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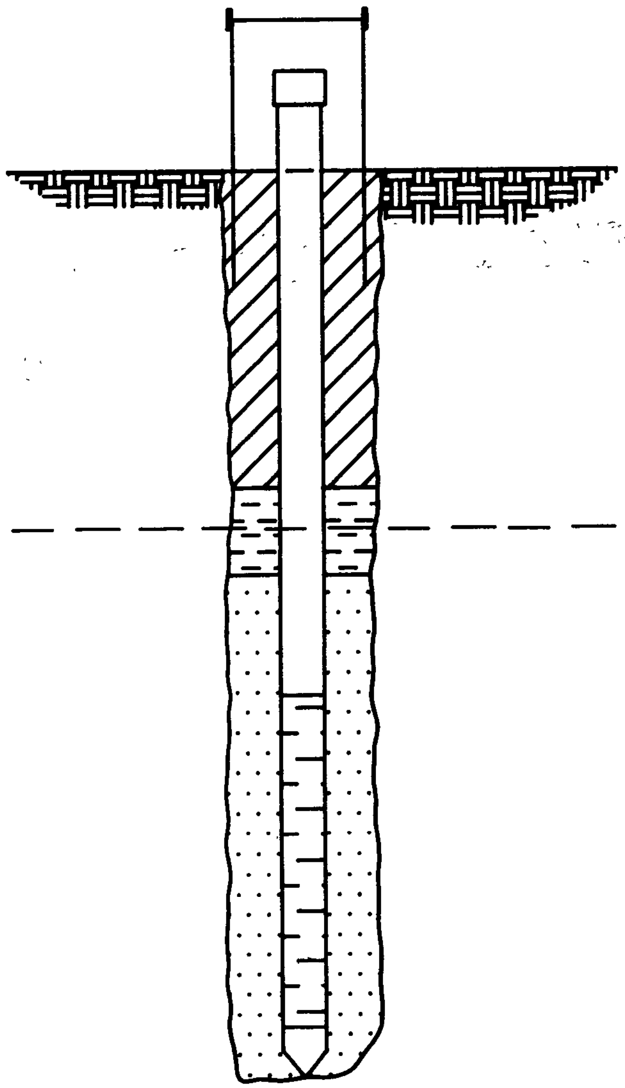
Water-Resources Investigations Report 88-4219

AN INVESTIGATION OF SHALLOW GROUND-WATER QUALITY NEAR EAST FORK POPLAR CREEK, OAK RIDGE, TENNESSEE



Prepared by the
U.S. GEOLOGICAL SURVEY

in cooperation with the
U.S. DEPARTMENT OF ENERGY

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By John K. Carmichael

U.S. GEOLOGICAL SURVEY

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Prepared in cooperation with the
U.S. DEPARTMENT OF ENERGY

Nashville, Tennessee
1989

DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

For readers who may prefer to use metric (International System) units rather than the inch-pound units herein, the conversion factors are listed below:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeters (mm)
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Sea Level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

Use of trade or firm names in this report is for identification only and does not constitute endorsement by the U.S. Geological Survey.

Well-Numbering System: Wells are identified according to the numbering system used by the U.S. Geological Survey throughout Tennessee. The well number consists of three parts: (1) an abbreviation of the name of the county in which the well is located; (2) a letter designating the $7^1/_2$-minute topographic quadrangle on which the well is plotted; and (3) a number generally indicating the numerical order in which the well was inventoried. The symbol An:D-1, for example, indicates that the well is located in Anderson County on the "D" quadrangle and is identified as well 1 in the numerical sequence. Quadrangles are lettered from left to right, beginning in the southwest corner of the county.

AN INVESTIGATION OF SHALLOW GROUND-WATER QUALITY NEAR EAST FORK POPLAR CREEK, OAK RIDGE, TENNESSEE

By John K. Carmichael

ABSTRACT

Alluvial soils and fill materials in and near the flood plain of East Fork Poplar Creek in Oak Ridge, Tennessee, are contaminated with various trace metals (primarily mercury), organic compounds, and radionuclides that were lost to the stream as a result of past operations at the Y-12 Plant, a nuclear-processing facility located within the U.S. Department of Energy's Oak Ridge Reservation. Observation wells were installed in the shallow (above bedrock) aquifer in and near the flood plain of East Fork Poplar Creek and water-quality samples were collected to determine if contaminants found in the soils and fill are also present in the shallow ground water.

The shallow aquifer in the East Fork Poplar Creek flood plain consists primarily of alluvial silt and clay with lesser amounts of sand and gravel. Thickness of the shallow aquifer ranges from essentially zero to as much as 20 feet. A silty-clay glei horizon is present between the base of the alluvium and the top of bedrock at most flood-plain locations and, where present, likely impedes downward ground-water movement.

Water in the shallow aquifer near East Fork Poplar Creek occurs under water-table conditions. Recharge to the shallow aquifer is principally from precipitation, and discharge is through springs and seeps to East Fork Poplar Creek and its tributaries. During spring, summer, and fall, evapotranspiration also accounts for the removal of water in storage in the shallow aquifer.

Water levels in the shallow aquifer fluctuate seasonally in response to variations in recharge and evapotranspiration. Generally, the depth to water in the observation wells ranged from about 1 to 4 feet below land surface in late winter, and from about 2 to 7 feet below land surface in late fall. During extremely dry periods, the water table recedes below the top of bedrock in some flood-plain areas, possibly causing East Fork Poplar Creek to lose water to the shallow aquifer along some reaches.

Contaminants found in water samples collected from several of the observation wells in concentrations (total and (or) total-recoverable) which equaled or exceeded drinking-water standards established by the U.S. Environmental Protection Agency are antimony, chromium, lead, mercury, selenium, total phenols, and strontium-90. Total and dissolved uranium concentrations exceeded 1.0 microgram per liter in samples from nearly 70 percent of the wells in the East Fork Poplar Creek flood

plain. Organic compounds that were identified in low concentrations in samples from a few wells in the flood plain are: Arochlor 1260, benzo(a)anthracene, benzo(b)fluoranthene, chrysene, 3,3-dichlorobenzidine, di-n-butylphthalate, N-nitrosodiphenylamine, and pyrene. Water from one well in the East Fork Poplar Creek flood plain at a contaminated fill site contained 37 and 8 micrograms per liter of trichloroethene and trans-1,2-dichloroethene, respectively.

Comparison of the results of total and (or) total-recoverable trace-metal determinations with those from dissolved determinations demonstrates that elevated concentrations of these substances in water collected from several of the wells in the East Fork Poplar Creek flood plain resulted from sorption of trace metals (and possibly organic compounds and radionuclides) by fine sediment suspended in the samples. The occurrence of contaminated sediment in these samples is suspected to be the result of borehole contamination during well installation.

INTRODUCTION

During the past 40 years, operations at the Y-12 Plant, a nuclear-processing facility located within the U.S. Department of Energy's (DOE) Oak Ridge Reservation at Oak Ridge, Tennessee (fig. 1), have resulted in disposal and loss to the environment of a variety of chemical constituents and compounds (Union Carbide Corporation-Nuclear Division, 1983; Geraghty and Miller, 1985). For example, it has been estimated that since 1950, more than 733,000 pounds of elemental mercury have been lost from the Y-12 Plant, including an estimated 239,000 pounds of which were discharged directly into the headwaters of East Fork Poplar Creek, a small stream that begins as an industrial ditch inside the Y-12 facility and then flows through business and residential areas of Oak Ridge (Union Carbide Corporation-Nuclear Division, 1983, p. 14). Analyses of soil samples collected from borings in the flood plain of East Fork Poplar Creek as part of the Tennessee Valley Authority's (TVA) Instream Contaminant Study indicate that a substantial quantity of the mercury is now in the upper 18 inches of the alluvial material in the flood plain and stream channel (Tennessee Valley Authority, 1985b,c). In general, flood-plain soil-mercury concentrations decrease downstream, but occasionally occur in concentrations of 1,000 micrograms per gram (μg/g) or greater as far as 4 miles downstream from the Y-12 Plant.

The distribution and concentration of mercury and other trace metals, organic compounds, and radionuclides residing in the East Fork Poplar Creek flood-plain sediments have been documented as a result of part of the TVA's Instream Contaminant Study (Tennessee Valley Authority, 1985b,c), and by additional off-site (off the Oak Ridge Reservation) sampling by the Oak Ridge Associated Universities (ORAU), the results of which are maintained in the Environmental Monitoring and Compliance Section data base at the Oak Ridge National Laboratory (K. Daniels, Oak Ridge National Laboratory, oral commun., 1988). However, the Oak Ridge Task Force (ORTF), a panel established to evaluate off-site contamination and health effects and to make recommendations for remedial action, has expressed concern over the lack of information on concentrations of mercury and other contaminants in the shallow ground water occurring within the flood-plain alluvium. In response to this lack of information, the U.S. Geological Survey, in cooperation with the DOE, initiated an investigation to determine whether shallow ground water near East Fork Poplar Creek contains mercury and other contaminants originating from the Y-12 Plant.

PURPOSE AND SCOPE

The purpose of this report is to present the results of the investigation of shallow ground-water contamination near East Fork Poplar

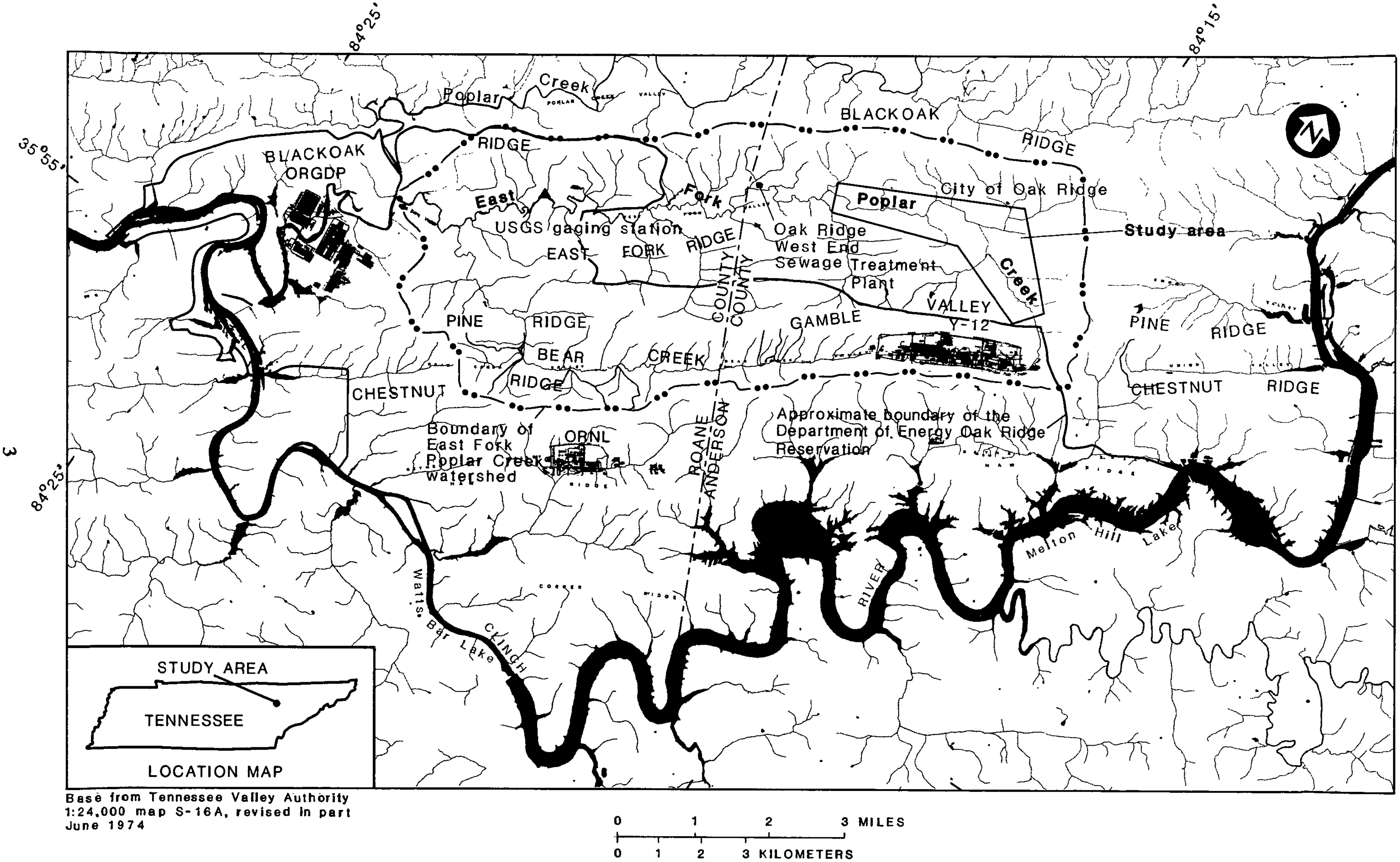


Figure 1.--Location of the East Fork Poplar Creek watershed and study area.

Creek. The study, which was designed to furnish water-quality and water-level data from the shallow (above bedrock) aquifer in areas where soil contamination is present, primarily included installation of a series of observation wells at off-site locations in and near the flood plain of East Fork Poplar Creek and at uncontaminated background sites along two similar streams in the greater Knoxville, Tennessee area, and collection of two rounds of water-quality samples from the wells. The following section presents a more-detailed, chronological description of all tasks performed during the investigation.

APPROACH

The investigation, which began in August 1986 and ended in September 1987, consisted of the following elements:

(1) review of TVA and ORAU soil-sampling data by members of the ORTF (a) to identify sites for observation wells, and (b) to develop a list of constituents whose presence and concentrations in water samples from the wells would be determined;

(2) review of TVA and ORAU soil-sampling data by the Geological Survey for the selection of appropriate observation-well design, construction materials, and installation techniques;

(3) installation of 16 observation wells in and near the flood plain of East Fork Poplar Creek and two additional observation wells, each at separate background sites in the greater Knoxville area, and compilation of lithologic data for the boreholes as they were drilled;

(4) development and collection of water-quality samples from 17 of the 18 observation wells (excluding 1 background-site well) for preliminary mercury-concentration determinations and scans for detectable levels of organic compounds;

(5) re-development and sampling of seven of the observation wells near East Fork Poplar Creek to obtain additional water-quality data for comparison with results of first-round samples from these wells;

(6) collection of water-quality samples from 16 of the 18 observation wells (excluding 1 well in the East Fork Poplar Creek flood plain and 1 background-site well) and analysis of the samples for concentrations of a broad range of organic and inorganic substances (including radionuclides) at a private laboratory and the DOE's K-25 Gaseous Diffusion Plant laboratory, respectively, and;

(7) measurement of water levels in each of the observation wells after drilling was completed, during development and sampling, and at various times throughout the study.

PREVIOUS STUDIES

Subsurface mercury contamination in both ground water and the geologic materials beneath the Y-12 Plant and property has been characterized by Rothchild and others (1984). The occurrence of contaminants in surface water, stream and flood-plain sediments, and the flora and fauna in and near East Fork Poplar Creek has been described in several reports by the Tennessee Valley Authority (1985 a-e, 1986). Other reports that were useful during this investigation include a map and description of the geology of the Oak Ridge Reservation and surrounding area by McMaster (1963), a summary of hydrologic data for the Oak Ridge area by McMaster (1967), soil surveys of Anderson county (1981) and Knox County (1955) by the U.S. Department of Agriculture, Soil Conservation Service, geologic maps of the Knoxville 7.5-minute quadrangle by Catermole (1958) and the Bearden 7.5-minute quadrangle by Catermole (1960), the annual water-resources data report for Tennessee by Lowery and others (1988), a summary of the 1983 Union Carbide Corporation-Nuclear Division Task Force study by Union Carbide Corporation-Nuclear Division (1983), and publications describing evaluations of remedial and sediment-control alternatives for East Fork Poplar Creek by Advanced Sciences, Incorporated (1986, 1987).

Acknowledgments

The author expresses appreciation to Dr. Clayton Gist, formerly of the Environmental Surveillance and Monitoring Section of the Manpower Education, Research, and Training (MERT) Division of ORAU, and now with the Environmental Protection Division of the U.S. Department of Energy, Oak Ridge Operations; and Mr. Henry Beiro of the MERT Division of ORAU, for their guidance in the selection of sites for observation wells, for the collection and analysis of soil samples obtained at the sites prior to well constructions, and for permission to include the analytical results of soil sampling in this report; to Mr. Tom Fortner, Services Superintendent for the Public Works Department of the city of Oak Ridge, for allowing the use of storage space and equipment at the Public Works facility while field work for the project was being conducted; and to the land owners who granted permission to construct observation wells on their property.

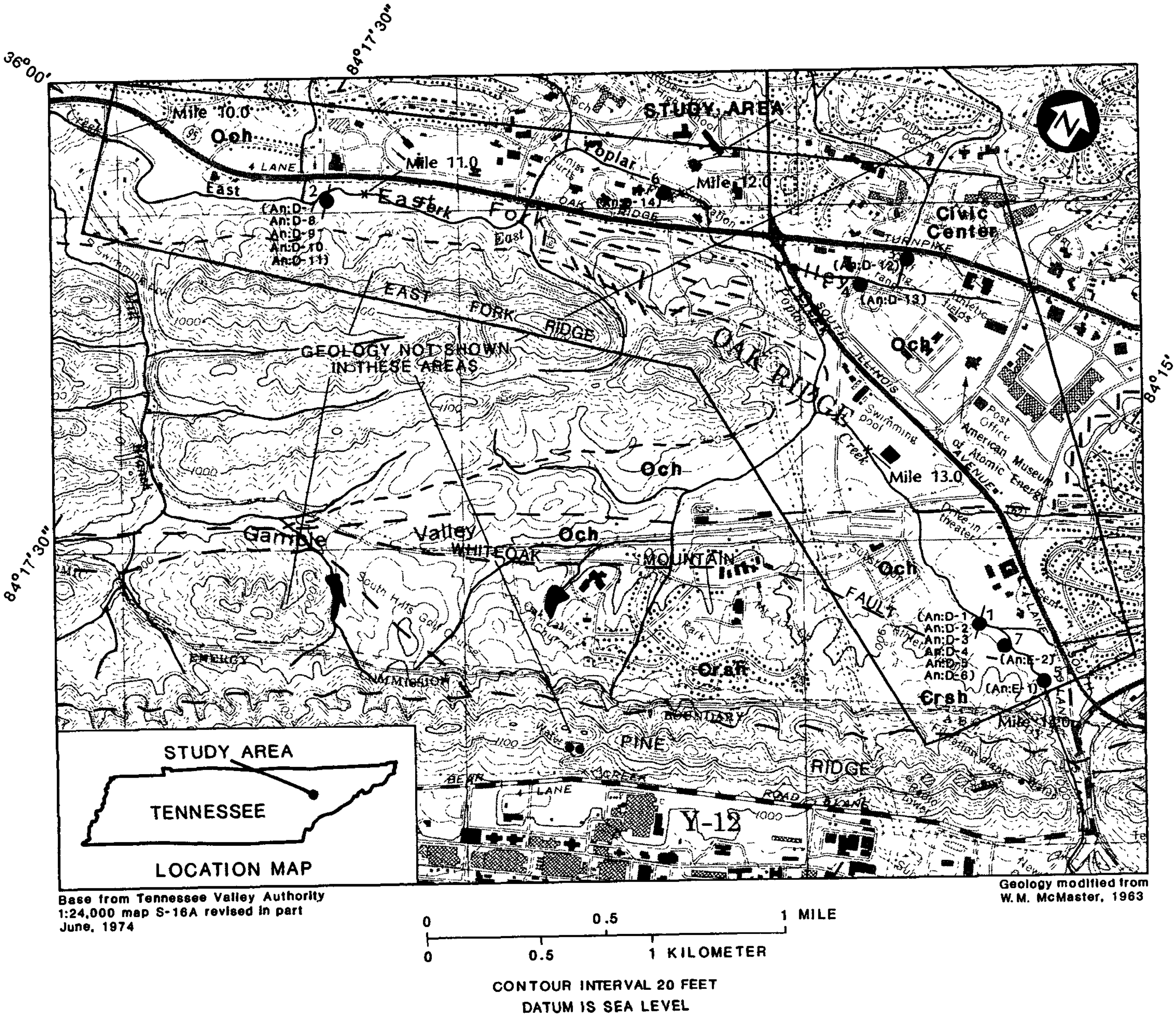
DESCRIPTIONS OF THE AREAS UNDER INVESTIGATION

For this investigation, a primary study area and two background sites were selected for observation-well installations and water-quality and water-level data collection. The study area is limited to off-site parts of the city of Oak Ridge which lie within the East Fork Poplar Creek watershed (fig. 1) and have been identified as being or having been contaminated with mercury and other substances originating from the Y-12 Plant. This area includes the flood plain of the stream between approximately river miles 10.0 and 14.0 (fig. 2), where mercury concentrations present in flood-plain sediments locally exceed 1,000 μg/g, and "low-level" sites at the Oak Ridge Civic Center (fig. 2) where fill from the flood plain was placed and later removed by the DOE after it was discovered to contain mercury and other contaminants. The two background sites, each at separate locations in the greater Knoxville area (figs. 3 and 4), were selected for the collection of background water-quality data. Observation well site-selection criteria, descriptions of each well-site location, and the basis for their selection are discussed in the Observation Wells section.

EAST FORK POPLAR CREEK STUDY AREA

The study area is located in Anderson County in the eastern half of the East Fork Poplar Creek watershed (fig. 1). The watershed has a drainage area of 29.8 mi^2 above the confluence of East Fork Poplar Creek and Poplar Creek. It is bounded by Blackoak Ridge on the northwest and Chestnut Ridge on the southeast. Altitudes range from about 740 feet at the mouth of East Fork Poplar Creek to about 1,280 feet at the crest of Pine Ridge. Land use within the watershed is primarily residential and woodland, with commercial and industrial development being limited to areas of the city of Oak Ridge no longer within the Oak Ridge Reservations, and to the Y-12 Plant.

East Fork Poplar Creek originates within the Y-12 Plant (fig. 1) as a drainage ditch which primarily receives process water from the Plant.



EXPLANATION

3 (An:D-12) ●	SINGLE OBSERVATION WELL SITE, SITE NUMBER, AND OBSERVATION WELL NUMBER (IN PARENTHESES)	— —	FAULT--Approximately located
2 (An:D-7 An:D-8 An:D-9 An:D-10 An:D-11) ●	OBSERVATION WELL TRANSECT SITE, SITE NUMBER, AND OBSERVATION WELL NUMBERS (IN PARENTHESES)--Lithologic cross sections along transect site traces shown on figure 20	- - - -	CONTACT--Approximately located
		Och	CHICKAMAUGA LIMESTONE
		Ꞓrsh	ROME FORMATION

Figure 2.--Geology of the East Fork Poplar Creek study area and locations of observation well sites.

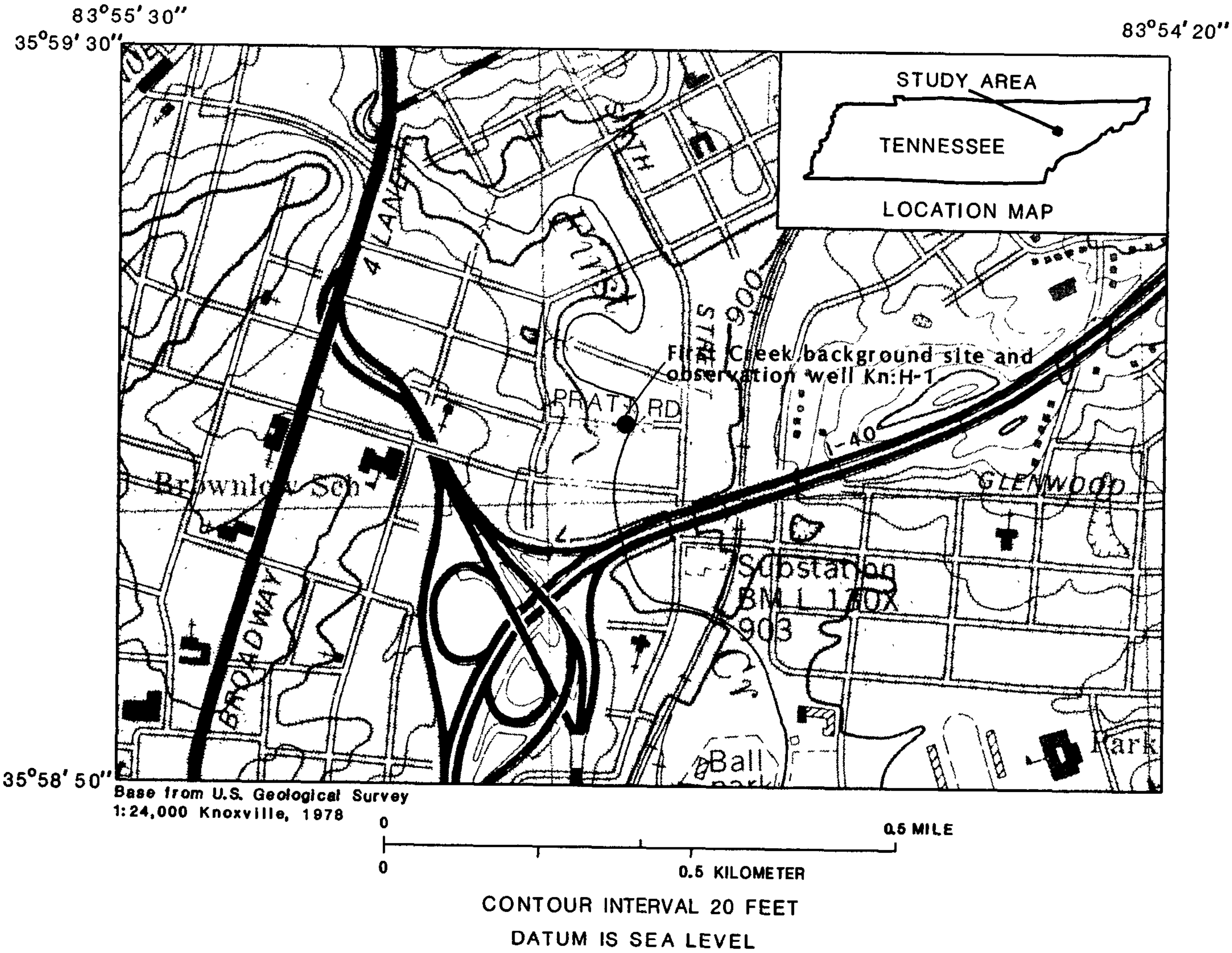
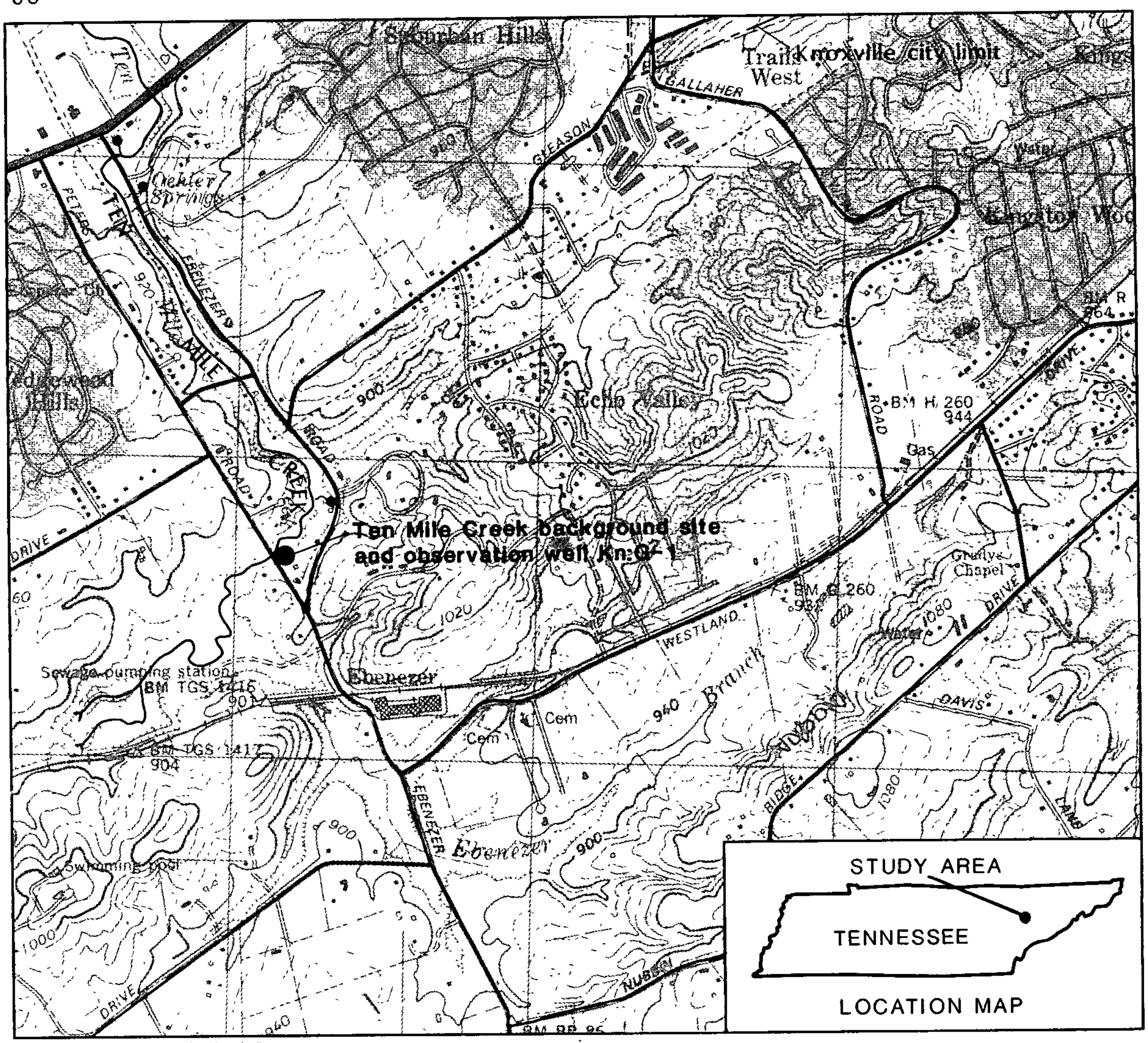


Figure 3.--Location of the First Creek background site and observation well Kn:H-1.

84°05' 84°02'30"

35°55'



35°53'10"

Base from U.S. Geological Survey
1:24,000 Bearden, 1978

0 0.5 1 MILE
0 0.5 1 KILOMETER

Figure 4.--Location of the Ten Mile Creek background site and observation well Kn:G-1

From the Y-12 Plant, the stream flows northwest, leaving the Oak Ridge Reservation at river mile 14.10. At about river mile 12.50, the stream turns to the southwest, reentering and remaining within the Reservation from river mile 4.80 until its confluence with Poplar Creek. Bear Creek, whose drainage area lies within the East Fork Poplar Creek basin, is the only major tributary to East Fork Poplar Creek (fig. 1). Also beginning at the Y-12 Plant, Bear Creek flows southwestward, south of and parallel to East Fork Poplar Creek, entering East Fork Poplar Creek at river mile 1.47. East Fork Ridge, Pine Ridge, and Gamble Valley separate Bear Creek from East Fork Poplar Creek (fig. 1).

From its origin at the Y-12 Plant to its confluence with Poplar Creek, East Fork Poplar Creek falls approximately 200 feet, having an average fall of about 13 feet per mile. Bed gradient is steepest in the upper reaches, where the stream cuts through Pine Ridge, producing a narrow flood plain less than 100 feet wide. Downstream from Pine Ridge and within the study area, creek banks along parts of the northwesterly flowing section of the stream have been built up with fill and lined with rip-rap where development has occurred, essentially destroying the natural flood plain. After the stream turns southwest (about river mile 12.50), bed gradient decreases and the stream begins to meander across a broad, flat flood plain in places reaching a width of greater than 500 feet. Natural features common along the entire stream and flood plain are seeps and springs, point-bar and channel-fill deposits, cutbanks, and scour and overflow channels.

Records of streamflow have been collected by the Geological Survey at its gaging station (gage 03538250) at East Fork Poplar Creek mile 3.30 (fig. 1) since August 1960. Flow measured at this gage includes inputs of as much as 20 ft^3/s from the Y-12 Plant and 10 ft^3/s from the Oak Ridge West End Sewage Treatment Plant (Lowery and others, 1988), located at river mile 8.30 (fig. 1). Average flow (including inputs) for the period August 1960 through September 1987 is 50.3 ft^3/s, with a minimum of 12 ft^3/s and a maximum of 4,100 ft^3/s recorded (Lowery and others, 1988).

Geologic Setting

The study area is located in the Valley and Ridge physiographic province, an area characterized by an alternating succession of northeast-southwest trending ridges and valleys. Most of the valleys have developed in areas underlain by limestone and shale, whereas the ridges have formed on the more resistant units of shale, sandstone, and cherty dolomite. Beds commonly dip to the southeast as a result of thrust faulting.

Within the East Fork Poplar Creek watershed, bedrock consists of sedimentary rock of Cambrian to Mississippian age. Structural features within the watershed include several regional and local thrust faults oriented parallel to strike which produce repeating stratigraphic sequences, and East Fork Ridge, a syncline formed by folding of bedrock along the Whiteoak Mountain Fault.

Two major geologic units underlie the study area. The southeast corner of the area is underlain by the Rome Formation of Early Cambrian age, specifically by a maroon- to tan-colored shale bed that was mapped and described by McMaster (1963, p. 11) as the lower shale member of the Rome Formation. The remaining section of the study area is underlain by the Chickamauga Limestone of Middle and Late Ordovician age. Locally, the Chickamauga is characterized as a gray to blue-gray, shalely to silty limestone occasionally containing sinkholes and solution cavities that decrease in number and size with depth.

The Whiteoak Mountain fault cuts through the southeast corner of the study area, marking the contact where the older Rome Formation has been thrust-faulted over the younger Chickamauga Limestone. Locations of the outcrop belts of the two major geologic units within the study area are shown in figure 2.

Shallow Aquifer Materials

The shallow aquifer in the study area, as well as at the background sites, was defined for this investigation as being any alluvium, regolith, and (or) fill materials that occur above bedrock and are water bearing. This is not to imply that a separate aquifer exists at greater depth; it is intended only to define the source of shallow ground water for this investigation. As determined by visual inspection, soil sampling, and observation-well drilling at selected sites in the study area, thickness of the naturally occurring shallow-aquifer materials generally ranges from essentially zero where bedrock is exposed at land surface (commonly occurring along the flood-plain periphery) to about 10 feet near the center of the flood plain. Locally, thickness may be as much as 20 feet where fill materials have been placed above the flood-plain deposits. Alluvial soils consisting primarily of silt and clay with lesser amounts of sand and gravel comprise the upper 1 to 5 feet of the undisturbed flood-plain sediments. These soils are classified as either Hamblen or Newark varieties--silt-clay-loams which have vertical permeability rates ranging from 1 to 4 ft/d and are moderately resistant to erosion (U.S. Department of Agriculture, 1981).

In parts of the study area, coal particles which washed into East Fork Poplar Creek from the Y-12 Plant have been deposited, along with mercury and other contaminants, in a dark-colored layer several inches thick in the upper 18 inches of the flood-plain alluvium. Exposures of this layer in the upper parts of the stream's banks at certain locations are coincident with flood-plain areas having the highest identified soil concentrations of mercury and other contaminants.

At most observation-well locations in the flood-plain section of the study area, a blue-gray to brown, moderately to highly erosion-resistant, silty-clay glei horizon underlies the alluvium, the top of the glei marking the base of the more recent alluvial deposits. As determined from observation-well drilling, where present, this material directly overlies bedrock and ranges from only inches to as much as 5 feet in thickness. Because of its higher clay content relative to the overlying alluvium, the glei horizon likely impedes the rate of ground-water movement downward through the alluvium, probably causing perched water-table conditions during drier periods. At river mile 10.93 (adjacent to site 2) (fig. 2), East Fork Poplar Creek flows directly on the glei, exemplifying its relatively high degree of resistance to erosion. No samples of the glei collected in undisturbed flood-plain areas and analyzed as part of the ongoing off-site sediment sampling program have shown mercury contamination (C. Gist, Oak Ridge Associated Universities, oral commun., 1986).

BACKGROUND SITES

The two background sites chosen for this investigation are located in Knox County, in the greater Knoxville area, which also lies within the Valley and Ridge physiographic province. Both sites are located in the flood plains of small streams draining mainly commercial and residential areas; First Creek, which flows southward through north-central Knoxville and empties into the Tennessee River (fig. 3); and Ten Mile Creek, which flows southwestward in southwestern Knox County, just outside the western city limits of Knoxville, and then flows into a swallet about $^1/_2$ mile west of Ebenezer, continuing underground from this point to discharge into Fort Loudon Lake (fig. 4).

The shallow aquifers at each site consist mainly of alluvial silt and clay with lesser amounts of sand and gravel. Alluvial soils at the First Creek and Ten Mile Creek sites are classified as Melvin and Lindside silt-loam types, respectively (U.S. Department of Agriculture, 1955). Because only one well was installed at each site, relative ranges of thickness for the shallow aquifers at each site were not determined. However, bedrock outcrops locally in the flood plains and along the banks of both streams suggest that thickness of the alluvium is quite variable, ranging from essentially zero to as much as 15 feet in the vicinity of each site.

Alluvium at the First Creek background site is underlain by crystalline limestone of the Holston Formation of Middle Ordovician age (Catermole, 1958). At the Ten Mile Creek background site, underlying bedrock is dolomite of the upper Newala Formation, as used in Tennessee, and equivalent to the Mascot Dolomite of Early Ordovician age, which is the uppermost formation of the Knox Group (Catermole, 1960).

OBSERVATION WELLS

Eighteen shallow observation wells were installed at 9 sites for this investigation; 16 wells were installed at 7 sites (numbered 1 through 7) in the study area (fig. 2), and one well was installed at each of the two background sites (figs. 3 and 4). The background sites are not numbered--instead, they are referred to as the First Creek and Ten Mile Creek background sites.

GENERAL SITE-SELECTION CRITERIA

Observation-well sites in the study area were selected for this investigation on the basis of the results of soil sampling and trace-metal analysis (primarily for mercury) conducted by both the TVA and ORAU. From part of the TVA's Instream Contaminant Study (Tennessee Valley Authority, 1985b,c), two areas of the East Fork Poplar Creek flood plain were identified as having the highest soil-mercury concentrations: between river miles 10.0 and 11.5, and 13.5 and 14.0 (fig. 2). These two areas were prioritized for well sites so that water-quality samples could be collected from locations where the probability of shallow ground-water contamination was the greatest. Furthermore, the results of the TVA study also indicate a correlation between high concentrations of mercury in the flood-plain soils and elevated concentrations of other contaminants, particularly other trace metals and radionuclides (Tennessee Valley Authority, 1986). Therefore, it was thought likely that some of these other substances might also be identified in the shallow ground water from areas where high soil-mercury concentrations have been identified. Additional sites for wells were also selected in the study area to allow investigation of the shallow ground-water contamination in disturbed areas (both in and away from the East Fork Poplar Creek flood plain) where mercury-contaminated soil has been used as fill material.

The background sites were selected for the collection of water-quality data from the shallow alluvial aquifers along streams which drain areas similar to Oak Ridge and which, as far as is known, have not been subjected to the types of contaminants released to East Fork Poplar Creek.

DESCRIPTION OF SITE LOCATIONS AND REASON FOR SELECTION

Site 1 is located in an undeveloped wooded area south of South Illinois Avenue and in the flood plain of East Fork Poplar Creek at river mile 13.61 (fig. 2). This site was selected for shallow observation-well installations because of the high mercury concentrations (up to 1,800 μg/g) occurring in the undisturbed flood-plain soils between river miles 13.5 and 14.0. Six wells were installed at this site (three wells on each side of the stream) along a north-south transect spanning the entire flood plain perpendicular to the stream. The wells are numbered An:D-1 through 6, beginning with the northernmost well.

Site 2 is located south of State Highway 95 in an undeveloped, partially-wooded area in the flood plain of East Fork Poplar Creek at river mile 10.93 (fig. 2). This site was selected because it lies within the area where the highest mercury concentrations (as high as 3,900 μg/g) in the East Fork Poplar Creek flood-plain soils have been identified. Five wells (two north of and three south of the stream) were installed at this site along a north-south transect spanning the entire flood plain perpendicular to the stream. The wells are numbered An:D-7 through 11 beginning with the northernmost well.

Sites 3 and 4 are located south of State Highway 95 at the Oak Ridge Civic Center (fig. 2), near small tributaries to East Fork Poplar Creek. These two locations were chosen as "low-level" sites because soil-mercury concentrations are now less than 10 μg/g following removal of the mercury-contaminated soil used as backfill for the nearby sewer beltway. Individual wells at sites 3 and 4 are numbered An:D-12 and An:D-13, respectively.

Site 5 is located southwest of Scarboro Road and adjacent to and northeast of East Fork Poplar Creek at river mile 13.97 (fig. 2). This site was selected for installation of a single well (An:E-1) because fill material containing mercury-contaminated soil and various construction debris has been placed over contaminated flood-plain deposits at this location.

Site 6 is located in the East Fork Poplar Creek flood plain northwest of State Highway 95 and southeast of and adjacent to East Fork Poplar Creek at river mile 11.98 (fig. 2). This site was selected for installation of a single well (An:D-14) because mercury-contaminated fill has been placed over relatively uncontaminated flood-plain deposits at this location.

Site 7 is located in an undisturbed, sparsely wooded area in the flood plain and south of East Fork Poplar Creek at river mile 13.80 (fig. 2). This site was selected for installation of a single well (An:E-2) because soil-mercury concentrations as high as 2,600 μg/g have been identified at this location.

The First Creek background site is located in a relatively undisturbed flood-plain area east of the dead end of Pratt Road and west of First Creek, on property owned by the city of Knoxville (fig. 3). The Ten Mile Creek background site is also located in an undisturbed flood-plain area, east of Peters Road and south of Ten Mile Creek (fig. 4). First Creek and Ten Mile Creek background-site wells are numbered Kn:H-1 and Kn:G-1, respectively.

WELL CONSTRUCTION AND INSTALLATION

All 18 observation wells installed for this investigation were constructed with 2-inch diameter, stainless-steel well casing and 0.010-inch slot, wire-wrapped, stainless-steel drive-point screens in 2-, 3-, 4-, or 5-foot lengths. For wells requiring its use, 8-inch diameter black-steel pipe was installed for surface casing, as explained later in this section. High purity (98.4 percent silica minimum), 8-35 grit blasting sand was used to pack screens in all wells. Bentonite pellets ($^1/_2$-inch diameter) were used to develop a seal above the sand packs, and Portland cement was poured into the remaining annular space above the bentonite. After installation, all wells were outfitted with stainless-steel well caps (except well An:D-12 which was fitted with a slip-type PVC cap because the threads at the top of the casing were cut off after the well was installed), and 6-inch diameter steel well protectors with locking caps to prevent unauthorized entry.

Prior to the installation of each well, both the interior and exterior of the auger flights, casing, and screens were (1) steam cleaned with a detergent solution, (2) rinsed with steam-cleaner water without detergent, (3) rinsed with a commercial grade of acetone, and (4) rinsed again with steam-cleaner water without detergent. The steam cleaner was furnished by the city of Oak Ridge and was supplied by city tap water.

Two versions of the same basic design were used for well construction, with the design used for each well being dependent on the soil-mercury concentrations identified at each well location. For wells at locations where mercury concentrations in the soil or fill materials are higher than about 1 μg/g, the well design consisted of the installation of surface casing prior to the well casing and screen to prevent contaminated material in the upper soil zones from being transported down the borehole during drilling and to seal the contaminated zone from the screened interval. For wells of this design, a 12-inch diameter borehole was augered through the upper contaminated zone and an appropriate length of 8-inch diameter steel casing was cemented into the hole (except in the case of site 2 well An:D-8 and D-9 and site 5 well An:E-1, where the surface casing was inadvertently installed in too short a length to completely seal off the contaminated zone). Lengths of surface casing used for each well were determined by the depth of mercury contamination (as identified by soil sampling and analysis) at each well location. After the cement had hardened, each borehole was completed to bedrock (as required for all wells by the USEPA) by drilling through the surface casing with 6-inch diameter augers. For wells at "low-level" and background sites, the installation of surface casing was omitted. At these sites, a 6-inch diameter borehole was augered from land surface to refusal. Schematic diagrams of the two shallow observation-well construction designs used for this investigation are shown in figure 5.

Upon completing the 6-inch diameter boreholes for each well, the auger flights were removed and an appropriate length of screen and casing were connected together and lowered into the hole. Due to the cohesiveness of the materials penetrated while drilling, all boreholes remained open after the auger flights were removed. For most wells, screen lengths were selected based upon the distance between the water table and top of bedrock at the time of drilling. However, because of drought conditions which were occurring throughout the southeastern United States during August 1986, bedrock was encountered before reaching the water table in a few of the boreholes in the study area and at the First Creek background site. At these locations, screen lengths were selected based upon both depth to bedrock and estimates of the water-table altitude above bedrock during wetter periods of the year.

After emplacing the casing and screen, the annular space adjacent to the entire screened interval was backfilled with sand. Bentonite pellets were then emplaced above the sand, creating a seal layer at least 6-inches thick in each well to prevent the downward migration of fluids in the annular space around the casing. The remainder of the annular space was then filled to land surface with cement and a well protector was installed over that part of the casing rising above land surface.

Two drilling methods were used for observation-well installations. Where site access was not a problem, a trailer-mounted auger rig and 5-foot long hollow-stem auger flights were used. Where access with the trailer-mounted rig was unobtainable, a portable, gasoline-powered auger with 3-foot long solid-stem auger flights was used. This drilling method performed satisfactorily except at the

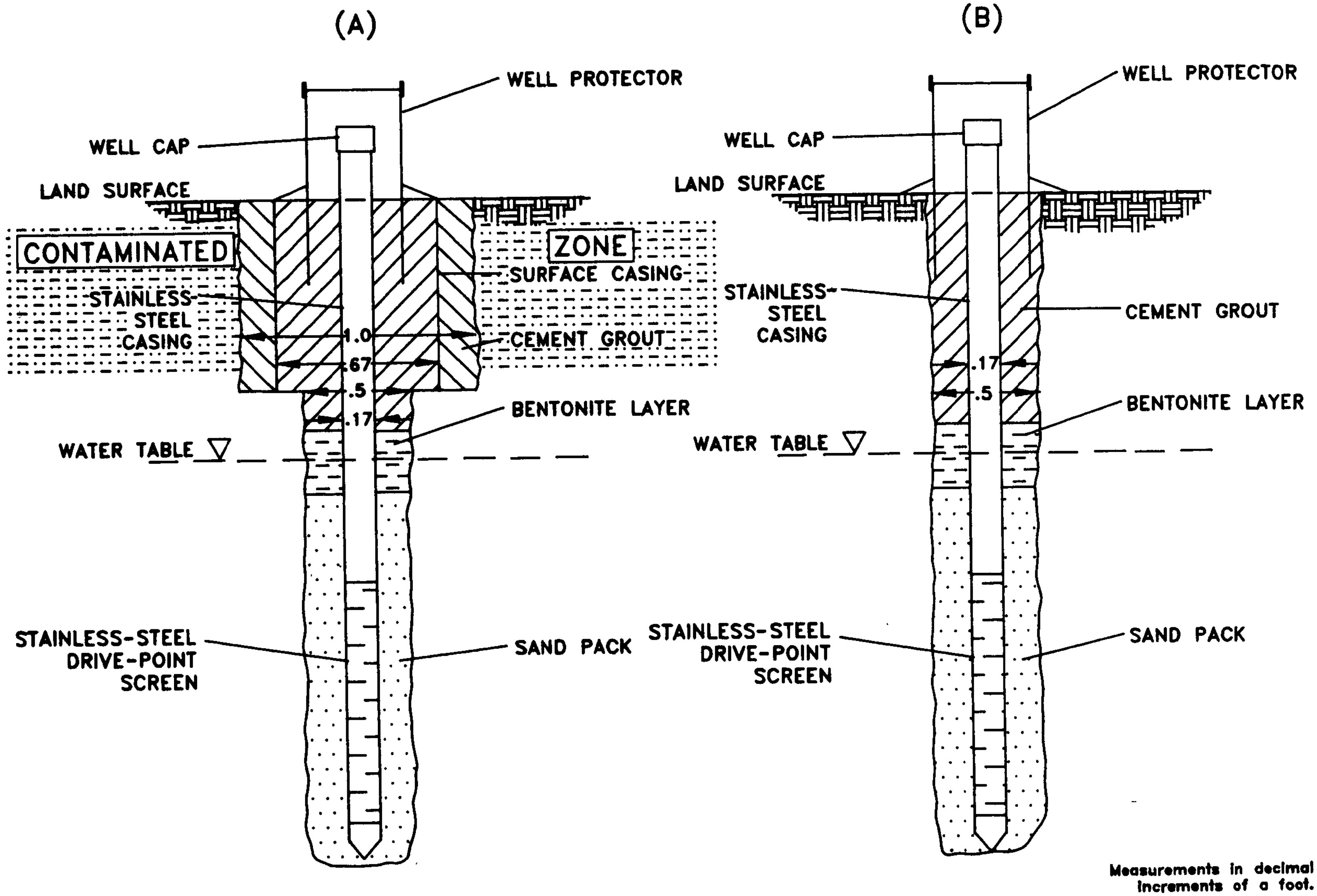


Figure 5.--Generalized construction of observation wells installed at (A) contaminated sites and (B) "low-level" and background sites.

site 2 well locations south of East Fork Poplar Creek (wells An:D-9 through 11). At these locations, the glei horizon underlying the flood-plain alluvium was relatively thick and the portable auger would not penetrate its entire thickness. Therefore, wells An:D-9, 10, and 11 were not completed to bedrock. The drilling method used to install each well is listed in table 1. Construction data for each well are shown in figures 6 through 19.

SITE LITHOLOGY AND SOIL-MERCURY CONCENTRATIONS

Lithologic descriptions of the soil horizons penetrated while drilling the observation wells and graphic representation of ORAU soil-analysis data showing mercury concentrations with depth at all well locations (except the First Creek background site, where soil-mercury samples were not collected) are shown in figures 6 through 19.

DEVELOPMENT AND YIELDS

After all of the observation wells were completed, they were developed to remove fine formation sediment from the borehole walls adjacent to the screened intervals in order to maximize yields during sample collection. However, the low water table in the study area and at the background sites delayed completion of this task until January 1987, at which time water levels in

Table 1.--*Drilling method, time in development, and estimated maximum yield of observation wells in the study area and at background sites*

Well No./Site No.	Drilling method	Time in development, in hours	Estimated maximum yield, in gallons per minute
An:D-1/1	Portable Auger	2	1/4
An:D-2/1	do	2	1/4
An:D-3/1	do	2	<1/4
An:D-4/1	do	2	<1/4
An:D-5/1	do	2	<1/4
An:D-6/1	do	2	<1/4
An:D-7/2	Trailer-mounted auger rig.	1	<1/4
An:D-8/2	do	3	<1/4
An:D-9/2	Portable auger	3	3/4
An:D-10/2	do	4	1/4
An:D-11/2	do	4	1/4
An:D-12/3	Trailer-mounted auger rig.	8	1/4
An:D-13/4	do	8	1/4
An:E-1/5	do	4	1/4
An:D-14/6	do	4	1/4
An:E-2/7	Portable auger	3	1/4
Kn:G-1/Ten Mile Creek background site	Trailer-mounted auger rig.	3	3/4
Kn:H-1/First Creek background site	do	--	--