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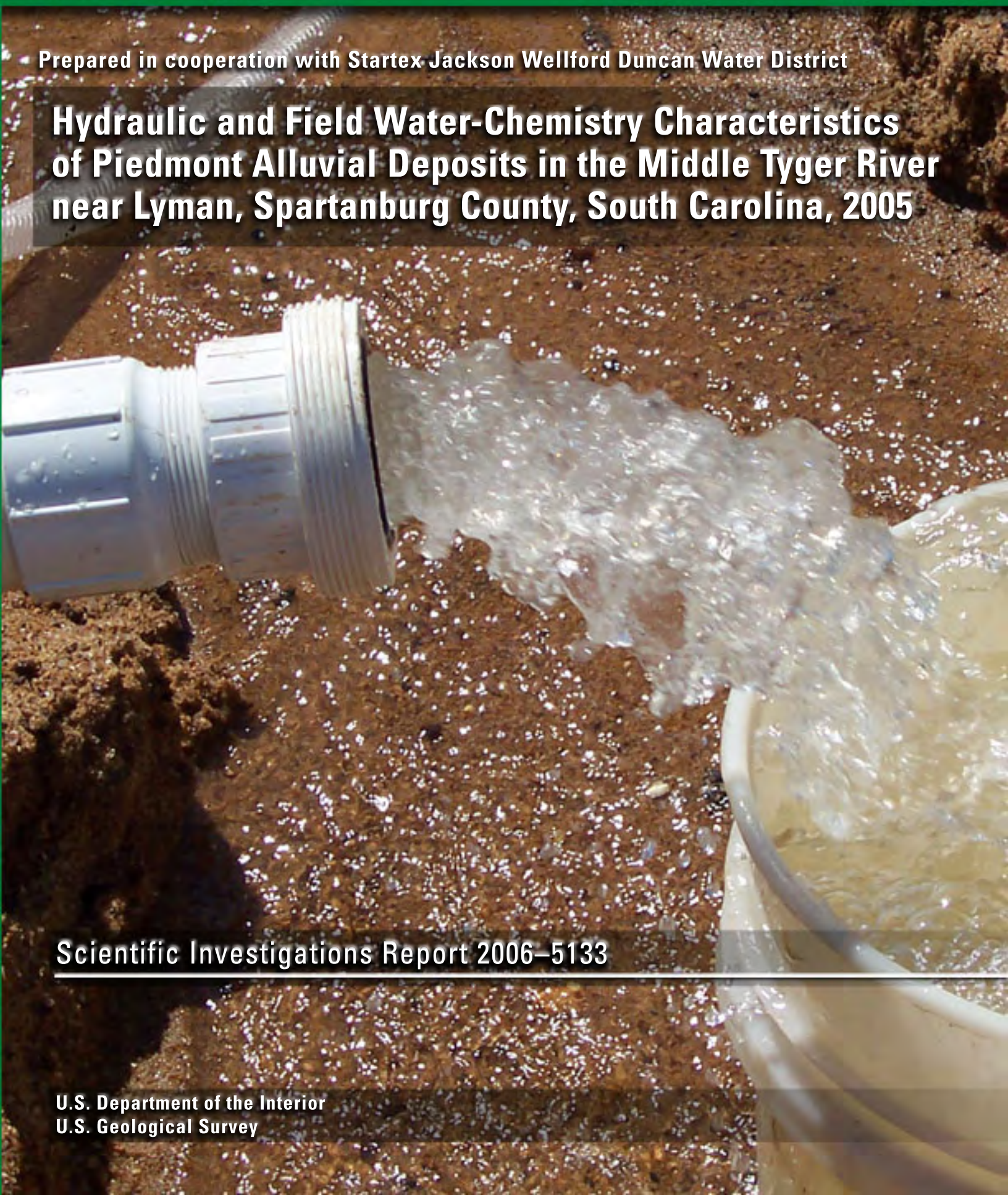

Prepared in cooperation with Startex Jackson Wellford Duncan Water District

Hydraulic and Field Water-Chemistry Characteristics of Piedmont Alluvial Deposits in the Middle Tyger River near Lyman, Spartanburg County, South Carolina, 2005

Scientific Investigations Report 2006–5133

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

Front Cover Image:
Pore-water discharge after 1 hour and 15 minutes of pumping from the temporary observation well SP–3150 constructed in the channel sediments of the Middle Tyger River near Lyman, Spartanburg County, South Carolina, September 8, 2005

Back Cover Image:
Initial pore-water discharge from the temporary observation well SP–3150 constructed in the channel sediments of the Middle Tyger River near Lyman, Spartanburg County, South Carolina, September 8, 2005

Photographs from U.S. Geological Survey files

Design:
James R. Douglas, U.S. Geological Survey

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By Larry G. Harrelson and Adrian D. Addison

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U.S. Geological Survey

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Conversion Factors

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
	Area	
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
	Flow rate	
liter per second (L/s)	15.85	gallon per minute (gal/min)

In this report, right and left refer to directions that would be reported by an observer facing downstream.

Temperature may be converted as follows:

$$°F = (1.8 \times °C) + 32$$

$$°C = (°F - 32) / 1.8$$

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Hydraulic and Field Water-Chemistry Characteristics of Piedmont Alluvial Deposits in the Middle Tyger River near Lyman, Spartanburg County, South Carolina, 2005

By Larry G. Harrelson[1] and Adrian D. Addison[2]

Abstract

This study explores the possibility of developing a bank-filtration process to improve water quality in which alluvial deposits serve as a natural sand filter to pretreat water to be used as a secondary drinking-water source in a small piedmont reservoir along the Middle Tyger River near Lyman in Spartanburg County, South Carolina. From January 2004 to September 2005, data from 10 auger borings, 2 sediment cores, 29 ground-penetrating radar transects, and 3 temporary observation wells, and field water-chemistry data were collected and analyzed. These data were collected and used to characterize the lithology, geometry, hydraulic properties, yield potential, and water-chemistry characteristics of the alluvial deposits in the channel and on the right bank of the reservoir. The assessment was undertaken to determine if an adequate amount of water could be withdrawn from the alluvial deposits to sustain a bank-filtration process and to characterize the water chemistry of the surface water and pore water.

The heterogeneous alluvial and fill material at the study site—clay, silty clay, clayey sand, fine- to coarse-grained sand, and mica—on the right bank of the Middle Tyger River ranges in thickness from 0.6 to 7 meters, has a calculated horizontal hydraulic conductivity of 1 meter per day, and yields approximately 0.07 liter per second of water. The small calculated horizontal hydraulic conductivity and water yield for these deposits restrict the use of the right bank as a potential bank-filtration site.

The coarse-grained alluvial sand deposit in the channel of the Middle Tyger River, however, may be used for a limited bank-filtration process. The discharge during pumping of the channel deposit yielded water at the rate of 1.9 liters per second. The coarse-grained channel deposit is approximately 49 meters wide and 3 meters thick near the dam. At approximately 183 meters upstream from the dam, the channel narrows to roughly 9 meters and the channel deposits thin to approximately 0.1 meter. Slug tests conducted in the channel deposits near the dam produced a calculated horizontal hydraulic conductivity of 60 meters per day. The limited thickness and aerial extent of the coarse-grained channel deposits coupled with large horizontal hydraulic conductivity likely would allow rapid transmission of water and may degrade the effectiveness of some water-chemistry improvements typical of a bank-filtration process.

Field water-chemistry data were collected for approximately 1 hour and 45 minutes at 10 to 15 minute intervals to compare the surface-water and pore-water quality in and beneath the channel of the Middle Tyger River. The water-chemistry data indicate that (1) the mean water temperature was higher in surface water (22.5 degrees Celsius) than in pore water (18.5 degrees Celsius), (2) the mean specific conductance was less in surface water (56.9 microsiemens per centimeter at 25 degrees Celsius) than in pore water (125.7 microsiemens per centimeter at 25 degrees Celsius), (3) alkalinity was lower in surface water (22.5 milligrams per liter) than in pore water (44.6 milligrams per liter), and (4) recorded pH values ranged between 6.2 and 6.3 in the surface water and pore water during the sampling period. The flow velocity was orders of magnitude slower in the pore water than in the surface water; therefore, the pore water interacts with the alluvial sediment for a longer period of time producing the variation in water-chemistry data between the two waters.

Introduction

For over 100 years, bank filtration has been used as a natural process for improving source-water quality in Germany and other European countries. Recently, water utilities in the United States have shown an interest in bank filtration to treat raw surface water, thereby reducing the expense associated with traditional surface-water treatment processes (Tufenkji and others, 2002). In the bank-filtration process, surface water is artificially forced through clastic deposits adjacent to or below the channel of a river, stream,

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or waterbody. Ideally, filtered surface water combines with shallow ground water and is extracted by a well at a specified distance from the surface-water source. The magnitude of the improvement in source-water quality is controlled primarily by the amount of time the filtrate is in direct contact with the subsurface sediment and the length of the flow path between the subsurface sediment and the point of extraction. In general, a longer flow path provides additional contact time between the water and the subsurface sediment and, thus, greater opportunity for removal or degradation of suspended particles, viruses, parasites, and inorganic and organic compounds.

The bank-filtration process may not be practical in areas where the horizontal hydraulic conductivity or permeability of the clastic sediment is large and does not allow sufficient residence time underground to improve the quality of the water. Conversely, this process may not work in areas where the horizontal hydraulic conductivity or permeability of the clastic sediment is small, thus limiting the quantity of water that can be extracted (Kuehn and Mueller, 2000).

The geologic lithologies that compose the piedmont landscape are not well suited conventionally for use in a bank-filtration process. The differential weathering of parent rock in the Piedmont Physiographic Province produces regolith or saprolite. This saprolite and the underlying fractured basement rock do not possess the characteristics required for a bank-filtration process. These complex issues have limited the development and use of bank filtration by water utilities in the South Carolina Piedmont. In the piedmont region of the Southeastern United States where the lithology, geometry, hydraulic properties, withdrawal potential, and water chemistry of alluvial deposits are appropriate for a bank-filtration process, water utilities could use these deposits as a pretreatment filter to improve the quality of source water and thereby reduce the amount of traditional water treatment required.

Typically, a river or stream in the South Carolina Piedmont is dammed to form a reservoir for use as a source-water supply. Such an impoundment allows surface water to be stored and regulated. As the surface water from a river or stream enters the impoundment, the stream velocity decreases and causes suspended sediment and other solids to fall from the water column and settle on the streambed. These alluvial deposits may extend some distance upstream from a dam. This type of sediment deposition occurs in the Middle Tyger River channel adjacent to the Startex Jackson Wellford Duncan (SJWD) Water District Water Treatment Plant study area (fig. 1). Excavations along the right bank and in the channel of the Middle Tyger River indicated the presence of alluvial deposits that potentially could be used as a pretreatment filter (Black and Veatch, Engineers, Greenville, South Carolina, written commun., 1999). In this report, right and left refer to directions that would be reported by an observer facing downstream.

The SJWD Water District is in a rapidly growing area of Spartanburg County, South Carolina (fig. 1). Historically, surface water released from Lyman Lake on the Middle Tyger River has been the primary source of raw water for the utility. Raw water is extracted from a shallow reservoir located behind a low-head dam at the SJWD Water District Water Treatment Plant adjacent to the Middle Tyger River near Lyman, South Carolina (fig. 1). In 2005, the SJWD Water District withdrew and processed approximately 8.3 billion liters of raw water from the Middle Tyger River (D. Holliday, Startex Jackson Wellford Duncan Water District, written commun., 2005).

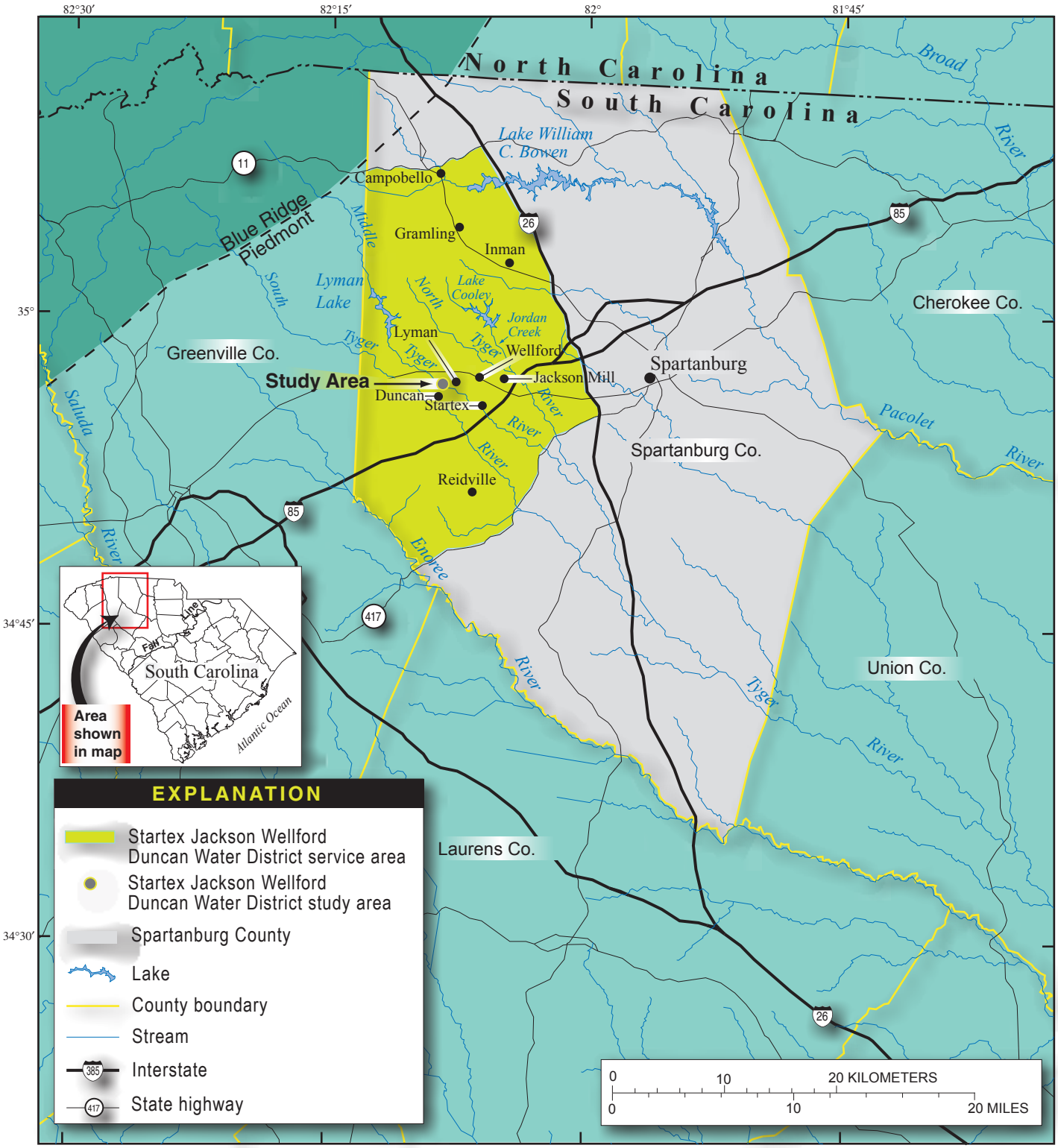
From January 2004 to September 2005, the U.S. Geological Survey (USGS), in cooperation with the SJWD Water District, conducted an investigation to collect, compile, and interpret the geotechnical, hydraulic, and ground-penetrating radar data needed to determine the water-transmitting properties, thickness, and aerial extent of the alluvial deposits in the SJWD Water District study area. Basic water-chemistry data (pH, temperature, specific conductance, and alkalinity) also were collected to examine the water chemistry of the surface water and pore water (the water present in the pore spaces of sediments) in and beneath the Middle Tyger River. This investigation was designed to explore the possibility of using alluvial deposits in a piedmont reservoir as a natural filter in a bank-filtration process to pretreat water to be used as a secondary drinking-water source. The study findings will enhance the understanding of basic water chemistry and capacity of piedmont alluvial deposits to transmit water, and provide the SJWD Water District with quantitative data to evaluate the potential of bank filtration to supplement its source of raw surface water.

This site-specific study quantifies the lithology, geometry, hydraulic properties, yield potential, and water-chemistry characteristics of piedmont alluvial deposits and provides water managers with the required knowledge to evaluate the potential of bank filtration. The use of ground-penetrating radar as a passive geophysical tool to define the geometry of piedmont alluvial sediments helps to advance the knowledge of the capability of this methodology for future studies. The geotechnical and hydraulic data help to advance the understanding of the composition and hydraulic characteristics of piedmont alluvial deposits.

Bank filtration provides an important option for water utilities in reducing costs associated with established water-treatment technologies. This option also is true for water utilities near surface-water resources connected to adjacent shallow aquifer(s) or in piedmont localities with similar geotechnical, hydraulic, and water-chemistry characteristics. The results of this investigation will be transferable to other water utilities in the Southeastern Piedmont region of the United States.

Purpose and Scope

The purpose of this report is to present the relations among the lithology, geometry, hydraulic properties, yield potential, and basic water-chemistry characteristics of the alluvial deposits in and adjacent to the Middle Tyger River, and to explore the possibility of using these alluvial deposits



Base from U.S. Geological Survey 1:24,000-, 1:100,000-, and 1:500,000-scale digital line graphs. UTM projection, zone 17, datum NAD27.

Figure 1. Locations of the Startex Jackson Wellford Duncan Water District service and study areas near Lyman, Spartanburg County, South Carolina.

as a natural filter in a bank-filtration process to pretreat water to be used as a secondary drinking-water source. This report includes lithologic descriptions for alluvial sediments taken from auger borings and sediment cores. The vibracore, an instrument used for sediment collection, could not penetrate the full thickness of the alluvial deposit because of the frictional forces exerted by the sediment against the interior of the core barrel. Therefore, sediment recovered from these two cores was limited to 1 meter (m) and 0.6 m. The alluvial deposits in the river channel, however, are homogeneous in texture and composition. Because of the similarity in the texture and composition of the two sediment cores, only data from the 1-m core are discussed in this report.

Ground-penetrating radar data were collected, processed, and interpreted to determine the geometry of the sediments. Basic water-chemistry data are given for surface water and pore water in and beneath the Middle Tyger River. Interpretations are limited to a generalized discussion of the potential feasibility of using the alluvial sediments as a bank-filtration medium.

Previous Investigations

Previously published results from numerous investigations provide an abundance of literature describing the bank-filtration technique and resulting water-quality improvement efficiencies for sites in Europe, China, the United States, and other countries. Generally, these studies were completed in areas with relatively thick and areally extensive aquifers or alluvial deposits connected to a surface-water source. Considerable information has been published in reports, journal articles, and text books that provides an understanding of the physical and chemical processes at work during the operation of a bank-filtration site. For this study, two publications were used to provide an overview of the bank-filtration process. Kuehn and Mueller (2000) published an article that gave an overview of the bank-filtration process, and Tufenkji and others (2002) published an article that described bank filtration in terms of a technology that may inexpensively improve poor-quality raw surface water.

In contrast to the larger studies, this study is in the Piedmont Physiographic Province of South Carolina in an area consisting of thin and areally limited alluvial deposits. No previous investigation describing the geotechnical, hydraulic, and chemical conditions of piedmont alluvial deposits in South Carolina has been published. One report relative to this study is Bloxham and others (1970), which presents a comprehensive description of the water resources of Spartanburg County, South Carolina.

Description of Study Area

The study area is in the Middle Tyger River watershed downstream from Lyman Lake on the Middle Tyger River behind and adjacent to a low-head dam that impounds the river water next to the SJWD Water District Water Treatment Plant (fig. 1). In the study area, thin alluvial deposits are present on the right bank and in the channel of the Middle Tyger River near Lyman in Spartanburg County, South Carolina (fig. 1). Along the right bank is a narrow area consisting of flood-plain deposits that range from approximately 20 m to 50 m wide. The flood plain is clear cut near the low-head dam and has thick riparian vegetation upstream from the dam. The river channel (reservoir) consists of an alluvial deposit that is approximately 49 m wide near the dam and narrows to approximately 9 m at a distance of 183 m upstream from the dam.

The annual mean precipitation for the Middle Tyger River watershed ranged from approximately 127 centimeters (cm) to 152 cm for the period of record 1961 to 1990 (Eidson and others, 2005). The Middle Tyger River watershed (hydrologic unit 0305010701) has a drainage area of approximately 92 square kilometers (km^2) and is in the Tyger River sub-basin (hydrologic unit 03050107; fig. 2). Lakes and ponds cover approximately 2.3 km^2 of the watershed. Land use in the watershed includes approximately 63 percent forest, 22 percent agricultural, 11 percent urban, 2 percent shrub, less than 1 percent barren land, and 1 percent water (South Carolina Department of Environmental Control, 2001). Based on short periods of record, the annual mean surface-water discharge in the Middle Tyger River at USGS streamgaging stations 02157470, Middle Tyger River near Gramling, South Carolina (period of record 2002–04), and 02157510, Middle Tyger River near Lyman, South Carolina (period of record 2000–04), is 2.0 cubic meters per second (m^3/s) and 2.4 m^3/s, respectively (fig. 2). Based on these same periods of record, the annual mean runoff from precipitation and ground-water discharge to the Middle Tyger River watershed for gaging stations 02157470 and 02157510 is 0.028 cubic meter per second per square kilometer ($(m^3/s)/km^2$) and 0.016 $(m^3/s)/km^2$, respectively (Cooney and others, 2005). Based on longer periods of record, the annual average surface-water discharge at USGS streamgaging stations 02157500, Middle Tyger River at Lyman, South Carolina (period of record 1938–67), and 02160105, Tyger River near Delta, South Carolina (period of record 1973–2005), located below the confluence of the North, Middle, and South Tyger Rivers, is 2.9 m^3/s and 27.8 m^3/s, respectively (U.S. Department of the Interior, 1967; Cooney and others, 2005). Based on the 1973–2005 period of record, the annual mean runoff at streamgaging station 02160105 is 0.018 $(m^3/s)/km^2$ (Cooney and others, 2005). In an earlier study of the water resources of Spartanburg County, South Carolina, an annual runoff for the Middle Tyger River watershed was reported to be 0.016 $(m^3/s/)km^2$ (Bloxham and others, 1970). Other sources of water for the SJWD Water District are Lake Cooley and the North Tyger River reservoir (fig. 2).

The study area and the SJWD service area are situated in the Piedmont Physiographic Province of South Carolina (fig. 1). The Piedmont Province consists of gently rolling uplands that slope progressively toward the Fall Line

Base from U.S. Geological Survey 1:24,000-, 1:100,000-, and 1:500,000-scale digital line graphs. UTM projection, zone 17, datum NAD27.

Figure 2. Locations of U.S. Geological Survey streamgaging stations, North Tyger River reservior, Tyger River subbasin, and Middle Tyger River watershed in Greenville, Spartanburg, and Union Counties, South Carolina.

(Bloxham and others, 1970). Underlying the study area are metamorphosed sedimentary and volcanic rocks of the Inner Piedmont Belt of Upper Precambrian and Cambrian age (Overstreet and Bell, 1965).

Description of the Bank-Filtration Process

The bank-filtration process incorporates the natural filtration capacity of sediment and the physical and biological processes that take place in the subsurface beneath or beside a river, stream, or waterbody to remove waterborne contaminants (Kuehn and Mueller, 2000). Changes in the physical and biological processes taking place in the surface water or pore water may enhance or degrade the efficiency of the bank-filtration process and can vary temporally and seasonally. Study over extended periods of time is needed to determine the efficiency of the bank-filtration process under changing physical and biogeochemical conditions (Tufenkji and others, 2002).

The hydraulic behavior and quantity of water available have an important influence on the efficiency and operation of the bank-filtration process. The bank-filtration process is not feasible if either of the following two conditions exist: (1) the hydraulic conductivity or transmissivity of the geologic strata is too small to allow the transmission of water through the sediment, or (2) the hydraulic conductivity or transmissivity of the geologic strata is too large to allow sufficient residence time for water to remain underground for the physical and biological processes to improve the water chemistry or remove contaminants (Kuehn and Mueller, 2000). An adequate supply of water in a river, stream, waterbody, or associated shallow aquifer must consistently provide water to wells. Temporal increases or decreases in the amount of water available affect the efficiency of the bank-filtration process. Changes in water temperature may affect the rate of infiltration and the effectiveness of biological processes responsible for many of the improvements in water quality (Tufenkji and others, 2002).

Contamination in the source water must not exceed levels that can be improved sufficiently by the physical or biological processes taking place in the subsurface (Kuehn and Mueller, 2000). Variations in pH, water temperature, sediment load, dissolved oxygen, inorganic and organic compounds, nutrient, and microorganism concentrations, and any other potential contaminants in the water can affect the efficiency of the bank-filtration process (Kuehn and Mueller, 2000).

During low-flow conditions, water passing through the external openings in the bank sediment contains minute suspended particles that can clog the surficial pore space of the sediment, thereby reducing the effective porosity. Clogging within the topmost layer and in the deeper layer (produced by deep filtration) may form a seal or skin along and below the interface between the surface water and pore water. Microbial activity also may clog the interface between the surface water and pore water by the accumulation of bacterial cells, bacterial gases produced by organic degradation, and extracellular polymeric biofilm substances (Tufenkji and others, 2002). Any single or combination of the aforementioned sedimentary or biological factors may substantially reduce the permeability of the bank sediments, which also reduces the vertical and horizontal hydraulic conductivity. Reduction in the hydraulic conductivity of the sediment can substantially reduce the quantity and quality of water extracted from wells (Tufenkji and others, 2002).

Data-Collection Methods

Data for this investigation were collected from January 2004 to September 2005. Auger borings, sediment cores, ground-penetrating radar (GPR) transects, pore-water discharge measurements, slug tests, and field water-chemistry data were collected in and adjacent to the Middle Tyger River near the SJWD Water District Water Treatment Plant. The auger borings, sediment cores, and GPR data were used to characterize the lithology and geometry of the alluvial deposits. Two observation wells were completed in selected auger boring, and one well was completed in the river channel sediment. These temporary wells were used to determine the water-yielding capacity and to estimate the horizontal hydraulic conductivity for the alluvial deposits. Field water-chemistry data were used to compare the basic water chemistry of the surface water and pore water.

Lithologic Characteristics of the Alluvial Deposits

To determine the lithology and geometry of the alluvial deposits during this investigation, 10 auger borings were drilled on March 7, 2005, and 2 sediment cores were drilled on August 18, 2005, and September 8, 2005, at the study site. The auger borings and sediment cores were drilled along the right bank and in the channel of the Middle Tyger River, respectively (fig. 3). The auger borings were drilled by using a track-mounted auger rig. Analysis of the auger-boring data revealed that the alluvial deposits along the right bank consist of heterogeneous fill material, clay, silty clay, clayey sand, fine- to coarse-grained sand, and minor amounts of mica (table 1).

Along the auger-boring transect, the auger-penetration depths ranged from 0.6 m at AH–8 to 7.0 m at AH–9 (table 1). Auger borings were terminated when the auger bit encountered basement rock or the material produced by the boring was primarily clay or regolith. The auger-boring data indicated that the thicknesses of the alluvial deposits in the study area are variable. Located near the low-head dam, auger borings AH–1 and AH–10 penetrated the alluvial sediment to a depth of 6 m and 6.4 m, respectively (table 1; fig. 3). Auger borings AH–2 through AH–7 were drilled progressively farther upstream from the low-head dam and revealed that the thicknesses of the alluvial deposits ranged from 3 to 4.3 m. The

Aerial images from S.C. Department of Natural Resources digital orthophoto quarter quadrangles, Wellford, S.C., northwest, 1999 and Greer, S.C., northeast, 1999.

Figure 3. U.S. Geological Survey auger borings, sediment cores, and temporary observation wells SP–3142, SP–3143, and SP–3150 near Lyman, Spartanburg County, South Carolina.

Table 1. Generalized lithologic descriptions of auger borings along the right bank of the Middle Tyger River near Lyman, Spartanburg County, South Carolina.

[—, no data]

Auger boring identifier (fig. 3)	Latitude	Longitude	Sample interval depth (meters below land surface)	Generalized lithologic description	Lithologic color (Geological Society of America, 1991)
AH–1	34°56'21.9"	82°07'29.6"	0–0.6	Fill material and clay	Dark yellowish brown, 10YR 4/2
			0.6–1.5	Clay	Olive gray, 5Y 4/1
			1.5–3.0	Medium-grained sand	Dark yellowish brown, 10YR 4/2
			3.0–4.5	Coarse-grained sand	Dark yellowish brown, 10YR 4/2
			4.5–6.0	Silty clay with a minor amount of sand	Olive gray, 5Y 4/1
AH–2	34°56'22.3"	82°07'30.6"	0–1.0	Clayey, fine-grained sand	Moderate brown, 5YR 3/4
			1.0–4.1	Medium- to coarse-grained sand	Moderate brown, 5YR 4/4
AH–3	34°56'22.6"	82°07'31.3"	0–0.3	Root mat	—
			0.3–3.0	Clayey, fine-grained sand	Moderate brown, 5YR 3/4
AH–4	34°56'22.6"	82°07'32.8"	0–0.1	Root mat	—
			0.1–1.2	Medium, coarse-grained sand	Dark yellowish brown, 10YR 4/2
			1.2–2.4	Medium, coarse-grained sand	Dark yellowish brown, 10YR 4/2
			2.4–3.6	Clayey, fine-grained sand	Dark yellowish brown, 10YR 4/2
AH–5	34°56'22.5"	82°07'33.7"	0–3.6	Clayey, fine-grained sand	Moderate brown, 5YR 3/4
			3.6–4.3	Silty clay with a minor amount of sand	Olive gray, 5Y 4/1
AH–6	34°56'23.0"	82°07'34.4"	0–1.2	Coarse-grained sand	Moderate brown, 5YR 3/4
			1.2–2.4	Medium, course-grained sand	Dark yellowish brown, 10YR 4/2
			2.4–3.0	Medium- to course-grained sand with a minor amount of clay	Dark yellowish brown, 10YR 4/2
AH–7	34°56'22.9"	82°07'34.0"	0–3.6	Coarse-grained sand	Moderate brown 5YR 3/4
AH–8	34°56'22.4"	82°07'34.7"	0–0.6	Saprolite	Dark reddish brown, 10R 3/4
AH–9	34°56'21.9"	82°07'28.4"	0–0.6	Fill material and clay	Dark yellowish brown, 10YR 4/2
			0.6–1.5	Sticky clay	Olive gray, 5Y 4/1
			1.5–3.4	Medium-grained sand	Dark yellowish brown, 10YR 4/2
			3.4–4.9	Clayey, fine-grained sand	Dark yellowish brown, 10YR 4/2
			4.9–7.0	Silty clay with minor sand and mica	Olive gray, 5Y 4/1
AH–10	34°56'22.7"	82°07'20.2"	0–1.0	Fill material	Dark yellowish brown, 10YR 4/2
			1–2.4	Fine-grained sand with a minor amount of clay	Moderate yellowish brown, 10YR 5/4
			2.4–3.6	Medium-grained sand	Dark yellowish brown, 10YR 4/2
			3.6–5.5	Fine- to medium-grained sand	Dark yellowish brown, 10YR 4/2
			5.5–6.4	Silty clay with minor amounts of sand and mica	Olive gray, 5Y 4/1

shallowest auger boring (AH–8) was drilled in the regolith and was terminated at 0.6 m (table 1; fig. 3). Auger borings AH–1 and AH–9 were used to construct temporary observation wells to investigate the horizontal hydraulic conductivity and the potential ground-water discharge of these alluvial deposits.

After lowering the water level and exposing the river channel behind the low-head dam on the Middle Tyger River, two sediment cores were collected from the river channel deposits (fig. 3). The sediment cores were obtained by using vibracore equipment provided by the Department of Geological Sciences, University of South Carolina.

A laser particle-size analyzer also provided by the Department of Geological Sciences, University of South Carolina, was used to analyze the grain-size distribution of the cored sediment. The core sediments were analyzed in a top-down manner throughout the 1-m (100-cm) core. Samples were taken at 5 cm, 20 cm, 30 cm, 72 cm, and 92 cm. Selected geotechnical data for all sampling depths are presented in tables 2 and 3 and figure 4.

The grain-size analyses of the channel sediment indicate that the mean grain size was between 0.65 millimeters (mm) and 0.70 mm. The mean grain-size for a sample is the arithmetic mean or average, which is the sum of all the grain-size data for a selected sample divided by the number of data samples. The median grain size of the samples ranged between 0.70 mm and 0.76 mm at all sample depths (table 2). The median grain size for a sample indicates that half of the grains are coarser and half are finer than the median grain diameter of the sample (Tucker, 1995). The modal classification of 0.91 mm for all sample depths (table 2) represents the most common grain size calculated from the grain-size distribution in the samples (Tucker, 1995). The core-sample analyses provided the skewness values, ranging from –0.95 to –1.38 for all sample depths (table 2), which is representative of very coarse material. Skewness is a positively or negatively signed dimensionless number that lies within the range –1 to 1. The skewness of a sediment sample has a positive or negative value when finer or coarser material are present than in a normal grain-size distribution. Skewness is a statistical parameter determined from the mean grain size of a sample less the median grain size, divided by the range of grain sizes used in defining the mean grain size in the sample (Tucker, 1995). Table 3 and figure 4 illustrate the percent grain-size distribution for 5-, 20-, 30-, 72-, and 92-cm sampling intervals.

Table 2. Selected soil-property data from a laser particle-size analysis of sediment cored in the channel of the Middle Tyger River near Lyman, Spartanburg County, South Carolina.

Selected soil property data	Sample depth of sediment core				
	5 centimeters	20 centimeters	30 centimeters	72 centimeters	92 centimeters
Mean grain size, in millimeters	0.69	0.67	0.66	0.70	0.65
Median grain size, in millimeters	0.74	0.72	0.72	0.76	0.70
Modal classification, in millimeters	0.91	0.91	0.91	0.91	0.91
Skewness	–1.20	–1.04	–1.06	–1.38	–0.95

Table 3. Results of a laser grain-size analysis showing the percentage of the sample that is less than the grain size indicated for selected sampling depths of the channel sediment core from the Middle Tyger River near Lyman, Spartanburg County, South Carolina.

Percentage of sample less than designated grain size	Grain size, in millimeters, at 5 centimeters below top of core	Grain size, in millimeters, at 20 centimeters below top of core	Grain size, in millimeters, at 30 centimeters below top of core	Grain size, in millimeters, at 72 centimeters below top of core	Grain size, in millimeters, at 92 centimeters below top of core
10	0.41	0.36	0.34	0.41	0.36
25	0.59	0.55	0.54	0.62	0.53
50	0.74	0.72	0.72	0.76	0.70
75	0.85	0.84	0.84	0.85	0.83
90	0.91	0.90	0.90	0.91	0.90

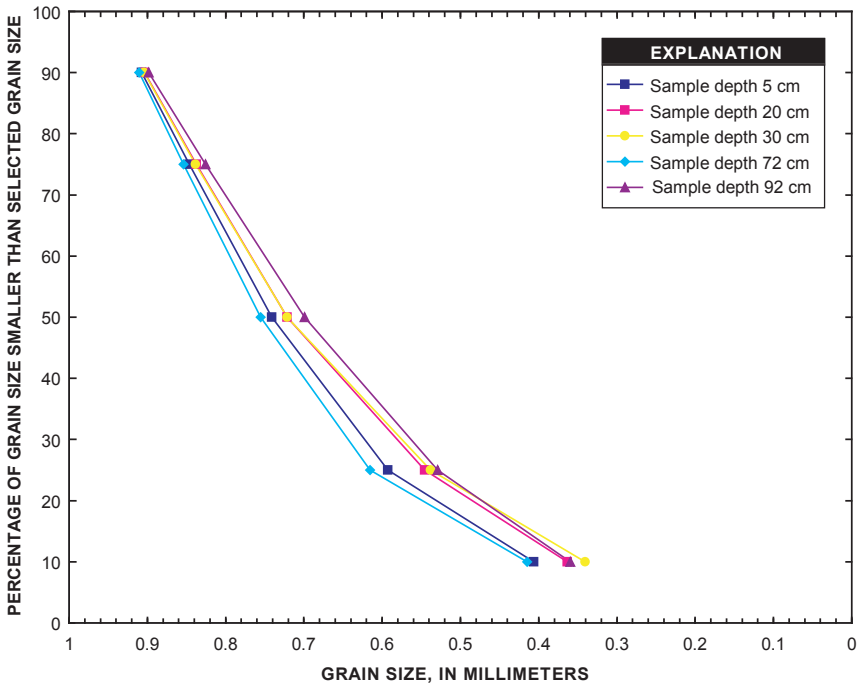


Figure 4. Percentage of alluvial sediment grain size smaller than selected grain size for selected sampling depths from the Middle Tyger River channel sediment core near Lyman, Spartanburg County, South Carolina.

Description of Ground-Penetrating Radar System

Ground-penetrating radar (GPR) is a geophysical method that measures electrical impedance differences in subsurface features at high resolution in the vertical and horizontal plains. The GPR was used for this investigation because it has many advantages over other techniques—GPR is mobile, non-intrusive, capable of rapid data acquisition, and cost-effective. Additionally, the GPR data provide near real-time interpretation capabilities. These qualities make GPR an attractive tool for studying the shallow subsurface.

The GPR emits an electromagnetic (EM) pulse into the subsurface through a transmitting antenna and records the echoes from underground changes in electrical properties through a receiving antenna. Similar to traditional seismic methods, these echoes produce a radar image that is subsequently processed and interpreted. The difference between seismic reflections and GPR echoes is that seismic reflections are produced by changes in the subsurface of elastic velocities and densities; the GPR echoes represent changes in dielectric permittivity, magnetic permeability, and electrical conductivity, often delineating subsurface interfaces that cannot be seen in seismic-reflection data (Baker and others, 2001).

The GPR data were collected by using three antennas that emitted frequencies of 50, 100, and 250 megahertz (MHz) in common-offset and central midpoint (CMP) reflection-acquisition modes. The common-offset mode was used as a single-fold profiling tool for large spatial coverage, and the CMP mode was used for velocity analysis and additional calibration with the common-offset mode (fig. 5). During this investigation, 29 GPR transects were completed to facilitate the delineation of the alluvial deposits near the SJWD Water

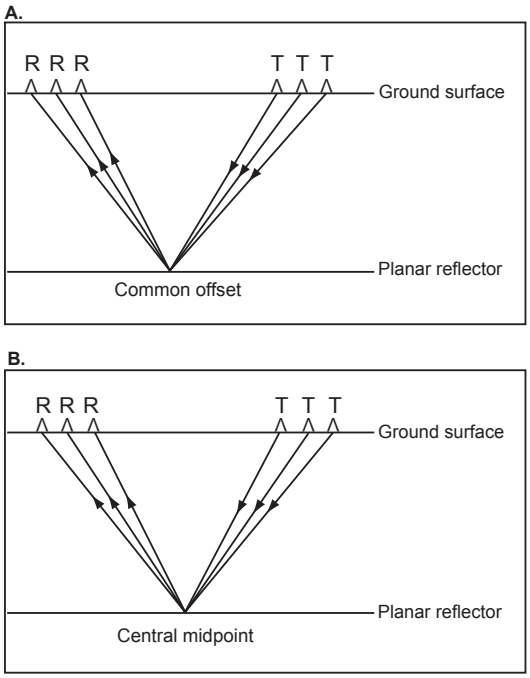


Figure 5. Generalized examples of gound-penetrating radar (A) common-offset and (B) central midpoint data acquisition modes.

District Water Treatment Plant. These data were collected to define the geometry of the alluvial deposits and also to verify the effectiveness of the GPR as a viable tool in the evaluation of the stratigraphy at a piedmont bank-filtration site.

Ground-Penetrating Radar Data Collection

During several site visits, GPR data were collected along both banks and in the river channel near the low-head dam. The GPR data were collected to assist in the determination of the dimensions of the alluvial deposits for the evaluation of bank filtration at the study site. Determination of the thickness and geometry of the alluvial deposits is central to the evaluation of a bank-filtration site. GPR data also were collected as far as 125 m upstream from the low-head dam to investigate the thickness and geometry of the alluvial sediments. In addition to the GPR data, global-positioning system (GPS) data were collected to provide accurate positional data for the GPR transects and to define accurate spatial relations between transects. The GPS data were collected simultaneously with GPR data by synchronizing the GPS measurements with those of the GPR. The first GPR dataset (14 transects) were completed using 100- and 250-MHz antennas and four stacks per transect to increase the signal-to-noise ratio. The second GPR dataset represents 10 transects and 64 stacks per trace for improved signal-to-noise ratio. These transects were restricted to the channel sediments in Middle Tyger River. The third dataset consists of four common-offset profiles and a CMP profile along the right bank of the river (fig. 6).

For the first and second sets of GPR transects, shielded antennas were used for optimal data collection in noisy environments; for the third GPR transect along the river, equipment with unshielded antennas was used. Shielded antennas are used primarily for mid- to high-resolution GPR surveys because they restrict the penetration depth of the signal, whereas unshielded antennas are commonly of a lower frequency to allow deeper signal penetration with less resolution (noisier data). The benefit of using unshielded antennas is that the antennas are independent of each other, allowing the user to run CMP transects with increasing antenna separation. By using equipment with unshielded antennas, common-offset surveys were conducted so that a fixed-separation distance was maintained between the receiver and transmitter antennas while being moved in a step mode at a constant rate in the direction of the survey. During the CMP survey, the 50-MHz receiver and transmitter antennas started with a separation distance of 2 m, and the receiver and transmitter antennas were further separated by one-half the step size (50 cm). Common-offset data differ from the CMP data in that all CMP data were collected at set time intervals in a continuous acquisition mode.

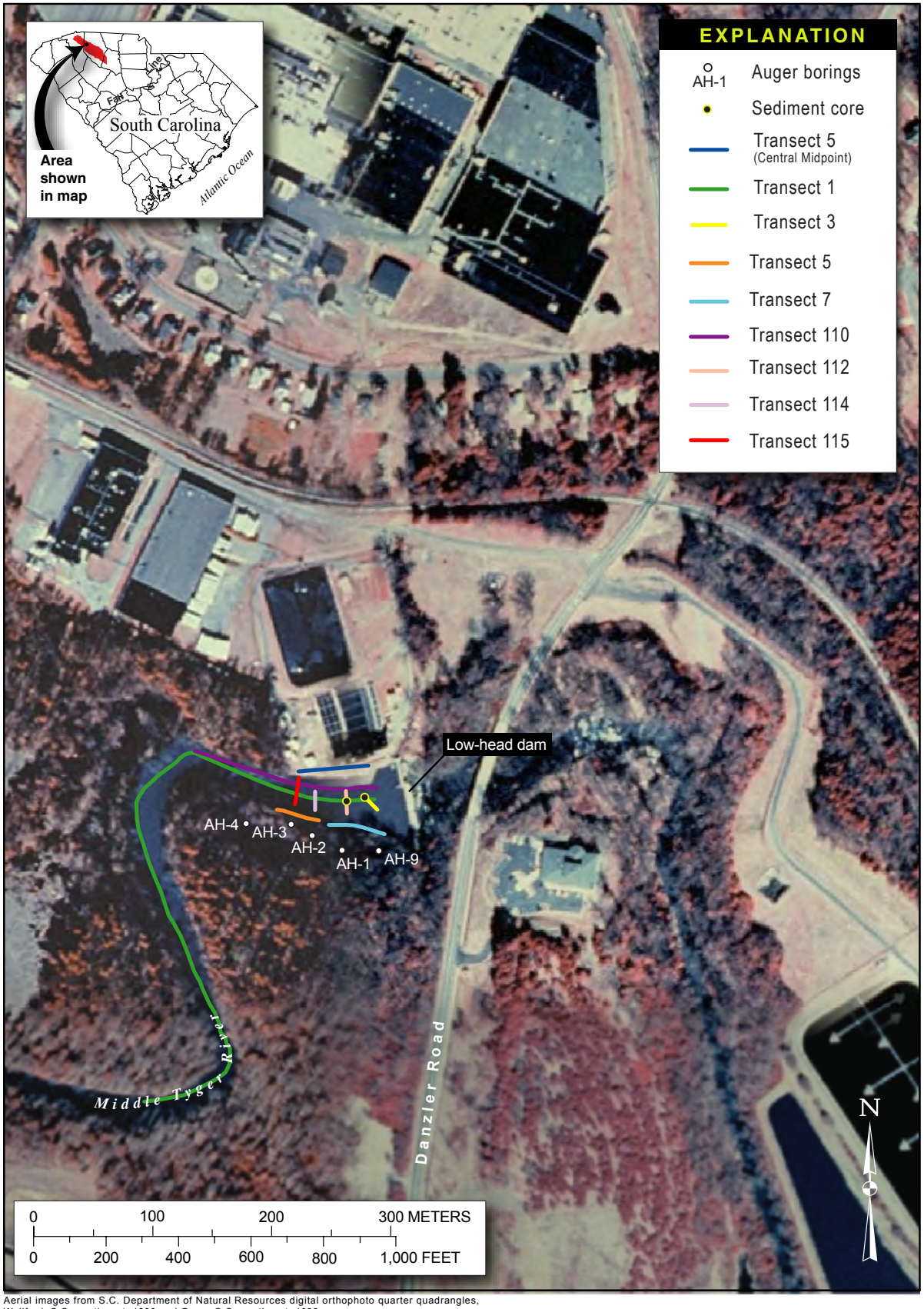
Ground-Penetrating Radar Data Processing

The processing of the GPR data was accomplished by applying a “dewowing” filter, a bandpass filter, automatic gain control (AGC), and velocity analysis. These processing techniques were applied to selected GPR datasets to improve the signal-to-noise ratio inherent in the data and to permit accurate lithologic interpretation. After processing the GPR data, the interpretations were compared with auger-hole logs and sediment cores to corroborate the lithologic interpretation (table 1; fig. 6).

All unprocessed GPR transect data contain “wow” (very low-frequency inductive phenomena). Wow is from the saturation of the receiver electronics by high-amplitude signals (Gerlitz and others, 1993). The wow is present along with the data signal but the wow skews the data to a more negative than positive or more positive than negative reflection coefficient, which results in the data having a non-zero mean. This wowing causes the data to appear to have high amplitude reflectors near time zero but no reflectors below 112.5 nanoseconds (ns), (fig. 7A). In figure 7B, however, the GPR reflectors can be seen throughout the time section from the GPR data collected during this investigation from the minimum to the maximum recording time. The wow was removed from the GPR data collected during this investigation by applying a small-pass frequency filter to the processing software that removes the high frequencies.

A bandpass frequency filter is used to remove unwanted frequencies that are commonly associated with noisy data. A bandpass filter is programmed to analyze the average amplitude spectrum of a dataset and note the range of frequencies that are required. For the SJWD dataset, a bandpass filter was used with center frequencies set at 50 and 150 MHz. A smaller band width was programmed for the bandpass filter used for a velocity analysis.

A velocity analysis is performed to acquire accurate electromagnetic velocities for the various geologic lithologies being imaged with the objective of calculating the correct depths for the GPR reflectors. Velocities of radar-wave propagation generally decrease with depth (Fisher and others, 1991). The velocity analysis performed on the SJWD dataset yielded a range of velocities from 0.13 to 0.25 meter per nanosecond (m/ns) (table 4; fig. 8). The analysis yielded mixed results because the velocities calculated were too high for the expected geologic setting. Surface and subsurface interfaces may have attributed to the higher velocity, considering the air wave velocity is 0.30 m/ns. The velocity of 0.15 m/ns is realistic for dry sand or soil, based on the location (left bank) of the central midpoint transect (transect 114, fig. 6) located near the water-treatment plant. The surveys completed on the right bank and in the channel differ, however, because



Aerial images from S.C. Department of Natural Resources digital orthophoto quarter quadrangles, Wellford, S.C., northwest, 1999 and Greer, S.C., northeast, 1999.

Figure 6. Locations of ground-penetrating radar transects, auger borings, and sediment cores along the banks and in the channel of the Middle Tyger River near Lyman, Spartanburg County, South Carolina.

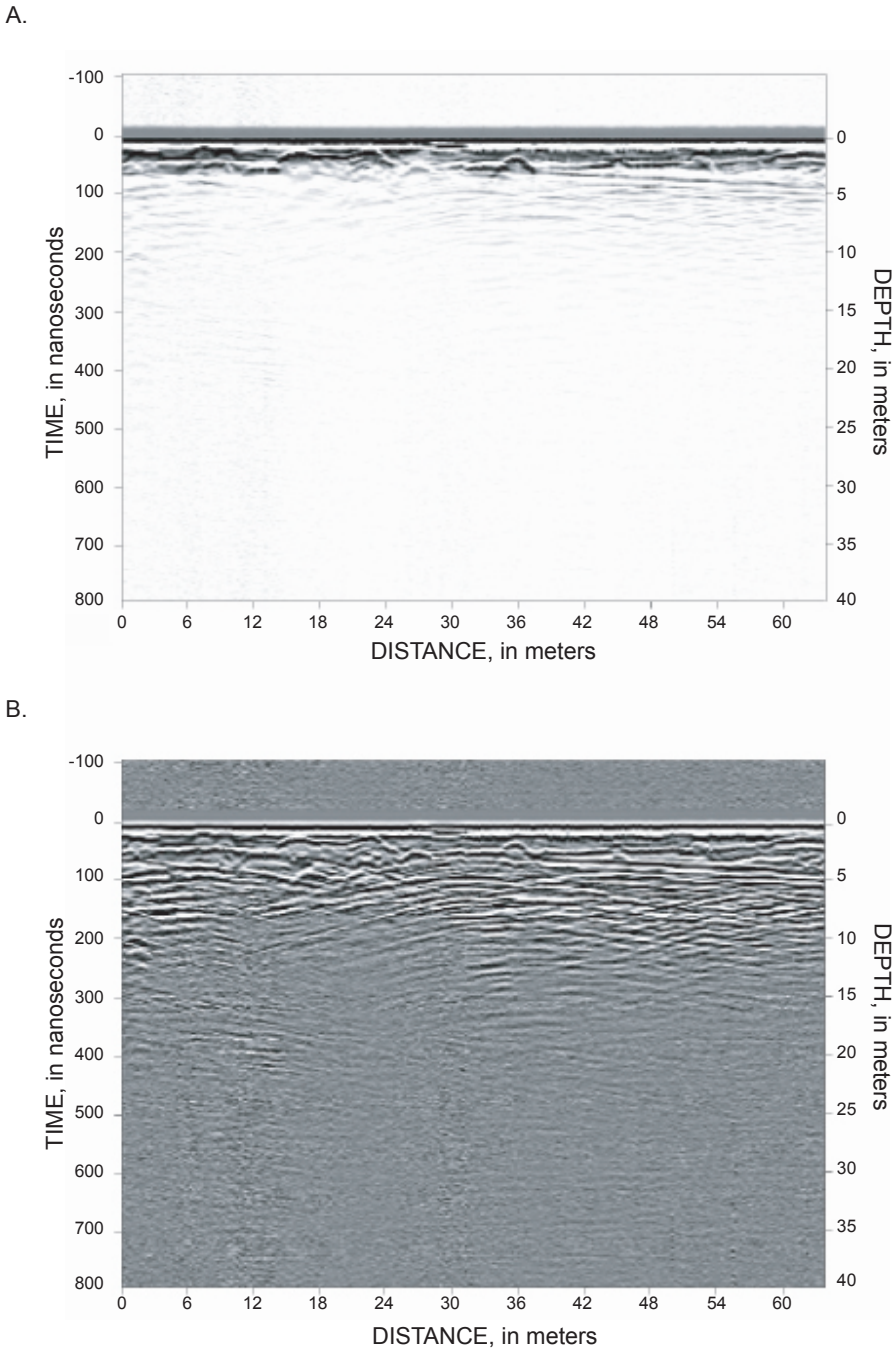


Figure 7. Ground-penetrating radar transect 1 along the right bank of the Middle Tyger River near Lyman, Spartanburg County, South Carolina, (A) without a “dewow” filter applied and (B) with a “dewow” filter applied.

Table 4. Results of ground-penetrating radar bandpass filter velocity analysis of data collected along the Middle Tyger River near Lyman, Spartanburg County, South Carolina.

Time (nanosecond)	Velocity (meter per nanosecond)
100	0.25
200	0.23
300	0.20
400	0.19
500	0.15
600	0.14
700	0.13

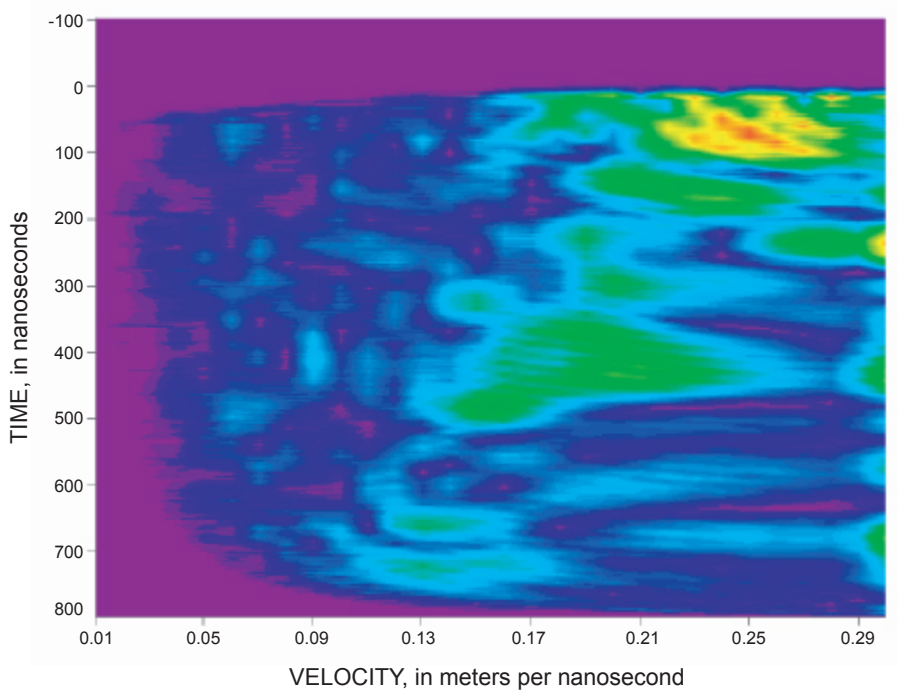


Figure 8. Ground-penetrating radar bandpass filter velocity analysis of data collected along the Middle Tyger River near Lyman, Spartanburg County, South Carolina.

the water table is shallow on the right bank, and the subsurface is saturated with water. Therefore, a velocity of 0.06 m/ns (average velocity of wet sand) was used to convert the travel time to depth by using the formula:

$$D = v \times \frac{t}{2},$$

where

D is depth, in meters;
v is velocity, in meters per second; and
t is time, in nanoseconds.

Automatic gain control (AGC) is a time-dependent exponential amplitude gain constraint that compensates empirically for amplitude attenuation with depth (Fisher and others, 1991). An AGC was applied to the data to boost the reflectors at greater depths. In processing the SJWD dataset, an AGC with a window length of 200 ns and a scaling factor of 2,000 was applied.

Correlation of Data from Auger Borings, Core Holes, and Ground-Penetrating Radar

Data from 10 auger borings and 2 core holes (fig. 3; table 1) were used to support the lithologic delineations and correlation with the GPR data. The sediment cores were obtained at two locations in the river channel and yielded mixed results. The cores contained dense clay deposits overlain primarily by coarse-grained sand. The thickness of the alluvial deposit could not be delineated because of the limitations of the vibracoring process. The combination of auger and core data, however, provided adequate calibration for lithologic interpretation of the GPR data.

There were 29 GPR transects collected; however, 8 transects (1, 3, 5, 7, 110, 112, 114, and 115) were used to delineate the geometry of the alluvial sediments (fig. 6). Preliminary transects were taken to explore the study area and beyond, then subsequent transects were taken that focused on a specific area of interest. Data from the GPR transects completed on the left bank of the river near the water-treatment plant were used for the CMP velocity analysis (figs. 6, 8; table 4). The results and interpretation of the GPR data are reported in order from the right bank to the channel.

Data were collected along transect 5 on the right bank of the Middle Tyger River (fig. 6). After processing, the data were compared with data from auger holes AH–2, AH–3, and AH–4 (fig. 6; table 1). The air wave in figure 9 is at time zero (red) and the ground wave is in blue. The GPR data appear to correlate well with the auger borings in that the sediment tends to thicken downstream toward the dam. Note two main reflectors in figure 9 that stand out—one at approximately 2 m below the surface, and the other that starts from 4.5 m upstream and thickens to approximately 5.5 m downstream. These two reflectors divide the data into three distinct layers—clayey sand, medium-grained sand, and clay that correlate with the auger-boring data. The horizontal distance in figure 9 was estimated by using commercial software.

Transect 7 also is on the right bank of the river but is closer to the dam (fig. 6). The GPR data collected along this transect seem to correlate well with the data from auger holes AH–1 and AH–9 (fig. 6; table 1). The GPR signals are attenu-

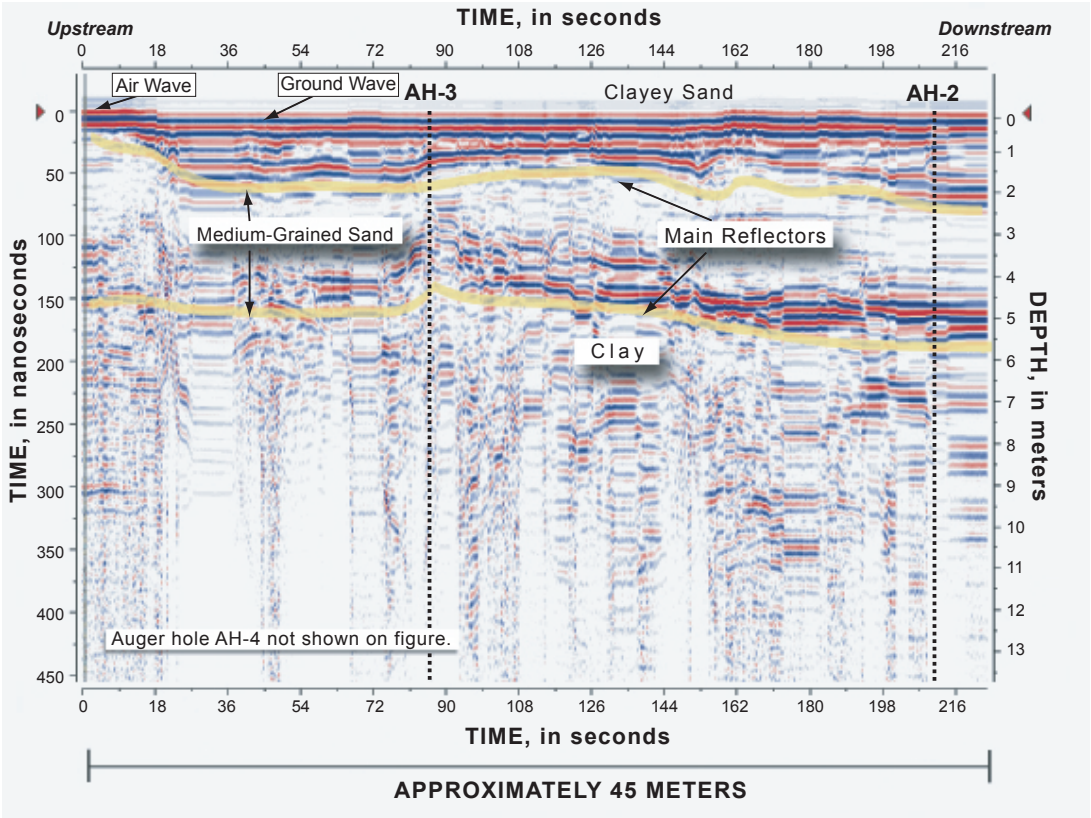


Figure 9. Ground-penetrating radar data collected with a 100-megahertz antenna along transect 5 on the right bank of the Middle Tyger River near Lyman, Spartanburg County, South Carolina.

ated by clay, clayey sediments, or other similar materials. On the right bank is a layer of fill material mixed with clay, which explains the loss of energy below 1 m (fig. 10). The bottom of the medium-grained sand layer is difficult to define, but based on borings AH–1 and AH–9, the bottom may be at about the 4-m depth. Below the medium-grained sand layer is a silty-clay layer. Two diffractions were recorded, one at the beginning and one at the end of the line; these two diffractions may be associated with buried metallic pipes along the survey transect.

The results of data collection along transect 1 in the river (fig. 6) were particularly interesting (fig. 11). The horizontal distance of 125 m was estimated by using commercial GPS software, and the depth was calculated by using the mean velocity of 0.06 m/ns. The reflector at the 4-m depth or 150 ns is interpreted to be the contact between coarse-grained sand and clay based on correlation with coring and observation-well data. The locations where transects 3, 112, 114, and 115 intersect transect 1 are identified in figures 6 and 11, and the locations of these lines relative to transect 1 are essential in the interpretations. The thickness of the alluvial sands varies along the section from 3 m near the dam to 0.5 m between transects 114 and 115 (figs. 6, 11). GPR data for transects 1 and 110 contain multiple reflections that appear to mimic the river channel bottom (figs. 11, 12).

Cross sectional transects 3, 112, 114, and 115 (fig. 6) were collected to determine the extent of the alluvial deposits perpendicular to the river channel. Transect 3 is closest to the dam, and transect 115 is farthest from the dam (fig. 6). The horizontal distances of the lines were calculated by using commercial GPS software, and range from about 30 m (transect 3) to 20 m (transect 114). The alluvial sand layer is indicated by the yellow line shown on each section in figure 13. Transect 3 has the best overall reflection of the bottom of the sand at approximately 7 m with a thickness of 3 m. Transects 112, 114, and 115 were interpreted by comparing their locations with that of transect 1. The cross section for transect 112 illustrates that the thickness of the alluvial sand ranges from 2 to 3 m. The cross section for transect 114 illustrates that the alluvial sand is 2.5 m thick, and the cross section for transect 115 indicates that the sand is approximately 1 m thick.

The GPR equipment and subsequent analysis proved to be a viable, cost-effective, and non-invasive approach in the delineation of the alluvial deposits along the right bank

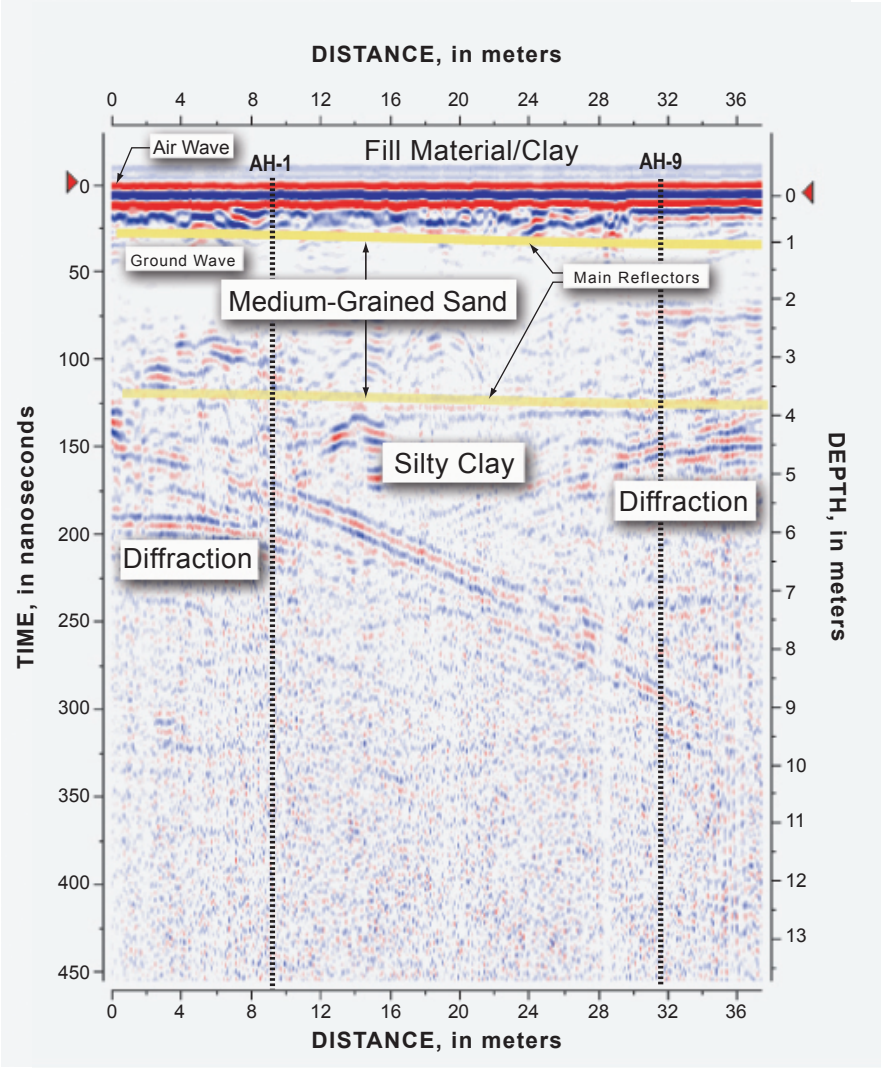


Figure 10. Ground-penetrating radar data collected with a 100-megahertz antenna along transect 7 on the right bank of the Middle Tyger River near Lyman, Spartanburg County, South Carolina.

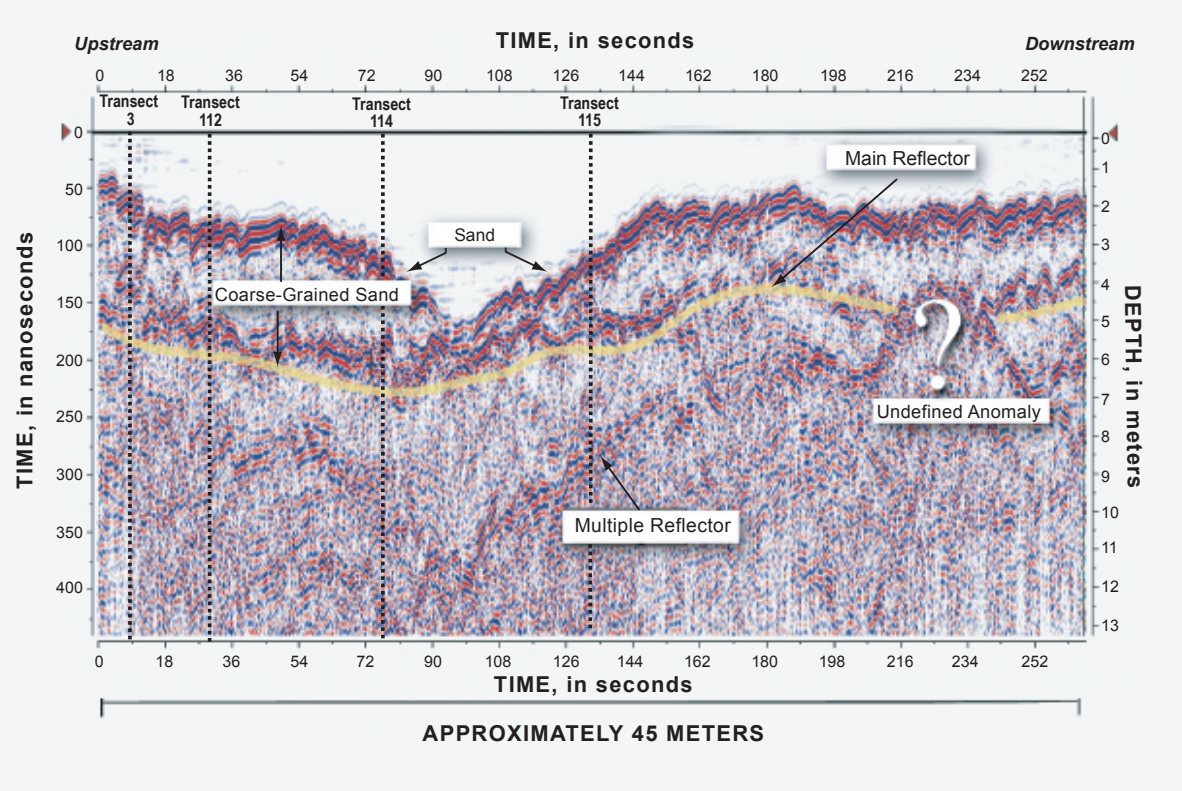


Figure 11. Ground-penetrating radar data collected with a 100-megahertz antenna along transect 1 in the channel of the Middle Tyger River near Lyman, Spartanburg County, South Carolina.

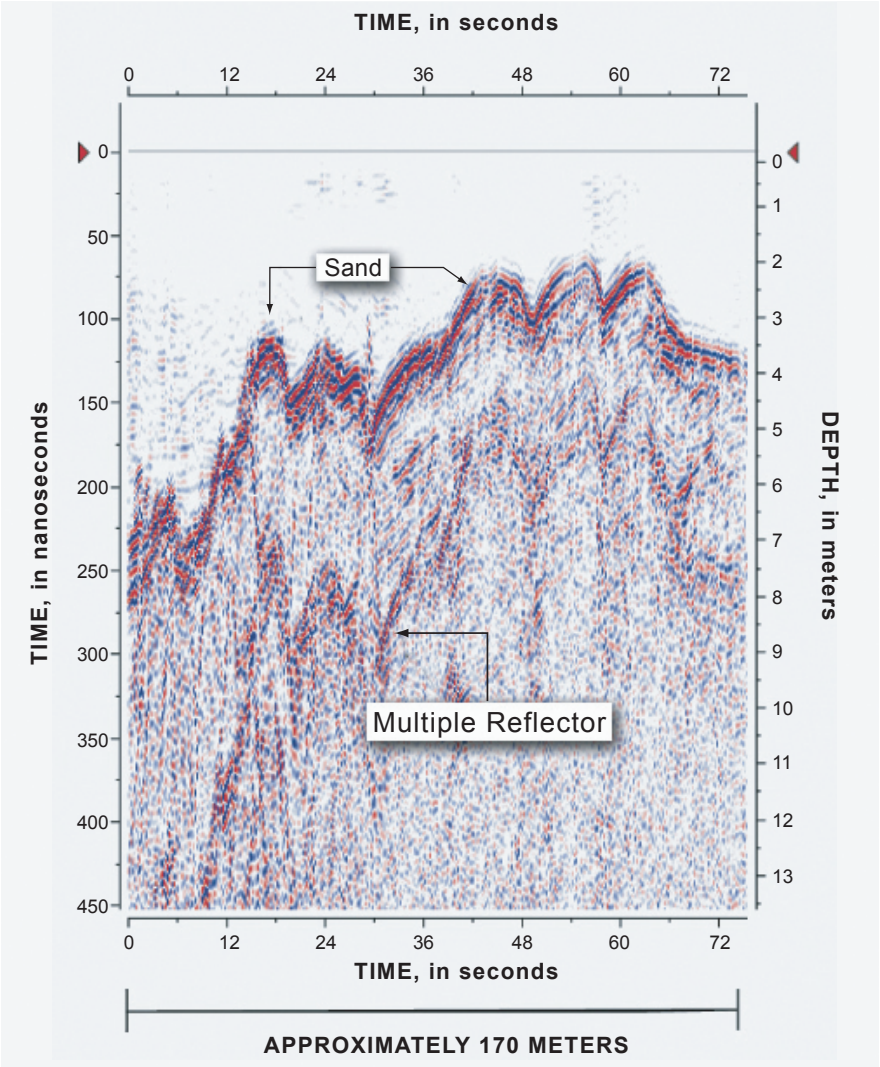


Figure 12. Ground-penetrating radar data collected with a 100-megahertz antenna along transect 110 in the channel of the Middle Tyger River near Lyman, Spartanburg County, South Carolina.

and channel of the Middle Tyger River. The delineation of the sands on the banks proved more difficult because of the larger clay content and nosier data resulting from cultural objects, such as buildings, electrical lines, and underground pipes. The combination of the auger boring and core-hole data provided an appropriate calibration for the GPR data analysis. The thickness of the alluvial channel sediment varies along the section but generally is thickest near the dam (3 m) and thinnest (0.1 m) approximately 47 m upstream from the dam. Below the alluvial channel sediments is a clay deposit of unknown thickness (fig. 14). Transects 3, 112, 114, and 115 were difficult to interpret; however, they correlate well with transect 1.

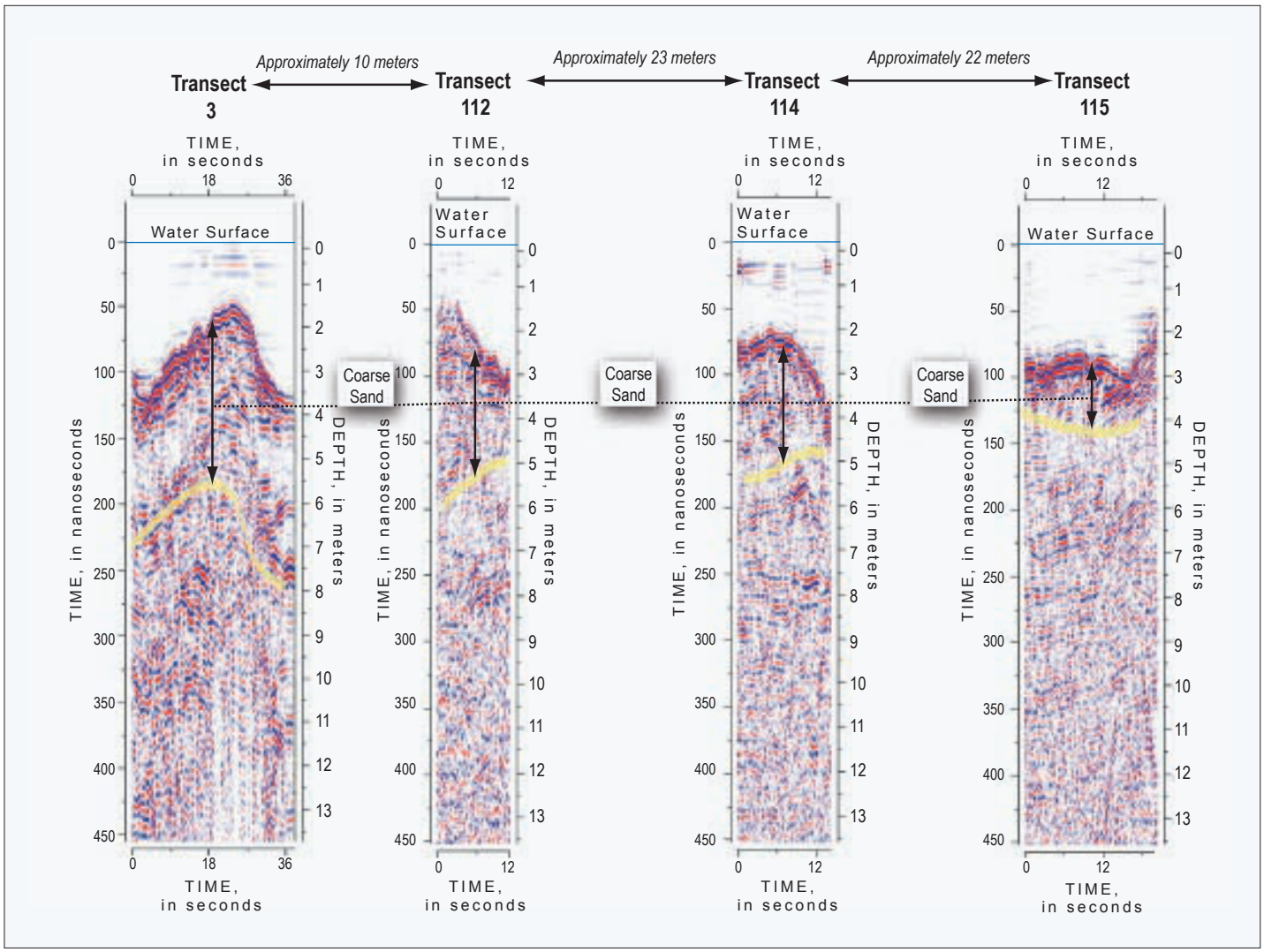


Figure 13. Ground-penetrating radar data collected with a 100-megahertz antenna for cross-section transects 3, 112, 114, and 115 in the channel of the Middle Tyger River near Lyman, Spartanburg County, South Carolina.

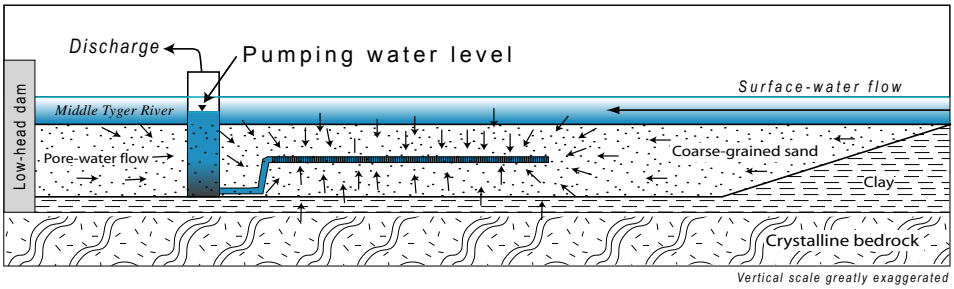


Figure 14. Schematic cross section of the alluvial deposits and hypothetical flow paths to a horizontal well in the Middle Tyger River upstream from the low-head dam adjacent to the Startex Jackson Wellford Duncan Water District Water Treatment Plant near Lyman, Spartanburg County, South Carolina.

Hydraulic Data Collection

The hydraulic characteristics of a potential bank-filtration site have an important influence on the storage and movement of water. To investigate the hydraulic properties of the alluvial sediments along the right bank and in the channel sediments of the Middle Tyger River, six slug tests were completed for three observation wells (fig. 3). These data provide an estimate of the horizontal hydraulic conductivity of the right bank and river channel alluvial deposits.

For wells inventoried in South Carolina, the USGS uses an identification system in which each well is sequentially numbered in each county using an alphanumeric well designation (Harrelson and others, 2002). The alphabetic prefix refers to the county and the number refers to the chronological order in which wells were inventoried in the county. Thus, the first well inventoried in Spartanburg County is designated SP–1.

Hydraulic Characterization of the Alluvial Deposits

On May 2 and 3, 2005, temporary observation wells were installed in existing auger borings AH–1 (SP–3142) and AH–9 (SP–3143) on the right bank and at SP–3150 in the river channel (fig. 3). The observation wells were tested to estimate the capacity of the alluvial deposits to transmit water, which is a means of estimating how much water can be produced from the alluvial deposits. Selected well construction information and associated data for the observation wells are given in table 5.

The observation wells were developed to improve the well connection to the alluvial deposit prior to conducting the production test. The quantity of water produced by the wells was measured by using a 3.8 liter (L) bucket and a stop watch. A 4-horsepower, gasoline-powered centrifugal pump designed to extract water at approximately 11.7 liters per second (L/s) was used as the lift device for the production tests. Wells SP–3142 and SP–3143 were pumped for approximately 2 hours and produced a mean yield of 0.004 and 0.07 L/s, respectively (fig. 3; table 5).

On September 8, 2005, after the surface-water levels were lowered behind the low-head dam adjacent to the SJWD Water District Water Treatment Plant, a production test also was conducted for observation well SP–3150 (fig. 3; table 5). The observation well was completed in the alluvial deposits in the channel of the Middle Tyger River. The same procedures for this production test were followed as previously described for wells SP–3142 and SP–3143. The production test for observation well SP–3150 gave a mean yield of 1.9 L/s (table 5). It should be noted that the channel sediments are capable of sustaining a larger yield than the production test indicate. During the production test, the decrease in surface-water levels in the reservoir reduced the hydrostatic pressure or force acting on the sediments behind the low-head dam. Under normal conditions, higher surface-water levels behind the dam would exist, thus increasing the hydrostatic pressure available to support water yield from the sediments (Fetter, 1980). With the rise in surface-water levels, there would be a linear increase in hydrostatic pressure that would affect the rate at which water may be pumped from the sediments. The duration of the production test was limited by SJWD Water District Water Treatment Plant operational requirements.

Four slug tests were conducted on the right bank flood plain of the Middle Tyger River for this investigation. The horizontal hydraulic conductivity estimates for the alluvial sediments were calculated using standard analytical methods (Bouwer and Rice, 1976; Bouwer, 1989). The hydraulic conductivity of a material is defined as the ratio of flow velocity to driving force for viscous flow under saturated conditions of a specified liquid in a porous medium (American Geological Institute, 1976).

One falling head and one rising head slug tests were performed in each of the three observation wells. The slug-test analyses for wells SP–3142 and SP–3143 resulted in a horizontal hydraulic conductivity estimate for the right bank flood-plain alluvial sediments of 1 meter per day (m/d; fig. 3; table 5). The slug-test analysis for well SP-3150 resulted in a horizontal hydraulic conductivity estimate for the channel sediments of 60 m/d (fig. 3; table 5).

The estimated horizontal hydraulic conductivity of 1 m/d is too small to allow water to flow in large quantities through

Table 5. Well data for three temporary observation wells on the right bank and in the channel of the Middle Tyger River near Lyman, Spartanburg County, South Carolina.

[USGS ID, U.S. Geological Survey well identifier]

USGS ID (fig. 3)	Latitude	Longitude	Well depth (meters below land surface)	Top of open zone (meters below land surface)	Bottom of open zone (meters below land surface)	Horizontal hydraulic conductivity (meters per day)	Mean water yield (liters per second)
SP–3142	34°56'22"	82°07'29.6"	4.4	2.9	4.4	1	0.004
SP–3143	34°56'22"	82°07'28.5"	5.8	2.5	4.0	1	0.07
SP–3150	34°56'23"	82°07'29"	2.4	0.9	2.4	60	1.9

the sediment and thus restricts the use of the alluvial deposits along the right bank of the Middle Tyger River near Lyman as a potential bank-filtration site. The estimated horizontal hydraulic conductivity for the alluvial channel deposits of approximately 60 m/d, however, is adequate to sustain a limited bank-filtration process at the study site. It should be noted, however, that the nominal thickness of the alluvial sediments coupled with the large hydraulic conductivity likely will result in the rapid transmission of water and may not allow sufficient residence time underground, thus reducing the effectiveness of water-quality improvements.

Surface-Water and Pore-Water Chemistry Characterization

On September 8, 2005, during the development of well SP–1350, basic water-chemistry data (pH, temperature, specific conductance, and alkalinity) were collected and recorded in the field for the surface water and pore water in and beneath the channel of the Middle Tyger River, respectively. During the development period, pH, temperature, and specific conductance were measured at 10- to 15-minute intervals by using a calibrated automated water-quality instrument. The alkalinity values were calculated at the South Carolina Water Science Center water-quality laboratory.

Results of the water-chemistry data analysis indicate that (1) the mean surface-water temperature of 22.5 degrees Celsius (°C) was higher than the average pore-water temperature of 18.5 °C; (2) the mean surface-water specific conductance of 57 microsiemens per centimeter (µS/cm) at 25 °C was less than the average pore-water specific conductance of 126 µS/cm; (3) the surface-water alkalinity of 22.5 milligrams per liter (mg/L) was less than the pore-water alkalinity of 44.6 mg/L; and (4) pH values ranged between 6.2 and 6.3 for the surface water and pore water sampled during this investigation (table 6). These water-quality results indicate the general differences between the surface-water and pore-water chemistry during the pumping period for observation well SP–3150. The flow velocity of the pore water is orders of magnitude slower than the flow velocity of the surface water; therefore, the pore water interacts with the sediment for a longer period of time, which results in the differing temperature, specific conductance, and alkalinity values.

Table 6. Water-chemistry data for surface-water and pore-water samples from the channel of the Middle Tyger River near Lyman, Spartanburg County, South Carolina.

[°C, degrees Celsius; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter; —, no data]

Sampling time	pH	Temperature (°C)	Specific conductance (µS/cm at 25 °C)	Alkalinity (mg/L)
Surface water				
11:50	6.2	22.1	57.4	22.5
12:00	6.2	22.3	58.5	—
12:15	6.3	22.4	56.3	—
12:30	6.3	22.5	56.4	—
12:45	6.3	22.6	56.1	—
13:00	6.3	22.7	56.3	—
13:15	6.3	22.8	57.8	—
Pore water				
11:30	6.2	19.8	102.4	44.6
11:45	6.2	18.4	130.7	—
12:00	6.2	18.4	132.8	—
12:15	6.2	18.3	130.6	—
12:30	6.2	18.3	129.6	—
12:45	6.2	18.4	126.9	—
13:00	6.2	18.4	128.3	—
13:15	6.2	18.3	124.7	—

Summary

A cooperative investigation was undertaken between the U.S. Geological Survey and the Startex Jackson Wellford Duncan Water District to explore the possibility of using alluvial deposits in a piedmont reservoir as a natural filter in a bank-filtration process to pretreat water to be used as a secondary drinking-water source. Alluvial deposits located on the right bank and along the bottom of a small reservoir on the Middle Tyger River near Lyman in Spartanburg County, South Carolina, were analyzed to determine if an adequate amount of water could be withdrawn to sustain a bank-filtration process and to characterize the water chemistry of the surface water and pore water in the study area. The data from 10 auger borings, 2 sediment cores, and 29 ground-penetrating radar transects were analyzed to characterize the lithology, geometry, and hydraulic properties of the alluvial deposits.

The auger data indicate that the general lithologies of the alluvial deposits along the right bank consist of heterogeneous fill material, clay, silty clay, clayey sand, and fine- to coarse-grained sand with minor amounts of mica. The thickness of the alluvial deposits beneath the right bank ranges from 7 meters near the low-head dam to 3.0 meters approximately 180 meters upstream. The thickness of the deposits was defined by the top of a distinct clay layer or refusal depth of the auger borings.

The lithologic data provided by sediment cores collected from the channel of the Middle Tyger River facilitated the delineation of the grain-size distribution, lithology, and sorting of the alluvial deposits. Sediment samples from the cores were analyzed using a laser particle-size analyzer. The particle-size analysis revealed that the alluvial deposit from the channel is homogeneous and primarily coarse-grain sand that remains very well sorted with increasing depth.

Ground-penetrating radar data were collected along the right and left banks and in the channel of the Middle Tyger River. The radar data indicate that the thickness of the alluvial deposits beneath the right bank correlate well with the auger data and the deposits are thickest near the low-head dam and thin in the upstream direction. The ground-penetrating radar data collected on the left bank were used to calibrate the radar-penetration velocities. The interpolation of the radar data indicates that the thickness of the channel deposit ranges from 3 meters near the dam to 0.1 meter approximately 47 meters upstream from the dam.

Temporary observation wells were installed and used to investigate the potential quantity of ground water produced from the alluvial deposits. Two observation wells on the right bank and one observation well in the channel were pumped and produced mean water yields of 0.004, 0.07, and 1.9 liters per second, respectively. It should be noted that the channel sediments are capable of sustaining a larger yield than the production test indicates. During the production test, the decrease in surface-water levels in the reservoir reduced the hydrostatic pressure or force acting on the sediments behind the low-head dam. Under normal conditions, higher surface-water levels behind the dam would exist, thus increasing the hydrostatic pressure available to support water yield from the sediments. With the rise in surface-water levels there would be a linear increase in hydrostatic pressure that would affect the rate at which water may be pumped from the sediments.

Slug tests were conducted in the three observation wells to calculate the hydraulic properties of the alluvial deposits along the right bank flood plain and in the channel of the Middle Tyger River. The slug tests for the two observation wells on the right bank produced an estimated horizontal hydraulic conductivity of 1 meter per day for each well. The slug test for the observation well in the channel produced an estimated horizontal hydraulic conductivity of 60 meters per day.

The estimated horizontal hydraulic conductivity values derived from the observation wells on the right bank are too small to allow water to flow freely through the sediment and thus restrict the use of the right bank deposits as a potential bank-filtration site. The estimated horizontal hydraulic conductivity, derived from the observation well in the channel, however, is adequate to sustain a limited bank-filtration process. It should be noted that the limited thickness of the channel deposits coupled with large horizontal hydraulic conductivity likely will result in the rapid transmission of water and may reduce the effectiveness of some water-quality improvements.

During pumping of the channel well, water-chemistry data were collected from the surface water and pore water in and beneath the channel of the Middle Tyger River. The water-chemistry data indicate differences in temperature, specific conductance, and alkalinity between the surface water and pore water. The surface-water temperature is several degrees higher than the pore-water temperature, and values of surface-water specific conductance and alkalinity are smaller than values in the pore water. The velocity of the pore water is several orders of magnitude slower than the surface-water velocity, which enables pore water to interact with the subsurface environment for a longer period of time, likely producing the gradients in temperature, specific conductance, and alkalinity.

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Selected References

American Geological Institute, 1976, Dictionary of geologic terms (rev. ed.): Garden City, NY, Anchor Press/Double Day, 472 p.

Baker, G.S., Steeples, D.W., Schmeissner, C., Pavlovic, M., and Plumb, R., 2001, Near-surface imaging using coincident seismic and GPR data: Geophysical Research Letters, v. 28, no. 4, p. 627–630.

Bloxham, W.M., Siple, G.E., and Cummings, T.R., 1970, Water resources of Spartanburg County, South Carolina—South Carolina Water Resources Commission Report no. 3, 112 p.

Bouwer, H., 1989, The Bouwer and Rice slug test-an update: Journal of Ground Water, v. 27, no. 3, p. 304–309.

Bouwer, H., and Rice, R.C., 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells: Water Resources Research, v. 12, p. 423–428.

Cooney, T.W., Drewes, P.A., Ellisor, S.W., Lanier, T.H., and Melendez, F., 2005, Water resources data, South Carolina, water year 2004: U.S. Geological Survey Water-Data Report SC–04–1, 662 p.

Eidson, J.P., Lacy, C.M., Nance, Luke, Hansen, W.F., Lowery, M.A., and Hurley, N.M., Jr., 2005, Development of a 10- and 12-digit hydrologic unit code numbering system for South Carolina, 2005: U.S. Department of Agriculture, Natural Resources Conservation Service, 38 p. + 1 pl.

Fetter, C.W., Jr., 1980, Applied hydrogeology: University of Wisconsin, Oshkosh, 488 p.

Fisher, E., McMechan, G.A., Annan, A.P., and Cosway, S.W., 1991, Examples of reverse-time migration of single-channel, ground-penetrating radar profiles: Journal of Geophysics, v. 557, no. 4, p. 578.

Geological Society of America, 1991, Rock color chart with genuine Munsell color chips: Boulder, CO, Geological Society of America.

Gerlitz, K., Knoll, M.D., Cross, G.M., Luzitano, R.D., and Knight, R., 1993, Processing ground penetrating radar data to improve resolution of near-surface targets, *in* Proceedings of the 6th Annual Symposium on the Application of Geophysics to Engineering and Environmental Problems: Environmental and Engineering Geophysical Society, p. 564–565.

Harrelson, L.G, Falls, W.F., and Prowell, D.C., 2002, Groundwater levels in the Floridan-Midville aquifer in the Breezy Hill area, Aiken and Edgefield Counties, South Carolina, April 1999–November 2000: U.S. Geological Survey Water-Resources Investigations Report 02–4075, 36 p. + 5 pls.

Kuehn, Wolfgang, and Mueller, Uwe, 2000, River bank filtration—An overview: Journal of the American Water Works Association, v. 92, no. 12, p. 60–69.

Neal, Adrian, 2004, Ground-penetrating radar and its use in sedimentology—Principles, problems, progress: Earth-Science Reviews, v. 66, p. 261–330.

Overstreet, W.C., and Bell H., 1965, The crystalline rocks of South Carolina: U.S. Geological Survey Bulletin 1183, 126 p.

South Carolina Department of Environmental Control, 2001, Watershed water quality assessment—Broad basin: Technical Report, 001-01, 2d ed., p. 68–70.

Tucker, M.E., 1995, Techniques in sedimentology: Oxford, Blackwell Science, 394 p.

Tufenkji, Nathalie, Ryan, J.N., and Elimelech, M., 2002, The promise of bank filtration, A simple technology may inexpensively clean up poor-quality raw surface water: Journal of Environmental Science and Technology, v. 36, p. 423A–428A.

U.S. Department of the Interior, 1967, Water resources data for South Carolina, part 1, surface-water records: U.S. Department of the Interior, U.S. Geological Survey, Water Resources Division, 91 p.

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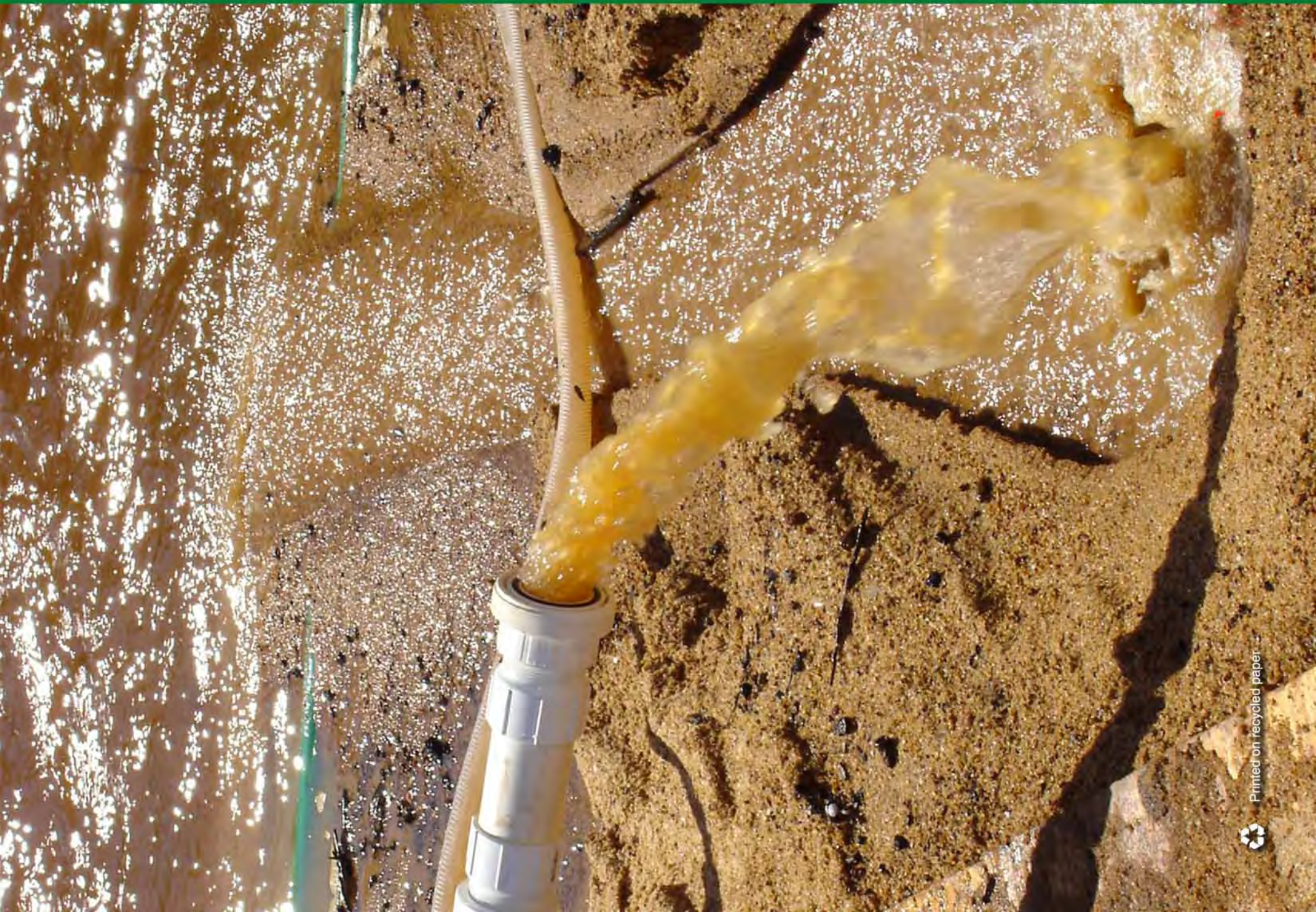

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