Radon-222 and Other Naturally-Occurring Radionuclides in Private Drinking Water Wells and Radon in Indoor Air in Selected Counties in Western North Carolina, 2006

by Ted R. Campbell

Ground Water Circular 2006-01

N.C. DEPARTMENT OF ENVIRONMENTAL AND NATURAL RESOURCES
DIVISION OF WATER QUALITY, AQUIFER PROTECTION SECTION
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ABSTRACT

High levels of naturally occurring carcinogenic radionuclides – most notably radon-222 (radon) – were observed in ground water drinking supplies in the eight county study area of Western North Carolina. This is problematic because about half of the residents in the region rely on ground water as their principal potable supply. Five of these 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 these radionuclides is uranium rich rock – including granites and gneisses – prevalent across much of the region.

Ground water samples collected from 80 private wells within Madison, Mitchell, Watauga, Jackson, Buncombe, Henderson, and Transylvania Counties were found to contain ubiquitously high levels of radon (87 to 15,742 pCi/L; median = 1889 pCi/L). Radon exceeded EPA's proposed maximum contaminant level (MCL) of 300 pCi/L in 91 percent of the wells, and exceeded the proposed alternate MCL of 4000 pCi/L in 30 percent of the wells. Uranium (maximum = 30 ug/L) exceeded the EPA MCL in just over 1 percent of wells. Radium-226 and radium-228 were relatively low in all sampled wells (less than 2.2 pCi/L).

Ground water in the study area tended to be slightly acidic (median pH = 6.1), oxygenated (median dissolved oxygen = 7.4 milligrams per liter (mg/L)), and minimally conductive (median specific conductance = 82 microsiemens per centimeter (uS/cm)). The buffering capacity of the ground water was fairly low (median alkalinity = 34 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 moderately high (median raw ORP = 344 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.

Indoor air radon measured in homes associated with the private wells exceeded the EPA action level of 4 pCi/L in 29 percent of homes and ranged from less than 0.3 to 19.9 pCi/L with a median of 1.6 pCi/L.

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INTRODUCTION

Studies have shown elevated levels of carcinogenic radionuclides – most notably radon – occur in the ground water drinking supplies of Western North Carolina. This is problematic because about half of the population relies on ground water as their 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, 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).

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 Division, 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).

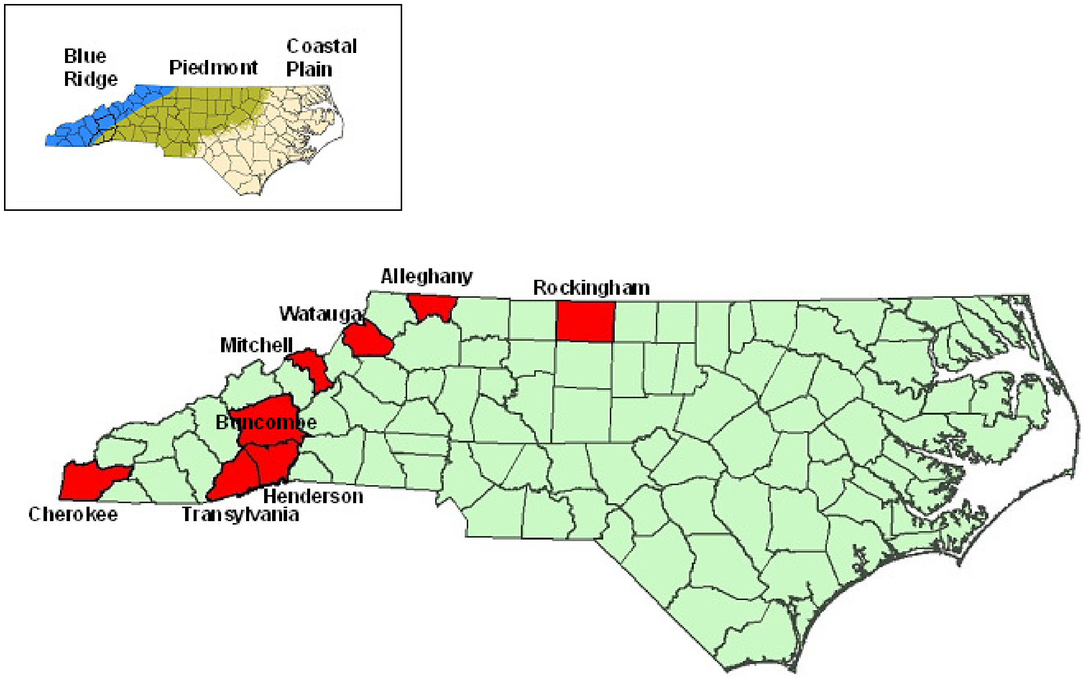

Figure 1. EPA Zone 1 counties in North Carolina (in red) with predicted indoor radon levels of 4 pCi/L or higher, and North Carolina physiographic provinces (in inset).

Because radionuclides are known to occur in the region and because they are linked to an increased risk of cancer, several key questions must be 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 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 areas of Western North Carolina and therefore is limited in scope. It is part of a multi-phased approach to help officials 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 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 targeted areas of Madison, Mitchell, Jackson, Watauga, 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 80 private drinking water wells. All wells sampled in the study were open boreholes completed in fractured bedrock with the overlying soil and regolith sealed by polyvinyl chloride or steel casing. The wells were sampled for total uranium (uranium), radium-226 (Ra-226), radium-228 (Ra-228), radon-222, iron, manganese, lead, arsenic, and field parameters. Additional data obtained at the wells included well-construction details, yield, latitude and longitude, topographic setting, and surrounding rock type and structure information. In addition, indoor air radon was measured in 59 of the 80 homes associated with the sampled private wells.

Acknowledgments

The author would like to thank Dr. Felix Fong and Talytha Moore at the North Carolina Division of Radiation Protection for their support and assistance during this investigation. The author would also like to thank David Vinson (Duke University PhD candidate) for his dedicated assistance in data collection and laboratory analysis. 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 issued by the North Carolina Division of Radiation Protection.

Data Collection and Analytical Methods

Ground-water samples were collected between July and September 2006, from 80 private wells within the study area (fig. 2). In addition, 59 indoor air radon samples were collected from the homes associated with the sampled wells. The remaining 21 homes did not participate in the indoor-air radon sampling or did not obtain reliable results. Collecting samples in well-defined target areas helped to maximize limited resources by focusing on areas that were presumed to be among those with the greatest radionuclide concentrations. Newspaper advertisements and word of mouth were used to solicit volunteers for the study.

Each ground water sample was analyzed for total uranium, Ra-226, Ra-228, radon, iron, manganese, lead, arsenic, alkalinity, bicarbonate, pH, DO, specific conductance, and temperature. Quality control replicate samples were collected and analyzed at about 10 percent of the wells. Each well sample was identified by a sequential number from 104 to 183 (fig. 2).

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.

Indoor air radon samples generally were obtained from a walkout basement (if present) or a first floor room with minimal ventilation. 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 as close to the wellhead as possible. 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.

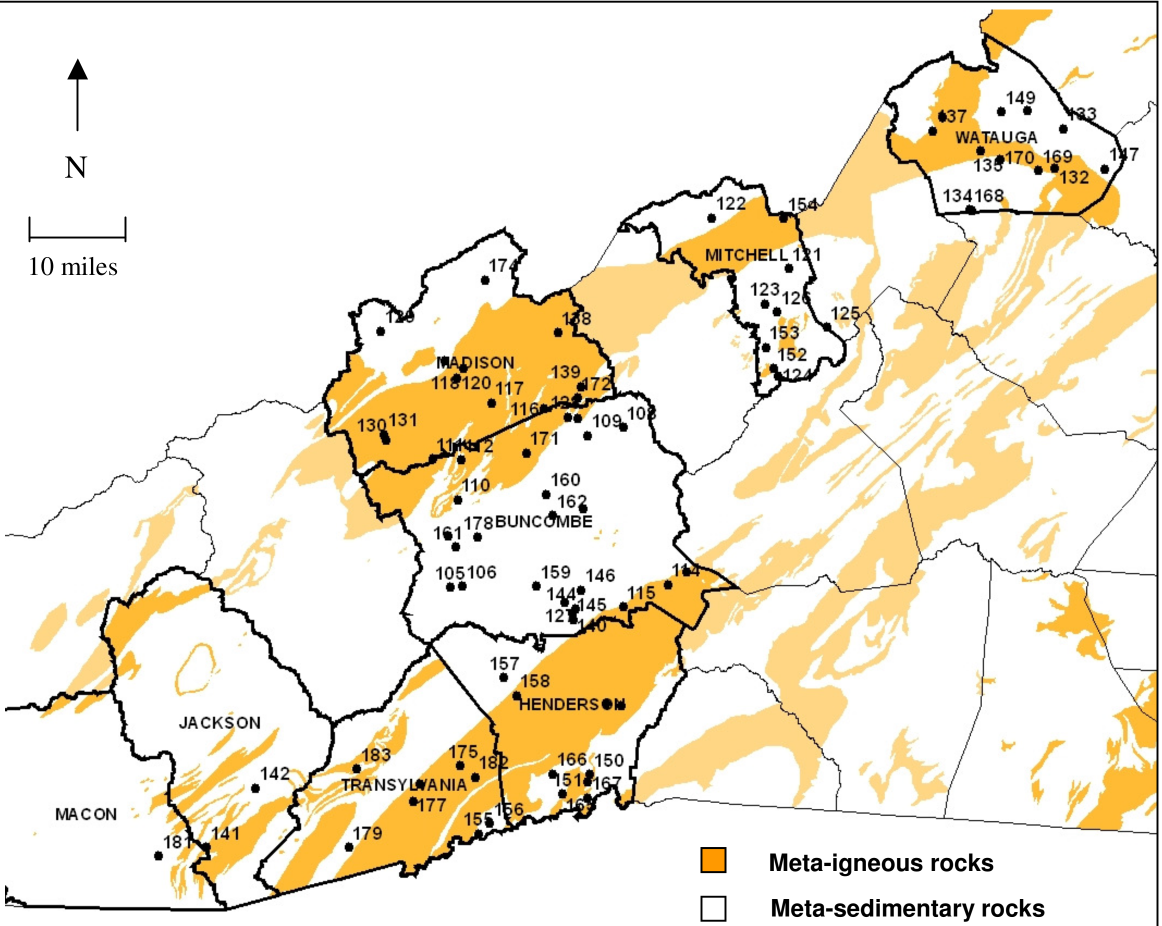

Figure 2. Private wells sampled during study, superimposed on map of meta-igneous versus meta-sedimentary rocks, Buncombe, Henderson, Transylvania, Mitchell, Watauga, Jackson, and Macon Counties, North Carolina, 2006.

Field parameters such as DO, specific conductance, pH, ORP, and temperature, were measured in the field using calibrated instrumentation. Information about well construction (depth, casing depth, yield, and others) was noted and recorded in the field. Survey-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 using deployable 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).

STUDY AREA SETTING

The study area is located in Western North Carolina and is comprised of mainly six counties – Madison, Mitchell, Watauga, Buncombe, Henderson, and Transylvania. It also includes very small portions of Jackson and Macon Counties. 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.

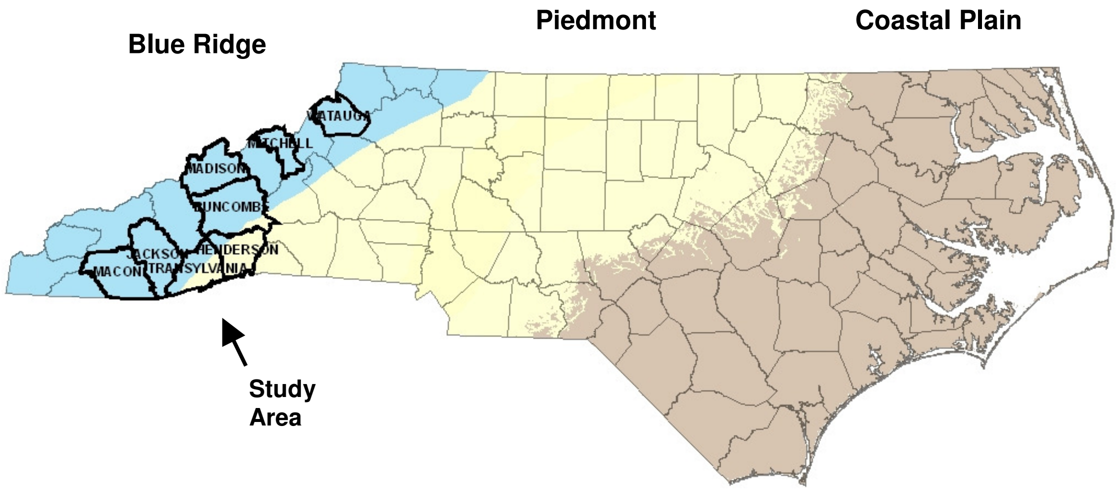

Figure 3. Physiographic provinces in North Carolina and the 2006 study area.

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.

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, as shown in 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.

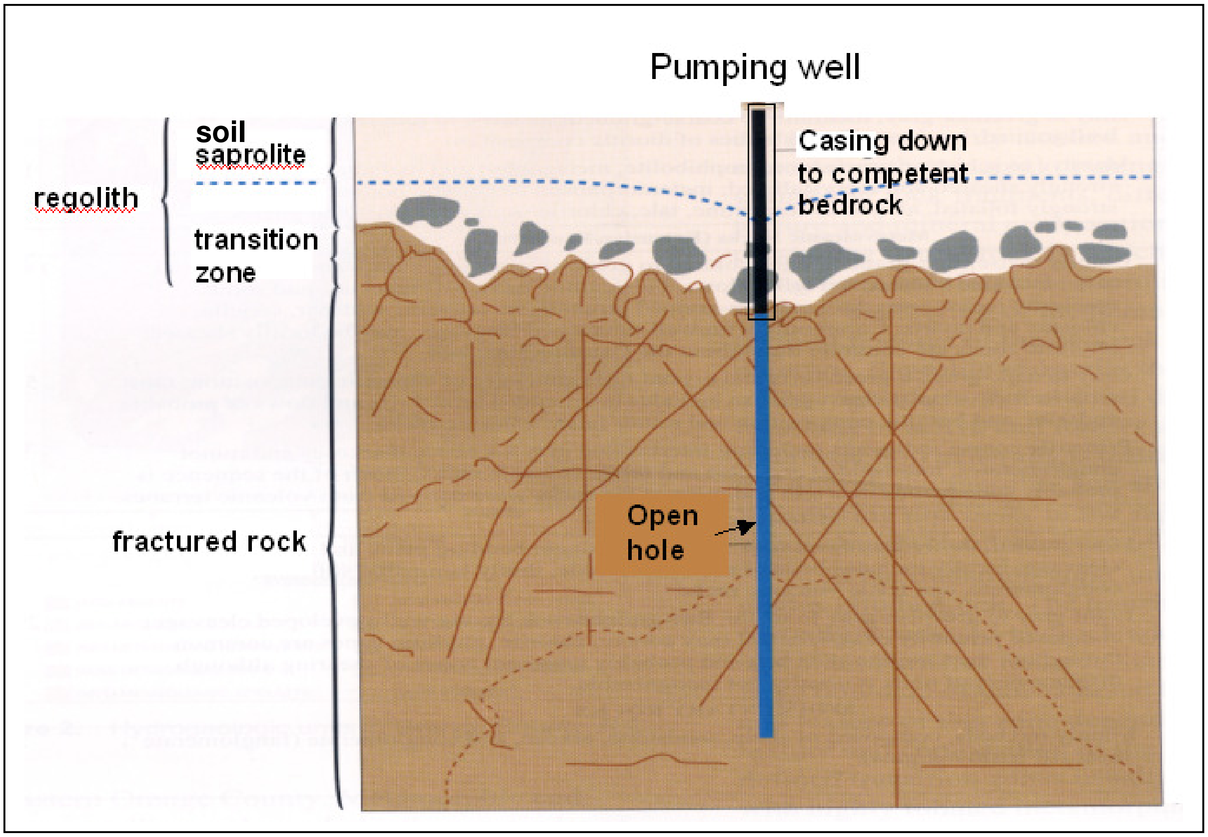

Figure 4. Schematic showing construction of typical private drinking water well in study area.

Geochemical results obtained during the study are summarized in Table 1. The table also provides information on casing depth, a proxy used in this study to estimate the regolith thickness, and well depth. Taken as a whole, sampled ground water tended to be slightly acidic (median pH = 6.1), oxygenated (median DO = 7.4 mg/L), and minimally conductive (median SC = 81 uS/cm). The buffering capacity of the ground water was fairly low (median alk = 34 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 moderately high (median raw ORP = 344 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 Buncombe, Henderson, and Transylvania Counties, North Carolina, 2005.

Parameter	No. of samples	Maximum value	Minimum value	Median value
pH	80	8.3	<4.5	6.1
Specific conductivity, in uS/cm	78	286	2	82
Temperature, in degrees Celsius	80	>18	10.7	14.7
Dissolved oxygen, in mg/L	79	16.3	0.1	7.4
Oxidation reduction potential, in mV	48	660	-181	344
Total dissolved solids, mg/L	80	210	16	83
Lead, in ug/L	78	<10	<10	<10
Arsenic, in ig/L	78	<5	<5	<5
Iron, in ug/L	80	7300	4	<50
Manganese, in ug/L	80	280	3	<10
Alkalinity, in mg/L	80	160	1	34
Casing depth, in feet	25	121	20	65
Well depth, in feet	48	850	55	265
Well yield, in gpm	40	60	1	10

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

OCCURRENCE AND DISTRIBUTION OF SELECTED RADIONUCLIDES IN PRIVATE DRINKING WATER WELLS

Samples of raw, untreated ground water were collected at 80 private wells in the study area comprising parts of Buncombe, Henderson, Transylvania, Mitchell, Madison, Watauga, Jackson, and Macon Counties, North Carolina (fig. 2). Indoor air radon was measured in 59 of the 80 homes associated with the sampled wells. The remaining 21 homes did not sample indoor air radon or results were not reliable.

ESRI ArcMap 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 almost all 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.

Wells with radionuclides above the EPA standards are shown in figure 5. A major finding of this study is that over 90 percent of the wells sampled during the investigation contained radon concentrations well above the EPA proposed standard of 300 pCi/L, and about one-third were above the EPA proposed alternate standard of 4000 pCi/L. The large majority of wells contained low or non-detectable concentrations of uranium, Ra-226, and Ra-228. About a third of the measured homes contained indoor air radon concentrations above the EPA action level of 4 pCi/L.

As shown in Table 3, radon concentrations ranged from 87 to 15,742 pCi/L, with a median value of 1889 pCi/L. Of 80 sampled wells, 91 percent exceeded the proposed EPA MCL of 300 pCi/L, and 30 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 29.6 ug/L, with a median value of less than 1 ug/L. Radium-226 concentrations ranged from less than the analytical detection limit (about 0.4 pCi/L) to 2.2 pCi/L, with a median value of less than 0.4 pCi/L.

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, 2006.

radionuclide	percent of samples above detection limit	detection limit
radon	100	50 pCi/L
indoor radon	91	0.3 pCi/L
uranium	17	1 ug/L
radium-226	27	0.4 to 0.7 pCi/L
radium-228	21	0.1 to 0.4 pCi/L

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

Table 3. Summary of radionuclide results obtained from study wells in study area, 2006.

Radionuclide	No. of samples	Maximum value	Minimum value	Median value	USEPA Standard	% exceeding standard
Radon, pCi/L	80	15742	87	1889	300*/4000**	91/30
Uranium, ug/L	75	29.6	<1	<1	30	1.3
Radium-226, pCi/L	75	2.2	<0.4	<0.4	5***	0
Radium-228, pCi/L	75	1.1	<0.1	<0.1	5***	0
Indoor radon, pCi/L	56	19.6	<0.3	1.6	4	29

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

As shown in Table 4, little differences were observed between radionuclide concentrations in wells in meta-igneous versus wells in meta-sedimentary rocks. In contrast, a 2005 study of 103 private wells in Buncombe, Henderson, and Transylvania Counties of Western North Carolina, radon concentrations were significantly higher in wells in meta-igneous rocks than in wells in meta-sedimentary rocks (Campbell, 2006).

Table 4. Radionuclide concentrations observed in private wells in meta-igneous rocks versus meta-sedimentary rocks, Western North Carolina, 2006.

	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	40	2153	15742	38	1	29.6	38	0.30	1.40	38	0.1	1.1	30	1.6	7.3
Meta-sedimentary	38	1889	7561	37	1	19.6	37	0.30	2.20	37	0.1	0.8	29	1.8	19.6

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

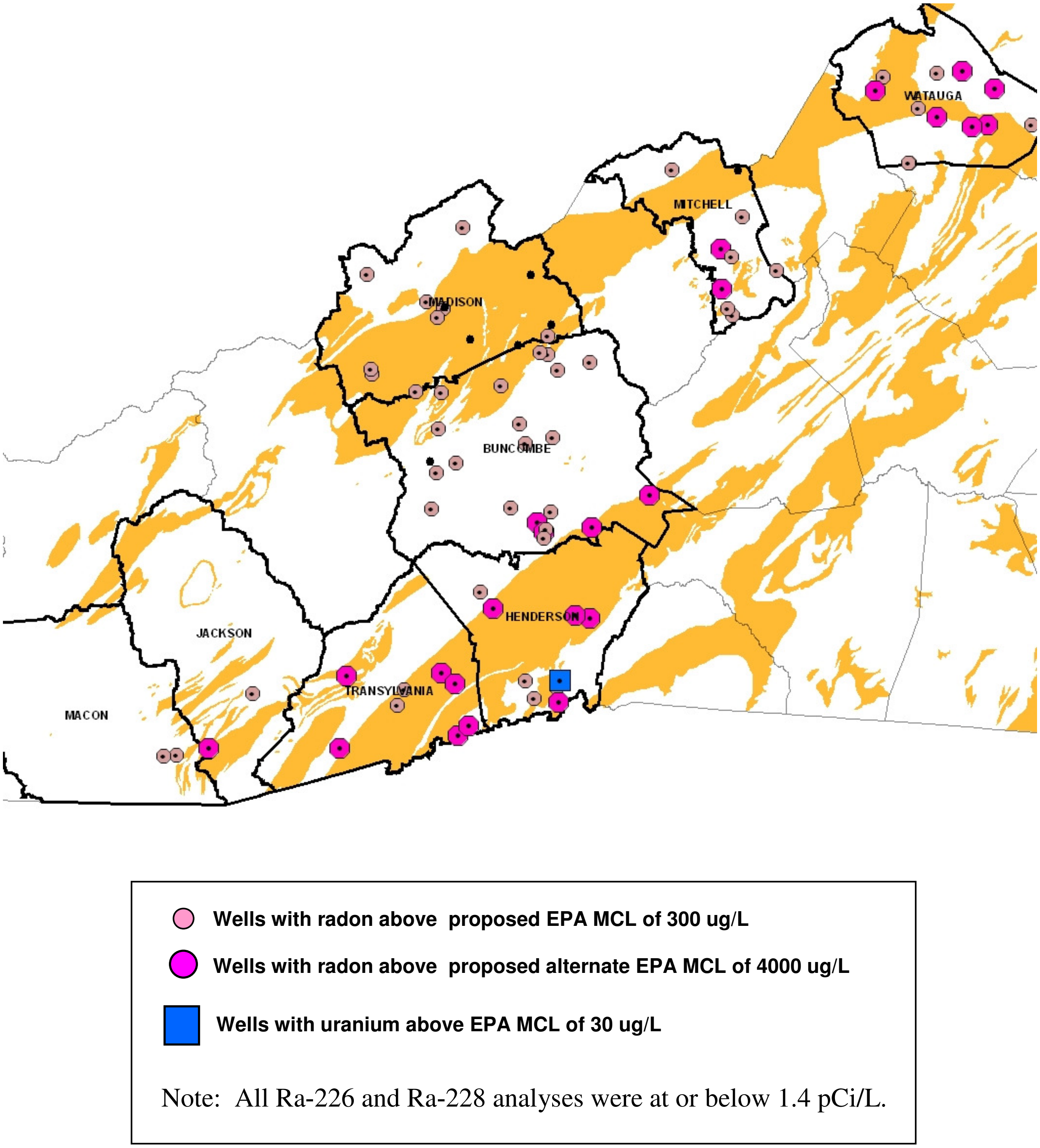

Figure 5. Study wells with radionuclide concentrations above EPA standards, superimposed on map of meta-igneous versus meta-sedimentary rock, Western North Carolina study area, 2006.

Additional analysis will be conducted to evaluate controls on radionuclide occurrence and distribution. 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 59 well owners' homes ranged from 0.3 to 19.6 pCi/L, with a median value of 1.6 pCi/L. Of the 59 homes in which indoor-air radon was measured, 29 percent exceeded the EPA MCL of 4 pCi/L (fig. 6).

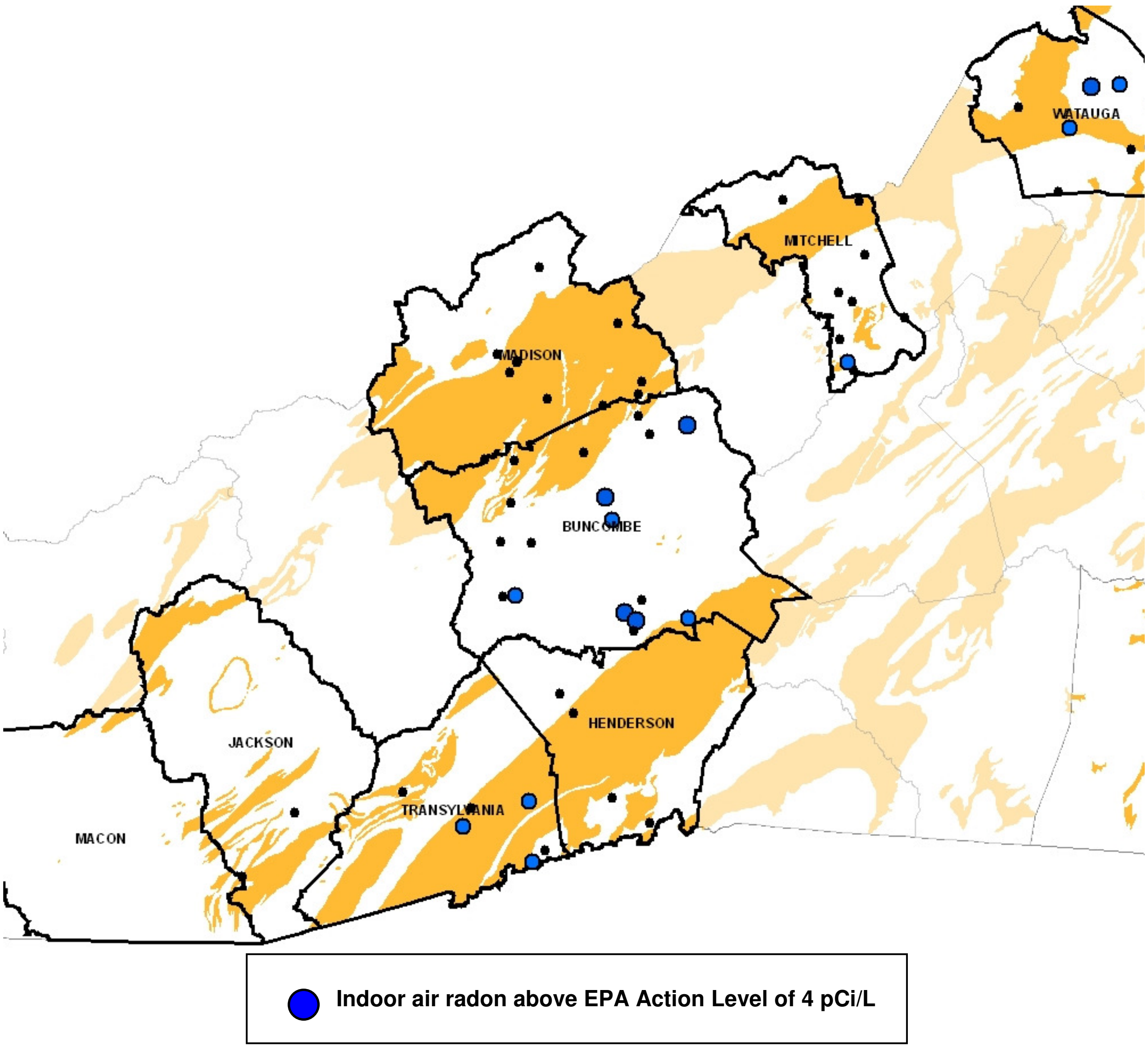

Figure 6. Study homes with indoor air radon levels above EPA Action Level of 4 pCi/L, Western North Carolina, 2006.

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 80 private wells within Mitchell, Madison, Watauga, Macon, Jackson, Buncombe, Henderson, and Transylvania Counties were found to contain ubiquitously high levels of radon (87 to 15,742 pCi/L; median = 1889 pCi/L). Radon exceeded EPA's proposed maximum contaminant level (MCL) of 300 pCi/L in 91 percent of the wells, and exceeded the proposed alternate MCL of 4000 pCi/L in 30 percent of the wells. Uranium (maximum = 29.6 ug/L) exceeded the EPA MCL in 1.3 percent of wells. Radium-226 and radium-228 concentrations were relatively low in all sampled wells (less than 2.2 pCi/L). Indoor radon ranged from 0.3 to 19.6 pCi/L, with a median value of 1.6 pCi/L. About one third of the sampled homes had indoor air radon above the EPA action level of 4 pCi/L.

Subsequent investigation 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 103 private drinking water wells in Buncombe, Henderson, and Transylvania Counties, North Carolina, 2005. [ft = feet; blank = no data; I = meta-igneous; S = meta-sedimentary; PVC = polyvinyl chloride; U = uranium, Ra-226 = Ra-226; Ra-223 = radium-223; Ra-224 = radium-224; GA = gross alpha activity; pCi/L = picocuries per liter; ug/L = micrograms per liter; Rn = radon; ns = not sampled; BDL = below detection limit; gpm = gallons per minute; uS/cm = microsiemens per centimeter; T = temperature; C = degrees Celsius; DO = dissolved oxygen; mg/L = milligrams per liter; ORP = oxidation reduction potential; mV = millivolts; alk = alkalinity as bicarbonate; Pb = lead, As = arsenic.]

WELL NUMBER	SAMPLE DATE	URANIUM, ug/L	RADON, pCi/L	RADIUM-226, pCi/L	RADIUM-228, pCi/L	INDOOR RADON, pCi/L
104	31-Jul-06	BDL of 1	90	BDL of 0.62	BDL of 0.27	0.9
105	31-Jul-06	BDL of 1	720	BDL of 0.54	BDL of .12	3.6
106	31-Jul-06	BDL of 1	830	0.811	0.518	5.9
107	2-Aug-06	BDL of 1	390	BDL of 0.48	0.532	2.5
108	2-Aug-06	BDL of 1	670	BDL of 0.43	BDL of 0.13	8.8
109	2-Aug-06	BDL of 1	2520	BDL of 0.43	BDL of 0.12	1.4
110	2-Aug-06	BDL of 1	350	BDL of 0.61	0.205	1.8
111	2-Aug-06	BDL of 1	1960	1.47	0.363	<0.3
112	2-Aug-06	BDL of 1	1880	0.662	0.761	0.5
113	2-Aug-06	BDL of 1	4310	BDL of 0.49	BDL of 0.18	
114	2-Aug-06	4.4	10150	BDL of 0.50	BDL of 0.26	1.6
115	2-Aug-06	8.25	9860	BDL of 0.46	0.976	4.2
116	3-Aug-06	BDL of 1	150	BDL of 0.63	BDL of 0.17	<0.3
117	3-Aug-06	BDL of 1	230	BDL of 0.56	BDL of 0.22	<0.3
118	3-Aug-06	BDL of 1	320	BDL of 0.54	BDL of 0.19	2.2
119	3-Aug-06	BDL of 1	200	BDL of 0.57	0.512	2
120	3-Aug-06	BDL of 1	2600	BDL of 0.64	0.735	<0.3
121	7-Aug-06	BDL of 1	1760	1.15	1.11	1.1
122	7-Aug-06	BDL of 1	480	1.35	BDL of 0.15	<0.3
123	7-Aug-06	BDL of 1	4130	BDL of 0.57	BDL of 0.17	1.5
124	7-Aug-06	BDL of 1	800	BDL of 0.54	BDL of 0.30	2.4
125	7-Aug-06	BDL of 1	310	1.25	BDL of 0.15	1.6
126	7-Aug-06	BDL of 1	1010	BDL of 0.61	BDL of 0.33	0.2
127	8-Aug-06	BDL of 1	4490	BDL of 0.50	BDL of 0.19	8.1
128	8-Aug-06	BDL of 1	1400	BDL of 0.46	BDL of 0.18	
129	8-Aug-06	BDL of 1	1080	BDL of 0.47	BDL of 0.21	
130	8-Aug-06	BDL of 1	2160	BDL of 0.77	BDL of 0.24	
131	8-Aug-06	BDL of 1	1310	BDL of 0.49	BDL of 0.20	
132	8-Aug-06	BDL of 1	5620	BDL of 0.48	BDL of 0.28	1.7
133	8-Aug-06	BDL of 1	4760	BDL of 0.45	BDL of 0.21	6
134	8-Aug-06	BDL of 1	3020	BDL of 0.43	BDL of 0.29	
135	10-Aug-06	BDL of 1	3000	BDL of 0.47	BDL of 0.15	6.3
136	10-Aug-06	BDL of 1	680	1.42	0.388	
137	10-Aug-06	2.1	9510	1.42	0.653	0.2
138	10-Aug-06	BDL of 1	120	BDL of 0.41	BDL of 0.14	3.5
139	10-Aug-06	BDL of 1	230	BDL of 0.47	0.218	0.2
140	10-Aug-06	BDL of 1	4120	1.63	BDL of 0.12	1
141	14-Aug-06	1.21	6460	BDL of 0.59	BDL of 0.12	1.6
142	14-Aug-06	7.06	3170	2.21	BDL of 0.13	1

WELL NUMBER	SAMPLE DATE	URANIUM, ug/L	RADON, pCi/L	RADIUM-226, pCi/L	RADIUM-228, pCi/L	INDOOR RADON, pCi/L
143	14-Aug-06	BDL of 1	590	1.15	BDL of 0.17	
144	14-Aug-06	BDL of 1	2570	BDL of 0.61	BDL of 0.22	8.4
145	14-Aug-06	BDL of 1	1360	0.966	BDL of 0.22	0.8
146	14-Aug-06	19.6	1090	0.784	BDL of 0.29	4
147	15-Aug-06	3.52	2760	1.19	BDL of 0.26	
148	15-Aug-06	BDL of 1	6250	BDL of 0.62	0.11	4.4
149	15-Aug-06	BDL of 1	670	BDL of 0.60	BDL of 0.11	19.6
150	15-Aug-06	29.6	1690	0.893	BDL of 0.17	
151	15-Aug-06	BDL of 1	1490	BDL of 0.54	BDL of 0.18	
152	16-Aug-06	BDL of 1	2150	BDL of 0.54	BDL of 0.15	5.5
153	16-Aug-06	2.8	13820	0.795	BDL of 0.16	0.8
154	16-Aug-06	BDL of 1	240	1.14	BDL of 0.11	2.6
155	16-Aug-06	1.36	4990	BDL of 0.67	BDL of 0.18	7.6
156	16-Aug-06	1.08	4810	BDL of 0.59	0.123	0.9
157	16-Aug-06	BDL of 1	2480	BDL of 0.49	BDL of 0.20	2.1
158	16-Aug-06	BDL of 1	6640	BDL of 0.62	1.02	1.8
159	17-Aug-06	BDL of 1	3730	0.867	BDL of 0.14	
160	17-Aug-06	BDL of 1	1250	0.654	BDL of 0.09	17.6
161	17-Aug-06	BDL of 1	1120	BDL of 0.64	BDL of 0.12	
162	17-Aug-06	BDL of 1	1370	BDL of 0.64	0.385	7.7
163	17-Aug-06	BDL of 1	4320	BDL of 0.65	BDL of 0.11	
164	17-Aug-06	14.5	15740	BDL of 0.64	BDL of 0.14	
165	17-Aug-06	BDL of 1	2480	BDL of 0.57	BDL of 0.23	
166	17-Aug-06	BDL of 1	1510	1	BDL of 0.14	1.2
167	17-Aug-06	BDL of 1	12840	BDL of 0.52	BDL of 0.37	3.3
168	22-Aug-06	BDL of 1	1080	BDL of 0.37	BDL of 0.14	1.4
169	22-Aug-06	BDL of 1	6430	BDL of 0.64	BDL of 0.18	1.5
170	22-Aug-06	BDL of 1	7560	BDL of 0.72	BDL of 0.28	
171	23-Aug-06	BDL of 1	2490	BDL of 0.67	BDL of 0.12	1.1
172	23-Aug-06	BDL of 1	440	BDL of 0.71	BDL of 0.16	0.9
173	23-Aug-06	BDL of 1	320	BDL of 0.68	BDL of 0.18	0.8
174	23-Aug-06	BDL of 1	2430	BDL of 0.74	BDL of 0.14	1
175	24-Aug-06	3.7	7150	BDL of 0.51	BDL of 0.33	
176	24-Aug-06	BDL of 1	1810	BDL of 0.56	BDL of 0.28	1
177	24-Aug-06	BDL of 1	1670	BDL of 0.56	BDL of 0.26	7.3
178	24-Aug-06	BDL of 1	1900	BDL of 0.54	BDL of 0.24	0.2
179	6-Sep-06		6100			
180	6-Sep-06		510			
181	6-Sep-06		750			
182	21-Jul-06		4930			6.8
183	19-Jul-06		4370			0.2

WELL NUMBER	pH	SPEC COND, uS/cm	TEMP, C	DO, mg/L	Fe, ug/L	Mn, ug/L	Pb, ug/L	Alk, ug/L	As, ug/L
104	5.7	33	14.6	9.8	72	<10	<10	12	<5
105	5.9	47	15.2	5.6	<50	<10	<10	17	<5
106	7.4	135	16.1	0.3	580	68	<10	62	<5
107	7.3	286	14.9	0.6	<50	<10	<10	160	<5
108	6.4	41	15.1	6.4	<50	<10	<10	21	<5
109	6.6	78	15.0	5.1	330	16	<10	36	<5
110	6.4	123	16.3	9.4	<50	<10	<10	43	<5
111	6.4		15.4	5.8	250	160	<10	62	<5
112	6.2		16.7	3.3	220	33	<10	75	<5
113	6.5	31	19.5	10.2	<50	<10	<10	11	<5
114	5.8	80	15.8	10.5	<50	<10	<10	35	<5
115	5.5	140	14.6	11.5	<50	<10	<10	47	<5
116	6.5	171	17.4	4.8	120	<10	<10	84	<5
117	6.8	208	16.5	1.9	<50	140	<10	98	<5
118	5.9	71	14.1	6.4	<50	<10	<10	33	<5
119	7.0	206	15.5	3.1	110	<10	<10	100	<5
120	6.2	100	15.1	2.4	7300	25	<10	43	<5
121	6.6	122	14.6	0.3	1500	36	<10	57	<5
122	6.9	90	14.7	2.9	130	<10	<10	43	<5
123	6.6	125	14.3	0.3	<50	<10	<10	58	<5
124	4.7	28	11.4	12.5	<50	<10	<10	9.5	<5
125	6.0	21	16.2	14.1	<50	240	<10	1	<5
126	5.8	72	14.2	7.6	160	<10	<10	24	<5
127	5.8	115	15.6	6.4	670	38	<10	44	<5
128	6.1	102	15.6	12.1	73	<10	<10	44	<5
129	6.4	128	15.5	12.5	660	24	<10	56	<5
130	6.3	102	13.6	7.2	<50	<10	<10	30	<5
131	6.1	125	13.7	8.5	<50	<10	<10	41	<5
132	5.7	37	13.2	7.9	<50	<10	<10	12	<5
133	5.7	116	13.4	5.7	<50	<10	<10	18	<5
134	5.4	147	12.7	8.9	130	<10	<10	8.5	<5
135	6.6	90	13.4	6.8	<50	<10	<10	36	<5
136	6.9	102	13.7	1.5	580	22	<10	48	<5
137	8.0	2	13.7	0.6	<50	<10	<10	44	<5
138	5.4	82	11.9	10.3	<50	<10	<10	34	<5
139	5.8	95	15.1	11.7	57	<10	<10	45	<5
140	5.8	239	15.2	1.8	<50	84	<10	80	<5
141	5.6	106	12.4	9.9	<50	17	<10	17	<5
142	6.4	40	14.1	8.7	<50	<10	<10	16	<5

WELL NUMBER	pH	SPEC COND, uS/cm	TEMP, C	DO, mg/L	Fe, ug/L	Mn, ug/L	Pb, ug/L	Alk, ug/L	As, ug/L
143	6.2	154	14.3	0.1	4500	42	<10	62	<5
144	5.1	50	13.6	7.4	180	<10	<10	16	<5
145	5.5	184	16.2	3.9	6100	280	<10	58	<5
146	7.0	127	15.6	2.3	<50	<10	<10	49	<5
147	7.8	142	15.1	0.8	<50	<10	<10	49	<5
148	6.2	96	11.3	5.1	68	<10	<10	38	<5
149	5.3	28	10.9	8.4	<50	<10	<10	10	<5
150	7.5	150	18.0	3.1	<50	<10	<10	56	<5
151	5.6	65	15.9	7.0	210	<10	<10	24	<5
152	5.7	44	14.5	8.1	<50	<10	<10	11	<5
153	6.0	118	13.8	6.6	280	<10	<10	52	<5
154	6.2	29	10.7	8.2	<50	<10	<10	16	<5
155	6.2	87	12.8	2.1	<50	<10	<10	26	<5
156	5.2	26	12.5	7.4	<50	<10	<10	8.5	<5
157	4.9	22	13.1	7.4	3700	<10	<10	7.5	<5
158	4.5	38	14.0	5.8	78	<10	<10	13	<5
159	6.3	66	14.7	7.9	54	<10	<10	38	<5
160	6.0	81	15.9	0.6	<50	17	<10	21	<5
161	7.3	134	17.4	1.9	<50	<10	<10	65	<5
162	6.4	176	17.9	1.5	2000	81	<10	38	<5
163	5.8	66	15.2	10.1	<50	<10	<10	34	<5
164	5.2	97	16.9	2.1	<50	23	<10	40	<5
165	7.4	50	14.9	8.9	<50	<10	<10	23	<5
166	6.9	65	17.3	15.0	<50	<10	<10	32	<5
167	6.2	41	23.0	11.2	<50	<10	<10	12	<5
168	6.0	21	14.2	15.9	<50	<10	<10	9	<5
169	6.0	64	12.2	15.2	<50	<10	<10	14	<5
170	6.0	45	12.3	16.3	81	45	<10	2.5	<5
171	5.3	161	15.1	10.7	60	<10	<10	54	<5
172	8.3	145	16.2	10.7	210	<10	<10	94	<5
173	4.8	133	15.7	1.1	140	<10	<10	65	<5
174	3.1	56	13.4	10.2	<50	<10	<10	29	<5
175	6.5	63	14.1	11.6	<50	<10	<10	34	<5
176	5.1	57	14.6	13.9	<50	<10	<10	18	<5
177	5.5	67	17.5	8.3	<50	13	<10	24	<5
178	6.9	30	15.2		1100	<10	<10	9	<5
179	6.9	49	18.8	9.1	<50	<10	<10	23	<5
180	5.5	45	14.5	9.6	76	<10	<10	19	<5
181	7.0	10	13.1	14.4	<50	<10	<10	4	<5
182	6.1	52	13.6	8.4				23	
183	6.2	76	16.2	4.8				23	

WELL NUMBER	COUNTY	CASING DEPTH, ft	WELL DEPTH, ft	YIELD, gpm	HYDROLOGIC SETTING	ROCK ORIGINS	ROCK TYPE
104	Buncombe		610	1	recharge	S	Muscovite-biotite gneiss
105	Buncombe	94	250	20	midslope	S	Muscovite-biotite gneiss
106	Buncombe		248		midslope	S	Muscovite-biotite gneiss
107	Buncombe	48	265	5	recharge	S	Muscovite-biotite gneiss
108	Buncombe	65	510	3	recharge	S	Muscovite-biotite gneiss
109	Buncombe				midslope	S	Muscovite-biotite gneiss
110	Buncombe	66	160	15	recharge	S	Biotite gneiss
111	Madison		110		midslope	S	Migmatitic biotite hornblende gneiss
112	Buncombe				recharge	S	Migmatitic biotite hornblende gneiss
113	Buncombe				recharge	I	Henderson Gneiss
114	Buncombe		400	4	recharge	I	Henderson Gneiss
115	Buncombe				recharge	I	Henderson Gneiss
116	Madison				discharge	I	Migmatitic biotite hornblende gneiss
117	Madison		325		recharge	I	Migmatitic biotite hornblende gneiss
118	Madison				recharge	I	Biotite granitic gneiss
119	Madison	67	610	1	recharge	I	Biotite granitic gneiss
120	Madison				discharge	I	Biotite granitic gneiss
121	Mitchell				midslope	I	Amphibolite
122	Mitchell				recharge	I	Granodiorite gneiss
123	Mitchell				midslope	S	Muscovite-biotite gneiss
124	Mitchell		55		recharge	I	Amphibolite
125	Mitchell				midslope	S	Gneiss
126	Mitchell	57	260	4	midslope	S	Muscovite-biotite gneiss
127	Buncombe		280	16	midslope	S	Muscovite-biotite gneiss
128	Buncombe	113	385	4	recharge	I	Amphibolite
129	Madison		320	14	recharge	S	Rome Formation
130	Madison			12	midslope	I	Biotite granitic gneiss
131	Madison				discharge	I	Biotite granitic gneiss
132	Watauga	42	284	5	discharge	I	Biotite granitic gneiss
133	Watauga	30	245	25	midslope	S	Gneiss
134	Watauga	87	305	4	recharge	S	Metagraywacke
135	Watauga	20	245	7	midslope	I	Biotite granitic gneiss
136	Watauga	23	185	10	midslope	I	Biotite granitic gneiss
137	Watauga	46	384	60	midslope	I	Biotite granitic gneiss
138	Madison		400		recharge	I	Biotite granitic gneiss
139	Madison				recharge	I	Migmatitic biotite hornblende gneiss
140	Buncombe	45	205	15	midslope	S	Metagraywacke
141	Jackson	50	250	12	recharge	I	Granodiorite
142	Jackson		325	3	recharge	S	Biotite gneiss

WELL NUMBER	COUNTY	CASING DEPTH, ft	WELL DEPTH, ft	YIELD, gpm	HYDROLOGIC SETTING	ROCK ORIGINS	ROCK TYPE
143	Buncombe				midslope	S	Muscovite-biotite gneiss
144	Buncombe		123		midslope	S	Metagraywacke
145	Buncombe				midslope	S	Metagraywacke
146	Buncombe	74	645	1	midslope	S	Metagraywacke
147	Watauga		850	0.5	recharge	S	Gneiss
148	Watauga	121	181	12	midslope	S	Muscovite-biotite gneiss
149	Watauga		565	2	midslope	S	Muscovite-biotite gneiss
150	Henderson				recharge	I	Caesars Head Granite
151	Henderson				discharge	I	Caesars Head Granite
152	Mitchell		360		recharge	I	Amphibolite
153	Mitchell	58	250	10	midslope	I	Amphibolite
154	Mitchell					I	Migmatitic biotite hornblende gneiss
155	Transylvania	40	120	12	midslope	S	Garnet mica schist
156	Transylvania		225	6	midslope	S	Garnet mica schist
157	Henderson		65	20	midslope	S	Muscovite-biotite gneiss
158	Henderson				recharge	I	Henderson Gneiss
159	Buncombe				midslope	S	Muscovite-biotite gneiss
160	Buncombe	23	385	15	recharge	S	Muscovite-biotite gneiss
161	Buncombe				recharge	S	Muscovite-biotite gneiss
162	Buncombe		350		midslope	S	Muscovite-biotite gneiss
163	Henderson				recharge	I	Henderson Gneiss
164	Henderson				recharge	I	Granite gneiss
165	Henderson		170		discharge	S	Garnet mica schist
166	Henderson		147		recharge	S	Garnet mica schist
167	Henderson				midslope	I	Caesars Head Granite
168	Watauga	70	204	25	recharge	S	Metagraywacke
169	Watauga				midslope	I	Biotite granitic gneiss
170	Watauga				midslope	S	Metasiltstone
171	Buncombe				recharge	I	Migmatitic biotite hornblende gneiss
172	Madison		265	60	midslope	I	Meta ultramafic rock
173	Madison		605	10	recharge	I	Granodiorite gneiss
174	Madison	67	165	15	midslope	I	Granodiorite gneiss
175	Transylvania		230	6	midslope	I	Henderson Gneiss
176	Transylvania			5	midslope	I	Henderson Gneiss
177	Transylvania				midslope	I	Henderson Gneiss
178	Buncombe	65	81	25	midslope	S	Muscovite-biotite gneiss
179	Transylvania				discharge	S	Rocks of the Brevard Fault Zone
180	Macon				midslope		
181	Macon				discharge		
182	Transylvania	90	305	3	recharge	I	Henderson Gneiss
183	Transylvania		425	20	discharge	I	Granodiorite