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

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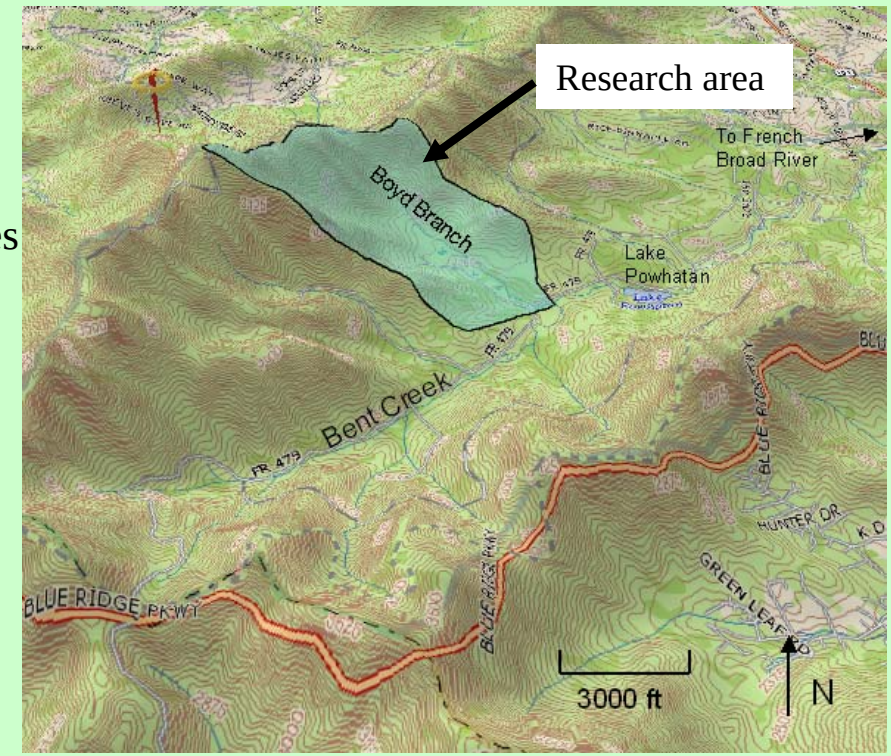
Division of Water Quality

Aquifer Protection Section

North Carolina, USA

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?

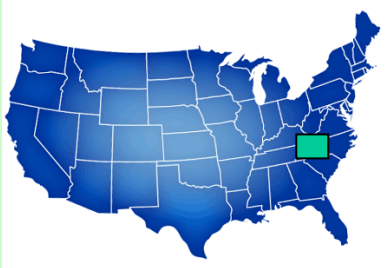
- what are the aquifer properties in this setting?

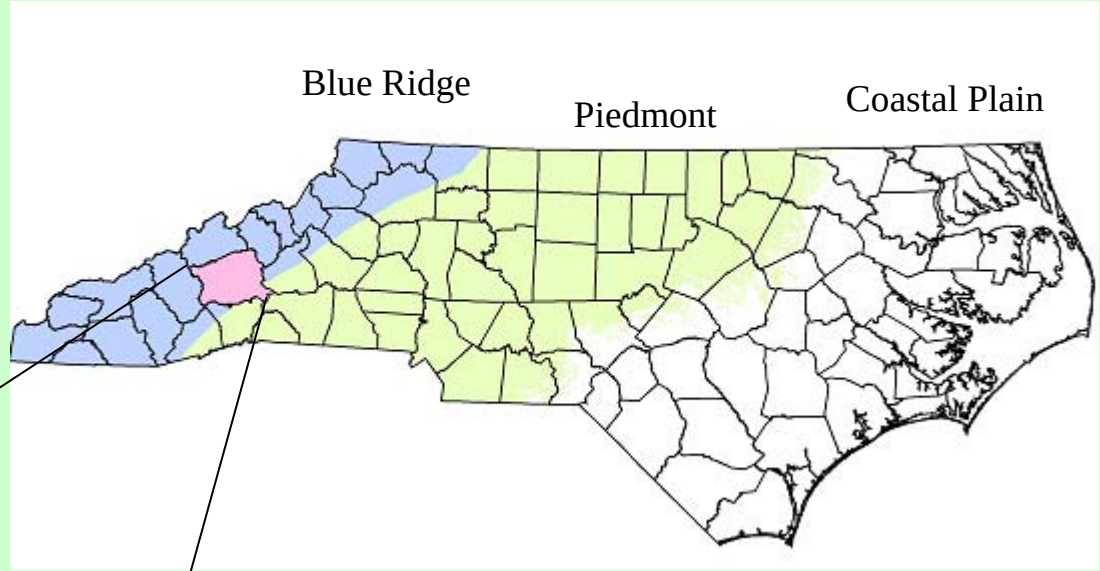
- what is the quality of the ground and surface water?

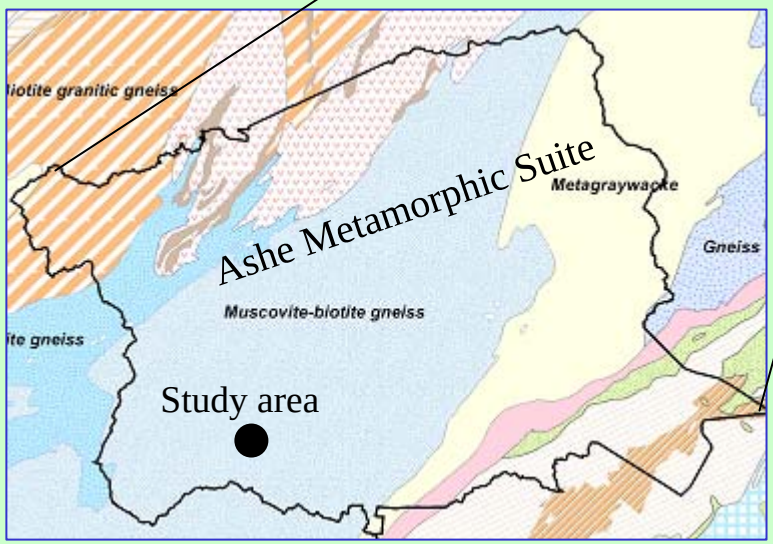
Tools used to evaluate hydrogeology at Bent Creek

- 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)

Location and geologic setting…





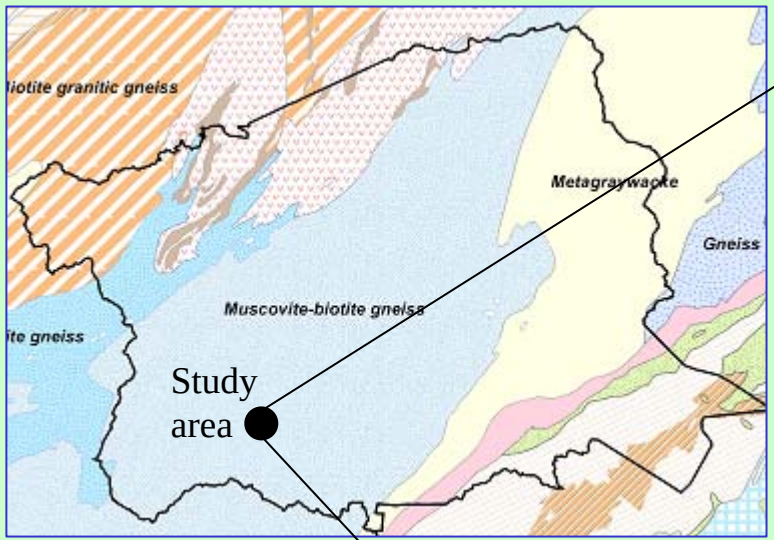


Blue Ridge Belt

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…

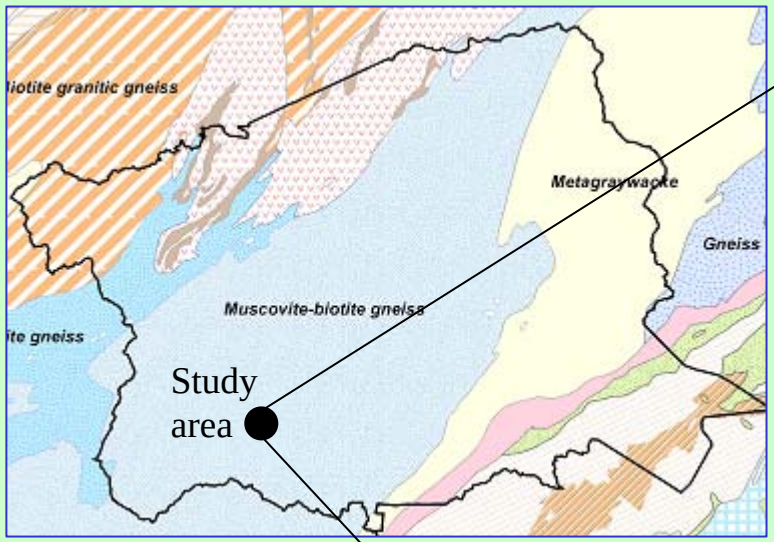


Zatm - Muscovite-biotite gneiss

…interlayered and gradational with mica schist and minor amphibolite, and hornblende gneiss

Basin geology….

Regional geology…



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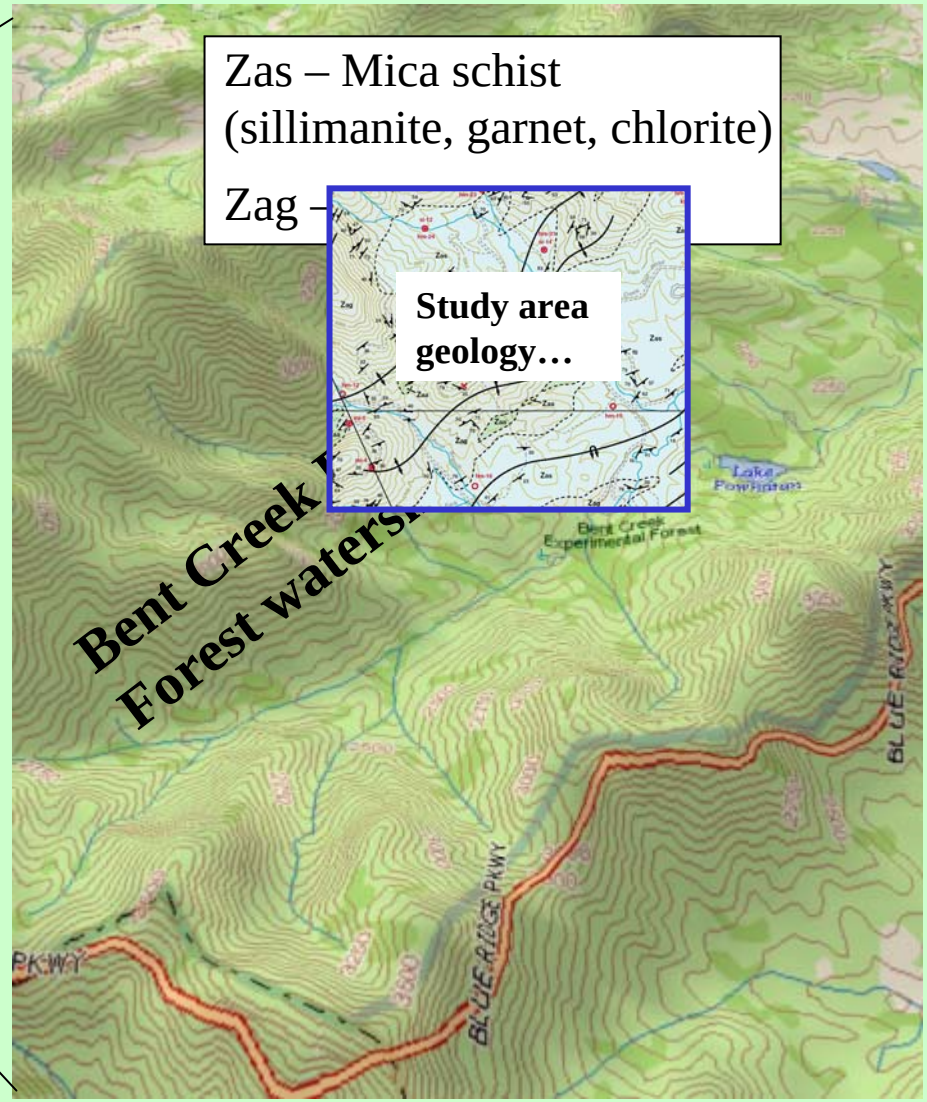
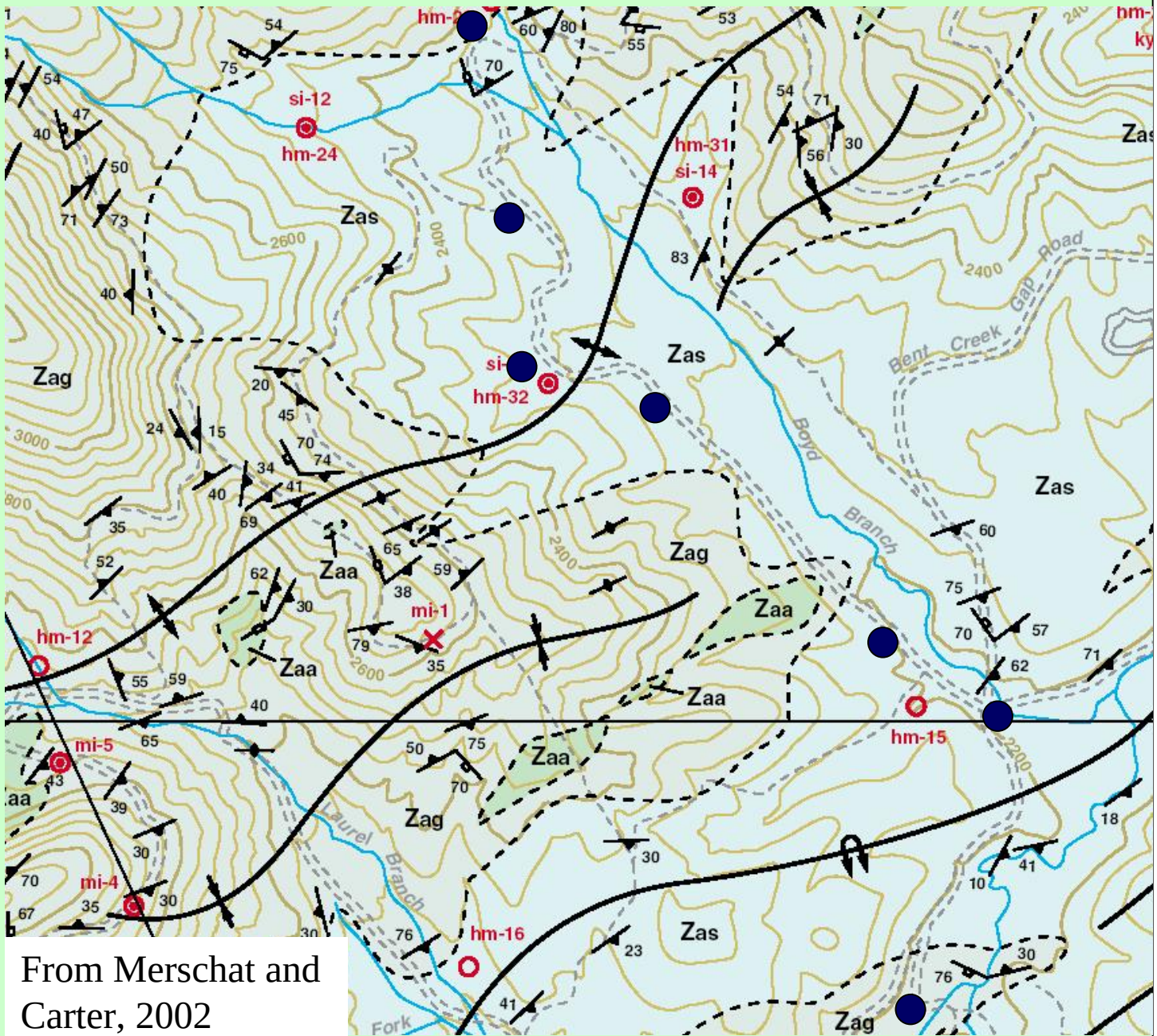
Basin geology….

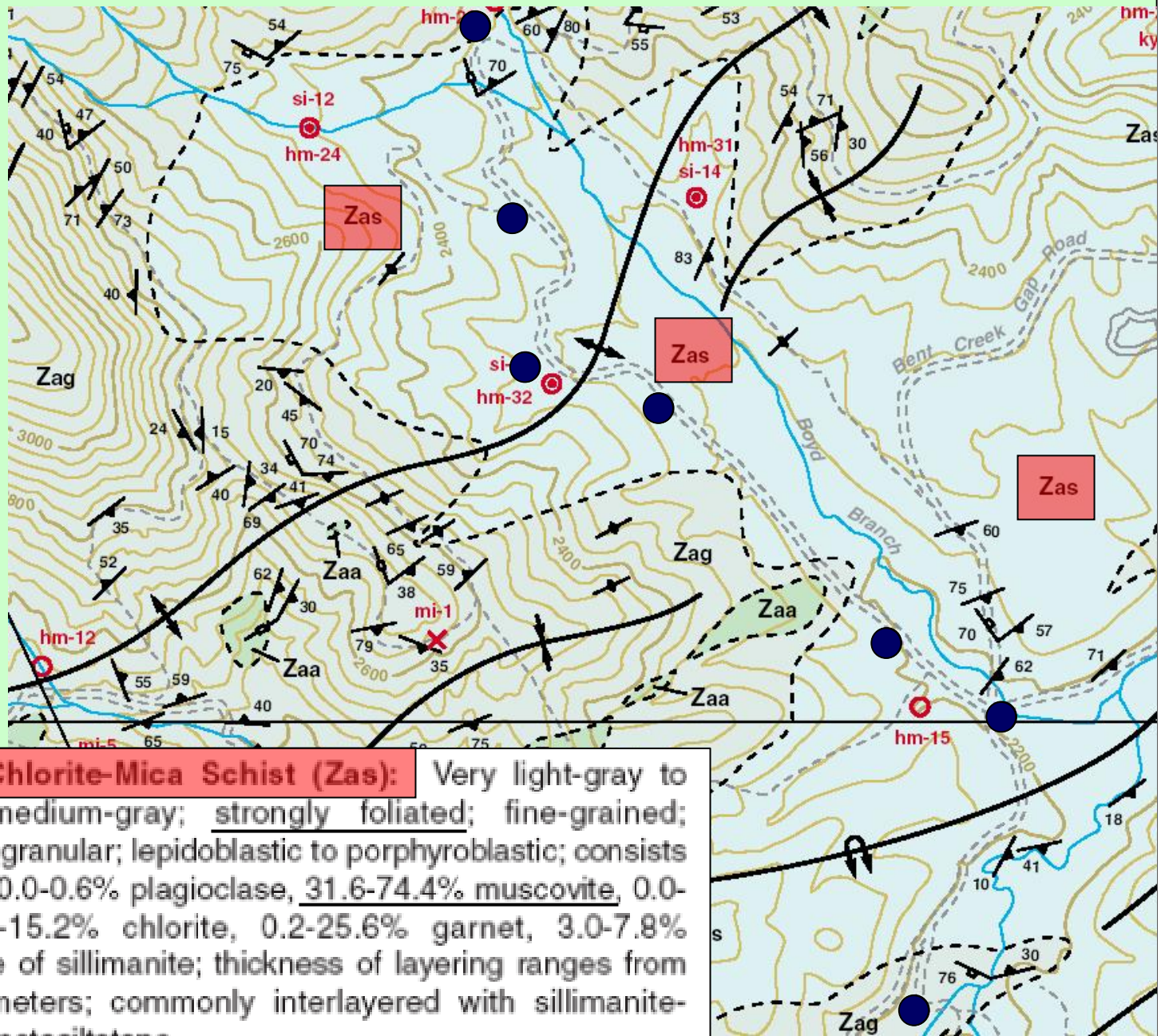


Study area geology



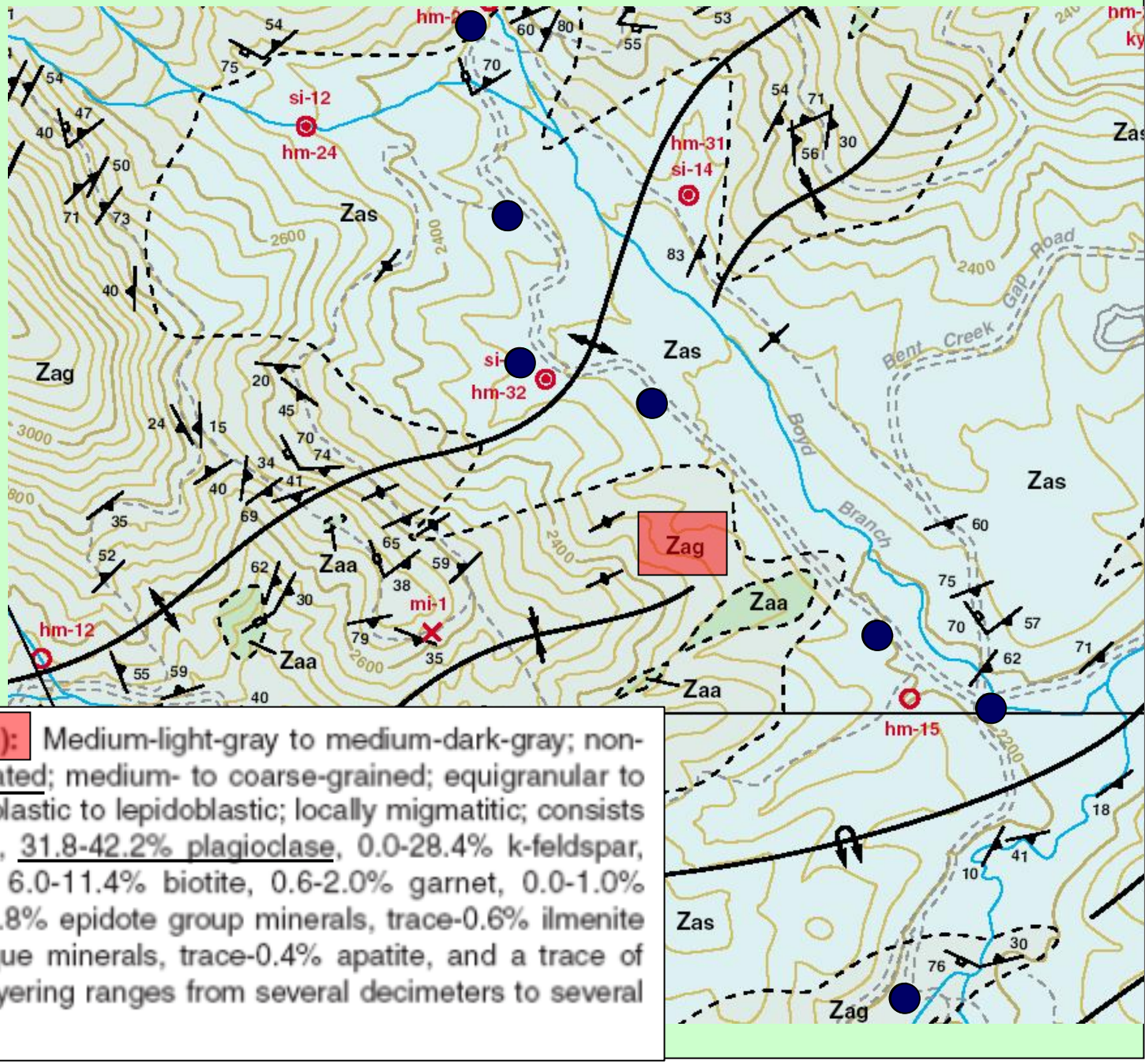
From Merschat and Carter, 2002

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.

Study area geology



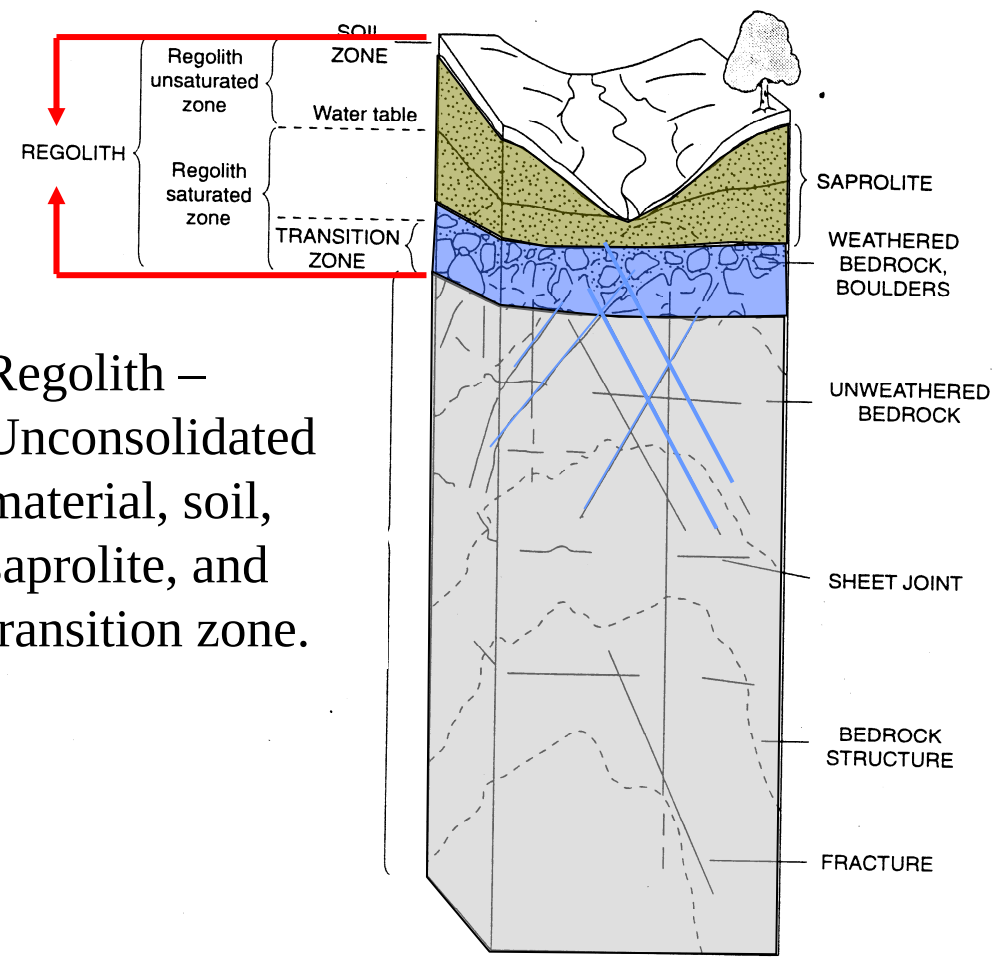
Metagraywacke (Zag): Medium-light-gray to medium-dark-gray; non-foliated to weakly foliated; medium- to coarse-grained; equigranular to inequigranular; granoblastic to lepidoblastic; locally migmatitic; consists of 26.4-37.2% quartz, 31.8-42.2% plagioclase, 0.0-28.4% k-feldspar, 3.8-8.0% muscovite, 6.0-11.4% 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.

Geologic setting through which ground water flows – our conceptual model

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

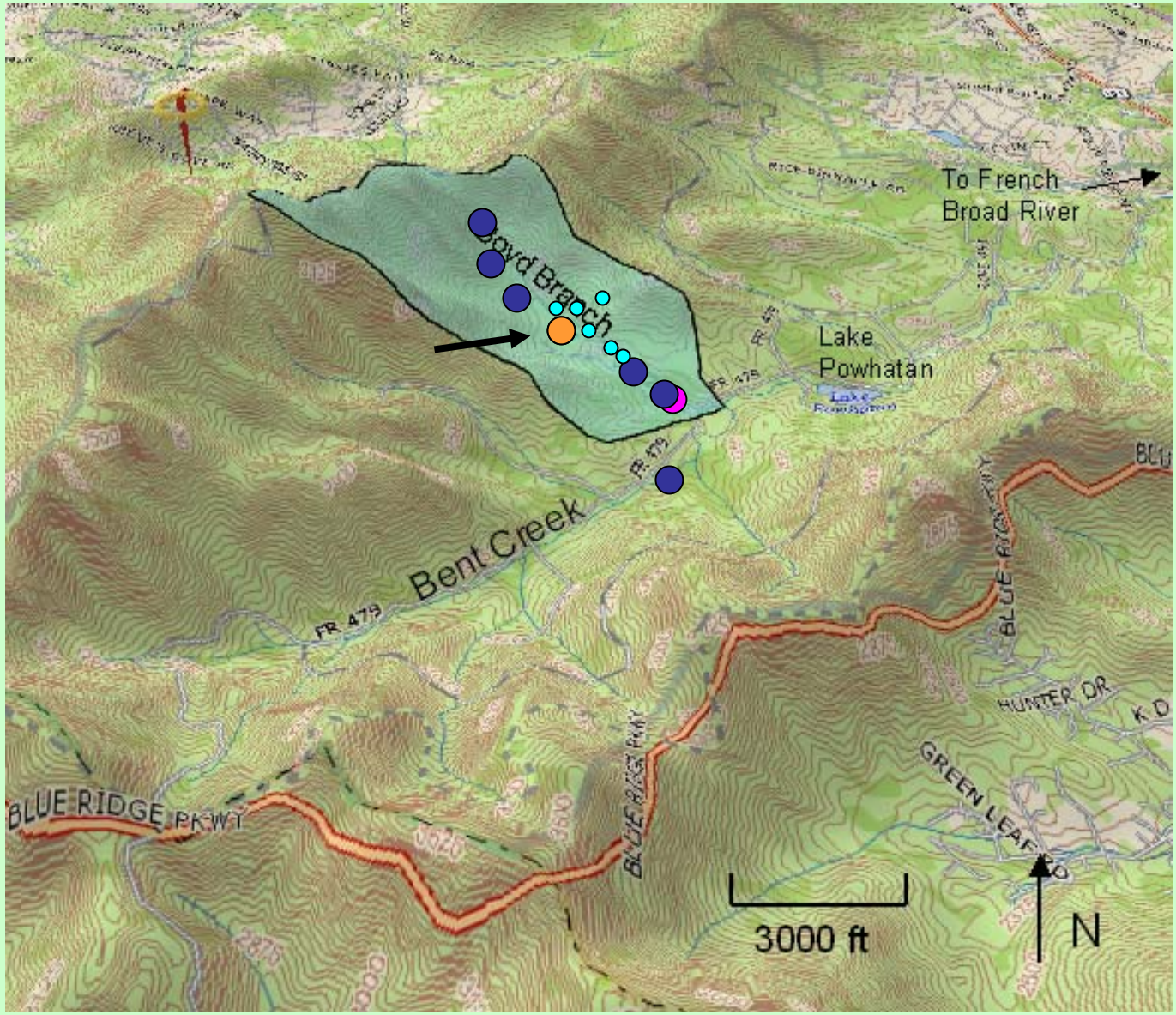
Transition Zone – Weathering zone between saprolite and bedrock, generally more transmissive than the overlying saprolite zone.

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).



Station equipment installation

- 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 -

Core 3: 0-21 ft

Core 3: 38-54 ft

Core 3: 21-38 ft

Core 3: 54-66 ft

saprolite

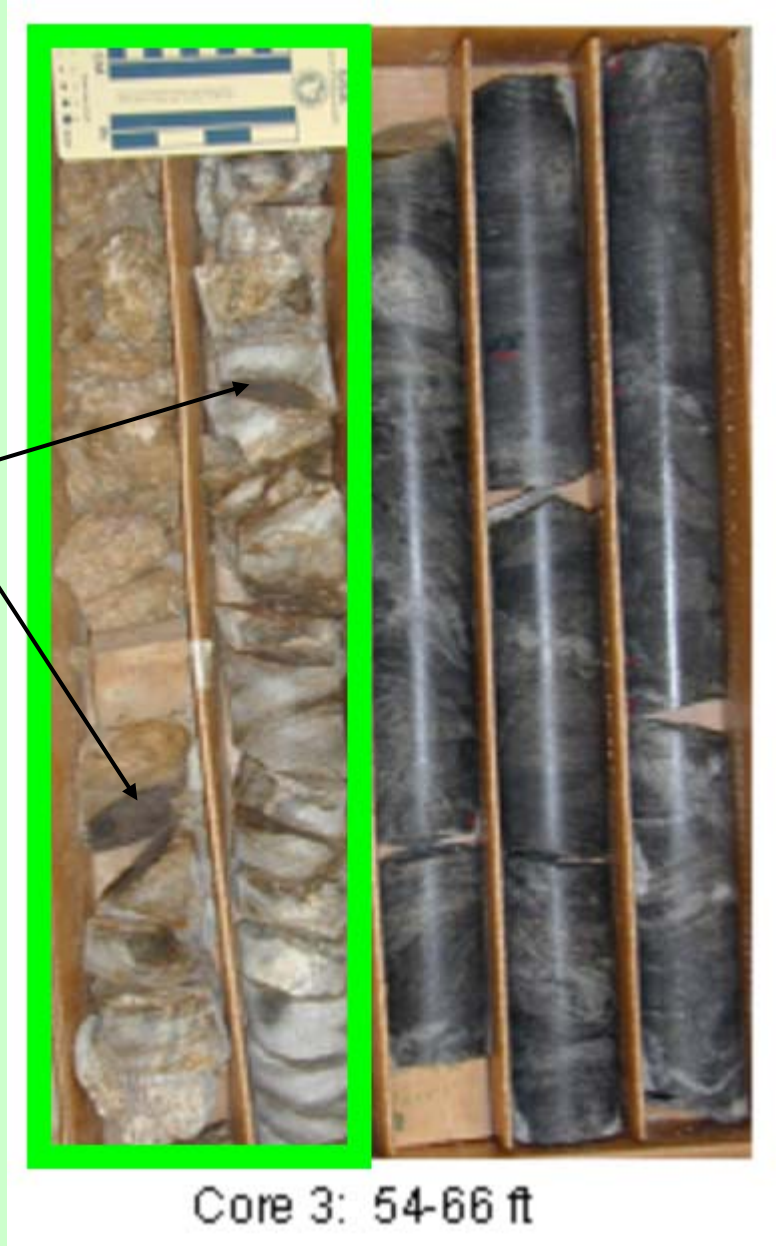
transition zone

The remaining rock core, down to the completion depth of 168 ft, was similar to the 54-66 ft interval.

Rock Core Example

- Core 3 -

Fe oxide stains are common in transition zone material



migmatite

Study area geology

Rock Core Example

- Core 5 -

Core 5: 0-18 ft

Core 5: 36-46 ft

Core 5: 18-36 ft

Core 5: 46-56 ft

saprolite

transition zone

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

Rock Core Example

- Core 5 -

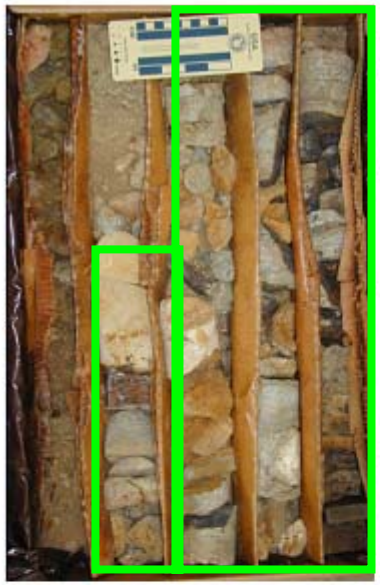
Fe oxide staining

Core 5: 46-56 ft

migmatite

Rock Core Example

- Core 1 -



Core 1: 0-13 ft

Core 1: 22-31 ft

Core 1: 13-22 ft

Core 1: 31-39 ft

saprolite

transition zone

Rock Core Example

- Core 1 – (continued)

Core 1: 39-49 ft

Core 1: 58-67 ft

Core 1: 49-58 ft

The remaining rock core, down to the completion depth of 189 ft, was similar to the 58-67 ft interval.

saprolite

transition zone

Ground water occurrence

Saprolite – Highly weathered

Saprolite: 0 to 38 ft thick (median = 10 ft)

Site	1	2	3	4	5	6	7
	0	20	38	26	33	18	25

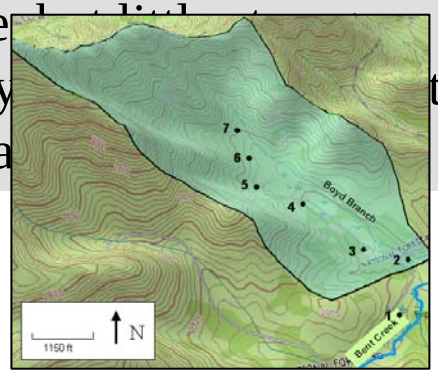
Transition Zone – Weathering zone

Transition zone: 5 to 44 ft thick (median = 16 ft)

Site	1	2	3	4	5	6	7
	44	20	18	7	27	18	22

Bedrock: 33 to 63 ft to top of rock (median = 48 ft)

Site	1	2	3	4	5	6	7
	48	43	61	35	63	38	50



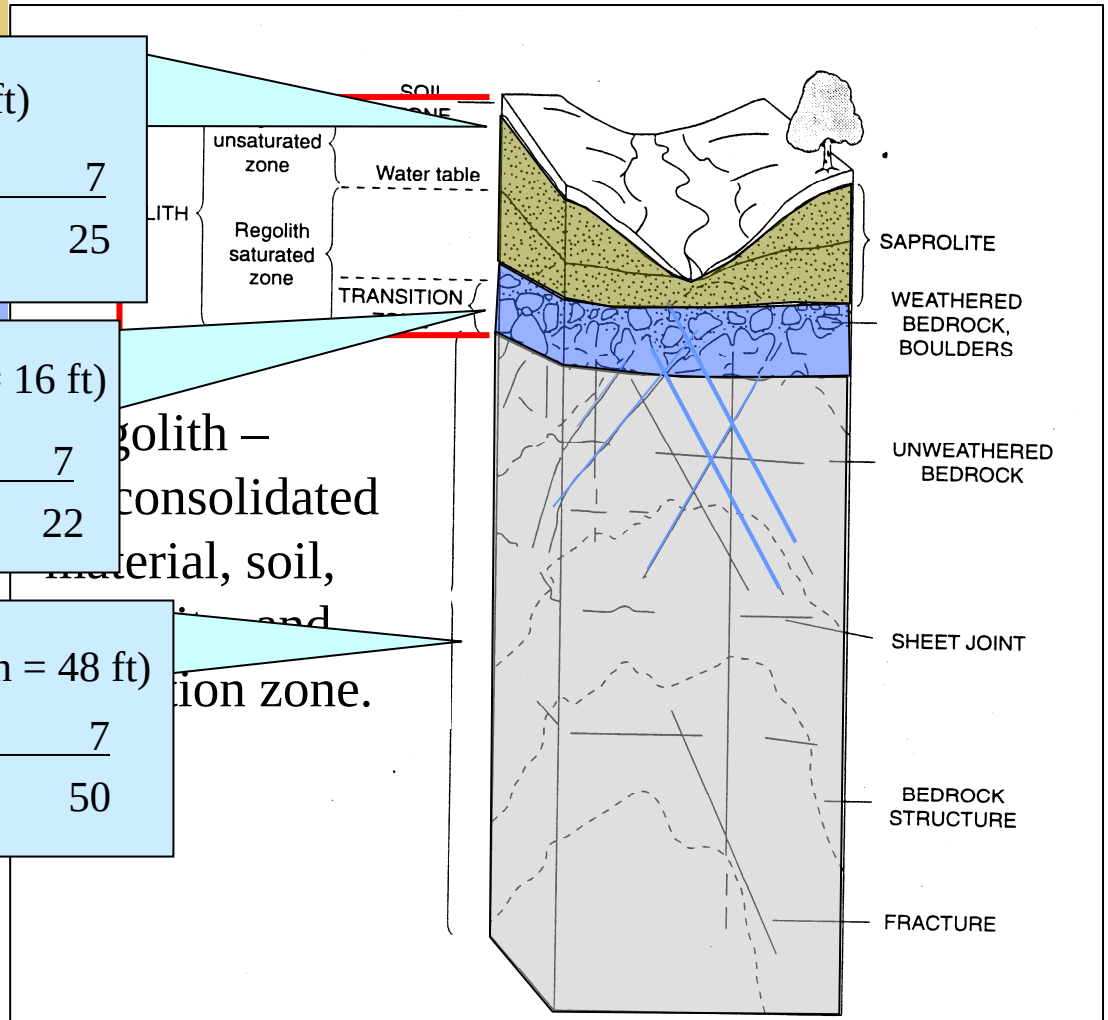


Figure 2. Principal components of the ground-water system in the Piedmont physiographic province of North Carolina (from Harned and Daniel, 1992).

Surface water hydrology

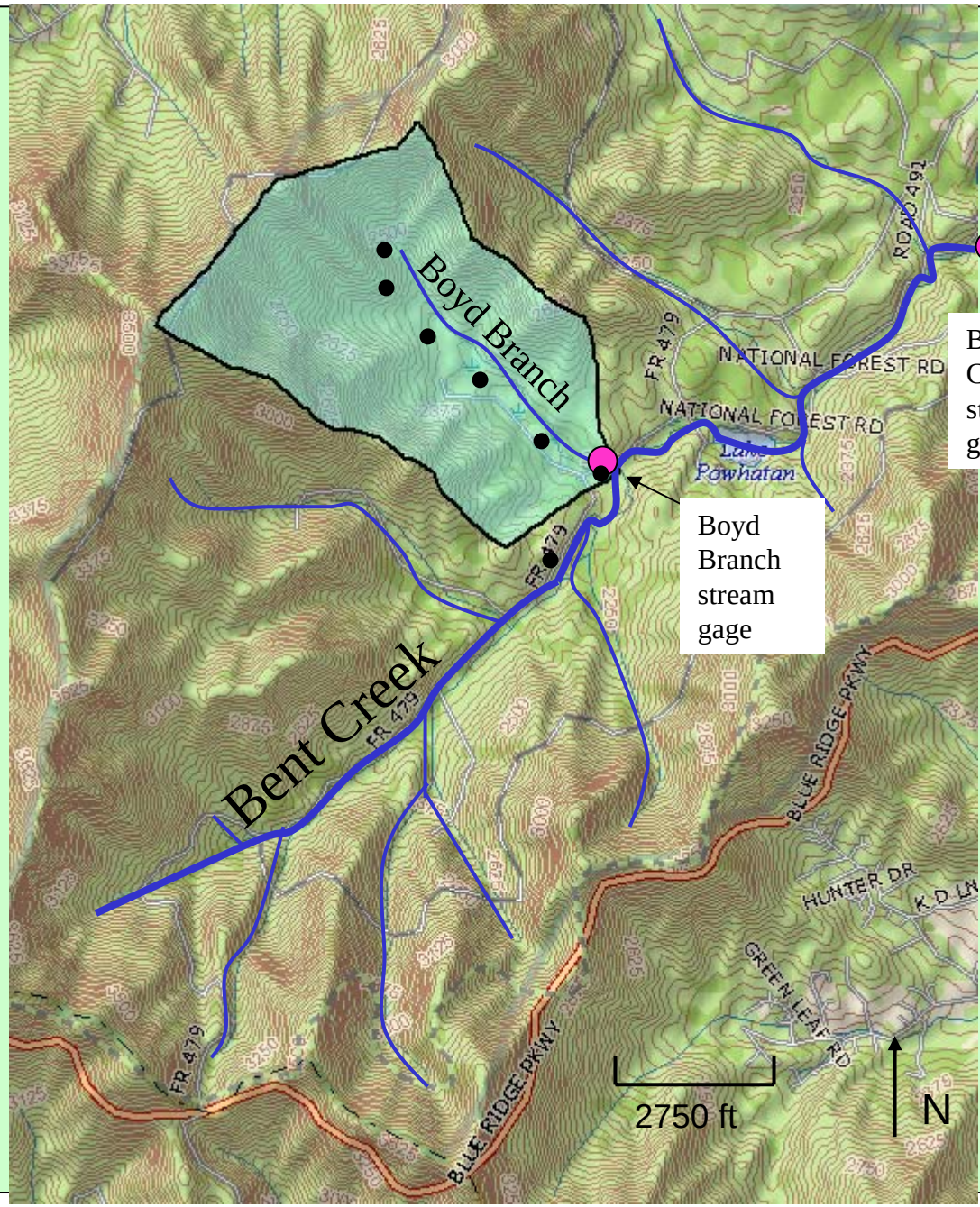
- rainfall ~ 47 in/yr

- area ~ 8.5 sq miles

- 13 tributaries (Boyd Branch avg flow ~ 1.5 cfs)

- Bent Creek drains the entire watershed (avg flow ~ 15 cfs)

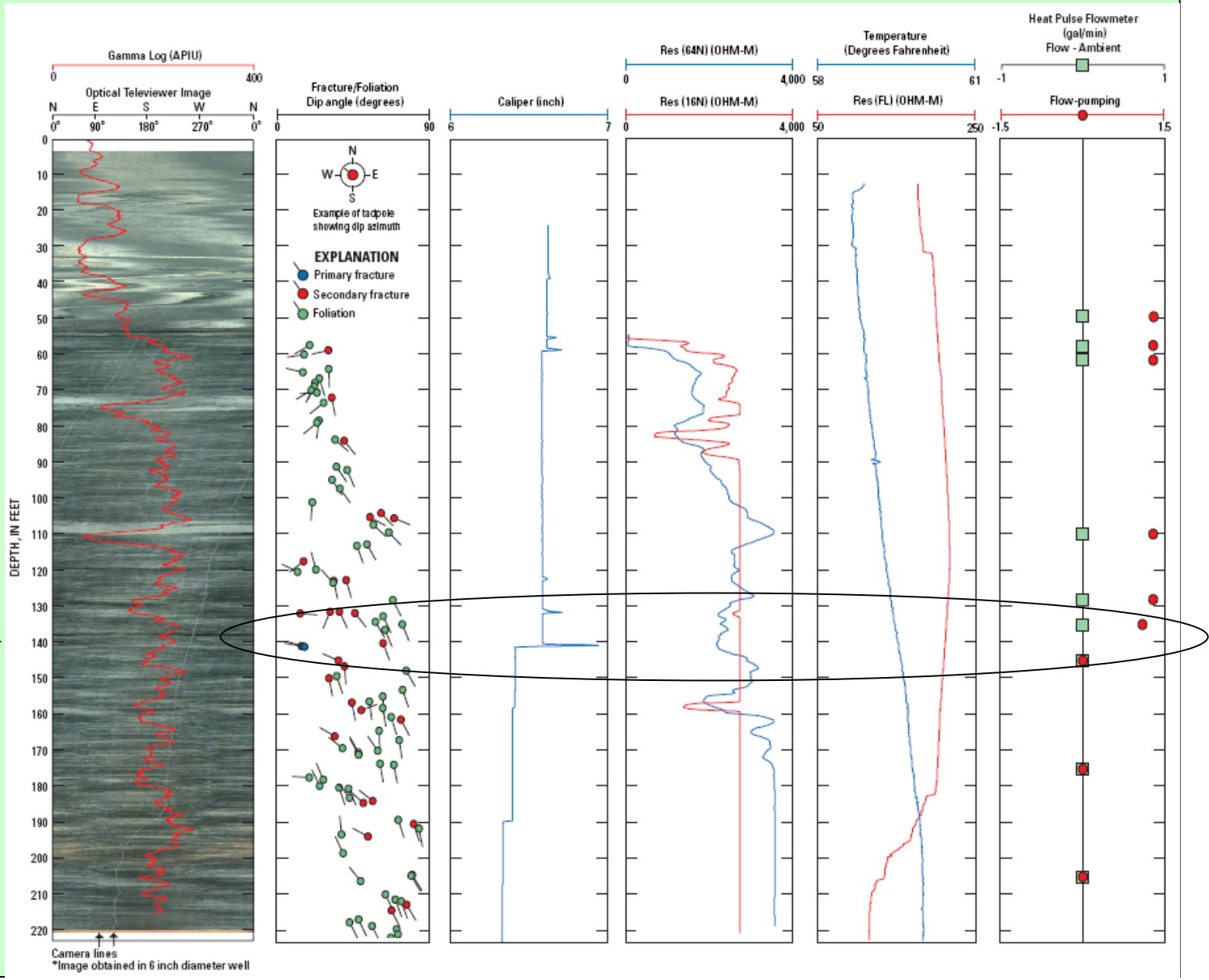
- recharge ~ 23 in/yr…and baseflow ~ 19 in/yr (USGS PART program, 1998)



Borehole geophysics

- Well 1D -

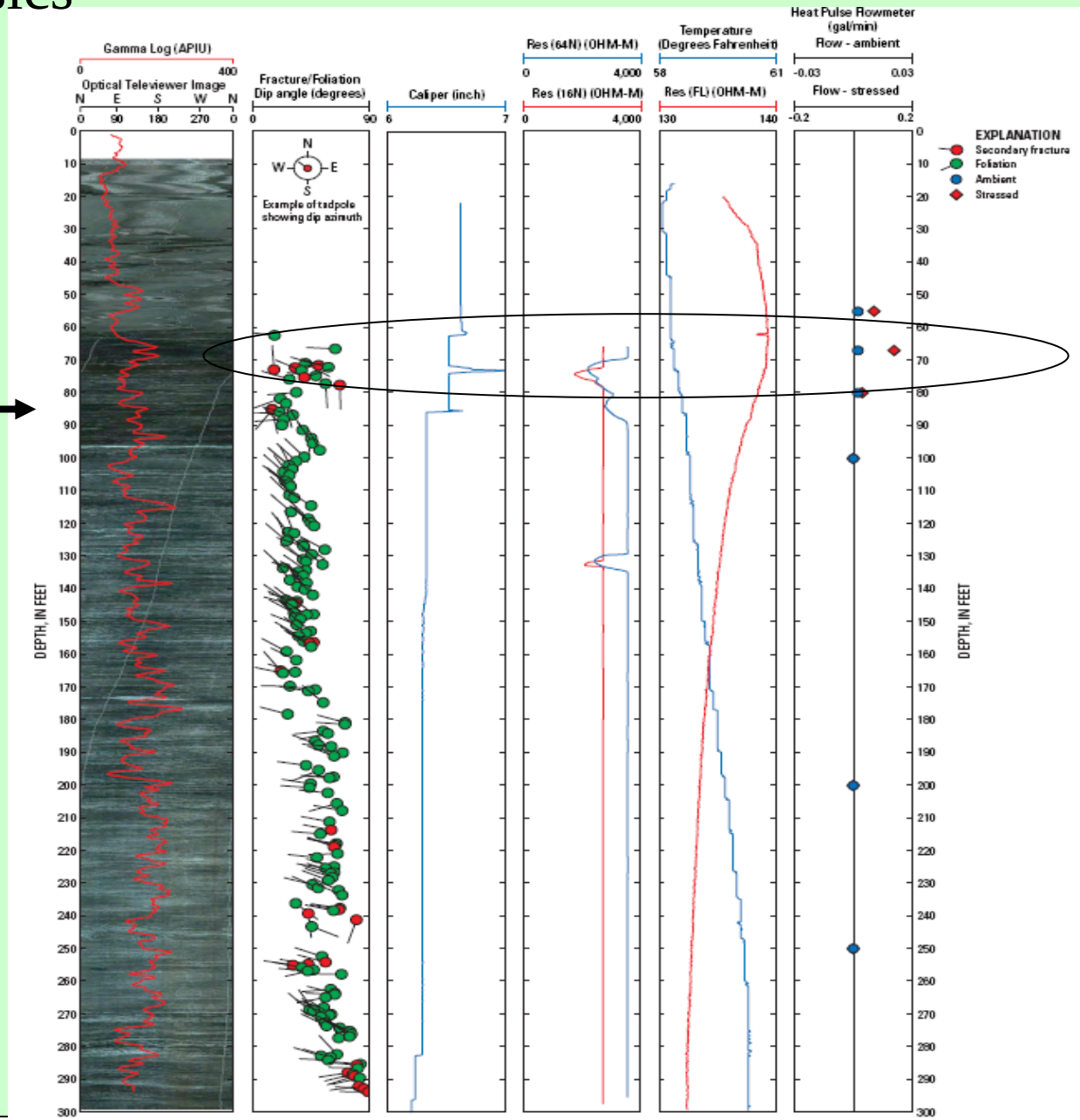
40 gpm yield



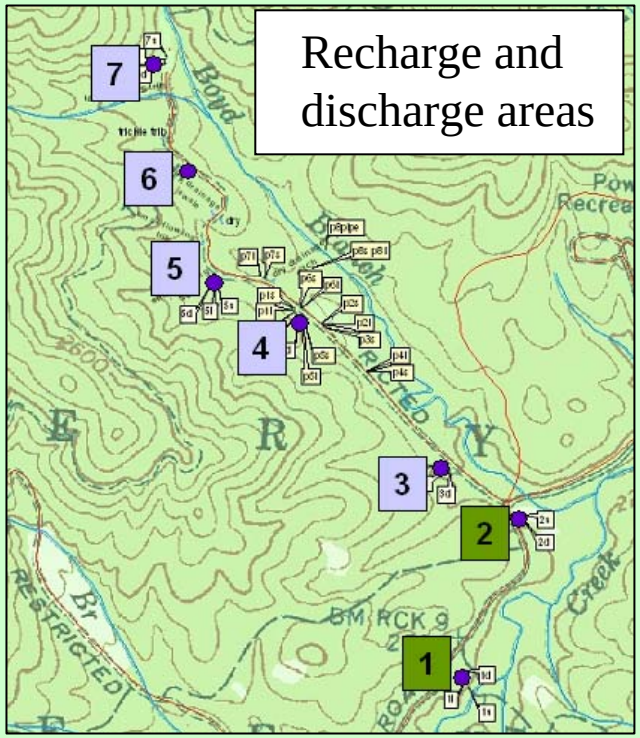
Borehole geophysics

- Well 5D -

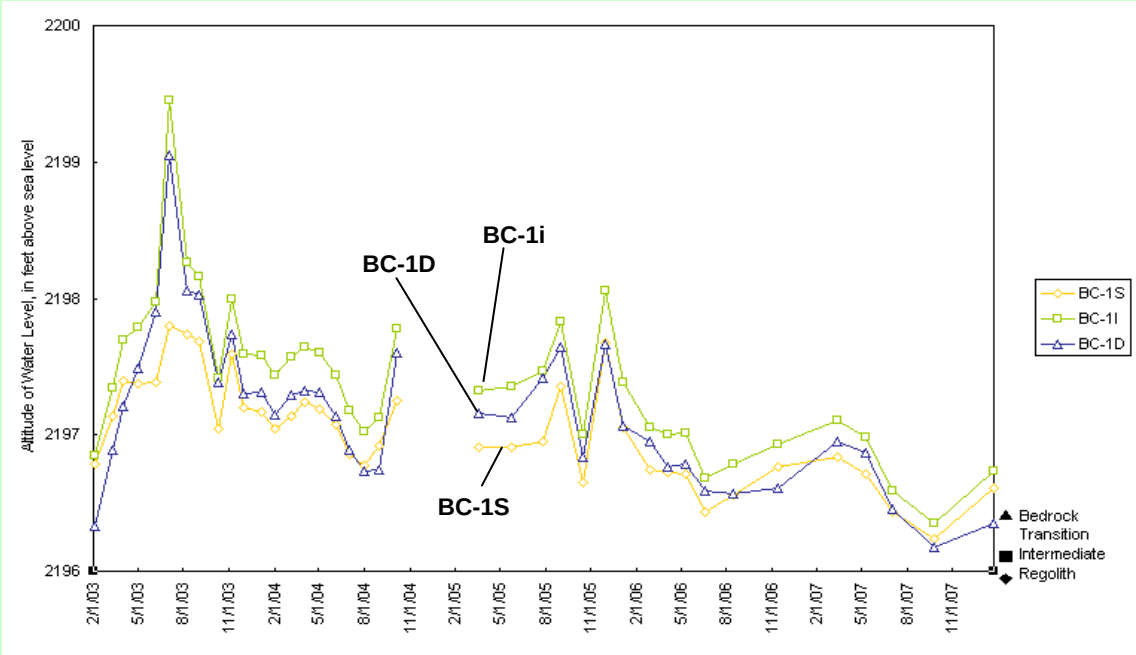
1 gpm yield

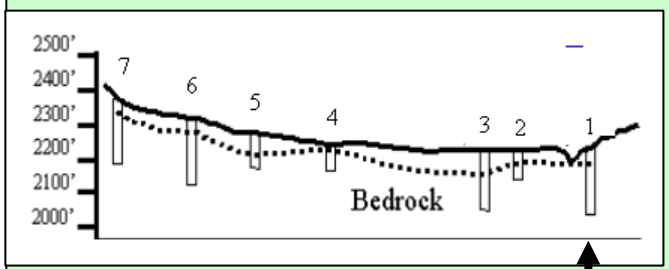


Ground water hydrographs - fluctuations with time
- vertical gradients



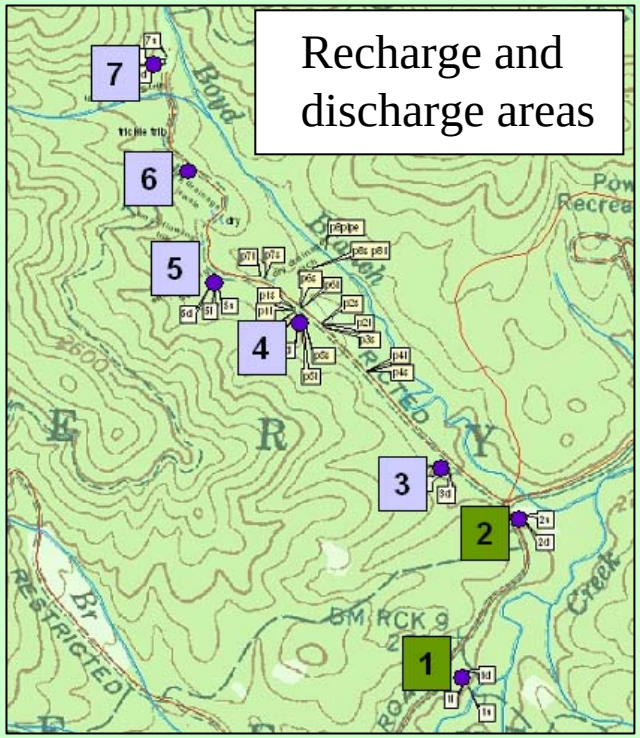
Ground water hydrograph: water level vs time at well cluster 1



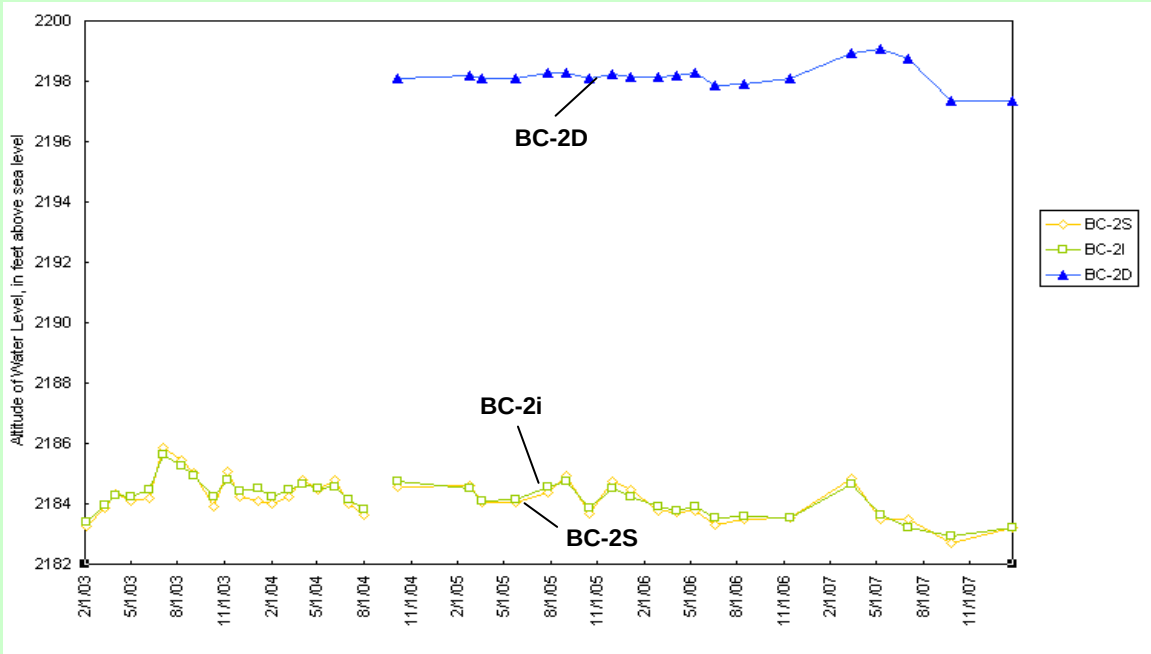


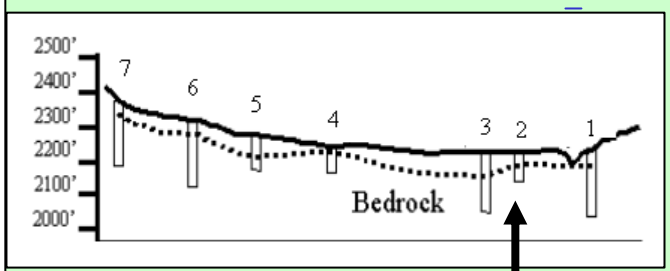
Well 1 is in discharge area

Ground water hydrographs - fluctuations with time
- vertical gradients



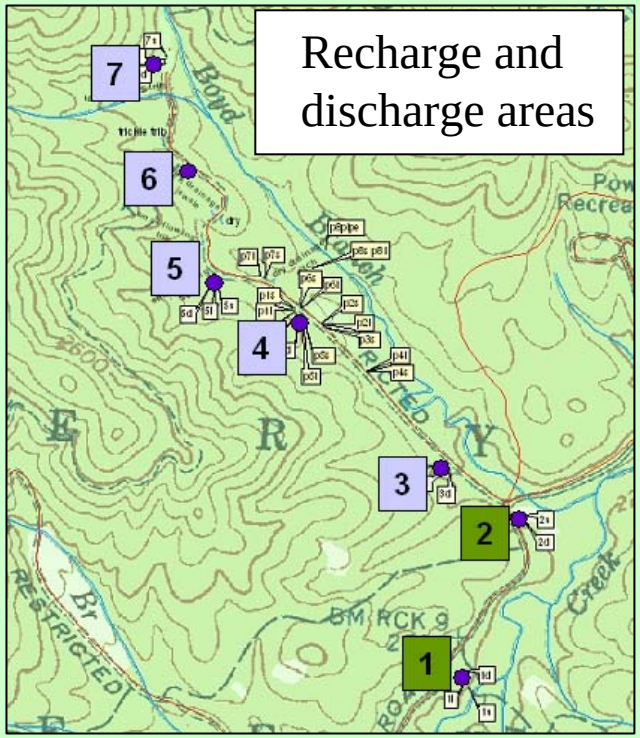
Ground water hydrograph: water level vs time at well cluster 2



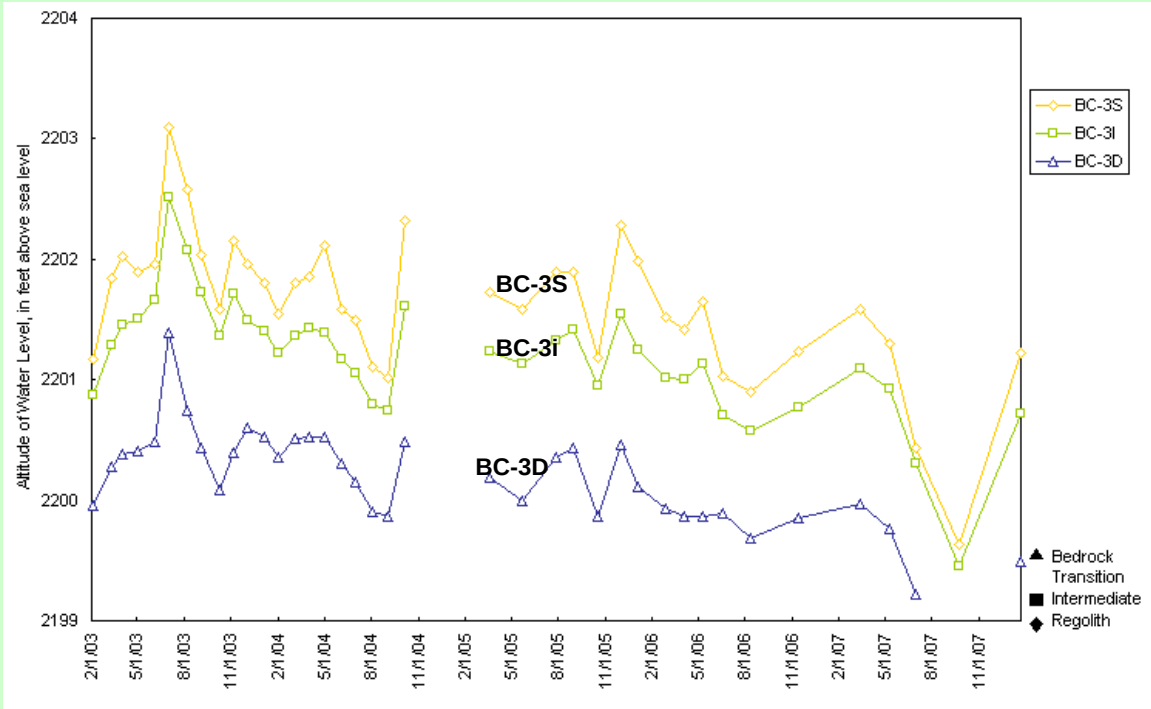


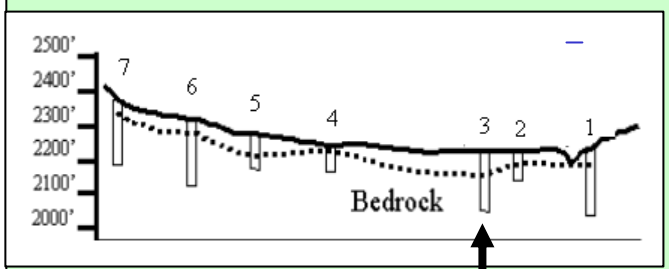
well 2 (artesian, flowing well) is in discharge area

Ground water hydrographs - fluctuations with time
- vertical gradients



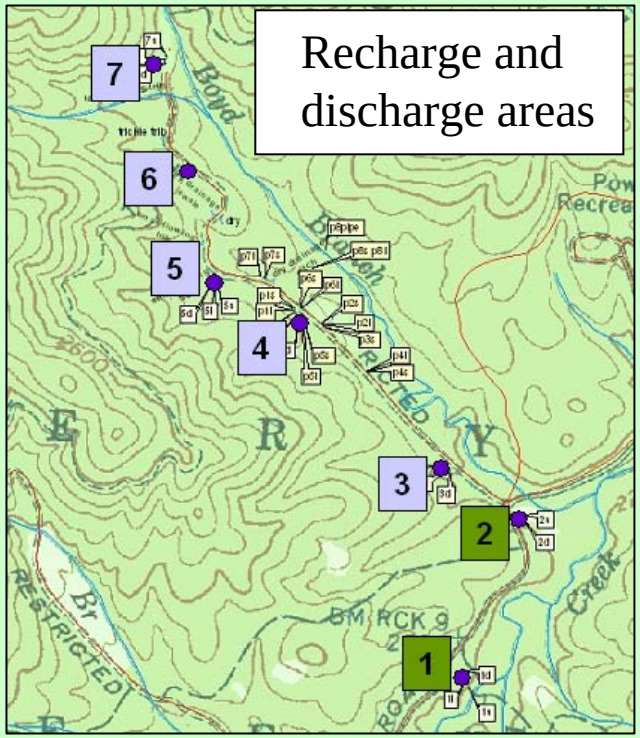
Ground water hydrograph: water level vs time at well cluster 3



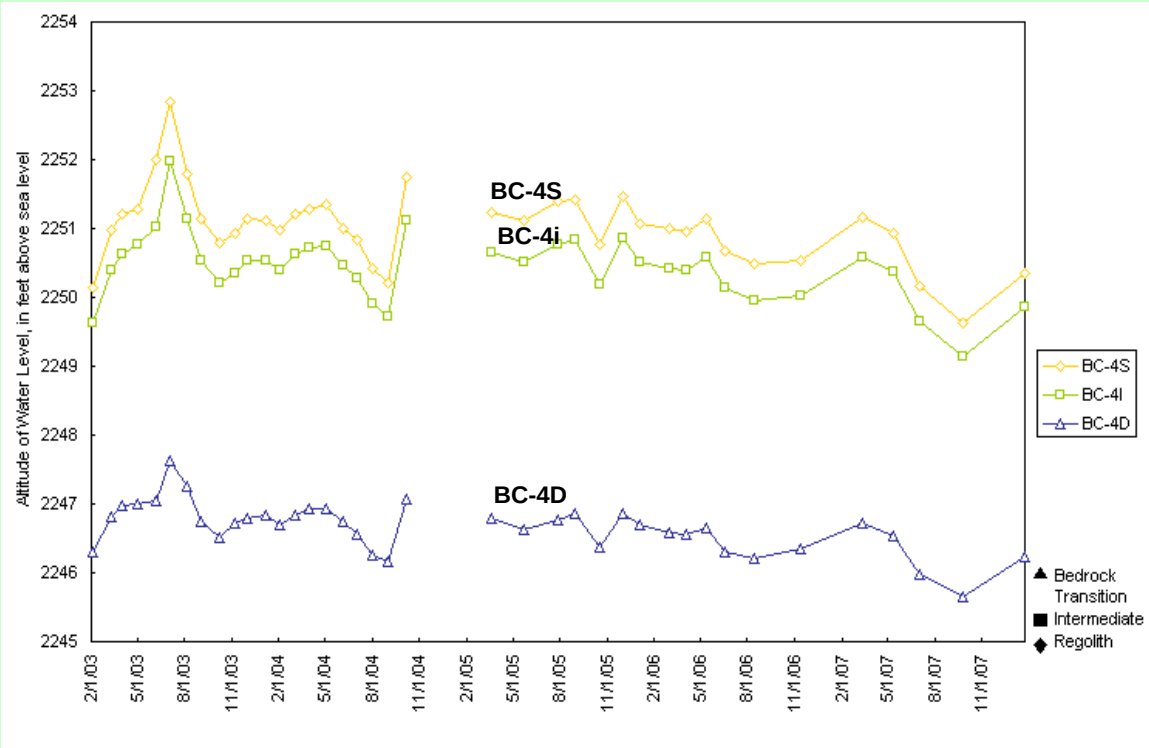


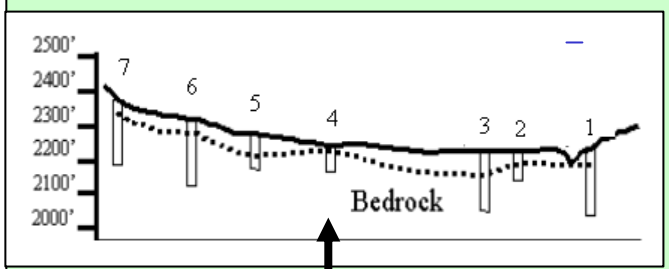
well 3 is in recharge area

Ground water hydrographs - fluctuations with time
- vertical gradients



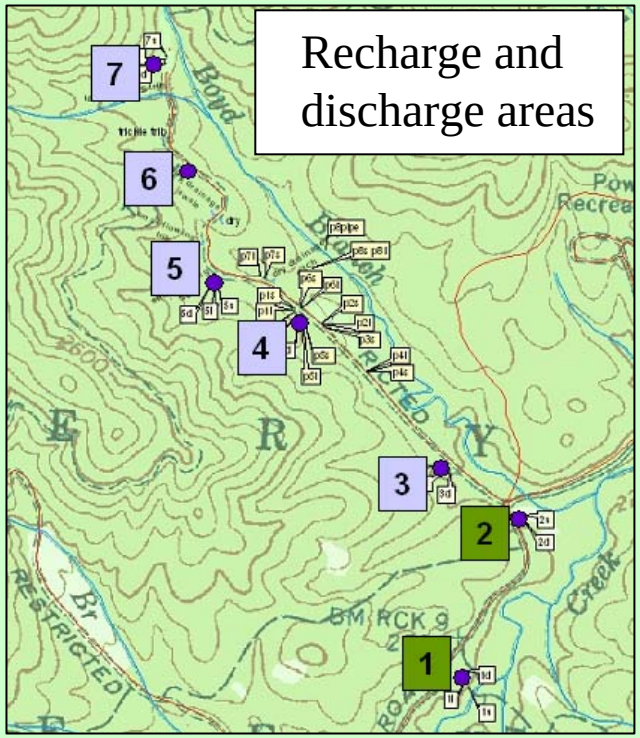
Ground water hydrograph: water level vs time at well cluster 4



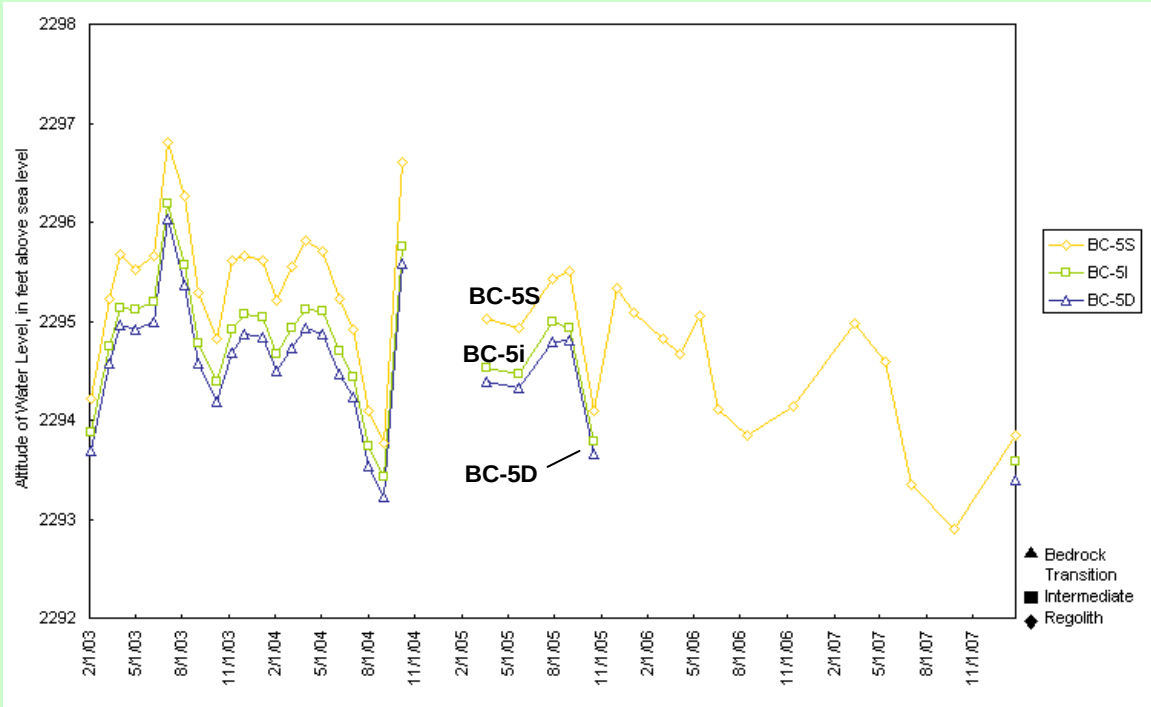


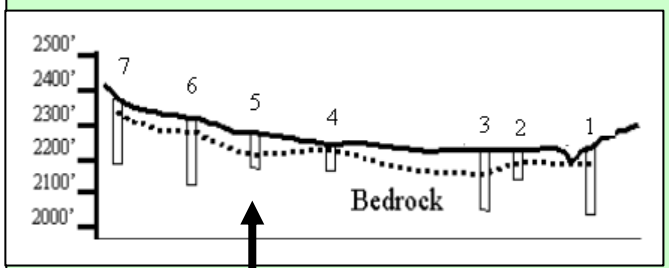
well 4 is in recharge area

Ground water hydrographs - fluctuations with time
- vertical gradients



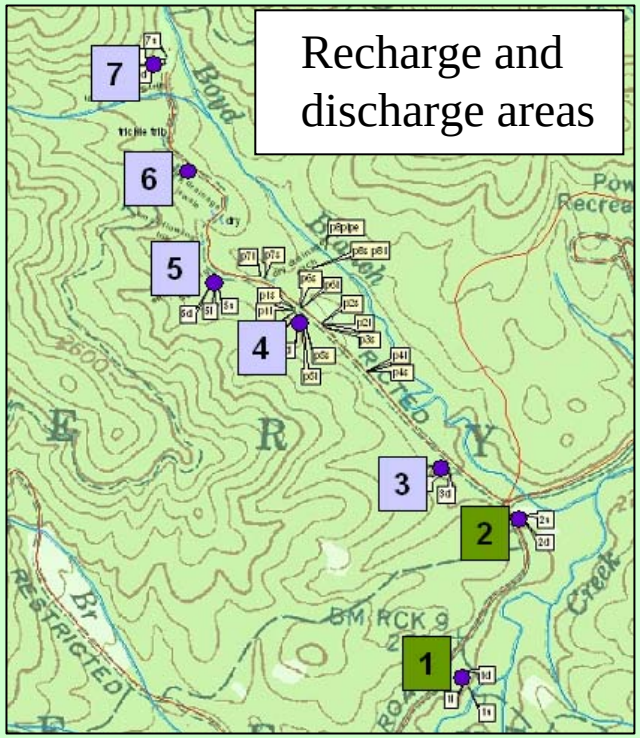
Ground water hydrograph: water level vs time at well cluster 5



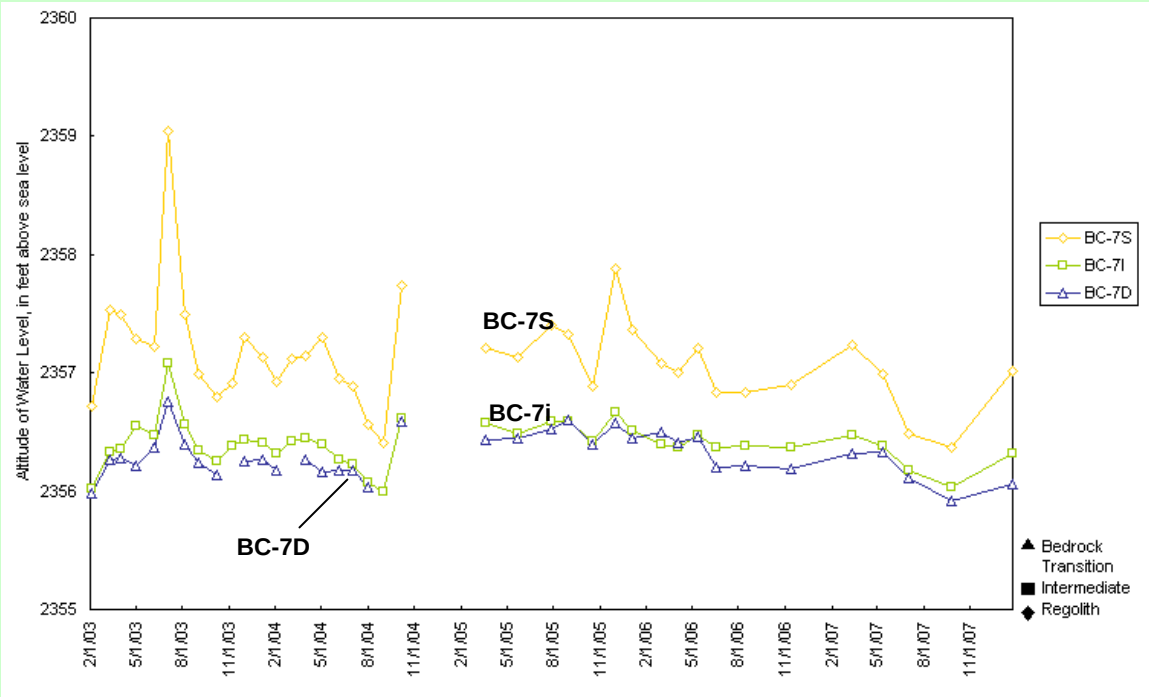


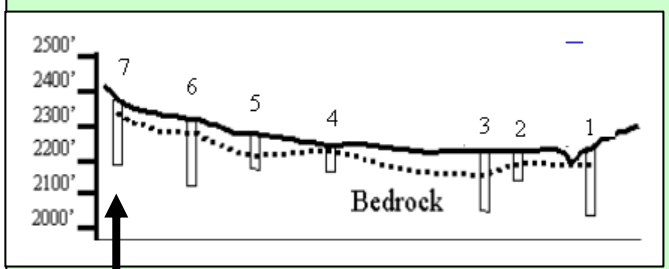
well 5 is in recharge area

Ground water hydrographs - fluctuations with time
- vertical gradients



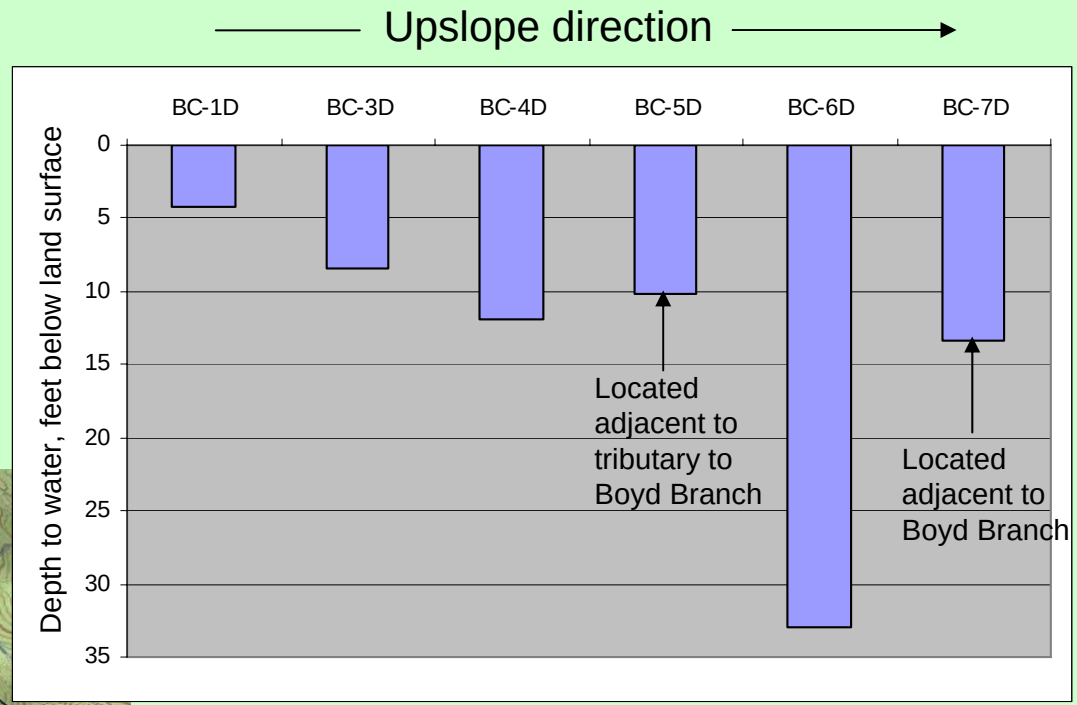
Ground water hydrograph: water level vs time at well cluster 7

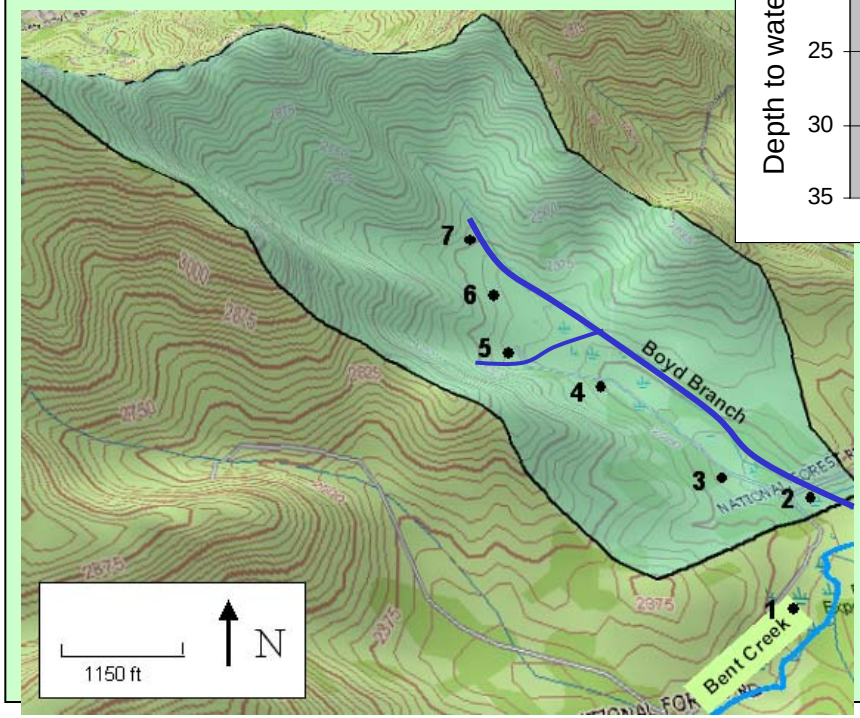




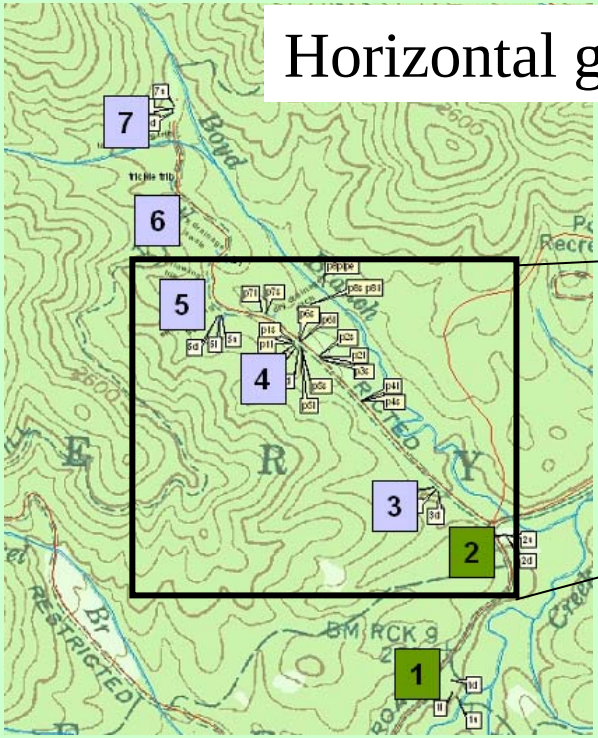
well 7 is in recharge area

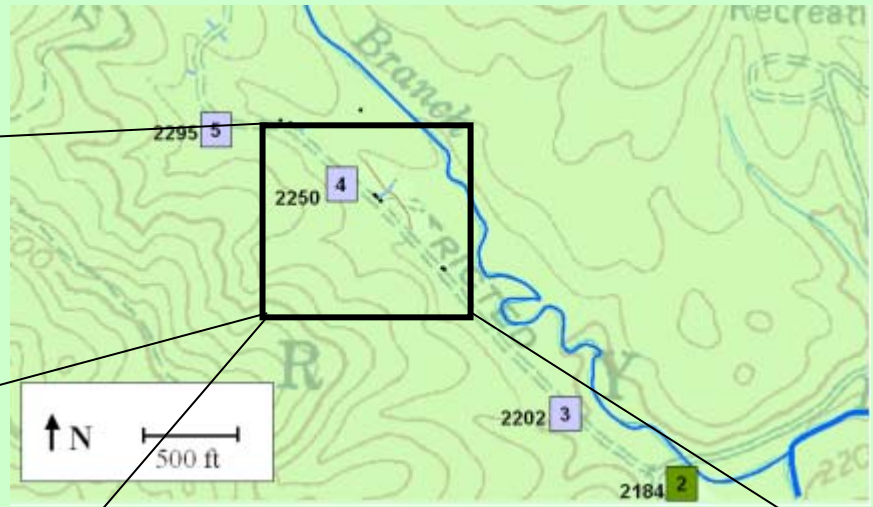
Depth to ground water, in ft below land surface

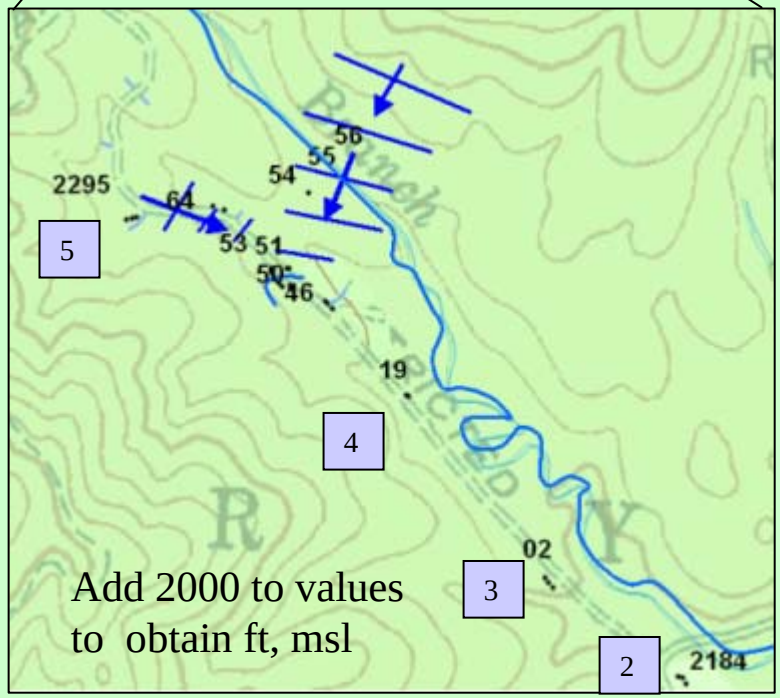




Horizontal gradients - direction of ground water flow







Water levels, Oct 05, 2004

Add 2000 to values to obtain ft, msl

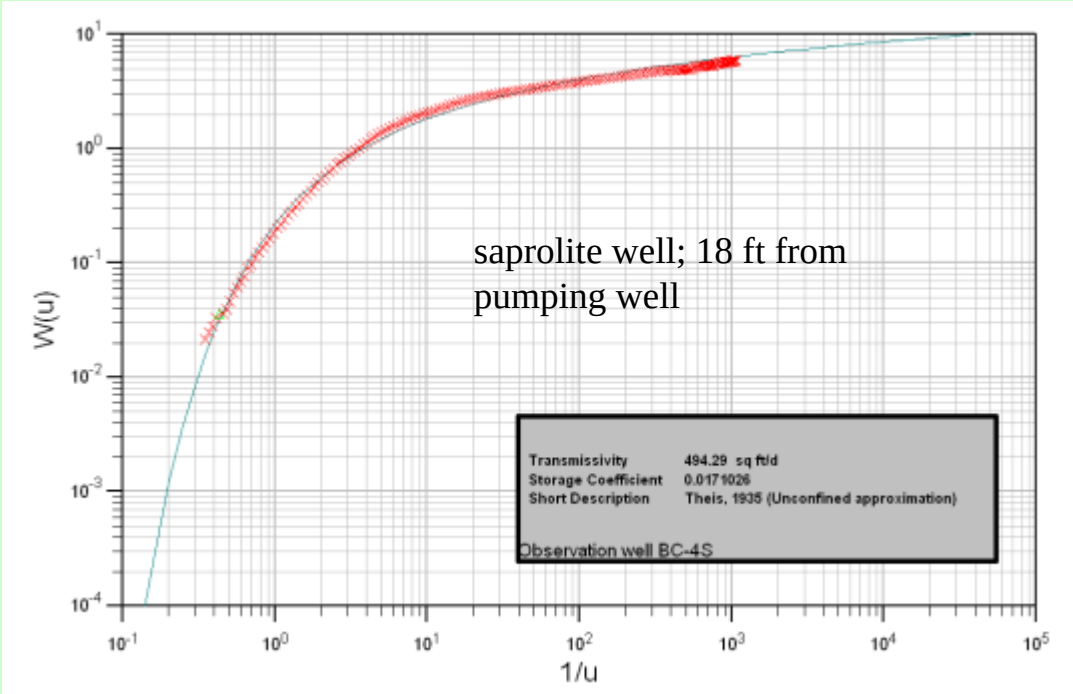
Hydraulic conductivities obtained from slug testing

	Aquifer material	Hydraulic conductivity, ft/day		Aquifer material	Hydraulic conductivity, ft/day
Well 1S	TZ	30	Well 1I	TZ	10
Well 2S	saprolite	3	Well 2I	TZ	5
Well 3S	saprolite	0.5	Well 3I	TZ	5
Well 4S	saprolite	2			
Well 5S	saprolite	2	Well 5I	TZ	10
Well 3D	fractured rock	0.04			
Well 4D	fractured rock	0.2			

Results of aquifer testing in regolith

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

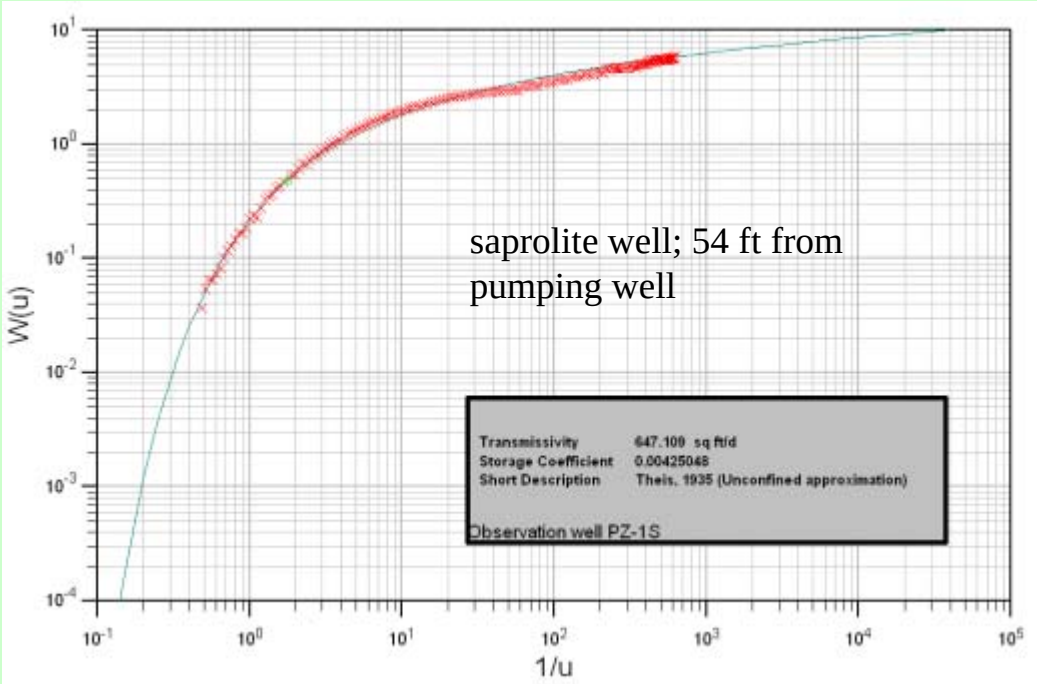
Observation well 4S



Results of aquifer testing in regolith

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

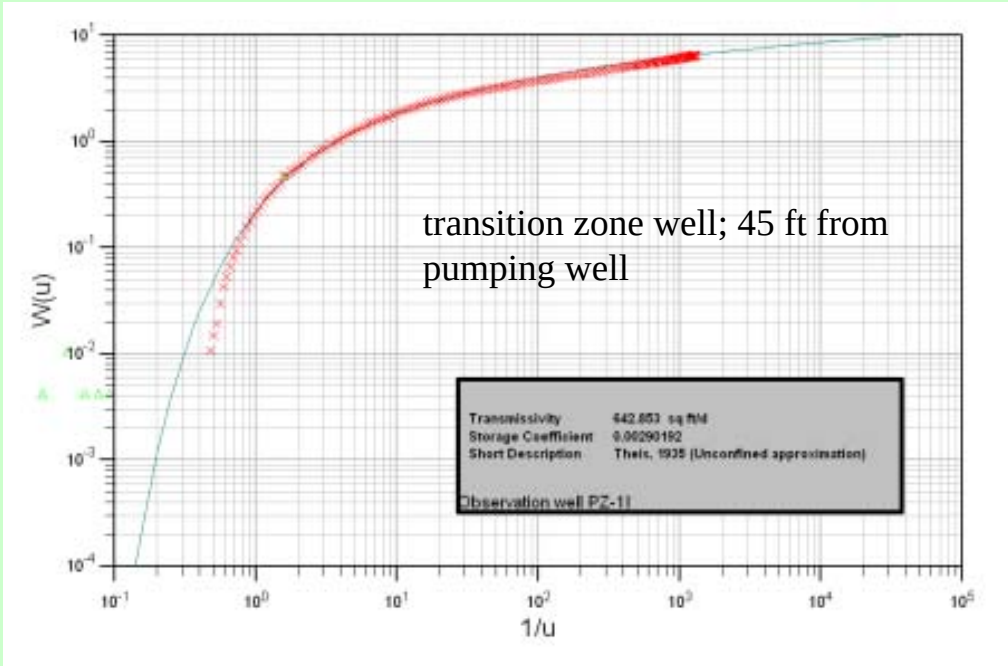
Observation well 1S



Results of aquifer testing in regolith

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

Observation well 1I



T and S obtained from aquifer testing in regolith

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

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

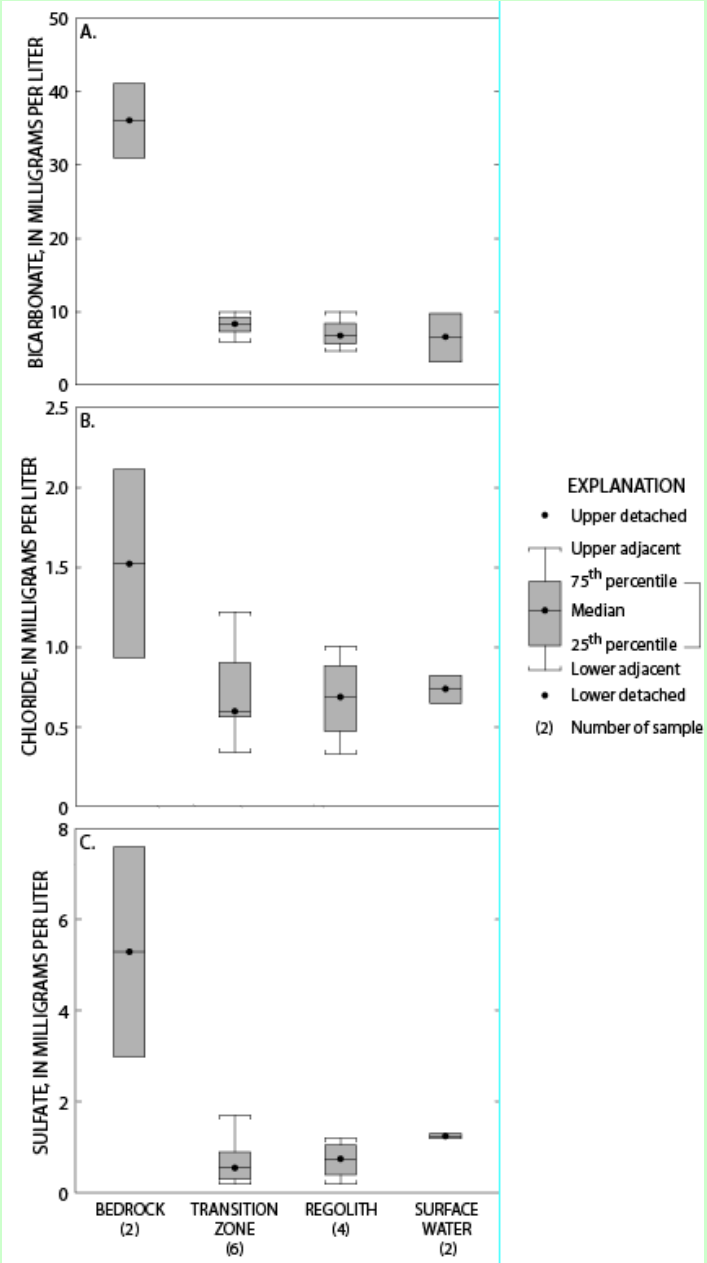
Evidence of preferential flow along the foliation strike in schist

Water Quality

Bicarbonate, mg/L

Chloride, mg/L

Sulfate, mg/L



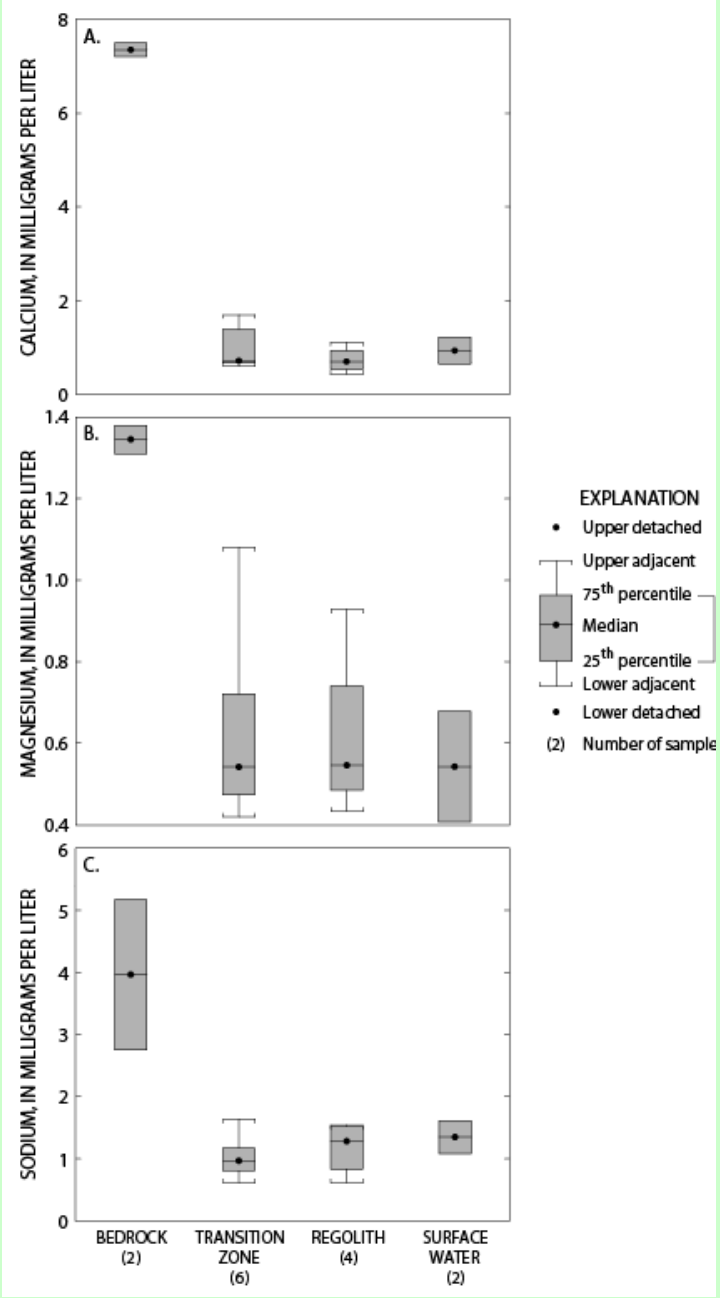
Deep wells generally more mineralized…

Water Quality

Calcium, mg/L

Magnesium, mg/L

Sodium, mg/L



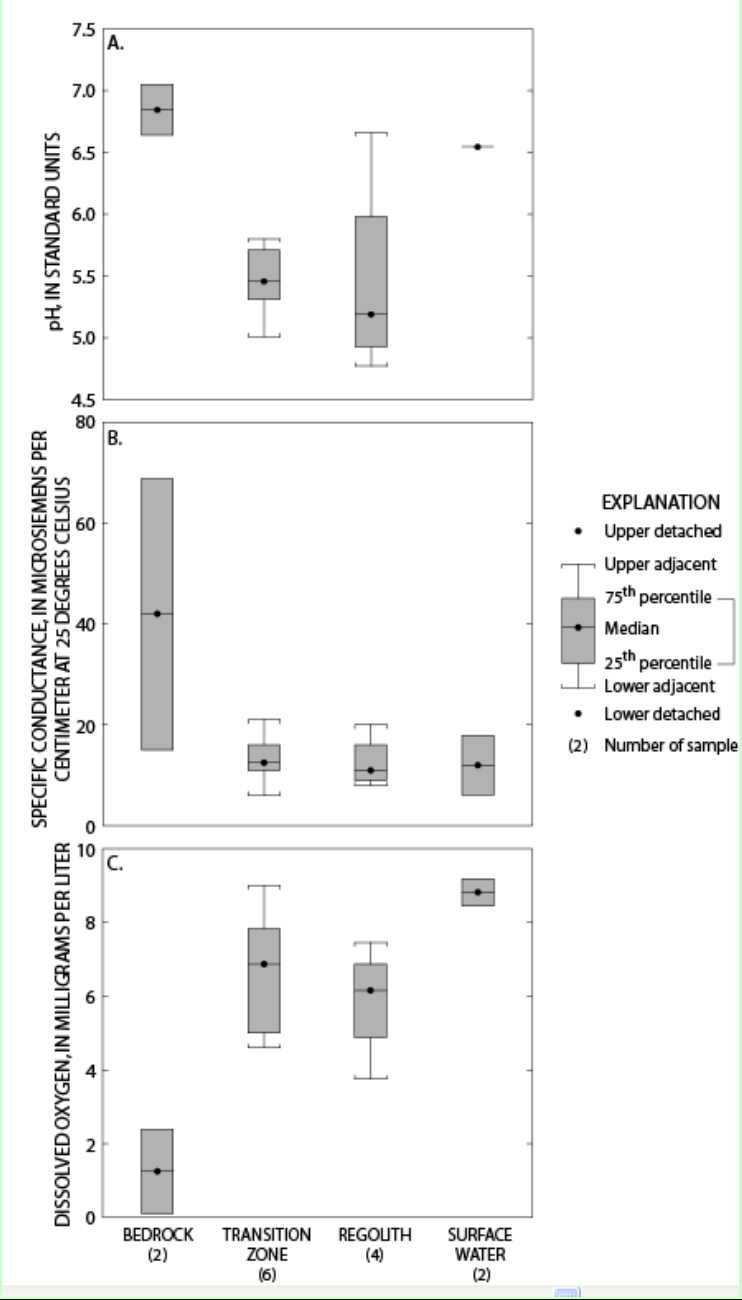
Deep wells generally more mineralized…

Water Quality

pH

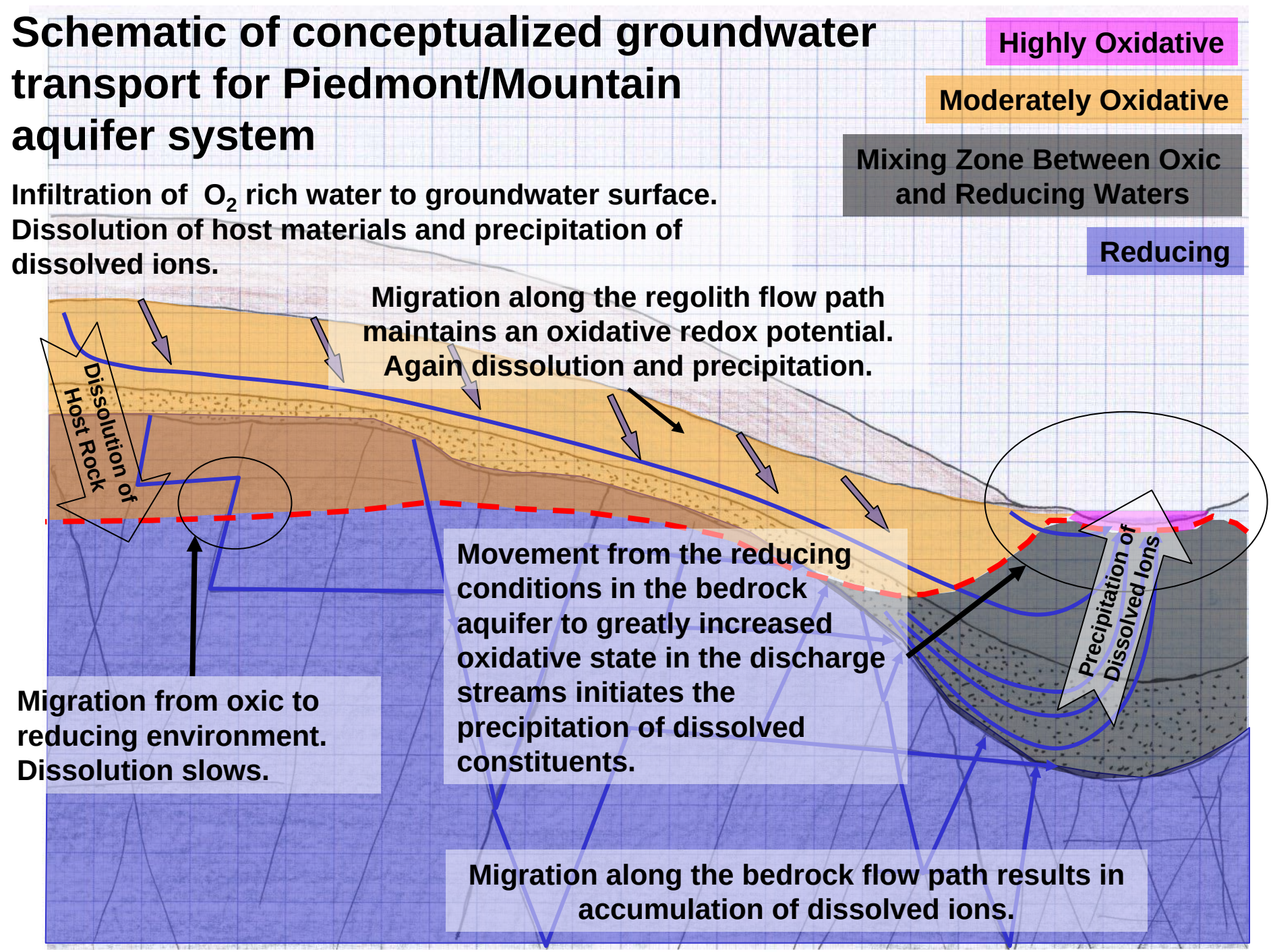
Specific Conductance, uS/cm

Dissolved Oxygen, mg/L

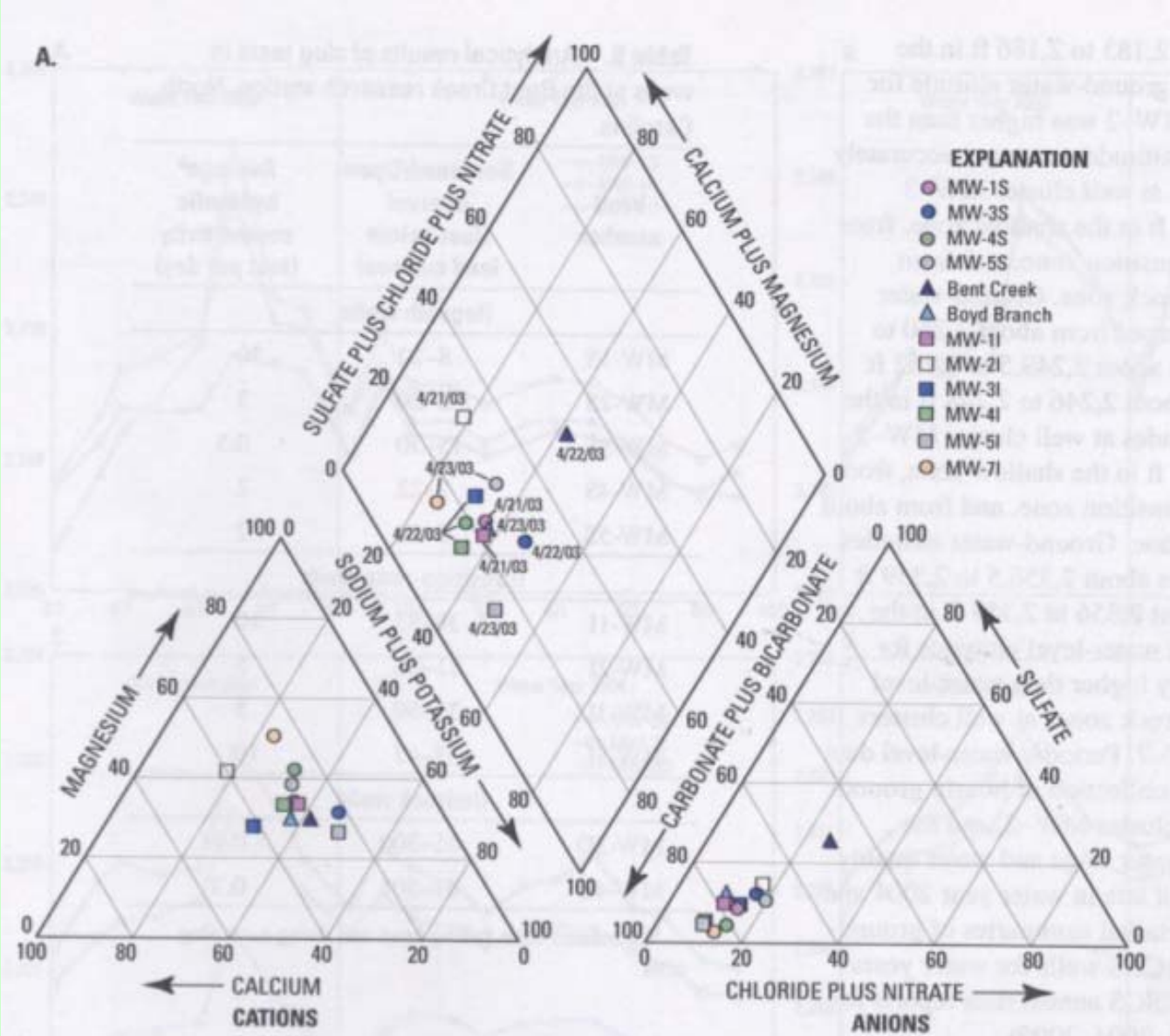


Deep wells generally less oxygenated…

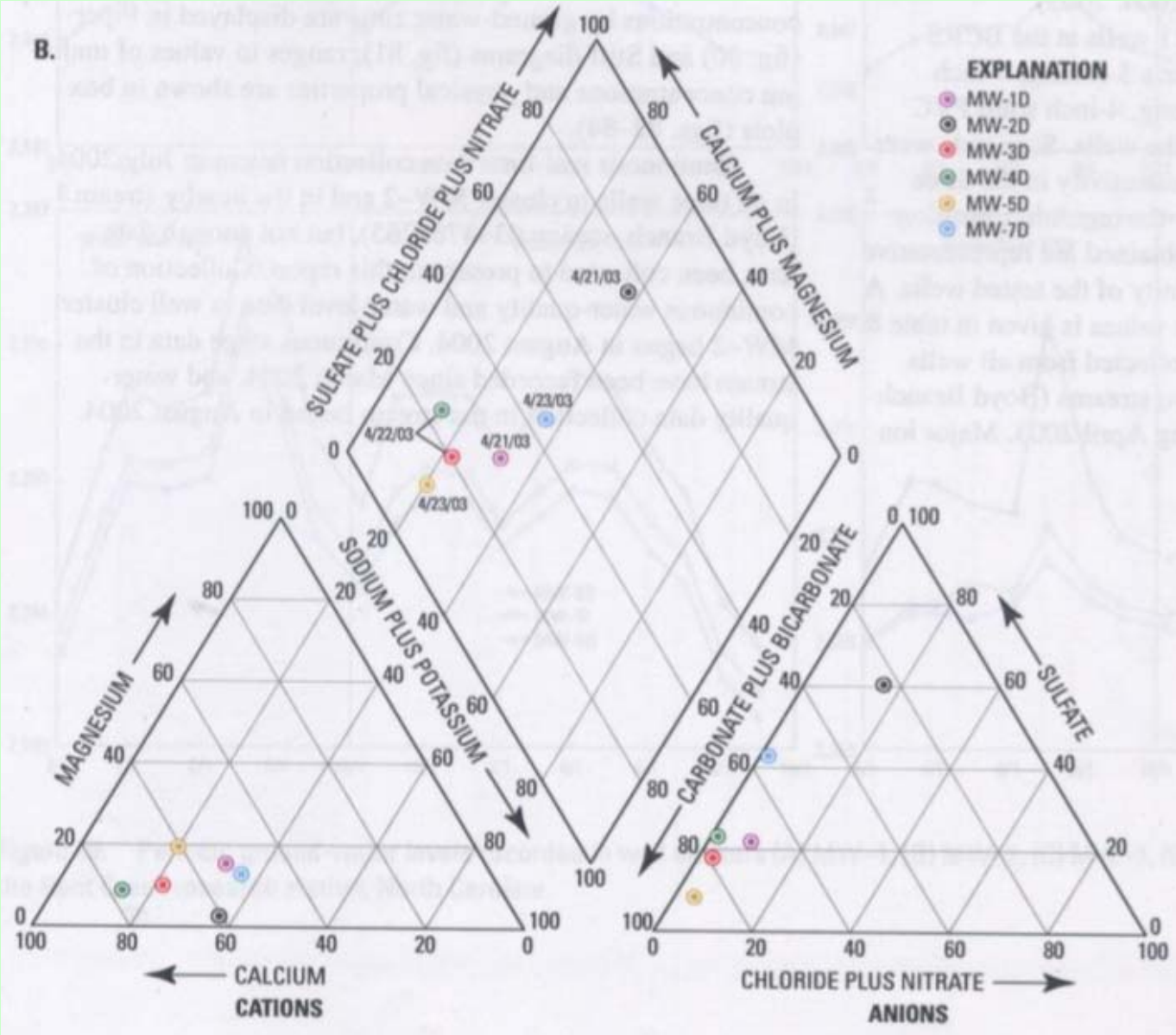
Schematic of conceptualized groundwater transport for Piedmont/Mountain aquifer system



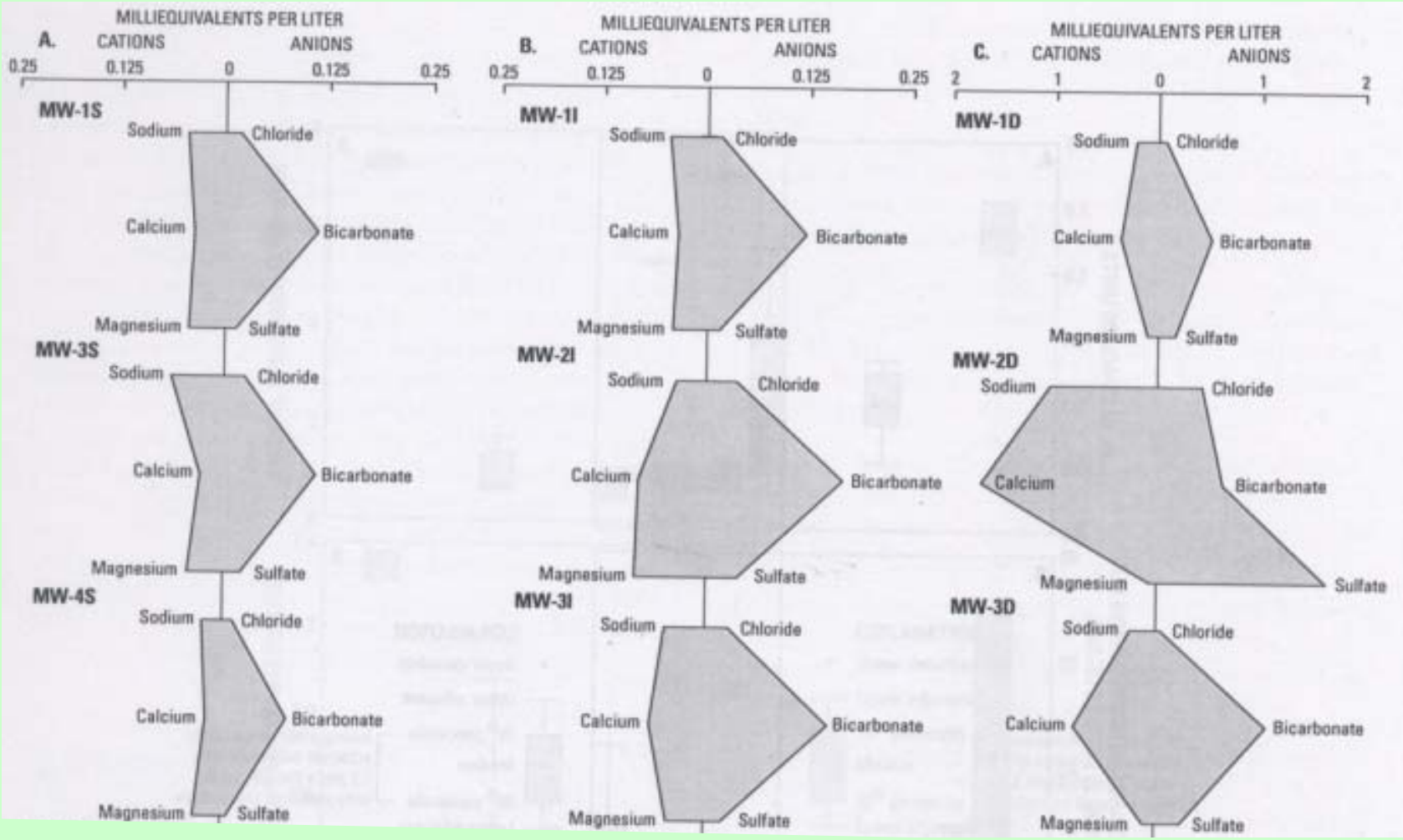
Water Quality



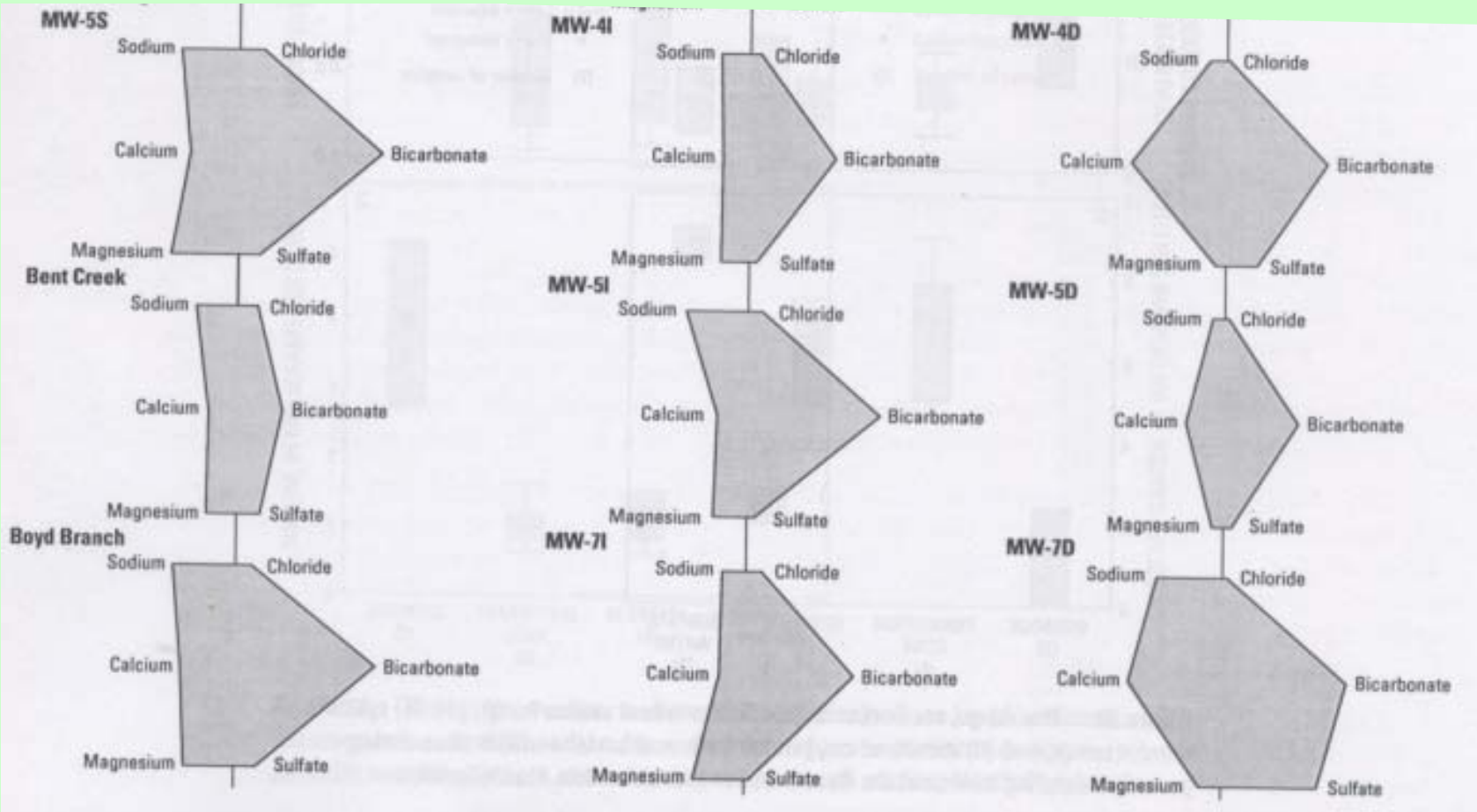
Water Quality



Water Quality



Water Quality



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