Radon-222 and Other Naturally-Occurring Radionuclides in Private Drinking Water Wells and Radon in Indoor Air in Selected Counties in Western North Carolina, 2007

by Ted R. Campbell

Ground Water Circular Number 2008-01

N.C. Department of Environment and Natural Resources
Division of Water Quality, Aquifer Protection Section
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ABSTRACT

Radon-222 – a naturally occurring carcinogenic radionuclide – was found at elevated levels (140 to 16,900 pCi/L; median = 1560 pCi/L) in ground water samples collected from 87 private wells in Alleghany, Caldwell, Burke, McDowell, Cleveland, Rutherford, Polk, Cherokee, Buncombe, Henderson, and Transylvania Counties. Radon exceeded EPA's proposed maximum contaminant level (MCL) of 300 pCi/L in 93 percent of the wells, and exceeded the proposed alternate MCL of 4000 pCi/L in 17 percent of the wells. Five of the counties are classified as EPA Zone 1 counties, with predicted indoor air radon concentrations above the action level of 4 picocuries per liter (pCi/L). The main source of radon is uranium rich rock – including granites and gneisses – prevalent across much of the region.

The highest dissolved radon concentrations were observed in wells in younger granitic rocks (less than 500 million years old to include the Cherryville Granite, Henderson Gneiss, and Caesar's Head Granite formations) (median = 4020 pCi/L; median = 1360 pCi/L in wells in all other rock types). Wells in meta-igneous rocks were higher in dissolved radon (median = 1810 pCi/L) than wells in meta-sedimentary rocks (median = 1390 pCi/L). Wells characterized by oxidizing conditions were higher in dissolved radon (median = 1610 pCi/L) than wells characterized by reducing conditions (median = 1090 pCi/L). Each of these findings is consistent with previous studies in this region (Campbell, 2005; 2006, Campbell, written communication).

Uranium (maximum = 72 ug/L) exceeded the EPA MCL in about 2 percent of wells and typically was detected in wells in granitic rocks. Radium-226 and radium-228 were relatively low in all sampled wells (less than 2.8 pCi/L), and were above 1 pCi/L in only 7 percent (radium-226) and 3 percent (radium-228) of samples.

Ground water in the study area tended to be slightly acidic (median pH = 6.2), oxygenated (median dissolved oxygen = 6.5 milligrams per liter (mg/L)), and minimally conductive (median specific conductance = 77 microsiemens per centimeter (uS/cm)). The buffering capacity of the ground water was low (median alkalinity = 29 mg/L), and the levels of iron and manganese also were low (median iron < 50 ug/L and median manganese < 10 ug/L). Raw oxidation-reduction potential (ORP) values were moderate (median raw ORP = 164 mV).

Lead was below the detection limit of 10 ug/L in all samples. Arsenic was below the method detection limit of 5 ug/L in all samples. The median concentration for potassium was 1500 ug/L.

Indoor air radon measured in homes serviced by the private wells exceeded the EPA action level of 4 pCi/L in 23 percent of cases (0.2 to 10.6 pCi/L; median = 2.1 pCi/L).

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INTRODUCTION

Studies have repeatedly shown elevated levels of carcinogenic radionuclides – most notably uranium and radon – in the ground water drinking supplies of Western North Carolina. This is problematic because about half of the population relies on ground water as its principal potable supply (U.S. Geological Survey, website http://nc.water.usgs.gov/wateruse/data/Data_Tables_2000.html, accessed May 22, 2006). A 1993 study reported that of 277 private wells sampled across the mountain region of North Carolina, 83% were above 300 pCi/L for radon, 56% were above 1000 pCi/L, and 10% were above 5000 pCi/L (University of North Carolina, 1993). A study of 103 private wells in Buncombe, Henderson, and Transylvania Counties in Western North Carolina found a median radon level of 6060 pCi/L and a maximum of 45,600 pCi/L (Campbell, 2006). And a study of 80 private wells in Madison, Mitchell, Watauga, Jackson, Buncombe, Henderson, and Transylvania Counties found a median radon level of 1889 pCi/L and a maximum of 15,752 pCi/L (Campbell, in preparation).

Eight counties in North Carolina - all in Western North Carolina – are classified as EPA Zone 1 counties, with predicted indoor radon concentrations above the EPA recommended action level of 4 pCi/L (EPA Radon Map, accessed via internet, 8/19/05, http://www.ncradon.org/zone.htm). These include Watauga, Alleghany, Mitchell, Buncombe, Henderson, Transylvania, Cherokee, and Rockingham Counties (fig. 1). According to a statewide statistical survey of indoor air in homes (North Carolina Radiation Protection Section, 1990), average radon concentrations were as follows: Buncombe County, 2.2 pCi/L (94 samples), Cherokee, 3.4 (8 samples), Henderson, 4.5 (45 samples), Mitchell, 1.8 (5 samples), and Transylvania, 4.4 (17 samples). Concentrations were somewhat higher in a statewide non-statistical data compilation study.

Elevated levels of radon are due to the presence of uranium rich rocks – including granites and gneisses - across much of the region. Rock type has been strongly associated with concentrations of dissolved radon, with ground water in granites often containing high levels, up to 100,000 pCi/L (Asikainen and Kahlos, 1979; Brutsaert and others, 1981; Snihs, 1973) and ground water in sedimentary rocks often containing much lower levels, often less than 500 pCi/L (Andrews and Wood, 1972; King and others, 1982; and Mitsch and others, 1984).

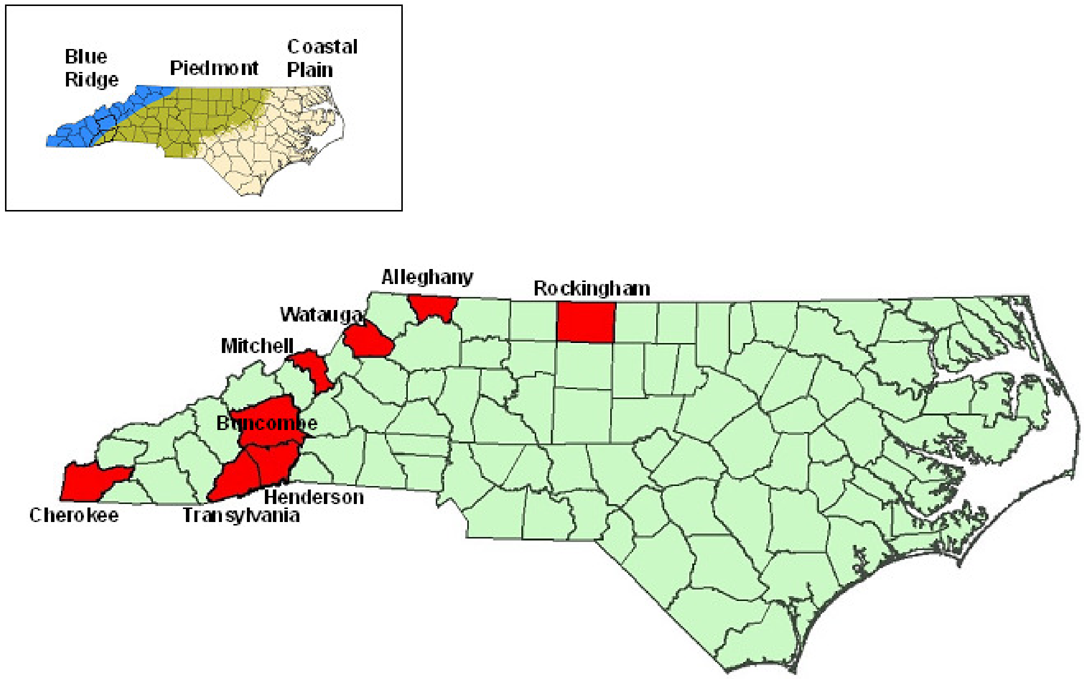

Figure 1. EPA Zone 1 counties in North Carolina (in red) with predicted indoor radon levels of 4 pCi/L or higher, and North Carolina physiographic provinces (in inset).

Because radionuclides are known to occur in the region and because they are linked to an increased risk of cancer, several key questions are now being addressed. What is the occurrence and distribution of dissolved radionuclides in the region? Are the observed levels safe to drink? Are the dissolved radon levels high enough to cause a substantial increase in the overall exposure to inhaled radon? Is it possible to develop regional radionuclide susceptibility maps on the basis of knowledge of local geology, geochemical conditions, and topographic settings? Are well owners aware of the implications of elevated levels of dissolved radionuclides in their drinking water? Is current policy regarding radionuclides in drinking water adequately protective of public health?

This study was designed to evaluate the occurrence and distribution of naturally occurring radionuclides in private drinking water wells in selected counties in Western North Carolina. The study also evaluated the levels of indoor air radon in homes associated with the sampled wells. The study was targeted to specific counties within Western North Carolina and therefore is limited in scope. It is part of a multi-phased approach to help policy makers and the public to understand the quality of the ground water supply and the extent to which radionuclides may pose a health threat to the citizens of Western North Carolina. This study is a direct response to the North Carolina

Division of Water Quality's mandate to help ensure that North Carolina's ground water resources are safe and sustainable. This study was made possible by a matching funds grant from the EPA, and carried out in consultation with the North Carolina Division of Environmental Health's Radiation Protection Section.

Purpose and Scope

The purpose of this report is to document the occurrence and distribution of selected radionuclides in drinking water collected from private wells in Alleghany, Caldwell, Burke, McDowell, Cleveland, Rutherford, Polk, Cherokee, Buncombe, Henderson, and Transylvania Counties of Western North Carolina. Data used to draw conclusions in this report were obtained from raw, untreated, unfiltered ground water samples collected using a consistent method at 87 private drinking water wells. Wells sampled in the study generally were fractured bedrock wells that were cased (polyvinyl chloride or steel) to the top of the rock and, beneath this, were open borehole to depth. Well samples were analyzed for total uranium (uranium), radium-226 (Ra-226), radium-228 (Ra-228), radon-222 (radon), potassium, iron, manganese, lead, arsenic, alkalinity, bicarbonate, total dissolved solids, and field parameters. Additional data obtained at the wells included well-construction details (casing material, total depth, casing depth, and well yield), latitude and longitude, topographic setting, and surrounding rock type information. In addition, indoor air radon was measured in 40 of the 87 homes associated with the sampled private wells.

Acknowledgments

The author would like to thank Dr. Felix Fong and the staff at the North Carolina Radiation Protection Section for their support and assistance during this investigation. The staff of the North Carolina Division of Water Quality, Aquifer Protection Section, was instrumental in ensuring timely completion of all field work. The staff of the North Carolina Geological Survey provided valuable expertise on geologic interpretations and rock classifications. Special thanks also are offered to the well owners in Western North Carolina who participated in this study. This investigation was made possible by a grant from the EPA administered by the North Carolina Radiation Protection Section.

Data Collection and Analytical Methods

Ground-water samples were collected between January and September 2007, from 87 private wells within the eleven-county study area (fig. 2). In addition, 40 indoor air radon samples were collected from the homes associated with the sampled wells. The remaining 47 homes did not participate in the indoor-air radon sampling or did not obtain reliable results.

Ground water sample locations were designed to cover broad portions of the study area. No attempt was made to cover all areas of each county or to produce a statistically weighted and representative dataset. Newspaper advertisements and word of mouth were used to solicit volunteers for the study.

Since each well was sampled on only one occasion, data collected in this study represent a "snap shot" of radionuclide concentrations at a point in time, and do not account for potential temporal variations due to long-term, seasonal, or pumping-related fluctuations. A single sample does not necessarily represent the overall quality of the ground water resource over a long period of time at that location, but it does provide an indication of the quality of the local ground water contributing water to the well for the time at which it was sampled.

With few exceptions, ground water samples were analyzed for total uranium (uranium), radium-226 (Ra-226), radium-228 (Ra-228), radon-222, potassium, iron, manganese, lead, arsenic, alkalinity, bicarbonate, total dissolved solids, pH, DO, specific conductance, ORP, and temperature. Quality control replicate samples were collected and analyzed for about 10 percent of the samples. Each well sample was identified by a sequential number from 184 to 270 (fig. 2).

Indoor air radon samples generally were obtained by the homeowner from the lowest living level in the home and under mostly closed-house conditions. One indoor air sample was collected per site on one occasion, over a three-day period. Because of this, the sample did not account for changes that may occur due to long-term or seasonal fluctuations. Factors that may affect the observed concentration over time include height of the water table, timing and amount of recent rainfall, degree of indoor ventilation and fresh air circulation, variations in well operation and its proximity to the home, and other factors.

Rock type and structure were identified by on-site observation or by statewide or local scale geologic maps (North Carolina Geological Survey, 1985). Because of the geologic complexity of the region, in some cases the geologic setting of a particular home or well had to be inferred. Nevertheless, the designations used in this study were believed to be reasonable characterizations that allowed meaningful evaluations of geologic influence on radionuclide concentrations.

Sample-collection methods

A ground water sample was collected as an unfiltered, raw water sample from a plumbing fixture as close to the wellhead as possible, usually at the wellhead itself. The sample was collected after the pump had been operating for at least 20 minutes. This helped to ensure that the sampled water was from the formation and not from a stagnant water column from within well bore. Ground water was placed in a 1-liter plastic container for the analysis of total uranium, Ra-226, and Ra-228. The sample date, time, and location were written on the sample container and on the chain of custody form. The sample was shipped to a certified contract laboratory in Oklahoma. Radon samples were collected using a special procedure designed to prevent aeration. Specifically, 40-milliliter (or similar) glass radon vials were carefully submerged, filled, and sealed inside a 1.8-liter glass beaker or similar container that had been slowly filled with well water. The radon samples were iced to maintain a consistent cool temperature and, for quality control samples, were shipped to the certified laboratory by overnight mail in order to meet the 4-day holding time requirement. The metals samples (arsenic, lead, manganese, and iron) were preserved using ultra-pure nitric acid prior to shipment to the laboratory.

Parameters such as DO, specific conductance, pH, ORP, and temperature, were measured in the field using a calibrated multimeter. Information about well construction (depth, casing depth, yield, and others) was noted and recorded in the field. Mapping-grade Global Positioning System (GPS) receivers were used to identify the locations of the private water supply wells sampled, and the resulting data were entered into Geographic Information System (GIS) data files.

Indoor air radon samples were collected by the homeowner using deployable short-term activated carbon air-sample kits. The sampler was placed in the lowermost unventilated area of the home – typically a walkout basement if it existed - and left undisturbed for 72 hours. The sampler was then sealed and shipped overnight to the laboratory for analysis of the radon concentration.

Laboratory analytical methods

Radon in water was analyzed using the E-Perm ion electret chamber de-emanation procedure (Kotrappa and Jester, 1993). In this method, radon in water off-gases inside a sealed oversized mason jar, and an electret ion chamber measures the voltage drop as the radon de-emanates. The voltage drop is then used in a calculation to determine the amount of radon in water. Quality control samples were analyzed for radon using a procedure based on Standard Method 7500-Rn (EPA, 1999). In this method, radon is partitioned selectively into a mineral-oil scintillation cocktail immiscible with the water sample. The sample is dark-adapted, equilibrated, and then counted in a liquid scintillation counter using a region or window of the energy spectrum optimal for the specific alpha particles emitted from radon. Radium-226 was analyzed using a modification of method SM7500 Ra (EPA, 1995). The method uses alpha spectroscopy methodology. Radium-228 was analyzed using EPA method 904.0 (EPA, 1980). The method uses a gas flow proportional counter methodology. Total uranium was analyzed using method KPA ASTM 5174M (ASTM, 1994). The sample was digested with nitric acid and peroxide and measured by the laser-based kinetic phosphorescence analyzer (KPA).

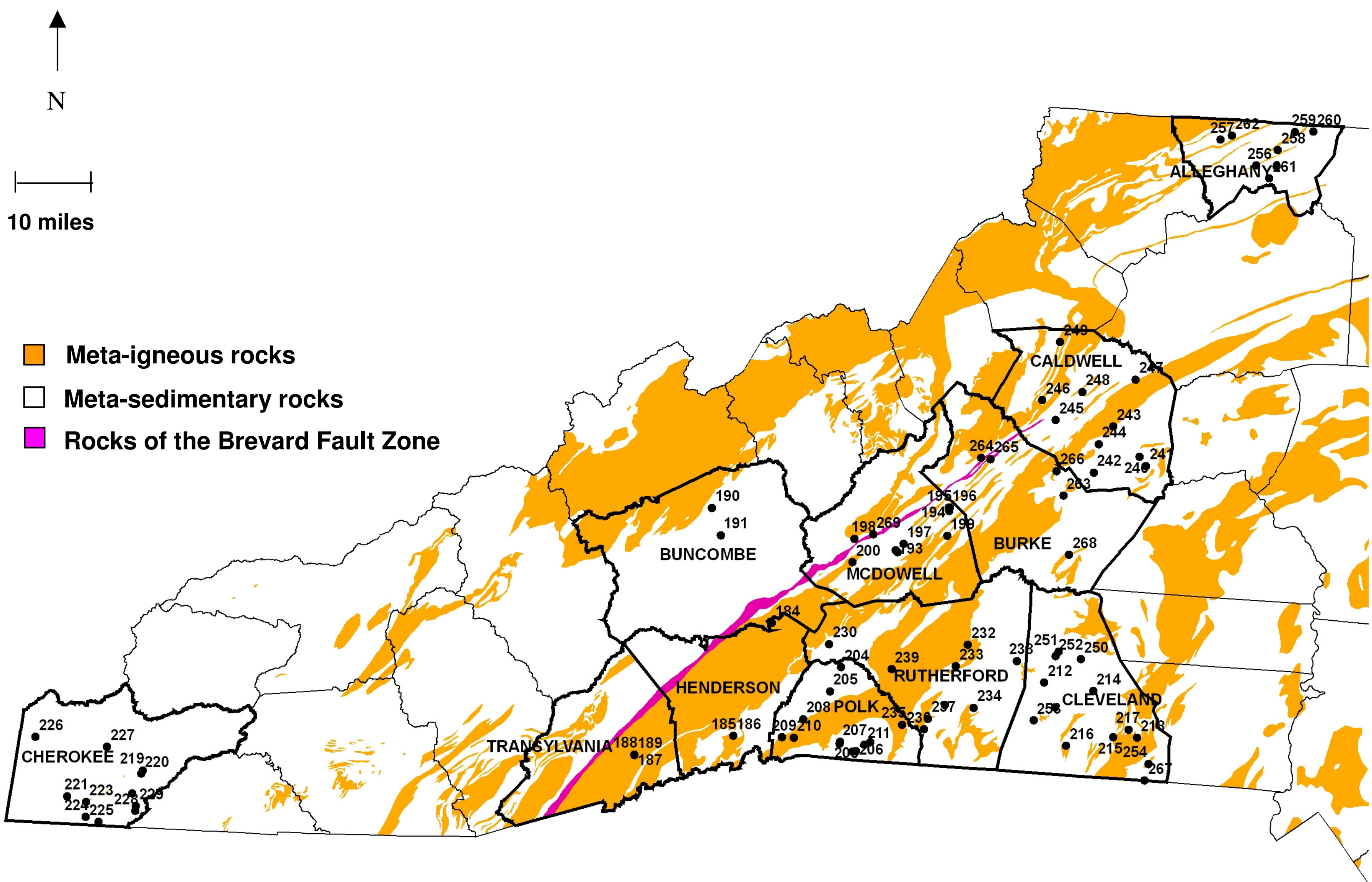

Figure 2. Private wells sampled during study, superimposed on map of meta-igneous versus meta-sedimentary rocks, Alleghany, Caldwell, Burke, McDowell, Cleveland, Rutherford, Polk, Cherokee, Buncombe, Henderson, and Transylvania Counties, North Carolina, 2007.

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STUDY AREA SETTING

The study area is located in Western North Carolina and is comprised of mainly eleven counties – Alleghany, Caldwell, Burke, McDowell, Cleveland, Rutherford, Polk, Cherokee, Buncombe, Henderson, and Transylvania. This area straddles the Blue Ridge and Inner Piedmont physiographic provinces (fig. 3). The topography of the Blue Ridge province was formed by uplift, erosion, and rock resistance, and is characterized by steep, rugged, incised, mountainous terrain, intermontane basins, and valleys. Part of the Appalachian Mountain system, the Southern Blue Ridge province has a large number of peaks, some with elevations of over 6000 ft above sea level (asl). The topography of the Inner Piedmont was formed through the same earth processes and is characterized by gently rolling, rounded hills, long low ridges, and shallow valleys, with elevations ranging from about 600 to 1500 ft asl.

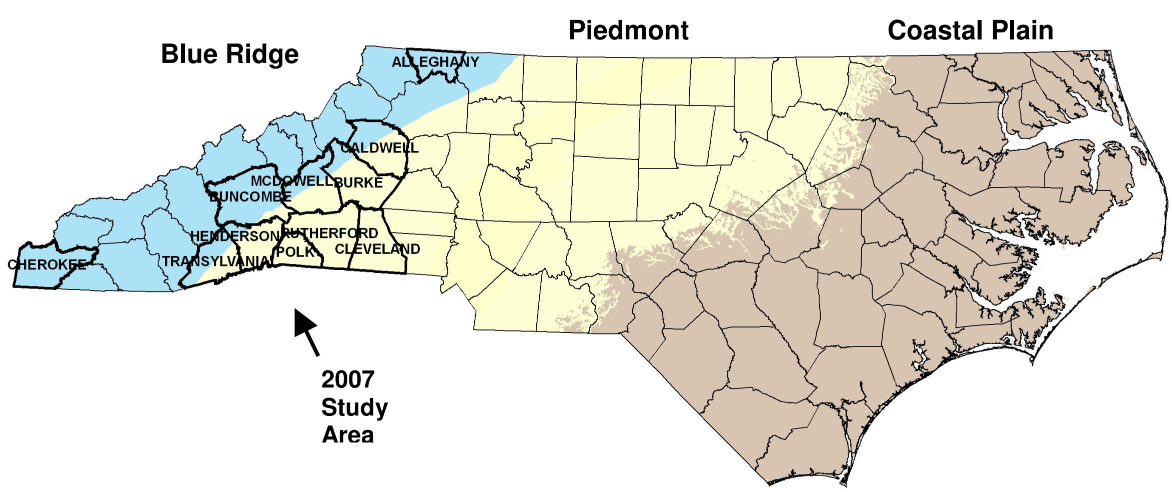


Figure 3. Physiographic provinces in North Carolina and the 2007 study area.

Precipitation in the study area ranges from about 45 to 60 inches per year, but approaches 100 inches in localized areas. Ground water is particularly important to this region, and about half of the residents rely on it as their principal drinking supply. Yields from private wells typically range from about 1 to 50 gallons per minute (gpm), with averages of about 10 to 15 gpm (Daniel and Dahlen, 2002). Figure 4 shows a cross section of a typical well in the study area.

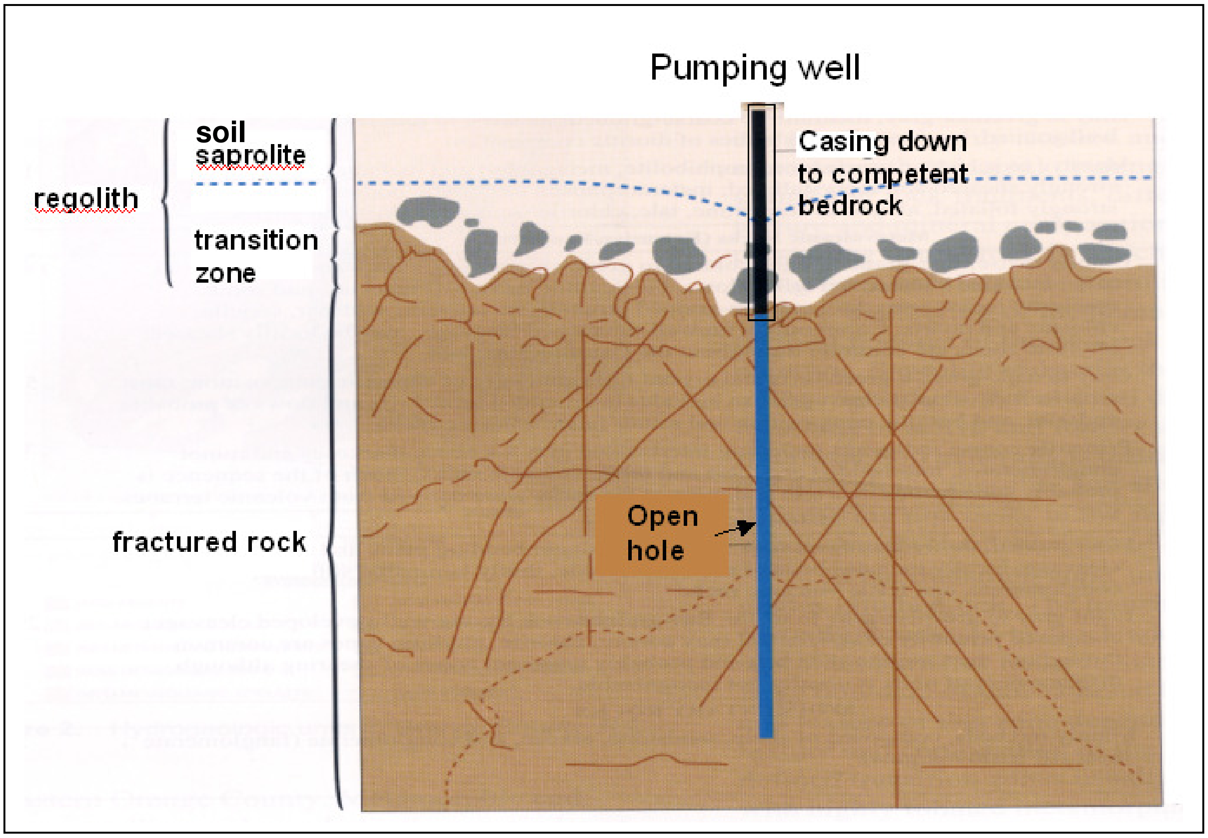


Figure 4. Schematic showing construction of typical private drinking water well in study area.

Bedrock geology in the study area is complex and consists of inter- and intra-layered, folded, and faulted meta-igneous and meta-sedimentary rocks of Silurian to Pre-Cambrian age. These rocks outcrop throughout the region or, when not present at land surface, they occur beneath a variably thick layer (typically 20 to 80 ft) of soil and weathered saprolite. The Brevard Fault Zone trends to the northeast through the study area and separates the Blue Ridge geologic belt to the west from the Inner Piedmont Belt to the east.

In the broadest sense, rocks in the study area can be grouped into either *meta-igneous* or *meta-sedimentary* rocks (fig. 2). Meta-igneous rocks are of igneous origin, and meta-sedimentary rocks are of metamorphosed sedimentary origin. Minor amounts of igneous metavolcanic rocks may occur within the rocks grouped as meta-sedimentary in nature.

The meta-igneous and meta-sedimentary rocks in the study area may be further divided into individual formal and informal rock units. Meta-igneous rocks in the study area include, for example, Caesar's Head Granite, Cherryville Granite, granitic gneiss, Henderson Gneiss, porphyroblastic gneiss, and amphibolite. Meta-sedimentary rocks in the study area include schists, (para)gneisses, metagraywacke, and rocks of the Brevard Fault Zone.

The rock type/formation of each well location was identified by on-site observation or by statewide or local scale geologic maps (North Carolina Geological Survey, 1985). It should be noted that the percentage of sampled wells located in a given rock type (fig. 5) was not intended to correspond to the percentage of area represented by that rock type within the study area.

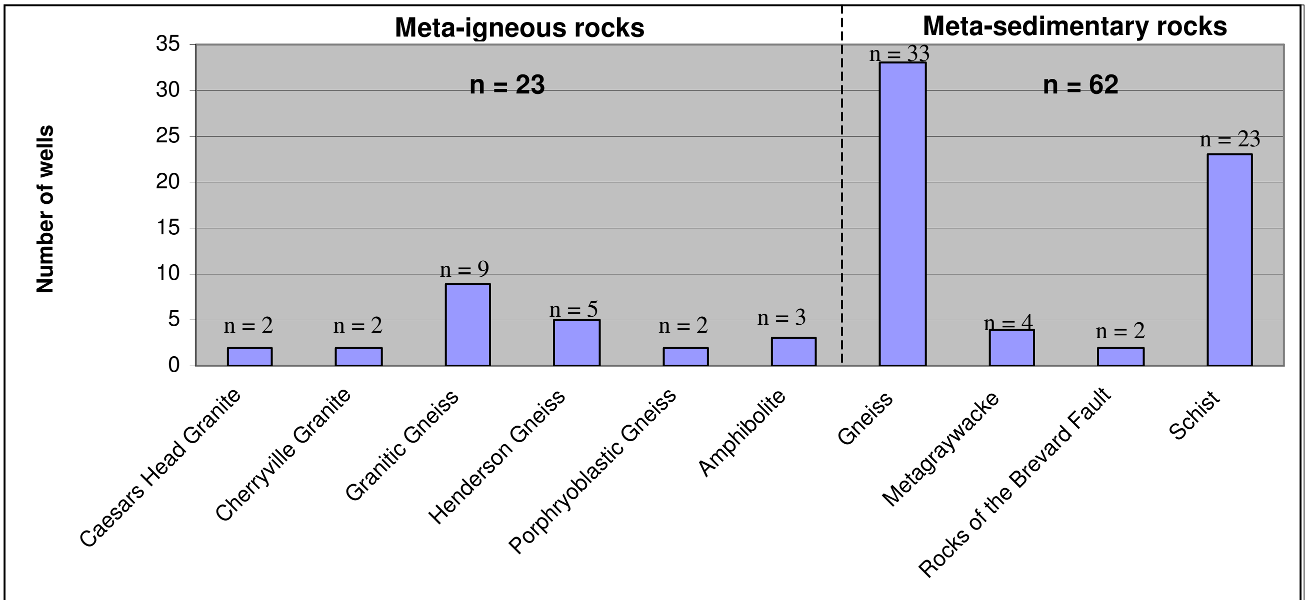


Figure 5. Number of wells sampled within each rock type, 2007.

Geochemical results obtained during the study are summarized in Table 1. The table also provides information on well depth and on casing depth, a proxy used in this study to estimate the regolith thickness. Taken as a whole, sampled ground water tended to be slightly acidic (median pH = 6.2), oxygenated (median DO = 6.5 mg/L), and minimally conductive (median SC = 77 uS/cm). The buffering capacity of the ground water was low (median alk = 29 mg/L), and the levels of iron and manganese also were low (median Fe < 50 ug/L and median Mn < 10 ug/L). Raw oxidation-reduction potential (ORP) values were moderate (median raw ORP = 164 mV). Lead was below the detection limit of 10 ug/L in all samples. Arsenic was below the detection limit of 5 ug/L in all samples.

Table 1. Descriptive statistics for field parameters and well characteristics measured in study wells in Alleghany, Caldwell, Burke, McDowell, Cleveland, Rutherford, Polk, Cherokee, Buncombe, Henderson, and Transylvania Counties, North Carolina, 2007.

Parameter	No. of samples	Maximum value	Minimum value	Median value
pH	86	8.4	4.4	6.2
Specific conductivity, in uS/cm	86	350	10	77
Temperature, in degrees Celsius	84	>20	12.8	16.4
Dissolved oxygen, in mg/L	84	11.4	0.1	6.5
Raw oxidation reduction potential, in mV	84	252	-76	164
Total dissolved solids, mg/L	80	260	20	66
Lead, in ug/L	80	<10	<10	<10
Arsenic, in ug/L	80	<5	<5	<5
Potassium, in ug/L	89	6200	4	1600
Iron, in ug/L	89	14000	<50	<50
Manganese, in ug/L	89	100	<10	<10
Alkalinity, in mg/L	84	140	2	29
Casing depth, in feet below land surface	18	120	18	73
Well depth, in feet below land surface	47	705	29	205
Well yield, in gpm	26	126	0.3	15

uS/cm, microSiemens per centimeter
mg/L, milligrams per liter
ug/L, micrograms per liter
gpm, gallons per minute
mv, millivolts

Because of moderately high DO levels, moderate ORP levels, and low dissolved iron and manganese, most ground water in the study area was considered to be oxidizing. However, a more thorough analysis (including, for example, dissolved hydrogen and the speciation of iron, nitrogen, manganese, sulfur, and carbon) would be needed to definitively determine the oxidation-reduction state of the ground water system, and it is recognized that conditions can change with time and location and are dependent upon many variables not measured in this study. Further, it should be noted that in some cases otherwise *an*oxic ground water (formation water) may become oxygenated inside the well bore due to water level fluctuations caused by intermittent pumping, chlorination, and (or) to a "cascade effect" that can occur when water enters the bore hole from a fracture located above the water level in the well. Reducing or moderately reducing conditions were observed in four sample locations (well numbers 214, 223, 226, and 256), where DO values ranged from 0.1 to 0.6 mg/L, ORP values ranged from –13 to -68 mV, and SC values ranged from 109 to 174 uS/cm (well above the normal range for the study area as a whole) (Appendix 1).

OCCURRENCE AND DISTRIBUTION OF SELECTED RADIONUCLIDES IN PRIVATE DRINKING WATER WELLS

Samples of raw, untreated ground water were collected at 87 private wells in the study area comprising parts of Alleghany, Caldwell, Burke, McDowell, Cleveland, Rutherford, Polk, Cherokee, Buncombe, Henderson, and Transylvania Counties, North Carolina (fig. 2). Indoor air radon was measured in 40 of the 87 homes associated with the sampled wells. The remaining 47 homes did not sample indoor air radon or results were not reliable.

ESRI geographic information system software was used to map selected values of radon, indoor air radon, uranium, and radium isotopes and to evaluate geologic and other spatial influences on the observed data. The data were plotted on a geologic map of North Carolina (N.C. Geological Survey, 1985) and assessed for distributions and trends. Elevated radon was observed in most wells, uranium was elevated in only a small percentage of wells, and radium isotopes were low in all wells. Analytical results are provided in the following section and in tabular form in Appendix 1.

Concentrations and Distribution in Ground Water

Table 2 shows the detection rates (percentage of samples that were above the laboratory's method detection limit) for radon, indoor air radon, uranium, Ra-226, and Ra-228 in the study area. Table 3 shows summary data (maximum, minimum, median) and number of samples exceeding the EPA standard for radon, uranium, Ra-226, Ra-228, and indoor radon.

Table 2. Detection rates (percentage of samples that were above the laboratory's method detection limit) for radon, indoor air radon, uranium, Ra-226, and Ra-228 in the Western North Carolina study area, 2007.

radionuclide	percent of all samples above detection limit	working detection limit
Radon	100	50 pCi/L
Indoor radon	92	0.3 pCi/L
Uranium	14	1 ug/L
Radium-226	7	1 pCi/L
Radium-228	4	1 pCi/L

pCi/L, picocuries per liter
ug/L, micrograms per liter

Radon concentrations ranged from 140 to 16,900 pCi/L, with a median value of 1560 pCi/L (Table 3). Of 87 sampled wells, 93 percent exceeded the proposed EPA MCL of 300 pCi/L, and 17 percent exceeded the EPA proposed alternate MCL of 4000 pCi/L. Total uranium concentrations ranged from below the analytical detection limit (about 1 ug/L) to 72.4 ug/L, with a median value of less than 1 ug/L. Radium-226 concentrations ranged from less than the analytical detection limit (about 1 pCi/L) to 2.8 pCi/L, with a median value of less than 1 pCi//L. Radium-228 concentrations ranged from less than the analytical detection limit (about 1 pCi/L) to 1.5 pCi/L, with a median value of less than 1 pCi/L. Figure 5 shows study wells with radionuclide concentrations above EPA standards, superimposed on a map of meta-igneous versus meta-sedimentary rocks.

Table 3. Summary of radionuclide results obtained from study wells in study area, 2007.

Radionuclide	No. of samples	Maximum value	Minimum value	Median value	USEPA Standard	% exceeding standard
Radon, pCi/L	87	16900	140	1560	300*/4000**	93/17
Uranium, ug/L	83	72.4	<1	<1	30	2
Radium-226, pCi/L	82	2.8	<1	<1	5***	0
Radium-228, pCi/L	82	1.5	<1	<1	5***	0
Indoor radon, pCi/L	40	10.6	<0.3	2.1	4	23

* proposed
** proposed alternate
*** combined, Ra-228 + Ra-226
pCi/L, picocuries per liter
ug/L, micrograms per liter

Wells drilled in meta-igneous rocks tended to have higher dissolved radon (median = 1810 pCi/L) than wells drilled in meta-sedimentary rocks (median = 1390 pCi/L) (Table 4). Higher uranium concentrations also were associated with wells in meta-igneous rocks (maximum = 72.4 ug/L) over that of wells in meta-sedimentary rocks (maximum = 3.0 ug/L).

Table 4. Radionuclide concentrations observed in private wells in meta-igneous rocks versus meta-sedimentary rocks, Western North Carolina, 2007.

	RADON, pCi/L			URANIUM, ug/L			RADIUM-226, pCi/L			RADIUM-228, pCi/L			INDOOR RADON, pCi/L		
Rock Origin	n	median	max	n	median	max	n	median	max	n	median	max	n	median	max
Meta-igneous	24	1810	16900	22	<1	72.4	21	<1	1.4	21	<1	1.5	11	1.3	10.6
Meta-sedimentary	63	1390	9950	61	<1	3.0	61	<1	2.8	61	<1	1.1	29	2.2	10.6

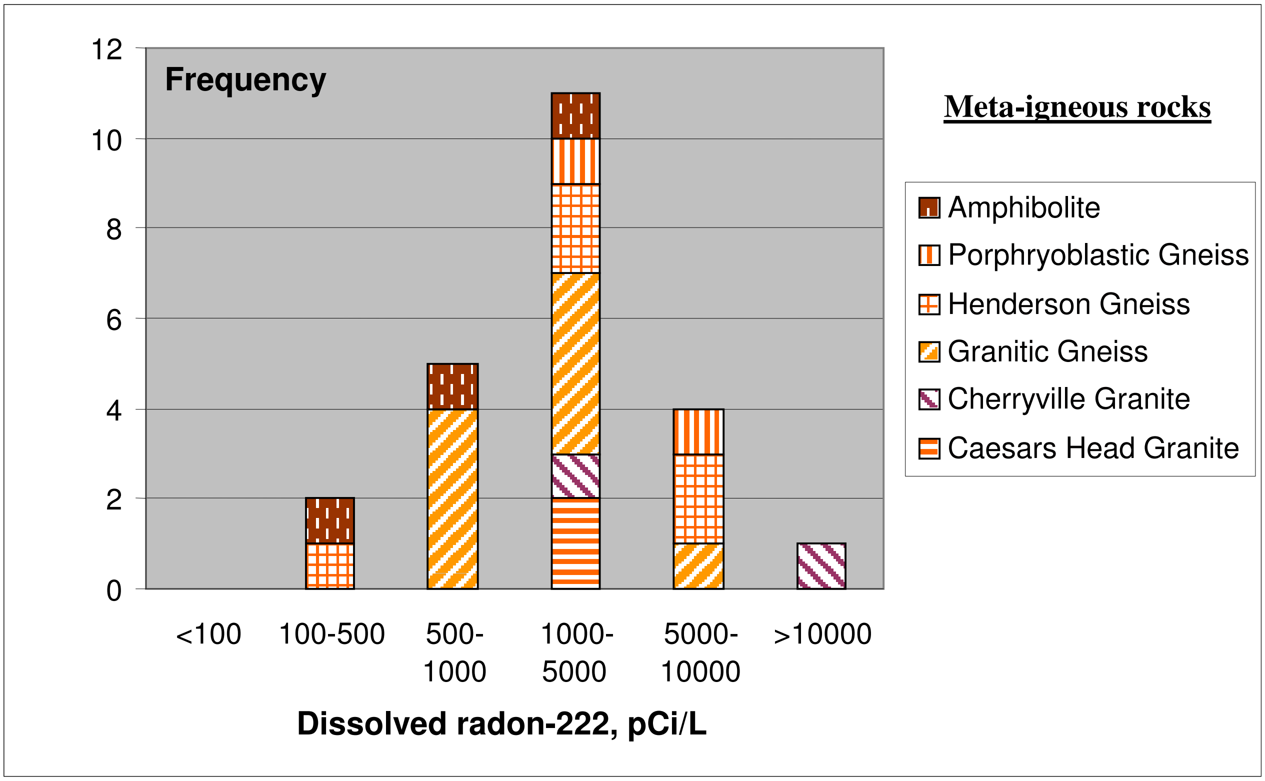
pCi/L, picocuries per liter
ug/L, micrograms per liter

Radon concentrations by rock type/formation are shown in figure 6. Most well samples contained dissolved radon in the range between 1000 and 5000 pCi/L. An analysis of raw data (Appendix 1) shows that wells drilled in younger granitic rocks (less than 500 million years old, which includes the Cherryville Granite, Henderson Gneiss, and Caesar's Head Granite formations) were higher in dissolved radon (median = 4020 pCi/L) than wells drilled in other rock types (median = 1360 pCi/L). Wells characterized by oxidizing conditions were higher in dissolved radon (median = 1610 pCi/L) than wells characterized by reducing conditions (median = 1090 pCi/L).

Additional analyses are being conducted to evaluate controls on radionuclide occurrence and distribution and will be presented in a regional statistical synthesis report. Variables will include geologic formations, geochemistry, hydrologic setting, well construction details, and others.

Concentrations and Distribution of Radon in Indoor Air

Indoor air radon concentrations from 40 well owners' homes ranged from 0.3 to 10.6 pCi/L, with a median value of 2.1 pCi/L. Of the 40 homes in which indoor-air radon was measured, 23 percent exceeded the EPA MCL of 4 pCi/L (fig. 6).



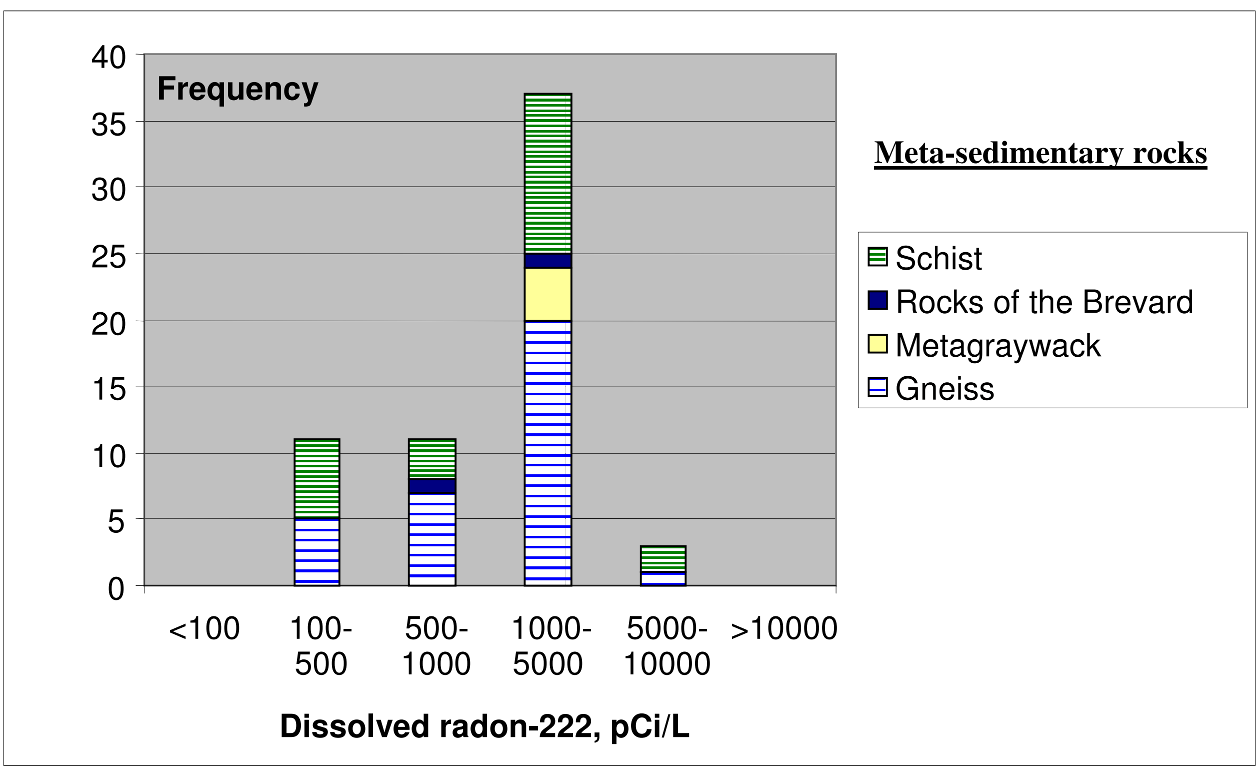


Figure 6. Dissolved radon-222 water concentrations by meta-igneous and by meta-sedimentary rock type.

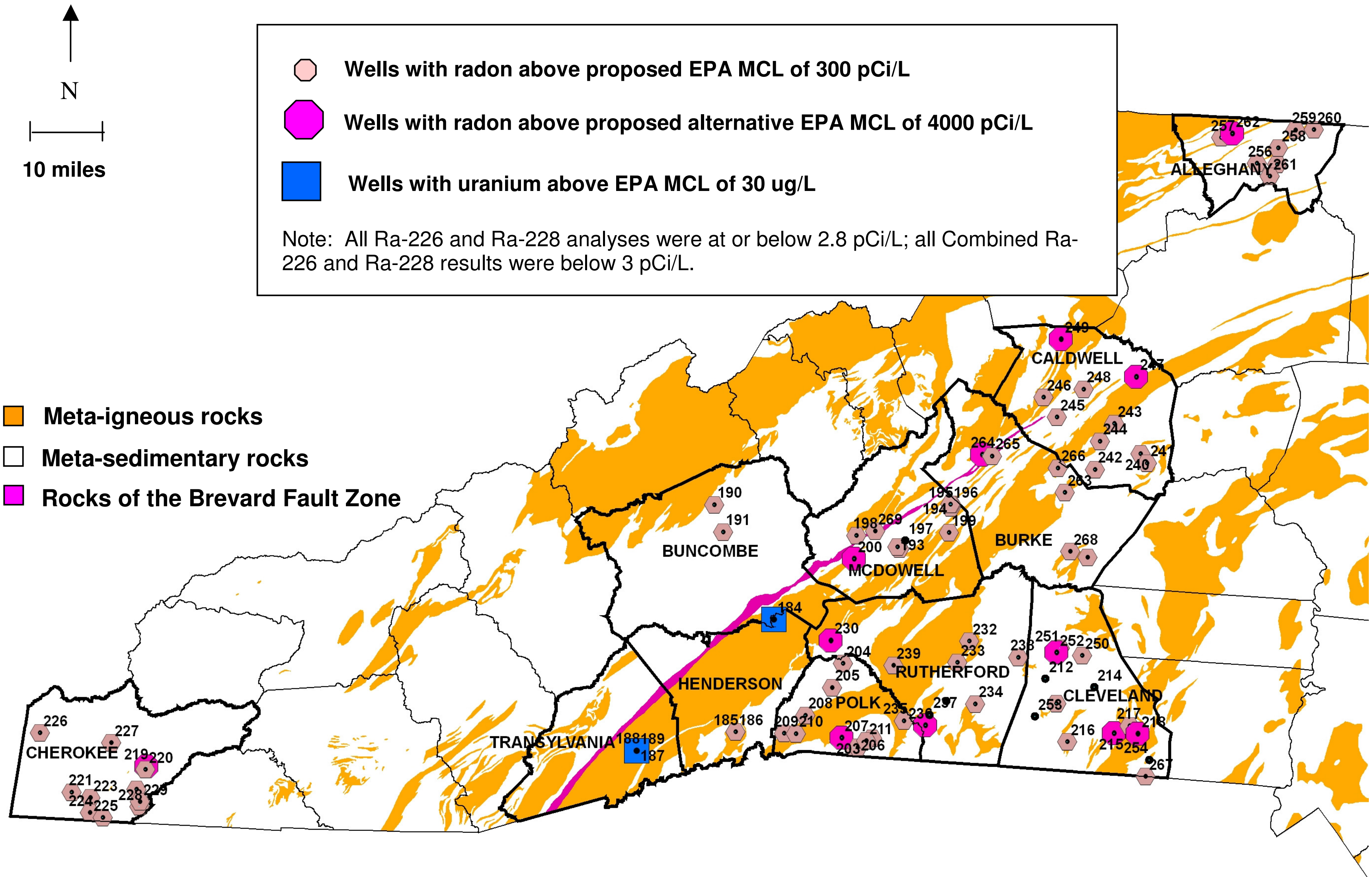


Figure 7. Study wells with radionuclide concentrations above EPA standards, superimposed on map of meta-igneous versus meta-sedimentary rock (NC Geological Survey, 1985), Western North Carolina study area, 2007.

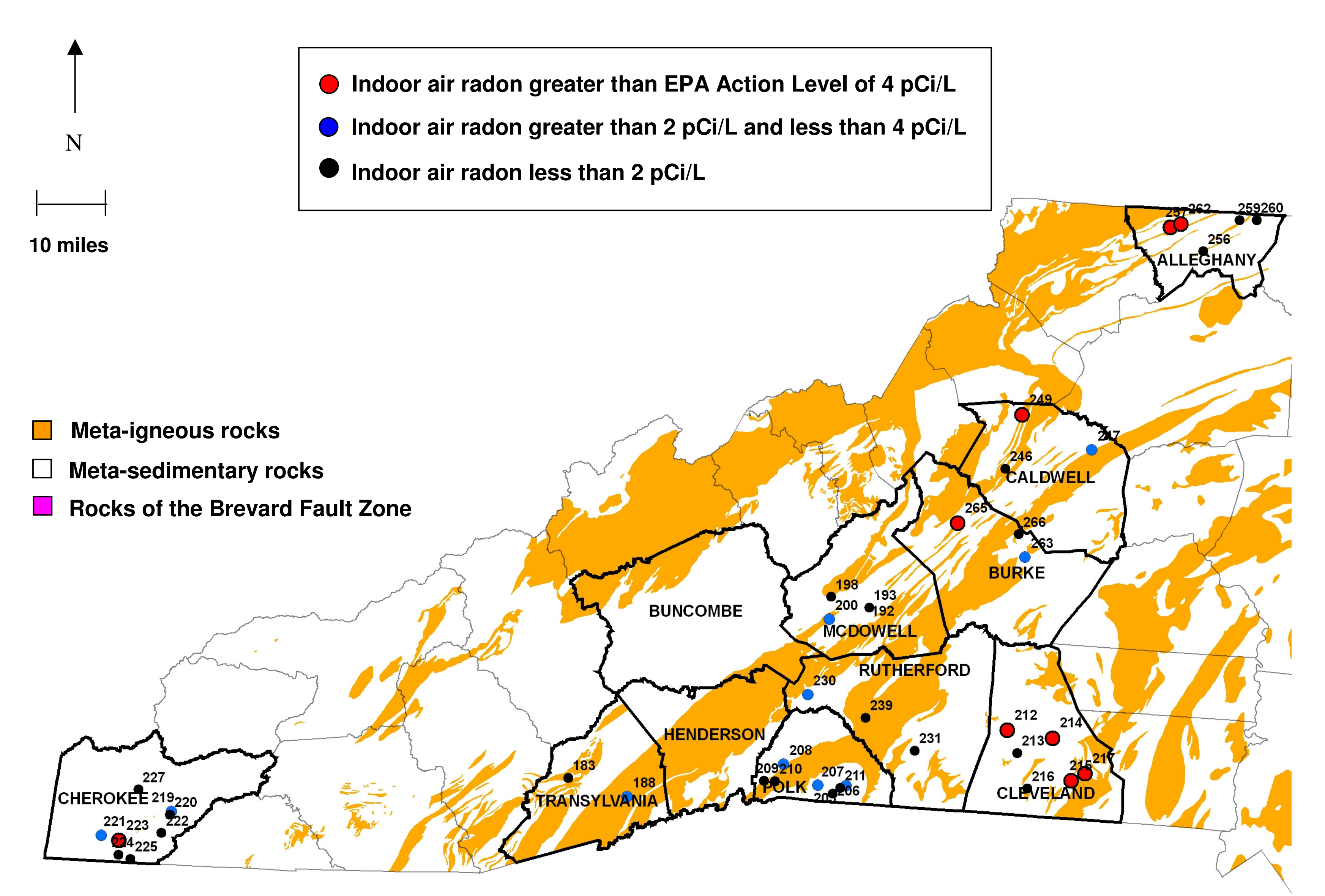


Figure 8. Indoor air radon levels in study homes, superimposed on map of meta-igneous versus meta-sedimentary rock (NC Geological Survey, 1985), Western North Carolina, 2007.

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SUMMARY

Elevated levels of naturally occurring radionuclides are known to occur in ground water and indoor air (radon) in the Blue Ridge and Piedmont Provinces of Western North Carolina. This occurrence is due to the presence of uranium rich rocks – including granites and gneisses - across much of the region. Radionuclides are human carcinogens and have been linked to bone, kidney, and lung cancers, among others. About half of the citizens of Western North Carolina rely on public and private ground water wells for their principal drinking water supply. Indoor air in Western North Carolina is susceptible to elevated levels of radon, and eight counties in North Carolina - all in Western North Carolina – are classified as EPA Zone 1 counties, with predicted indoor radon concentrations above the action level of 4 pCi/L (EPA Radon Map, accessed via internet, 8/19/05, http://www.ncradon.org/zone.htm).

Ground water samples collected from 87 private wells within Alleghany, Caldwell, Burke, McDowell, Cleveland, Rutherford, Polk, Cherokee, Buncombe, Henderson, and Transylvania Counties were found to contain elevated levels of radon (140 to 16,900 pCi/L; median = 1560 pCi/L). Radon exceeded EPA's proposed maximum contaminant level (MCL) of 300 pCi/L in 93 percent of the wells, and exceeded the proposed alternate MCL of 4000 pCi/L in 17 percent of the wells.

The highest dissolved radon concentrations were observed in wells in younger granitic rocks (less less than 500 million years old to include the Cherryville Granite, Henderson Gneiss, and Caesar's Head Granite formations) (median = 4020 pCi/L; median = 1360 pCi/L in wells in all other rock types). Wells in meta-igneous rocks were higher in dissolved radon (median = 1810 pCi/L) than wells in meta-sedimentary rocks (median = 1390 pCi/L). Wells characterized by oxidizing conditions were higher in dissolved radon (median = 1610 pCi/L) than wells characterized by reducing conditions (median = 1090 pCi/L). Each of these findings is consistent with previous studies in this region (Campbell, 2005; 2006, written communication).

Uranium (maximum = 72.4 ug/L) exceeded the EPA MCL in 2 percent of wells. Radium-226 and radium-228 concentrations were relatively low in all sampled wells (less than 2.8 pCi/L). Indoor radon ranged from 0.3 to 10.6 pCi/L, with a median value of 2.1 pCi/L. About one quarter of the sampled homes had indoor air radon above the EPA action level of 4 pCi/L.

Subsequent investigation and data analysis will seek to evaluate the occurrence and distribution of radionuclides in additional areas of concern in Western North Carolina. Subsequent investigation will also evaluate potential changes in radionuclide concentrations over time.

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APPENDIX 1. Raw data collected during study of 87 private drinking water wells in Alleghany, Caldwell, Burke, McDowell, Cleveland, Rutherford, Polk, Cherokee, Buncombe, Henderson, and Transylvania Counties, North Carolina, 2007. [ft = feet; blank = no data; K = potassium; Fe = Iron; Mn = manganese; Pb = lead; As = arsenic; pCi/L = picocuries per liter; ug/L = micrograms per liter; Temp = temperature; C = degrees Celsius; Spec Cond = specific conductance; DO = dissolved oxygen; ORP = oxidation reduction potential; Alk = alkalinity as bicarbonate; BDL = below detection limit; gpm = gallons per minute; uS/cm = microsiemens per centimeter; mg/L = milligrams per liter; mV = millivolts.]

WELL NUMBER	SAMPLE DATE	URANIUM ug/L	RADON pCi/L	RADIUM-226 pCi/L	RADIUM-228 pCi/L	INDOOR RADON pCi/l
184	8-Jan-07	72.4	4390	0.4	0.5	
185	5-Feb-07	15.9	3820	1.4	1.5	
186	5-Feb-07	BDL of 1	1940	0.6	0.2	
187	2-Apr-07	BDL of 1	270			
188	2-Apr-07	BDL of 1	3550	0.6	0.5	3.6
189	2-Apr-07	61.6	7010	BDL of 1	0.6	
190	9-May-07	BDL of 1	2020	0.9	BDL of 1	
191	15-May-07	BDL of 1	740	BDL of 1	BDL of 1	
192	4-Jun-07	BDL of 1	1610	0.2	BDL of 1	
193	4-Jun-07	BDL of 1	320	BDL of 1	BDL of 1	0.6
194	4-Jun-07	BDL of 1	3790	BDL of 1	BDL of 1	2.2
195	4-Jun-07	BDL of 1	2390	0.4	BDL of 1	
196	4-Jun-07	BDL of 1	620	BDL of 1	BDL of 1	
197	4-Jun-07	BDL of 1	200	BDL of 1	BDL of 1	
198	4-Jun-07	BDL of 1	1050	BDL of 1	BDL of 1	0.8
199	4-Jun-07	BDL of 1	3550	BDL of 1	BDL of 1	
200	4-Jun-07	BDL of 1	7600	BDL of 1	BDL of 1	2.4
201	5-Jun-07	BDL of 1	460	BDL of 1	BDL of 1	
202	5-Jun-07	2.1	990	BDL of 1	BDL of 1	
203	5-Jun-07	BDL of 1	4100	BDL of 1	BDL of 1	2.1
204	5-Jun-07	BDL of 1	2960	0.4	BDL of 1	
205	5-Jun-07	3	3330	BDL of 1	BDL of 1	
206	6-Jun-07	BDL of 1	1050	BDL of 1	BDL of 1	0.8
207	6-Jun-07	BDL of 1	1130	BDL of 1	BDL of 1	2.4
208	6-Jun-07	BDL of 1	1490	BDL of 1	BDL of 1	3.0
209	6-Jun-07	BDL of 1	1680	BDL of 1	BDL of 1	1.3
210	6-Jun-07	BDL of 1	1560	BDL of 1	BDL of 1	1.3
211	6-Jun-07	BDL of 1	1390	BDL of 1	BDL of 1	0.5
212	12-Jun-07	BDL of 1	280	BDL of 1	BDL of 1	5.9
213	12-Jun-07	BDL of 1	660	BDL of 1	BDL of 1	1.3
214	12-Jun-07	BDL of 1	260	BDL of 1	BDL of 1	5.7
215	12-Jun-07	BDL of 1	5390	BDL of 1	BDL of 1	6.5
216	12-Jun-07	BDL of 1	330	BDL of 1	BDL of 1	0.9
217	12-Jun-07	BDL of 1	3220	1.5	BDL of 1	9.8
218	12-Jun-07	2	4020	BDL of 1	BDL of 1	
219	19-Jun-07	BDL of 1	5040	BDL of 1	BDL of 1	3.2
220	19-Jun-07	BDL of 1	1540	0.7	BDL of 1	2.0
221	19-Jun-07	BDL of 1	3490	0.8	BDL of 1	3.0
222	19-Jun-07	BDL of 1	2200	0.6	BDL of 1	0.7
223	19-Jun-07	BDL of 1	1140	0.6	BDL of 1	4.5
224	19-Jun-07	1.21	780	0.3	BDL of 1	0.8
225	19-Jun-07	BDL of 1	1930	BDL of 1	BDL of 1	0.8
226	20-Jun-07	BDL of 1	3150	1.7	1.1	
227	20-Jun-07	1.27	2670	BDL of 1	BDL of 1	0.8
228	20-Jun-07	BDL of 1	300	0.3	0.3	

WELL NUMBER	SAMPLE DATE	URANIUM ug/L	RADON pCi/L	RADIUM-226 pCi/L	RADIUM-228 pCi/L	INDOOR RADON pCi/l
229	20-Jun-07	1.2	3910	BDL of 1	0.6	
230	25-Jun-07	15.2	6420	0.6	BDL of 1	3.0
231	25-Jun-07	BDL of 1	140	0.4	BDL of 1	BDL of 0.3
232	25-Jun-07	BDL of 1	510	BDL of 1	BDL of 1	
233	25-Jun-07	BDL of 1	330	BDL of 1	BDL of 1	
234	25-Jun-07	BDL of 1	3610	2.8	BDL of 1	
235	26-Jun-07	BDL of 1	750	BDL of 1	BDL of 1	
236	26-Jun-07	BDL of 1	4440	BDL of 1	BDL of 1	
237	26-Jun-07	BDL of 1	190	BDL of 1	BDL of 1	
238	26-Jun-07	BDL of 1	1170	0.4	BDL of 1	
239	26-Jun-07	1.3	980	0.4	BDL of 1	0.9
240	9-Jul-07	BDL of 1	450	BDL of 1	BDL of 1	
241	9-Jul-07	BDL of 1	1060	BDL of 1	BDL of 1	
242	9-Jul-07	BDL of 1	530	BDL of 1	BDL of 1	
243	9-Jul-07	BDL of 1	1660	BDL of 1	BDL of 1	
244	9-Jul-07	BDL of 1	880	BDL of 1	BDL of 1	
245	10-Jul-07	BDL of 1	1100	BDL of 1	0.4	
246	10-Jul-07	BDL of 1	2760	BDL of 1	0.4	0.9
247	10-Jul-07	BDL of 1	4510	0.3	BDL of 1	3.3
248	10-Jul-07	BDL of 1	1990	BDL of 1	BDL of 1	
249	10-Jul-07		8820			10.6
250	17-Jul-07	BDL of 1	3910	BDL of 1	0.5	
251	17-Jul-07	BDL of 1	580	BDL of 1	0.4	
252	17-Jul-07	BDL of 1	9950	BDL of 1	BDL of 1	
253	17-Jul-07	BDL of 1	210	BDL of 1	BDL of 1	
254	17-Jul-07	BDL of 1	16900	BDL of 1	BDL of 1	
255	6-Aug-07	BDL of 1	1010	BDL of 1	BDL of 1	
256	6-Aug-07	BDL of 1	1030	1.1	BDL of 1	0.6
257	6-Aug-07	BDL of 1	1330	BDL of 1	0.5	7.2
258	6-Aug-07	BDL of 1	2620	1.4	0.5	
259	6-Aug-07	1.7	990	BDL of 1	1.0	BDL of 0.3
260	6-Aug-07	BDL of 1	2290	BDL of 1	0.4	BDL of 0.3
261	6-Aug-07	BDL of 1	1710	BDL of 1	BDL of 1	
262	6-Aug-07	BDL of 1	8300	BDL of 1	BDL of 1	10.6
263	27-Aug-07	BDL of 1	440	BDL of 1	0.5	3.8
264	27-Aug-07	BDL of 1	4200	BDL of 1	0.8	
265	27-Aug-07	BDL of 1	3060	BDL of 1	BDL of 1	4.8
266	27-Aug-07	BDL of 1	590	BDL of 1	BDL of 1	
267	27-Aug-07	BDL of 1	970	0.6	0.7	
268	10-Sep-07		700			
269	10-Sep-07		980			
270	10-Sep-07		3450			

WELL NUMBER	pH	SPEC COND uS/cm	TEMP C	DO mg/L	Raw ORP mV	ALK mg/L
184						48
185	6.4	32				43
186	5.2	28				7
187	4.4	10	13.7	5.9	141	3
188	4.8	24	14.7	5.6	218	13
189	7.7	128	14.5	4.7	163	67
190	6.3	157	14.5	10.0	61	60
191	5.8	54	14.7	7.4	179	18
192	5.9	58	16.7	4.9	138	22
193	6.0	147	15.4	5.4	190	23
194	6.0	57	15.3	7.2	222	18
195	6.0	130	19.2	1.1	109	40
196	7.4	151	17.7	0.3	78	65
197	6.0	100	15.8	7.4	191	28
198	6.5	66	15.4	6.2	150	30
199	6.0	50	14.9	8.9	135	24
200	6.0	70	16.3	5.5	104	29
201	6.8	35	19.8	4.4	220	10
202	6.8	120	17.7	0.7	176	44
203	6.8	57	16.9	8.5	174	26
204	5.8	25	16.7	8.5	226	9
205	6.9	217	25.1	2.4	175	39
206	5.8	58	17.5	8.8	180	29
207	5.8	44	16.7	7.3	171	15
208	6.3	75	15.1	6.4	132	36
209	6	59	13.5	6.9	142	22
210	5.8	42	15	6.2	152	17
211	6.2	89	17	4.7	97	39
212	6.4	293	17.1	8.1	164	94
213	5.8	160	17.3	5.7	197	58
214	8.4	174	17.4	0.1	-68	78
215	5.3	72	18.8	7.7	218	17
216	5.8	94	17.7	5.1	160	14
217	6.1	105	18	7.8	172	31
218	5.9	126	16.4	5.1	197	52
219	5.9	34	15.3	5.8	252	14
220	7.4	139	16.4	0.37	138	59
221	4.7	15	14.4	6.7	220	4
222	6.2	100	15.1	0.26	47	34
223	6.3	144	14.9	0.34	-22	58
224	5.2	22	15.5	7.3	217	6
225	5.8	33	15.8	7.8	236	14
226	6.8	109	14.4	0.6	-13	42
227	7.2	69	14.5	10.1	129	32
228	8	126	18.4	6.8	122	56

WELL NUMBER	pH	SPEC COND uS/cm	TEMP C	DO mg/L	Raw ORP mV	ALK mg/L
229	7.9	93	15.8	3.9	-76	36
230	6.2	350	16.3	1.1	143	53
231	6.5	313	20.1	4.6	150	140
232	6	42	17.3	7.6	183	10
233	6	51	16.6	7.9	189	21
234	5.8	83	19	7.4	173	12
235	6.7	58	17.1	8.5	170	25
236	6.9	98	16.4	0.6	21	35
237	6.4	56	23.6	8.1	155	24
238	7.6	106	16.9	1.6	97	41
239	8	154	16.8	1.2	119	65
240	5.8	31	17.4	11	228	2
241	6.4	39	16.9	9.3	209	15
242	6.2	39	27.9	7.6	200	6
243	6.9	119	18.2	4.9	164	43
244	6.9	91	18.2	10.6	180	12
245	6.8	80	15.1	7.7	200	36
246	7	43	20.3	7.9	166	16
247	6.9	94	14	9.5	171	32
248	7	102	17.5	9.5	192	30
249	5.6	31	13	9.7	201	10
250	6.1	76	15.7	6.6	197	74
251	7.1	286	17.2	8.2	178	96
252	6.7	28	16.4	11.4	212	7
253	8.2	135	16.6	1.6	126	53
254	6.2	31	16.9	6.6	181	8
255	5.4	57	13.7	6.4	119	7
256	6.8	118	13.9	0.7	-24	39
257	6	67	19.2	5.9	117	24
258	6	80	16.3	2.6	135	22
259	7	152	13.8	2.7	76	51
260	5.9	46	12.8	7.8	140	18
261	5.4	63	14.2	7.2	218	11
262	6.2	131	13.6	4.9	137	32
263	5.7	88	15.7	5.9	129	29
264	5.5	54	16.4	6.8	180	21
265	5.1	49	16.3	8	206	18
266	5.6	78	17.3	7.7	157	32
267	6.3	126	16.4	6.4	114	38
268	7.3	94	16.3	4.3	-12	
269	7.5	130	16.7	7.9	88	
270	6.5	33	16.7	6.2	163	

WELL NUMBER	COUNTY	Fe ug/L	Mn ug/L	K ug/L	Pb ug/L	As ug/L	HYDROLOGIC SETTING
184	Buncombe	<50	<10	6200	<10	<5	recharge
185	Henderson	<50	<10	1500	<10	<5	recharge
186	Henderson	<50	<10	1300	<10	<5	recharge
187	Transylvania	<50	23	530	<10	<5	midslope
188	Transylvania	<50	<10	690	<10	<5	recharge
189	Transylvania	<50	<10	410	<10	<5	discharge
190	Buncombe	3400	44	3100	<10	<5	midslope
191	Buncombe	61	1	1700	<10	<5	midslope
192	McDowell	<50	<10	1700	<10	<5	discharge
193	McDowell	<50	<10	2500	<10	<5	midslope
194	McDowell	<50	42	2100	<10	<5	recharge
195	McDowell	<50	<10	2000	<10	<5	midslope
196	McDowell	<50	19	1100	<10	<5	discharge
197	McDowell	530	<10	2700	<10	<5	discharge
198	McDowell	<50	<10	790	<10	<5	midslope
199	McDowell	<50	<10	1200	<10	<5	midslope
200	McDowell	<50	<10	980	<10	<5	discharge
201	Polk	<50	<10	770	<10	<5	midslope
202	Polk	160	<10	2600	<10	<5	
203	Polk	<50	<10	2100	<10	<5	midslope
204	Polk	<50	<10	1200	<10	<5	discharge
205	Polk	380	12	2300	<10	<5	discharge
206	Polk	<50	<10	880	<10	<5	recharge
207	Polk	<50	<10	650	<10	<5	recharge
208	Polk	<50	<10	1500	<10	<5	midslope
209	Polk	1300	<10	1400	<10	<5	discharge
210	Polk	<50	<10	1300	<10	<5	discharge
211	Polk	<50	<10	1500	<10	<5	midslope
212	Cleveland	<50	<10	2800	<10	<5	recharge
213	Cleveland	<50	<10	2000	<10	<5	midslope
214	Cleveland	<50	<10	220	<10	<5	discharge
215	Cleveland	<50	16	1600	<10	<5	midslope
216	Cleveland	<50	21	2400	<10	<5	midslope
217	Cleveland	<50	<10	2900	<10	<5	midslope
218	Cleveland	<50	<10	1800	<10	<5	midslope
219	Cherokee	480	<10	370	<10	<5	midslope
220	Cherokee	<50	21	660	<10	<5	recharge
221	Cherokee	14000	100	1600	20	<5	midslope
222	Cherokee	4000	71	1600	<10	<5	recharge
223	Cherokee	670	90	2200	<10	<5	recharge
224	Cherokee	<50	12	290	<10	<5	discharge
225	Cherokee	67	<10	1000	<10	<5	recharge
226	Cherokee	220	75	2200	<10	<5	midslope
227	Cherokee	<50	<10	1900	<10	<5	recharge
228	Cherokee	66	<10	510	<10	<5	midslope

WELL NUMBER	COUNTY	Fe ug/L	Mn ug/L	K ug/L	Pb ug/L	As ug/L	HYDROLOGIC SETTING
229	Cherokee	330	<10	530	<10	<5	midslope
230	Rutherford	<50	<10	2100	<10	<5	midslope
231	Rutherford	380	10	3300	<10	<5	midslope
232	Rutherford	<50	<10	1300	<10	<5	midslope
233	Rutherford	<50	<10	1100	<10	<5	recharge
234	Rutherford	<50	53	3400	<10	<5	recharge
235	Polk	<50	<10	1400	<10	<5	recharge
236	Rutherford	3200	59	1800	<10	<5	recharge
237	Rutherford	<50	<10	640	<10	<5	recharge
238	Rutherford	550	<10	810	<10	<5	recharge
239	Rutherford	<50	<10	3400	<10	<5	recharge
240	Caldwell	<50	12	1200	<10	<5	discharge
241	Caldwell	<50	10	790	<10	<5	midslope
242	Caldwell	<50	12	2000	<10	<5	midslope
243	Caldwell	<50	<10	2400	<10	<5	midslope
244	Caldwell	<50	<10	3000	<10	<5	recharge
245	Caldwell	750	13	1400	<10	<5	recharge
246	Caldwell	79	<10	2200	<10	<5	midslope
247	Caldwell	<50	<10	1100	<10	<5	recharge
248	Caldwell	220	<10	1600	<10	<5	
249	Caldwell	<50	<10	2300	<10	<5	recharge
250	Cleveland	<50	<10	2300	<10	<5	midslope
251	Cleveland	<50	<10	5200	<10	<5	recharge
252	Cleveland	<50	<10	1300	<10	<5	recharge
253	Cleveland	<50	17	2600	<10	<5	recharge
254	Cleveland	<50	<10	660	<10	<5	recharge
255	Alleghany	840	65	960	<10	<5	midslope
256	Alleghany	760	57	2400	<10	<5	discharge
257	Alleghany	<50	<10	1500	<10	<5	recharge
258	Alleghany	98	58	1900	<10	<5	recharge
259	Alleghany	<50	<10	3.7	<10	<5	recharge
260	Alleghany	<50	<10	1300	<10	<5	recharge
261	Alleghany	<50	<10	950	<10	<5	midslope
262	Alleghany	<50	<10	2800	<10	<5	recharge
263	Burke	<50	<10	1100	<10	<5	midslope
264	Burke	<50	<10	1600	<10	<5	midslope
265	Burke	<50	<10	1600	<10	<5	recharge
266	Burke	110	<10	2200	<10	<5	recharge
267	Cleveland	<50	<10	950	<10	<5	midslope
268	Burke	3000	57	2300	<10	<5	recharge
269	McDowell	<50	<10	1800	<10	<5	recharge
270	Burke	<50	<10	1200	<10	<5	recharge

WELL NUMBER	WELL DEPTH ft	CASING DEPTH ft	WELL YIELD ft	ROCK ORIGINS	ROCK TYPE
184				meta-igneous	Henderson Gneiss
185	528		15	meta-igneous	Caesars Head Granite
186	359			meta-igneous	Caesars Head Granite
187			0.3	meta-igneous	Henderson Gneiss
188				meta-igneous	Henderson Gneiss
189				meta-igneous	Henderson Gneiss
190				meta-sedimentary	muscovite biotite gneiss
191				meta-sedimentary	muscovite biotite gneiss
192				meta-sedimentary	biotite gneiss and schist
193				meta-sedimentary	biotite gneiss and schist
194				meta-sedimentary	biotite gneiss and schist
195				meta-sedimentary	biotite gneiss and schist
196				meta-sedimentary	biotite gneiss and schist
197				meta-sedimentary	biotite gneiss and schist
198				meta-sedimentary	gneiss
199				meta-sedimentary	biotite gneiss and schist
200				meta-igneous	Henderson Gneiss
201				meta-sedimentary	biotite gneiss
202	457		126	meta-sedimentary	biotite gneiss and schist
203	365	80		meta-sedimentary	biotite gneiss and schist
204	405	120	5	meta-igneous	porphyroblastic gneiss
205				meta-sedimentary	biotite gneiss and schist
206	235		14	meta-sedimentary	biotite gneiss
207	225	84	25	meta-sedimentary	biotite gneiss
208				meta-sedimentary	biotite gneiss and schist
209	125	64	50	meta-igneous	granitic gneiss
210				meta-igneous	granitic gneiss
211	260		91	meta-sedimentary	biotite gneiss
212	50	50		meta-sedimentary	mica schist
213	29	29		meta-sedimentary	mica schist
214	484	18	16	meta-sedimentary	biotite gneiss and schist
215	55	55		meta-sedimentary	mica schist
216	230			meta-igneous	mica schist
217	70	70		meta-sedimentary	mica schist
218				meta-igneous	Cherryville granite
219	300	105	7.5	meta-sedimentary	schist
220	520		10.6	meta-sedimentary	schist
221				meta-sedimentary	metagraywacke
222	160			meta-sedimentary	schist
223	360		60	meta-sedimentary	schist
224	42	42		meta-sedimentary	schist
225	520		1.5	meta-sedimentary	metagraywacke
226	187	48	10	meta-sedimentary	metagraywacke
227				meta-sedimentary	metagraywacke
228				meta-sedimentary	marble

WELL NUMBER	WELL DEPTH ft	CASING DEPTH ft	WELL YIELD ft	ROCK ORIGINS	ROCK TYPE
229				meta-sedimentary	schist
230	265		20	meta-igneous	porphyroblastic gneiss
231	60			meta-sedimentary	schist
232				meta-igneous	amphibolite
233	120	120		meta-sedimentary	schist
234	64	64		meta-sedimentary	schist
235	305		8	meta-igneous	granitic gneiss
236	135			meta-sedimentary	schist
237	38			meta-igneous	amphibolite
238				meta-sedimentary	schist
239	365			meta-igneous	granitic gneiss
240				meta-sedimentary	schist
241				meta-sedimentary	schist
242				meta-sedimentary	biotite gneiss and schist
243				meta-igneous	granitic gneiss
244				meta-sedimentary	biotite gneiss and schist
245	705	76	4	meta-sedimentary	biotite gneiss and schist
246	205		12	meta-igneous	granitic gneiss
247	200		20	meta-sedimentary	biotite gneiss and schist
248	125			meta-sedimentary	schist
249				meta-igneous	granitic gneiss
250	57		18	meta-sedimentary	biotite gneiss and schist
251	40			meta-sedimentary	biotite gneiss and schist
252	114			meta-sedimentary	schist
253	180			meta-sedimentary	schist
254				meta-igneous	Cherryville granite
255	200		35	meta-sedimentary	schist
256				meta-igneous	amphibolite
257	360	80	25	meta-sedimentary	muscovite biotite gneiss
258				meta-sedimentary	muscovite biotite gneiss
259				meta-sedimentary	muscovite biotite gneiss
260	204	84	3	meta-sedimentary	muscovite biotite gneiss
261				meta-sedimentary	gneiss
262	500		4	meta-sedimentary	muscovite biotite gneiss
263				meta-sedimentary	biotite gneiss and schist
264	129			meta-sedimentary	gneiss
265	245	84	15	meta-sedimentary	rocks of the Brevard Fault Zone
266				meta-igneous	granitic gneiss
267				meta-sedimentary	schist
268	300			meta-igneous	granitic rock
269	85			meta-sedimentary	rocks of the Brevard Fault Zone
270	325		15	meta-sedimentary	mica schist