Prepared in cooperation with the North Carolina Department of Environment and Natural Resources, Division of Water Quality

Hydrogeologic Setting, Ground-Water Flow, and Ground-Water Quality at the Langtree Peninsula Research Station, Iredell County, North Carolina, 2000–2005

Scientific Investigations Report 2008–5055

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

Cover. **Left—Water-quality samples being collected** *(photograph by Matthew J. Heller, Virginia Department of Mines, Minerals, and Energy, Division of Geology and Mineral Resources)* and
Right—Drilling at the Langtree Peninsula Research Station, Iredell County, North Carolina *(photograph from U.S. Geological Survey files).*

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U.S. Geological Survey

U.S. Department of the Interior
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Conversion Factors and Datums

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Pressure	
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)
	Radioactivity	
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

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

Altitude, as used in this report, refers to distance above the vertical datum.

Hydrogeologic Setting, Ground-Water Flow, and Ground-Water Quality at the Langtree Peninsula Research Station, Iredell County, North Carolina, 2000–2005

By Charles G. Pippin,[1] Melinda J. Chapman,[2] Brad A. Huffman,[2] Matthew J. Heller,[1] and Melissa E. Schelgel[3]

Abstract

A 5-year intensive field study (September 2000–September 2005) of a complex, regolith-fractured bedrock ground-water system was conducted at the Langtree Peninsula research station on the Davidson College Lake Campus in Iredell County, North Carolina. This research station was constructed as part of the Piedmont and Mountains Resource Evaluation Program, a cooperative study being conducted by the North Carolina Department of Environment and Natural Resources and the U.S. Geological Survey. Results of the study characterize the distinction and interaction of a two-component ground-water system in a quartz diorite rock type. The Langtree Peninsula research station includes 17 monitoring wells and 12 piezometers, including 2 well transects along high to low topographic settings, drilled into separate parts of the ground-water-flow system. The location of the research station is representative of a metaigneous intermediate (composition) regional hydrogeologic unit. The primary rock type is mafic quartz diorite that has steeply dipping foliation. Primary and secondary foliations are present in the quartz diorite at the site, and both have an average strike of about N. 12° E. and dip about 60° in opposite directions to the southeast (primary) and the northwest (secondary). This rock is cut by granitic dikes (intrusions) ranging in thickness from 2 to 50 feet and having an average strike of N. 20° W. and an average dip of 66° to the southwest. Depth to consolidated bedrock is considered moderate to deep, ranging from about 24 to 76 feet below land surface. The transition zone was delineated and described in each corehole near the well clusters but had a highly variable thickness ranging from about 1 to 20 feet. Thickness of the regolith (23 to 68 feet) and the transition zone do not appear to be related to topographic setting. Delineated bedrock fractures are dominantly low angle (possibly stress relief), which were observed to be open to partially open at depths of as much as 479 feet below land surface. Well yields ranged from about 3 to 50 gallons per minute. The connection of fracture zones at depth was demonstrated in three bedrock wells during a 48-hour aquifer test, and drawdown curves were similar for all three wells.

General findings of this study help characterize ground-water flow in the Piedmont and Mountains ground-water systems. Ground-water flow generally is from high to low topographic settings. Ground-water flow discharges toward a surface-water boundary (Lake Norman), and vertical hydraulic gradients generally are downward in recharge areas and upward in discharge areas. Dominant water types are calcium-bicarbonate and are similar in all three zones (regolith, transition zone, and bedrock) of the ground-water system. Results of continuous ground-water-quality monitoring indicate that ground-water recharge may occur seasonally over a period of several months or after heavy rainfall periods over a shorter period of a few to several weeks.

Introduction

In 1999, the U.S. Geological Survey (USGS) and the North Carolina Department of Environment and Natural Resources (NCDENR) Division of Water Quality (DWQ) began a multiyear cooperative study to characterize ambient ground-water quality and describe the ground-water-flow system in the Piedmont and Blue Ridge (Mountains) Physiographic Provinces in North Carolina (Daniel and Dahlen, 2002). The study is supported by the North Carolina Piedmont and Mountains Resource Evaluation Program (PMREP) to ensure the long-term availability, sustainability, and quality of ground water in the State (North Carolina Division of Water

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Quality, 1999). The study is planned as a 10-year intensive field investigation and is directed toward the establishment of research stations in representative geologic settings of the Piedmont and Mountains region of the State. To date (March 2008), eight research stations have been established and one other initiated as part of the PMREP (fig. 1).

The Langtree Peninsula research station (LPRS) is in Iredell County and lies within the Charlotte Belt (North Carolina Geological Survey (NCGS), 1985; fig. 2), which is representative of a foliated to massive (no foliation) quartz diorite geologic setting, designated as the metaigneous intermediate regional hydrogeologic unit (MII) by Daniel and Payne (1990). (This characterization differs from the regional map shown in figure 2, which places the study area in the felsic gneiss (GNF) unit.) The MII unit represents about 1.9 percent (Daniel and Dahlen, 2002) of the designated regional hydrogeologic units in the State (Daniel and Payne, 1990). The LPRS site was selected to evaluate the effects of intrusive rock types having dioritic compositions on ground-water quality, thickness and composition of the regolith, thickness and characteristics of the transition zone, and the development and characteristics of bedrock fractures. Also, because the study area is located adjacent to Lake Norman (fig. 1), the largest freshwater reservoir in the State, potential surface-water and ground-water interactions are of interest at the LPRS.

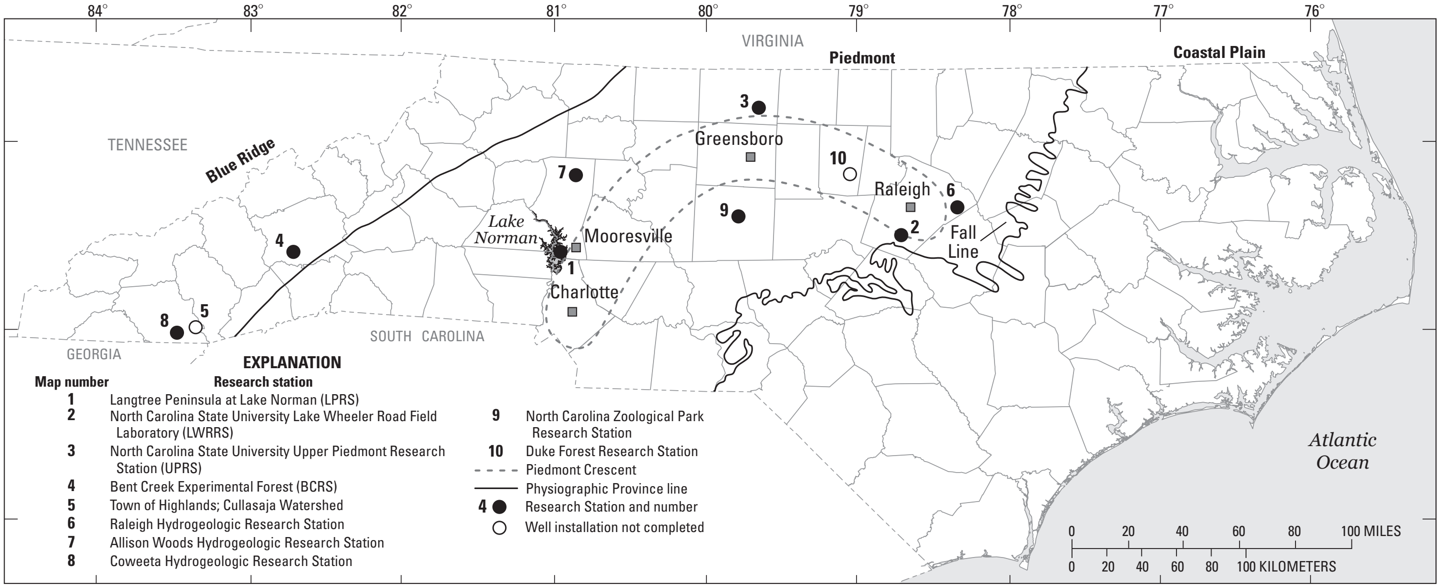
Background

The Blue Ridge and Piedmont Physiographic Provinces in North Carolina cover approximately 30,544 square miles (mi^2) over 65 counties (fig. 1; Daniel and Dahlen, 2002). In 2000, the population of the region was approximately 6 million people (U.S. Census Bureau, 2005), of which about one-third were served by ground water (U.S. Geological Survey, 2003).

Population concentration is near the three metropolitan areas of Raleigh/Durham, Greensboro/Winston-Salem, and Charlotte, known as the “Piedmont Crescent” (fig. 1). The Piedmont Crescent is described as the Nation’s fourth largest manufacturing region, producing $32 billion in goods in 1997 (U.S. Census Bureau, 2004). The Charlotte area (including Gastonia, North Carolina, and Rock Hill, South Carolina) had an estimated population of about 1.3 million people in 2000, an increase of 30 percent since 1990 (U.S. Census Bureau, 2005).

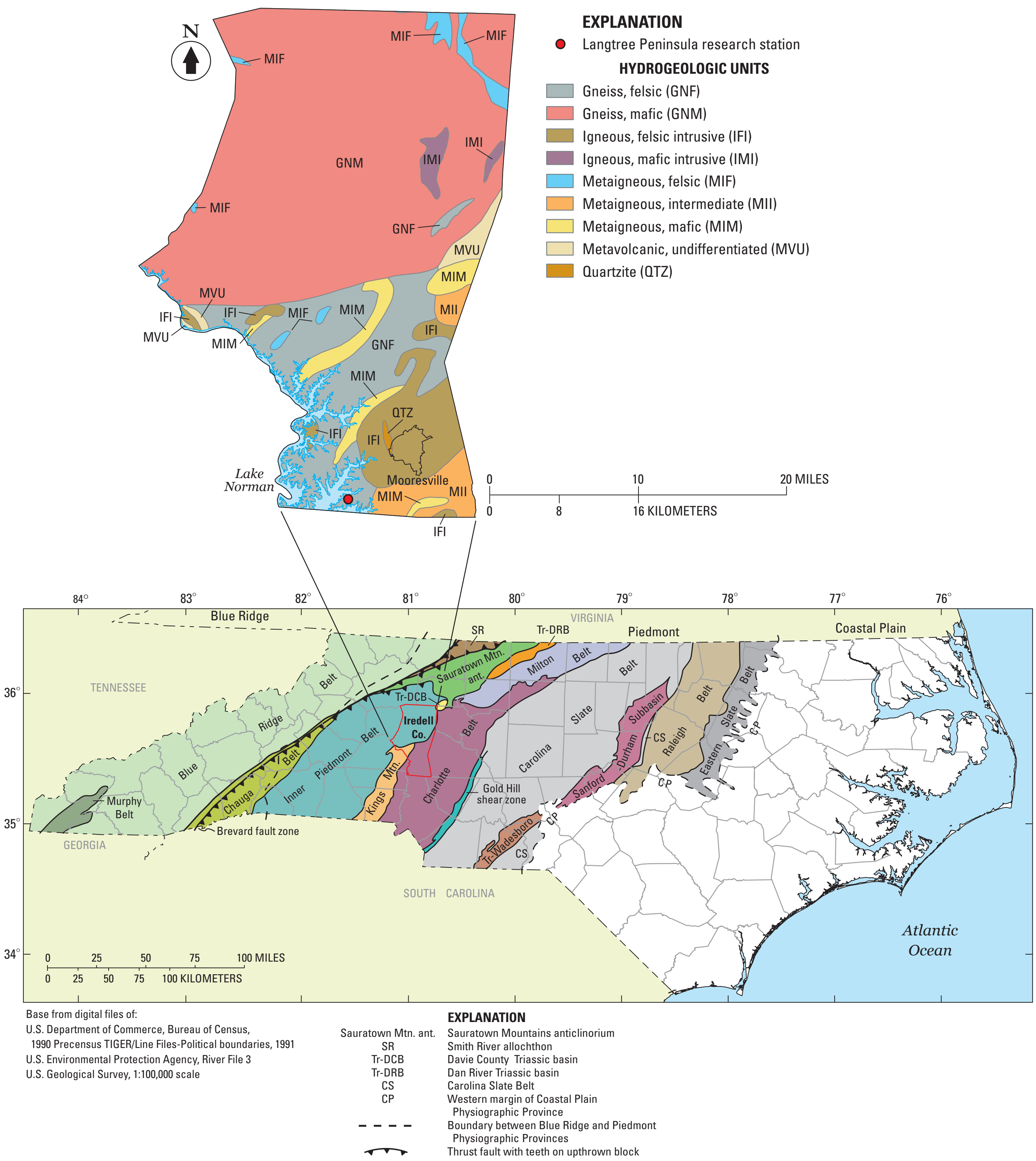
In August 2000, the Langtree Peninsula area of Lake Norman was reported to have 5 active public supply wells serving 6 housing developments and approximately 390 private wells (Heller and Rollins, 2000). The area surrounding the LPRS has a high percentage of urban and suburban land use, primarily single-family homes.

Ground water in the Piedmont and Blue Ridge Physiographic Provinces occurs in complex hydrogeologic settings



Base from digital files of:
U.S. Department of Commerce, Bureau of Census,
1990 Precensus TIGER/Line Files-Political boundaries, 1991
U.S. Environmental Protection Agency, River File 3
U.S. Geological Survey, 1:100,000 scale

Figure 1. Locations of research stations selected for investigations as part of the cooperative U.S. Geological Survey and North Carolina Division of Water Quality Piedmont-Mountains Resource Evaluation Program in North Carolina.



Base from digital files of:
U.S. Department of Commerce, Bureau of Census,
1990 Precensus TIGER/Line Files-Political boundaries, 1991
U.S. Environmental Protection Agency, River File 3
U.S. Geological Survey, 1:100,000 scale

Figure 2. Locations of Langtree Peninsula research station, hydrogeologic units in Iredell County (Daniel and Payne, 1990), and geologic belts delineated in the Blue Ridge and Piedmont Physiographic Provinces of North Carolina (modified from North Carolina Geological Survey, 1985).

composed of assemblages of metamorphic, igneous, and sedimentary rocks (Triassic basins) and secondary fracture networks. Weathered regolith, composed of soil, saprolite, alluvium, and colluvium, overlies the fractured bedrock (fig. 3). Piedmont aquifers, though simply described as a two-component (regolith and bedrock) ground-water system, are quite complex systems. The regolith, which provides storage to the underlying fractures in the bedrock, can be very heterogeneous with varying anisotropies and relict features, such as quartz veins and dikes, which substantially can alter the local hydraulic characteristics of the materials (fig. 3). A third component of the ground-water system is the transition zone, which is commonly present near the top of bedrock and typically is composed of numerous, open fractures in partially weathered to competent rock (fig. 3). The transition zone conceptually has a higher permeability compared to the overlying regolith and underlying bedrock. The characteristics of the transition zone and its role in the ground-water-flow system are being investigated as part of the PMREP.

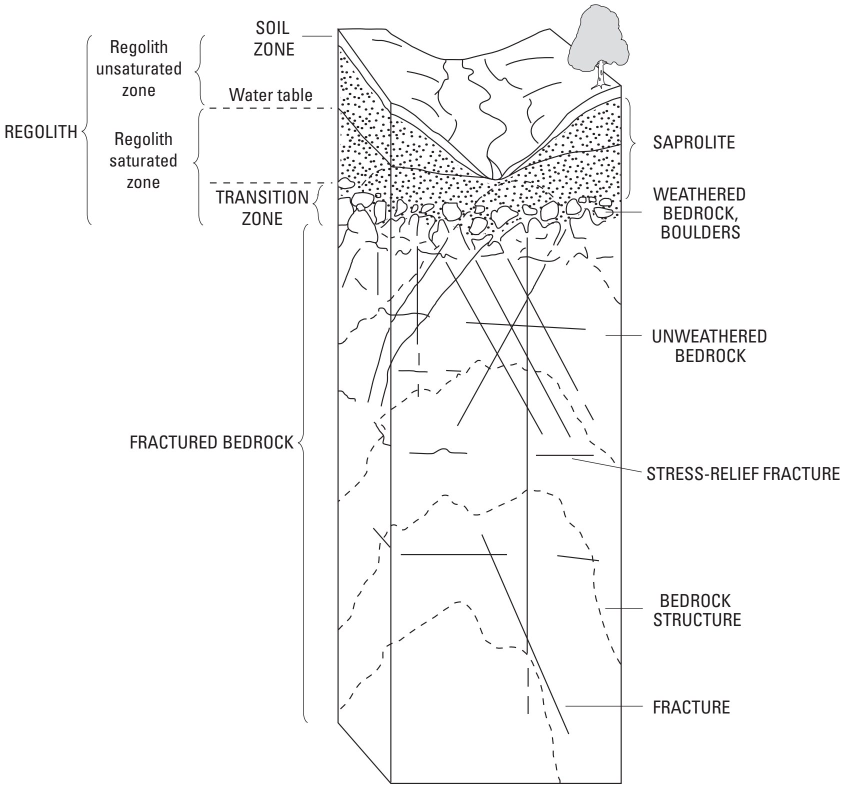


Figure 3. Conceptual components of the ground-water system in the North Carolina Piedmont and Blue Ridge Physiographic Provinces (from Harned and Daniel, 1992).

Conceptual models for natural (unaffected by pumping) ground-water flow in the Piedmont and Mountains ground-water systems have been described by LeGrand (1967, 2004), Heath (1983, 1984), Harned and Daniel (1992), and Daniel and Dahlen (2002). Typically, natural ground-water recharge occurs in uplands and along slopes, while ground-water discharge occurs in valleys (fig. 4). LeGrand (2004) described the region as a slope-aquifer system composed of individual ground-water-flow cells within drainage basins. The well transects at the LPRS were drilled along conceptual ground-water-flow paths, which have both recharge and discharge areas.

Because the regolith and bedrock components of the ground-water system are connected, the aquifers of the Piedmont and Blue Ridge Physiographic Provinces are considered unconfined, although local confinement may occur in discontinuous water-bearing fracture zones surrounded by nearly impermeable bedrock. As the aquifers in these provinces usually are shallow, they also are susceptible to contamination by activities on the land surface (Daniel and Dahlen, 2002).

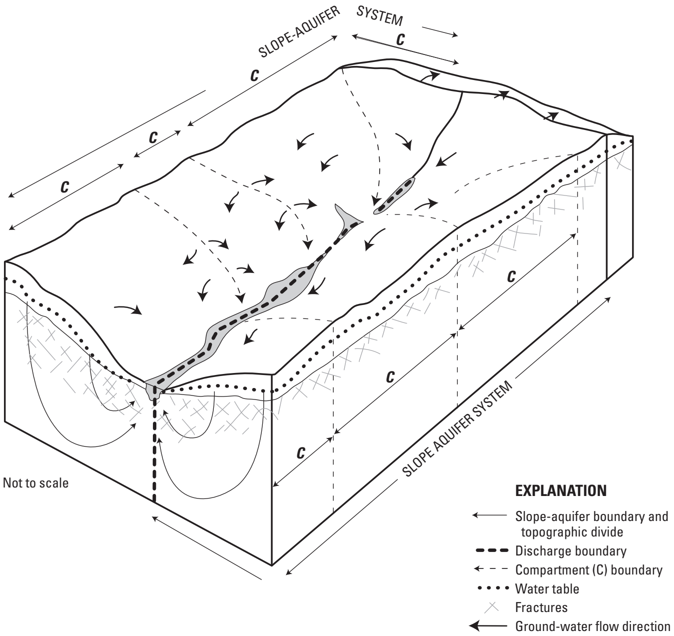


Figure 4. Conceptual view of the slope-aquifer system and related compartments of the Piedmont and Blue Ridge Physiographic Provinces (modified from LeGrand, 2004).

Program Objectives

A primary goal of the PMREP is to develop an understanding of contaminant transport in the complex regolith-fractured bedrock ground-water system in order to better protect and manage the resource (Chapman and others, 2005). Objectives of the regional PMREP are to

1. define the hydrogeologic framework of the Blue Ridge and Piedmont Physiographic Provinces;
2. identify and characterize the hydrologic processes active in each province;
3. investigate the functioning of representative ground-water-flow systems in the regolith-fractured rock aquifer systems by means of applied research, analytical methods, and computer simulation;
4. refine the present understanding of recharge and discharge processes and their role in determining ground- and surface-water quality;
5. estimate regional water budgets, including rates of natural discharge and recharge; changes in aquifer storage; and withdrawals;
6. determine the importance and interrelation of surface- and ground-water-flow systems and their effects on water quality and the potential for development; and
7. develop a comprehensive ground-water database for the region.

Results of this study, when combined with other studies in the Blue Ridge and Piedmont Physiographic Provinces of North Carolina and the eastern United States, will help in the management of the Nation's water resources by defining the quality and quantity of these resources (Daniel and Dahlen, 2002).

Purpose and Scope

The purpose of this report is to present the results of a 5-year study of the hydrogeologic setting, ground-water quality, and ground-water flow at the LPRS. The report includes descriptions of the regional surficial geology, research station design, well characteristics, and ground-water-level and ground-water-quality data. Additionally, a study of ground-water and surface-water interaction and the influence of Lake Norman was conducted at the site, and the results are reported here.

This report describes the hydrogeologic framework of the LPRS from field investigations conducted from September 2000 through September 2005. The research station was designed to distinguish and evaluate ground water in three zones of the Piedmont and Mountains ground-water system—the shallow regolith, the transition zone (partially weathered rock near the base of the regolith and open fractures near the top of bedrock), and the crystalline bedrock (characterized by deeper and fewer fractures; fig. 3). Components of the ground-water system were characterized in relation to water quality, hydraulic properties, and flow.

Description of the Study Area

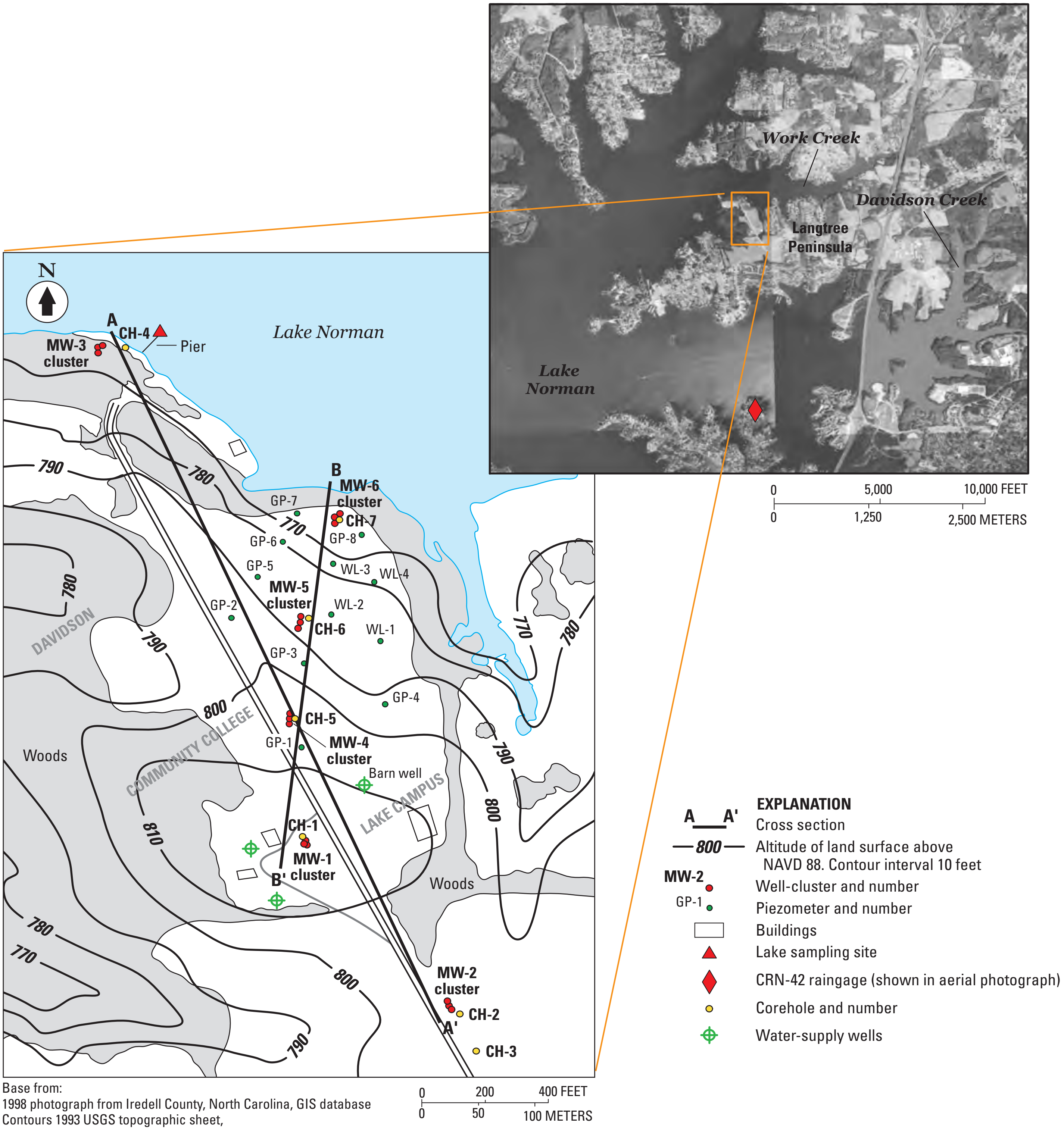
The LPRS is located in the Piedmont Physiographic Province (fig. 1), which is characterized by gently rolling hills and moderately well developed drainage features. The LPRS consists of about 10 acres on the Davidson College Lake Campus on Lake Norman in Iredell County, NC (figs. 2, 5). The research station is about 5 miles (mi) southwest of Mooresville, NC (fig. 1; U.S. Geological Survey, 1993). The site is used primarily for recreational activities, such as boating and swimming. Historically, the site was used for agricultural purposes and as a horse farm (Mr. Sterling Martin, Davidson College, oral commun., 2001).

The LPRS is a formerly rural area that is undergoing substantial population expansion and increasing dependence on ground-water resources for household use. The LPRS site was selected for study because the Davidson College Lake Campus is an unpopulated tract of land near the center of the highly populated residential developments in the Langtree Peninsula area of Lake Norman (fig. 5). The residents of the Langtree Peninsula obtain ground water either from private wells or one of the many community-supply wells on the peninsula. The conceptual hydrogeologic model of the LPRS is representative of larger areas in the Charlotte Belt (fig. 2) and the North Carolina Piedmont (fig. 1).

According to Daniel and Payne (1990), the LPRS is located in the GNF (felsic gneiss) unit (fig. 2). Local complexities in the geologic setting can be missed in regional maps, however, and bedrock core collected at the LPRS dominantly is a quartz diorite rock type, which is part of the metaigneous intermediate rocks (MII) hydrogeologic unit described as gray to greenish-gray medium- to coarse-grained, massive to foliated, well-jointed, metamorphosed bodies of dioritic composition (Daniel and Payne, 1990).

Rock types composing the Charlotte Belt (fig. 2) generally are of plutonic igneous origin, having a range of silicic to mafic compositions, with local occurrences of extrusive rock bodies. Most of the Charlotte Belt has been metamorphosed to amphibolite facies as part of a Barrovian-type regional metamorphic suite.

The LPRS consists of 6 ground-water-quality monitoring-well clusters, each containing 2 to 3 wells completed in the regolith, transition zone, and bedrock; and 12 piezometers completed in the shallow regolith (fig. 5; table 1). Seven continuous soil and bedrock coreholes also were collected at the site. The topography at the LPRS resembles a northwest-trending spur that juts into Lake Norman (fig. 5). Two well



Base from:
1998 photograph from Iredell County, North Carolina, GIS database
Contours 1993 USGS topographic sheet,
Lake Norman Quadrangle, 1:24,000 scale

Figure 5. Locations of well clusters, piezometers, and lines of section at the Langtree Peninsula research station in Iredell County, North Carolina.

transects and piezometer fields are positioned along the northwest trend of the topographic spur (A-A', figs. 5, 6*A*) and on the northeast side of the spur (B-B', figs. 5, 6*B*) following generalized flow paths from recharge to discharge areas. The land-surface altitude at the LPRS ranges from approximately 813 feet (ft) to approximately 762 ft above North American Vertical Datum of 1988 (NAVD 88). Surface-water runoff drains to the northeast or north-northwest on either slope of the topographic spur (fig. 5). Runoff and tributary streams flow into Lake Norman, which at full stage is 760 ft above NAVD 88 (The Louis Berger Group, Inc., 2001).

Previous Studies

LeGrand and Mundorff (1952) described rock types and well yields in the Charlotte area. The gabbro-diorite rock characteristics are described as distinctly massive and not closely jointed. Of 69 wells inventoried in the diorite rock type, the range of reported well yields was from 0 to 75 gallons per minute (gal/min), with an average yield of about 14 gal/min.

LeGrand (1954) included a description of the geology, well yields, and ground-water quality in Iredell County as part of a report on the Statesville area of North Carolina. The area of the LPRS was mapped as part of the gabbro-diorite unit that is consistent with the subsurface rock types observed during LeGrand's study. LeGrand (1954) compared ground-water quality of dioritic rocks to that of granitic rocks of the area. Water from the diorite and hornblende gneiss rock types contained almost three times as much mineral matter in solution compared with water from the granitic rocks. LeGrand (1954) discussed potentially larger yields from the more mafic rocks from solutioning processes of fractures. The median concentrations of calcium, bicarbonate, and sulfate in the dioritic rocks were notably higher than the concentrations

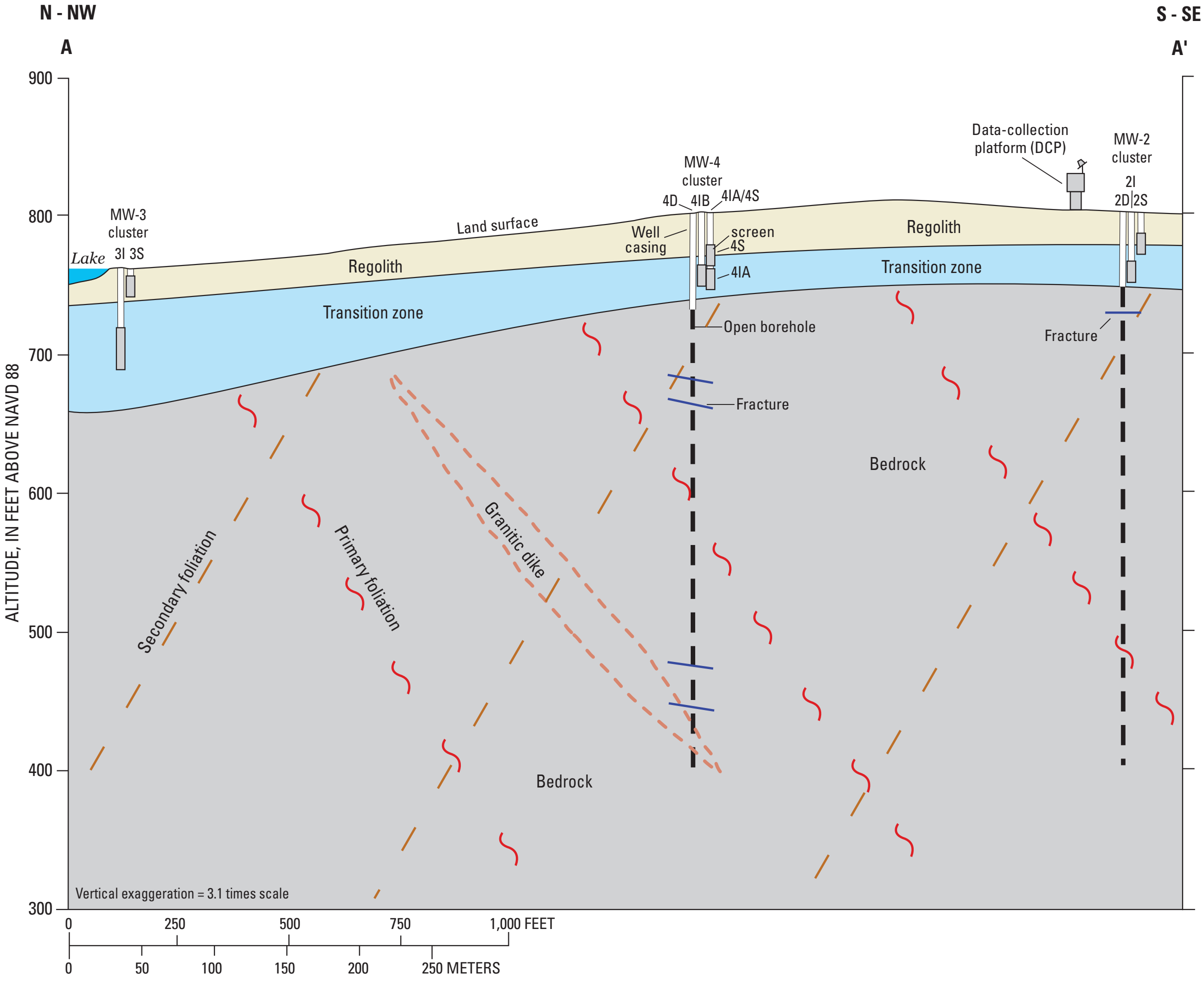


Figure 6*A*. Thickness of regolith, transition zone, depth to bedrock, and representative bedrock fractures along well transect A-A′ at the Langtree Peninsula research station, North Carolina (section location shown in fig. 5).

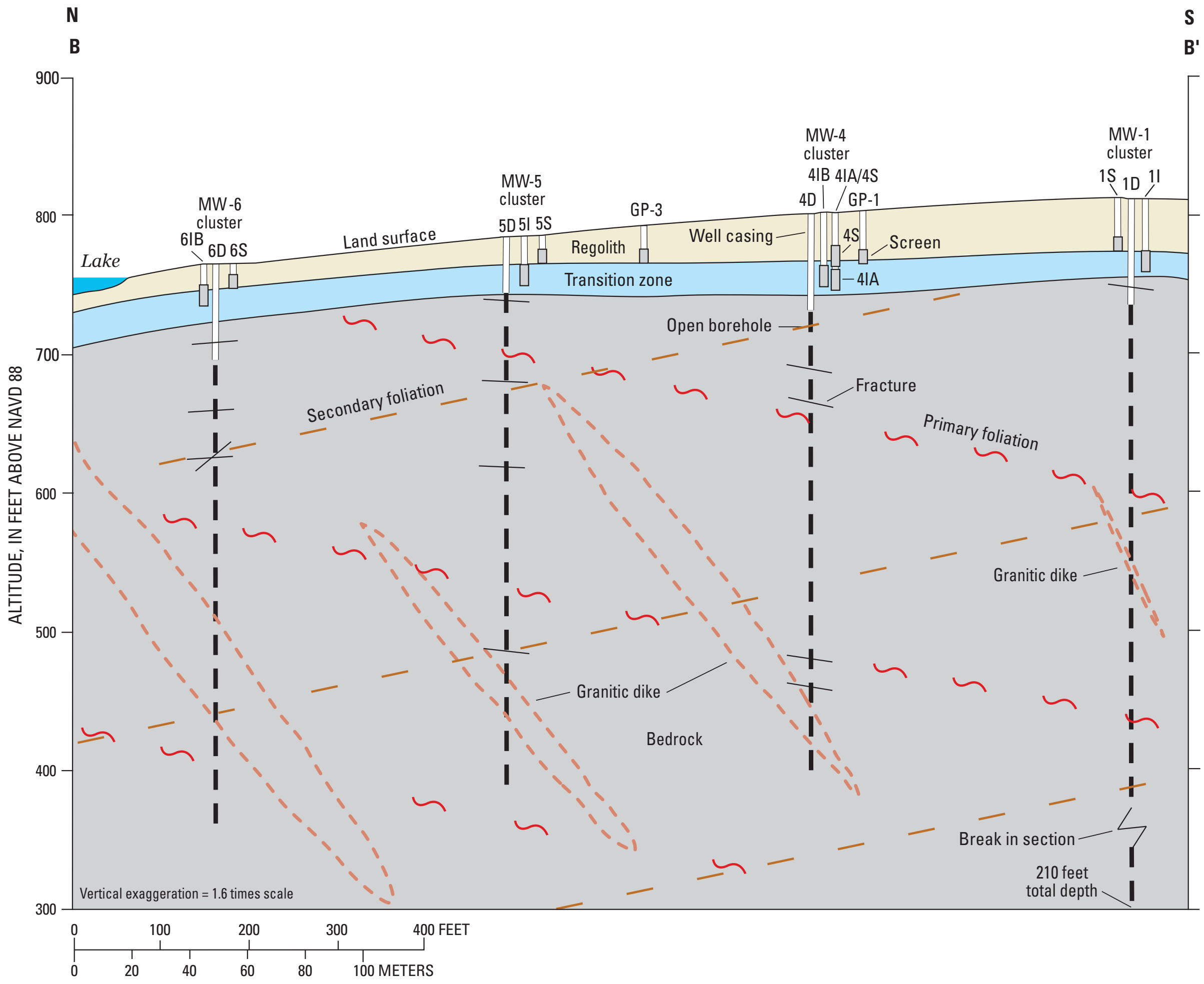


Figure 6*B*. Thickness of regolith, transition zone, depth to bedrock, and representative bedrock fractures along well transect B-B′ at the Langtree Peninsula research station, North Carolina (section location shown in fig. 5).

of these minerals in granitic rocks, supporting the conceptual model of increased mineral dissolution in the dioritic rock types.

Heller and Rollins (2000) conducted a study of ground-water resources in the Langtree Peninsula area of Iredell County. The authors described an increase in the demand for ground-water resources and inventoried 5 community-supply wells and approximately 390 private wells. The well depths ranged from 46 to 900 ft, and the well yields ranged from about 10 to 150 gal/min.

Daniel and Dahlen (2002) described the overall regional goals and study design of the PMREP. Major ground-water issues and problems in the State were identified, and research station selection and site-characterization procedures were discussed. A list of applicable investigative methods also were presented by Daniel and Dahlen (2002).

Chapman and others (2005) presented results of a 2-year characterization of the Lake Wheeler Road research station (LWRRS), which also was constructed as part of the PMREP. The LWRRS is representative of a felsic gneiss having well-developed, steeply dipping foliation. This research station contained one well transect from high to low topographic settings. All three components of the ground-water system—regolith, transition zone, and bedrock—were studied. Ground-water system characteristics, flow, hydraulic data, and quality were described for the LWRRS. Primary findings generally support the conceptual model of ground-water flow, with local variations in vertical gradients. Elevated nitrate concentrations were detected in ground water, most likely from historical agricultural activities in the study area. Continuous ground-water-quality monitoring at a well cluster located in a discharge area indicated upwelling of ground water from the transition zone into the shallow regolith following recharge events and a subsequent rise in the nearby surface-water tributary stage (Chapman and others, 2005).

Huffman and others (2006) presented data collected at four PMREP research stations—Lake Wheeler Road, Langtree Peninsula, Upper Piedmont, and Bent Creek. The data included well-construction characteristics for 110 wells, periodic ground-water levels for 96 wells, borehole geophysi-

Table 1. Construction characteristics of monitoring wells and the surface-water sampling site at the Langtree Peninsula research station in Iredell County, North Carolina.

[NAVD 1988, North American Vertical Datum of 1988; MW, monitoring well; S, shallow regolith; I, transition zone; D, deep; GP or WL, piezometer; IR, Iredell County; PVC, polyvinyl chloride casing; R, shallow regolith; B, bedrock; SW, surface-water site; na, not applicable; nr, not reported]

Site identification	Station name	County number	Construction date	Altitude (feet above NAVD 1988)	Well depth (feet below land surface)	Casing depth (feet below land surface)	Casing material	Casing diameter (inches)	Screened interval or open borehole interval (feet)		Screen type	Zone monitored	Yield (gallons per minute)
									from	to			
353141080524701	MW-1S	IR-145	10/17/2000	812.57	38	28	PVC	4.0	28	38	0.01 slotted PVC	R	na
353141080524702	MW-1I	IR-146	10/11/2000	812.65	53	38	PVC	4.0	38	53	0.01 slotted PVC	I	na
353141080524703	MW-1D	IR-147	11/13/2000	812.51	602	76	PVC	6 with 4-inch liner[a]	55.5/76	602	Open Hole	B	50[b]
353135080524201	MW-2S	IR-130	12/13/2000	803.08	28	13	PVC	4.0	13	28	0.01 slotted PVC	R	na
353135080524202	MW-2I	IR-131	12/13/2000	802.89	48	33	PVC	4.0	33	48	0.01 slotted PVC	I	na
353135080524203	MW-2D	IR-132	11/13/2000	802.69	400	53	PVC	6.0	53	400	Open Hole	B	nr
353157080525301	MW-3S	IR-148	1/24/2001	761.96	20	5	PVC	4.0	5	15	0.01 slotted PVC	R	na
353157080525302	MW-3I	IR-149	1/24/2001	762.92	73	43	PVC	4.0	43	73	0.01 slotted PVC	I	na
353157080525303	MW-3D[c]	IR-150	1/23/2001	762.62	400	90	PVC	6.0	90	400	Open Hole	B	3
353145080524702	MW-4S[d]	IR-152	3/27/2001	802.39	38	23	PVC	2.0	23	38	0.01 slotted PVC	R	na
353145080524701	MW-4IB	IR-151	3/26/2001	802.93	53	38	PVC	4.0	38	53	0.01 slotted PVC	I	na
353145080524704	MW-4IA	IR-152A	2/26/2002	802.39	55	40	PVC	2.0	40	55	0.01 slotted PVC	I	na
353145080524703	MW-4D	IR-153	3/14/2001	801.84	400	69	PVC	6 with 4-inch liner[a]	69	400	Open Hole	B	5[b]
353148080524701	MW-5S	IR-154	3/27/2001	786.18	20	10	PVC	4.0	10	20	0.01 slotted PVC	R	na
353148080524702	MW-5I	IR-155	3/27/2001	785.07	35	20	PVC	4.0	20	35	0.01 slotted PVC	I	na
353148080524703	MW-5D	IR-156	3/7/2001	784.73	400	40	PVC	6.0	40	400	Open Hole	B	20
353151080524601	MW-6S	IR-157	3/28/2001	765.32	18	8	PVC	4.0	8	18	0.01 slotted PVC	R	na
353151080524602	MW-6I[e]	IR-158	4/2/2001	764.59	35	20	PVC	4.0	20	35	0.01 slotted PVC	I	na
353151080524604	MW-6I B	IR-160	3/4/2002	765.73	30	15	PVC	4.0	15	30	0.01 slotted PVC	I	na
353151080524603	MW-6D	IR-159	2/27/2001	765.84	400	69	PVC	6 with 4-inch liner[a]	69	400	Open Hole	B	35[b]

Table 1. Construction characteristics of monitoring wells and the surface-water sampling site at the Langtree Peninsula research station in Iredell County, North Carolina. — Continued

[NAVD 1988, North American Vertical Datum of 1988; MW, monitoring well; S, shallow regolith; I, transition zone; D, deep; GP or WL, piezometer; IR, Iredell County; PVC, polyvinyl chloride casing; R, shallow regolith; B, bedrock; SW, surface-water site; na, not applicable; nr, not reported]

Site identification	Station name	County number	Construction date	Altitude (feet above NAVD 1988)	Well depth (feet below land surface)	Casing depth (feet below land surface)	Casing material	Casing diameter (inches)	Screened interval or open borehole interval (feet)		Screen type	Zone monitored	Yield (gallons per minute)
									from	to			
353144080524601	GP-1	IR-133	9/13/2000	805.10	38.5	29.5	PVC	0.5	29.5	38.5	0.01 slotted PVC	R	na
353148080524901	GP-2	IR-134	9/21/2000	793.48	36	27	PVC	0.5	27	36	0.01 slotted PVC	R	na
353146080524601	GP-3	IR-135	10/3/2000	791.04	31	22	PVC	0.5	22	31	0.01 slotted PVC	R	na
353145080524401	GP-4	IR-136	9/19/2000	793.08	34	25	PVC	0.5	25	34	0.01 slotted PVC	R	na
353149080524801	GP-5	IR-137	10/3/2000	786.81	32	23	PVC	0.5	23	32	0.01 slotted PVC	R	na
353150080524701	GP-6	IR-138	10/4/2000	776.58	25	16	PVC	0.5	16	25	0.01 slotted PVC	R	na
353151080524701	GP-7	IR-139	10/4/2000	767.37	18	9	PVC	0.5	9	18	0.01 slotted PVC	R	na
353151080524501	GP-8	IR-140	10/10/2000	768.04	18	8	PVC	0.5	8	18	0.01 slotted PVC	R	na
353147080524401	WL-1	IR-141	10/10/2000	784.27	35	20	PVC	1.0	20	30	0.01 slotted PVC	R	na
353148080524601	WL-2	IR-142	10/9/2000	780.74	26	16	PVC	1.0	16	26	0.01 slotted PVC	R	na
353150080524501	WL-3	IR-143	10/10/2000	770.46	20	10	PVC	1.0	10	20	0.01 slotted PVC	R	na
353149080524401	WL-4	IR-144	10/10/2000	775.85	30	17	PVC	1.0	17	26	0.01 slotted PVC	R	na
0214262175	Lake Norman (Work Creek arm) near Mount Mourne, NC			762.18	na	na	na	na	na	na	na	SW	na

[a] Four-inch liner installed in December 2001.

[b] Initial well yield prior to 4-inch liner installation.

[c] Abandoned in March 2002.

[d] Well drilled deeper in February 2002 and renamed MW-4IA.

[e] Well drilled deeper in February 2002 and renamed MW-6IB.

cal logs for 23 wells, hourly ground-water levels for 12 wells, continuous stage for 2 streams, continuous water-quality measurements for 8 wells and 2 streams, periodic water-quality measurements for 58 wells and 6 stream sites, slug-test results for 48 wells, and shallow ground-water-flow maps. In addition, the geology and hydrogeology at each research station were described.

Results of two regional studies of ground-water quality in the Piedmont and Mountains region of North Carolina were presented by Reid (1993) and Briel (1997). Reid (1993) presented the results of the National Uranium Resource Evaluation (NURE) Program in which ground-water samples from 5,778 wells in North Carolina were analyzed for uranium, vanadium, dysprosium, sodium, aluminum, manganese, bromide, chloride, and fluoride. Briel (1997) summarized ground-water quality from wells in North Carolina as part of the Appalachian Valleys-Piedmont Regional Aquifer System Analysis (APRASA) study.

Acknowledgments

The authors graciously thank Sterling Martin, site manager, and Davidson College for permission and facilitation of site access to establish and conduct studies at the LPRS. The authors also thank the well drillers with the NCDENR Aquifer Protection Section for their hard work, perseverance, and patience in dealing with adverse conditions in the field and their willingness to do whatever was necessary to complete the work. Assistance from DWQ PMREP hydrogeologists Donald J. Geddes, Jr., Richard E. Bolich, Ted R. Campbell, and USGS hydrographer Cassandra Pfeifle is greatly appreciated. The use of "FracView" software from Paul Hsieh (USGS, Menlo Park, CA), was used to visualize the three-dimensional fracture network. Cartographic assistance from students Ashley Evans (North Carolina State University) and Erik Gulbranson (University of Minnesota) is greatly appreciated. The foundation for this study was established by previous work of retired USGS ground-water hydrologists Charles Daniel, Ralph Heath, and Harry LeGrand, and their contributions to the science of Piedmont and Mountains ground-water hydrology. The authors value ongoing technical discussions with these renowned scientists.

Methods of Investigation

Most of the methods used at the LPRS are summarized in Chapman and others (2005) and in standard operating procedures (SOP) for the PMREP study (Richard E. Bolich, North Carolina Department of Environment and Natural Resources, Division of Water Quality, written commun., 2008). More specific details of methods applied during this study, however, are discussed here.

Research Station Design and Monitoring

The topography in the vicinity of the well transects at the LPRS slopes gently toward Lake Norman and a draw to the east (fig. 5). The land-surface altitude along the transects ranges from approximately 803 ft above NAVD 88 at well cluster MW-2 to approximately 762 ft at well cluster MW-3, and from approximately 813 ft above NAVD 88 at well cluster MW-1 to approximately 765 ft at well cluster MW-6 (table 1). The LPRS consists of 6 ground-water-quality monitoring-well clusters constructed along 2 topographic transects, and 12 shallow piezometers installed in a grid pattern surrounding 3 well clusters (fig. 5). The two well transects are located along a high to low topographic profile, similar to that described by LeGrand (2004) as a "slope-aquifer" system (fig. 4), from recharge to discharge areas (figs. 6*A*, 6*B*). Each well cluster at the LPRS consists of two to three monitoring wells—a shallow well completed in the regolith, an intermediate well completed in the transition zone, and a deep bedrock well completed in the underlying fractured bedrock. The bedrock well associated with cluster MW-3 was abandoned in March 2002 because of collapse in the open borehole following its completion.

Geologic Coring

Prior to well construction, continuous soil and bedrock cores were collected at each well-cluster location and at a location south of well cluster MW-2. The coreholes at these locations were designated CH-1, CH-2, CH-3, CH-4, CH-5, CH-6, and CH-7 (fig. 5). Data from the coreholes were used to determine construction design for the monitoring wells and to describe geologic materials within the ground-water system (app. 1).

The coreholes were drilled using State-owned equipment consisting of a wire-line coring rig and a 5-ft long, 2.5-inch core barrel (2.5-inch inner diameter), as described in Chapman and others (2005). The site hydrogeologist logged each core upon retrieval from the sample barrel, noting soil characteristics and properties, rock type, fracture type and orientation, weathering, and any significant geologic features. Detailed

Ground-water sampling equipment.

descriptions of regolith materials, including saprolite and bedrock lithology and fracture characteristics, are provided in appendix 1 of this report. Guidelines for core descriptions are discussed in the SOP for the PMREP (North Carolina Department of Environment and Natural Resources, Division of Water Quality, and U.S. Geological Survey, Water Resources Division, 2002). The coreholes were abandoned later in accordance with the State of North Carolina Subchapter 2C, Well Construction Standards (North Carolina Department of Environment and Natural Resources, Division of Water Quality, 2002).

Well-Cluster Transects and Piezometers

Criteria for determining well-cluster locations included topographic position, accessibility, and site boundaries. During this investigation, 18 wells and 12 piezometers initially were installed at the LPRS (fig. 5; table 1). Conceptual hydrogeologic cross sections were constructed along the well transects. Transect A-A' (figs. 5, 6*A*) extends from well cluster MW-2 (recharge area) to MW-3 (discharge area), and transect B-B' (figs. 5, 6*B*) extends from well cluster MW-1 (recharge area) to cluster MW-6 (discharge area). The piezometers were installed near well clusters MW-4, MW-5, and MW-6 to determine the direction of lateral ground-water flow in the shallow regolith.

Well Construction

Monitoring wells at the LPRS were constructed by using air-rotary, mud-rotary, hollow-stem auger, and direct-push drilling methods. Air-rotary drilling methods were used to construct the shallow regolith (MW-_S) wells and intermediate depth (MW-_I) transition-zone wells. For the bedrock (MW-_D) wells, mud-rotary methods were used to install the surface casing, and the open-borehole section was drilled by using air-rotary methods. Hollow-stem auger techniques were used to construct the four shallow regolith (WL-_) piezometers (table 1). Direct-push drilling methods were used to install a grid of eight shallow (GP-_) piezometers (table 1) tapping the regolith. Mud-rotary, air-rotary, and hollow-stem auger drilling methods, and well-completion techniques used at the LPRS were similar to those described in Chapman and others (2005). Screened wells generally were completed by using coarse sand as a filter across the screened interval and up to 2 ft above the top of the screen. At least 2 ft of bentonite sealing material then was placed on top of the sand (sediment) filter pack, and the remainder of the well annulus was grouted by using cement to land surface. Specific well-construction details for each well are listed in table 1. Completion problems occurred in bedrock wells MW-3D, MW-1D, MW-4D, and MW-6D when sediment collapsed into the open borehole. Well MW-3D was abandoned, and 4-inch polyvinyl chloride (PVC) liners were installed in wells MW-1D, MW-4D, and MW-6D (table 1). Additional sediment problems in wells MW-4S and MW-6I resulted in deeper drilling of well MW-4S (renamed MW-4IA) and the replacement of well MW-6I (new well MW-6IB) (table 1).

All wells were developed after completion in order to remove drilling fluids and improve hydraulic communication between the wells and the aquifer. Submersible pumps and surge blocks were used to develop the regolith and transition-zone wells, and the bedrock wells were developed by using air lift from the drill rig. All of the wells installed during this investigation were completed with a locking, steel, protector casing with keyed padlocks.

Investigative Field Methods

Methods of investigation at the LPRS included borehole geophysical logging, optical televiewer (OTV) imaging, continuous ground-water-level and ground-water-quality monitoring (1-hour (hr) intervals), periodic ground-water-level measurements, ground-water-quality sampling, slug tests, and aquifer tests. Borehole geophysical logs run in all bedrock wells included the collection of caliper, electrical resistivity, natural gamma, temperature, fluid resistivity, and heat-pulse flowmeter logs. In addition, OTV images were collected to determine orientations of foliation and fractures (Chapman and others, 2005).

In this report, continuous near real-time (transmitted every 4 hrs) ground-water levels recorded at well cluster MW-2 (figs. 5, 6*A*; wells MW-2S, MW-2I, and MW-2D) are presented from March 2001 through September 2005. Water-level instrumentation consisted of a float-tape encoder system. Continuous ground-water-quality monitoring of temperature, pH, specific conductance (SC), and dissolved oxygen (DO) was conducted in regolith well MW-2S from August 2002 through July 2003 and in bedrock well MW-2D

Ground-water-level monitoring equipment being installed at well cluster MW-2 (photograph by Stephen Howe, retired, U.S. Geological Survey).

from August 2002 through March 2004. Water-quality monitors were set within the screened interval of 13 to 28 ft for regolith well MW-2S and near a fracture at about 73 ft below land surface in bedrock well MW-2D. Periodic ground-water levels were measured in all 17 wells and 12 piezometers at monthly intervals. Ground-water-quality samples were collected from all 17 wells and Lake Norman in August 2002 and March 2003. Data from one well sampled in June 2004 also are presented in this report. Quality-assurance procedures for these methods of investigation are discussed and referenced in Chapman and others (2005) and in the SOP for the PMREP study (North Carolina Department of Environment and Natural Resources, Division of Water Quality, and U.S. Geological Survey, Water Resources Division, 2002).

Slug Tests

Slug tests were performed on eight wells at the LPRS to assess the horizontal hydraulic conductivity at the site. A 5-ft long, 3-inch diameter PVC bailer was used as the slug to displace water inside the wells. The PVC slug was cleaned before use in each well. A 15-pounds-per-square-inch (psi) pressure transducer was used to measure water-level fluctuations during each test. The pressure transducer also contained an integrated electronic data logger, which was used to provide backup data-recording capability.

After the slug was inserted and the water level in each well stabilized (after the bailer had filled with water), the slug was removed as quickly as possible. The rising-head slug test was conducted by initiating a new logarithmic recording step on the data logger simultaneously with the removal of the PVC slug. The data were field checked using hand-held water-level readings, and the test was terminated after water levels recovered to within 95 percent of the pre-test level.

The slug-test data were analyzed using the Bouwer and Rice (1976) method, which accounts for partial-penetration effects and changing aquifer thickness (water-table conditions). A basic assumption of this analytical method is that the aquifer is representative of a porous medium and is considered isotropic, having no directional variation in hydraulic properties within the zone being tested. Additional assumptions are that the effects of elastic storage can be neglected, and the position of the water table does not change during the slug test (Butler, 1998). The Bouwer and Rice (1976) analytical solution is widely used for slug-test analyses. Spreadsheets developed by Halford and Kuniansky (2002) were used for analytical interpretations of the slug-test data. The combined thickness of the regolith and transition zones at each well cluster (app. 1) was used for the total aquifer thickness for slug-test analyses of the wells. Thickness of the fractured bedrock part of the aquifer was assumed to be equal to the length of open borehole.

Aquifer Test

Step-drawdown and constant-rate aquifer tests were conducted in January 2003 to obtain an estimate of the transmissivity and storage coefficients for the bedrock part of the aquifer. A variable-speed, 4-inch diameter, one-half horsepower electric submersible pump was installed in well MW-5D (figs. 5, 6*B*) at a depth of about 196 ft. The pump was supported by 1.25-inch inner diameter schedule-80 PVC pipe, and a 1.5-inch diameter polyethylene hose was used as a discharge line. A digital, in-line flowmeter was used to estimate pump-discharge rates. The flow rates were verified manually using a graduated 5-gallon (gal) bucket and stopwatch. The pump discharge was directed through a polyethylene hose into an adjacent drainage approximately 300 ft east of the pumped well.

A step-drawdown test was first conducted on January 7, 2003, for 3 hours at rates ranging from about 6 to 14 gal/min. The results of the step-drawdown test indicated that the optimum pumping rate for the constant-rate discharge test was approximately 12 gal/min. A 48-hr constant-rate aquifer test was conducted January 14–16, 2003, at a rate of 12 gal/min; approximately 34,296 gal of ground water was pumped from well MW-5D. Discharge from the pumped well was sampled periodically for selected major ions and monitored for pH, SC, and temperature.

During the MW-5D January 2003 aquifer test, the following wells and piezometers were instrumented with electronic pressure transducers to monitor water levels: MW-1I, MW-1D, MW-4I, MW-4D, MW-5I, MW-5D, MW-6I, MW-6D, WL-2 and WL-3 (figs. 5, 6). Tape downs also were recorded in the Davidson campus barn well (fig. 5). The pressure transducers were placed in the designated observation wells several days before the start of the pumping test in order to allow time for the transducers to stabilize and to monitor background water-level fluctuations. The remaining shallow regolith wells and piezometers that were not instrumented were manually measured at regular intervals throughout the aquifer test. Pressure transducers near the pumped well were set initially to record water levels at logarithmic time intervals and subsequently at 10-minute intervals for the duration of the test. Water levels in the MW-2 well cluster were recorded at hourly intervals using a float/encoder/data-logger configuration and transmitted by satellite telemetry to the USGS National Water Information System (NWIS) database.

Water-Quality Sampling

Water-quality samples were collected for laboratory analyses from the LPRS well clusters and from Lake Norman in August 2002 and March 2003, and from one well that was sampled in June 2004. All samples were analyzed at the USGS

National Water Quality Laboratory in Denver, Colorado. Additional sampling was conducted at all LPRS wells by DWQ personnel (Joju Abraham, North Carolina Department of Environment and Natural Resources, Division of Water Quality, Mooresville Regional Office, oral commun., 2007), but those data are not presented here. Sampling methods included the use of variable-speed, submersible 2-inch pumps; smaller submersible plastic, single-speed pumps; peristaltic pumps; and disposable bailers. Water-quality characteristics (pH, SC, DO, and temperature) were monitored continuously as water was pumped from the wells and at specific depth intervals in the lake. For the regolith and transition-zone well samples, at least three well volumes of ground water were pumped prior to sample collection. Stabilization of water-quality characteristics (temperature, pH, SC, and DO) was a requirement prior to sampling all wells (Chapman and others, 2005). Ground-water samples were compared with whole-rock analyses of core that were analyzed by the USGS laboratory in Reston, Virginia.

For the deep, 6-inch diameter, open-borehole bedrock wells, the extraction of three volumes of ground water prior to sample collection was impractical using the low-rate sampling pumps. Therefore, one volume of surface casing water was removed at a minimum, and stabilization of water-quality characteristics was obtained prior to sample collection. In addition, the sampling pump was placed near the more dominant fracture zones at depth to obtain a representative sample (Chapman and others, 2005).

Continuous Ground-Water-Quality Monitoring

Continuous (hourly) water-quality data were recorded in LPRS regolith well MW-2S during August 2002 through July 2003 and in bedrock well MW-2D during August 2002 through March 2004. The purpose of collecting continuous ground-water-quality data was to determine seasonal fluctuations and to identify short-term fluctuations and response to recharge. Each well was equipped with a multiparameter water-quality probe for collecting temperature, pH, SC, and DO. The data from each water-quality probe were stored in an electronic data recorder and transmitted by satellite every 4 hrs. The water-quality probes were cleaned and calibrated at least once a month following USGS guidelines (Wagner and others, 2006) and methods described in Chapman and others (2005).

Climate Data

Daily rainfall data used in this report were obtained from the USGS Norman Shores raingage (station number 353014080524945, CRN-42), located about 1.6 mi south of the LPRS (fig. 5). These data were recorded at 15-minute intervals and summed for the day. Records are published in the USGS North Carolina Water Science Center Annual Data Reports, accessible online at *http://nc.water.usgs.gov/reports/WDR/.* Records for precipitation station CRN-42 used in this report are published for the water years[4] 2001–2005 in Ragland and others (2002, 2003, 2004) and Walters and others (2005, 2006). Daily air-temperature records were compiled from the Statesville 2NNE station (Ashley Frazier, Staff Meteorologist, State Climate Office of North Carolina, written commun., 2006), which is part of the North Carolina Climate Retrieval and Observations Network of the Southeast (CRONOS) database (North Carolina State Climate Office, 2004).

Well and Surface-Water Station Numbering System

A unique identification number was assigned to each USGS well and surface-water station based on geographic location. A latitude-longitude system was used for wells, and a downstream-order system was used for surface-water stations. The latitude and longitude of each well cluster at the LPRS were determined by using a differential global positioning system (DGPS) and are considered accurate to within 5 ft.

Wells were assigned a 15-digit site number along with a local number and name. The first 13 digits represent the latitude and longitude of each well, and these digits are followed by 2-digit sequence numbers that distinguish the wells in the well clusters. Thus, each well in a cluster has the same site-identification number except for the last two digits. Typically, the assigned sequence numbers begin with 01 for the shallowest well and progress with well depth. Thus, the deeper the well, the higher the sequence number.

In addition, the wells in this study were assigned a local identifier, which consists of a two-letter county code followed by a three-digit sequence number. For example, wells in Iredell County are identified by the “IR” prefix followed by three numbers assigned sequentially (table 1). The station name includes the site identifier (Langtree Peninsula research station), well descriptor, and number. The well descriptors used in this study are MW for monitoring well and WL or GP for piezometer. Following the well descriptor is a cluster number and letter, which indicates the aquifer section or “zone” that is being monitored: S for shallow zone in the regolith, I for intermediate transition zone, and D for deeper zone in the bedrock. For example, monitoring well MW-1S is located in well cluster 1 and is completed in the shallow regolith zone.

The downstream order number or station number assigned to a surface-water station is based on the location of the station in the downstream direction along the main stem. The first 2 digits of the 8- to 10-digit station number identify the hydrologic unit (U.S. Geological Survey, 1974, 1975), which designates the major river basin in which the station is located. The next 6 digits indicate the downstream order within the river basin, and an additional 2 digits are used following the station number to further distinguish stations in areas of high station density.

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[4] Water year is the period October 1 through September 30 and is identified by the year in which the period ends. For example, water year 2001 began on October 1, 2000, and ended on September 30, 2001.

Hydrogeologic Setting

The hydrogeologic settings of the Piedmont and Mountains region in North Carolina are highly variable and local (scale of typically 1 mi or less) as a result of complex geologic characteristics. These geologic factors, including lithology and structural features, directly control ground-water flow in the bedrock and influence the development and characteristics of the shallow regolith and transition zone. A detailed description of the hydrogeologic setting, both at land surface and at depth, is needed to understand controls on flow and occurrence of ground water in this region.

Regional Geology

The geologic setting of most areas in the Piedmont and Mountains region is complex. Rocks in this region have undergone intense metamorphism, folding, faulting, and igneous intrusion. In North Carolina, the regional sequences of rock bodies are grouped into "belts" (North Carolina Geological Survey, 1985). Although rock bodies within the belts generally are similar with regard to lithologic and tectonic genesis, details of variation and complexity are observed on the local scale. More recently, researchers have referred to these rock bodies as exotic terranes distinguished by varying characteristics attributed to their accretion to the Laurentian craton (Hibbard, 2000; Wortman and others, 2000; Hibbard and others, 2002).

The works of Hibbard (2000), Wortman and others, (2000), and Hibbard and others (2002) describe the distribution and characteristics of various peri-Gondwanan exotic terranes that docked onto the Laurentian craton during the Neoproterozoic and early Paleozoic Eras. These exotic terranes, which include the former Kings Mountain Belt, Charlotte Belt, and Carolina Slate Belt, are collectively referred to as the Carolina zone (fig. 7). As a result of regional-style metamorphism across the Carolina zone, the metamorphic grade ranges from epidote-amphibolite to amphibolite facies. Locally occurring higher-grade rocks were emplaced by contact metamorphism from post-metamorphic igneous intrusives (Goldsmith and others, 1988). Post-metamorphic igneous intrusives are predominantly present as diabase and granitic dikes or as batholith-scale intrusives of felsic composition.

The rock assemblages that traditionally have been assigned to the Charlotte and Kings Mountain Belts were grouped by Hibbard and others (2002) into the Charlotte terrane (fig. 7). The Charlotte terrane is characterized mostly by plutonic rocks that range in age from Neoproterozoic to late Paleozoic and intrude a suite of mainly metaigneous rocks and minor metasedimentary rocks. The timing of accretion for the Charlotte terrane is thought to have occurred between the Neoproterozoic Era and early Cambrian period. By the end of the Ordovician period, the suturing of the Carolina terrane to the North American craton was completed (Hibbard and others, 2002). Subsequent metamorphism occurred during the Alleghanian Orogeny, and emplacement of dikes occurred across the region during Mesozoic Era extension (Butler and Secor, 1991; Ragland, 1991

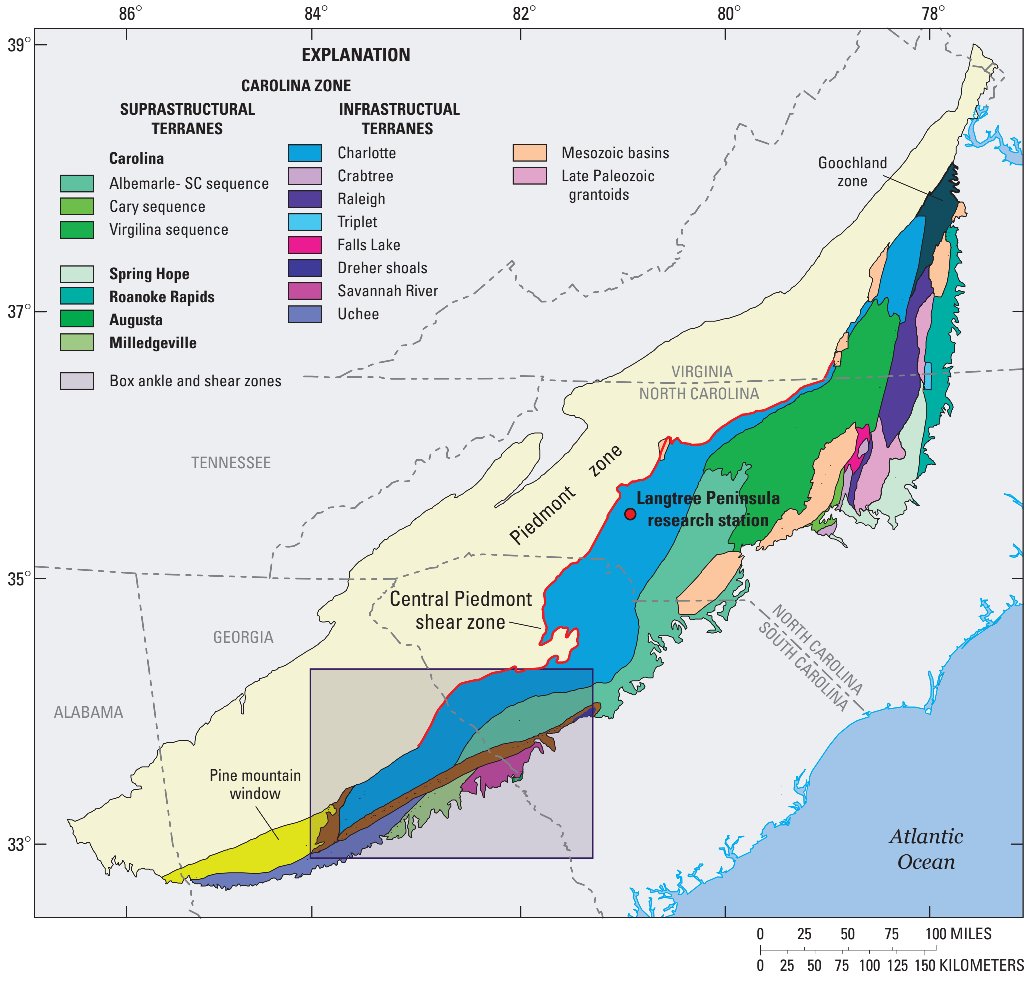


Figure 7. Geologic map of sutured terranes in the Piedmont of Georgia, South Carolina, North Carolina, and Virginia (adapted from Hibbard and others, 2002).

The LPRS lies in the central part of the Charlotte terrane (fig. 7; North Carolina Geological Survey, 1985; Goldsmith and others, 1988; Hibbard and others, 2002). The Charlotte terrane is characterized mostly by felsic to mafic plutonic rocks that range in age from Neoproterozoic to late Paleozoic and intrude a suite of mainly metaigneous rocks and minor metasedimentary rocks (Goldsmith and others, 1988; Hibbard and others, 2002). The various rock bodies of the Charlotte terrane were emplaced between 300 and 500 million years ago (Butler and Fullagar, 1978; Fullagar and Butler, 1979; Horton and Stern, 1983; Kish, 1983; Sutter and others, 1983; Goldsmith and others, 1988). Three intrusive events are responsible for the emplacement of the majority of the plutonic rock bodies that are present in the Carolina zone (Fullagar, 1971; Goldsmith and others, 1988). The igneous intrusives that compose the bedrock at the LPRS were grouped by Goldsmith and others (1988) with other similar rocks and designated as the “Older Plutonic Complex.” The older plutonic complex rocks generally are metamorphosed gabbros, syenites, diabase, granodiorite, and quartz diorites. Geochronology performed on zircons separated from a metagranodiorite sample collected in York County, South Carolina, yielded a uranium-lead concordia age of 532 ±15 million years (Law Engineering and Testing Company, 1976; Goldsmith and others, 1988). This age indicates that rocks of the older plutonic complex are related to the plutonic activity associated with the Taconic Orogeny. Across the Charlotte terrane (fig. 7), rock bodies that have undergone deformation generally can be characterized as having a subvertical foliation that trends north to northeast. Several post-deformation intrusive rock bodies are present in the Charlotte terrane as well. The regional metamorphic grade generally peaked at amphibolite facies and is considered to be related to regional metamorphism of Taconic age.

The intensive chemical weathering of crystalline metamorphic and igneous rocks in the Piedmont region produces soil, residuum, and saprolite. Collectively, these materials, along with alluvium and colluvium (where present), compose the regolith, which overlies competent bedrock. Saprolite retains much of the fabric of the underlying parent rock. Weathering of feldspars and micas produces clay as residuum. As a result, soil, residuum, and saprolite typically have high porosity but low to moderate hydraulic conductivity. Ground water flows through intragranular pore spaces or through relict features, such as fractures or vein deposits, in soil and saprolite. In contrast, ground water in the underlying bedrock flows through secondary fractures and discontinuities because the unweathered bedrock has very low primary porosity and permeability.

Daniel and Dahlen (2002) provide an overview of Daniel and Payne’s (1990) major hydrogeologic units of the Piedmont and Mountains of North Carolina. Within the Carolina zone, hundreds of rock units have been classified using conventional geologic nomenclature; however, in terms of hydraulic properties, the many units of rock that compose the Carolina zone have been grouped into more generalized hydrogeologic units (Daniel, 1989; Daniel and Payne, 1990). The 12 hydrogeologic units identified by Daniel and Payne (1990) are located in the Charlotte terrane; of these 12 units, the MII unit is one of the most widespread and represents the hydrogeologic unit that underlies the LPRS site.

Local Geology

Based on analyses of bedrock-core samples, interpretations of downhole video logs and OTV images from the LPRS, and published geologic maps of the study area (Goldsmith and others, 1988), the shallow subsurface at the site consists primarily of metamorphosed quartz diorite. This rock type corresponds to the metamorphosed quartz diorite (mqd) and tonalite designation previously determined by Goldsmith and others (1988), which was described as “Gray, usually medium- to coarse-grained, generally foliated rock composed dominantly of plagioclase, quartz, biotite, hornblende, and epidote. Biotite, hornblende, and epidote are commonly associated in clots replacing original mafic phenocrysts.” These minerals may be smeared out, defining a weak foliation. This description is applicable to the principal rock type (quartz diorite) observed in the extracted core at the LPRS. In addition, localized zones of migmatitic rock are present at various depths, as observed in OTV images (fig. 8). Granitic dikes also

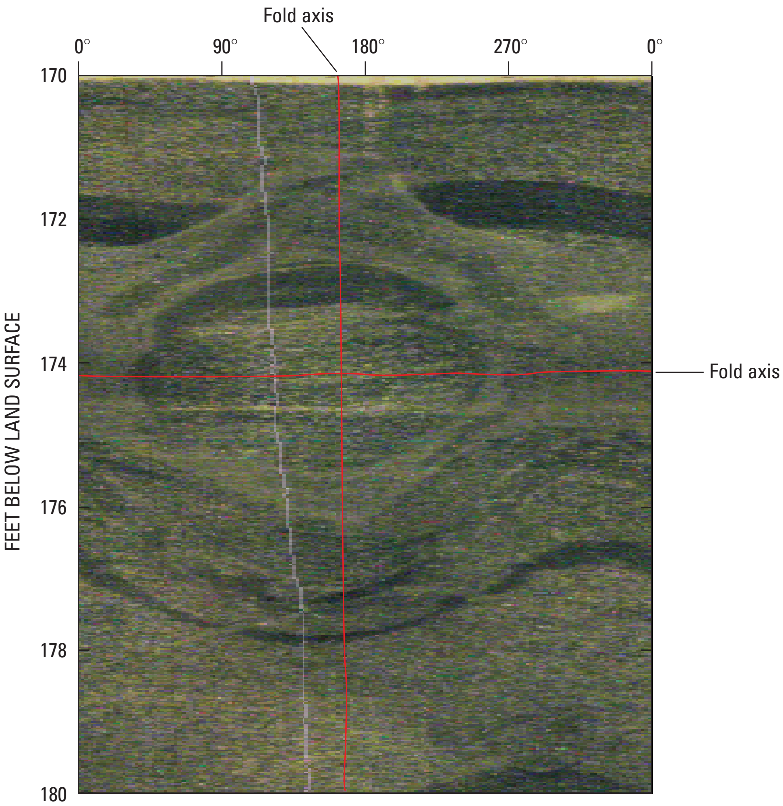
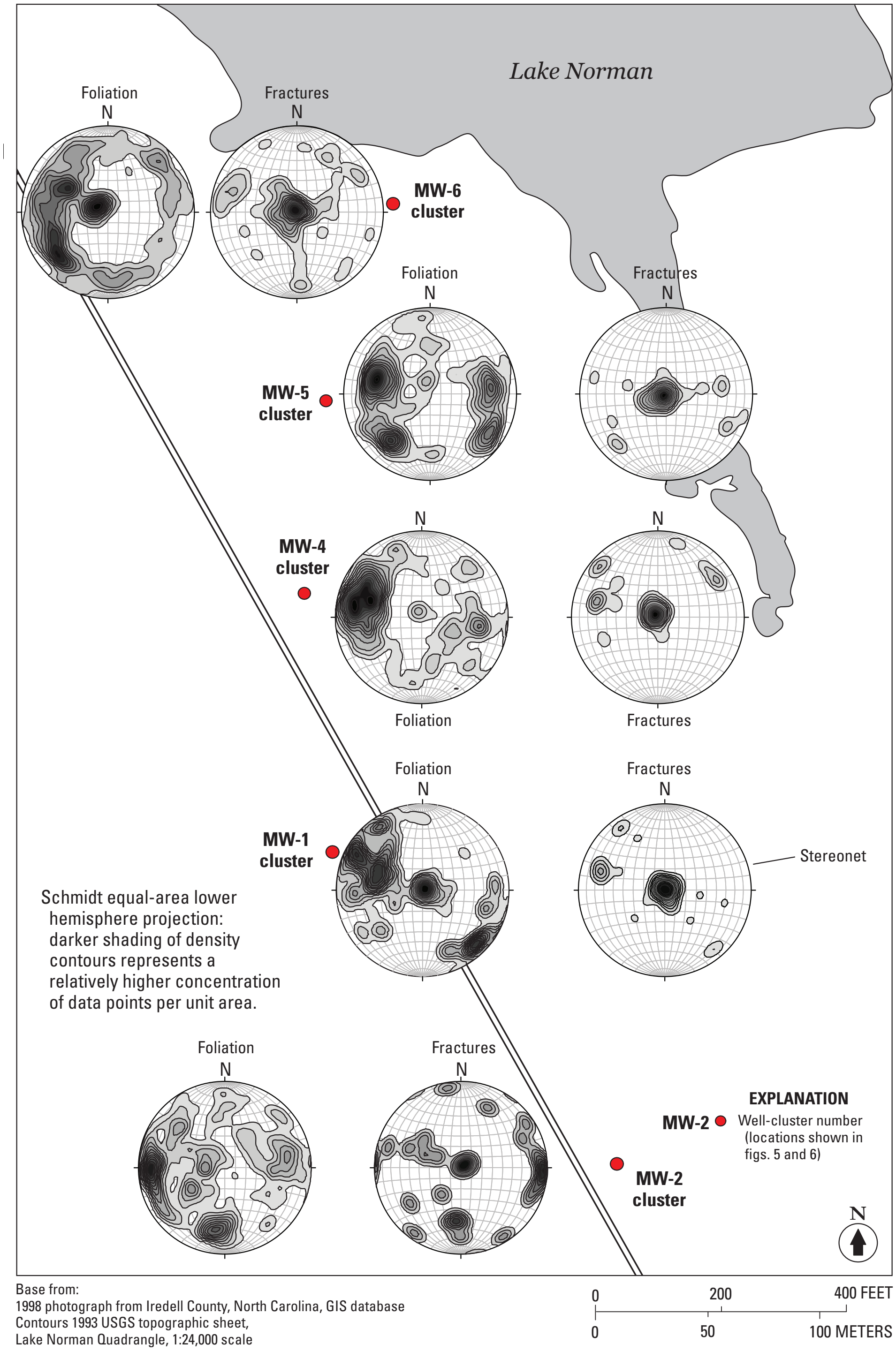


Figure 8. Optical televiewer image showing two foliation orientations near isoclinal folds and overall migmatitic structures.

were observed in four of the five bedrock wells, ranging in thickness from about 2 to 50 ft (fig. 6).

Structurally, the LPRS lies approximately 13 mi east of the northeast-trending Central Piedmont shear zone (fig. 7). Northeast-trending foliations having eastward dips, typical of the style of deformation commonly observed in the southern Appalachians, also are present in rocks underlying the site. Analyses of downhole OTV data collected from the bedrock wells at the LPRS revealed a bimodal distribution for foliation dip azimuths observed from individual bedrock monitoring-well boreholes (figs. 9, 10; app. 2). At least two periods of deformation represented by two foliation orientations were



Base from:
1998 photograph from Iredell County, North Carolina, GIS database
Contours 1993 USGS topographic sheet,
Lake Norman Quadrangle, 1:24,000 scale

Figure 9. Map view of stereonet diagrams showing dip azimuth orientation of bedrock foliation and fractures interpreted from optical televiewer images of the open boreholes in bedrock wells MW-1D, -2D, -4D, -5D, and -6D at the Langtree Peninsula research station in Iredell County, North Carolina.

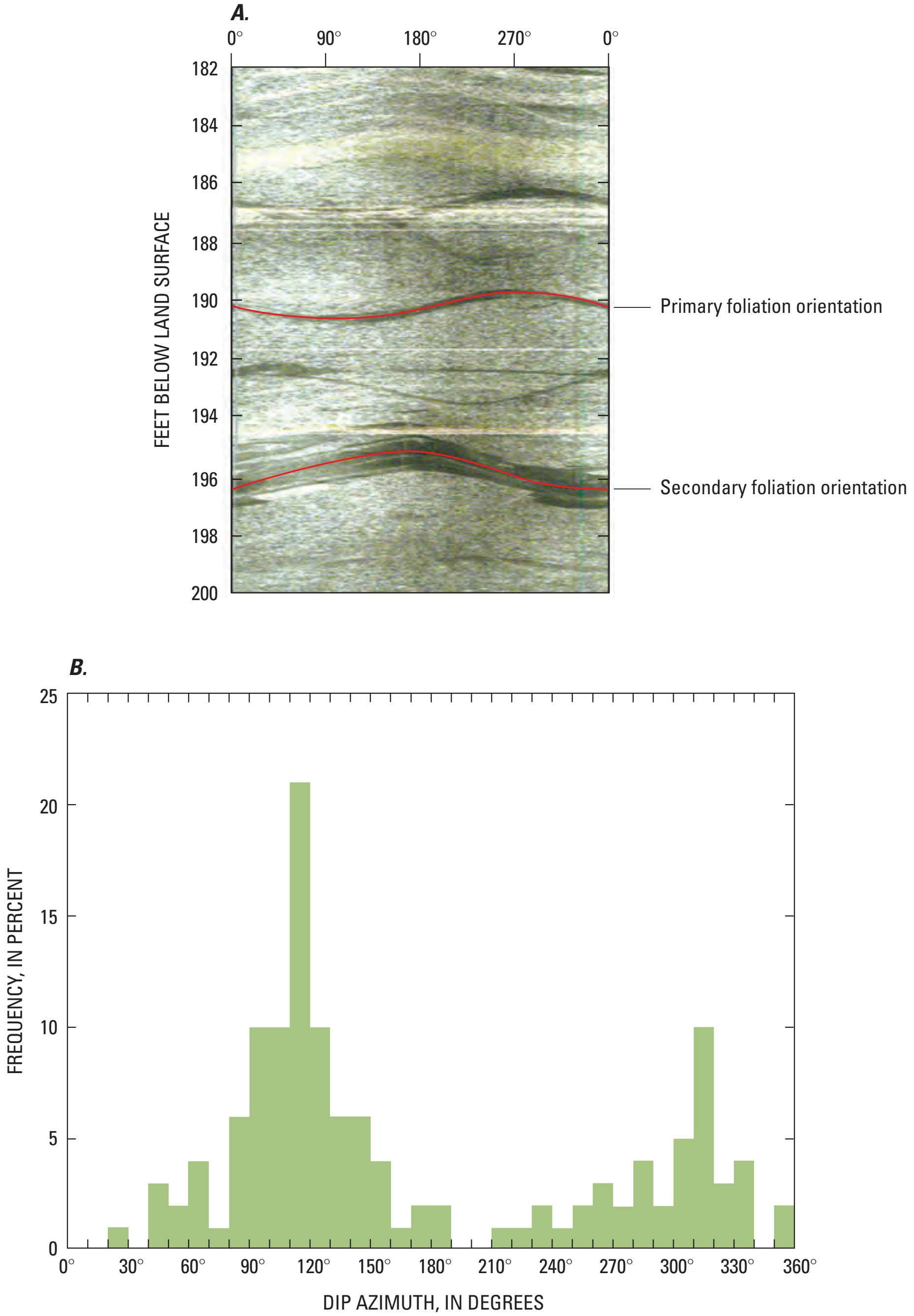


Figure 10. Bimodel distribution of foliation dip azimuth orientation in *(A)* optical televiewer image of bedrock well MW-5D and *(B)* frequency of foliation orientation measured throughout the borehole in bedrock well MW-1D at the Langtree Peninsula research station, North Carolina.

observed in the core and in OTV images. These two foliation sets have the same general strike orientations, with strike averaging N. 12° E., but opposite dip directions that can be grouped into southeast-dipping and northwest-dipping groups. The dip angle of both foliation groups is similar and averages about 60° (figs. 9, 10; app. 2). The southeast-dipping foliation likely is related to regional formation related to the Taconic Orogeny. The secondary (weaker) foliation dipping to the northwest may be related to regional folding. Orientation of the granitic dikes averages N. 20° W., dipping 66° to the southwest.

From the analyses of core samples, the upper (shallow) regolith underlying the site is primarily composed of reddish brown, soft to firm silty clay (CL in the Unified Soil Classification System; American Society for Testing and Materials, 2004) to clayey silt (MH to ML; app. 1). Mica and quartz grains are prevalent throughout the regolith soils as are iron and manganese oxyhydroxide coatings on mineral grains. The lower regolith is composed primarily of clayey to sandy silt (ML) and commonly displays relict textures of the host material (for example, relict foliations and heterogranular phaneritic textures). The lower regolith is composed of saprolite, which grades downward to partially weathered rock (transition zone). Regolith thicknesses, based on auger refusals and core-sample descriptions, range from 23 to 68 ft in the down-slope well locations (well clusters MW-6 and MW-3, respectively, figs. 6*A*, 6*B*) and from 23 to 39 ft in the mid-slope and ridge hill-top well locations (well clusters MW-1, MW-2, MW-4, and MW-5, figs. 6*A*, 6*B*; app. 1). The transition zone is below the regolith and has less feldspar alteration to clay but includes partially weathered rock that commonly grades downward to competent bedrock that is characterized by abundant fracturing. Thickness of the transition zone ranges from about 1 to 20 ft.

Although the quartz diorite is the predominant rock type at the LPRS, occurrences of biotite hornblende gneiss, hornblende gneiss, and granitic gneiss are common. The shallowest bedrock typically is a medium- to fine-grained, heterogranular, phaneritic, quartz-hornblende, biotite-pyroxene quartz diorite. In corehole CH-1 (fig. 5; app. 1), the bedrock becomes more gneissic below about 142 ft, and foliations become steeper and more pronounced. This is further supported in other coreholes that show deformation intensifying with depth. Optical televiewer images recorded in bedrock wells also show that ductile deformation is more intense with depth and is characterized by steeply dipping foliations, depth-repetitive isoclinal recumbent folds, and local occurrences of partial melting (migmatite zones, including enclaves, fig. 11).

Secondary fractures in the bedrock are primarily stress-relief or exfoliation fractures formed during uplift from the erosion of overburden materials (fig. 12). A few fractures (parting plane) also were parallel to foliation (fig. 12). Exfoliation fractures typically have horizontal to subhorizontal dips. Secondary fractures were noted in core samples, OTV data, and in quartz-diorite boulders observed on site. Some of these fractures have been subject to significant dissolution of mineral phases, as evidenced by observations of borehole video logs and OTV images with productive low dip angle, stress-relief bedrock fractures having apertures as large as 0.5 ft in the air-rotary borehole (MW-1D at 59 ft; app. 2).

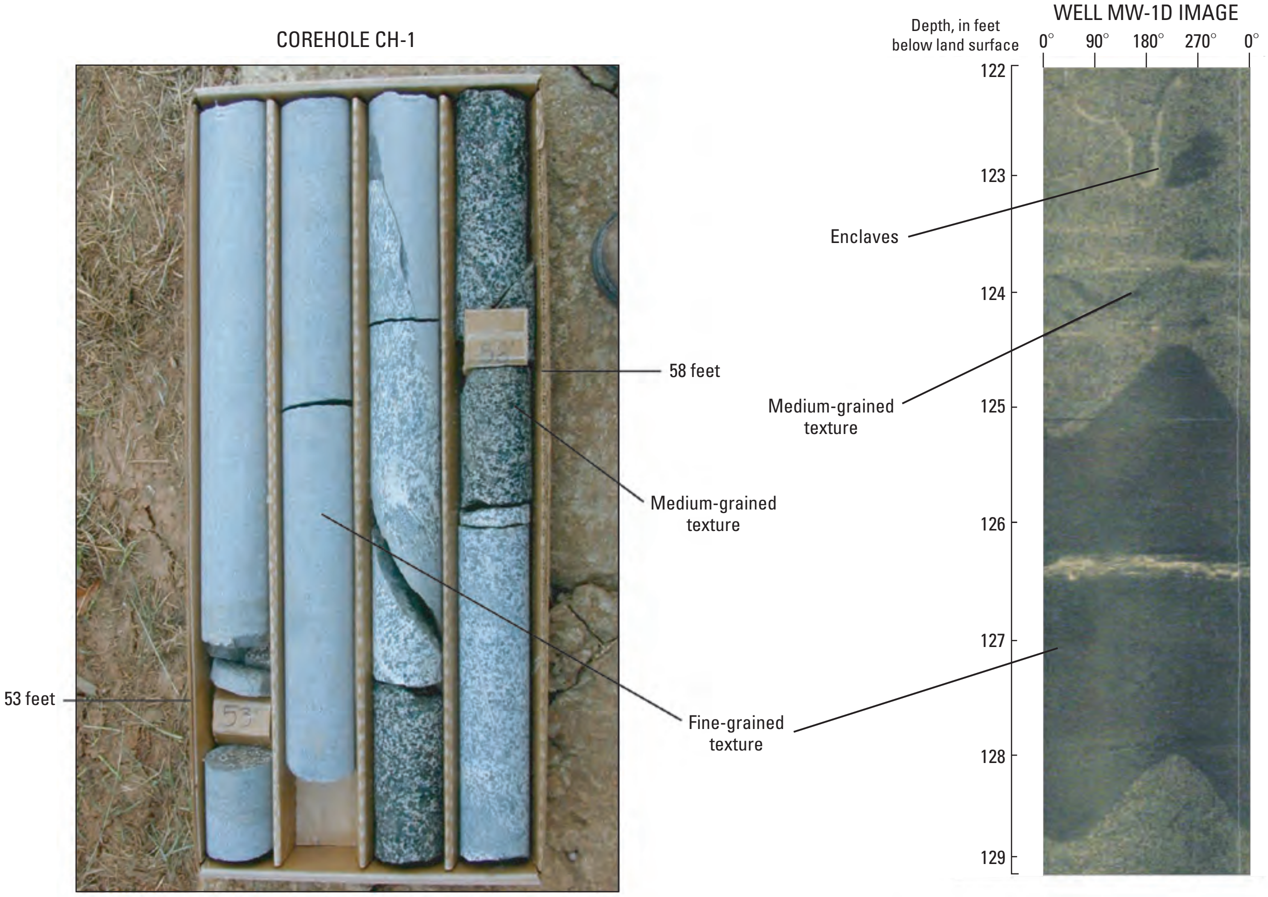


Figure 11. Whole rock core from corehole CH-1 (location in fig. 5) and optical televiewer image of well MW-1D showing examples of alternating fine- and medium-grained texture in the quartz diorite bedrock at the Langtree Peninsula research station, North Carolina.

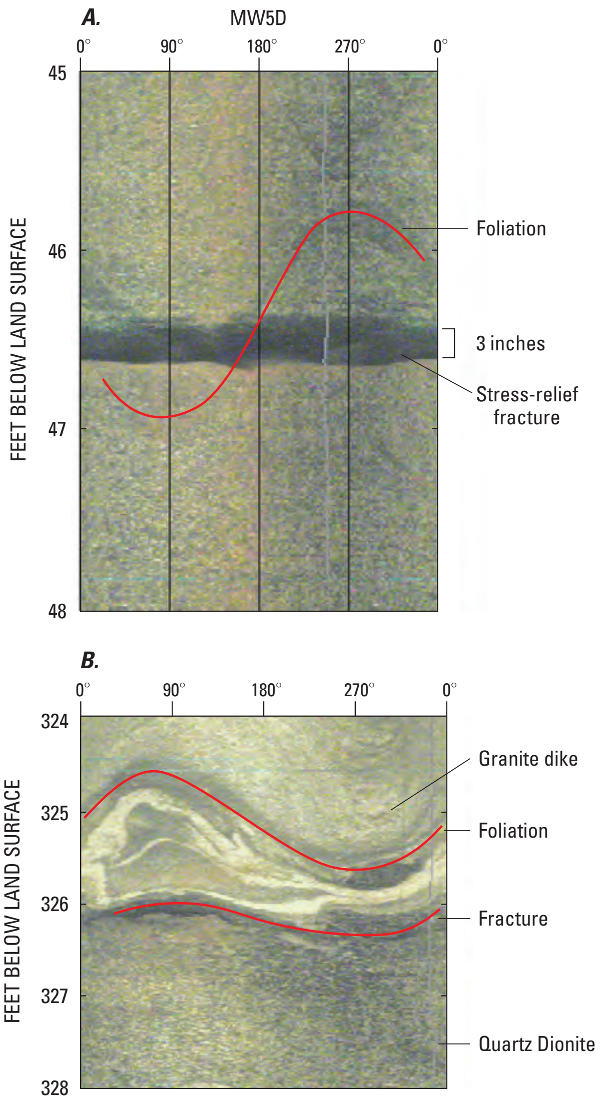


Figure 12. Optical televiewer image of bedrock well MW-5D showing *(A)* a typical stress-relief fracture and *(B)* a parting plane fracture parallel to foliation and in contact with an overlying granitic dike at the Langtree Peninsula research station, North Carolina.

Other fractures have a more vertical to subvertical dip and parallel foliation or lithologic contacts. These steeper fractures likely provide connectivity of the exfoliation fractures to the overlying saturated regolith.

Ground-Water System Characteristics

The ground-water system of the Piedmont and Mountains region is considered to have two primary components—the shallow weathered regolith and the deeper consolidated bedrock. Ground water occupies pore spaces in the shallow regolith. Directional hydraulic properties (anisotropy) also are possible where relict structural features, such as foliations, fractures, and quartz veins, are well preserved in the saprolite. Ground water occurs in the bedrock in secondary fractures, because the bedrock has little primary porosity or permeability. The regolith is considered the primary storage reservoir, providing recharge to the bedrock fractures (Heath, 1983, 1984, 1991, 1994). Additionally, a transition zone commonly is present between the regolith and bedrock parts of the aquifer. The transition-zone characteristics are highly variable across the Piedmont and Mountains region and even across a smaller local area. Where measurable, the transition zone has an important role in the ground-water system, especially in terms of contaminant transport (Harned and Daniel, 1992).

The ground-water system at the LPRS was characterized from interpretations of data collected in 7 coreholes, 6 well clusters, and 12 piezometers. The well clusters were drilled along topographic transects that generally follow assumed ground-water-flow paths from recharge to discharge areas (fig. 5). Detailed core descriptions are provided in appendix 1. Borehole geophysical logs and images are provided in appendix 2. Core descriptions and interpretations of geophysical logs are summarized in the following sections.

Regolith

The regolith is the shallow component of the Piedmont ground-water system and represents the weathered materials overlying deeper bedrock. The regolith at the LPRS is gradational in nature and includes soil, residuum, and saprolite. The shallow part of the regolith includes residuum, where all relict textures of the parent bedrock are destroyed (fig. 13). The shallow regolith grades into the lower regolith where relict bedrock features are preserved in saprolite (fig. 13). Relict features include structural characteristics, such as foliation, mineral boundaries, and vein deposits that are present in the lower regolith and typically grade into the transition zone and then to competent bedrock. The transition zone consists of partially weathered rock and the highly fractured upper bedrock. The transition into competent bedrock is recognized with infrequent bedrock fractures (fig. 13). Identification of the boundaries between these different zones can be subjective and requires careful observation of the extracted cores.

The physical characteristics of the regolith were recorded during coring and split-spoon sampling at each site. In general, the regolith is composed of reddish-brown clayey silt to silty clay with minor sand and mica, and becomes sandy silt with depth. Regolith characteristics, such as dry strength, color, moisture content, dilatancy, toughness, and plasticity, were determined during coring before the regolith materials were classified using the Unified Soil Classification System (American Society for Testing and Materials, 2004). In general, these characteristics vary substantially with increasing depth in the regolith—dry strength generally decreases; color changes from red tones to brown tones; toughness decreases; dilatancy generally becomes more rapid; and plasticity generally changes from high to moderate to non-plastic with

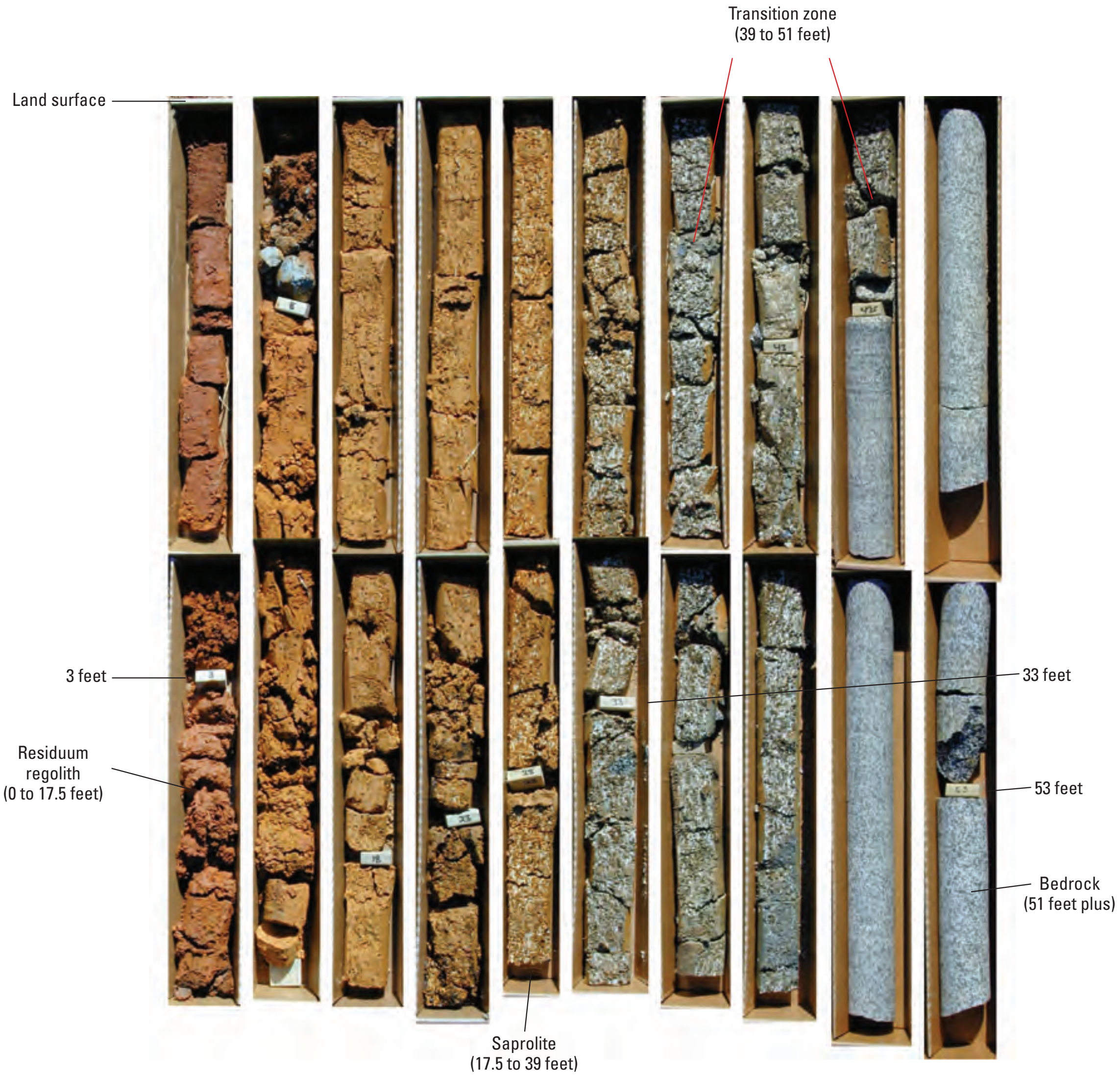


Figure 13. Core samples from corehole CH-5 near well cluster MW-4 at the Langtree Peninsula research station, North Carolina.

increasing depth. Many of the variations observed in the regolith characteristics are attributed to the parent material and the degree of weathering.

Residuum and Saprolite

The residuum and saprolite are part of the shallow regolith zone of the aquifer. The residuum generally is described as in-place weathered material lacking geologic structure. At the LPRS, the residuum is red to yellowish red, clayey silt to silt with minor clay and fine sand. The residuum typically is dry, becoming moist with depth, and is relatively tough with no apparent relict rock textures. The saprolite, formed by chemical weathering of the underlying bedrock, displays relict phaneritic textures, quartz veins, and some foliations. Kaolinite is readily observable as a weathering product after feldspar. The saprolite zone typically is brown to yellowish brown, clayey to sandy silt that grades into partially weathered rock.

The thickness of the residuum and saprolite parts of the regolith at the LPRS do not appear to be related to topographic position. The thickness of the residuum at the LPRS averages approximately 15 ft (app. 1). The thickest residuum (27.5 ft) was observed at well cluster MW-1, which is in the highest topographic area of the research station (fig. 5). The thinnest residuum observed (9.5 ft) was in the core from well cluster MW-2 (coreholes CH-2 and CH-3, app. 1), also in a relatively high topographic area. Residuum thicknesses measured in cores from well clusters MW-3 and MW-6, located in the lowest topographic settings adjacent to Lake Norman, were 11 ft and 11.5 ft, respectively (coreholes CH-4 and CH-7, fig. 5; app. 1). Saprolite thickness also varies substantially across the LPRS, averaging 22 ft. The topographic high area around well cluster MW-1 has the thinnest saprolite of about

11 ft (corehole CH-1, app. 1); however, the topographic low area around well cluster MW-3 has the thickest saprolite of approximately 57 ft. At well cluster MW-6 (corehole CH-7, fig. 5; app. 1), another topographic low area, the saprolite thickness is approximately 11.5 ft.

Six monitoring wells and 12 piezometers were installed in the regolith (table 1). The piezometers (GP-1–8 and WL1–4, fig. 5) were completed in the residuum part of the regolith. Each of the six well clusters includes a shallow well (MW-1S, -2S, -3S, -4S, -5S, and -6S) that targeted the saprolite zone of the regolith section of the aquifer. Monitoring wells MW-3S, -5S, and -6S have sections of their screens completed in the residuum as well. The purpose of these wells is to monitor water-level fluctuations and ground-water quality in the shallow regolith zone of the aquifer.

Transition Zone

The transition zone between the weathered regolith materials (residuum and saprolite) and consolidated bedrock can be difficult to delineate and describe. Analyses of the transition-zone materials at the LPRS and at other PMREP research stations indicate that characteristics of the transition zone vary, depending on many interacting factors that include but are not limited to rock type, presence of systematic fracturing, presence of stress-relief fracturing, grain size, and angle and pervasiveness of foliation. The transition zone usually is composed of partially weathered rock (PWR) and(or) numerous open fractures near the top of bedrock. Chapman and others (2005) describe the transition zone in a felsic gneiss rock type as “partially weathered rock, having both secondary (fractures) and primary porosity.” At the LPRS, the transition zone in the quartz diorite rock type is defined similarly, having an upper part consisting of PWR and a lower part containing numerous open fractures near the top of consolidated bedrock.

From the analyses of core samples and video and OTV imaging, the average transition-zone thickness across the LPRS is approximately 12 ft (app. 1); the thickest transition zones (18 and 19.5 ft) were observed in corehole CH-7 and CH-1 near well clusters MW-6 (low topographic area near Lake Norman) and MW-1 (high topographic area), respectively (fig. 5). The thinnest transition zone observed in the cores extracted from the LPRS was in corehole CH-6 located at well cluster MW-5 (fig. 5). Only 1 ft of PWR was observed; however, solid unfractured bedrock begins at 24 ft below land surface at this location.

Two bedrock wells at the LPRS tap open, shallow fractures that are part of the transition zone. Well MW-1D has an open fracture zone at a depth of 59 ft, and well MW-5D has an open fracture at a depth from 46 to 47 ft. Strike orientations of these transition-zone fractures are N. 49° E. dipping 24° SE. (MW-1D) and N. 17° E. dipping 10° SE. (MW-5D; app. 2). (The 59-ft fracture in bedrock well MW-1D was later cased off.) Additional shallow fractures that were not open were delineated at depths of 73 ft in well MW-2D; 74 ft in well MW-4D; and 43–44 ft, 48 ft, and 51–52 ft in well MW-6D.

Seven transition-zone wells (MW-1I, -2I, -3I, -4IA, -4IB, -5I, and -6I; table 1) were installed to monitor changes in ground-water-level fluctuations and ground-water quality in this part of the aquifer. Observations and identifications of transition-zone material were made from extracted cores near each well cluster (fig. 5), and screened intervals were selected from these descriptions.

Bedrock

Bedrock at the LPRS consists of igneous and metamorphic rocks of the Charlotte Belt (fig. 2; Goldsmith and others, 1988) and Charlotte terrane (fig. 7; Hibbard and others, 2002). The only outcrop observed in the area (quartz diorite cobbles at the LPRS) is light-colored, fine- to coarse-grained granite, likely a member of the Churchland Plutonic Suite (North Carolina Geological Survey, 1985). A weak foliation striking N. 30° E. and dipping 80° SE. was observed in the granite outcrop. Non-penetrative fractures having trends of approximately N. 30° W., N. 45° E., N. 80° E., and N. 80° W. also were noted on the outcrop. Well cuttings and loose rock having apparent mafic compositions were observed in other parts of Langtree Peninsula (fig. 5 inset).

The interpretations of bedrock lithologies at the LPRS were based on descriptions from geologic cores and drill cuttings, natural gamma logs, and oriented OTV images. Fractures in the bedrock initially were described from the core samples and then characterized using caliper and resistivity logs, fluid resistivity and temperature logs, heat-pulse flowmeter logs, and oriented OTV images.

The rocks underlying the site primarily are quartz diorite with lesser amounts of quartzofeldspathic, biotite, hornblende gneiss. The quartz diorite can be described generally as fine- to coarse-grained, weakly foliated to massive (non-foliated) dark greenish-gray quartz diorite (fig. 13). The primary mineralogies are quartz, biotite, hornblende, and plagioclase feldspar with minor amounts of pyrite, epidote, and chlorite. (Pyrite also was observed in the OTV images.) Chlorite and epidote were observed commonly replacing hornblende in the core samples. Hornblende gneiss is the second most common rock type underlying the site. The primary mineralogy of this rock body is similar to the quartz diorite. The gneiss may represent localized shearing within the quartz diorite. Additionally, granite or granitic gneiss are present, as well as zones of migmatization. Evidence of migmatization is present at many depths (fig. 8); however, migmatization is more prevalent at greater depths and is evidenced by anastomosing patterns of light and dark mineralogies that lack a discernible foliation.

After the initial core collection, six open-borehole bedrock wells, one at each well cluster, were drilled (fig. 6). Five of the six wells were completed to a depth of about 400 ft below land surface, and the remaining well (MW-1D) was drilled to a depth of about 600 ft. Poor bedrock seals that allowed overlying sediment to infill from the overlying regolith occurred at four wells (MW-1D, -3D, -4D, and

-6D). Four-inch liners were installed in these wells (table 1); however, well MW-3D was abandoned in March 2002 because of a ruptured casing that was not repairable. Depth to bedrock ranged from about 24 to 76 ft at the LPRS based on observations from core (figs. 6*A*, 6*B*; app. 1).

Initial well yields measured in the bedrock wells ranged from about 3 gal/min to more than 50 gal/min. The highest yielding well was MW-1D, located at the topographic high. The highest yield of more than 50 gal/min likely was reduced following the installation of a 4-inch liner (installed to about 76 ft below land surface) that sealed off a large transition zone fracture at 59 ft (described in this report), just below the original casing depth of 55.5 ft (table 1; app. 1).

Flow occurs within the open borehole of the bedrock wells, even near low-yielding fracture zones. For example, geophysical logs for bedrock well MW-1D indicate ambient (natural) inflow near depths of about 125 and 350 ft, with outflow between those two zones at about 225 ft (app. 2A). Fracture images indicate low dip angle, 10° or more commonly less than 5°, stress-relief fractures having a weathered appearance.

The bedrock underlying the LPRS has relatively consistent and identifiable structures. The rocks observed at the LPRS vary from generally or weakly massive to strongly foliated with increasing depth. Interpretations of foliation orientations from the OTV borehole images suggest that two deformation events may be responsible for the foliations observed in the core and OTV data (figs. 8, 10). Both foliations have an average strike of about N. 12° E. and dip about 60° in opposite directions to the southeast (primary) and the northwest (secondary; figs. 8, 9). Foliation dip azimuth variations with depth are shown in appendix 2 and appear to be equally distributed throughout the borehole length.

Bedrock fractures, visually observed in returned core intervals and recorded in the borehole using OTV imaging, generally have horizontal to subhorizontal dip angles (stress relief less than 10° dip angle, fig. 12*A*; app. 2), and fractures are more frequent in the upper bedrock surface (see corehole descriptions in appendix 1). Other fracture orientations are parallel to foliation, or “parting plane” fractures (fig. 12*B*; app. 2). Because of the massive nature of the quartz diorite bedrock at the LPRS, parting-plane fractures and the development of permeable pathways that parallel foliation may tend to be reduced relative to a more foliated rock type.

The topographic drainages at the LPRS may represent areas of greater fracture density in the subsurface and dissolution of the diorite bedrock (LeGrand, 1952). The north-south trending drainage east of the bedrock well transect (MW-1D, -4D, -5D, and 6D, fig. 5) is similar to foliation orientation and foliation-parallel fractures (fig. 9; app. 2). The west-trending drainage west of well cluster MW-2 (fig. 5) parallels a secondary fracture set and subset of foliation measurements (at depth) striking east-west (fig. 9; app. 2).

Within the bedrock section of the aquifer at the LPRS, a strong degree of hydraulic connectivity was observed between bedrock wells MW-4D, -5D and -6D, and to a lesser extent MW-1D. The transect line of bedrock wells MW-4D, -5D, and -6D is oriented at about N. 8° E. (figs. 5, 6*B*), which is roughly parallel to the primary foliation strike N. 12° E. Fractures in the transition zone and at depth in wells MW-5D and MW-6D also have strike orientations that parallel the nearby drainage to the east and this well transect. Wells MW-4D (310 ft south-southeast), -5D, and -6D (330 ft north-northeast) had linear responses to bedrock pumping in well MW-5D (presented in a later section of this report), which indicates a direct connection in the three-dimensional fracture network underlying these wells (fig. 14). Well MW-1D, located about 670 ft south of the pumped well, also responded to pumping

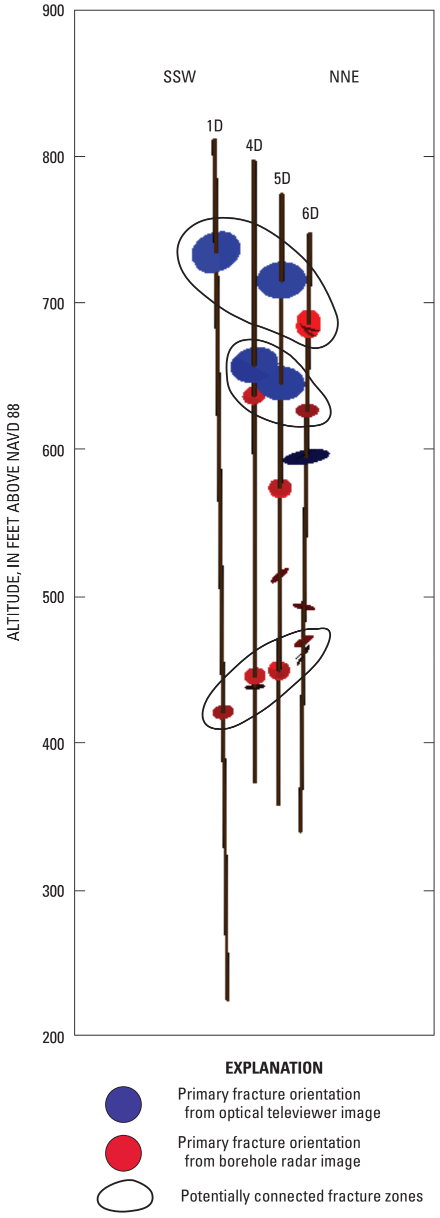


Figure 14. Primary and secondary fracture network between bedrock wells MW-1D, -4D, -5D, and -6D at the Langtree Peninsula research station, North Carolina (see fig. 6 for well locations).

with a lesser magnitude of drawdown. Open (primary) fracture sets measured in the these bedrock wells from OTV images are N. 49–70° E. dipping 10–24° SE. (wells MW-1D and -4D); N. 17° E. dipping 10° SE. (well MW-5D); and N. 20–21° W. dipping 5–28° NE.-SW. (wells MW-5D and -6D). Depths of open to partially open fractures in wells MW-1D, -4D, -5D, and -6D ranged from 46.5 ft to 479 ft below land surface (app. 2). The lack of response in the regolith wells during the 48-hr aquifer test indicates that little (measurable) short-term hydraulic connectivity occurs between the shallow regolith and the bedrock that immediately underlies it, or that the regolith has low vertical hydraulic conductivity. Recharge must occur from the regolith through the fracture network eventually, however, as the fracture network itself has little storage, as is evidenced by large drawdowns. For the LPRS conceptual model, it was assumed that recharge occurs to the fracture system from natural downward leakage from the overlying regolith and transition zone into the bedrock.

Ground-Water Levels

Periodic ground-water levels were measured monthly or bimonthly at the LPRS to monitor seasonal trends in the regolith (piezometers and MW-_S wells), transition zone (MW-_I wells), and bedrock (MW-_D wells; figs. 15, 16). Ground-water levels have been measured in the cluster wells since January 2001 and in the piezometers since September 2000 (table 2). Hourly ground-water-level data have been recorded at all three MW-2 cluster wells (2S, 2I, and 2D) since March 2001 (fig. 17). Data are presented in this report through September 30, 2005.

Seasonal Trends and Water Year Comparisons

From September 2000 through September 2005 (complete water years (WYs) 2001–2005), water levels in wells at the LPRS responded to climatic conditions, including seasonal trends and extreme conditions, such as droughts and the stage of nearby Lake Norman (figs. 15–17). Generally, seasonal high ground-water levels occur during the spring, in response to winter and spring precipitation (typical recharge period for the Piedmont region). Ground-water levels decline as evapotranspiration (ET) processes increase during the spring and summer months, and the lowest water levels occur during the fall months.

Ground-water levels in the well clusters and piezometers responded to seasonal trends of winter/spring recharge and summer ET processes (figs. 15–17). Hourly ground-water levels recorded in well cluster MW-2 indicate seasonal patterns of an overall rise in water levels during the recharge periods and a gradual decline during the warmer summer months and into the fall months (fig. 17). Additionally, a recognizable difference in climatic conditions is evident in comparisons between WYs 2001 and 2002 (drought conditions) and WY 2003 when above-normal rainfall was recorded. For the study period at the LPRS, ground-water levels were lowest during fall 2002 (figs. 15–17) in response to an extended 4-year drought throughout the State (Weaver, 2005). In contrast, above-normal rainfall occurred at the LPRS during WY 2003, and ground-water levels in the regolith and transition zone rose about 9 ft in well MW-5I and about 12 ft in well MW-2 (fig. 16). Rainfall totals at USGS rainfall gage CRN-42 (fig. 5), located about 1.6 mi south of the LPRS, were nearly 69 inches for WY 2003 compared with about 28 inches for WY 2002 (Ragland and others, 2003, 2004). Mean annual rainfall for the period of record (1948–2006) at the Charlotte-Douglas Airport is 32.35 inches (North Carolina State Climate Office, 2004). Below-normal rainfall also was recorded at station CRN-42 in WY 2001 (31 inches) and WY 2005 (35 inches), and slightly above-normal rainfall (about 48 inches) was recorded in WY 2004. Ground-water-level data recorded at the LPRS wells were summarized for WYs 2001–2005 and published in USGS annual data reports (Howe and others, 2002, 2003, 2004, 2005; Fine and others, 2006).

Comparison of Water Levels in Well Clusters

Comparison of the water levels in the well clusters was used to qualitatively interpret the vertical gradients in the ground-water system. Five of the six well clusters at the LPRS have at least one shallow well completed in the regolith. The exception is cluster MW-4, which has two transition zone wells. All six well clusters have wells completed in the transition zone and deeper bedrock.

A rise in ground-water levels in regolith well MW-2S rarely occurred during the summer months (except during the summer of 2003 in response to above-normal rainfall), because ET generally exceeded rates of ground-water recharge. Periodic ground-water levels recorded in well clusters MW-1, MW-4, and MW-5 (fig. 16) also showed seasonal and climatic trends, similar to water levels recorded hourly in well cluster MW-2 (fig. 17). Seasonal trends were less evident in well clusters MW-3 and MW-6 as a result of the close proximity of these wells to Lake Norman. The stage of Lake Norman is controlled by Cowan’s Ford Dam, which is used for hydroelectric power generation and is located about 8 mi southeast of Langtree Peninsula.

Water-level altitudes in the shallow regolith and transition zone were similar in all well-cluster locations (both recharge and discharge areas) at the LPRS. Vertical gradients are evident when the shallow part of the ground-water system (regolith and transition zone) is compared to the deeper bedrock. In recharge or slope areas (well clusters MW-1, -2, -4, and -5), a downward vertical gradient was observed (fig. 16*A*, *B*, *D*, *E*, respectively). However, in discharge areas, such as the location of MW-6 (excluding abandoned bedrock well MW-3D, also in a discharge area), an upward vertical gradient from the bedrock is evident (fig. 16*F*). This result supports the historical conceptual model of the Piedmont ground-water system described by LeGrand (1967, 2004), Heath (1983, 1984), Harned and Daniel (1992), and Daniel and Dahlen (2002).

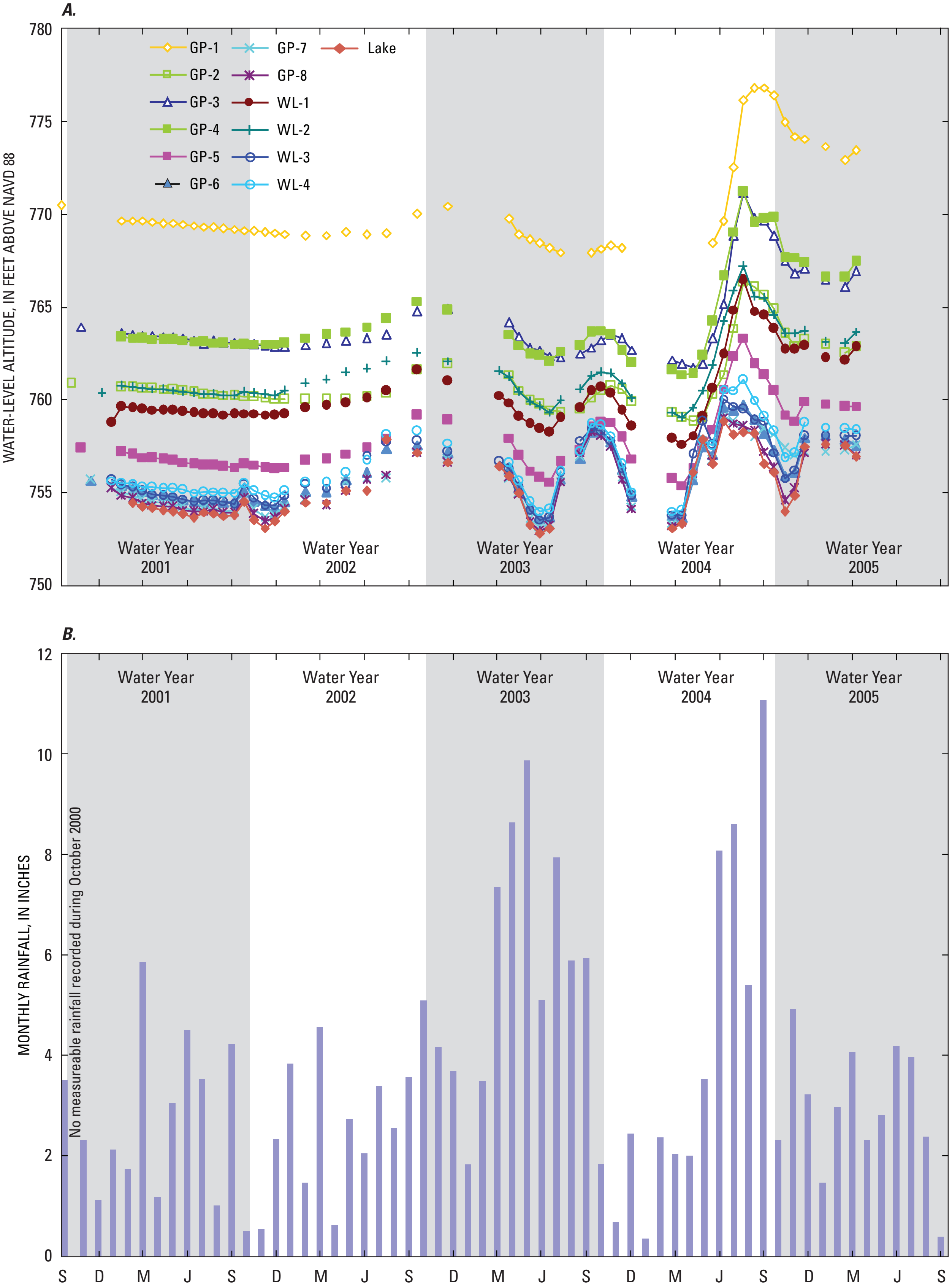


Figure 15. *(A)* Periodic ground-water levels recorded in all piezometers at the Langtree Peninsula research station, North Carolina, and *(B)* monthly rainfall recorded at USGS station CRN-42, September 2000 through September 2005.

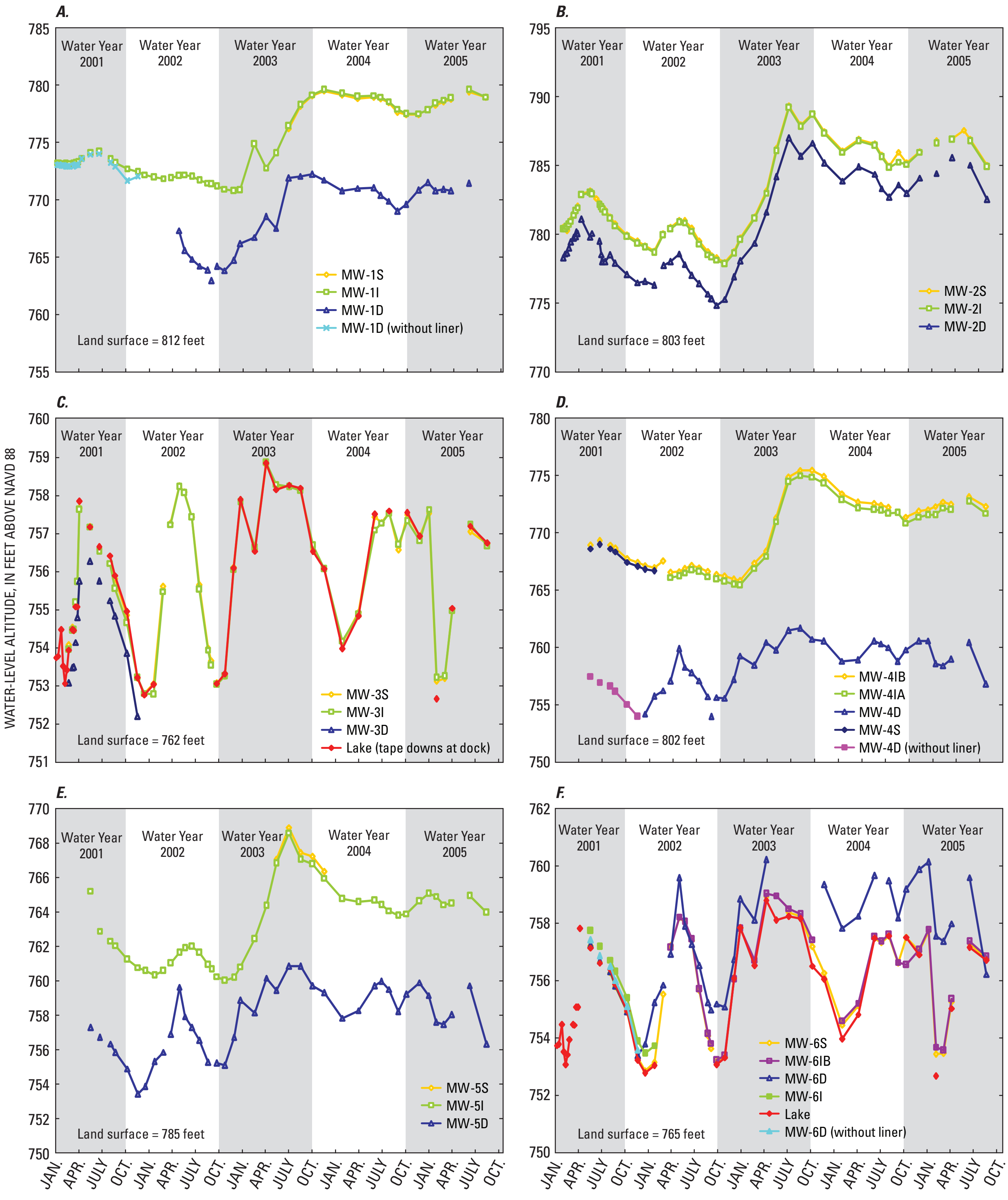


Figure 16. Periodic ground-water levels recorded in well clusters *(A)* MW-1, *(B)* MW-2, *(C)* MW-3, *(D)* MW-4, *(E)* MW-5, and *(F)* MW-6 at the Langtree Peninsula research station, North Carolina, January 2001 through September 2005.

Table 2. Period of data collection for ground-water levels and water-quality measurements in cluster wells at the Langtree Peninsula research station, North Carolina. (End date is September 2004, unless otherwise noted.)

[MW, monitoring well; s, shallow regolith well; I, transition zone well; D, bedrock well; GP, Geoprobe well; na, not applicable]

Station name	Water-level/Stage		Water quality (temperature, pH, specific conductance, and dissolved oxygen)
	Start date periodic data	Continuous data start date (1-hour recording interval)	Continuous water-quality data (1-hour recording interval)
MW-1S	January 2001	na	na
MW-1I	January 2001	na	na
MW-1D	January 2001	na	na
MW-2S	February 2001	March 2001	August 2002 discontinued July 2003
MW-2I	February 2001	March 2001	na
MW-2D	February 2001	March 2001	August 2002 discontinued March 2004
MW-3S	February 2001	na	na
MW-3I	February 2001	na	na
MW-3D[a]	February 2001 discontinued November 2001	na	na
MW-4S[b]	May 2001 discontinued March 2002	na	na
MW-4I B	May 2001	na	na
MW-4I A	March 2002	na	na
MW-4D	May 2001	na	na
MW-5S	May 2001	na	na
MW-5I	May 2001	na	na
MW-5D	May 2001	na	na
MW-6S	May 2001	na	na
MW-6I[c]	May 2001	na	na
MW-6I B	March 2002	na	na
MW-6D	March 2001	na	na
GP-1	September 2000	na	na
GP-2	September 2000	na	na
GP-3	October 2000	na	na
GP-4	September 2000	na	na
GP-5	October 2000	na	na
GP-6	October 2000	na	na
GP-7	October 2000	na	na
GP-8	October 2000	na	na
AUGER (WL) 1	October 2000	na	na
AUGER (WL) 2	October 2000	na	na
AUGER (WL) 3	October 2000	na	na
AUGER (WL) 4	October 2000	na	na
Lake Norman (Work Creek arm) near Mount Mourne, NC[d]	October 2000	na	na

[a] Well abandoned in March 2002.

[b] Well drilled deeper in February 2002 and renamed MW-4I A.

[c] Well drilled deeper in February 2002 and renamed MW-6I B.

[d] Periodic staff plate reading.

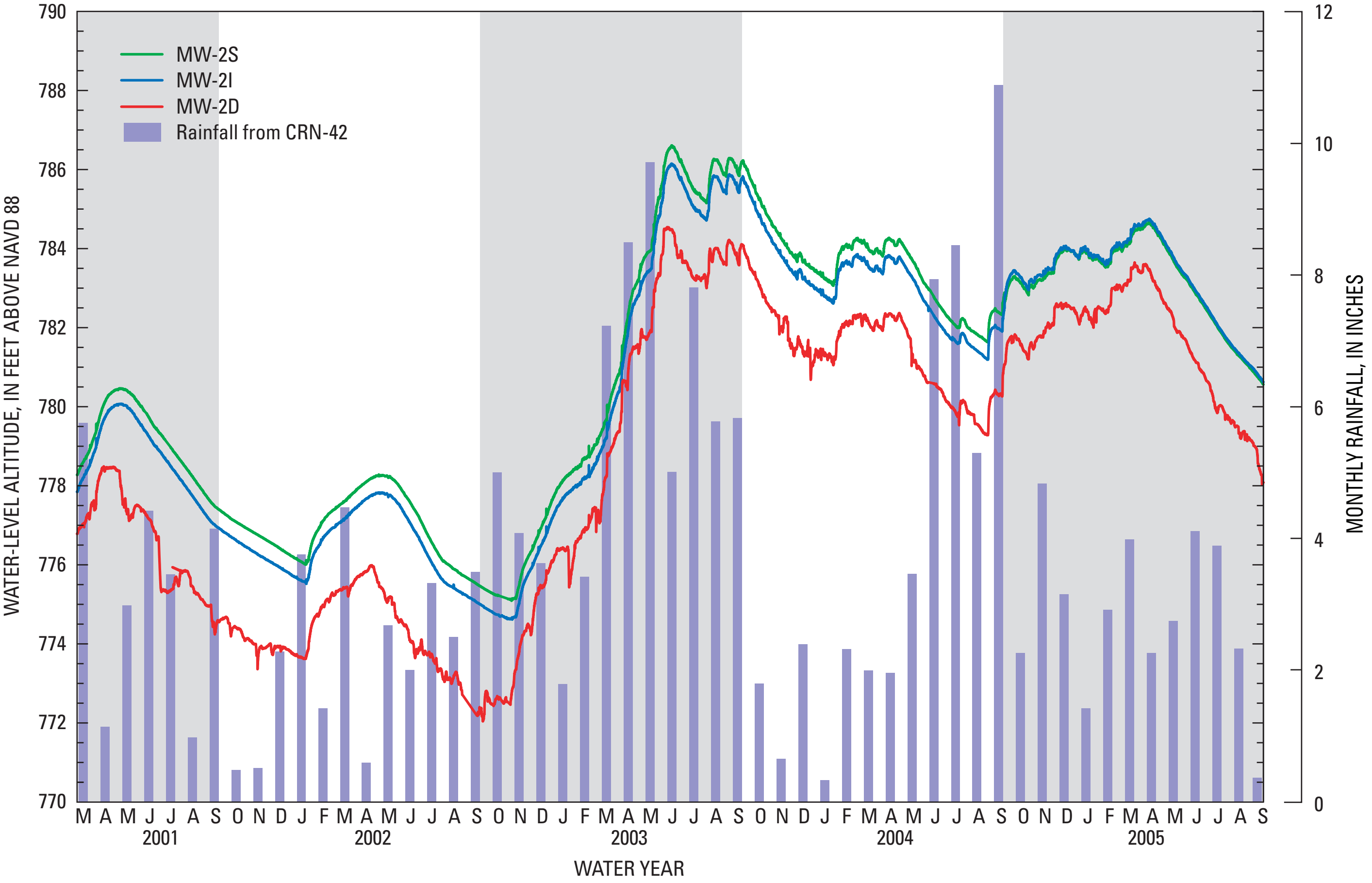


Figure 17. Continuous hourly ground-water levels recorded in well cluster MW-2 at the Langtree Peninsula research station, North Carolina, overlain with monthly rainfall recorded at USGS station CRN-42, March 2001 through September 2005.

Regional Comparison

Water-level trends in regolith well MW-2S at the LPRS were compared with long-term water-level records for two regolith observation wells in the Piedmont—one in Davie County, NC (Mocksville well NC-142; USGS station number 355359080331701, DV-025) and one in Rowan County, NC (Piedmont research station well NC-193; USGS station number 354057080362601, RO-149). This comparison was made to determine if ground-water-level data collected from the LPRS were representative of regional conditions. Ground-water levels at all three locations had similar seasonal and climatic trends for water years 2001 through 2005 (fig. 18). Following the drought in 2002, ground-water levels in wells NC-142 and NC-193 recovered to normal conditions within about 7 to 8 months (Howe and others, 2004). (The period of record for LPRS well MW-2S began in 2001 in drought conditions; therefore, “normal” long-term conditions have not yet been recorded.)

Preparing to sample well cluster MW-3 near Lake Norman.

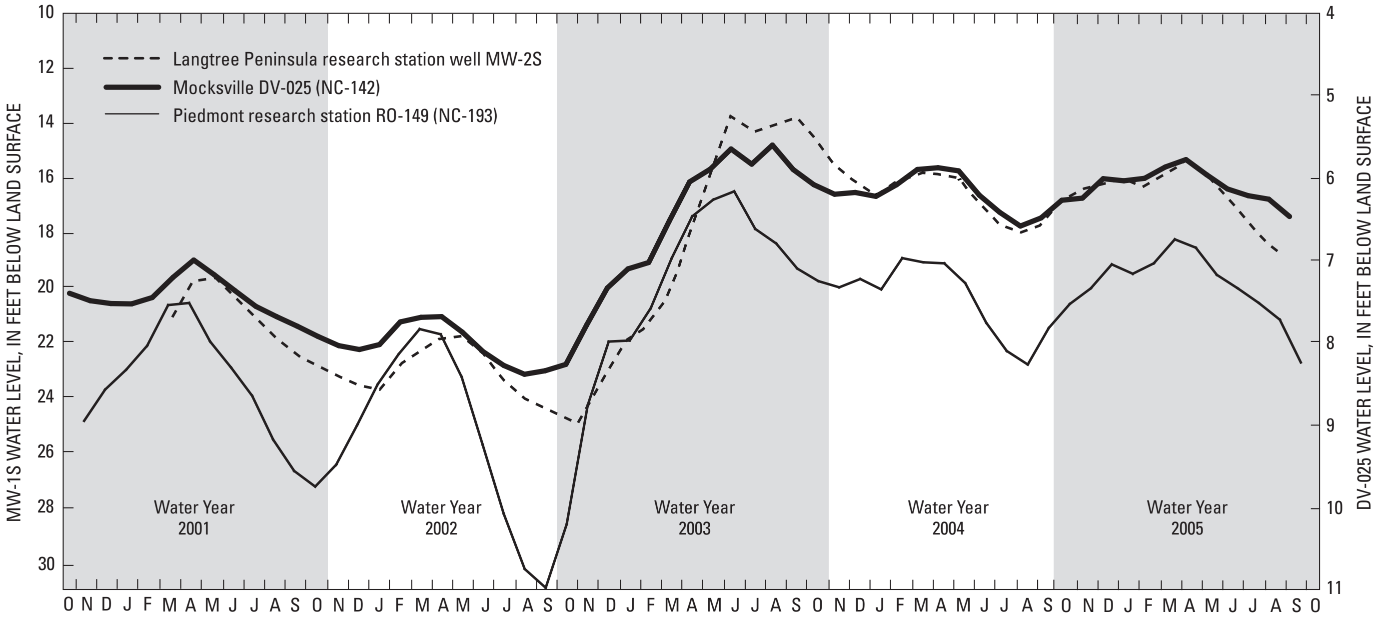


Figure 18. Monthly mean water levels in regolith wells DV-025 (near Mocksville, NC), RO-149 (Piedmont research station), and MW-2 (Langtree Peninsula research station) during water years 2001–05.

Bedrock Ground-Water Levels

Continuous ground-water-level data collected from four bedrock wells at the LPRS indicate a similar response in all of the wells to seasonal recharge and local pumping. Water-level data for bedrock well MW-2D indicate an overall seasonal correlation with shallower wells MW-2S and MW-2I (fig. 17) and an underlying influence from local pumping. Three bedrock water-supply wells are on the Davidson College property (fig. 5), and other community-supply wells are located within a quarter mile of the LPRS. Local pumping effects are recognized by sharp declines and recovery occurring in daily cycles. The graphs in figure 19 illustrate the correlation of bedrock ground-water levels observed during short-term monitoring in 2002 and the influence of nearby pumping (Davidson College wells or community-supply wells).

Care should be taken in the interpretation of open-borehole water levels in the bedrock wells because the data represent a composite of the hydraulic heads in several fractures tapped by the well. The hydraulic head in a specific fracture may be different from that measured in the entire open borehole.

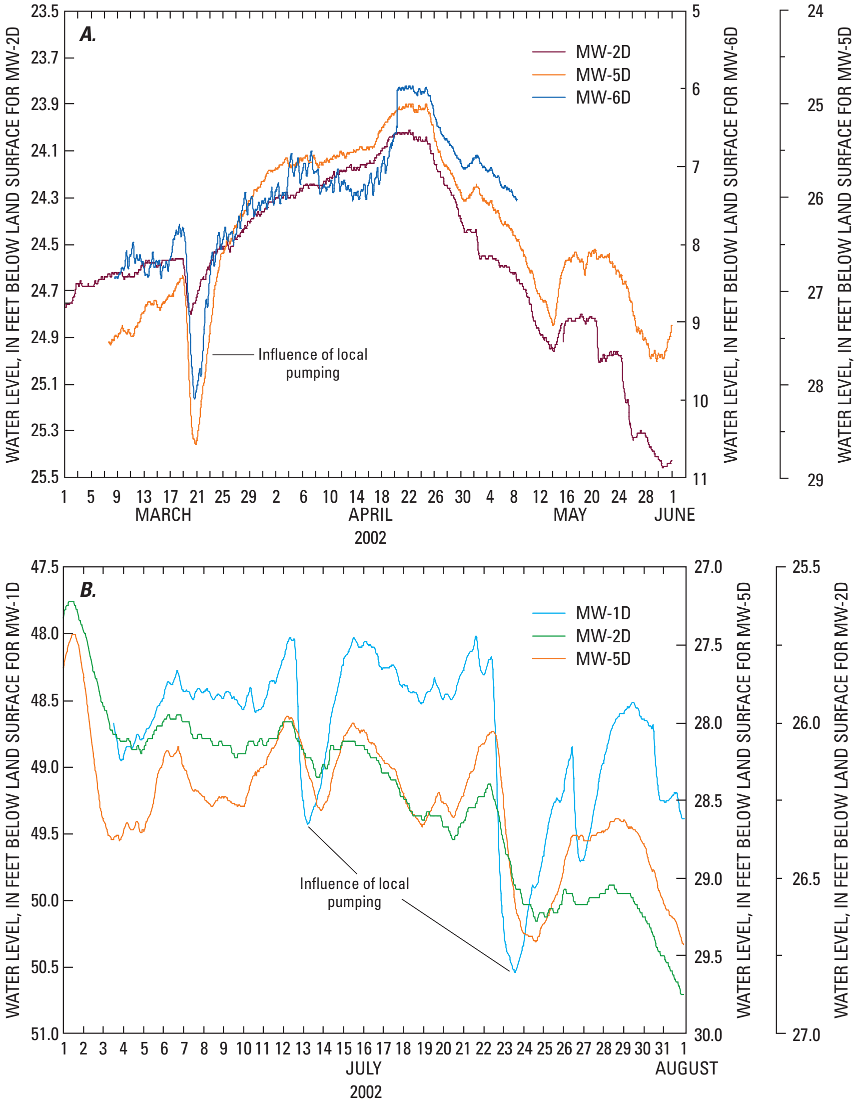


Figure 19. Continuous ground-water levels recorded in bedrock wells *(A)* MW-2D, -5D, and -6D, March–May 2002, and *(B)* MW-1D, -2D, and -5D, July 2002, at the Langtree Peninsula research station, North Carolina.

Lake Stage and Ground-Water Levels

The LPRS is located adjacent to Lake Norman, which is the largest manmade surface-water impoundment in North Carolina and encompasses an area of more than 31,984 acres (50 mi^2) at the full stage of 760-ft altitude (The Louis Berger Group, Inc., 2001). Based on periodic ground-water-level measurements and readings of lake stage using a staff plate (referenced to altitude above land surface), the hydraulic gradient in the shallow part of the ground-water system (regolith and transition zone) near Lake Norman is flat. Ground-water-level altitudes measured in wells MW-3S, MW-3I, MW-6S, MW-6I, and MW-6IB were within a few hundredths of a foot to 1 ft of the lake stage (fig. 16*C*, *F*). These wells are located within 100 ft of the lake shore. Additionally, piezometers GP-6, -7, and -8 and WL-3 and -4, located within about 300 ft of the lake shore, had ground-water-level altitudes that were generally within 1 ft of the lake-stage altitude (fig. 15). Surface water stored in the lake likely affects shallow ground-water levels near shore (lateral interactions), as is evidenced by similar lake altitudes and ground-water levels in the regolith and transition zone. At depth, however, vertical gradients in well cluster MW-6 are upward (fig. 16*F*), and the ground-water-level altitude is higher in the bedrock than in the regolith and transition zones and the lake.

In comparing hourly stage data for Lake Norman to bedrock ground-water levels, the influence of the lake on the deeper part of the ground-water system is uncertain. For example, during the drought water years when releases from Lake Norman were less frequent because water was being held for storage (Bill Stroud, Duke Power Co., Charlotte, NC, oral commun., 2005), an overall seasonal (climatic) correlation for both shallow and deep ground-water-level data and lake stage appears to be evident (fig. 20). However, as lake stage rose in WY 2003 in response to increased rainfall, releases from Lake Norman became more frequent, which lowered the stage while ground-water levels continued to rise in bedrock well MW-2D (fig. 20*A*). By overlaying ground-water-level data from bedrock wells MW-5D (fig. 20*B*) and MW-6D (fig. 20*C*) during 2002 with lake-stage data, a drought year seasonal correlation can be noted with local pumping effects (underlying sharp declines in ground-water levels).

Bedrock ground-water levels from well MW-2D at the LPRS were compared with water levels recorded in a bedrock well at the Troutman research station (North Carolina Department of Environment and Natural Resources, Division of Water Resources well L67U2; fig. 21) also located on Lake Norman about 10 mi north of the study site. The water-level data from the Troutman research station and bedrock well MW-2D had similar seasonal patterns during WYs 2001 and 2002 (drought years), and both had a large rise during WY 2003 as a result of above-normal rainfall. Water-levels recorded in the Troutman bedrock well, however, do not appear to be affected by local pumping, as a

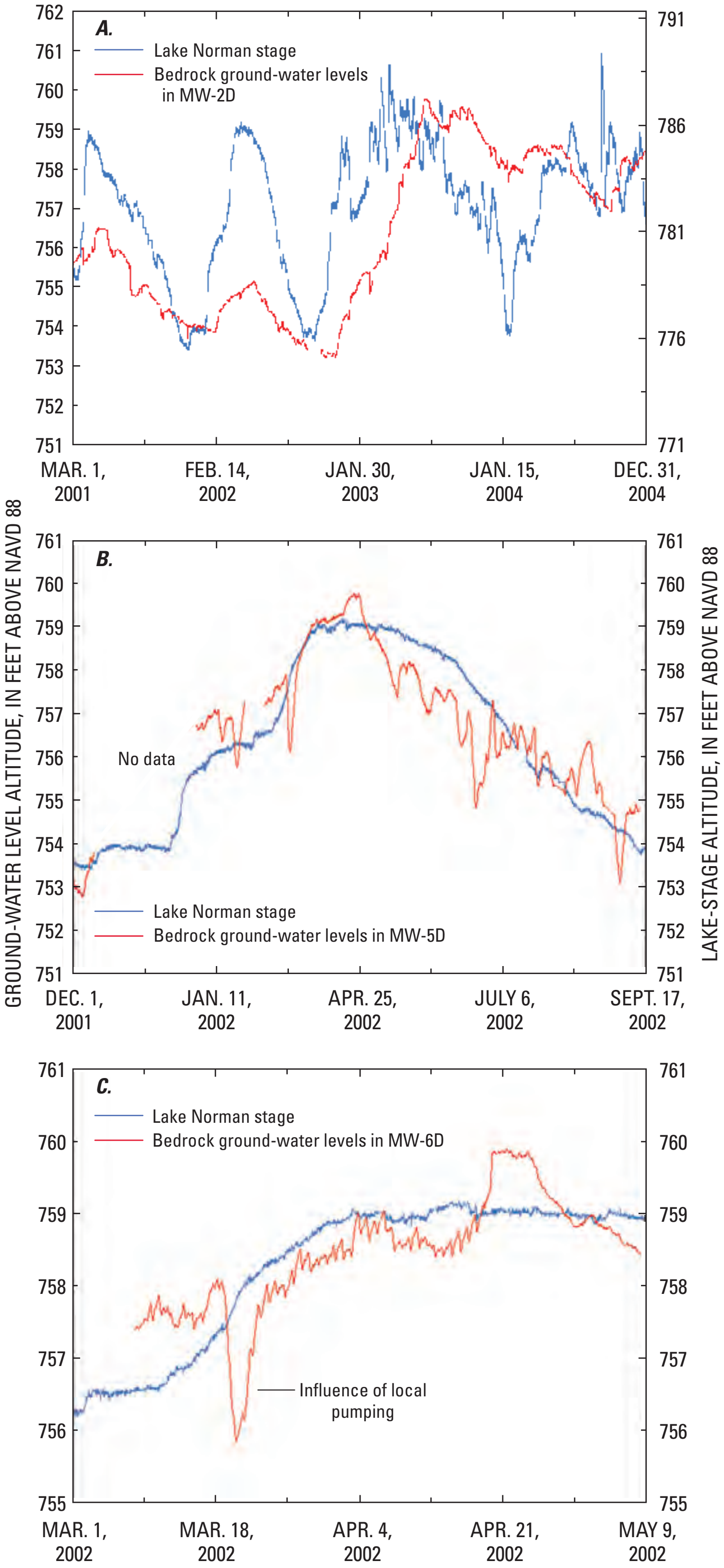


Figure 20. Hourly bedrock ground-water levels and Lake Norman stage in *(A)* well MW-2D, March 2001–December 2004, *(B)* well MW-5D, December 2001–September 2002, and *(C)* well MW-6D, March–May 9, 2002.

secondary pattern similar to that recorded in LPRS well MW-2D was not observed. LPRS bedrock well MW-2D is located about 1,350 ft from Lake Norman, whereas the Troutman bedrock well is located about 400 ft from the lake.

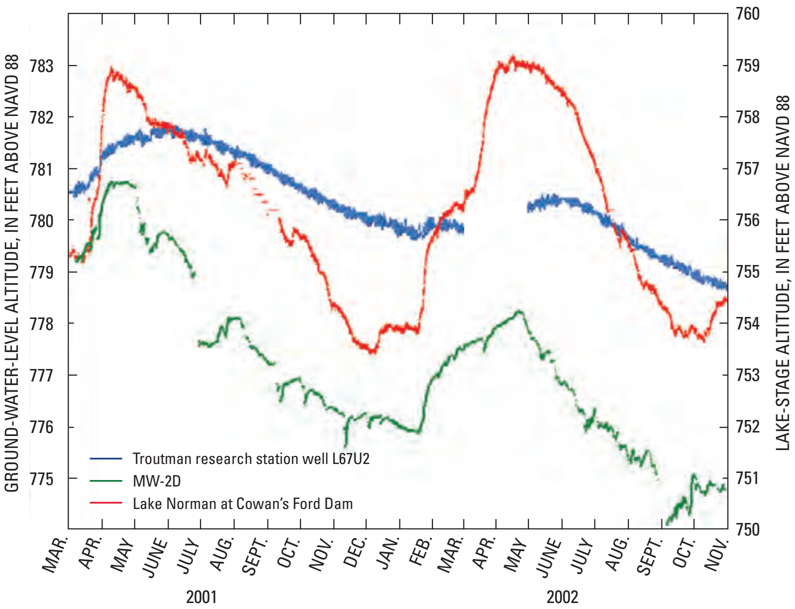


Figure 21. Hourly bedrock ground-water levels in Langtree Peninsula research station well MW-2D and North Carolina Department of Environment and Natural Resources Troutman research station well L67U2 and Lake Norman stage during the 2001–2002 drought.

Aquifer Hydraulic Properties

Aquifer hydraulic properties at the LPRS were computed by analyzing data from rising-head slug tests in eight wells and an aquifer test in bedrock well MW-5D. Slug tests are considered to provide estimates of the horizontal hydraulic conductivity of near-borehole aquifer materials. A step-drawdown test and a constant-rate aquifer test were conducted using bedrock well MW-5D as the pumped well.

Slug Tests

Slug tests provide a relatively quick and economical method to assess spatial trends in horizontal hydraulic conductivity across a study area. These methods test near-borehole materials. Methods and equipment used for slug testing are described in the “Methods” section of this report. Slug tests were conducted in eight wells at the LPRS during May 2002 and November 2003—three wells in the regolith, two in the transition zone, and three in the bedrock (table 3).

The slug-test data collected at the LPRS were analyzed using the Bouwer and Rice (1976) method, which accounts for water-table conditions and partial-penetration effects. For the shallow regolith wells and the transition zone wells, aquifer thickness was assumed to include both zones; the base of the aquifer (thickness) was considered to be the bottom of the transition zone. For the bedrock wells, the aquifer thickness was considered to be the length of open borehole, from casing depth to total well depth. A summary of results of the slug-test data analyses is given in table 3.

Analytical results of the slug tests conducted in wells at the LPRS indicate hydraulic conductivities of a similar order of magnitude: 2 to 7 feet per day (ft/d) for the regolith, transition zone, and high-yield bedrock wells. A lower order of magnitude of hydraulic conductivities of 0.4 to 0.6 was measured in one transition-zone well (MW-1I, table 3) and bedrock well (MW-2D, table 3).

Table 3. Analytical results of slug tests conducted during May 2002 and November 2003 at the Langtree Peninsula research station, North Carolina.

[ft bls, feet below land surface; B/R, Bouwer and Rice (1976) analytical solution; *k*, hydraulic conductivity estimate; ft/d, feet per day; PWR, partially weathered rock; *, ground-water levels did not fully recover to static conditions. Note: All analyses are from rising-head slug tests]

Well number and ground-water zone tapped	Materials	Screened or open interval (ft bls)	B/R *k* (ft/d)	Order of magnitude *k*
MW-2S (regolith)	fine sand	13–28	5	1
MW-3S (regolith)	fine sand	5–15	2	1
MW-6S (regolith)	fine sand	8–18	3	1
MW-1I (transition zone)	PWR	38–53	0.6	0.1
MW-3I (transition zone)	PWR	43–73	2	1
MW-2D (bedrock)	low-yield fractures	53–400	*0.4	0.1
MW-5D (bedrock)	high-yield fractures	40–400	7	1
MW-6D (bedrock)	high-yield fractures	69–400	2	1

Aquifer Test

A 48-hr constant-rate aquifer test was conducted to observe the response of the fracture network and overlying regolith to pumping stress. Quantitative estimates of transmissivity and storage coefficients for the bedrock were not possible because widely accepted analytical methods are not available for the complex regolith-fractured bedrock ground-water system. Equipment and procedures used in the aquifer test are described in the “Methods” section of this report.

A total of 34,296 gal of ground water was pumped from bedrock well MW-5D during a 48-hr constant-rate aquifer test conducted during January 14–16, 2003. The average discharge rate was 12 gal/min. Several observation wells and piezometers were monitored during the aquifer test: MW-1I, MW-1D, MW-4IA, MW-4D, MW-5I, MW-5D, MW-6IB, MW-6D, WL-2, and WL-3 (figs. 5, 6). Hourly ground-water levels also were monitored in well cluster MW-2. Drawdown in the pumped well was about 122 ft, resulting in a calculated specific capacity of 0.1 gal/min per foot ([gal/min]/ft) of drawdown. The pumping water level was about 150 ft below land surface, and the two uppermost fractures at 46 and 106 ft were dewatered; however, the deeper fractures in bedrock well MW-5D at 171 ft (app. 2) likely continued to supply water to the well during the aquifer test.

Several bedrock wells had measured drawdown during the January 2003 aquifer test in well MW-5D at the LPRS. The three bedrock wells that were known to tap the same fracture network— pumped well MW-5D and observation wells MW-6D (360 ft from the pumped well) and MW-4D (290 ft from the pumped well; fig. 6*B*)—all exhibited similar responses to pumping (fig. 22*A*) and had a total drawdown greater than 100 ft. Observation well MW-6D appears to be more closely connected to the pumped well by having nearly the same magnitude of drawdown characteristics throughout the aquifer test. Compared to well MW-4D, well MW-6D had more open fractures. Additionally, bedrock wells MW-1D (about 690 ft away) and the Davidson College campus barn well (about 1,000 ft away) had measurable drawdowns of about 20 ft and 4 ft, respectively (fig. 22*A*). (The water level in bedrock well MW-2D rose by about 0.02 ft during the aquifer test.) As previously mentioned, these data were not analyzed quantitatively because the complex fractured-bedrock/regolith aquifer system does not satisfy assumptions of commonly used aquifer-test analytical solutions.

Responses of nearby shallow observation wells measured during the 2-day aquifer test indicated a slight measurable decline in nearby transition-zone wells and no measurable decline in nearby regolith wells or piezometers. Background water-level trends in regolith well MW-2S and transition zone well MW-2I (cluster MW-2, fig. 5) rose by about 0.05 ft during the 2-day aquifer test. The decline in water levels for transition zone wells MW-4I, -1I, and -5I was about 0.1 ft during the 2-day aquifer test (fig. 22*B*). (The water level in MW-6I (fig. 22*B*) most likely responded to fluctuations in the lake level.) No measurable declines in water levels in regolith piezometers WL-1, -2, -3, and -4 and GP-2, -3, -4, -5, -6, -7, and -8 were observed.

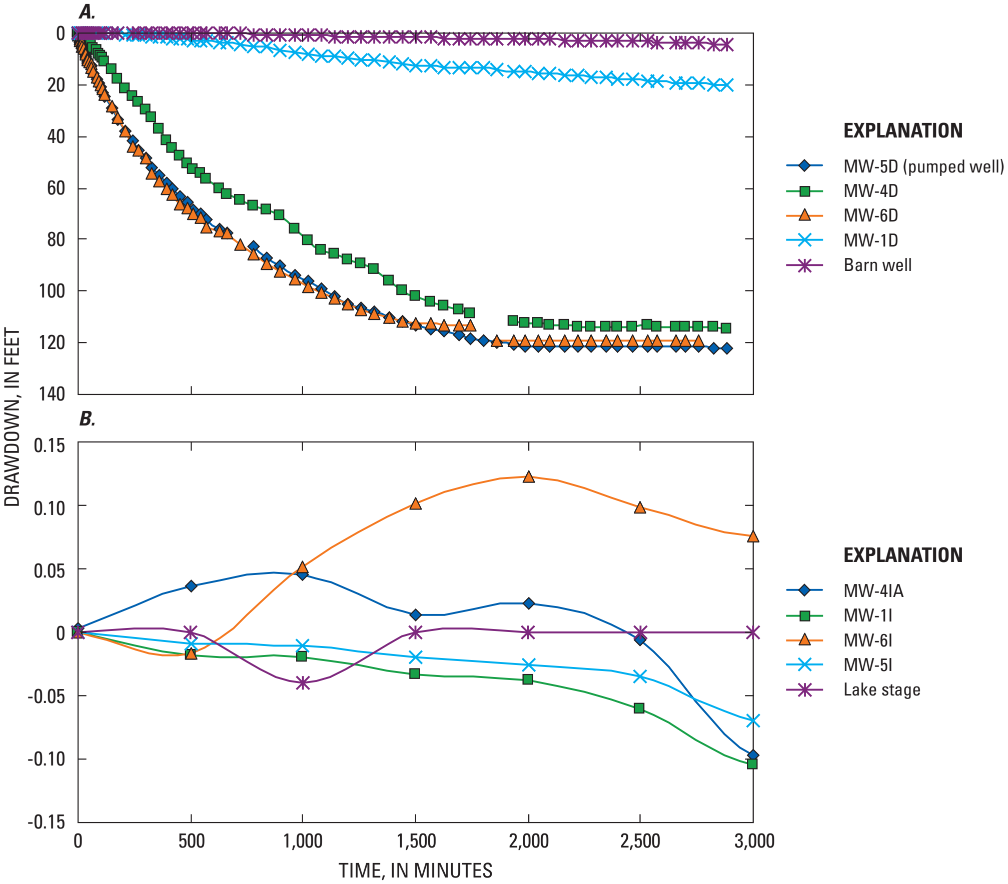


Figure 22. Drawdown response of pumped well (MW-5D) and observation wells measured during the January 2003 aquifer test in *(A)* bedrock wells and *(B)* transition-zone wells at the Langtree Peninsula research station, North Carolina.

Ground-Water Flow

Ground-water flow in hydrogeologic settings of the Piedmont Physiographic Province of North Carolina is assumed to flow from high topographic areas (recharge) to lower topographic areas (discharge; fig. 5). This system was designated a "slope-aquifer system" by LeGrand (2004). Discussions of conceptual ground-water flow and influence of topography can be found in LeGrand (1967), Heath (1983, 1984), Harned and Daniel (1992), and Daniel and Dahlen (2002).

Conceptual models of ground-water flow indicate that depth to ground water is greater at topographic highs in recharge areas than in topographic lows in ground-water discharge areas. Ground-water-level data collected at the LPRS generally support this concept. In general, water levels are closer to land surface at well clusters MW-3 and MW-6 in discharge areas near Lake Norman than in well clusters MW-2 and MW-1 in recharge areas (figs. 5, 16).

Shallow Regolith

The general direction of ground-water flow in the regolith underlying the LPRS is consistently toward Lake Norman to the north (fig. 23), as determined from data collected from 5 to 6 wells (well MW-4S later was drilled deeper into the transition zone, table 1) and 12 piezometers. Water-level altitudes measured in wells tapping the regolith generally correspond to topographic setting; the highest water-level altitudes during this study were in regolith well MW-2S in the higher topographic (recharge) area (table 1), and the lowest water-level altitude was near the lake (discharge area; figs. 5, 23). This is in general agreement with the conceptual ground-water-flow model indicating ground-water discharge to Lake Norman. Two ground-water-flow maps of the shallow regolith are presented in figure 23—one representing conditions during the drought (October 18, 2002; fig. 23*A*) and one representing high water-level conditions (September 23, 2003; fig. 23*B*). Water-level altitudes measured in regolith wells MW-3S and MW-6S and piezometers GP-7, GP-8, GP-6, WL-3, and WL-4 are within 1 ft of the lake stage and each other during October 2002 (fig. 23*A*), resulting in a flat hydraulic gradient near Lake Norman. During high water-level conditions (September 2003; fig. 23*B*), gradients are slightly steeper toward the lake.

Transition Zone

Although only 6 to 7 wells were used to evaluate the ground-water-flow direction in the transition zone compared to 18 wells and piezometers in the shallow regolith (well MW-4IB was added after the study was initiated; table 1), the general flow direction in the transition zone is similar to ground-water-flow directions in the regolith—toward Lake Norman to the north (fig. 24). (These flow directions are general only, as the locations of all of the wells are along two transects (fig. 5).) Ground-water-flow maps of the transition zone are presented in figure 24—one representing conditions during the drought (October 18, 2002; fig. 24*A*) and one representing high water-level conditions (September 23, 2003; fig. 24*B*). Water-level altitudes measured in wells tapping the transition zone generally correspond to topographic setting; the highest water-level altitudes were recorded in well MW-2I in the higher topographic (recharge) area (fig. 6*A*), and the lowest water-level altitudes in the transition zone were recorded near the lake (discharge area) in wells MW-3I and MW-6I (figs. 5, 24). This is in general agreement with the conceptual ground-water-flow model, which depicts ground-water discharge to Lake Norman. Water-level altitudes in transition zone wells MW-3I and MW-6I were within a few tenths of a foot of each other and the lake (fig. 24), which results in a flat hydraulic gradient near Lake Norman.

Bedrock

The direction of ground-water flow in the bedrock part of the ground-water system at the LPRS, as determined from open-borehole water-level data, was similar to the flow in the shallow regolith and transition zones—toward Lake Norman to the north (fig. 25). (These flow directions are general only, as the locations of all of the wells are along a transect from south to north at the LPRS.) Water-level altitudes measured in wells tapping the bedrock generally correspond to topographic setting; the highest water-level altitudes in the bedrock were recorded in well MW-2D in the higher topographic (recharge) area (fig. 6*A*), and the lowest water-level altitudes in the bedrock were recorded near the lake (discharge area) in wells MW-6D, -5D, and -4D (figs. 5, 25). This is in general agreement with the conceptual ground-water-flow model, which depicts ground-water discharge to Lake Norman. Two ground-water-flow maps of the bedrock are presented in figure 25—one representing conditions during the drought (October 18, 2002; fig. 25*A*) and one representing high water-level conditions (November 7, 2003; fig. 25*B*). Comparable water-level altitudes in wells MW-6D, -5D, and -4D indicate that fracture zones tapped by these wells have similar hydraulic heads and are likely interconnected, as confirmed during sampling and hydraulic testing.

Interpretation of the open-borehole water levels in bedrock wells is complicated because the data represent a composite of the hydraulic heads in several fractures tapped more than a few hundred feet by the well. The hydraulic head within a specific fracture may be different from that measured in the entire open borehole. For these reasons, care must be taken in the use and interpretation of open-borehole water levels in the bedrock wells.

Ground-Water Quality

Water-quality data from the wells and surface water at the LPRS were collected both continuously and at periodic sampling events. Continuous monitoring of temperature, pH, SC, and DO was conducted at wells MW-2S (in the regolith) and MW-2D (in the bedrock). Hourly data were collected from August 2002 to July 2003 in well MW-2S, and from August 2002 to March 2004 in well MW-2D. Periodic samples were

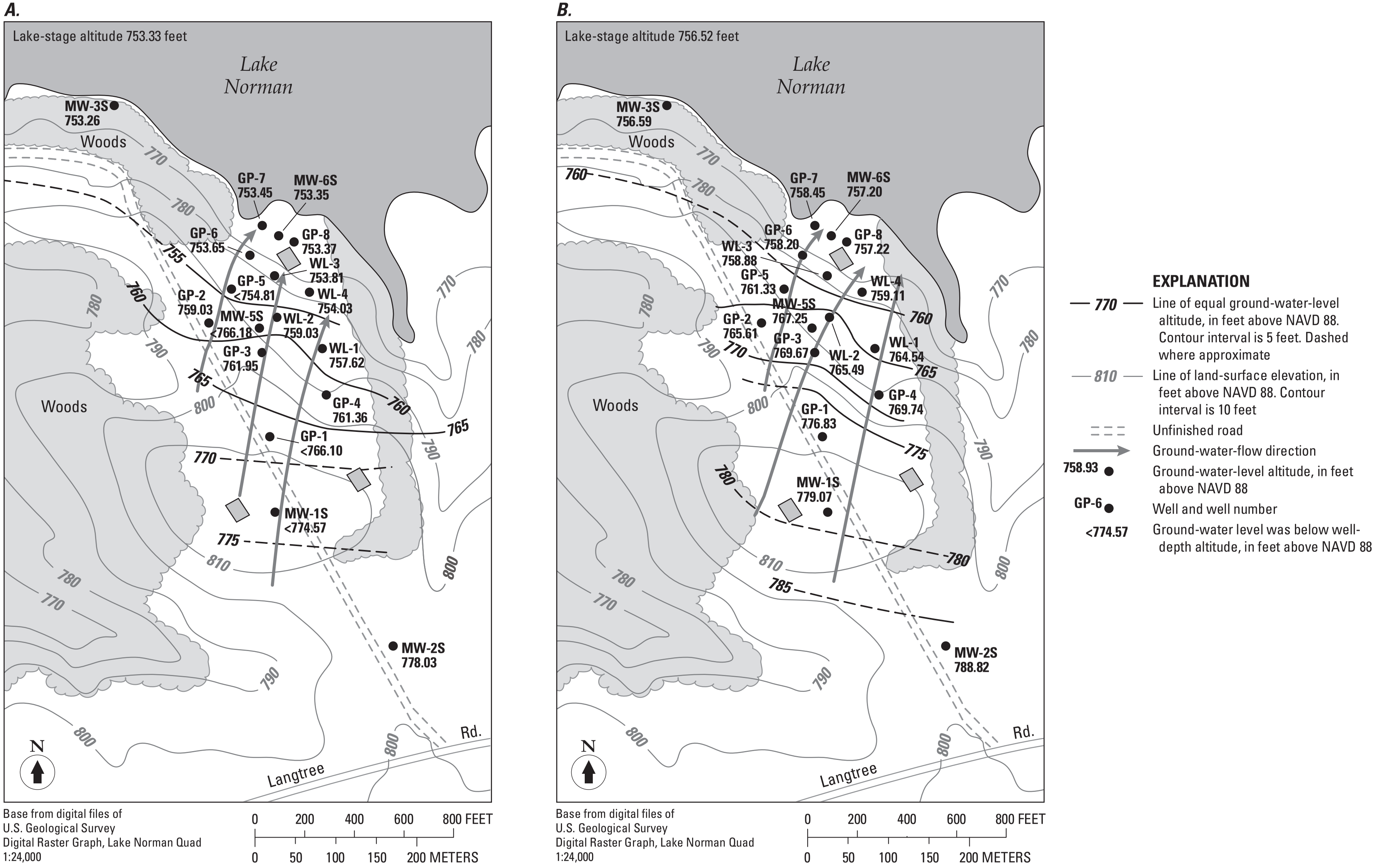


Figure 23. General ground-water-level altitude and flow direction in the shallow regolith at the Langtree Peninsula research station, North Carolina, for *(A)* October 18, 2002, (drought conditions) and *(B)* September 23, 2003 (high ground-water-level conditions).

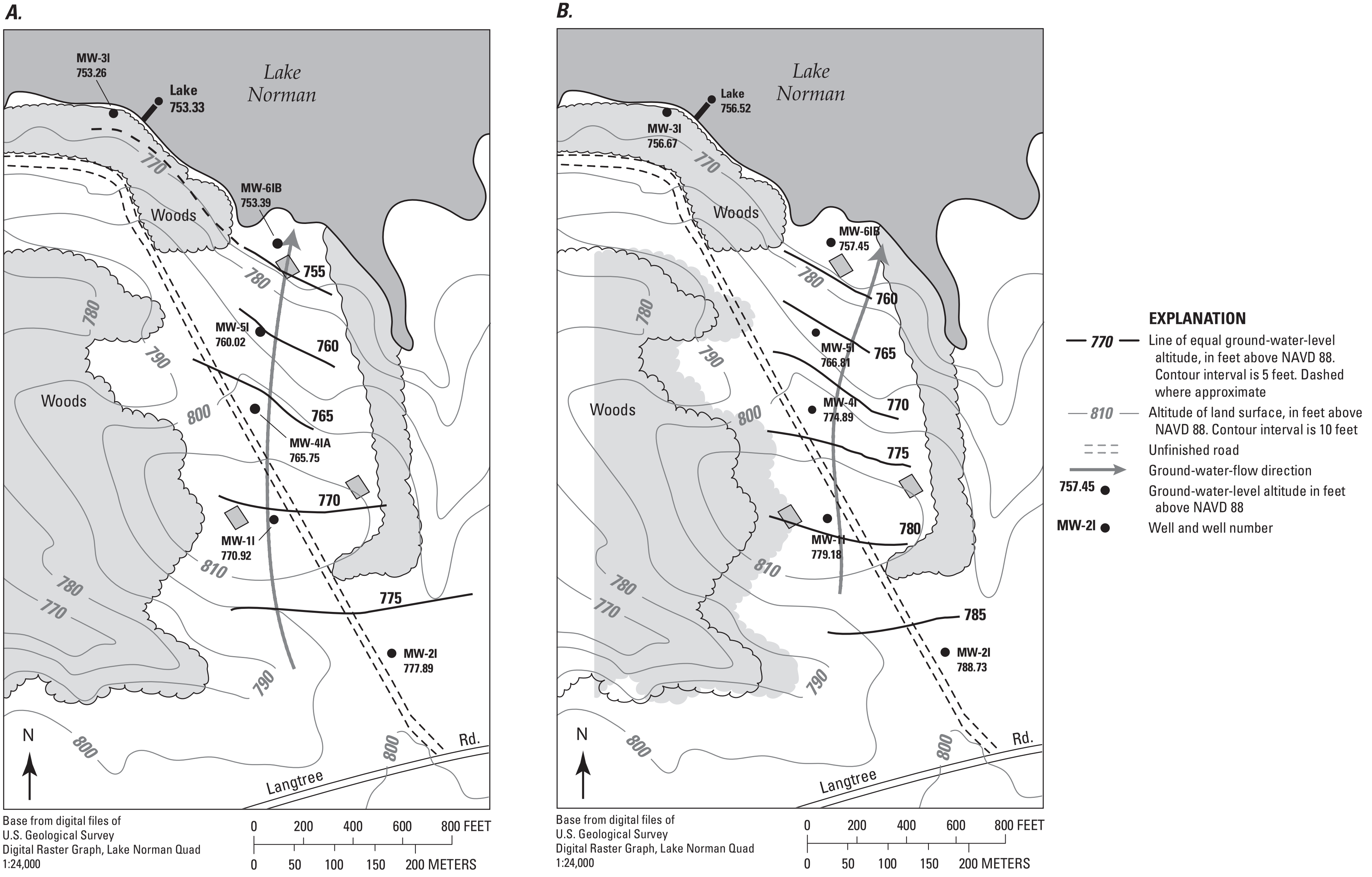


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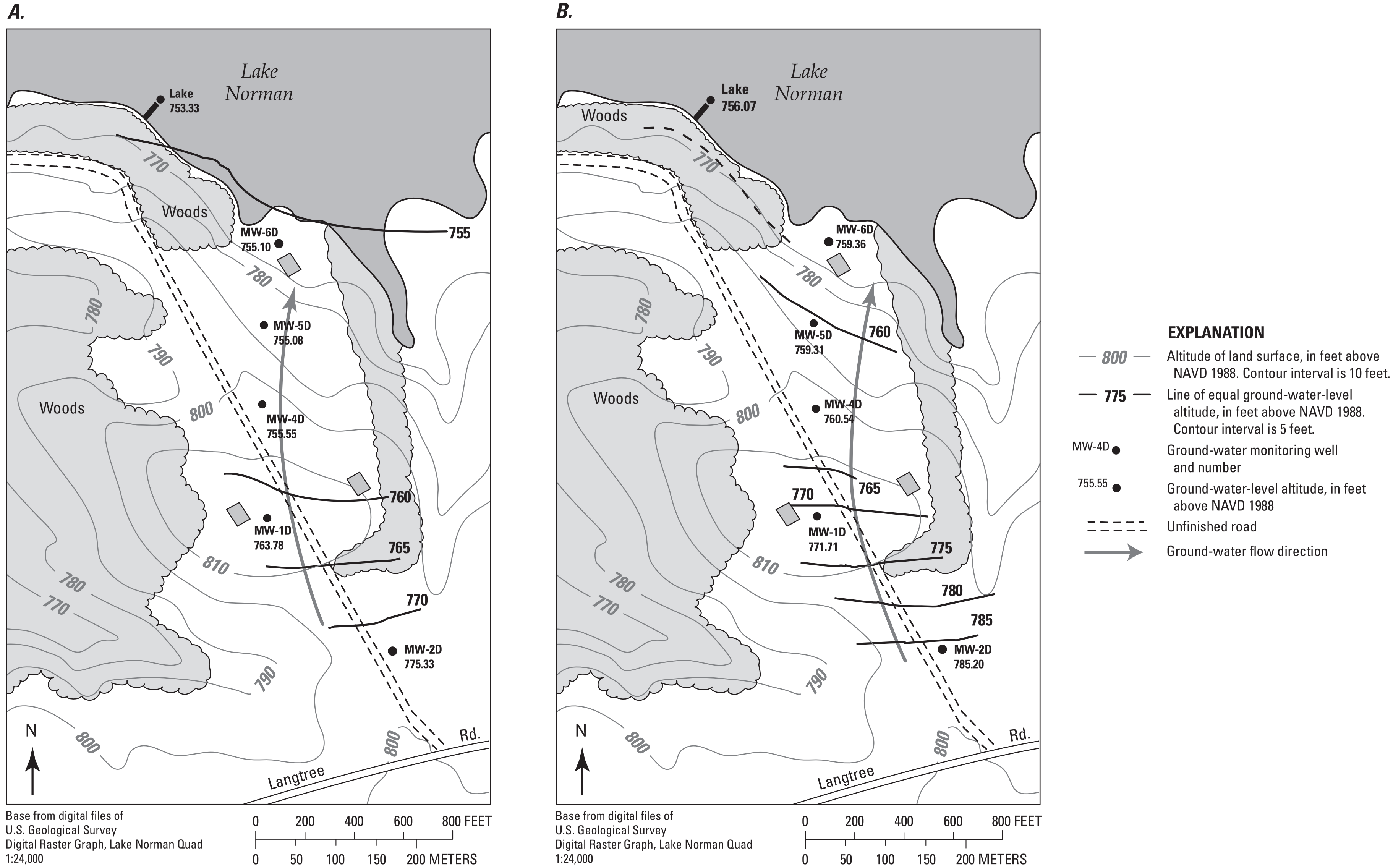
Figure 24. Ground-water-level altitude and flow direction in the transition zone at the Langtree Peninsula research station, North Carolina, for *(A)* October 18, 2002, (drought conditions) and *(B)* September 23, 2003 (high ground-water-level conditions).



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Digital Raster Graph, Lake Norman Quad
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Figure 25. Ground-water-level altitude and flow direction in the transition zone at the Langtree Peninsula research station, North Carolina, for *(A)* October 18, 2002, (drought conditions) and *(B)* November 7, 2003 (high ground-water-level conditions).

collected from the cluster wells and Lake Norman during two sampling events in August 2002 and March 2003 and from one well in June 2004. Water-quality analyses included selected major ions, nutrients, metals, radiochemicals, and physical properties (table 4). Methods and instrumentation used for both the continuous monitoring and periodic sampling are described in the "Methods" section of this report and in the SOP for this study (North Carolina Department of Environment and Natural Resources, Division of Water Quality, and U.S. Geological Survey, Water Resources Division, 2002). Continuous water-quality monitoring data and periodic water-quality sampling data are published in USGS water-data reports for water years 2002, 2003, and 2004 (Howe and others, 2003, 2004, 2005).

Continuous Monitoring Data

An important use of continuous ground-water-quality monitoring data is to evaluate the chemical response of the aquifer system during climatic variations (seasonal trends) in the hydrologic system and short-term rainfall events. Seasonal trends are a function of recharge, which typically is greatest during the winter and early spring months, and evapotranspiration, which is greatest during the late spring and summer months. Chemistry of the aquifer may change as a result of the infiltration of rainfall and potential interaction of components of the ground water.

Seasonal Trends

Continuously monitored field properties recorded in regolith well MW-2S (fig. 26) and bedrock well MW-2D (fig. 27) changed slowly (seasonally) throughout the monitoring period. This was not unexpected, as a similar response was observed in continuously recorded ground-water-level data (fig. 17).

General trends with well depth in the ground-water system are evident from a comparison of shallow ground water in regolith well MW-2S (fig. 26) and deep bedrock ground water in well MW-2D (fig. 27). In general, pH increases, DO decreases, and temperature becomes stable at increasing depths in the ground-water system. These findings are similar to those reported at the Lake Wheeler Road research station (Chapman and others, 2005). These observations most likely are the result of a lesser degree of interaction with rainfall at depth. In the bedrock, ground water has a longer residence time, and the pH increases from dissolution of the alkaline minerals. Shallow ground water in the regolith receives larger amounts of acidic (lower pH) rainfall than deep ground water. Overall, the shallow ground water in regolith well MW-2S had a larger seasonal fluctuation in water-quality properties (fig. 26) than ground water in the deep bedrock well MW-2D (fig. 27). The observed seasonal temperature fluctuation in regolith well MW-2S was substantially greater than the temperature range in the deeper bedrock well MW-2D.

Temperature

The magnitude of seasonal ground-water temperature fluctuations was less with increasing depth at the LPRS. Temperatures in shallow regolith well MW-2S fluctuated about 0.6 degree Celsius (°C) during a year of monitoring (fig. 26), but water temperatures in bedrock well MW-2D fluctuated only 0.1° C during more than 20 months of monitoring (fig. 27).

Table 4. Analyses conducted on water-quality samples collected during periodic sampling events at the Langtree Peninsula research station, North Carolina.

[NC, not collected]

Sampling date	Major ions[a, b] (dissolved)	Nutrients[a, c] (dissolved)	Metals[a, d] (dissolved)	Radon 222 (gas)[a] (total)	Gross alpha[e] (total)
August 26–28; September 3, 2002[f]	X	X	NC	X	X
March 3–5, 2003	X	X	X	X	X
June 15–17, 2004[g]	X	X	X	NC	NC

[a] Analyzed by the U.S. Geological Survey National Water Quality Laboratory, Denver, Colorado.

[b] Major ions analyzed were bromide, calcium, chloride, fluoride, magnesium, potassium, silica (as SiO_2), sodium, and sulfate.

[c] Nutrients analyzed were ammonia, nitrogen as nitrate, nitrogen as nitrite, nitrate plus nitrite, organic nitrogen, orthophosphorus, and orthophosphate.

[d] Metals analyzed were aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, uranium, and zinc.

[e] Analyzed by STL Laboratories, Richland, Washington (contracted by the U.S. Geological Survey National Water Quality Laboratory).

[f] Only Lake Norman samples were collected on September 3, 2002.

[g] Only well MW-2D was sampled in June 2004.

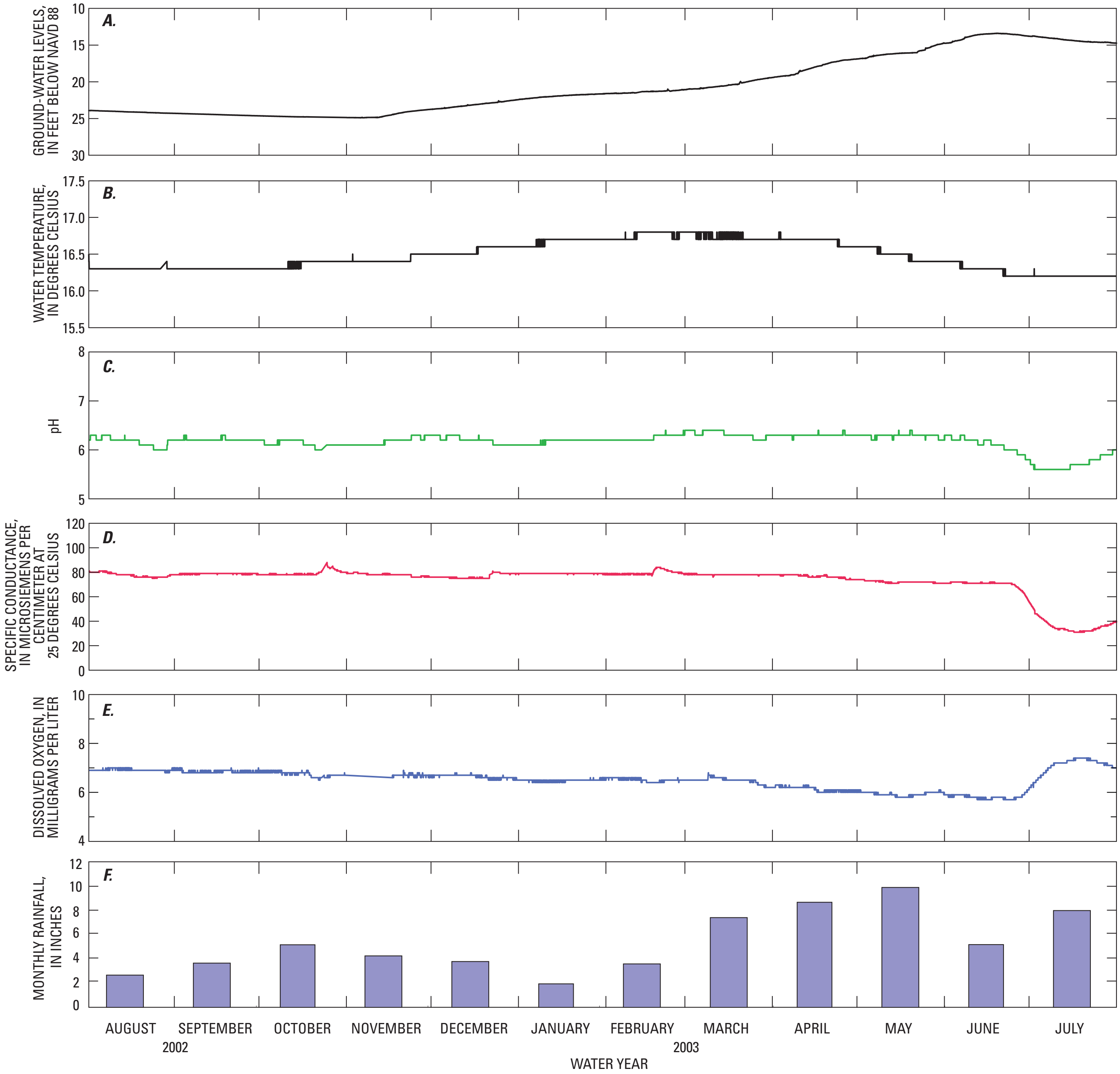

Figure 26. Hourly record of *(A)* ground-water levels, *(B)* temperature, *(C)* pH, *(D)* specific conductance, and *(E)* dissolved oxygen in well MW-2S in the shallow regolith at the Langtree Peninsula research station, North Carolina; and *(F)* monthly rainfall data from Norman Shores rain gage, Lake Norman, North Carolina.

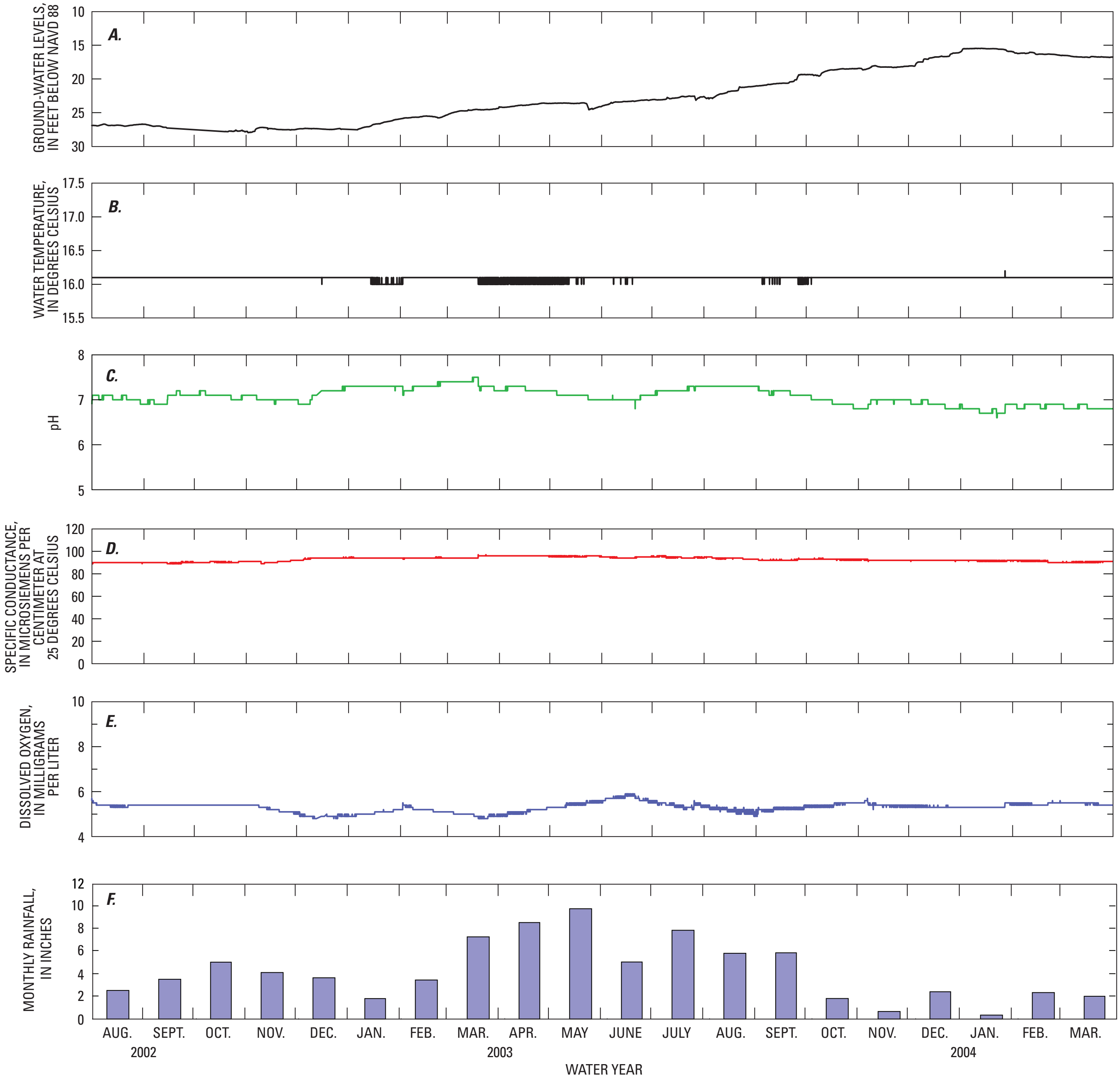

Figure 27. Hourly record of *(A)* ground-water levels, *(B)* temperature, *(C)* pH, *(D)* specific conductance, and *(E)* dissolved oxygen in well MW-2D in the bedrock at the Langtree Peninsula research station, North Carolina; and *(F)* monthly rainfall data from Norman Shores rain gage, Lake Norman, North Carolina.

A seasonal pattern was observed in the shallow regolith ground-water temperature recorded in well MW-2S; however, the pattern was substantially delayed (about 5 months) with respect to air temperature (fig. 28). The highest shallow ground-water temperatures were recorded during February–March 2003 and the lowest during August–September 2002 and June–July 2003. By contrast, as is typical of air temperature, the highest temperatures were recorded during summer months (July and August) and the lowest temperatures were recorded during late January and early February 2003 (fig. 28). The delay of the air-temperature "signal" may indicate slow ground-water recharge and is similar to the responses recorded at the Lake Wheeler Road research station (Chapman and others, 2005).

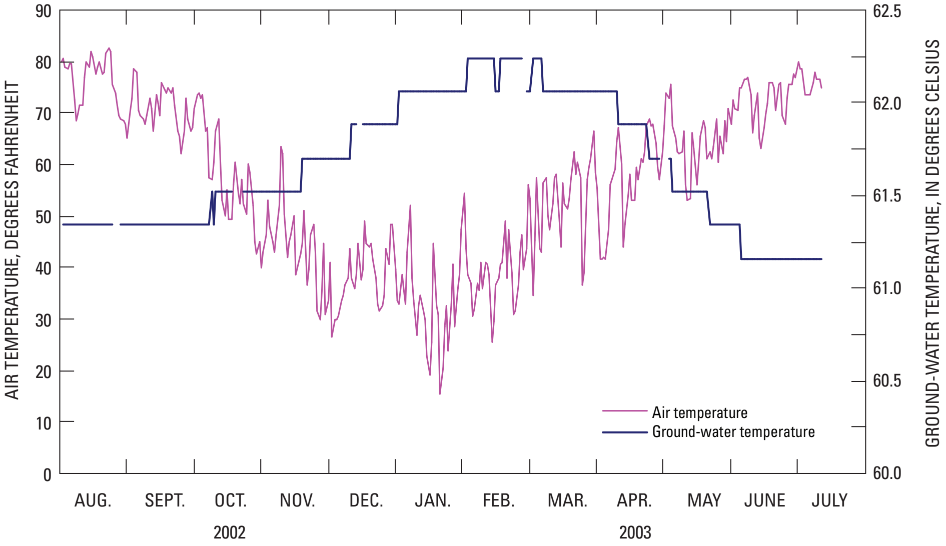

Figure 28. Ground-water temperature recorded in shallow regolith well MW-2S in relation to air temperature recorded at the North Carolina State Climate Weather Station (2NNE) in Statesville.

pH

Ground water in the shallow regolith and bedrock has a slightly acidic to acidic pH and generally increases with depth (figs. 26, 27). The lower pH in shallow zones likely is the result of infiltration of acidic precipitation and the presence of carbonic acid (produced as carbon dioxide from the decay of organic matter (Drever, 1988)). The increase in pH at depth in the bedrock indicates increased residence time for the dissolution of minerals. Values of pH in the regolith ranged from about 5.6 to 6.4, whereas values in the bedrock ground water ranged from about 6.4 to 7.5.

Specific Conductance

As with pH, specific conductance (SC) slightly increased when shallow ground water in the regolith was compared to ground water in the deeper bedrock (figs. 26, 27). Specific conductance for well MW-2S ranged from about 31 to 88 microsiemens per centimeter at 25 degrees Celsius (μS/cm) during the period of study (fig. 26), whereas SC for well MW-2D ranged from about 89 to 97 (fig. 27). The values of SC for well MW-2D are somewhat low in relation to SC values for most areas of the Piedmont. Initially, casing leakage was thought to be a potential means of connection with the overlying regolith. However, heat-pulse flowmeter logging of well MW-2D (app. 2) did not measure any downward flow near the bottom of the casing, which indicates the well was sealed properly. Daniel and Dahlen (2002) reported a mean SC value of about 387 μS/cm for the Piedmont, which is considerably higher than the SC values recorded in bedrock well MW-2D. The influence of nearby pumping wells (fig. 19) and the naturally downward vertical gradient (figs. 16, 17) may induce interaction with the more diluted overlying regolith and lower the overall SC values in this well.

Dissolved Oxygen

Dissolved-oxygen (DO) concentrations in wells MW-2S and MW-2D decreased slightly with depth. Dissolved-oxygen concentrations in the shallow regolith well (MW-2S) ranged from about 5.7 to 7.4 milligrams per liter (mg/L; fig. 26), and DO concentrations in the deeper bedrock well (MW-2D) ranged from about 4.8 to 5.9 mg/L (fig. 27). The higher DO concentrations in the regolith well indicate a more direct interaction with precipitation. Dissolved-oxygen concentrations in the bedrock well were higher than expected. Casing leakage was again suspected; however, as stated above, no leakage was measured using heat-pulse flowmeter logging near the bottom of the casing. These DO values are comparable to the mean DO values reported by Daniel and Dahlen (2002) for the Piedmont region in a report that summarized data collected as part of the APRASA study (Briel, 1997) in North Carolina that focused primarily on domestic wells that are pumped. The elevated DO value in the bedrock well at the LPRS may be influenced by nearby pumping wells (fig. 19) and the naturally downward vertical gradient in this area, as observed in the water-level data recorded in this well (figs. 16, 17).

Response to Recharge

Continuous water-quality monitoring data provide insights into the processes and interactions of components of the ground-water system during short-term rainfall events or extended periods of increased precipitation. During water years 2001 and 2002 (drought years), water levels in MW-2 wells did not respond to short-term rainfall events or longer periods of increased recharge (fig. 17; see discussion in the “Ground-Water Levels” section of this report). However, following above-normal rainfall during water year 2003, the ground-water level in well MW-2S rose more than 1 ft over about a 2-week period in June and July 2003 (fig. 29). Water-quality changes also were observed in regolith well MW-2S within 2–3 weeks after the ground-water-level rise began and occurred for a similar duration as the water level rose. During this period, DO concentrations increased in the shallow regolith ground water in well MW-2S (+1.7 mg/L, fig. 29*A*), while pH and SC decreased (-0.5 and -39 µS/cm, respectively, fig. 29*B*, *C*). Temperature continued to respond seasonally and did not markedly fluctuate during this recharge period. All of these water-quality property changes are indicative of rainfall infiltration over a period of a few to several weeks and likely reflect saturation from above-normal rainfall during March through July 2003 and a resulting shorter-term flux of water-quality interactions between rainfall and shallow ground water in the regolith. (Rainfall generally is more acidic, has higher DO concentrations, and is more dilute [lower specific conductance] than ground water.) Water-quality properties recorded in bedrock well MW-2D did not fluctuate in response to this recharge period.

Results from Periodic Water-Quality Sampling

Water-quality samples were collected periodically from the LPRS wells to characterize ground-water chemistry in the quartz diorite rock type. Water-quality samples were collected from the cluster wells and the lake during three sampling events (table 4). Samples were analyzed for major ions and nutrients for two sampling events; additionally, metals, radon 222 (gas) concentrations, and gross alpha activity were analyzed in samples collected during two events. All of the cluster wells were sampled in August 2002 and March 2003, and one well was sampled in June 2004. Two samples, “top” (about 1 ft below the water surface) and “bottom” (about 1 ft above the lake bottom), were collected from Lake Norman during each sampling event. These analytical results are published in USGS North Carolina annual water-data reports for the respective water years (Howe and others, 2003, 2004, 2005).

One of the objectives of this study was to compare ground-water-quality data from each water-bearing zone of the ground-water system—the regolith, transition zone, and bedrock. Field properties measured during periodic sampling events provide a means of comparing geochemical conditions. General trends in field water-quality properties during periodic sampling events (fig. 30; Howe and others, 2003, 2004, 2005) were similar to trends in the continuous water-quality data (figs. 26, 27) in that pH and SC increased and DO decreased with depth in the ground-water system.

Standard graphical tools used for the geochemical comparison of ground-water-quality data are Piper trilinear diagrams and Stiff diagrams. The Piper diagram is a multiple-trilinear diagram that segregates analytical data with respect to dissolved major cations and anions in ground water (Piper, 1953). The Stiff diagram is used to display dominant cations and anions (Stiff, 1951). Figures 31 and 32 display Piper and Stiff diagrams, respectively, for each zone of the ground-water system—regolith, transition zone, and bedrock. Comparisons of the range of major ion concentrations in each of the three zones are shown in figures 33 and 34. The bedrock has the highest median concentrations of calcium, sodium, and bicarbonate, and concentrations generally increased with depth in the ground-water system. Samples collected from the transition zone had the highest median concentrations of magnesium, while samples collected from Lake Norman had a higher overall concentration of chloride.

Most of the ground-water samples collected at the LPRS are calcium-bicarbonate water types (figs. 31, 32). Samples from all three zones of the ground-water system have similar geochemistry at the LPRS. Regolith well MW-3S, located near Lake Norman, was somewhat different in that sodium was the dominant cation. Similarly, the sample collected from the top of the water column in Lake Norman was a sodium-chloride type, potentially indicating the influence of local septic systems. The Davidson College Lake Campus includes restrooms and a nearby septic field within 100 ft of the lake and well cluster MW-3. No distinction could be made in ground-water samples collected from recharge areas compared with ground-water samples from discharge areas based on these major ion analyses. (Some well samples [bedrock wells MW-4D, -5D, and -6D] are not included in this report because they potentially were affected by well-construction practices and grout contamination, possibly indicated by a calcium-sulfate water type and high SC concentrations.)

Ground-Water-Quality Changes with Depth

A comparison of water chemistry with depth (figs. 30, 32–34) indicates an increase in total solutes, such as calcium and bicarbonate. Along with an increase in pH with depth (fig. 30), this indicates an increase in ground-water residence time with depth, which allows greater dissolution of minerals in the bedrock. Also, the lower DO concentrations in ground water in the bedrock indicate reduced recharge from precipitation and partial disconnection of the deeper part of the ground-water system (bedrock) with the overlying regolith and transition zone, which receives and stores most of the recharge.

Shallow Regolith Ground Water and Surface Water

As previously discussed, samples from three shallow regolith wells had different geochemical characteristics. Water from well MW-2S (recharge area, fig. 6*A*) was a calcium/magnesium-bicarbonate type water (figs. 31, 32). The water

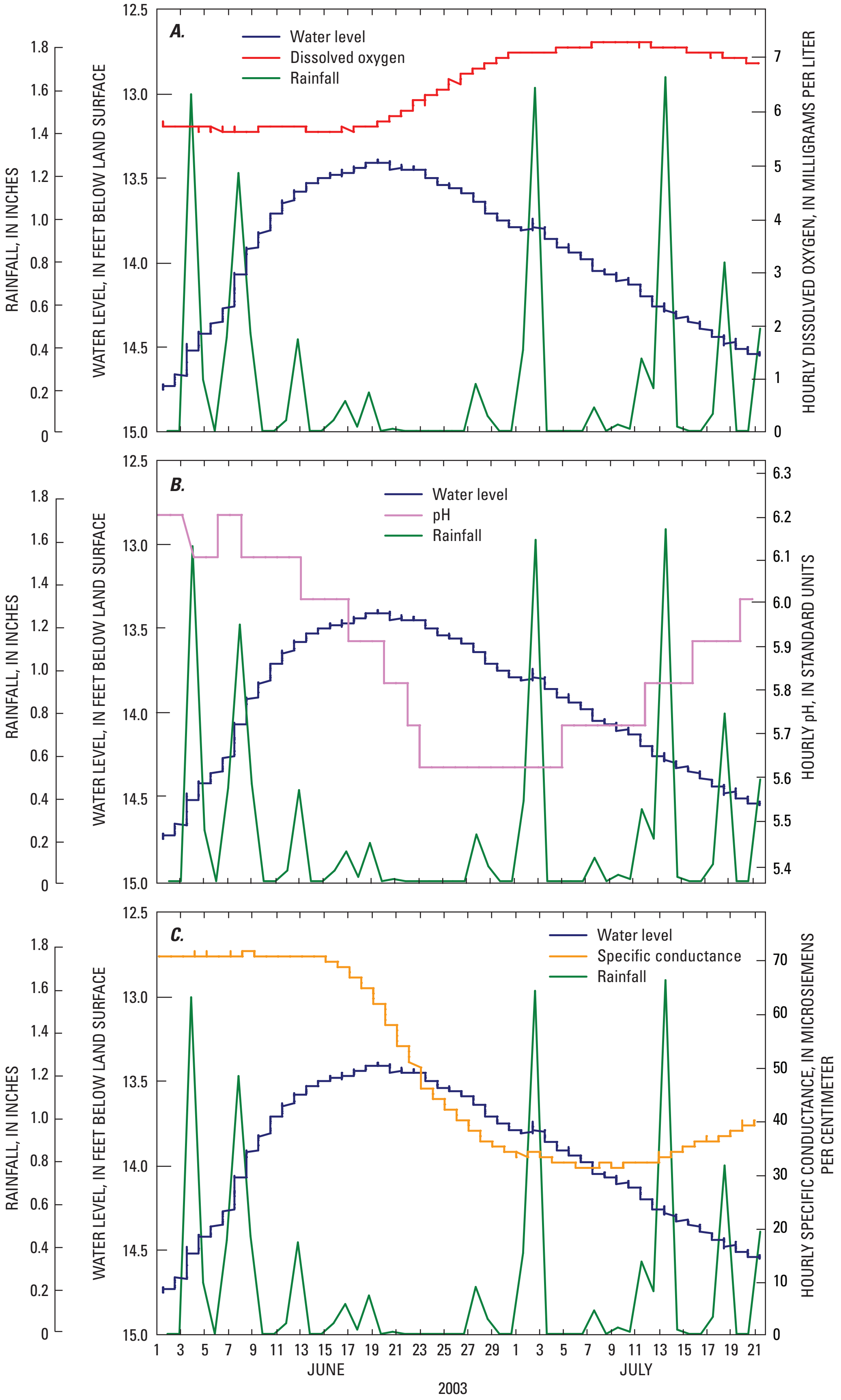

Figure 29. Response of *(A)* dissolved oxygen, *(B)* pH, and *(C)* specific conductance in regolith well MW-2S to rainfall in June and July 2003 at the Langtree Peninsula research station, North Carolina.

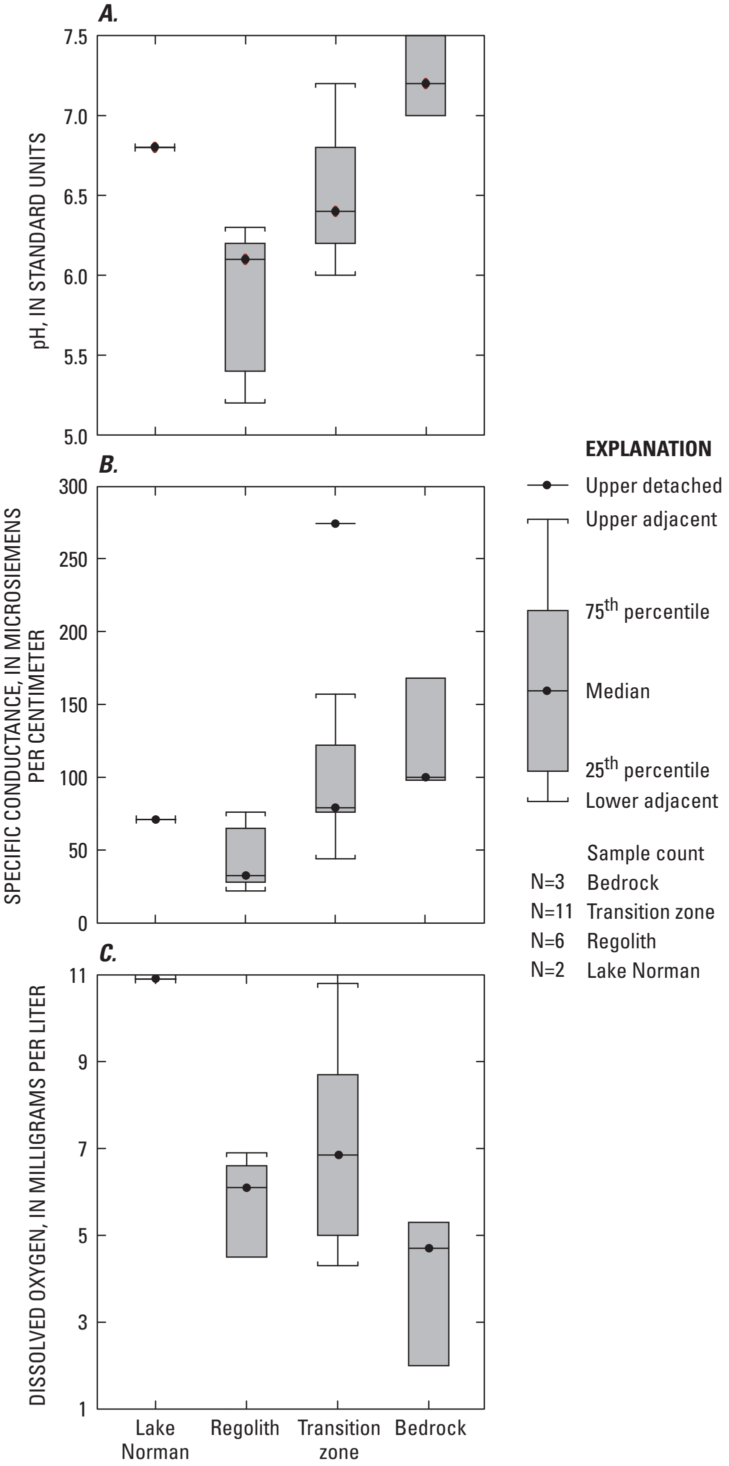

Figure 30. Box plots showing range, median, and quartile statistical values for *(A)* pH, *(B)* specific conductance, and *(C)* dissolved oxygen in the wells and Lake Norman recorded during periodic sampling events at the Langtree Peninsula research station, North Carolina.

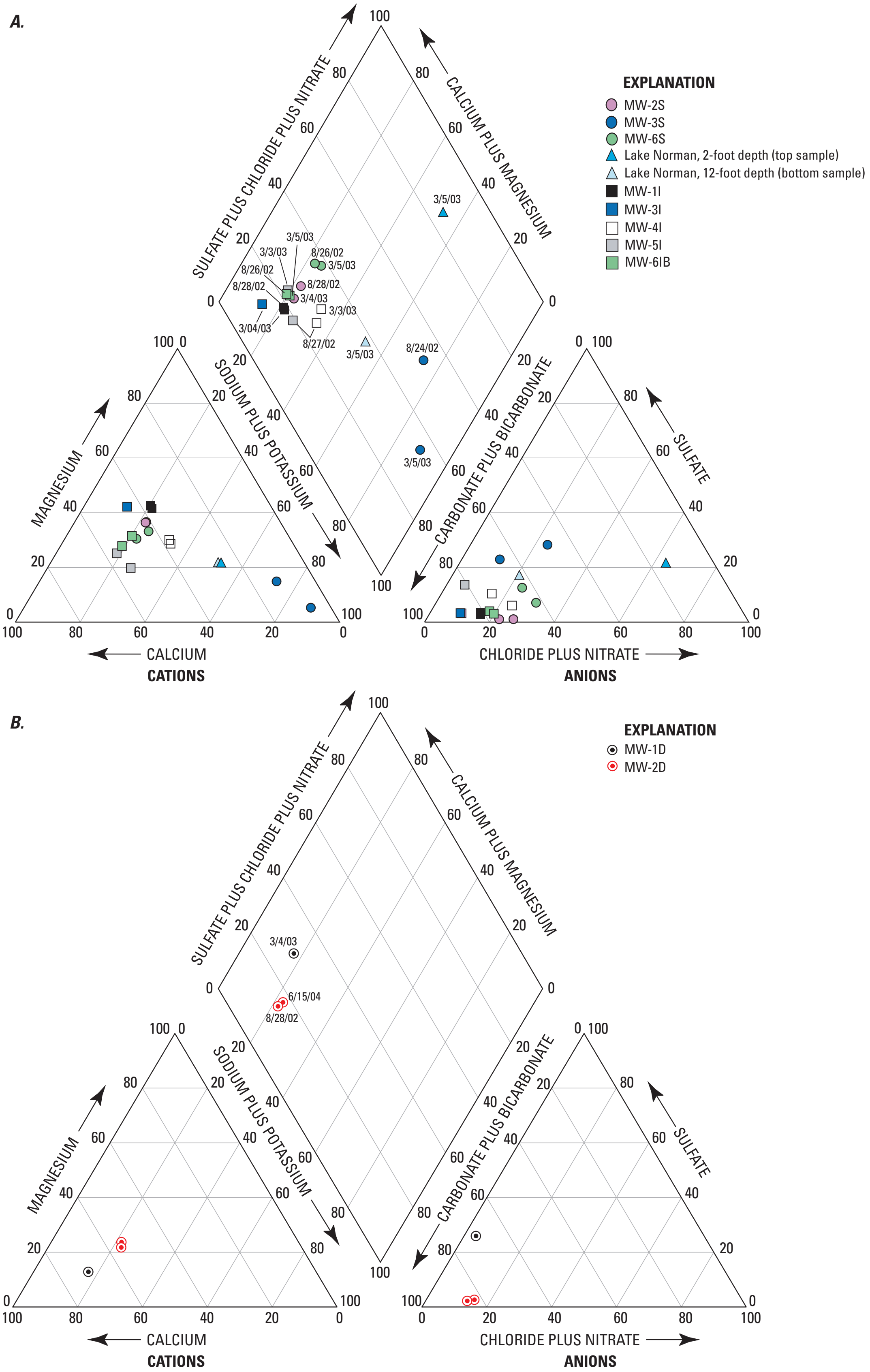

Figure 31. Piper diagrams showing the distribution of major ions in periodic ground-water and surface-water samples from the *(A)* regolith and transition-zone wells and Lake Norman, and *(B)* open-borehole bedrock wells at the Langtree Peninsula research station, North Carolina.

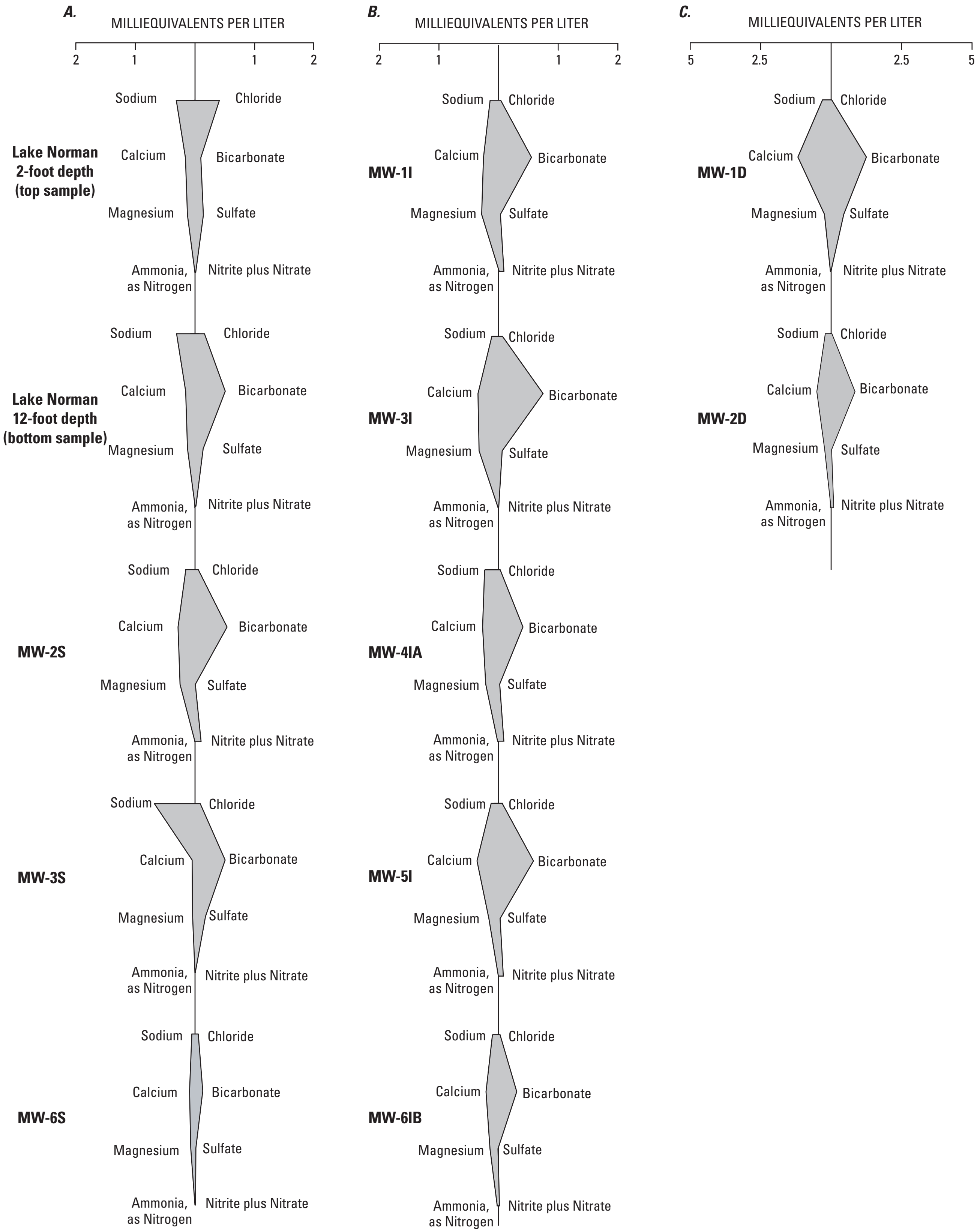

Figure 32. Stiff diagrams showing major ion milliequivalents in water samples collected from *(A)* the regolith wells and Lake Norman, *(B)* the transition-zone wells, and *(C)* the open-borehole bedrock wells at the Langtree Peninsula research station, North Carolina, March 2003.

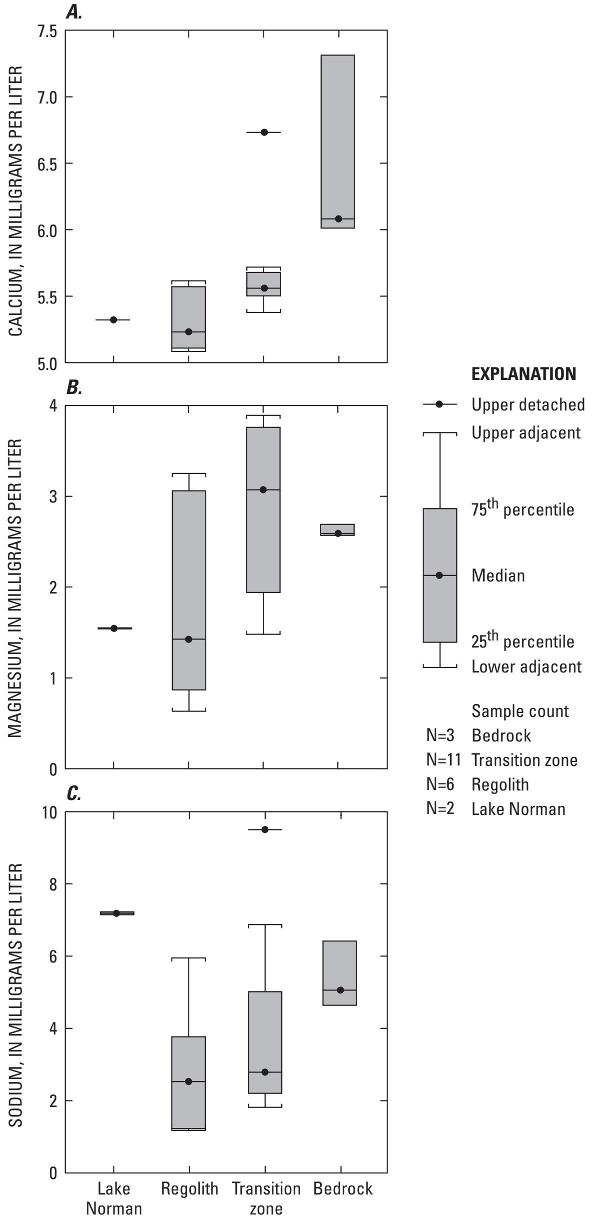

Figure 33. Box plots showing range, median, and quartile statistical values for *(A)* calcium, *(B)* magnesium, and *(C)* sodium in the wells and Lake Norman recorded during periodic sampling events at the Langtree Peninsula research station, North Carolina.

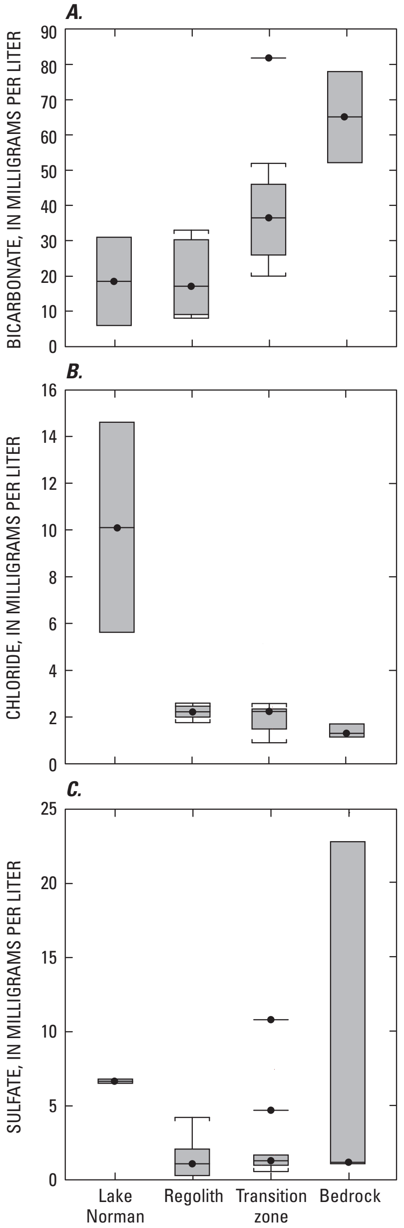

Figure 34. Box plots showing range, median, and quartile statistical values for *(A)* bicarbonate, *(B)* chloride, and *(C)* sulfate in the wells and Lake Norman recorded during periodic sampling events at the Langtree Peninsula research station, North Carolina.

types in wells MW-3S and MW-6S, both located in discharge areas near the lake (fig. 5), were sodium-bicarbonate and calcium/magnesium-bicarbonate, respectively (figs. 31, 32). Water samples collected from regolith well MW-3S had a dominant sodium cation, which was similar to the top samples collected from Lake Norman and likely indicates interaction of shallow ground water with the lake and potential effects of the nearby septic field. Restrooms used at the Davidson College Lake Campus are located within a few hundred feet of well MW-3S. Although well MW-6S also is located near the lake, samples from this well contained similar concentrations of calcium and magnesium. There was no apparent trend in ground-water-sample chemistry from recharge to discharge areas in the regolith part of the ground-water system. (Two shallow regolith wells, MW-1S and -5S, were dry at the time of sampling.)

Two Lake Norman samples differ in water type (fig. 32*A*). The top sample is a sodium-chloride type water, and the bottom sample is a sodium/magnesium-bicarbonate type water. The top sample water type seems to be affected by surface runoff and possibly septic discharge, as indicated by low bicarbonate and elevated sodium concentrations. The bottom sample water type is influenced more by ground water, as indicated by the increase in bicarbonate.

Transition-Zone Ground Water

Ground-water-quality samples from all five transition-zone wells at the LPRS had similar water types—calcium bicarbonate and calcium-magnesium bicarbonate (figs. 31, 32). Ground water from this zone generally was similar to that from the shallow regolith well (MW-2S) and the two bedrock wells (MW-1D and MW-2D) sampled. There was no apparent trend in ground-water chemistry from recharge to discharge areas in the transition zone.

Bedrock Ground Water

Water from two of the open-borehole bedrock wells was generally calcium-bicarbonate type (figs. 31, 32). The bedrock ground-water samples were collected near the most transmissive fracture zone in each well. A comparison of the shallow (regolith and transition zone) and deeper (bedrock) parts of the ground-water system indicates increased pH and lower DO concentrations with depth (fig. 30). Analytical results indicate that samples from the bedrock wells had higher concentrations of fluoride, calcium, sulfate, molybdenum, uranium, radon, and arsenic than samples from the shallower wells (Howe and others, 2002, 2003). Samples from bedrock wells also had high pH, which supports the concept of increased residence time for mineral dissolution within the quartz diorite.

Radiochemicals and Radon Gas

Radiochemicals and radon gas are of interest in igneous and metamorphic rocks because natural concentrations can be elevated. The concentration of radon gas in ground water has been the subject of much consideration by the U.S. Environmental Protection Agency (USEPA). The proposed Federal standards for public drinking-water supplies provide two options for the maximum allowable level of radon in community water systems (CWSs)—an untreated maximum contaminant level (MCL) of 300 picocuries per liter (piC/L) and a proposed alternative MCL (AMCL) of 4,000 piC/L (U.S. Environmental Protection Agency, 2000b). The AMCL would apply to States and CWSs for which a multimedia mitigation program has been developed to address radon concentrations in indoor air. Radon 222 samples from all components of the LPRS ground-water system (regolith, transition zone, and bedrock) in the mafic quartz diorite rock type were low compared with radon concentrations in the more granitic (felsic) rock types, such as at Lake Wheeler Road research station (Chapman and others, 2005). Samples collected at the Lake Wheeler Road research station had radon 222 concentrations ranging from about 400 piC/L in surface water to more than 12,000 piC/L in the transition zone (Howe and others, 2003, 2004). By contrast, radon 222 concentrations in LPRS wells ranged from about 20 to 500 piC/L. Gross alpha concentrations did not exceed the recommended drinking-water standard of 15 piC/L (U.S. Environmental Protection Agency, 2000a; North Carolina Department of Environment and Natural Resources, Division of Water Quality, 2002) and ranged from 0.3 to 1.6 piC/L (Howe and others, 2003, 2004).

Nutrients

Nitrate concentrations generally were low in ground-water samples collected at the LPRS and ranged from about 0.07 to 1.6 mg/L (Howe and others, 2003, 2004). Three transition-zone wells—MW-3I, 4I, and 5I—had nitrate concentrations greater than 1 mg/L. These slightly elevated concentrations may be related to the nearby Davidson College Lake Campus restroom septic system or to previous agricultural activities at the site.

Comparisons with Regional Ground-Water-Quality Data

To gain a perspective on how water-quality data from the LPRS compare with regional water quality, a summary of analytical data for bedrock wells tapping the metaigneous, intermediate (MII) regional hydrogeologic unit (Daniel and

Payne, 1990) was compiled from the arsenic database at the North Carolina Department of Environment and Natural Resources, Division of Water Quality, Mooresville Regional Office (Chuck Pippin, North Carolina Division of Water Quality, written commun., 2005). From the analyses of 326 water-quality samples collected from the MII unit, mean concentrations were 27 mg/L for calcium, 5 mg/L for chloride, 0.06 mg/L for fluoride, and 0.4 mg/L for iron. Laboratory results of pH indicated an average of about 7.2, and mean alkalinity was about 70 mg/L. Bedrock samples collected at the LPRS had mean field readings and ion concentrations of 13 mg/L for calcium, 1.4 mg/L for chloride, <0.1 mg/L for fluoride, <10 micrograms per liter (µg/L) for iron, 7.2 units for pH, and 56 mg/L for alkalinity.

Comparison of Ground-Water Chemistry to Rock Chemistry

Mean whole-rock analyses from quartz diorite core samples (three samples) were compared to mean dissolved ions and trace metals in ground-water samples collected from bedrock wells MW-1D and MW-2D (four samples total; table 5). The dominant major ion species from selected core samples (means) were silica (54 percent), followed by aluminum (18 percent), iron (9.3 percent), calcium (8.7 percent), magnesium (4.6 percent), and sodium (3.1 percent; table 5). Compared to the geochemical characteristics of the bedrock ground-water samples collected from well MW-1D (one sample) and MW-2D (3 samples), the major dissolved ions in ground water are silica (36 mg/L), calcium (13 mg/L), and sodium (5.2 mg/L). Substantial concentrations of the following trace metals also were detected in the bedrock ground-water samples at the LPRS, including molybdenum (8.5 µg/L), aluminum (7.6 µg/L), and barium (4.8 µg/L).

Summary

The Langtree Peninsula research station (LPRS), located on the Davidson College Lake Campus on Lake Norman in Iredell County, North Carolina, is representative of the meta-igneous, intermediate hydrogeologic unit within the Charlotte

Table 5. Analytical results of arithmetic mean whole-rock core composition from three quartz diorite bedrock cores and arithmetic mean dissolved major ion concentrations in five bedrock ground-water samples collected from wells MW-1D and MW-2D at the Langtree Peninsula research station, North Carolina.

[MW, monitoring well; %, percentage of sample weight; ppm, parts per million; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; na, not analyzed]

Composition of whole-rock quartz diorite core samples[a]		Major ion concentrations in ground water (bedrock wells MW-1D and MW-2D)	
Species or metal	Weight, in percent (%) or concentration (ppm)	Dissolved ion	Concentration (mg/L or µg/L)
Silica	53.9 %	Silica	36 mg/L as SiO_2
Aluminum	17.7 %	Aluminum	7.6 µg/L as Al
Calcium	8.7 %	Calcium	13 mg/L as Ca
Magnesium	4.6 %	Magnesium	2.6 mg/L as Mg
Sodium	3.1 %	Sodium	5.2 mg/L as Na
Potassium	0.8 %	Potassium	2.0 mg/L as K
Iron	9.3 %	Iron	< 10 µg/L as Fe
Manganese	0.2 %	Manganese	0.5 µg/L as Mn
Chromium	na	Chromium	0.9 µg/L as Cr
Silver	< 1 ppm	Silver	< 0.2 µg/L as Ag
Barium	155 ppm	Barium	4.8 µg/L as Ba
Cobalt	na	Cobalt	0.06 µg/L as Co
Copper	61 ppm	Copper	0.5 µg/L as Cu
Molybdenum	1.3 ppm	Molybdenum	8.5 µg/L as Mo
Nickel	21 ppm	Nickel	0.6 µg/L as Ni
Antimony	< 2 ppm	Antimony	1.3 µg/L as Sn
Uranium	3.5 ppm	Uranium	1.8 µg/L as U
Zinc	76 ppm	Zinc	1.4 µg/L as Zn

[a] J. Wright Horton, Jr., U.S. Geological Survey, Reston, Virginia, written commun., 2001.

lithotectonic belt/Charlotte terrane in the Piedmont region. This research station was established as part of the cooperative Piedmont and Mountains Resource Evaluation Program between the North Carolina Division of Water Quality and the U.S. Geological Survey. The dominant rock type at the LPRS is a mafic quartz diorite having steeply dipping foliation (60°) and variable depth to consolidated bedrock from about 24 to 76 ft. Thickness of the delineated transition zone was highly variable, from about 1 to 20 ft.

Primary and secondary foliations are present in the quartz diorite at the LPRS, both having a mean strike of about N. 12° E. and a mean dip of about 60° in opposite directions to the southeast (primary) and the northwest (secondary). The quartz diorite rock type also is cut by granitic dikes ranging in thickness from about 2 to 50 ft, with a mean strike of N. 20° W. and a mean dip angle of 66° to the southwest.

Bedrock well yields ranged from about 3 to 50 gal/min. The highest yield of 50 gal/min is from shallow transition-zone fractures at a depth of 59 ft. Delineated bedrock fractures dominantly are low angle (likely stress relief) and are open to partially open at depths up to 479 ft. Open (primary) fracture sets measured in the bedrock wells have orientations of N. 49–70° E. dipping 10–24° SE., N. 17 ° E. dipping 10° SE., and N. 20–21° W. dipping 5–28° NE.-SW.

Ground-water flow at the LPRS generally supports the historical conceptual models developed in previous studies. General ground-water flow was toward a surface-water drainage—Lake Norman. Additionally, the vertical gradient directions at well cluster MW-6 supported earlier concepts of upward movement of ground-water in discharge areas. In the recharge areas near clusters MW-2 and MW-1, vertical gradients were downward, as expected from the conceptual model. Vertical gradients at the mid-slope clusters MW-4 and MW-5 also were downward. Flat hydraulic gradients in the regolith zone of the ground-water system were noted at distances within 300 ft of the lake shore, indicating potential interactions between ground water and surface water in these areas.

The ground-water quality data (both continuous monitoring and periodic sampling) collected at the LPRS aid in understanding how various components of the ground-water system interact. Overall geochemistry was similar among major ions in ground water from the regolith, transition zone, and bedrock and was identified as calcium-bicarbonate water type. Continuous ground-water-quality data documented seasonal fluctuations and changes during short-term periods of increased rainfall. During increased rainfall recorded during June–July 2003, water-quality changes in regolith well MW-2S showed decreasing specific conductance and pH, and increasing dissolved-oxygen concentrations, which likely resulted from the infiltration of acidic and dilute rainfall. Comparison of ground-water temperatures to air temperatures indicated a potential seasonal lag of about 5 months, which may be indicative of slow, seasonal infiltration of recharge to the shallow part of the ground-water system.

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Appendixes

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1. **Geologic core descriptions from the Langtree Peninsula research station.**

    (A) Corehole CH-1.
    (B) Corehole CH-2.
    (C) Corehole CH-3.
    (D) Corehole CH-4.
    (E) Corehole CH-5.
    (F) Corehole CH-6.
    (G) Corehole CH-7.

2. **Geophysical logs and images showing lithologies and fracture zones tapped by bedrock wells.**

    (A) Well MW-1D (corehole CH-1).
    (B) Well MW-2D (coreholes CH-2 and CH-3).
    (C) Well MW-4D (corehole CH-5).
    (D) Well MW-5D (corehole CH-6).
    (E) Well MW-6D (corehole CH-7).

Abbreviations used in Appendix 1:

Dry/Wet

D, dry
M, moist, but no visable water
W, wet

Dry Strength

N, none — The dry specimen crumbles into powder with mere pressure of handling.
L, low — The dry specimen crumbles into powder with some finger pressure.
M, medium — The dry specimen breaks into pieces or crumbles with considerable finger pressure.
H, high — The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface.
VH, very high — The dry specimen cannot be broken between the thumb and a hard surface.

Dilatancy

N, none — No visible change in the specimen.
S, slow — Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing.
R, rapid — Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing.

Toughness

L, low — Only slight pressure is required to roll the thread near the plastic limit. The thread and the lump are weak and soft.
M, medium — Medium pressure is required to roll the thread to near the plastic limit. The thread and the lump have medium stiffness.
H, high — Considerable pressure is required to roll the thread near the plastic limit. The thread and the lump have very high stiffness.

Plasticity

N, nonplastic — A 3-millimeter thread cannot be rolled at any water content.
L, low — The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit.
M, medium — The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit.
H, high — It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.

Unified Class *(Unified Soil Classification System)*

ML — silt
CL — clay
MH — silt of high plasticity, elastic silt

Dip Angle

V — vertical
SV — subvertical
M — medium
SH — subhorizontal
H — horizontal

REGOLITH LOG SHEET **PAGE 1 OF 9**

PROJECT:	LANGTREE PENINSULA	**DRILLING METHOD:**	WIRELINE CORING
BORING ID:	CH-1	**CORE DIAMETER:**	2.25"
LOGGED BY:	PIPPIN/CASH/HELLER	**LATITUDE:**	35 31 40.92
BEGIN DATE:	8/22/2000	**LONGITUDE:**	80 52 46.80
END DATE:	10/4/2000	**LAND SURFACE ELEVATION:**	814.5'

Color descriptions referenced to Munsell soil color charts.

[ft bls, feet below land surface)

INTERVAL (ft bls)	RECOVERY	SOIL HORIZON	DRY/WET	COLOR	DRY STRENGTH	DILATANCY	TOUGHNESS	PLASTICITY	UNIFIED CLASS	DESCRIPTION	Ground-Water Zon
0 TO 1		A	D	10R/4/6 RED	H	N	M	M	CL	FIRM, HOMOGENEOUS TO BLOCKY, SILTY CLAY W/ ROOT FRAGS	REGOLITH (residuum)
1 TO 4	(0-3) 3'	B	D	2.5YR4/8 RED	M	N	L	N	MH	FIRM, HOMOGENEOUS TO BLOCKY, CLAYEY SILT TO SILTY CLAY. SOME YELLOWISH-RED ZONES AND MINOR ROOT FRAGS	REGOLITH (residuum)
4 TO 7	(3-8) 4'	B	D	5YR4/6 YELLOW RED	L to M	S	L	N	ML	FIRM, HOMOGENEOUS TO LENSED, CLAYEY SILT W/ MICA AND MORE COMMON YELLOWISH RED ZONES	REGOLITH (residuum)
7 TO 8		B-C	D	5YR 5/8 YELLOW RED	L to M	S	L	N	ML	AS ABOVE W/ MORE DEFINED AND COMMON YELLOWISH ZONES	REGOLITH (residuum)
8 TO 17.5	(8-13) 3'	C	M	5YR 5/8 YELLOW RED	L to M	S	L	N	ML	SOFT, LENSED TO BLOCKY, SOFT CLAYEY SANDY SILT W/ MINOR FE-MN OXIDES	REGOLITH (residuum)

UNIFIED CLASS: CL, clay; MH (American Society for Testing and Materials, 2004)

REGOLITH LOG SHEET **PAGE 2 OF 9**

PROJECT: LANGTREE PENINSULA **DRILLING METHOD:** WIRELINE CORING
BORING ID: CH-1
LOGGED BY: PIPPIN/CASH/HELLER
BEGIN DATE: 8/22/2000 **CORE DIAMETER:** 2.25"
END DATE: 10/4/2000
Color descriptions referenced to Munsell soil color charts.

INTERVAL	RECOVERY	SOIL HORIZON	DRY/WET	COLOR	DRY STRENGTH	DILATANCY	TOUGHNESS	PLASTICITY	UNIFIED CLASS	DESCRIPTION	Ground-Water Zone
13 TO 17.5	(13-18) 2'	C	M	7.5YR 5/8 STRONG BROWN	L	S	L	N	ML	FIRM, LENSED TO BLOCKY SANDY CLAYEY SILT W/ SOME WEAK RED OXIDATION ZONES, MICACEOUS ZONES AND MINOR TO MOD. BLACK MN-OXIDES	REGOLITH (residuum)
17.5 TO 27.5	(18-23) 4' (28-33) 3'	C	M	7.5 YR 5/6 STRONG BROWN	L	S	L	N	ML	FIRM, STRATIFIED TO LENSED, FIRM CLAYEY SILT W/ MORE ABUNDANT MICA AND MN-OXIDES...MICA INCREASES W/ DEPTH	REGOLITH (residuum)
27.5 TO 38.5	(33-38) 4'	C	M	7.5 YR 5/8 STRONG BROWN	L	S	L	N	ML	SOFT TO FIRM, LENSED SANDY CLAYEY SILT SAPROLITE W/ ABUNDANT WHITE CLAY AFTER FELDSPAR AND MN-OXIDES (RELICT PHANERITIC TEXTURE - COARSE GR. DIORITE)	REGOLITH (saprolite)
38.5 TO 41	(38-41) 2'	C	M	7.5 Y 5/4 LIGHT OLIVE BROWN	L	S	L	N	ML W/ SAND	FIRM, LENSED SANDY SILT W/ NO MN-OXIDES GRADING INTO PWR (SAPROLITIC FINE GR. DIORITE)	TRANSITION ZONE
TO										BEDROCK ENCOUNTERED AT 41' - SEE BEDROCK LOG SHEETS FOR REMAINDER OF LOG	

BEDROCK LOG SHEET

PAGE 3 OF 9

PROJECT: LANGTREE

DRILLING METHOD: WIRELINE CORING

BORING ID: CH-1

LOGGED BY: HELLER/CASH

BEGIN DATE: 8/24/2000

CORE DIAMETER: 2.25"

END DATE: 10/04/2000

LITHOLOGIC DESCRIPTION			FRACTURE INFO					
INTERVAL	**RECOVERY**	**DESCRIPTION**		**# ANNEALED**	**# OPEN**	**H20 BEARING**	**MINERALS**	**Ground-Water Zone**
41	1.5'	WEATHERED, FINE TO MED. GR., DARK GRAY TO OLIVE GRAY, MODERATELY FOLIATED QUARTZOFELDSPATHIC BIOTITE, HORNBLENDE GNEISS (FOLIATED QUARTZ DIORITE) - FOLIATION IS SUB-VERTICAL.	**V**				BIOTITE	TRANSITION ZONE
			SV	2				
TO			**M**					
			SH					
43			**H**			43-		
43	4.2'	WEATHERED TO FRESH, WEAKLY FOLIATED, FINE TO MED. GR., DARK GREENISH-GREY QUARTZOFELDSPATHIC BIOTITE- HORNBLENDE GNEISS (FOLIATED QUARTZ DIORITE). BECOMES FRESH AT 44.2'. FRESH COARSE GR., WHITE TO GREENISH-GRAY TO BLACK, MASSIVE QUARTZ DIORITE W/ ACCE	**V**		1	44.5	BIOTITE	TRANSITION ZONE
			SV		1			
TO			**M**		1	45.5		
			SH		9	46.5		
48			**H**		4	48.5		
48	4.8'	FRESH WEAKLY FOLIATED TO MASSIVE, DARK GREENISH-GREY, FINE TO MED. GR. QUARTZ DIORITE.	**V**				BIOTITE	TRANSITION ZONE
			SV	1	1	50.0		
TO			**M**	1	3	50.5		
			SH			51.0		
53			**H**		4			
53	4.7'	SAME AS ABOVE UNTIL 55.5' - SUBVERTICAL CONTACT W/ RELATIVELY FRESH, COARSE GR., MASSIVE QUARTZ DIORITE W/ ACCESSORY PYRITE - ROCK BECOMES MORE WEATHERED BEGINNING AT 57'	**V**				BIOTITE QUARTZ	TRANSITION ZONE
			SV	1				
TO			**M**	3				
			SH			56.5		
58			**H**		5	58.0		
58	4.2	CONTINUED WEATHERED APPEARANCE UNTIL 58.5' - THEN, FRESH, COARSE GR. MASSIVE QUARTZ DIORITE. CHLORITE-EPIDOTE REMINERALIZATION AFTER HORNBLENDE OBSERVED.	**V**			58.5	BIOTITE	BEDROCK
			SV	1				
TO			**M**	3				
			SH					
63			**H**		2			

BEDROCK LOG SHEET **PAGE 4 OF 9**

PROJECT: LANGTREE **DRILLING METHOD:**
BORING ID: CH-1 WIRELINE CORING
LOGGED BY: HELLER/CASH
BEGIN DATE: 8/24/2000 **CORE DIAMETER:** 2.25"
END DATE: 10/04/2000

LITHOLOGIC DESCRIPTION			FRACTURE INFO					
INTERVAL	RECOVERY	DESCRIPTION		# ANNEALED	# OPEN	H20 BEARING	MINERALS	Ground-Water Zon
63	4.7	SAME AS ABOVE	V	8			BIOTITE	BEDROCK
TO			SV	2				
			M	3				
			SH	1				
68			H	1	4			
68	5.3	SAME AS ABOVE W/ FINE TO MED. GR. ENCLAVES OF MORE HORNBLENDE-RICH ROCK @71-72. SMALL PYRITE-BEARING VEIN AT 71.	V			68-	BIOTITE QUARTZ	BEDROCK
TO			SV			69		
			M	8				
			SH	4		70-		
73			H	1		72		
73	5.3	SAME AS ABOVE - HORNBLENDE-RICH ENCLAVES MORE ABUNDANT QUARTZ AND EPIDOTE VEINING OBSERVED FROM 73' TO 75'. MINOR BRITTLE REVERSE FAULT @74'-75'. PYRITE, EPIDOTE AND QUARTZ BECOMING MORE COMMON (FRESHER ROCK?)	V				BIOTITE QUARTZ	BEDROCK
TO			SV	2				
			M	8				
			SH	1				
78			H		1			
78	5.2	SAME AS ABOVE	V				BIOTITE	BEDROCK
TO			SV	1				
			M	1				
			SH		2			
83			H	1	2			
83	4.8	FROM 83' TO 85' FINE GR. ENCLAVE? OF FINE GR., GRAY-BLACK, MODERATELY WELL FOLIATED QUARTZOFELDSPATHIC HORNBLENDE GNEISS (FOLIATED DIORITE?). 85' TO 88' SAME AS PREVIOUS INTERVAL.	V	1			BIOTITE QUARTZ EPIDOTE	BEDROCK
TO			SV					
			M	2				
			SH					
88			H	3				

BEDROCK LOG SHEET

PAGE 5 OF 9

PROJECT: LANGTREE

DRILLING METHOD: WIRELINE CORING

BORING ID: CH-1

LOGGED BY: HELLER/CASH

BEGIN DATE: 8/24/2000

CORE DIAMETER: 2.25"

END DATE: 10/04/2000

LITHOLOGIC DESCRIPTION			FRACTURE INFO					
INTERVAL	**RECOVERY**	**DESCRIPTION**		**# ANNEALED**	**# OPEN**	**H20 BEARING**	**MINERALS**	**Ground-Water Zone**
88	5.2	FRESH, COARSE GR. MASSIVE TO WEAKLY FOLIATED (MOD. DIP) QUARTZ DIORITE W/ ACCESSORY PYRITE, EPIDOTE AND CHLORITE. FRACTURES ARE MINERALIZED W/ QTZ, EPIDOTE AND CHLORITE?. MOST ARE ANNEALED BUT SOME PARTIALLY OPEN >1 MM APERATURE. 10 CM WIDE QUARTZ VEIN	**V**				BIOTITE QUARTZ	BEDROCK
TO			**SV**	3				
			M	7				
			SH					
93			**H**					
93	5.3	CONTINUATION OF QUARTZ VEIN TO 93.5' REMAINDER OF INTERVAL SAME AS ABOVE. TWO VERTICLE FRACTURES IN THE 94' TO 95.5' INTERVAL. THE REST OF THE FRACTURES ARE H. POSSIBLE ATER BEARING ZONE @96'.	**V**				BIOTITE	BEDROCK
TO			**SV**	1				
			M					
			SH		1	96?		
98			**H**	1	4			
98	4.6	SAME AS ABOVE, FOLIATION MORE PRONOUNCED, BUT STILL WEAK (MOD. DIP). EPIDOTE MORE ABUNDANT. 100.5' TO 102' - FINE GR., GRAY-BLACK, MOD. FOLIATED (MOD. DIP) BIOTITE HORNBLENDE GNEISS - APPEARS TO BE MORE MAFIC. CONTACTS ARE CLEAN W/ MOD. DIP. QTZ. DIOR	**V**				BIOTITE EPIDOTE QUARTZ	BEDROCK
TO			**SV**	2				
			M	2				
			SH		1			
103			**H**	2	4			
103	5.5	SAME AS ABOVE	**V**				BIOTITE	BEDROCK
TO			**SV**	1				
			M	1				
			SH	2	2			
108			**H**		3			
108	5.5	SAME AS ABOVE - LARGE, NEARLY VERTICAL LEUCOCRATIC FRACTURE/VEIN RANGING FROM 1 TO 10 MM IN WIDTH RUNNING ALMOST ENTIRE LENGTH OF INTERVAL.	**V**				BIOTITE QUARTZ	BEDROCK
TO			**SV**	3				
			M	3				
			SH	2				
113			**H**	2	3			

BEDROCK LOG SHEET	**PAGE 6 OF 9**
PROJECT: LANGTREE	**DRILLING METHOD:**
BORING ID: CH-1	WIRELINE CORING
LOGGED BY: HELLER/CASH	
BEGIN DATE: 8/24/2000	**CORE DIAMETER:** 2.25"
END DATE: 10/04/2000	

LITHOLOGIC DESCRIPTION			FRACTURE INFO					
INTERVAL	RECOVERY	DESCRIPTION		# ANNEALED	# OPEN	H20 BEARING	MINERALS	Ground-Water Zon
113 TO 118	4.2	SAME AS ABOVE. LEUCOCRATIC VEIN EXTENDS TO 114'. FINER GR. INTERVAL W/ MORE AMPHIBOLE FROM 114' TO 116'.	V				BIOTITE QUARTZ	BEDROCK
			SV	3				
			M	2				
			SH		1			
			H	1	3			
118 TO 123	5	SAME AS ABOVE, LEUCOCRATIC VEIN FROM 122' TO 123'.	V			118?	BIOTITE	BEDROCK
			SV			119?		
			M	4				
			SH		2			
			H		8			
123 TO 128	5.3	SAME AS ABOVE TO 126.5' W/ ENCLAVES OF FINER GR., AMPHIBOLE-RICH ROCK. FROM 126.5' TO 128.5' FINER GR. AMPHIBOLE-RICH ENCLAVE? W/ LARGE PLAGIOCLASE FELDSPAR GRAINS. QUARTZ VEINING AND MINOR REVERSE FAULTS IN THIS INTERVAL.	V				BIOTITE	BEDROCK
			SV					
			M	2				
			SH	5				
			H	1	3			
128 TO 133	4.8	SAME AS ABOVE W/ SEVERAL HORIZONTAL TO SUBHORIZONTAL FRACTURES. 2 VERTICAL QUARTZ VEING APPX. 2-2.5 FT IN LENGTH IN THE 129 TO 132' INTERVAL.	V				BIOTITE	BEDROCK
			SV					
			M	4				
			SH		3			
			H		2			
133 TO 138	4.7	SAME AS ABOVE - SOME QTZ VEINING IN THE 136 TO 138 INTERVAL.	V				BIOTITE	BEDROCK
			SV					
			M	2				
			SH		2			
			H		3			

BEDROCK LOG SHEET **PAGE 7 OF 9**

PROJECT: LANGTREE **DRILLING METHOD:** WIRELINE CORING
BORING ID: CH-1
LOGGED BY: HELLER/CASH
BEGIN DATE: 8/24/2000 **CORE DIAMETER:** 2.25"
END DATE: 10/04/2000

LITHOLOGIC DESCRIPTION			FRACTURE INFO					
INTERVAL	RECOVERY	DESCRIPTION		# ANNEALED	# OPEN	H20 BEARING	MINERALS	Ground-Water Zone
138	5	SAME AS ABOVE. SOME QUARTZ VEINING, SMALL VUGS IN QUARTZ AT 141.5. FINE GR. ENCLAVES OF MORE MAFIC ROCK THROUGHOUT 5' INTERVAL	V				BIOTITE	BEDROCK
TO			SV					
			M	4				
			SH	3	1			
143			H	2	3			
143	5.2	COARSE GR. DIORITE W/ FINE GR. ENCLAVES AT 145.5 AND 147.5 WEAK MOD. DIPPING FOLIATION DEFINED BY ALIGNED AMPHIBOLE.	V				BIOTITE	BEDROCK
TO			SV					
			M	1				
			SH		3			
148			H	2	1			
148	4.2	SAME AS ABOVE. ENCLAVE (XENOLITH?) TO 151'. FROM 151' TO 153' COARSE GR. FELDSPAR AND FINE GR. AMPHIBOLE. FOLIATION OBSERVED FROM 147.5 TO 151. FRACTURING IN THE 152-153 INTERVAL SHOWS SOME MINOR DISCOLORATION	V					BEDROCK
TO			SV					
			M					
			SH		2			
152			H		2			
152	4.9	COARSE FELDSPAR ZONE THROUGH 154.5. FINE GR. AMPHIBOLE(?) RICH ZONE THROUGH 156.5. FOLIATION WELL DEVELOPED THROUGH 156. ROCK BECOMES MORE MASSIVE W/ COARSER FELDSPAR AGAIN THROUGH 158.	V					BEDROCK
TO			SV					
			M					
			SH					
157			H	2	3			
157	6.4	FRESH, PORPHYRYTIC, GRAY-BLACK BIOTITE HORNBLENDE GNEISS CONT'D. ZONED AND IN SOME CASES TWINNED FELDSPAR PORPHYROCLASTS. FELDSPAR-RICH XENOLITHS(?) ALSO OBSERVED. FOLIATION BECOMES MORE PRONOUNCED W/ DEPTH, VERY PRONOUNCED AT 162. AT 162 - CONTACT W/	V				BIOTITE	BEDROCK
TO			SV					
			M	1				
			SH	2				
163			H	1	1			

BEDROCK LOG SHEET **PAGE 8 OF 9**

PROJECT: LANGTREE

DRILLING METHOD: WIRELINE CORING

BORING ID: CH-1

LOGGED BY: HELLER/CASH

BEGIN DATE: 8/24/2000

CORE DIAMETER: 2.25"

END DATE: 10/04/2000

LITHOLOGIC DESCRIPTION				FRACTURE INFO				
INTERVAL	RECOVERY	DESCRIPTION		# ANNEALED	# OPEN	H20 BEARING	MINERALS	Ground-Water Zon
163	5	FINE GR., MOD. FOLIATED BT. HBL GNEISS W/ ACCESSORY EPIDOTE W/ 10-20 MM BT-GRANITIC ORTHOGNEISS. FOLIATION IS SV TO V.	V				QUARTZ	BEDROCK
TO			SV					
			M	1				
			SH					
168			H	1	3			
168	4	BT-HBL GNEISS W/ EPIDOTE TO 169'. BT GRANITIC GNEISS FROM 169. CONTACT IS INTERLAYERED (INTUSIVE?) - FOLIATION IS SV	V				QUARTZ	BEDROCK
TO			SV					
			M	1				
			SH					
173			H	1	4			
173	5.7	BT GRANITIC GNEISS CONT'D W/ MOD TO SV CONTACT W/ BT HBL GNEISS @176. 1-2 CM WIDE REACTION RIM ALONG CONTACT.	V				BIOTITE	BEDROCK
TO			SV					
			M	1				
			SH					
178			H		7			
178	5.2	BT HBL GNEISS T0 180.5. W/ ABUNDANT ACCESSORY PYRITE. PYRITE AND EPIDOTE MOR ABUNDANT NEAR CONTACT. FROM 180.5 ON, BT-GRANITIC GNEISS W/ XENOLITH(?) OR BT HBL GNEISS @182.5. FRACTURE AT 182 COATED W/ UNKNOWN WHITE MINERAL W/ BOTRYOIDAL(?) SHAPE.	V				BIOTITE	BEDROCK
TO			SV					
			M	1				
			SH					
183			H		4			
183	5.3	BT GRANITIC GNEISS TO 185.5 - PORPHYRITIC BT HBL GNEISS FROM 185.5 ON. SV INTRUSIVE CONTACT. FELDSPAR IN BT HBL GNEISS ARE COARSER GR. NEAR CONTACT.	V					BEDROCK
TO			SV					
			M					
			SH					
188			H		4			

BEDROCK LOG SHEET **PAGE 9 OF 9**

PROJECT: LANGTREE

DRILLING METHOD: WIRELINE CORING

BORING ID: CH-1

LOGGED BY: HELLER/CASH

BEGIN DATE: 8/24/2000

CORE DIAMETER: 2.25"

END DATE: 10/04/2000

LITHOLOGIC DESCRIPTION **FRACTURE INFO**

INTERVAL	RECOVERY	DESCRIPTION		# ANNEALED	# OPEN	H20 BEARING	MINERALS	Ground-Water Zon
188	5.3	GRAY-BLACK, PORPHYRITIC BT HBL GNEISS	V					BEDROCK
TO			SV					
			M		2			
			SH		1			
193			H					
193	4	PORPHYRITIC BT HBL GNEISS W/ NEARLY VERTICAL STRINGERS (1 TO 20 MM) OR BT GRANITIC GNEISS. FELDSPAR "PHENOCRYSTS" UP TO 5 MM IN LENGTH.	V					BEDROCK
TO			SV					
			M					
			SH		3			
198			H		2			
198	6	SAME AS ABOVE W/ BT GRANITIC GNEISS INTRUSIONS THICKENING UP TO 50 MM. BT HBL GNEISS APPEARS TO BE RATHER MASSIVE IN THIS INTERVAL.	V					BEDROCK
TO			SV					
			M					
			SH					
203			H		2			
203	5.2	SAME AS ABOVE W/ THINNER BT GRANITIC INTRUSIONS FROM 203 O 205.5 - THICKER AGAIN FROM 205.5 TO 208	V				QUARTZ	BEDROCK
TO			SV					
			M					
			SH					
208			H	1	3			
208	1	SAME AS ABOVE	V					BEDROCK
TO			SV					
			M					
			SH					
209			H					

REGOLITH LOG SHEET **PAGE 1 OF 2**

PROJECT: LANGTREE PENINSULA
DRILLING METHOD: WIRELINE CORING
BORING ID: CH-2
CORE DIAMETER: 2.25"
LOGGED BY: HELLER
LATITUDE: 35 31 32.74
BEGIN DATE: 10/17/2000
LONGITUDE: 80 52 40.48
END DATE: 10/24/2000
LAND SURFACE ELEVATION: 797.13'

Color descriptions referenced to Munsell soil color charts.

INTERVAL	RECOVERY	SOIL HORIZON	DRY/WET	COLOR	DRY STRENGTH	DILATANCY	TOUGHNESS	PLASTICITY	UNIFIED CLASS	DESCRIPTION	Ground-Water Zon
0 TO 0.5	(0-3) 2.9'	A	D	5YR 4/6 YELLOW RED	M	N	M	L	MH	FIRM, MASSIVE MODERATELY CEMENTED SANDY CLAYEY SILT W/ SUBANGULAR QUARTZ COBBLES AND ROOT FRAGS	REGOLITH (residuum)
0.5 TO 1		A	D	2.5YR 4/6 RED	M TO H	N	M	L TO M	CL	HARD, MASSIVE STRONGLY CEMENTED SILTY CLAY W/ MINOR MICA AND SUBANGULAR QUARTZ PEBBLES UP TO 3 MM IN DIAMETER	REGOLITH (residuum)
1 TO 3+		B	D	2.5YR 4/8 RED	M	S	L	L		FIRM, HOMOGENEOUS TO LENSED, MODERATELY WELL CEMENTED CLAYEY SILT W/ MORE MICA THAN ABOVE AND NO QUARTZ PEBBLES - MICA INCREASES W/ DEPTH - MN-OXIDE STAINING BEGINNING AT 2.5'	REGOLITH (residuum)
TO										VERY LITTLE RECOVER FROM 3 TO 58'. MATERIAL IN END OF CORE BARRELS SUGGESTS SAPROLITE (ML) BEGINS AT 13' - 18' BLS. MATERIAL IN END OF BARRELS BAGGED - TEMPORARY CASING SET AT 58'.	

BEDROCK LOG SHEET	**PAGE 2 OF 2**
PROJECT: LANGTREE	**DRILLING METHOD:**
BORING ID: CH-2	WIRELINE CORING
LOGGED BY: HELLER	
BEGIN DATE:10/17/2000	**CORE DIAMETER:** 2.25"
END DATE: 10/24/2000	

LITHOLOGIC DESCRIPTION			FRACTURE INFO					
INTERVAL	**RECOVERY**	**DESCRIPTION**		**# ANNEALED**	**# OPEN**	**H20 BEARING**	**MINERALS**	**Ground-Water Zon**
58	1	NO RECOVERY FROM 58' TO 61.5'. BEGINNING AT 61.5', FINE GR., WEATHERED, MODERATELY FOLIATED (SV) AMPHIBOLITE ABRUPTLY CHANGING INTO WEATHERED COARSE GR. WEAK TO MOD. FOLIATED (SV) QUARTZ DIORITE W/ 2 EPIDOTE BEARING FRACTURES	**V**	9		62- 71	QUARTZ, FE OXIDES, EPIDOTE	TRANSITION ZONE
TO			**SV**					
			M					
			SH		1			
63			**H**					
63	4.3	WEATHERED, COARSE GR. WEAKLY FOLIATED QUARTZ DIORITE - NUMEROUS FRACTURES, MOST WATER BEARING. ANNEALED FRACTURES APPEAR TO BE PARTIALLY WEATHERED AWAY AND ALSO WATER BEARING. CONTACT AT 68'.	**V**	4			EPIDOTE, BIOTITE, FE OXIDES	TRANSITION ZONE
TO			**SV**	4				
			M		2			
			SH		6			
68			**H**	3	4			
68	2	WEATHERED, FINE GR. WEAKLY TO MODERATELY FOLIATED (M TO SV) BIOTITE HORNBLENDE GNEISS W/ ACCESSORY EPIDOTE AND ACTINOLITE NOTED - MAY BE MORE SIMILAR, COMPOSITIONALLY, TO THE FINE GR. DIORITE NOTED IN THE UPPER PORTION OF CH-1 THAN THE BT-HBL GNEISS UNIT	**V**	2			BIOTITE, FE OXIDES, QUARTZ	TRANSITION ZONE
TO			**SV**		2			
			M	1	7			
			SH					
73			**H**					
73	5.4	FRESHER, FINE GR. BT-HBL GNEISS TO 74'. RELATIVELY FRESH, COARSE GR. QUARTZ DIORITE BEGINNING @ 74'. LEUCOCRATIC QUARTZ VEIN AT 76'. A FEW MINOR FAULTS AND MORE INTENSE FRACTURING ADJACENT TO QUARTZ VEIN.	**V**				BIOTITE, FE OXIDES	BEDROCK
TO			**SV**	10				
			M		7			
			SH	1	3			
78			**H**					
78	5.3	COARSE GR., FRESH, WEAKLY FOLIATED TO MASSIVE QUARTZ DIORITE W/ SOME EPIDOTE/CHLORITE ALTERATION OF HORNBLENDE.	**V**				QUARTZ, BIOTITE, EPIDOTE	BEDROCK
TO			**SV**	1				
			M		1			
			SH		2			
83			**H**		1			

Appendix 1C

REGOLITH LOG SHEET **PAGE 1 OF 4**

PROJECT:	LANGTREE PENINSULA	**DRILLING METHOD:**	WIRELINE CORING
BORING ID:	CH-3	**CORE DIAMETER:**	2.25"
LOGGED BY:	HELLER	**LATITUDE:**	35 31 35.12
BEGIN DATE:	10/30/2000	**LONGITUDE:**	80 52 41.74
END DATE:	11/1/2000	**LAND SURFACE ELEVATION:**	800.33'

Color descriptions referenced to Munsell soil color charts.

INTERVAL	**RECOVERY**	**SOIL HORIZON**	**DRY/WET**	**COLOR**	**DRY STRENGTH**	**DILATANCY**	**TOUGHNESS**	**PLASTICITY**	**UNIFIED CLASS**	**DESCRIPTION**	**Ground-Water Zon**
0 **TO** 0.5	(0-8) 5.4	A-B	D	2.5YR 4/6 RED	M TO H	N	L TO M	M TO H	CL	FIRM, MASSIVE TO BLOCKY SILTY CLAY W/ ORGANIC MATERIAL AND ROOT FRAGS	REGOLITH (residuum)
0.5 **TO** 4		B	D	2.5YR 4/6 RED TO 5YR 4/6 YELLOW RED	L TO M	N	L	NP TO L	MH	HARD TO VERY HARD MASSIVE SILTY CLAY W/ MINOR MICA	REGOLITH (residuum)
4 **TO** 9.5		B	D	5YR 5/6 YELLOW RED	L	N TO S	L	L	MH	FIRM SANDY SILTY CLAY TO CLAYEY SILT W/ MORE MICA AND SLIGHTLY LENSED APPEARANCE	REGOLITH (residuum)
9.5 **TO** 13	(8-13) 4.4	B-C	D	5YR 5/6 YELLOW RED	L	S	L	L	ML	SOFT TO FIRM, BLOCKY TO LENSED, WEAKLY CEMENTED CLAYEY SILT W/ MICA AND MN-OXIDES - SAPROLITIC QUARTZ DIORITE	REGOLITH (saprolite)
13 **TO** 18.5	(13-18) 4.6	C	M	7.5YR 5/6 BROWN	N	S	L	NP TO L	ML	SAME AS ABOVE W/ INCREASED MICA AND KAOLIN AFTER FELDSPAR MORE COMMON	REGOLITH (saprolite)

REGOLITH LOG SHEET **PAGE 2 OF 4**

PROJECT: LANGTREE PENINSULA **DRILLING METHOD:** WIRELINE CORING
BORING ID: CH-3
LOGGED BY: HELLER
BEGIN DATE: 10/30/2000 **CORE DIAMETER:** 2.25"
END DATE: 11/1/2000

Color descriptions referenced to Munsell soil color charts.

INTERVAL	RECOVERY	SOIL HORIZON	DRY/WET	COLOR	DRY STRENGTH	DILATANCY	TOUGHNESS	PLASTICITY	UNIFIED CLASS	DESCRIPTION	Ground-Water Zon
18.5 TO 27.5	(18-23) 4.4	C	M	N/A	N	N TO S	L	NP	ML	SOFT TO FIRM, LENSED, WEAKLY CEMENTED SANDY CLAYEY SILT - SAPROLITIC QUARTZ DIORITE, LESS WEATHERED THAN ABOVE - FINE GR. SANDY CLAYEY SILT ZONE, 2.5Y 6/3, @ 18'. ZONE IS 1" THICK AND VERY MOIST - PREFERENTIAL PATHWAY?	REGOLITH (saprolite)
27.5 TO 28.5	(23-28) 4.4	C	M	2.5Y 6/3 LIGHT YELLOW BROWN	N TO L	S	L	NP	ML	FINE GR. ZONE SIMILAR TO THAT @ 18'. VERY MOIST	REGOLITH (saprolite)
28.5 TO 39.5	(28-33) 4.7	C	M	N/A	L	R	L	NP	ML	FIRM TO HARD, LENSED, WEAKLY TO MODERATELY CEMENTED CLAYEY SILT W/ SAND - COARSE GR. QUARTZ DIORITE SAPROLITE TO PWR - BECOMES MORE COMPETENT W/ DEPTH	TRANSITION ZONE
TO	(33-38) 4.2										
TO	(38-39.5) 1.6										

BEDROCK LOG SHEET **PAGE 3 OF 4**

PROJECT: LANGTREE
DRILLING METHOD: WIRELINE CORING
BORING ID: CH-3
LOGGED BY: HELLER
BEGIN DATE:10/30/2000
CORE DIAMETER: 2.25"
END DATE: 11/1/2000

LITHOLOGIC DESCRIPTION				FRACTURE INFO				
INTERVAL	RECOVERY	DESCRIPTION		# ANNEALED	# OPEN	H20 BEARING	MINERALS	Ground-Water Zon
39.5	3.9	COARSE GR., RELATIVELY FRESH, MASSIVE TO WEAKLY FOLIATED (M TO SV) QUARTZ DIORITE W/ ACCESSORY EPIDOTE - ROCK BEGINS @39.5'	**V**				BIOTITE QUARTZ	BEDROCK
TO			**SV**	2				
			M	1				
			SH					
43			**H**					
43	4.9	SAME AS ABOVE	**V**				BIOTITE EPIDOTE QUARTZ	BEDROCK
TO			**SV**	1				
			M	1	1			
			SH	3				
48			**H**					
48	5.1	SAME AS ABOVE W/ MINOR BRITTLE FAULT W/ REVERSE MOVEMENT AT 48.5' 10 CM WIDE BIOTITE-EPIDOTE ANNEALED FRACTURE (M) AT 51.5'.	**V**			49-51	BIOTITE EPIDOTE QUARTZ	BEDROCK
TO			**SV**	2				
			M	1	2			
			SH	1	3	52.5		
53			**H**					
53	5.1	SAME AS ABOVE - MORE WEATHERED HORIZON @56.5' - ABOUT 0.5' WIDE	**V**	1		55.0	BIOTITE EPIDOTE QUARTZ	BEDROCK
TO			**SV**	1				
			M	2		56.5		
			SH	2	2			
58			**H**		2			
58	5.1	SAME AS ABOVE	**V**				BIOTITE EPIDOTE QUARTZ	BEDROCK
TO			**SV**					
			M	2				
			SH					
63			**H**					

BEDROCK LOG SHEET **PAGE 4 OF 4**

PROJECT: LANGTREE
DRILLING METHOD: WIRELINE CORING
BORING ID: CH-3
LOGGED BY: HELLER
BEGIN DATE:10/30/2000
CORE DIAMETER: 2.25"
END DATE: 11/1/2000

LITHOLOGIC DESCRIPTION				FRACTURE INFO				
INTERVAL	RECOVERY	DESCRIPTION		# ANNEALED	# OPEN	H20 BEARING	MINERALS	Ground-Water Zon
63	5	SAME AS ABOVE - CORING TERMINATED AT 68'	V				BIOTITE EPIDOTE	BEDROCK
TO			SV	1				
			M	1				
			SH					
68			H					
			V					
TO			SV					
			M					
			SH					
			H					
			V					
TO			SV					
			M					
			SH					
			H					
			V					
TO			SV					
			M					
			SH					
			H					
			V					
TO			SV					
			M					
			SH					
			H					

REGOLITH LOG SHEET		**PAGE 1 OF 5**	
PROJECT:	LANGTREE PENINSULA	**DRILLING METHOD:**	WIRELINE CORING
BORING ID:	CH-4	**CORE DIAMETER:**	2.25"
LOGGED BY:	HELLER	**LATITUDE:**	35 31 57.09
BEGIN DATE:	11/7/2000	**LONGITUDE:**	80 52 53.16
END DATE:	11/16/2000	**LAND SURFACE ELEVATION:**	762'

Color descriptions referenced to Munsell soil color charts.

INTERVAL	RECOVERY	SOIL HORIZON	DRY/WET	COLOR	DRY STRENGTH	DILATANCY	TOUGHNESS	PLASTICITY	UNIFIED CLASS	DESCRIPTION	Ground-Water Zon
0 TO 0.5	(0-8) 5'	A	M	5YR 4/3 REDDISH BROWN	M	N	L	NP	ML TO MH	FIRM, MASSIVE, MODERATELY CEMENTED CLAYEY SILT W/ PEBBLES AND ROOT FRAGS	REGOLITH (residuum)
0.5 TO 6		B	D	2.5YR 4/6 RED	M TO H	N	L TO M	L	MH	HOMOGENEOUS TO LENSED, MODERATELY WELL CEMENTED SILTY CLAY W/ MICA AND MINOR QUARTZ SAND	REGOLITH (residuum)
6 TO 11		B-C	D	5YR 5/6 YELLOW RED	L TO M	S	L	NP	ML TO MH	FIRM, LENSED, MODERATELY CEMENTED SANDY SILTY CLAY W/ MORE ABUNDANT MICA THAN ABOVE AND SOME FE-MN OXIDES	REGOLITH (residuum)
11 TO 13	(8-13) 1.8'	C	M	5YR 5/8 YELLOW RED	L TO M	S	L	NP	ML	FIRM, LENSED, MODERATELY CEMENTED CLAYEY SILT W/ ABUNDANT MICA AND MN-OXIDES (DIORITE SAPROLITE)	REGOLITH (saprolite)
13 TO 18	(13-18) 5'	C	M	5YR 5/8 YELLOW RED	L TO M	S TO R	L	NP	ML	SAME AS ABOVE W/ MORE ABUNDANT MN-OXIDES - REDDISH CLAY-RICH ZONE (2" THICK) AT 16'.	REGOLITH (saprolite)

REGOLITH LOG SHEET **PAGE 2 OF 5**

PROJECT: LANGTREE PENINSULA **DRILLING METHOD:** WIRELINE CORING
BORING ID: CH-4
LOGGED BY: HELLER
BEGIN DATE: 11/7/2000 **CORE DIAMETER:** 2.25"
END DATE: 11/16/2000

Color descriptions referenced to Munsell soil color charts.

INTERVAL	RECOVERY	SOIL HORIZON	DRY/WET	COLOR	DRY STRENGTH	DILATANCY	TOUGHNESS	PLASTICITY	UNIFIED CLASS	DESCRIPTION	Ground-Water Zon
18 TO 19	(18-23) 2.3'	C	M	2.5YR 8/1 WHITE	L	R	L	NP	ML	COARSE GR. PEGMATITIC VEIN	REGOLITH (saprolite)
19 TO 26	(23-28) 4.2'	C	M	5YR 5/8 YELLOW RED	L	S TO R	L	NP	ML	SAME AS 13-18	REGOLITH (saprolite)
26 TO 33	(28-33) 1'	C	M	5YR 5/8 YELLOW RED	L	S TO R	L	NP	ML	FIRM, LAYERED SANDY CLAYEY SILT (FINE GR. QUARTZOFELDSPATHIC SAPROLITE W/ MODERATE DIP)	REGOLITH (saprolite)
33 TO 38	(33-38) 2'	C	M	5YR 5/8 YELLOW RED	L	R	L	NP	ML	SAME AS 13-18 W/ MORE KAOLINITIC CLAY REPLACING FELDSPAR	REGOLITH (saprolite)
38 TO 41		C	M	5YR 5/8 YELLOW RED	L	R	L	NP	ML	SAME AS 26-33	REGOLITH (saprolite)

REGOLITH LOG SHEET **PAGE 3 OF 5**

PROJECT: LANGTREE PENINSULA **DRILLING METHOD:** WIRELINE CORING
BORING ID: CH-4
LOGGED BY: HELLER
BEGIN DATE: 11/7/2000 **CORE DIAMETER:** 2.25"
END DATE: 11/16/2000

Color descriptions referenced to Munsell soil color charts.

INTERVAL	RECOVERY	SOIL HORIZON	DRY/WET	COLOR	DRY STRENGTH	DILATANCY	TOUGHNESS	PLASTICITY	UNIFIED CLASS	DESCRIPTION	Ground-Water Zon
41 TO 48	(38-43) 1.7'	C	M	10YR 4/6 DARK YELLOW BROWN	L	R	L	N P	ML	SOFT LENSED WEAKLY CEMENTED SANDY CLAYEY SILT W/ ABUNDANT WHITE CLAY AFTER FELDSPAR + FE-MN OXIDES AFTER AMPHIBOLE? - SAPROLITIC QUARTZ DIORITE - MINOR FINE GR. VEIN (MOD. DIP AND 1 CM WIDE @ 45'.	REGOLITH (saprolite)
48 TO 53	(43-48) 2.3'	C TO PWR	M	2.5 YR 5/2 GRAYISH BROWN	L	R	L	N P	ML	SOFT TO FIRM, LENSED WEAKLY CEMENTED SANDY CLAYEY SILT W/ MORE ABUNDANT MICA THAN ABOVE (QTZ DIORITE SAPROLITE)	REGOLITH (saprolite)
53 TO 58	(48-53) 2.5'	PWR	M	N/A	L	R	L	N P	ML	SAME AS ABOVE INTERLAYERED W/ FINE GR. MOD. FOLIATED HORNBLENDE GNEISS (SAPROLITIC)	REGOLITH (saprolite)
58 TO 66	(53-58) 0.5'	PWR	M	N/A	L	R	L	N P	ML	SAME AS 48-53	REGOLITH (saprolite)
66 TO 67	(58-63) 4.5'	PWR	M	N/A	L	R	L	N P	ML	FINE GR. INTERVAL (DIORITE SAPROLITE)	REGOLITH (saprolite)

REGOLITH LOG SHEET **PAGE 4 OF 5**

PROJECT: LANGTREE PENINSULA **DRILLING METHOD:** WIRELINE CORING
BORING ID: CH-4
LOGGED BY: HELLER
BEGIN DATE: 11/7/2000 **CORE DIAMETER:** 2.25"
END DATE: 11/16/2000

Color descriptions referenced to Munsell soil color charts.

INTERVAL	RECOVERY	SOIL HORIZON	DRY/WET	COLOR	DRY STRENGTH	DILATANCY	TOUGHNESS	PLASTICITY	UNIFIED CLASS	DESCRIPTION	Ground-Water Zon
67 TO 68	(63-68) 5.0'	PWR	M	N/A	L	R	L	NP	ML	SAME AS 48-53	REGOLITH (saprolite)
68 TO 73	(68-73) 4.5'	PWR	M	N/A	L	R	L	NP	ML	COARSE GR. QUARTZ DIORITE W/ EPIDOTE - BECOMING HARDER AND FRESHER W/ DEPTH - REFUSAL W/ MUD BIT AT 73'.	TRANSITION ZONE
TO											
TO											
TO											

BEDROCK LOG SHEET	**PAGE 5 OF 5**
PROJECT: LANGTREE	**DRILLING METHOD:**
BORING ID: CH-4	WIRELINE CORING
LOGGED BY: HELLER	
BEGIN DATE:17/7/2000	**CORE DIAMETER:** 2.25"
END DATE: 11/16/2000	

	LITHOLOGIC DESCRIPTION			FRACTURE INFO				
INTERVAL	**RECOVERY**	**DESCRIPTION**		**# ANNEALED**	**# OPEN**	**H20 BEARING**	**MINERALS**	**Ground-Water Zon**
73	2.2	WEATHERED COARSE GR. MASSIVE QUARTZ DIORITE TO 76'. BECOMES FRESH AT 76'. VERY LITTLE RECOVERY 72' TO 76'.	**V**				BIOTITE	TRANSITION ZONE/BEDROCK
TO			**SV**	2				
			M	2	2	76.0		
			SH					
78			**H**					
78	5	FRESH COARSE GR. MASSIVE QUARTZ DIORITE	**V**				BIOTITE QUARTZ	BEDROCK
TO			**SV**					
			M	3				
			SH					
83			**H**	2				
83	5	SAME AS ABOVE	**V**				BIOTITE EPIDOTE	BEDROCK
TO			**SV**			85.0		
			M	6	1			
			SH			87.5		
88			**H**	1	2	88		
88	5	SAME AS ABOVE - WEATHERED ZONE 88-89.	**V**			88.5	BIOTITE EPIDOTE QUARTZ	BEDROCK
TO			**SV**	2	1			
			M	1	4			
			SH	1				
93			**H**		1	93.0		
93	3.4	SAME AS ABOVE	**V**			93.5		BEDROCK
TO			**SV**		1	94.5		
			M		3	96.0		
			SH		3	97.5		
98			**H**		3			

REGOLITH LOG SHEET **PAGE 1 OF 3**

PROJECT:	LANGTREE PENINSULA	**DRILLING METHOD:**	WIRELINE CORING
BORING ID:	CH-5	**CORE DIAMETER:**	2.25"
LOGGED BY:	HELLER	**LATITUDE:**	35 31 44.91
BEGIN DATE:	2/6/2001	**LONGITUDE:**	80 52 47.21
END DATE:	2/7/2001	**LAND SURFACE ELEVATION:**	801.49'

Color descriptions referenced to Munsell soil color charts.

INTERVAL	RECOVERY	SOIL HORIZON	DRY/WET	COLOR	DRY STRENGTH	DILATANCY	TOUGHNESS	PLASTICITY	UNIFIED CLASS	DESCRIPTION	Ground-Water Zone
0 TO 0.5	(0-3) 2.3'	A?	M	2.5YR 3/4 DARK REDDISH BROWN	H	N	L	L TO M	CL	FIRM, MASSIVE, MODERATELY CEMENTED HOMOGENEOUS SILTY CLAY W/ ROOT FRAGS	REGOLITH (residuum)
0.5 TO 2	(3-8) 2.9'	B?	M	10R 4/6 RED	H	N	L	L TO M	CL	FIRM TO HARD, WELL CEMENTED, HOMOGENEOUS SILTY CLAY W/ SMALL, <1MM, ANGULAR TO SUB ANGULAR QUARTZ FRAGMENTS	REGOLITH (residuum)
2 TO 5	(8-13) 3.2'	B-C?	M	2.5YR 4/8 RED	H	N	L	L TO M	CL	SOFT TO FIRM, WEAKLY CEMENTED LENSED CLAYEY SILT W/ MINOR SAND-MN-OXIDES INCREASING W/ DEPTH	REGOLITH (residuum)
5 TO 6?	(13-18) 3.3'	B-C?	M	5YR 5/8 YELLOW RED	H	N TO R	L	NP	MH	SOFT TO FIRM, WEAKLY TO MOD. CEMENTED CLAYEY SILT W/ MINOR SAND. MN OXIDES AND SUB-ANGULAR TO ANGULAR, CHEMICALLY WEATHERED, FINE TO MED. GR. DIORITE CLASTS (?) W/ EPIDOTE - ONE CLAST BLOCKED CORE CATCHER @ 6' (?).	REGOLITH (residuum)
6? TO 17.5	(18-23) 3.3'	C	M	7.5YR 5/8 STRONG BROWN	M	R	L	NP	MH-ML	SOFT TO FIRM, WEAK TO MOD. CEMENTED, POORLY LAMINATED (SV DIP) CLAYEY SILT W/ MN-OXIDES. **NOTE: CONTACT W/ ABOVE HORIZION APPEARS TO BE ABRUPT. 0' TO 6' COLLUVIUM? ALLUVIUM? FILL?**	REGOLITH (residuum)

REGOLITH LOG SHEET		**PAGE 2 OF 3**	
PROJECT:	LANGTREE PENINSULA	**DRILLING METHOD:**	WIRELINE CORING
BORING ID:	CH-5		
LOGGED BY:	HELLER		
BEGIN DATE:	2/6/2001	**CORE DIAMETER:**	2.25"
END DATE:	2/7/2001		

Color descriptions referenced to Munsell soil color charts.

INTERVAL	RECOVERY	SOIL HORIZON	DRY/WET	COLOR	DRY STRENGTH	DILATANCY	TOUGHNESS	PLASTICITY	UNIFIED CLASS	DESCRIPTION	Ground-Water Zone
17.5 TO 30	(23-28) 3.7'	C	M	7.5YR 5/8 STRONG BROWN	L	R	L	NP	ML	SOFT, WEAKLY TO MODERATELY CEMENTED LENSED SILTY CLAY W/ SAND - MN-OXIDES ABUNDANT AND WHITE CLAY AFTER FELDSPAR PRESENT - SAPROLITIC DIORITE (COARSE GR.) - GRADUAL DECREASE IN WEATHERING W/ DEPTH	REGOLITH (saprolite)
30 TO 47.5	(28-33) 3.3'	PWR	M TO W	N/A	L	S	L	NP	ML	SOFT, WEAKLY TO MOD. CEMENTED SAPROLITIC TO WEATHERED COARSE GR. QUARTZ DIORITE W/ AMPHIBOLE AND MICA OBSERVED - SILT W/ SAND BECOMES FRESHER GRADUALLY W/ DEPTH - MUD BIT REFUSAL @47.5'.	REGOLITH (saprolite)/ TRANSITION ZONE
TO	(33-38) 4.3'										
TO	(38-43) 2.2'										
TO	(43-47.5) 3'										

BEDROCK LOG SHEET	**PAGE 3 OF 3**
PROJECT: LANGTREE	**DRILLING METHOD:**
BORING ID: CH-5	WIRELINE CORING
LOGGED BY: HELLER	
BEGIN DATE: 2/6/2001	**CORE DIAMETER:** 2.25"
END DATE: 2/7/2001	

		LITHOLOGIC DESCRIPTION		FRACTURE INFO				
INTERVAL	RECOVERY	DESCRIPTION		# ANNEALED	# OPEN	H20 BEARING	MINERALS	Ground-Water Zone
47.5	5.7'	COARSE GR. MASSIVE QUARTZ DIORITE W/ ACCESSORY EPIDOTE - RELATIVELY FRESH, BECOMING FRESHER W/ DEPTH	**V**				QUARTZ BIOTITE EPIDOTE	TRANSITION ZONE/BEDROCK
TO			**SV**					
			M	3				
			SH		2	52?		
53			**H**					
53	5'	SAME AS ABOVE - MINOR REVERSE FAULT, MODERATELY DIPPING W/ 1 CM OFFSET AT 55'.	**V**				QUARTZ BIOTITE EPIDOTE	BEDROCK
TO			**SV**					
			M	6				
			SH	1	3	56.5?		
58			**H**					
58	4.8'	SAME AS ABOVE	**V**			58.5	QUARTZ BIOTITE	BEDROCK
TO			**SV**					
			M	1				
			SH					
63			**H**	2	1			
63	4.9'	SAME AS ABOVE TO 65'. 65' TO 67', FINER GR. "PORPHYRITIC" INTERVAL. SOME MAFIC ENCLAVES (MOD. TO SV ORIENTED) IN THIS INTERVAL	**V**			64.0	QUARTZ BIOTITE	BEDROCK
TO			**SV**					
			M	1				
			SH					
68			**H**		3			
68	5.3'	COARSE GR. DIORITE 67' TO 70' AND 71.5' TO 73'. FINER GR. "PORPHYRITIC" INTERVAL 70' TO 71.5'.	**V**			68.5	QUARTZ BIOTITE	BEDROCK
TO			**SV**			69.0		
			M	2		70.5		
			SH	2				
73			**H**		3			

Appendix 1F

REGOLITH LOG SHEET			**PAGE 1 OF 2**
PROJECT:	LANGTREE PENINSULA	**DRILLING METHOD:**	WIRELINE CORING
BORING ID:	CH-6	**CORE DIAMETER:**	2.25"
LOGGED BY:	HELLER	**LATITUDE:**	35 31 48.25
BEGIN DATE:	2/7/2001	**LONGITUDE:**	80 52 46.79
END DATE:	2/8/2001	**LAND SURFACE ELEVATION:**	783.59'

Color descriptions referenced to Munsell soil color charts.

INTERVAL	RECOVERY	SOIL HORIZON	DRY/WET	COLOR	DRY STRENGTH	DILATANCY	TOUGHNESS	PLASTICITY	UNIFIED CLASS	DESCRIPTION	Ground-Water Zone
0 TO 1	(0-3) 2.5'	A	M	2.5YR 4/4 REDDISH BROWN	M TO H	N	L	L	MH	SOFT TO FIRM, MODERATELY TO WELL CEMENTED, BLOCKY SILTY CLAY TO CLAYEY SILT W/ ROOT FRAGS AND A FEW SUB-ANGULAR QUARTZ PEBBLES IN THE UPPER FEW INCHES	REGOLITH (residuum)
1 TO 7	(3-8) 4.9'	B	M	10R 4/6 RED	H	N	L	L TO M	CL	FIRM TO HARD, WELL CEMENTED, HOMOGENEOUS SILTY CLAY W/ MINOR MICA AND MN-OXIDES.	REGOLITH (residuum)
7 TO 12.5	(8-13) 3.7'	B-C	D	2.5YR 5/6 RED	L	N TO S	L	NP	ML	SOFT TO FIRM, MODERATELY CEMENTED LENSED CLAYEY SILT. MOTTLED APPEARANCE W/ TAN ZONES. INCREASED MN-OXIDES	REGOLITH (residuum)
12.5 TO 22	(13-18) 3.9'	C	M	5YR 5/8 YELLOW RED TO 7.5YR 5/6 STRONG BROWN	L	S	L	NP	ML	SOFT, WEAKLY TO MODERATELY CEMENTED CLAYEY SILT W/ SAND. LENSED/MOTTLED APPEARANCE. MN-OXIDES AND MICA INCREASE W/ DEPTH. SAPROLITIC COARSE GR. DIORITE.	REGOLITH (saprolite)
22 TO 24	(18-24) 3.9'	PWR	D	N/A	L	S	L	NP	ML	SOFT TO FIRM, MODERATELY CEMENTED SILT W/ SAND - WEATHERED QUARTZ DIORITE.	REGOLITH (saprolite)/ TRANSITION ZONE

BEDROCK LOG SHEET
PAGE 2 OF 2

PROJECT: LANGTREE
DRILLING METHOD: WIRELINE CORING
BORING ID: CH-6
LOGGED BY: HELLER
BEGIN DATE: 2/7/2001
CORE DIAMETER: 2.25"
END DATE: 2/8/2001

LITHOLOGIC DESCRIPTION			FRACTURE INFO					
INTERVAL	RECOVERY	DESCRIPTION		# ANNEALED	# OPEN	H20 BEARING	MINERALS	Ground-Water Zone
24	4'	COARSE GR. MASSIVE TO WEAKLY FOLIATED, RELATIVELY FRESH QUARTZ DIORITE.	V				QUARTZ BIOTITE	BEDROCK
			SV	3				
TO			M	3				
			SH	3				
28			H	1				
28	5'	SAME AS ABOVE W/ EPIDOTE-PYRITE VEIN (M TO SV, APPX. 2 CM WIDE) @27.5'.	V				QUARTZ BIOTITE EPIDOTE PYRITE	BEDROCK
			SV	5				
TO			M	2				
			SH	4				
33			H		1	32.0		
33	5.3'	SAME AS ABOVE- DIORITE IS VARIABLY FOLIATED W/ FOLIATION INCREASING FROM TOP TO BOTTOM (SV). VUGGY PYRITE-QUARTZ VEIN @35.5'. LAYERED ZONES AT 35.5' AND FROM 37' TO 38'.	V				QUARTZ BIOTITE EPIDOTE PYRITE	BEDROCK
			SV					
TO			M	1				
			SH	2		36.0		
38			H	2	1			
38	5.2'	FRESH, COARSE GR. WEAKLY FOLIATED (SV DIPPING) QUARTZ DIORITE.	V				QUARTZ BIOTITE EPIDOTE PYRITE	BEDROCK
			SV					
TO			M					
			SH					
43			H		1			
43	5'	DIORITE 43' - 45', 47' - 48' W/ ACCESSORY PYRITE. FINE GR. MOD. FOLIATED (SV) BIOTITE HORNBLENDE GNEISS XENOLITH? FROM 45' - 47'. THIS ZONE IS MORE WEATHERED THAN THE DIORITE ABOVE AND BELOW. BORING TERMINATED AT 48'.	V				QUARTZ BIOTITE EPIDOTE PYRITE	BEDROCK
			SV					
TO			M	4		45.5		
			SH		2	46.0		
48			H		2			

REGOLITH LOG SHEET **PAGE 1 OF 4**

PROJECT: LANGTREE PENINSULA
DRILLING METHOD: WIRELINE CORING
BORING ID: CH-7
CORE DIAMETER: 2.25"
LOGGED BY: HELLER
LATITUDE: 35 31 51.57
BEGIN DATE: 2/20/2001
LONGITUDE: 80 52 45.82
END DATE: 2/20/2001
LAND SURFACE ELEVATION: 764.64'

Color descriptions referenced to Munsell soil color charts.

INTERVAL	RECOVERY	SOIL HORIZON	DRY/WET	COLOR	DRY STRENGTH	DILATANCY	TOUGHNESS	PLASTICITY	UNIFIED CLASS	DESCRIPTION	Ground-Water Zon
0 TO 1.5	(0-3) 1.9'	A	D TO M	2.5YR 4/4 REDDISH BROWN	M TO H	N	L	L	MH	SOFT TO FIRM, MODERATELY TO WELL CEMENTED, BLOCKY TO HOMOGENEOUS SILTY CLAY TO CLAYEY SILT W/ ROOT FRAGS AND A FEW SUB-ANGULAR TO SUBROUND QUARTZ PEBBLES	REGOLITH (residuum)
1.5 TO 5	(3-8) 4.4'	B	M	10R 4/6 RED	H	N	L	L TO M	CL	FIRM TO HARD, WELL CEMENTED, HOMOGENEOUS SILTY CLAY W/ SUBANGULAR QUARTZ GRADING INTO BELOW	REGOLITH (residuum)
5 TO 11.5	(8-13) 4.5'	B-C	D	5YR 5/8 YELLOW RED	L	N TO S	L	NP	ML	SOFT TO FIRM, MODERATELY CEMENTED LENSED CLAYEY SILT. MOTTLED APPEARANCE W/ TAN ZONES. MINOR MN-OXIDES	REGOLITH (residuum)
11.5 TO 13	(13-18) 4.1'	C	M	7.5YR 5/8 STRONG BROWN	L	S	L	NP	ML	SOFT, WEAKLY TO MODERATELY CEMENTED CLAYEY SILT W/ SAND. LENSED/MOTTLED APPEARANCE. MN-OXIDES INCREASE W/ DEPTH. SAPROLITIC COARSE GR. DIORITE.	REGOLITH (saprolite)
13 TO 14	(18-23) 3.9'	C	M	7.5YR 5/8 STRONG BROWN	L	S	L	NP	ML	FINER GR. INTERVAL - SOFT CLAYEY SILT W/ SLIGHTLY LAYERED APPEARANCE	REGOLITH (saprolite)

REGOLITH LOG SHEET **PAGE 2 OF 4**

PROJECT: LANGTREE PENINSULA **DRILLING METHOD:** WIRELINE CORING
BORING ID: CH-7 **CORE DIAMETER:** 2.25"
LOGGED BY: HELLER
BEGIN DATE: 2/20/2001
END DATE: 2/20/2001

Color descriptions referenced to Munsell soil color charts.

INTERVAL	RECOVERY	SOIL HORIZON	DRY/WET	COLOR	DRY STRENGTH	DILATANCY	TOUGHNESS	PLASTICITY	UNIFIED CLASS	DESCRIPTION	Ground-Water Zone
14 TO 17	(23-28) 4'	C	M	7.5YR 5/8 STRONG BROWN	L	S	L	NP	ML	SAME AS 11.5 TO 13 W/ MORE MICA	REGOLITH (saprolite)
17 TO 20.5	(3-8) 4.4'	C	M	7.5YR 5/8 STRONG BROWN	L	S	L	NP	ML	SAME AS 14-17 BUT W/ WHITE CLAY AFTER FELDSPAR	REGOLITH (saprolite)
20.5 TO 26	(8-13) 4.5'	PWR	M	7.5YR 5/8 STRONG BROWN	L	S	L	NP	ML	BECOMING MORE FRESH W/ MORE RESISTANT DIORITIC ZONES - RELICT AMPHIBOLE VISIBLE AT THE END OF THE RUN - REFUSAL AT 26'.	REGOLITH (saprolite)/ TRANSITION ZONE
TO											
TO											

BEDROCK LOG SHEET **PAGE 3 OF 4**

PROJECT: LANGTREE **DRILLING METHOD:** WIRELINE CORING
BORING ID: CH-7
LOGGED BY: HELLER
BEGIN DATE: 2/20/2001 **CORE DIAMETER:** 2.25"
END DATE: 2/20/2001

LITHOLOGIC DESCRIPTION			FRACTURE INFO					
INTERVAL	**RECOVERY**	**DESCRIPTION**		**# ANNEALED**	**# OPEN**	**H20 BEARING**	**MINERALS**	**Ground-Water Zon**
26 TO 28	1.5'	WEATHERED, FINE GR. WEAKLY TO MOD. FOLIATED BIOTITE HORNBLENDE GNEISS	**V**				EPIDOTE FE-OXIDE	TRANSITION ZONE
			SV	1				
			M					
			SH					
			H					
28 TO 33	3.9	WEATHERED BIOTITE HORNBLENDE GNEISS TO 31'. WEATHERED COARSE GR., WEAKLY FOLIATED TO MASSIVE QUARRTZ DIORITE FROM 31' TO 33'. QUARTZ VEIN AT 31'.	**V**				EPIDOTE FE-OXIDE	TRANSITION ZONE
			SV		4			
			M		2			
			SH		2			
			H		6			
33 TO 38	3.9	WEATHERED QUARTZ DIORITE W/ FINE GR. XENOLITHS OF BIOTITE HORNBLENDE GNEISS @ 35.5' AND 37'. THESE ZONES SEEM TO BE MORE WEATHERED THAN SURROUNDING DIORITE AND MORE SATURATED W/ WATER	**V**				EPIDOTE FE-OXIDE	TRANSITION ZONE
			SV					
			M		4			
			SH		1			
			H		6			
38 TO 43	5.2	LESS WEATHERED QUARTZ DIORITE W/ FINE GR. XENOLITH OF BIOTITE HORNBLENDE GNEISS @38-39'.	**V**				QUARTZ BIOTITE EPIDOTE PYRITE	TRANSITION ZONE/ BEDROCK
			SV		1			
			M		2			
			SH		2			
			H		5			
43 TO 48	5.3	QUARTZ DIORITE, BECOMING FRESHER W/ DEPTH	**V**	1			BIOTITE QUARTZ	BEDROCK
			SV	2				
			M	2	1			
			SH					
			H		7			

BEDROCK LOG SHEET	**PAGE 4 OF 4**
PROJECT: LANGTREE	**DRILLING METHOD:**
BORING ID: CH-7	WIRELINE CORING
LOGGED BY: HELLER	
BEGIN DATE: 2/20/2001	**CORE DIAMETER:** 2.25"
END DATE: 2/20/2001	

INTERVAL	**RECOVERY**	**LITHOLOGIC DESCRIPTION** **DESCRIPTION**		**FRACTURE INFO** **# ANNEALED**	**# OPEN**	**H20 BEARING**	**MINERALS**	**Ground-Water Zone**
48	4.7	COARSE GR. MASSIVE TO WEAKLY FOLIATED, RELATIVELY FRESH QUARTZ DIORITE.	**V**				QUARTZ BIOTITE	BEDROCK
TO			**SV**		1			
			M		3			
			SH		3			
53			**H**		11			
TO								
TO								
TO								
TO								

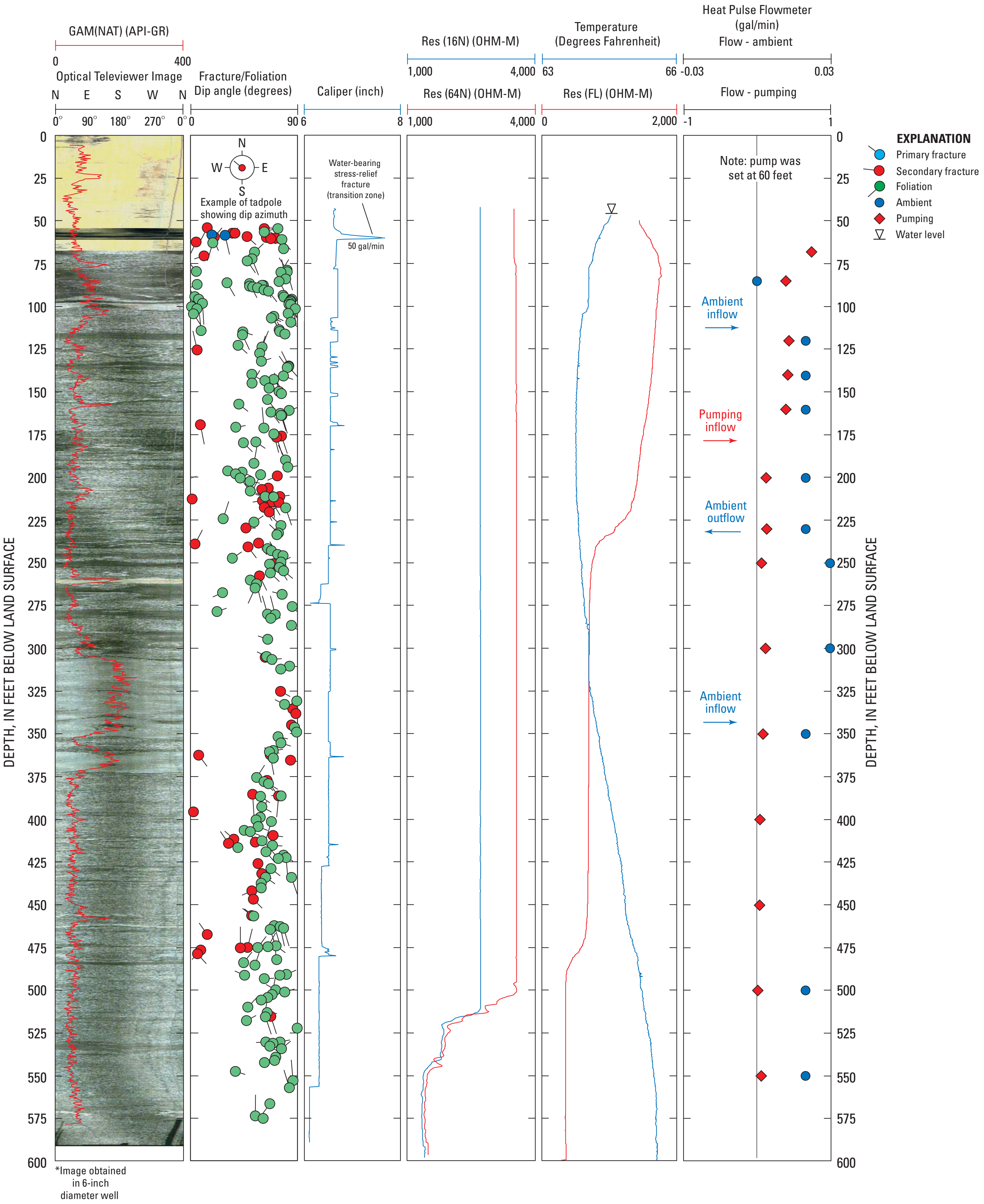


*Image obtained in 6-inch diameter well

Appendix 2A. Geophysical logs for bedrock well MW-1D at the Langtree Peninsula research station, North Carolina. See corehole CH-1 description in Appendix 1.

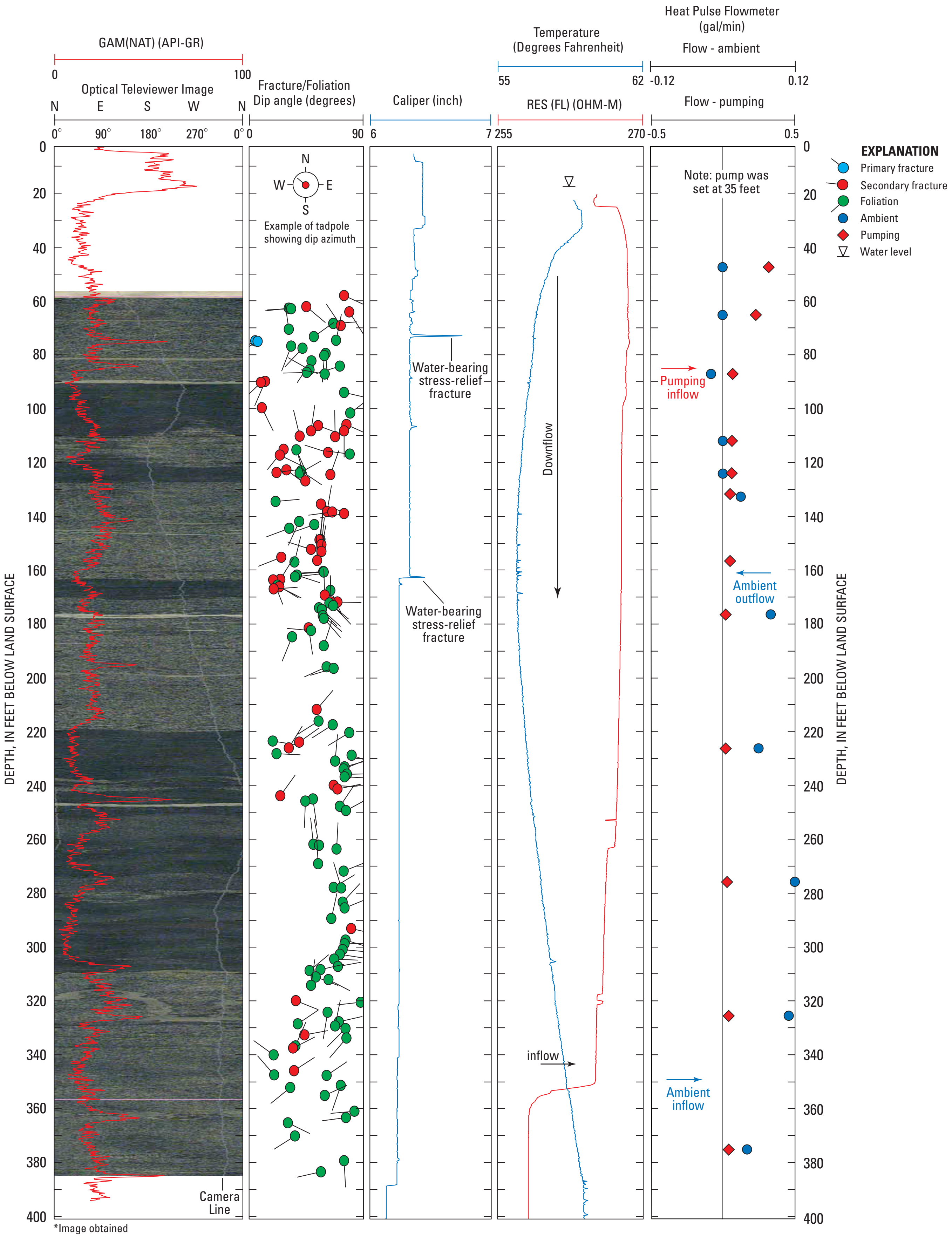
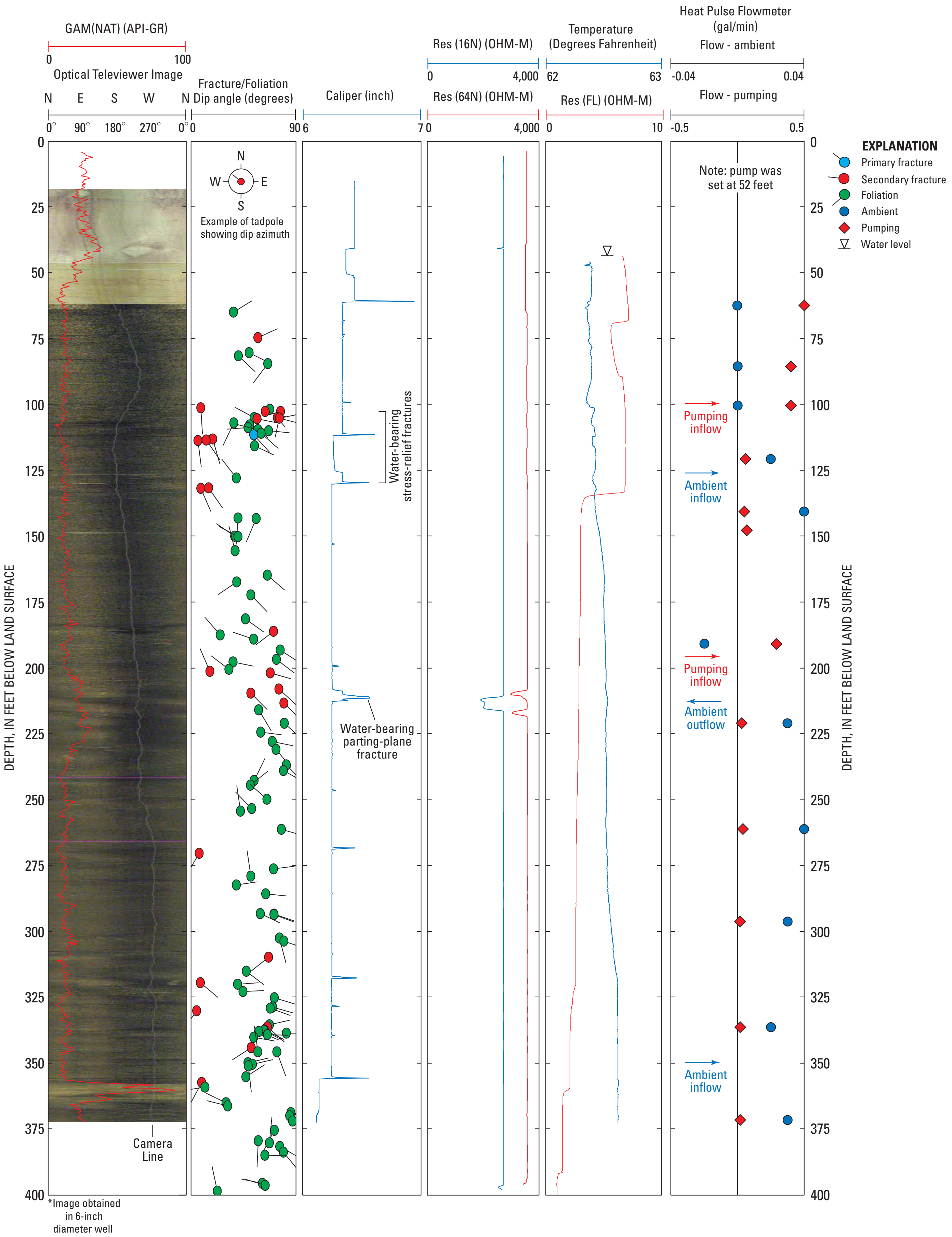


*Image obtained in 6-inch diameter well

Appendix 2B. Geophysical logs for bedrock well MW-2D at the Langtree Peninsula research station, North Carolina. See coreholes CH-2 and CH-3 descriptions in Appendix 1.



Appendix 2C. Geophysical logs for bedrock well MW-4D at the Langtree Peninsula research station, North Carolina. See corehole CH-5 desciption in Appendix 1.

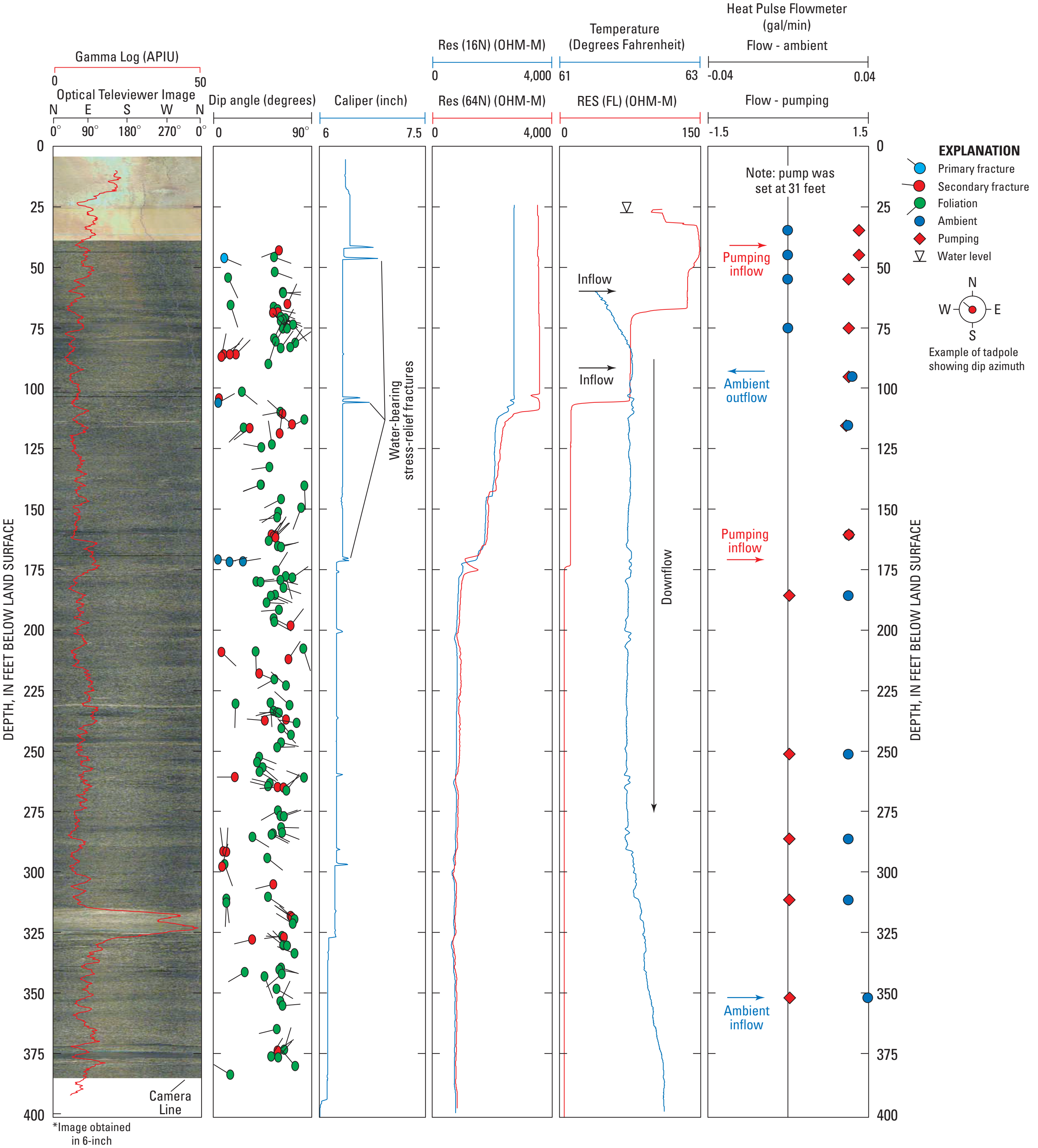


*Image obtained
in 6-inch
diameter well

Appendix 2D. Geophysical logs for bedrock well MW-5D at the Langtree Peninsula research station, North Carolina. See corehole CH-6 description in Appendix 1.

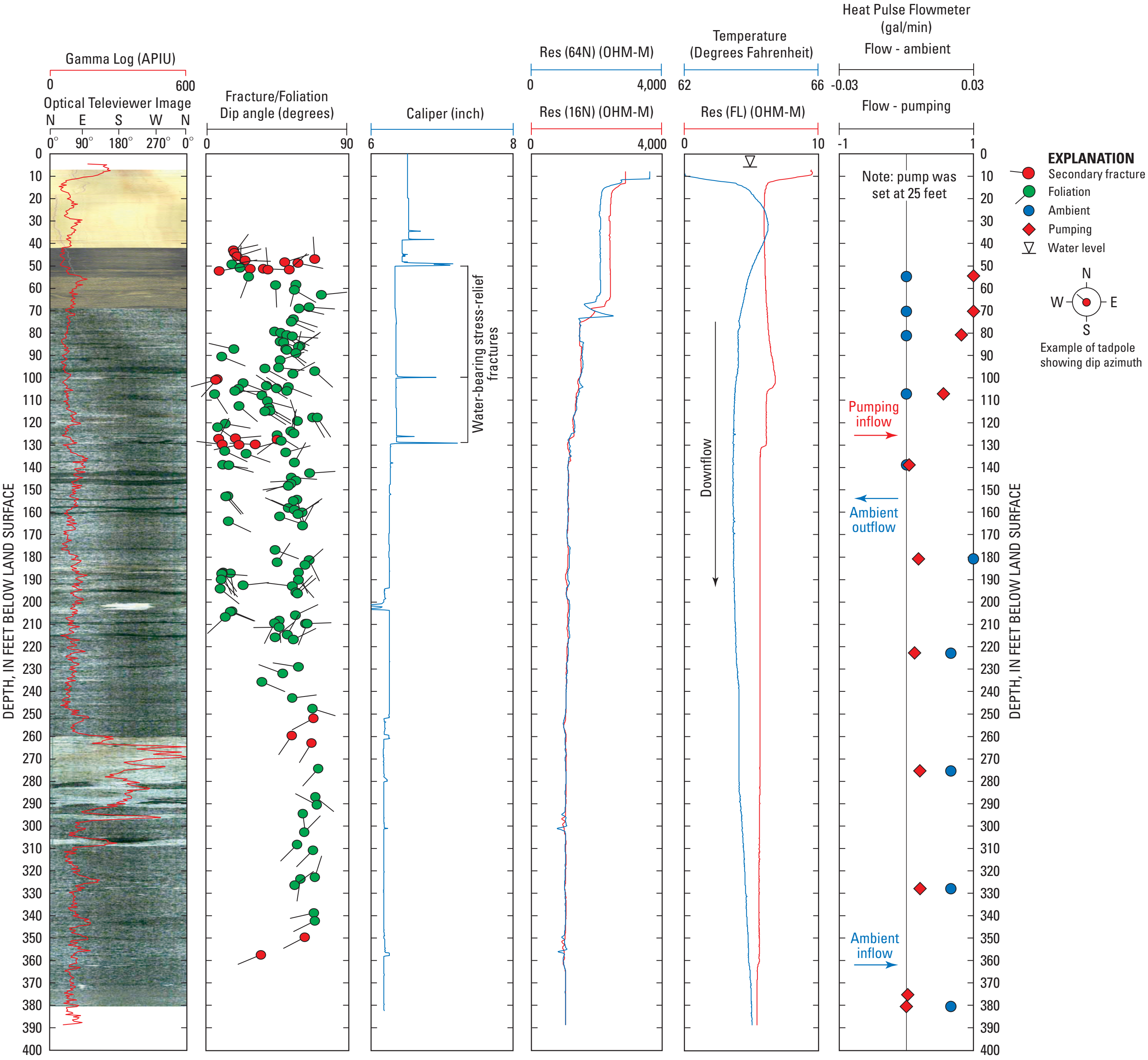


*Image obtained in 6-inch diameter well

Appendix 2E. Geophysical logs for bedrock well MW-6D at the Langtree Peninsula research station, North Carolina. See corehole CH-7 description in Appendix 1.

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Pippin and others—**Hydrogeologic Setting, Ground-Water Flow, and Ground-Water Quality at the Langtree Peninsula Research Station**—Scientific Investigations Report 2008–5055