HYDRAULIC GRADIENTS IN RECHARGE AND DISCHARGE AREAS AND APPARENT GROUND-WATER AGE DATES FROM THE CHARACTERIZATION OF MULTIPLE REGOLITH-FRACTURED BEDROCK GROUND-WATER RESEARCH STATIONS IN NORTH CAROLINA

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Abstract. As part of the North Carolina Piedmont and Mountains Resource Evaluation Program, research stations were established in representative, regional geologic belts to study ground-water flow and quality. Two major findings from the five research stations (more than 120 wells) include (1) similar vertical gradient directions from the regolith to the transition zone, such as downward gradients in recharge areas, and upward gradients in discharge zones (vertical gradients in the bedrock are variable depending on the fracture network tapped by the well); and (2) similar apparent ground-water ages and evidence of longer apparent flowpaths for older ground water in discharge areas compared to younger water in recharge areas. Additionally, shallow ground water in the regolith is older in discharge areas compared to recharge areas, indicating a longer flowpath and residence time.

INTRODUCTION

Ground-water flow systems in the fractured bedrock-regolith aquifers of the Piedmont and Blue Ridge regions of the Southeastern United States are highly complex and localized, as a result of the inherently diverse geology. Although the local setting is complex, comparison of similar studies in several representative regional hydrogeologic settings was undertaken to evaluate potential commonalities in the ground-water system. As part of the North Carolina Piedmont and Mountains Resource Evaluation Program (NC PMREP), ground-water research stations were established within representative regional geologic belts (North Carolina Geological Survey, 1985). An overall plan for this study is presented in Daniel and Dahlen (2002).

STUDY AREAS

Locations of the five ground-water research stations in the North Carolina Piedmont and Blue Ridge physiographic provinces are presented in Figure 1 and corresponding station numbers are listed in Table 1. Primary rock type and foliation characteristics of the five ground-water research stations also are listed in Table 1.

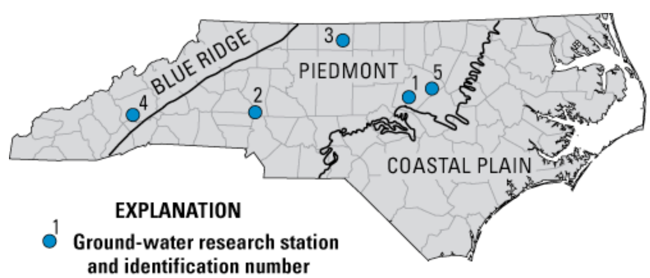

Figure 1. Locations of North Carolina Piedmont and Mountains Resource Evaluation Program ground-water research stations. See table 1 for list of station names.

Table 1. Physiographic province and lithologic setting of North Carolina Piedmont and Mountains Resource Evaluation Program ground-water research stations (RS).

Station number (figure 1)	Station name	Rock type(s)	Foliation
1	Lake Wheeler Road RS	Felsic gneiss	Well developed; steeply dipping; consistent orientation.
2	Langtree Peninsula RS	Quartz diorite	Weak to massive (none); two orientations where developed.
3	Upper Piedmont RS	Felsic gneiss, amphibolite, schist	Strong in some rock units; gently to moderately dipping.
4	Bent Creek RS	Felsic gneiss, amphibolite, schist	Well developed; moderate to steeply dipping; two orientations.
5	Raleigh Hydrogeologic RS	Granite	Massive (none) to weak with erratic orientations.

METHODS OF INVESTIGATION

Characterization of the NC PMREP ground-water research stations included detailed geologic mapping and structural analysis; collection and logging of soil and rock cores; and installation of observation wells grouped into clusters tapping the three different zones within the ground-water system—regolith, transition zone, and bedrock. The observation well clusters were aligned along topographic transects (Fig. 2). Additional piezometers (1-inch diameter) were installed to map lateral ground-water flow in the shallow regolith and to conduct aquifer tests. A data collection platform was installed at each research station at a single well cluster to continuously monitor water levels and water quality in all three zones. Additionally, ground-water-level data were collected monthly or bimonthly in wells tapping the three zones. Slug tests were conducted in most wells. Surface geophysical surveys were conducted at some research stations to evaluate the subsurface weathering profile and geologic setting. Borehole geophysical, video, and image logs, as well as packer sampling and testing, were conducted in the bedrock wells. Atmospheric tracer samples (Plummer and Friedman, 1999) used to evaluate apparent ground-water ages were collected from all three zones. Detailed discussions of methods used in the NC PMREP are described in Chapman and others (2005), and Huffman and others (2006).

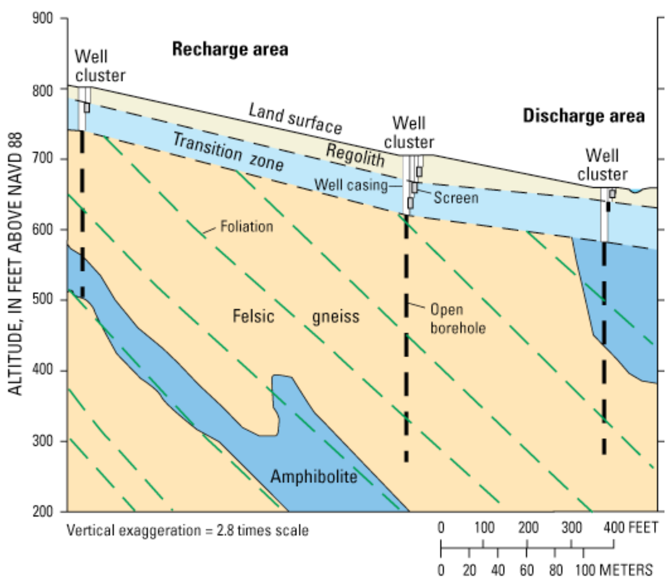

Figure 2. Typical North Carolina Piedmont and Mountains Resource Evaluation Program research station construction along a topographic transect. The dip-slope transect at the Upper Piedmont research station is shown (NAVD 88, North American Vertical Datum of 1988).

VERTICAL GRADIENTS AND RESPONSE TO RECHARGE FROM PRECIPITATION

Continuous ground-water levels were recorded hourly in both recharge and discharge areas to evaluate response to precipitation and monitor seasonal fluctuations. Water-level changes in recharge areas were gradual, showing a response to climatic factors (drought conditions occurred during water years[1] 2001 and 2002, and above-normal precipitation was observed in water year 2003) (Figs. 3 and 4). Additionally, ground-water levels recorded in recharge areas indicate a downward gradient from the shallow regolith to the underlying bedrock. Ground-water levels recorded in discharge areas (Fig. 4) indicate a more rapid response to rainfall events; this response most likely is from a rise in nearby stream stage (boundary condition). Ground-water levels in discharge areas indicate an upward gradient from the deeper bedrock to the shallow regolith (Fig. 4).

APPARENT GROUND-WATER AGES

Concentrations of atmospheric tracers—including chlorofluorocarbon compounds (CFC's) (International Atomic Energy Agency, 2006), tritium (Michel, 1989), tritium/helium ($^3H/^3He$) decay (Schlosser and others, 1988), and helium gas measurements (^4He) (Schlosser and others, 1989)—were used to interpret apparent ages of ground-water samples collected in the three zones in the ground-water system along topographic transects at the research stations. When interpretations of apparent ages of ground-water samples from different research stations are compared, similar distributions are observed. In general, apparent ground-water age increases with depth, as would be expected with downward infiltration of recharge from the atmosphere. Ground water in the regolith (shallowest part of the ground-water system) is the youngest, being a few to several decades younger than ground water from deep fractures in the underlying bedrock part of the ground-water system. An example of age distribution along the Lake Wheeler Road research station topographic transect is shown in Figure 5.

In some samples, binary mixing models were used to estimate the relative percentage of older, pre-tracer water (pre-1940s) mixed with younger water. The mixing models indicate that shallow ground water in discharge areas has a larger component of older water than shallow ground water in recharge areas. This finding supports the conceptual model of longer flowpaths (greater residence times) in discharge areas.

[1] Water year is October 1st through September 30th

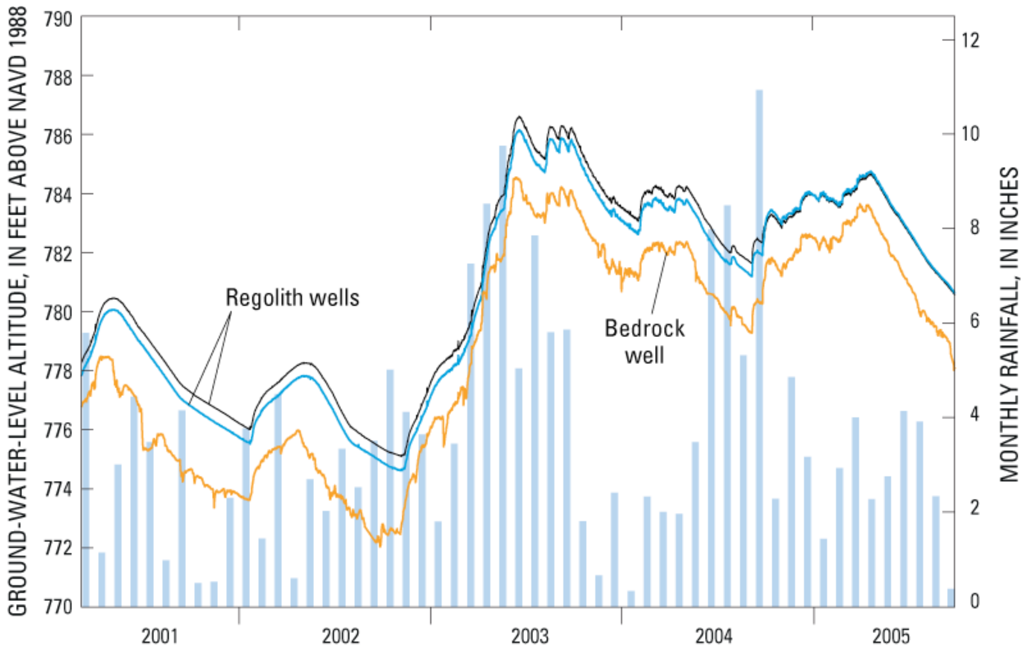

Figure 3. Continuous ground-water levels recorded in a recharge area at the Langtree Peninsula research station, North Carolina (NAVD 88, North American Vertical Datum of 1988).

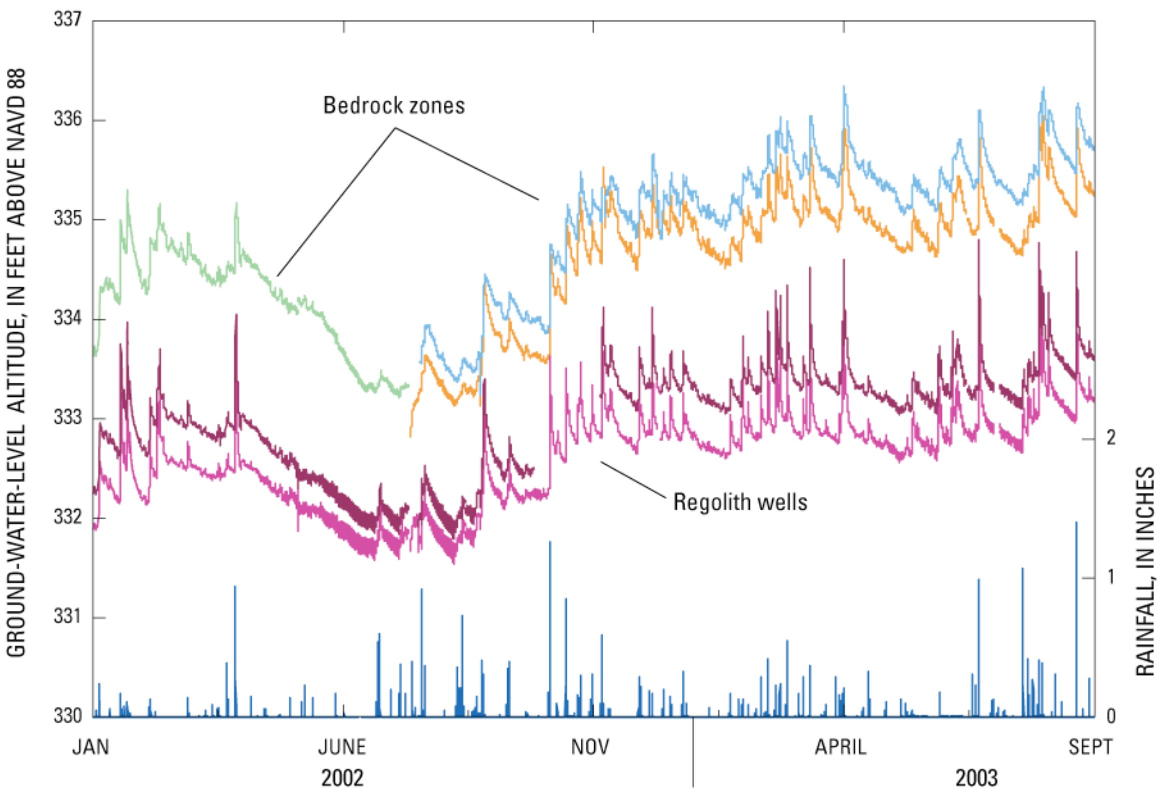

Figure 4. Continuous ground-water levels recorded in a discharge area at the Lake Wheeler Road research station, North Carolina (NAVD 88, North American Vertical Datum of 1988).

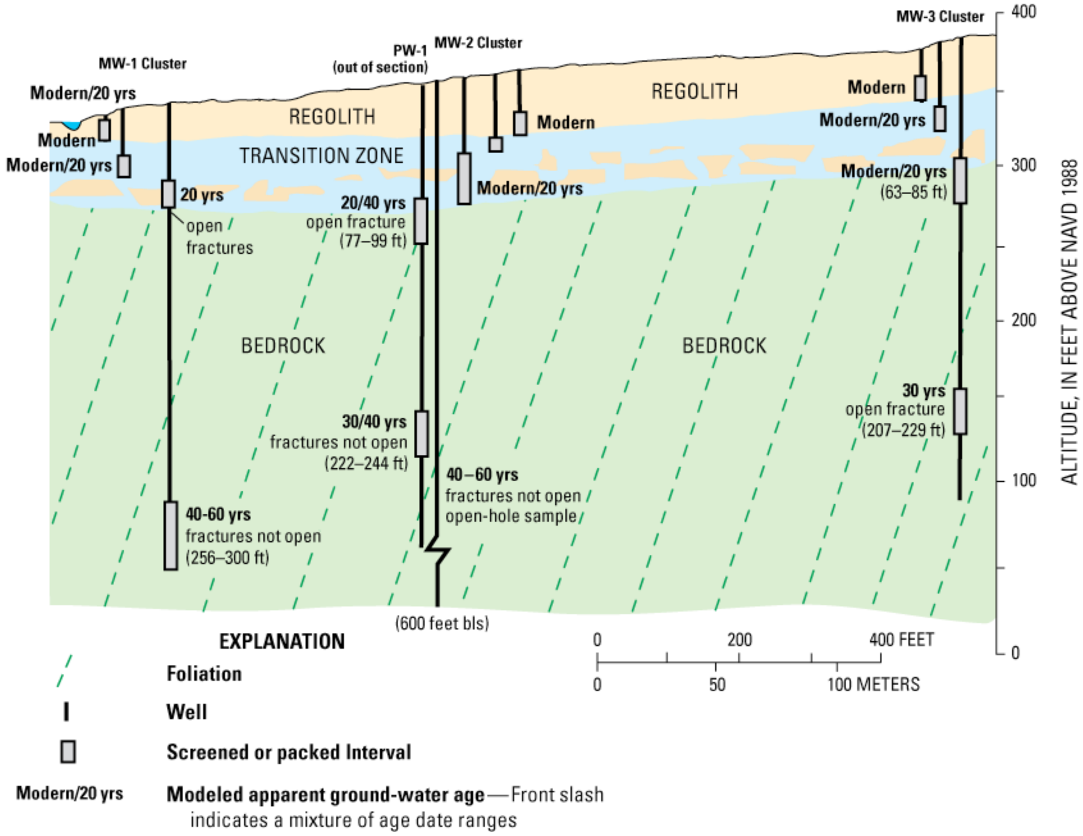

Figure 5. Overall apparent age interpretations for ground-water samples collected from different zones along a topographic transect (Lake Wheeler Road research station, North Carolina).

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