DISTRIBUTION OF TRICHLOROETHYLENE AND GEOLOGIC CONTROLS ON CONTAMINANT PATHWAYS NEAR THE ROYAL RIVER, MCKIN SUPERFUND SITE AREA, GRAY, MAINE

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ABSTRACT

Vapor-diffusion samplers were used in the autumn of 1997 to determine the lateral extent and distribution of concentrations of a trichloroethylene (TCE) plume in the ground-water discharge area near the McKin Superfund Site, Gray, Maine. Analyses of vapor in the samplers identified a plume about 800 feet wide entering the river near Boiling Springs, an area of ground-water discharge on the flood plain of the Royal River. The highest observed concentration of TCE in vapor was in an area of sand boils on the western bank of the river and about 200 feet downstream from Boiling Springs. Previous studies showed that most of the TCE load in the river originated in the area of the sand boils. In general, highest concentrations were observed on the western side of the river on the upgradient side of the plume, but TCE also was detected at numerous locations in the center and eastern bank of the river.

The TCE plume discharges to the river where fine-grained glaciomarine sediments of the Presumpscot Formation are absent and where coarse-grained facies of buried glaciomarine fan deposits provide a pathway for ground-water flow. Based on results of analyses of vapor-diffusion samples and other previous studies, the plume appears to pass under and beyond the river near Boiling Springs and along the river for about 300 feet downstream from the sand boils. A coarse-grained, organic-rich layer at the base of the alluvial flood plain sediments is confined by overlying fine-grained alluvial sediments and may provide a conduit for ground-water leaking upward from buried glaciomarine fan deposits.

INTRODUCTION

A plume of trichloroethylene (TCE) in ground water that originated at the McKin Superfund Site in Gray, Maine, extends about 4,000 ft eastward to the Royal River (Sevee & Maher Engineers, Inc., 1989; 1993; 1998; 1999). Because TCE concentrations in the Royal River often exceed the State of Maine’s water-quality standard of 2.7 µg/L (Tetra Tech NUS, Inc., 1998), a remediation program may be needed to limit the discharge of TCE to the river. Selection of a remediation program requires an understanding of the configuration of the TCE plume near the river, the distribution of TCE concentrations across the width of the plume, and geologic conditions that affect ground-water discharge into the Royal River.

During the autumn of 1997, the U.S. Geological Survey (USGS), in cooperation with the U.S. Environmental Protection Agency (USEPA), used vapor-diffusion samplers to determine the extent of the TCE plume in ground water near the Royal River and variations in TCE concentrations across the width of the plume. During subsequent studies in the spring and summer of 1998, the distribution of geologic materials near the river was examined to help identify pathways for TCE in ground water. In addition, available hydrologic and geologic information from previous investigations was synthesized with results of vapor-diffusion sampling and collection of geologic information. This report presents the results of the vapor-diffusion sampling and a discussion of potential geologic controls on contaminant pathways.

DESCRIPTION OF STUDY AREA

The study area is along the flood plain of the Royal River in Gray, Maine, about 4,000 ft east and

200 ft lower in altitude than the McKin Superfund Site (fig. 1). The flood plain along the river is largely forested with hardwood and softwood trees as well as a dense shrub layer in places. Some abandoned agricultural fields also are in or adjacent to the flood plain. Ground-water discharge points were apparent at several locations on the western bank of the river. The most prominent ground-water discharge point is a spring on the western bank of the river, known locally as Boiling Springs (fig. 2). Ground-water discharge is also evident in an area of sand boils located approximately 10 ft upstream from the confluence of the unnamed tributary with the Royal River.

The McKin Superfund Site is a former waste collection, transfer, and disposal facility that operated from 1965 to 1978. The McKin Superfund Site and study area are in a rural setting of farmland, woodland, and single-family homes. Most homes in the area were supplied by individual wells completed in bedrock until contaminants were detected in ground water. Since 1978, residents have received their water from a public-supply system (U.S. Environmental Protection Agency, 1992).

Mean annual flow of the Royal River at USGS streamflow-gaging station 01060000 at Yarmouth, Maine, for the period October 1, 1949 to September 30, 1996 was 273 ft^3/s (Nielsen and others, 1997, p. 115). Streamflow near the study area typically is about 55 percent of streamflow at Yarmouth (John Sevee, Sevee & Maher Engineers, Inc., written commun., 1997).

DATA COLLECTION AND ANALYSIS

Study methods included the installation of vapor-diffusion samplers to determine discharge areas along the Royal River for the TCE plume in ground water, on-site analysis of vapors in the diffusion samplers, synthesis of available hydrologic and geologic information, ground-penetrating-radar surveys along the flood plain of the Royal River, and manual installation of auger holes through alluvial sediments.

Construction and Analysis of Vapor-Diffusion Samplers

Vapor-diffusion samplers were constructed using the method described by Vroblesky and Hyde (1997). The samplers consist of a 40-mL, uncapped air-filled glass bottle wrapped in two polyethylene bags held in place with cable ties. A duplicate sample for quality control was constructed by placing an additional polyethylene-wrapped glass bottle in the outer bag. The sampler was attached to a survey flag for marking and retrieval. When placed in water or saturated sediments containing volatile organic compounds (VOCs), organic vapors diffuse through the two layers of polyethylene and equilibrate with air in the bottle. The time required for equilibration is 24 hours or less in a controlled setting (Vroblesky and others, 1996; Vroblesky and Hyde, 1997). Additional time may be required after placement of the samplers to allow concentrations of VOCs in ground-water to re-equilibrate in disturbed materials; a period of 2 weeks is recommended (Don Vroblesky, U.S. Geological Survey, oral commun., 1997). After retrieving the sampler, the outer bag is removed to shed attached sediment, and a cap is immediately screwed onto the bottle over the inner bag.

Vapor-diffusion samplers were installed at 156 locations (fig. 2) using one of two methods. Most were installed about 6 to 8 in. into the river-bottom sediments by penetrating the bottom sediments with a narrow-bladed shovel, forcing the shovel forward, and inserting the sampler in the gap that was formed between the shovel and sediment. The type of sediment each sampler was placed in was recorded. At about 20 percent of the locations, the river was too deep to use this method. In these locations, a driver method was used in which a steel pipe outfitted with an inner blocked pipe was driven into the sediment with a hand-held slide hammer. The inner pipe was then removed and the sampler was inserted to the bottom of the outer pipe. Finally, the outer pipe was removed leaving behind the sampler, and sediments were allowed to collapse around the sampler. Samplers installed by the driver method were typically about 1 ft into the river-bottom sediments.

Samplers were placed every 50 ft along the western bank of the river (fig. 2) starting about 800 ft upstream from the mapped edge of the TCE plume (fig. 1) (Sevee & Maher Engineers, Inc., 1993). The spacing was reduced to 25 ft from the area of Boiling Springs to the Maine Central Railroad trestle (fig. 2).

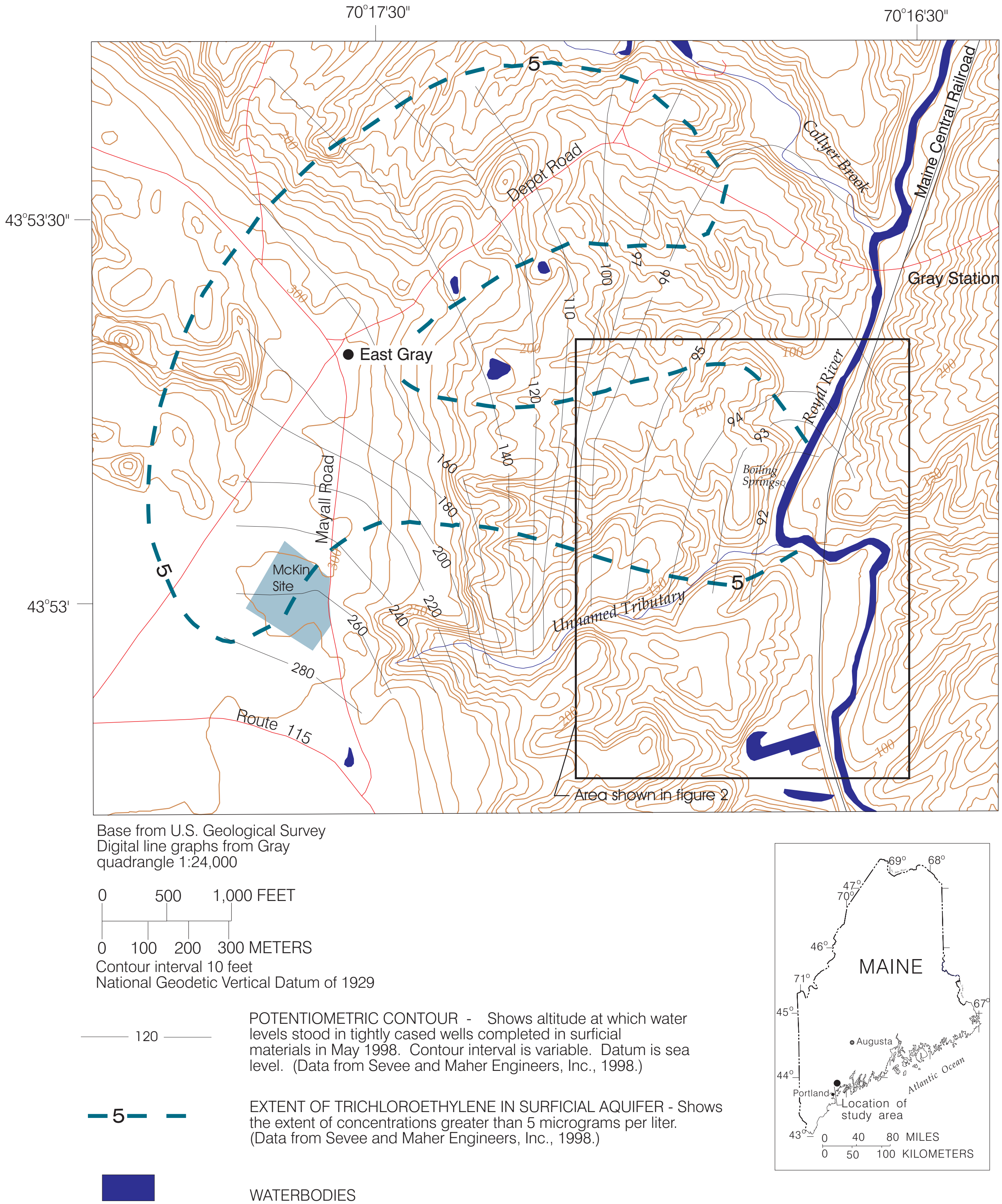

Figure 1. Location of McKin Superfund Site, study area, extent of trichloroethylene in ground water, and potentiometric surface contours for the surficial aquifer, Gray Maine.

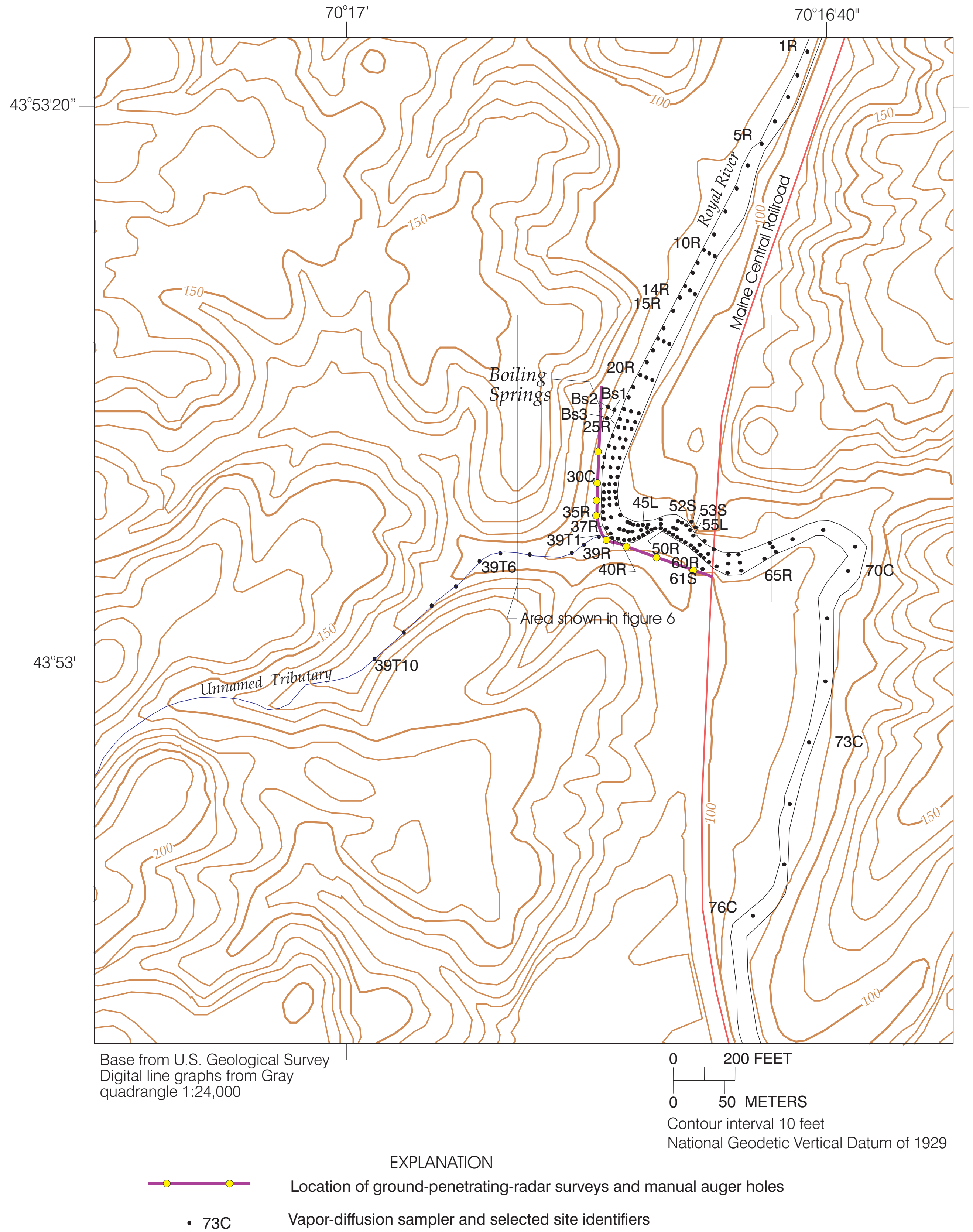

Figure 2. Location of vapor-diffusion samplers placed along and near the Royal River (September and October 1997), ground-penetrating-radar surveys, and manual-auger holes.

Samplers also were placed in the center and eastern bank of the river at many locations. The distance between samplers was expanded to 50 ft, 100 ft, and 200 ft downstream from the trestle. Near the sharp downstream bend in the river and beyond, samplers were placed only near the center of the river channel. Locations shown on figure 2 were determined on the basis of measured distances along the western bank of the river and the features apparent on the base map. The locations shown are estimated to be within 20 ft of actual locations.

Vapor-diffusion samplers also were placed along the unnamed tributary that enters the Royal River from the west near the first sharp bend, in Boiling Springs, and in seepage areas in two other locations near the river. Samplers in the unnamed tributary stream, which was typically 2 to 3 ft wide, were placed at distances of 50 ft and 100 ft in the center of the channel.

The vapor-diffusion samplers were retrieved by pulling the attached wire flag. Within minutes of retrieval, the outer polyethylene bag was removed and a cap was placed on the bottle over the inner bag. The inner bag was then cut away and the bottle was labeled.

Vapor-diffusion samples were analyzed on site for TCE using USEPA Region I standard air screening method (U.S. Environmental Protection Agency, 1998). Samples were analyzed within 4 hours of sample collection using Photovac gas chromatographs equipped with 4-ft by 1/8-in. SE-30 columns and photo-ionization detectors. TCE was the target compound for the vapor sample analyses. The reporting limit for TCE using this equipment and method was 8 ppb by volume.

Collection of Geologic Information

A combination of ground-penetrating radar (GPR), manually installed auger holes, and existing geologic information was used in this study. The geologic information collected from the GPR surveys and manual-auger holes was integrated and synthesized with existing geologic information from published geologic maps and logs of wells and test borings. This information was used to examine possible geologic controls on contaminant pathways where the plume discharges into the Royal River and to construct geohydrologic sections.

GPR surveys were completed in April 1998 to determine the underlying surficial geology along the Royal River. GPR transmits radio-frequency electromagnetic pulses into the ground from antennas. The signal reflects off materials in the subsurface back to the antennas and then the data are processed and displayed as a graphic image. A GPR traverse was run with a 300-Mhz and a 100-Mhz transmission-frequency antenna along the western bank of the Royal River from the railroad trestle west and north to approximately 100 ft upstream from Boiling Springs. The traverse ranged in distance from 5 to 50 ft from the river's edge (fig. 2).

Nine manual-auger holes were completed along the GPR traverse (fig. 2) to interpret the GPR record and to better determine the underlying surficial geology of the study area along the Royal River. Sediment types were recorded and samples were collected when a change in sediment type was observed. Logs made from the manual-auger holes were used to construct geohydrologic cross sections and were synthesized with existing geologic information.

GEOHYDROLOGY OF THE REGION AND STUDY AREA

The surficial geology and hydrology of the study area along the Royal River and surrounding region (as shown in fig. 3) are important to understanding potential TCE discharge areas along the Royal River. Much of the information discussed in the following sections is a synthesis of existing information from previous investigations as well as from observations and data collected during this study.

Surficial Geology of the Region and Study Area

The surficial materials in the region surrounding the study area and the McKin Superfund Site is shown in figure 3; this map is modified from the surficial geologic map of the Gray quadrangle (Weddle, 1997). Surficial materials in this area are underlain by granitic bedrock of the Sebago pluton (Creasy and Robinson, 1997). Logs of wells and test borings (Sevee and Maher, 1989; 1998; Tetra Tech NUS, Inc., 1998) indicate that the bedrock surface lies at depths of 50 to 100 ft beneath the eastern edge of the glaciomarine delta and slopes eastward toward the Royal River to a depth of nearly 200 ft beneath surficial materials. The vertical distribution and thickness of coarse- and fine-grained

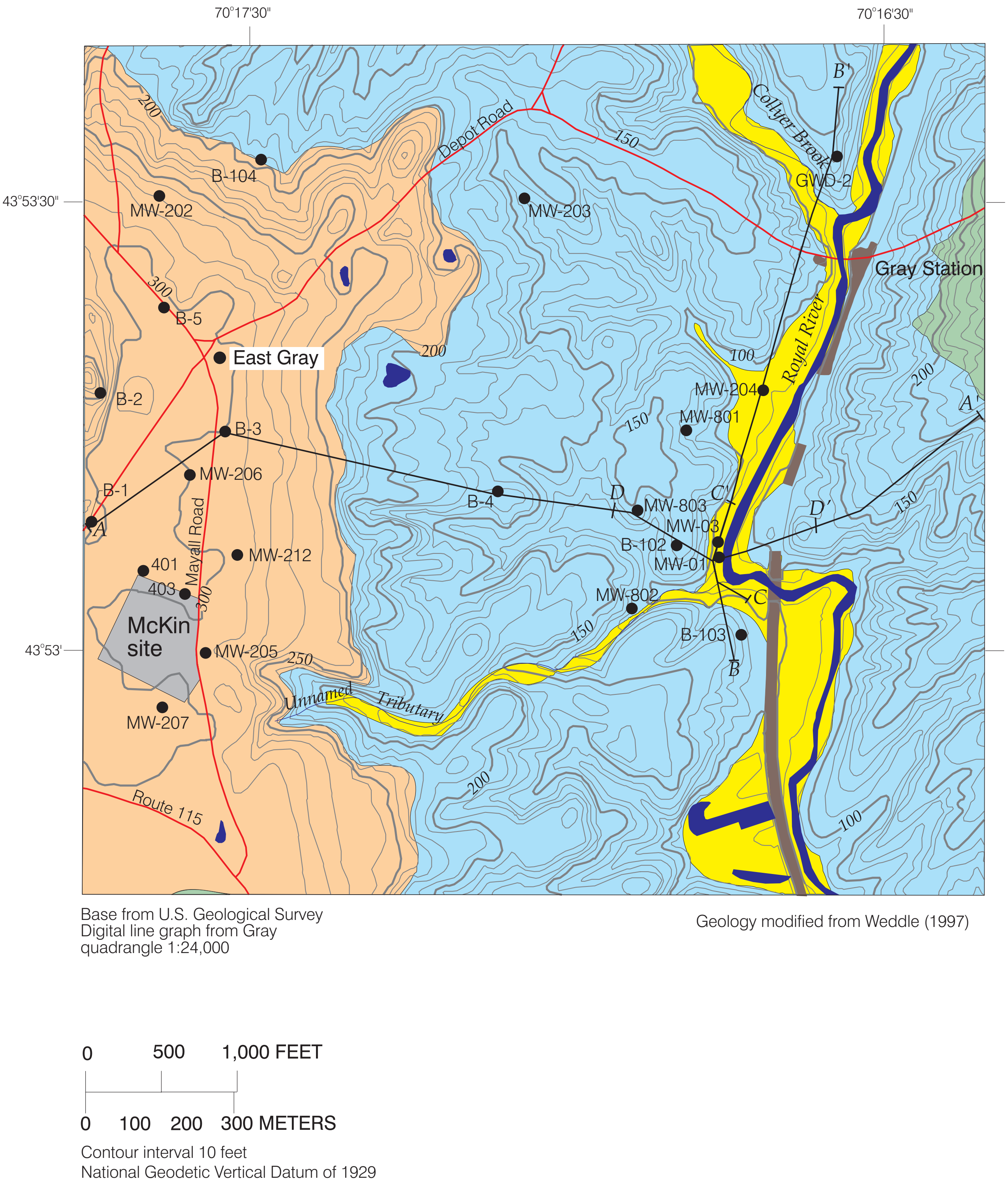

Figure 3. Surficial geology near the McKin Superfund Site.

EXPLANATION

POSTGLACIAL DEPOSITS

Flood Plain Alluvium-- Silt, sand and gravel, with variable amounts of organic material on the flood plains of the Royal River, Collyer Brook, and the Unnamed Tributary; deposits are 10-12 ft thick along the Royal River, thinner along smaller streams; alluvium overlies thicker glacial materials in most places.

GLACIAL DEPOSITS

Glaciomarine Deposits, fine-grained -- Massive to finely laminated, gray silty clay with minor amounts of fine sand and sparse fossil marine mollusk shells and ice-rafted dropstones; deposited in the deeper water glaciomarine environment, distal from the ice margin. Where sediment has been oxidized in the upper part of section, the color is dark olive gray. This unit is the Presumpscot Formation of Bloom (1960;1963). In some places the upper 5-10 ft of unit is finely laminated to massive, silty fine to medium sand; deposited in the shallow glaciomarine environment during regression of the sea.

Glaciomarine Deposits, coarse-grained-- Well to poorly sorted gravel, sand and gravel, sand, and local diamict sediment laid down as deltaic and subaqueous fan deposits in contact with the glacier margin during retreat of the ice sheet in the glacial sea. Deposits are coarse-grained, poorly sorted, and bedding is collapsed in ice-proximal (northerly) parts; sediments are finer grained, better sorted, and beds generally dip southerly farther from (distal to) the ice-margin position; in distal parts of the deposits, fan and delta sediments interfinger with fine-grained glaciomarine sediments. Coarse-grained fan deposits are present beneath fine-grained deposits in much of the area west of the McKin Superfund Site.

Glacial Till-- Nonsorted and nonstratified, compact mixture of grain sizes ranging from clay to large boulders; matrix is largely fine sand containing up to 25 percent silt and clay; deposited beneath glacial ice. Locally, a less compact, sandy, stony facies of till may overlie the more compact facies. In the map area, till is present at land surface in only two small areas; it forms a thin blanket over bedrock in most places in the subsurface.

MAP SYMBOLS

Contact between map units

A——**A′** Location of geologic section line; section shown in figures 4 and 5

● MW-802 Location of wells and test borings; numbers as reported in Sevee and Maher, Engineers Inc., 1998

Waterbodies

Artificial fill of railroad and road embankments

Figure 3. Surficial geology near the McKin Superfund Site—Continued.

surficial materials along a west-to-east line (A-A') and a south-to-north line (B-B') are shown in figures 4a and 4b. Sections C-C' and D-D' (figs. 5a and 5b) are large-scale vertical sections along and across the flood plain of the Royal River near Boiling Springs. All geohydrologic sections were constructed using available well, test hole, and manual-auger data, as well as existing geologic information and geologic interpretation.

The altitude of the glaciomarine sea level in the Gray area is marked by the Gray and East Gray deltas, which have a surface altitude of 305 to 315 ft; the East Gray delta has a measured topset-foreset contact recording sea level at 289 ft (Weddle, 1997). The McKin Superfund Site is near the eastern edge of the East Gray glaciomarine delta, which forms a relatively flat (locally kettled) surface north, west, and south of the contamination site. The delta is composed of layered sand and gravel that can be seen in excavations west and northwest of the McKin Superfund Site. A gravel pit west of Depot Road reveals delta foreset bedding that dips southwestward. Logs of wells and test borings at the McKin Superfund Site indicate that the coarsest grained delta deposits lie north-northeast of the site. The East Gray delta was built from an ice-margin position along its northeastern edge (Weddle, 1997). A bouldery ridge and hummocky topography on both sides of Depot Road northeast of East Gray may be part of an esker system that supplied sediment to the delta during its construction.

Fine-grained glaciomarine sediments (Presumpscot Formation) are present at land surface in most places at and below 240 ft altitude east of the McKin Superfund Site. This material consists of massive to finely laminated, gray to dark-bluish gray silt, clay, and minor fine sand that locally interfingers with the coarse-grained facies but mostly overlies it. The glaciomarine silt and clay ranges from a few to more than 100 ft in thickness. The permeability of these glaciomarine sediments is extremely low; if this material comprised the entire thickness of surficial materials in this area, ground-water flow toward the Royal River would be severely impeded. As seen in sections A-A' and B-B' (fig. 4a and 4b), however, coarse-grained materials of variable thickness underlie the marine silt and clay in most places east of the McKin Superfund Site (Weddle, 1997). This coarse-grained material consists of sand, gravel, and local diamict sediment deposited as subaqueous fans associated with NW-SE trending ice-margin positions from which the East Gray delta was built. The fan deposits are coarse grained in ice-proximal (northerly) directions and grade to finer gravel and sand within short distances in distal (southerly) directions. The distal sandy beds interfinger with fine-grained marine silt and clay. Subsurface data indicate that the cores of successive fan deposits lie beneath glaciomarine sediments in the 155- to 170-ft knoll south of the unnamed tributary and the 155-ft knoll north of the tributary. These highly permeable coarse-grained glaciomarine deposits in the subsurface east of the McKin Superfund Site provide a preferential pathway for ground-water discharge to the Royal River.

The irregular surface of glaciomarine silt and clay deposits (figs. 4a and 4b) is a result of erosion and downcutting in postglacial time by the Royal River, Collyer Brook, and many tributary streams and ephemeral-stream gullies. In some places, where the surface of coarse-grained material is at higher altitudes, postglacial streams have cut through the entire section of fine-grained sediment, leaving coarse-grained materials at or near land surface. Such is the case in a section in the modern flood plain along the western side of the Royal River near Boiling Springs (fig 5b).

Hydrology of the Region and Study Area

Ground water in the immediate vicinity of the McKin Superfund Site, as indicated by potentiometric contours and the plume map shown in figure 1, flows northward toward the intersection of Mayall and Depot Roads. Most of the flow then turns eastward toward the Royal River. Some of the flow near Mayall and Depot Road, however, continues northeastward toward Collyer Brook and eventually turns eastward toward the Royal River (Sevee & Maher Engineers, Inc., 1998). In most of the area west of the area covered by the Presumpscot Formation (fig. 3), ground water in surficial materials is unconfined and the saturated thickness is generally less than 40 ft. Hydraulic gradients are steep in this area (fig. 1), and the water table approximately parallels a steeply sloping bedrock surface (fig. 4a). Conceptually, the configuration of the bedrock surface serves as a major control on ground-water-flow patterns (Sevee & Maher Engineers, Inc., 1989). The potentiometric surface for shallow bedrock is similar to the potentiometric surface for the surficial aquifer (Sevee & Maher Engineers, Inc., 1989).

In the area where the Presumpscot Formation is present, thick, buried coarse-grained sediments are found in places, and ground water in these coarse-

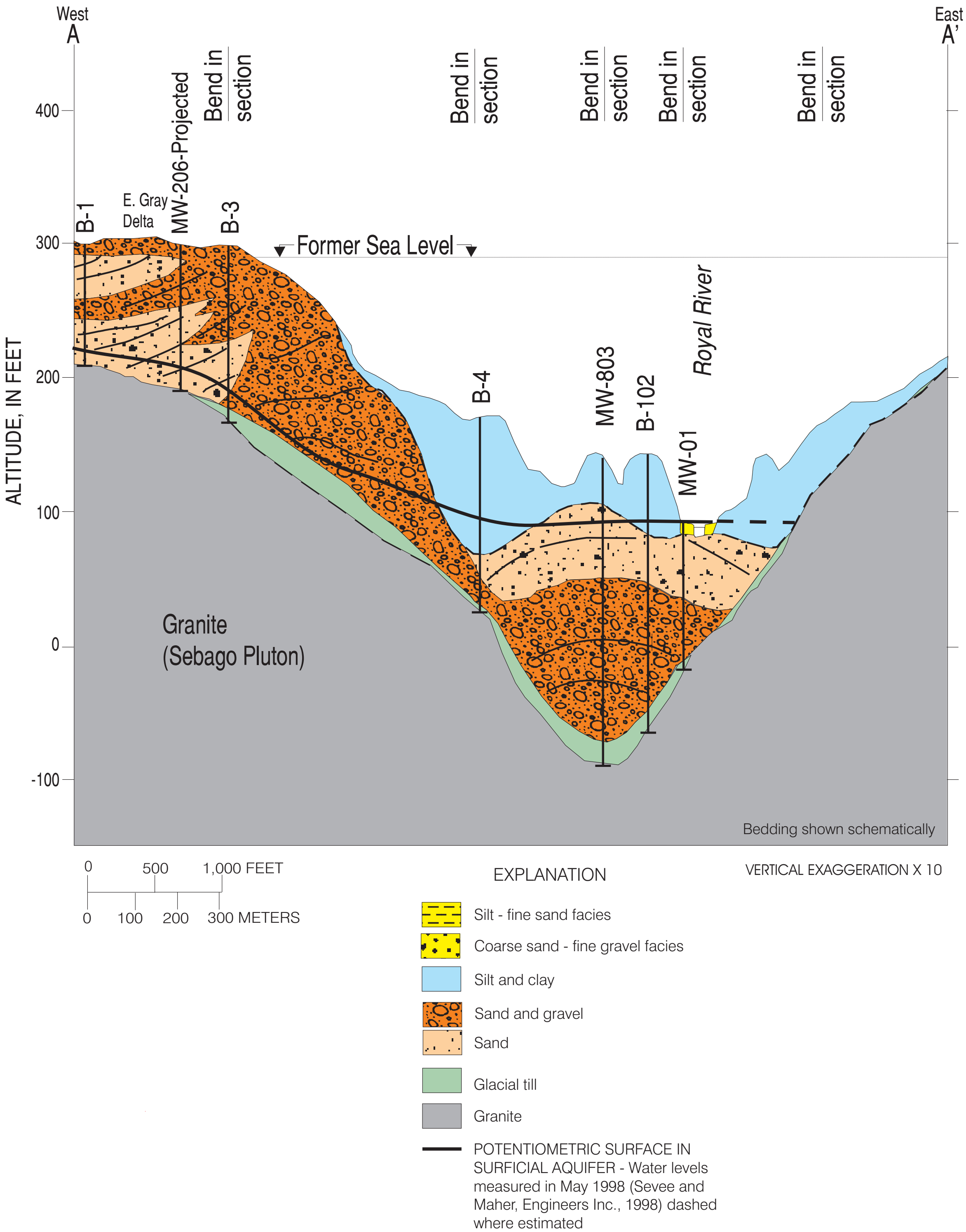

Figure 4a. Geohydrologic section A-A' near the McKin Superfund Site, Gray, Maine. (Location of section line shown on fig. 3.)

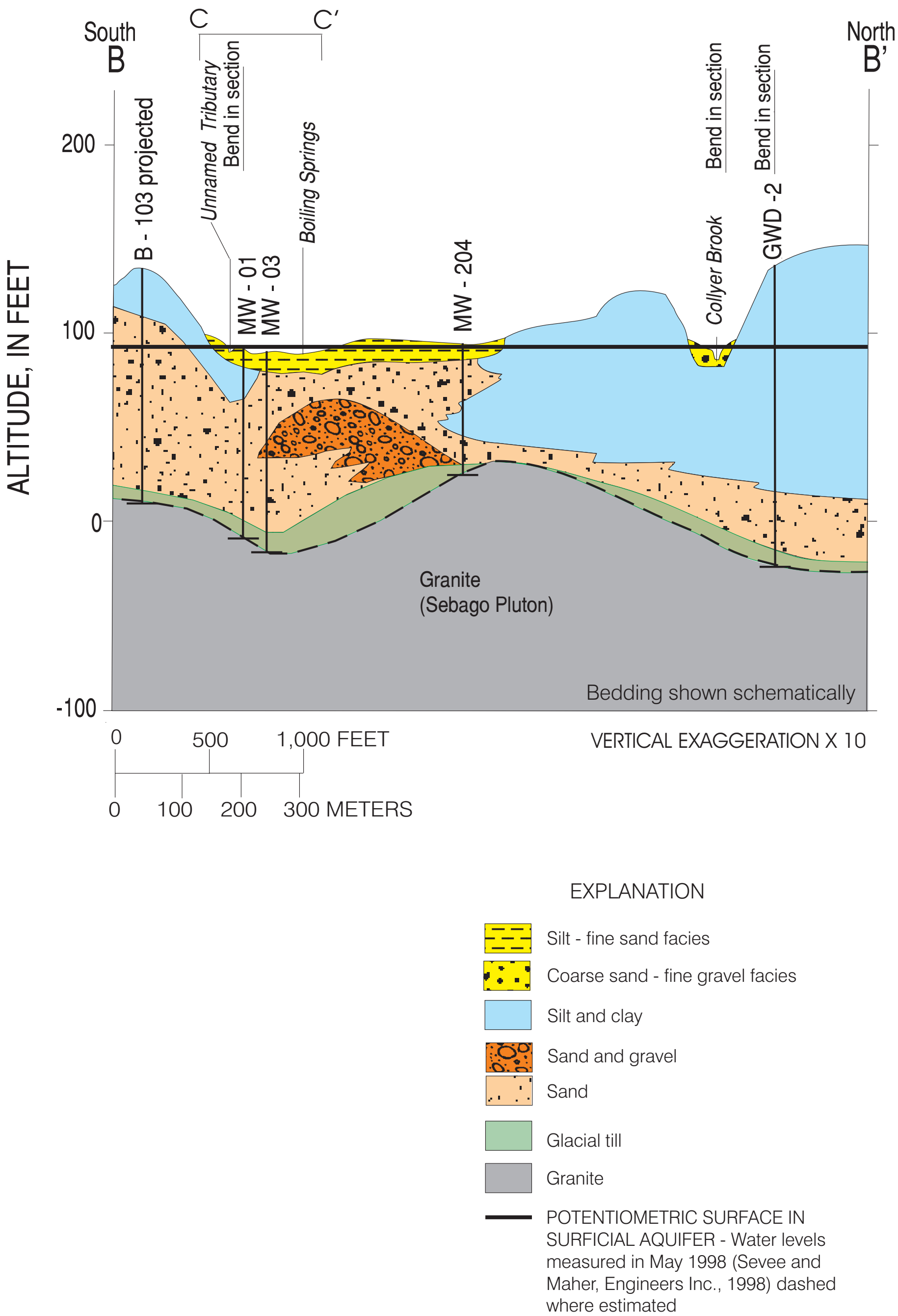

Figure 4b. Geohydrologic section B-B' near the McKin Superfund Site, Gray, Maine. (Location of section line shown on fig. 3.)

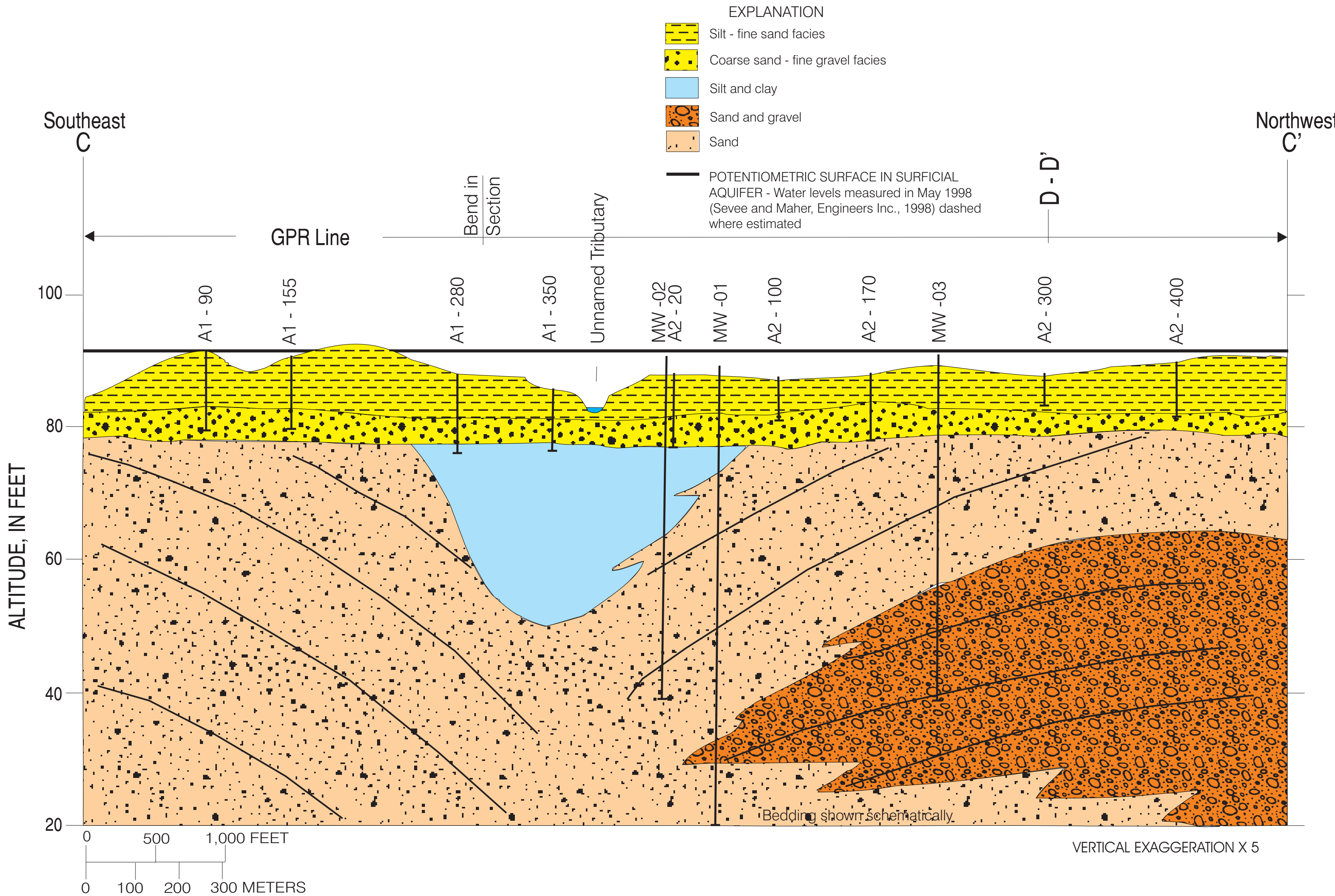

Figure 5a. Geohydrologic section C-C' near Boiling Springs, Gray, Maine. (Location of section line shown on fig. 3.)

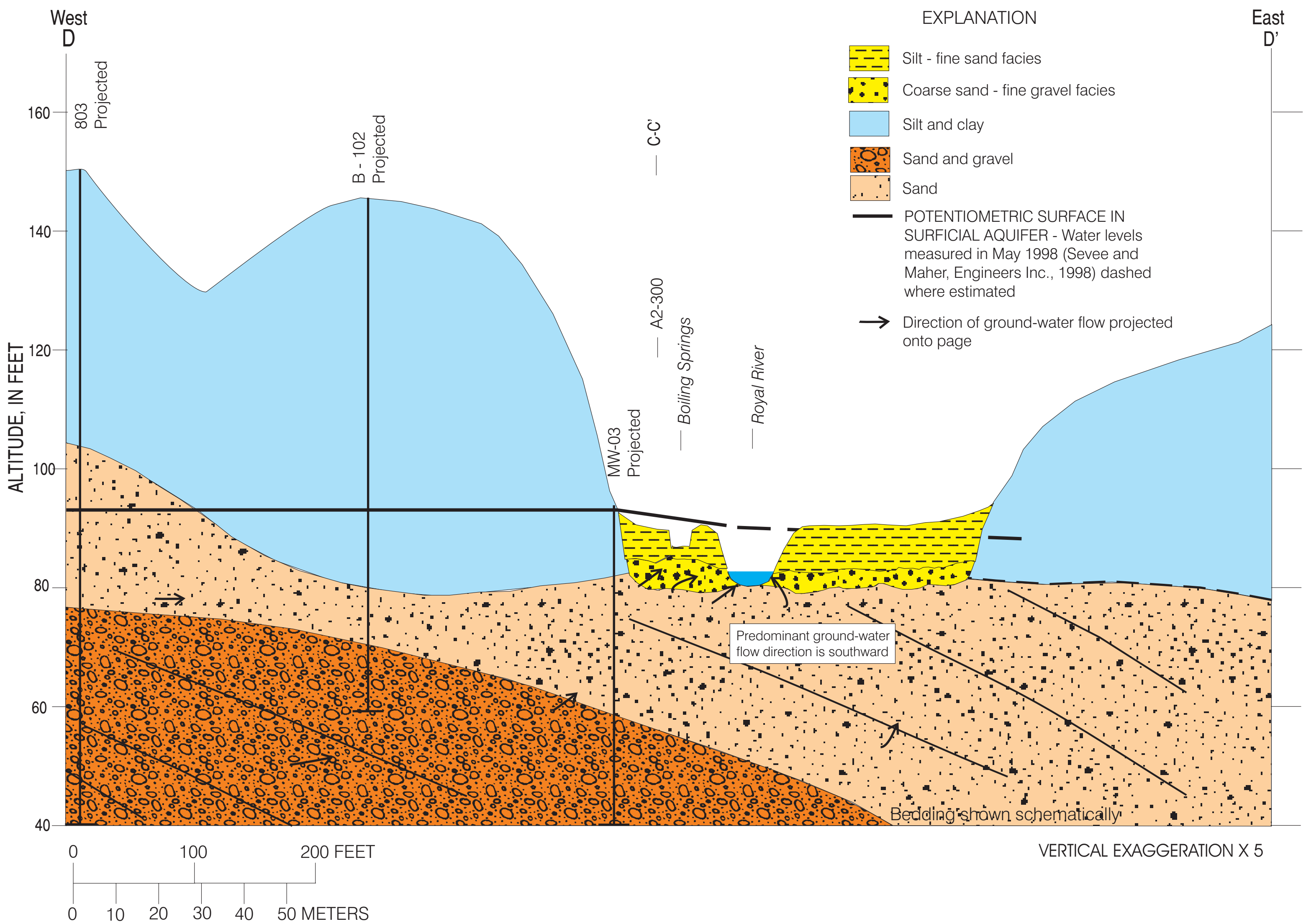

Figure 5b. Geohydrologic section D-D' near Boiling Springs, Gray, Maine. (Location of section line shown on fig. 3.)

grained deposits is confined by silt and clay of the Presumpscot Formation. The hydraulic gradients decrease appreciably (fig. 1) from about 0.1 in the unconfined part of the aquifer to about 0.003 in the confined part of the aquifer. The change in gradient can be attributed mainly to increased transmissivity caused by increased aquifer thickness in the area of the buried valley. Figure 1 shows a potentiometric low for the ground-water system where the river turns abruptly eastward. Boiling Springs (fig. 1) and sand boils downstream from Boiling Springs and a few feet upstream from the unnamed tributary in the western bank of the Royal River are evidence of ground-water discharge in this area.

The unnamed tributary flows perennially for several hundred feet upstream from its mouth. Because the altitude of this stream, as determined from topographic contours in figure 1, is above the potentiometric surface, except possibly near its confluence with the Royal River, perennial flow is most likely derived from ground-water discharge from coarser facies (silts and fine sands) of the Presumpscot Formation.

The plume of TCE in the surficial aquifer and fractured crystalline bedrock currently underlies several hundred acres and extends to the Royal River to the east (fig. 1); concentrations of TCE in ground water near the McKin Superfund Site in May 1998 were generally less than 2,700 μg/L (Sevee & Maher Engineers, Inc., 1998). The highest concentrations were along a band that extended from an area north of the McKin Superfund Site eastward toward the Royal River. The extension of the plume to the north may have been induced by pumping residential wells prior to installation of a public-supply system (Sevee & Maher Engineers, Inc., 1999).

Vertical profiling of water quality in surficial materials based on water samples from small-diameter wells along the flood plain of the Royal River between the unnamed tributary and Boiling Springs in March and April 1998 detected TCE in the coarse-grained sediments at most depths above the bedrock surface (Tetra Tech NUS, Inc., 1998). The highest concentrations of TCE exceeded 1,000 μg/L along a 200-ft wide band between the unnamed tributary and Boiling Springs. The band was 25 ft or less in thickness and rose from a depth of about 50 ft near the unnamed tributary to 10 ft at a distance of about 200 ft south of Boiling Springs. TCE concentrations in water from small-diameter wells placed at Boiling Springs were 300 μg/L or less (Tetra Tech NUS, Inc., 1998).

Loads of TCE in the Royal River downstream from the mapped plume were estimated to be about 0.8 kg/d in early 1999 (Sevee & Maher Engineers, Inc., 1999). Measurements of TCE were made during different flow conditions of the Royal River. No detections of TCE in river water were reported from sites upstream from Boiling Springs. TCE, however, was detected at the inflow point from Boiling Springs, and a sharp increase in concentration was observed near the mouth of the unnamed tributary and the bend in the river. There was no change in detections at high streamflows and a gradual decrease at low streamflows for several thousand feet downstream from the railroad trestle (John Sevee, written commun., 1997).

DISTRIBUTION OF TRICHLOROETHYLENE FROM VAPOR-DIFFUSION SAMPLERS

Analysis of vapor identified a plume about 800 ft wide entering the Royal River. Results of vapor analyses are given in table 1, and concentrations for the plume edge are shown in figure 6. TCE was detected in most vapor-diffusion samples placed in or near the Royal River downstream from sampler 14R, (fig. 2) which was near the northern edge of the mapped plume area. The highest concentration of TCE (30,400 ppb by volume) was in sampler 37R (fig. 2), which was collected from a sand boil on the western bank of the river approximately 270 ft downstream from Boiling Springs. TCE was not detected in several samples from the middle of the river near Boiling Springs where concentrations of at least 500 ppb by volume were detected in samples from each bank. TCE concentrations of less than 500 ppb by volume were observed in samples downstream from the unnamed tributary from the western bank and center of the river bend; clays of the Presumpscot Formation were apparent in the river bottom in this area. Concentrations exceeded 500 ppb by volume in some samples between the river bend and the railroad trestle. TCE was detected in all samples downstream from the railroad trestle, but most concentrations were below 500 ppb by volume.

Vapor-diffusion samples collected at three locations in Boiling Springs had TCE concentrations of 4,230 to 7,100 ppb by volume. One of two samples from a seepage area on the eastern side of the river between the river bend and railroad trestle had a TCE concentration that exceeded 500 ppb by volume. The TCE concentration from sampler 61S from a spring on

Table 1. Concentrations of trichloroethylene (TCE) from vapor-diffusion samplers collected near the Royal River, Gray, Maine, September to October 1997

[Samplers were placed during September 22 to 24, 1997 and removed and analyzed for TCE from October 6 to 9, 1997. All distances were measured along the western bank of the Royal River. Units for TCE concentrations in vapor are parts per billion by volume (ppb by volume). Samplers were labelled with an "R" on the western (right) bank, with a "C" in the center stream, and with an "L" on the eastern (left) bank. Samplers were labelled with a "T" on the unnamed tributary and with a "S" in a spring area. "ND" refers to nothing detected above the lower reporting limit (8 parts per billion by volume) for TCE using a Photovac gas chromatograph unit. The symbol "- -" means that vapor-diffusion samplers were not placed in these locations. Bottom material descriptions separated by slashes refer to the western bank, center stream, and eastern bank, respectively]

Vapor-diffusion sampler	Distance from origin (feet)[1]	TCE concentration in vapor (parts per billion by volume)			Bottom materials
		Western bank	Center stream[2]	Eastern bank	
1R	0	ND	- -	- -	silt
2R	50	ND	- -	- -	silt
3R	100	ND	- -	- -	silt
4R	150	ND	- -	- -	silt
5R	200	ND	- -	- -	silt
6R	250	ND	- -	- -	silt
7R	300	ND	- -	- -	silt
8R	350	ND	- -	- -	silt
9R	400	ND	- -	- -	silt
10R/10C/10L	450	ND	ND	ND	silt
11R	500	ND	- -	- -	silt
12R	550	ND	- -	- -	silt
13R/13C/13L	600	ND	ND	ND	silt/ sand/ silt
14R	650	95	- -	- -	silt
15R	700	1,390	- -	- -	cobbles/ boulders
16R	725	27	- -	- -	silt
17R/ 17C/ 17L	750	114	1,300	14	silt/ fine sand/ silt
18R	800	6,870	- -	- -	silt
19R	850	2,290	- -	- -	fine sand
20R/ 20C/ 20L	900	6,320	1,600	46	silty sand/ sand/ silt
21R	950	4,060	- -	- -	sand and mud
22R	1,000	4,260	- -	- -	silty sand
23R/ 23C/ 23L	1,050	2,840	4,260	2,840	silt/ sand/ silt
24R/ 24C/ 24L	1,100	2,430	ND	4,260	fine sand/ sand/ sand
25R/ 25C/ 25L	1,150	8,930	ND	1,470	silt/ sand/ sand
26R/ 26C/ 26L	1,175	7,200	ND	1,620	silt/ sand/ silt
27R/ 27C/ 27L	1,200	9,940	ND	5,480	silt/ sand/ fine sand
28R/ 28C/ 28L	1,225	203	ND	5,380	silt/ sand/ sandy silt
29R/ 29C/ 29L	1,250	1,220	18	3,250	silt/ sand/ silty sand
30C/ 30L	1,275	- -	16	22	silt/ silty sand
31R/ 31C/ 31L	1,300	710	7,200	4,060	silty sand/ sand/ silt
32R/ 32C/ 32L	1,325	18,300	8,320	4,360	fine sand/ sand/ silt
33R/ 33C/ 33L	1,350	19,450	14,700	14,900	fine sand/ sand/ silt
34R/ 34C/ 34L	1,375	12,700	10,400	5,370	silt/ sand/ silt
35R	1,370	13,240	- -	- -	silt
36R/ 36C/ 36L	1,400	13,700	8,110	4,600	silt/ coarse sand/ silt
37R	1,417	30,400	- -	- -	silt and fine gravel

Table 1. Concentrations of trichloroethylene (TCE) from vapor-diffusion samplers collected near the Royal River, Gray, Maine, September to October 1997--Continued

[Samplers were placed during September 22 to 24, 1997 and removed and analyzed for TCE from October 6 to 9, 1997. All distances were measured along the western bank of the Royal River. Units for TCE concentrations in vapor are parts per billion by volume (ppb by volume). Samplers were labelled with an "R" on the western (right) bank, with a "C" in the center stream, and with an "L" on the eastern (left) bank. Samplers were labelled with a "T" on the unnamed tributary and with a "S" in a spring area. "ND" refers to nothing detected above the lower reporting limit (8 parts per billion by volume) for TCE using a Photovac gas chromatograph unit. The symbol "- -" means that vapor-diffusion samplers were not placed in these locations. Bottom material descriptions separated by slashes refer to the western bank, center stream, and eastern bank, respectively]

Vapor-diffusion sampler	Distance from origin (feet)[1]	TCE concentration in vapor (parts per billion by volume)			Bottom materials
		Western bank	Center stream[2]	Eastern bank	
38R/ 38C/ 38L	1,425	19,100	13,400	1,060	sand/ coarse sand/ silty sand
39R	1,438	15,200	- -	- -	sand with gravel
40R/ 40C/ 40L	1,450	15,700	2,450	4,670	sand and gravel/ gravel/ fine sand
41R/ 41C/ 41L	1,475	20	10,500	3,040	silt/ gravel/ sand and gravel
42R/ 42C	1,500	218	154	- -	clay/ sand and gravel
43R/ 43L	1,525	89	- -	3,400	clay/ sand
44R/ 44C/ 44L	1,550	105	65	4660	cobbles over sand/ clay/ gravel bar
45R	1,575	145	- -	- -	clay
46R/ 46C/ 46L	1,600	84	243	3,140	gravel over sand/ gravel/ fine gravel
47R	1,625	27	- -	- -	silt
48R	1,650	8	- -	- -	silt
49R/ 49C/ 49L	1,675	13,800	8,320	4,560	coarse sand/ sand/ fine/medium sand
50R	1,700	1,680	- -	- -	gravel
51R/ 51C/ 51L	1,725	2,960	428	2,860	gravel/ gravel/ sand
52R/ 52C/ 52L	1,750	316	1,460	8	sand/ gravel/ silt
52S	1,750	- -	- -	954	silt
53R/ 53L	1,775	1,000	- -	ND	silty sand/ silt
53S	1,775	- -	- -	22	silt
54R/ 54L	1,800	2,610	- -	1,380	sand/ silt
55R/ 55C	1,825	2,610	877	- -	silty sand/ coarse sand
56R	1,850	522	- -	- -	silty sand
57R/ 57C/ 57L	1,875	9,290	159	23	coarse sand/ sand/ sand
58R	1,900	ND	- -	- -	coarse sand
59R	1,925	459	- -	- -	gravel
60R/ 60C/ 60L	1,950	1,570	4,180	ND	sand/ gravel/ sand
61R	1,975	ND	- -	- -	sand
61S	1,975	8	- -	- -	silt
62R	2,000	375	- -	- -	sand
63R/ 63C/ 63L	2,050	8	39	21	sand/ sand over clay/ silt with clay
64R/ 64C/ 64L	2,100	256	100	8	silt and sand/ sand and gravel/ silt
65R	2,150	33	- -	- -	clay
66R/ 66C/ 66L	2,200	101	254	355	clay/ cobbles/ gravel
67C	2,300	- -	436	- -	gravel
68C	2,400	- -	28	- -	sand
69C	2,500	- -	159	- -	cobbles
70C	2,600	- -	480	- -	gravel
71C	2,800	- -	84	- -	clay
72C	3,000	- -	449	- -	sand and gravel
73C	3,200	- -	188	- -	sand

Table 1. Concentrations of trichloroethylene (TCE) from vapor-diffusion samplers collected near the Royal River, Gray, Maine, September to October 1997--Continued

[Samplers were placed during September 22 to 24, 1997 and removed and analyzed for TCE from October 6 to 9, 1997. All distances were measured along the western bank of the Royal River. Units for TCE concentrations in vapor are parts per billion by volume (ppb by volume). Samplers were labelled with an “R” on the western (right) bank, with a “C” in the center stream, and with an “L” on the eastern (left) bank. Samplers were labelled with a “T” on the unnamed tributary and with a “S” in a spring area. “ND” refers to nothing detected above the lower reporting limit (8 parts per billion by volume) for TCE using a Photovac gas chromatograph unit. The symbol “- -” means that vapor-diffusion samplers were not placed in these locations. Bottom material descriptions separated by slashes refer to the western bank, center stream, and eastern bank, respectively]

Vapor-diffusion sampler	Distance from origin (feet)[1]	TCE concentration in vapor (parts per billion by volume)			Bottom materials
		Western bank	Center stream[2]	Eastern bank	
74C	3,400	- -	386	- -	coarse sand and gravel
75C	3,600	- -	29	- -	gravel
76C	3,800	- -	21	- -	sand
39T1	- -	- -	ND	- -	sand
39T2	- -	- -	ND	- -	sand and gravel
39T3	- -	- -	ND	- -	sand and gravel
39T4	- -	- -	ND	- -	sand and gravel
39T5	- -	- -	ND	- -	cobbles
39T6	- -	- -	ND	- -	sand
39T7	- -	- -	ND	- -	sand
39T8	- -	- -	ND	- -	sand
39T9	- -	- -	ND	- -	sand
39T10	- -	- -	ND	- -	fine sand and silt
BS1	- -	7,100	- -	- -	silt
BS2	- -	5,940	- -	- -	silt
BS3	- -	4,230	- -	- -	fine sand

[1] Vapor-diffusion samplers are listed in downstream order beginning approximately 1,150 feet upstream from the discharge point of Boiling Springs into the Royal River. Distance was measured along the western bank of the river only. Exceptions are 10 samplers placed along the unnamed tributary (labelled consecutively beginning with 39T) and 3 samplers placed in Boiling Springs (labelled with a “BS”), which appear at the end of the table.

[2] “Center stream” samplers were placed in the bottom of the river channel at half the channel’s width at that location.

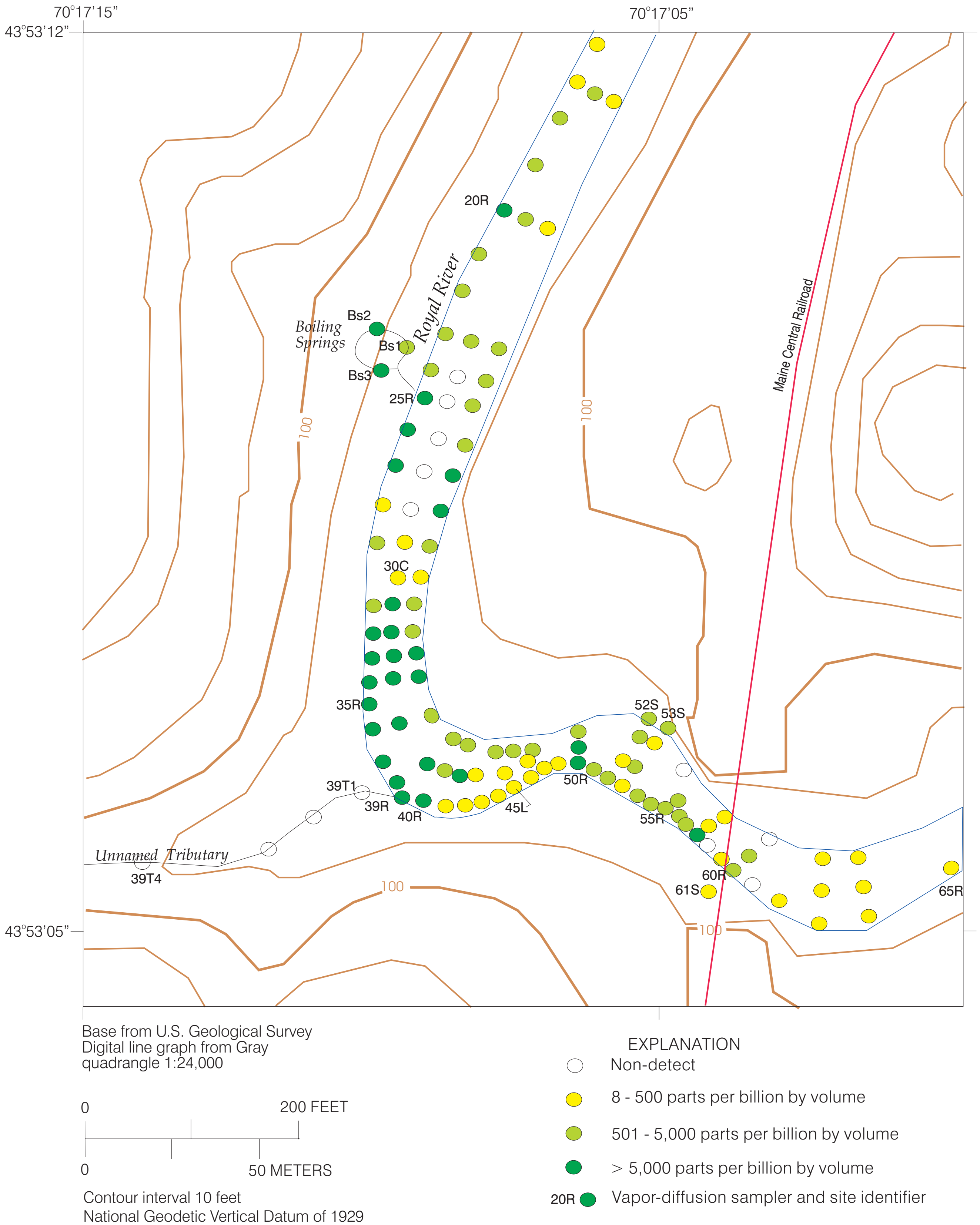

Figure 6. Concentrations of trichloroethylene in vapor-diffusion samplers installed near Boiling Springs, Gray, Maine, September and October 1997.

the western side of the river near the railroad trestle was 8 ppb by volume. TCE was not detected in vapor-diffusion samplers from the unnamed tributary.

Concentrations of TCE in vapor with units of parts per billion by volume can be roughly compared with TCE concentrations in water with units of micrograms per liter. The highest concentrations observed in water samples collected from nearby microwells in March to April 1998 were in the range of 1,200 to 1,500 µg/L (Tetra Tech NUS, Inc., 1998) as compared to 30,400 ppb by volume measured in vapor in sand boils in the Royal River. The concentration of TCE in a water sample from Boiling Springs collected on October 22, 1997 was 300 µg/L (John Sevee, written commun., 1998), as compared to 4,230 to 7,100 ppb by volume in three vapor samples collected during this study. These data indicate that concentrations in vapor in parts per billion by volume are about 20 times higher than the concentrations in water in micrograms per liter.

GEOLOGIC CONTROLS ON CONTAMINANT PATHWAYS NEAR THE ROYAL RIVER

Previously collected hydrogeologic and water-quality information contained in several reports for the study area, results from vapor-diffusion samplers, and results from new geologic investigations along the Royal River provide the basis for a discussion on potential geologic controls on contaminant pathways. Water-level data collected in May 1998 from wells near the river (Sevee & Maher Engineers, Inc., 1998) indicated that hydraulic heads in aquifer materials upstream from where the river is crossed by Depot Road were nearly 10 ft higher than river stage, and nearly 5 ft higher than river stage near Boiling Springs. Because of the head difference, ground water potentially discharges to the river throughout this approximately 2,500-ft reach. The presence of fine-grained sediments of the Presumpscot Formation upstream from well MW-204 (fig. 4b), however, limits the flow of ground water to the river. Much of the ground water in the aquifer system discharges to the river downstream from well MW-204, where the river has eroded through the Presumpscot Formation and into coarse-grained subaqueous fan deposits. The discharge rate may be further enhanced or focused in the area near Boiling Springs by the presence of a coarse-grained facies in the fan deposits that serve as a preferential pathway for ground-water flow. The width of the TCE plume near the river, as shown by Sevee & Maher Engineers, Inc. (1993), and reaffirmed using vapor-diffusion samplers, appears to correlate with where the Presumpscot Formation is thin or absent.

The flood plain surface lies at 90 to 95 ft in altitude along the Royal River near Boiling Springs. GPR data collected along the western bank of the river and manual-auger holes drilled at nine locations along the GPR line (fig. 2) indicate that the postglacial river alluvium beneath the flood plain is 10- to 12-ft thick and consists of two distinct facies along this reach of the river. Logs of microwells and test borings in this area (Tetra Tech NUS, Inc., 1998) also confirm the presence of two facies in the alluvium. The lower 2 to 5 ft of the alluvium is coarse to very coarse-grained sand and granule gravel with some layers of medium to coarse sand and fine to medium sand. This lower facies also contains large amounts of organic material including twigs, bark, pine cones, and finely disseminated organic fragments. Several of the manual-auger holes could not penetrate deeper than about 10 ft because buried logs were encountered in the coarse-grained alluvial sediments. South of the unnamed tributary, the upper 3 to 10 ft of the alluvium consists predominantly of very fine to fine sand, coarsening upward to fine to medium sand. North of the unnamed tributary, the upper facies is generally fine grained, predominantly very fine sand and silt. The upper facies also contains many finely disseminated organic fragments. The entire 10- to 12-ft alluvial section can be seen in two locations in the western bank of the river, south of the junction with the unnamed tributary. In both outcrops, a layer of ancient vegetational debris, including trunks of large trees, is present at the base of the alluvium. At one outcrop, approximately 1 ft of Presumpscot Formation is exposed above river level below the alluvial section.

During installation of the manual-auger holes in the flood plain north of the unnamed tributary, ground water was encountered only after the upper fine-grained alluvial facies was penetrated (at a depth of 4 to 5 ft). Within minutes after completion of each hole, water levels rose to ground surface, and water actually flowed out of several of the holes.

Hydraulic heads in the aquifer that are several feet above the river near Boiling Springs can be attributed to converging flow lines as ground water flows vertically towards the river. A lower vertical than horizontal hydraulic conductivity also may cause elevated heads at depth, relative to heads in the river. Highest vertical hydraulic gradients and highest ground-water discharges at the river would be expected at the edge of the river (McBride and Pfannkuch, 1975), and gradients would decrease across or along the river. Nevertheless, the presence of TCE in samples from the center and along the eastern bank of the river indicates that ground water near the TCE plume upstream from the bend in the river discharges across the width of the river. The presence of TCE along the eastern bank downstream from the bend may indicate that some ground water passes beyond the river near the bend and discharges downstream. Concentrations of TCE exceeding 1,000 ppb by volume at several locations downstream from the bend and upstream from the railroad trestle indicate the plume may parallel the river downstream from the sand boils and bend. The TCE that discharges downstream from the bend originates at greater depth in the aquifer system than water that discharges at the sand boils. Possible directions of ground-water flow near the river are shown as arrows in figure 5b.

Relatively low (less than 500 ppb by volume) TCE concentrations in samples collected downstream from the railroad trestle (fig. 6) indicate that most of the TCE inflow to the river ends at the trestle. The presence of TCE in vapor-diffusion samplers placed in river-bottom sediments downstream from the trestle may result from the introduction of river water that also contained TCE. A streamflow of about 27 ft^3/s, which was measured when samplers were retrieved, would be expected to contain from 15 to 20 µg/L of TCE (John Sevee, written commun. 1998). A concentration of 15 to 20 µg/L in water might yield a concentration of 300 to 400 µg/L in vapor, assuming a multiplication factor of 20. TCE may have reached the samplers by diffusion, by the introduction of river water at the time samplers were installed, by natural flow of river water through bottom materials, or some combination of these factors. Extension of the TCE plume in ground water beyond the railroad trestle, however, is possible and cannot be excluded on the basis of available information.

Water that leaks upward from the aquifer along the river and flood plain may enter the coarse-grained, organic-rich sediments at the base of the alluvium, which in turn could be a major pathway for ground water near the river. The overlying fine-grained alluvium may serve as a semi-confining layer for water in the fan materials and the gravel layer at the base of the alluvium. Boiling Springs may be the expression of a zone of relatively high vertical hydraulic conductivity in the alluvium that was enhanced by the removal of fine-grained sediments by flowing ground water.

The absence of TCE in several samples from the center of the Royal River near Boiling Springs (samplers 24C to 28C) is difficult to explain. Fine-grained alluvium that limits vertical flow of ground water may be present in a pooled area of the river near these samplers. Other possible explanations include circulation of river water through bottom sediments in this area, and very slow equilibration of water in the sediments with water in the aquifer after placement of the samplers. The absence of TCE in vapor-diffusion samples from sediments along the unnamed tributary reinforces the concept that the unnamed tributary does not receive water by upward leakage from the aquifers at depth.

SUMMARY AND CONCLUSIONS

Vapor-diffusion samplers were installed in September 1997 and retrieved and analyzed 2 weeks later in October 1997 to determine the lateral extent and distribution of TCE concentrations in the ground-water-discharge area near the McKin Superfund Site in Gray, Maine. Vapor-diffusion samples were analyzed on site using a portable gas chromatograph. Analyses of vapor in the samples confirmed the presence of a plume about 800 ft wide entering the Royal River. The highest observed concentration of TCE in vapor was 30,400 ppb by volume in an area of sand boils on the western bank of the river. Previous studies showed that much of the TCE load in the river originated in the area of the sand boils. In general, highest concentrations were observed on the side of the river nearest the source, but TCE also was detected at some locations in the center and eastern bank of the river.

A review of geologic conditions near the river indicates that the TCE plume discharges to the river where fine-grained sediments of the Presumpscot Formation are absent and where coarse-grained facies of buried glaciomarine fan deposits provide preferred pathways for ground-water flow. The plume probably passes under and beyond the river in the area of Boiling Springs and along the river downstream from the sand boils. A coarse-grained, organic-rich layer at the base of alluvial sediments along the river may be confined by overlying fine-grained alluvial sediments and may provide a conduit for ground water leaking upward from buried glaciomarine fan deposits. TCE vapors in samples downstream from both the railroad trestle and the likely extent of the plume can be attributed to the introduction of river water that contained TCE when samplers were installed, diffusion of TCE from the river into bottom sediments, local advective exchanges of water between the river and bottom sediments, or a combination of these factors. The possibility that the plume of TCE in ground water parallels the river downstream from the trestle, however, cannot be excluded on the basis of available hydrologic and water-quality information.

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