Hydrogeology and Water Quality at Bent Creek Experimental Forest, a Piedmont-Mountains Fractured Rock Ground Water Research Station

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Piedmont/Mountains Resource Evaluation Program
Research questions

- what is the geologic setting?
- what is the nature of ground water flow in this geologic/topologic setting and does this match our conceptual model of flow in the Piedmont and Mountains?
- what are the aquifer properties in this setting?
- what is the quality of the ground and surface water?
Tools used to evaluate hydrogeology at Bent Creek

- geologic mapping
- rock coring
- observation well clusters
- age dating chemistry
- downhole geophysics (caliper logs, resistivity logs, gamma logs, optical televiewer)
- packer tests, heat pulse flow metering, and others
- slug tests
- aquifer pumping tests
- water chemistry (ground and surface water)
Blue Ridge Belt

Ashe Metamorphic Suite

...heterogeneous unit consisting of repetitive layers of sedimentary and mafic volcanic rocks metamorphosed to sillimanite grade; metagraywacke, biotite and muscovite-biotite gneiss, amphibolite....
Regional geology…

Zatm - Muscovite-biotite gneiss
…interlayered and gradational with mica schist and minor amphibolite, and hornblende gneiss

Basin geology….

Zas – Mica schist (sillimanite, garnet, chlorite)
Zag – Metagraywacke
Bent Creek Experimental Forest watershed Study area

Zatm - Muscovite-biotite gneiss
…interlayered and gradational with mica schist and minor amphibolite, and hornblende gneiss

Zas – Mica schist (sillimanite, garnet, chlorite)
Zag – Metagraywacke

Regional geology… Basin geology…. Study area geology…
Study area geology

From Merschat and Carter, 2002
Study area geology

Sillimanite-Garnet-Chlorite-Mica Schist (Zas): Very light-gray to greenish-gray to medium-gray; strongly foliated; fine-grained; equigranular to inequigranular; lepidoblastic to porphyroblastic; consists of 0.6-13.6% quartz, 0.0-0.6% plagioclase, 31.6-74.4% muscovite, 0.0-18.0% sericite, 6.2-15.2% chlorite, 0.2-25.6% garnet, 3.0-7.8% opaques, and a trace of sillimanite; thickness of layering ranges from millimeters to centimeters; commonly interlayered with sillimanite-garnet-chlorite-mica metasiltstone.
Metagraywacke (Zag): Medium-light-gray to medium-dark-gray; nonfoliated to weakly foliated; medium- to coarse-grained; equigranular to inequigranular; granoblastic to lepidoblastic; locally migmatitic; consists of 26.4-37.2% quartz, 31.8-42.2% plagioclase, 0.0-28.4% k-feldspar, 3.8-8.0% muscovite, 6.0-11.4% biotite, 0.6-2.0% garnet, 0.0-1.0% hornblende, trace-10.8% epidote group minerals, trace-0.6% ilmenite and other black opaque minerals, trace-0.4% apatite, and a trace of zircon; thickness of layering ranges from several decimeters to several meters.
Saprolite – Highly weathered parent material, often bears relict features such as primary rock textures.

Transition Zone – Weathering zone between saprolite and bedrock, generally more transmissive than the overlying saprolite zone.

Fractured Bedrock – Igneous or metamorphic rocks. Groundwater is transmitted to discharge areas or wells via fracture network. Highly transmissive, but little storage. Connectivity to overlying regolith determines available water.

Regolith – Unconsolidated material, soil, saprolite, and transition zone.

Figure 2. Principal components of the ground-water system in the Piedmont physiographic province of North Carolina (from Harned and Daniel, 1992).
real-time stream gage

well cluster (saprolite, transition zone, & deep bedrock) and core location

piezometer cluster

aquifer test location
Study area geology

Rock Core Example
- Core 3 -

saprolite
transition zone

The remaining rock core, down to the completion depth of 168 ft, was similar to the 54-66 ft interval.
Fe oxide stains are common in transition zone material.
Study area geology

Rock Core Example

- Core 5 -

Core 5: 0-18 ft
Core 5: 18-36 ft
Core 5: 36-46 ft
Core 5: 46-56 ft

The remaining rock core, down to the completion depth of 103 ft, was similar to the 46-56 ft interval.

saprolite
transition zone
Rock Core Example

- Core 5 -

Fe oxide staining

migmatite

Core 5: 46-56 ft
Rock Core Example
- Core 1 -

Core 1: 0-13 ft
Core 1: 13-22 ft
Core 1: 22-31 ft
Core 1: 31-39 ft

saprolite
transition zone
Rock Core Example

- Core 1 – (continued)

The remaining rock core, down to the completion depth of 1189 ft, was similar to the 58-67 ft interval.
Ground water occurrence

Saprolite – Highly weathered parent material, often bears relict features such as primary rock textures.

Transition Zone – Weathering zone between saprolite and bedrock, generally more transmissive than the overlying saprolite zone.

Fractured Bedrock – Igneous or metamorphic rocks. Groundwater is transmitted to discharge areas or wells via fracture network. Highly transmissive, but little storage. Connectivity to overlying regolith determines availability.

Regolith – Unconsolidated material, soil, saprolite, and transition zone.

**Ground Water Occurrence**

- **Saprolite**: 0 to 38 ft thick (median = 10 ft)
  - Site 1: 0
  - Site 2: 20
  - Site 3: 38
  - Site 4: 26
  - Site 5: 33
  - Site 6: 18
  - Site 7: 25

- **Transition Zone**: 5 to 44 ft thick (median = 16 ft)
  - Site 1: 44
  - Site 2: 20
  - Site 3: 18
  - Site 4: 7
  - Site 5: 27
  - Site 6: 18
  - Site 7: 22

- **Bedrock**: 33 to 63 ft to top of rock (median = 48 ft)
  - Site 1: 48
  - Site 2: 43
  - Site 3: 61
  - Site 4: 35
  - Site 5: 63
  - Site 6: 38
  - Site 7: 50

**Figure 2.** Principal components of the ground-water system in the Piedmont physiographic province of North Carolina (from Harned and Daniel, 1992).
Surface water hydrology

- rainfall ~ 47 in/yr
- area ~ 8.5 sq miles
- 13 tributaries (Boyd Branch avg flow ~ 1.5 cfs)
- Bent Creek drains the entire watershed (avg flow ~ 15 cfs)
- recharge ~ 23 in/yr…and baseflow ~ 19 in/yr (USGS PART program, 1998)
Borehole geophysics

- Well 1D -

40 gpm yield
Borehole geophysics

- Well 5D -

1 gpm yield
Ground water hydrographs - fluctuations with time
- vertical gradients

Well 1 is in discharge area

Ground water hydrograph: water level vs time
at well cluster 1
Ground water hydrographs - fluctuations with time
- vertical gradients

Ground water hydrograph: water level vs time at well cluster 2

well 2 (artesian, flowing well) is in discharge area
Ground water hydrographs - fluctuations with time
- vertical gradients

Ground water hydrograph: water level vs time at well cluster 3

well 3 is in recharge area
Ground water hydrographs - fluctuations with time
- vertical gradients

Ground water hydrograph: water level vs time
at well cluster 4

well 4 is in recharge area
Ground water hydrographs - fluctuations with time - vertical gradients

Ground water hydrograph: water level vs time at well cluster 5

well 5 is in recharge area
Ground water hydrographs - fluctuations with time
- vertical gradients

Ground water hydrograph: water level vs time
at well cluster 7

well 7 is in recharge area
Depth to ground water, in ft below land surface

Upslope direction

![Diagram showing depth to ground water at various locations labeled BC-1D to BC-7D. The locations are located adjacent to Boyd Branch.](image-url)

Located adjacent to tributary to Boyd Branch

Located adjacent to Boyd Branch

Graph showing depth to water, feet below land surface for BC-1D to BC-7D.
Horizontal gradients - direction of ground water flow

Water levels, Oct 05, 2004

Add 2000 to values to obtain ft, msl
Hydraulic conductivities obtained from slug testing

<table>
<thead>
<tr>
<th>Well</th>
<th>Aquifer material</th>
<th>Hydraulic conductivity, ft/day</th>
<th>Aquifer material</th>
<th>Hydraulic conductivity, ft/day</th>
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<tbody>
<tr>
<td>1S</td>
<td>TZ</td>
<td>30</td>
<td>1I</td>
<td>TZ</td>
</tr>
<tr>
<td>2S</td>
<td>saprolite</td>
<td>3</td>
<td>2I</td>
<td>TZ</td>
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<td>3I</td>
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<td>2</td>
<td>5I</td>
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<tr>
<td>3D</td>
<td>fractured rock</td>
<td>0.04</td>
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<tr>
<td>4D</td>
<td>fractured rock</td>
<td>0.2</td>
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</table>
Results of aquifer testing in regolith

pumped transition zone well 4I at 20 gpm for 72 hrs
Results of aquifer testing in regolith

Observation well 1S

pumped transition zone well 4I at 20 gpm for 72 hrs

saprolite well; 54 ft from pumping well
Results of aquifer testing in regolith

Observation well 1I

pumped transition zone well 4I at 20 gpm for 72 hrs

transition zone well; 45 ft from pumping well
### T and S obtained from aquifer testing in regolith

<table>
<thead>
<tr>
<th>Aquifer material</th>
<th>Transmissivity, ft²/day</th>
<th>Storage Coefficient</th>
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<tr>
<td>Well 4S saprolite</td>
<td>494</td>
<td>0.09</td>
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<tr>
<td>Well P1S saprolite</td>
<td>647</td>
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<tr>
<td>Well P1I TZ</td>
<td>642</td>
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</tr>
<tr>
<td>Well P5S saprolite</td>
<td>640</td>
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<tr>
<td>Well P5I TZ</td>
<td>694</td>
<td>0.008</td>
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<tr>
<td>Well P6S saprolite</td>
<td>612</td>
<td>0.006</td>
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<tr>
<td>Well P6I TZ</td>
<td>604</td>
<td>0.003</td>
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median = 642  median = 0.02

Stressing the system showed that un-foliated metagraywacke appeared to significantly impede the movement of water through the regolith.

Evidence of preferential flow along the foliation strike in schist.
Water Quality

Bicarbonate, mg/L

Chloride, mg/L

Sulfate, mg/L

Deep wells generally more mineralized…
Water Quality

Calcium, mg/L

Magnesium, mg/L

Sodium, mg/L

Deep wells generally more mineralized...
Water Quality

pH

Specific Conductance, uS/cm

Dissolved Oxygen, mg/L

Deep wells generally less oxygenated...
Schematic of conceptualized groundwater transport for Piedmont/Mountain aquifer system

Infiltration of O₂ rich water to groundwater surface. Dissolution of host materials and precipitation of dissolved ions.

Migration along the regolith flow path maintains an oxidative redox potential. Again dissolution and precipitation.

Migration from oxic to reducing environment. Dissolution slows.

Movement from the reducing conditions in the bedrock aquifer to greatly increased oxidative state in the discharge streams initiates the precipitation of dissolved constituents.

Migration along the bedrock flow path results in accumulation of dissolved ions.

Highly Oxidative

Moderately Oxidative

Mixing Zone Between Oxic and Reducing Waters

Reducing
Water Quality
Water Quality
Water Quality
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