--	9.6	9.9	10.0	--
03-05-1998	1259	109	110	113	--	9.8	9.9	10.1	--
03-06-1998	0800	109	112	115	--	9.6	9.9	10.0	--
03-07-1998	0807	111	115	120	--	9.6	9.9	10.0	--
03-07-1998	1714	112	116	123	--	9.7	9.9	10.1	--
03-08-1998	1004	112	118	126	--	9.8	9.9	10.0	--
03-09-1998	0834	112	117	126	--	9.7	9.9	10.1	
03-09-1998	0923	--	--	--	110	--	--	--	10.1
03-10-1998	0747	113	119	126	--	9.7	9.9	10.0	--
03-11-1998	0830	112	117	123	--	9.9	10.0	10.1	--
03-13-1998	1440	107	115	122	--	10.0	10.0	10.1	--
03-16-1998	0802	112	116	120	--	9.6	9.9	10.0	--
03-18-1998	1032	111	114	118	--	9.8	9.9	10.0	--
03-20-1998	0809	112	115	118	--	9.6	9.9	10.0	--
03-23-1998	1003	113	115	118	--	9.9	10.0	10.0	--
03-26-1998	1117	113	116	118	--	9.9	10.0	10.0	--
03-30-1998	1326	111	113	116	--	9.9	10.0	10.1	--
04-02-1998	0830	112	114	116	--	9.8	10.0	10.0	--
04-14-1998	0836	109	112	113	--	9.6	9.9	10.0	--
				Well LC-26D					
02-27-1998	1405	136	137	138	--	10.1	10.1	10.1	--
03-03-1998	1125	136	136	136	--	10.1	10.1	10.1	
03-03-1998	1750	134	135	135	--	10.1	10.1	10.2	--
03-04-1998	0712	134	135	135	--	10.1	10.1	10.1	--

Table A1. Summary of specific electrical conductance and temperature data—Continued

Date	Time	Specific electrical conductance (microsiemens per centimeter)				Temperature (degrees Celsius)			
		Vertical profile				Vertical profile			
		Minimum	Mean	Maximum	Sample	Minimum	Mean	Maximum	Sample
				Well LC-26D					
03-04-1998	1540	134	135	135	--	10.1	10.1	10.2	--
03-05-1998	0708	134	135	136	--	10.1	10.1	10.1	--
03-05-1998	1302	134	135	136	--	10.1	10.1	10.2	--
03-06-1998	0804	133	133	134	--	10.1	10.1	10.1	--
03-07-1998	0816	133	134	134	--	10.2	10.2	10.2	--
03-08-1998	1006	133	134	135	--	10.1	10.1	10.2	--
03-09-1998	0840	133	134	134	--	10.1	10.1	10.1	--
03-10-1998	0751	133	134	134	--	10.1	10.1	10.1	--
03-11-1998	0837	133	134	136	--	10.1	10.2	10.2	--
03-13-1998	1446	136	136	137	--	10.1	10.1	10.1	--
03-16-1998	0806	136	137	138	--	10.1	10.1	10.1	--
03-18-1998	1038	137	137	139	--	10.1	10.1	10.2	--
03-20-1998	0814	138	139	140	--	10.1	10.1	10.1	--
03-23-1998	1006	139	140	140	--	10.2	10.2	10.2	--
03-26-1998	1120	139	140	141	--	10.0	10.1	10.2	--
03-30-1998	1332	136	137	137	--	10.1	10.1	10.2	--
04-02-1998	0834	138	138	139	--	10.1	10.1	10.2	--
04-14-1998	0840	133	134	135	--	10.1	10.1	10.1	--
				Well LR-1					
03-03-1998	0910	--	120	--	--	--	10.0	--	--
03-04-1998	0842	--	[1]196	--	--	--	9.2	--	--
03-04-1998	1601	--	[1]203	--	--	--	10.0	--	--
03-05-1998	0635	--	[1]192	--	--	--	9.0	--	--
03-05-1998	1333	--	--	--	[1]203	--	--	--	9.9
03-06-1998	0655	--	[1]200	--	--	--	9.5	--	--
03-07-1998	0738	--	206	--	--	--	9.9	--	--
03-07-1998	1449	--	216	--	--	--	10.2	--	--
03-08-1998	0943	--	192	--	--	--	10.1	--	--
03-09-1998	0758	--	125	--	--	--	10.1	--	--
03-10-1998	0722	--	122	--	--	--	10.1	--	--
03-11-1998	0745	--	125	--	--	--	10.2	--	--
03-13-1998	1355	--	124	--	--	--	10.3	--	--
03-16-1998	0739	--	126	--	--	--	10.0	--	--
03-18-1998	0948	--	127	--	--	--	10.1	--	--
03-20-1998	0733	--	128	--	--	--	9.8	--	--
03-23-1998	0944	--	128	--	--	--	10.3	--	--
03-26-1998	1026	--	128	--	--	--	10.1	--	--
04-02-1998	0809	--	127	--	--	--	9.9	--	--

Table A1. Summary of specific electrical conductance and temperature data—Continued

		Specific electrical conductance (microsiemens per centimeter)				Temperature (degrees Celsius)			
		Vertical profile				Vertical profile			
Date	Time	Minimum	Mean	Maximum	Sample	Minimum	Mean	Maximum	Sample
				Well LR-2					
02-26-1998	1549	104	119	125	--	10.2	10.2	10.2	--
02-26-1998	1657	--	--	--	104	--	--	--	10.3
03-03-1998	0940	104	127	155	--	10.1	10.2	10.2	--
03-03-1998	1753	105	125	148	--	10.2	10.2	10.3	--
03-04-1998	0700	105	124	147	--	10.2	10.2	10.2	--
03-04-1998	1531	111	129	160	--	10.2	10.2	10.3	--
03-05-1998	0658	111	129	147	--	10.2	10.2	10.2	--
03-05-1998	1251	104	128	146	--	10.2	10.2	10.3	--
03-06-1998	0749	104	135	146	--	10.2	10.2	10.2	--
03-06-1998	0751	105	137	146	--	10.2	10.2	10.2	--
03-07-1998	0755	103	143	153	--	10.2	10.2	10.3	--
03-07-1998	0759	104	143	155	--	10.2	10.2	10.3	--
03-07-1998	1000	--	--	--	144	--	--	--	10.1
03-07-1998	1705	141	153	157	--	10.2	10.2	10.3	--
03-08-1998	0956	131	155	158	--	10.2	10.2	10.2	--
03-09-1998	0824	134	158	164	--	10.2	10.3	10.3	--
03-10-1998	0738	126	156	164	--	10.2	10.2	10.2	--
03-11-1998	0815	125	152	162	--	10.2	10.3	10.3	--
03-13-1998	1422	121	143	167	--	10.2	10.2	10.2	--
03-13-1998	1730	123	142	148	--	10.2	10.2	10.4	--
03-16-1998	0754	122	138	158	--	10.1	10.2	10.2	--
03-16-1998	0921	120	135	149	--	10.1	10.2	10.2	--
03-16-1998	0939	--	--	--	136	--	--	--	10.4
03-18-1998	1008	117	136	159	--	10.1	10.2	10.3	--
03-20-1998	0757	115	132	159	--	10.1	10.2	10.2	--
03-23-1998	0956	116	133	161	--	10.2	10.2	10.3	--
03-26-1998	1047	114	132	168	--	10.2	10.2	10.2	--
03-30-1998	1314	112	129	160	--	10.2	10.2	10.2	--
04-02-1998	0824	112	129	162	--	10.2	10.2	10.2	--
04-14-1998	0827	105	124	160	--	10.1	10.2	10.2	--
				East Gate Pump-and-Treat Effluent					
02-25-1998	1505	--	--	--	123	--	--	--	10.8
02-26-1998	0745	--	--	--	141	--	--	--	9.7
02-27-1998	1655	--	--	--	123	--	--	--	--
03-04-1998	0610	--	--	--	135	--	--	--	10.0
03-04-1998	1138	--	--	--	131	--	--	--	12.5
03-06-1998	0835	--	--	--	126	--	--	--	9.6
03-07-1998	0711	--	--	--	124	--	--	--	9.4
03-07-1998	1637	--	--	--	129	--	--	--	10.7

Table A1. Summary of specific electrical conductance and temperature data—Continued

Date	Time	Specific electrical conductance (microsiemens per centimeter)				Temperature (degrees Celsius)			
		Vertical profile				Vertical profile			
		Minimum	Mean	Maximum	Sample	Minimum	Mean	Maximum	Sample
		East Gate Pump-and-Treat Effluent—Continued							
03-08-1998	0919	--	--	--	122	--	--	--	10.5
03-09-1998	0735	--	--	--	125	--	--	--	11.0
03-10-1998	0645	--	--	--	122	--	--	--	10.8
03-11-1998	0717	--	--	--	127	--	--	--	10.8
03-13-1998	1535	--	--	--	124	--	--	--	11.0
03-16-1998	0715	--	--	--	126	--	--	--	10.8
03-18-1998	0927	--	--	--	128	--	--	--	11.1
03-20-1998	0712	--	--	--	126	--	--	--	10.4
03-23-1998	0917	--	--	--	126	--	--	--	10.9
03-26-1998	0928	--	--	--	128	--	--	--	10.3
04-02-1998	0740	--	--	--	126	--	--	--	10.8
04-06-1998	1618	--	--	--	129	--	--	--	11.2
04-09-1998	0746	--	--	--	121	--	--	--	11.2
04-14-1998	0758	--	--	--	119	--	--	--	10.6
04-14-1998	1006	--	--	--	123	--	--	--	10.7

[1]Dosing with sodium chloride temporarily stopped for collection of sample.

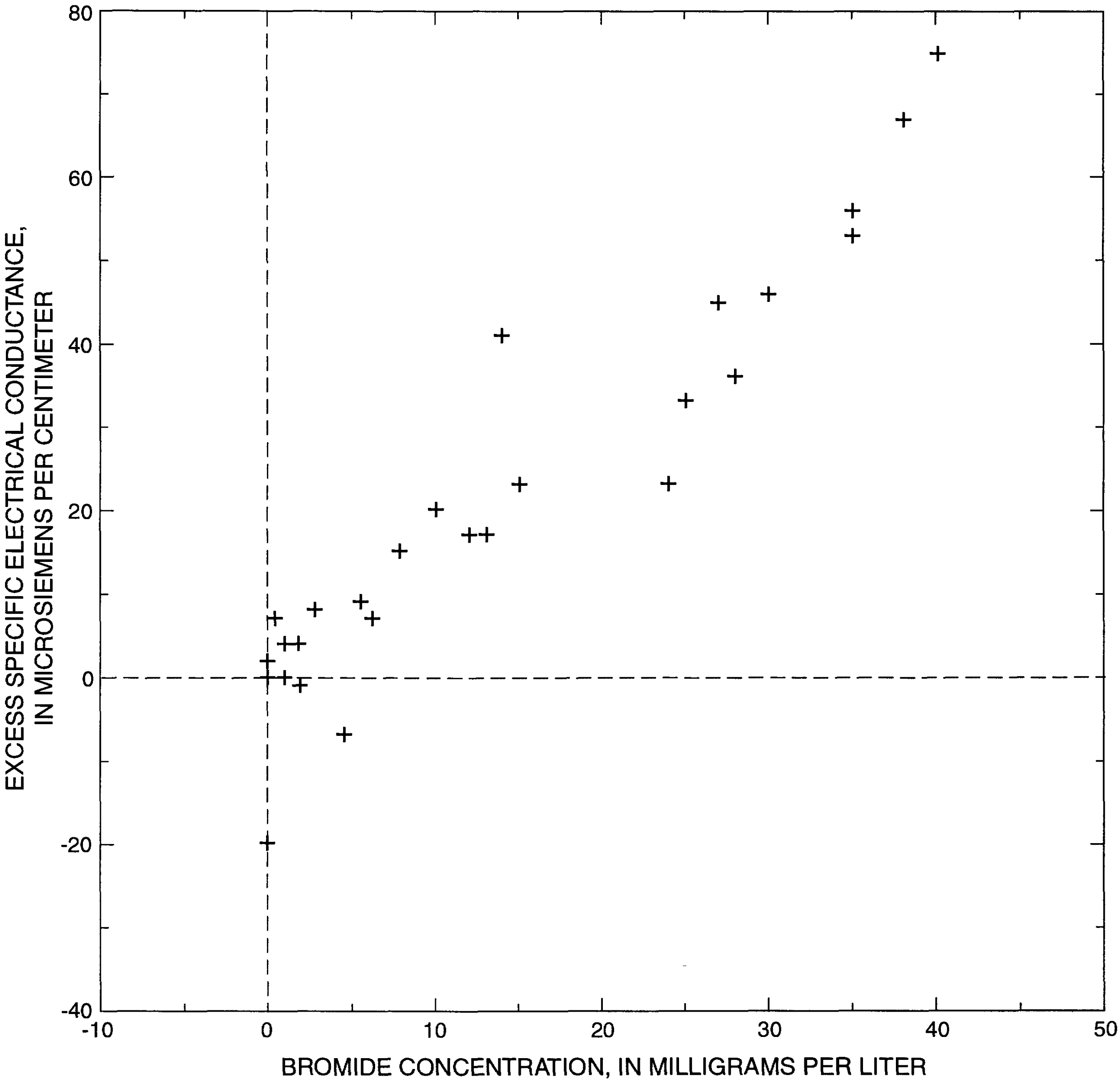

Figure A1. Excess specific electrical conductance as a function of bromide concentration in samples.

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E.A. Prych **A Tracer Test to Estimate Hydraulic Conductivities and Dispersivities of Sediments in the Shallow Aquifer at the East Gate Disposal Yard, Fort Lewis, Washington** USGS-WRIR 99-4244