Effects of Septic Tank Effluent on Groundwater Drinking Supplies in Haywood County, North Carolina

Ted R. Campbell

NC DIVISION OF WATER RESOURCES
RESOURCE EVALUATION PROGRAM

GROUNDWATER BULLETIN 2013-01

North Carolina Department of Environment and Natural Resources
John Skvarla, Secretary

North Carolina Division of Water Resources
Tom Reeder, Director

For additional information write to:

North Carolina Department of Environment and Natural Resources
North Carolina Division of Water Resources
Asheville Regional Office
2090 Highway 70
Swannanoa, North Carolina 28778

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Abbreviations used in report:

Max, maximum
min, minimum
SC, specific conductance
temp, temperature
DO, dissolved oxygen
ORP, oxidation reduction potential (raw)
TDS, total dissolved solids
Ca, calcium
Mg, magnesium
Na, sodium
K, potassium
HCO_3, bicarbonate
Cl, chloride
SO_4, sulfate
NO_3, nitrate
NO_2, nitrite
NH_3, ammonia
TKN, total kjeldahl nitrogen
P, phosphorous
PO_4, phosphate
COD, chemical oxygen demand
TOC, total organic carbon
DOC, dissolved organic carbon
MBAS, methylene blue active substances
B, boron
Ag, silver
Al, aluminum
As, arsenic
Ba, barium
Cd, cadmium
Cr, chromium
Cu, copper
Fe, iron
Fl, fluoride
Hg, mercury
Mn, manganese
Ni, nickel
Pb, lead
Se, selenium
Si, silica
Zn, zinc
Alk, alkalinity
turb, turbidity
susp res, suspended residue

Abbreviations used in report: (Continued)

Rn-222, radon-222
SWL, static water level
uS/cm, microsiemens per centimeter
C, celcius
mg/L, milligrams per liter
mV, millivolts
col, colonies
ml, milliliter; ug/L
microgram per liter
ft bls, feet below land surface
gpm, gallons per minute
NTU, nephelometric turbidity units
%, percent

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EXECUTIVE SUMMARY

Water quality data from 63 private wells and four springhouses in the Hyatt/Richland Creek watershed in Haywood County, NC were used to assess potential septic seepage impacts to groundwater drinking supplies in a rural, gently sloping, fractured bedrock setting. Most homes in the survey area make use of both a private supply well and an onsite septic system and most systems were several decades in age. Lot sizes ranged from less than one acre to several acres and several areas contained numerous homes with wells and septic systems in close proximity.

Evidence of septic effluent contamination to survey area wells and springhouses was very limited or inconclusive. Twenty-one percent of samples exceeded the state 2L groundwater standard for total coliform bacteria, 19 percent for Fe, and seven percent for Mn. These percentages are not uncommon in wells across the region, and each of these constituents may occur for reasons unrelated to septic effluent. One well contained fecal coliform bacteria above the 2L standard, but it was a buried, un-grouted well that was subsequently repaired, chlorinated, re-tested and found to be free of all bacteria. No other constituents exceed 2L standards at any sample locations.

Eight samples contained nitrate (NO_3) above 3 mg/L (max = 6.2 mg/L), a threshold often associated with anthropogenic sources, but co-occurrence with other septic tracers was minimal and nearby agricultural surface sources also were possible. Very low concentrations of total phosphorous (total P) (max = 0.36 mg/L) and (or) phosphate (PO_4) (max = 0.07 mg/L) also occurred in about half the samples at levels associated with a relatively ubiquitous, low grade source possibly attributable to the rural agricultural setting. All samples were below the detection level for nitrite (NO_2), ammonia (NH_3), total kjehldahl nitrogen (TKN), total organic carbon (TOC), dissolved organic carbon (DOC), and chemical oxygen demand (COD). Also below the detection level were a large suite of organic wastewater constituents (sometimes referred to as “emerging contaminants”) that were measured in 11 sample locations. Trace levels of methylene blue active substances (MBAS), a measure of anionic surfactants such as detergents or foaming agents, were observed in nine samples, but evidence suggests that these values may be due to laboratory interference. Co-occurrence with other septic tracers at these sample locations was minimal. Boron (B) was below the detection level in all samples except one very low level (5.9 ug/L) that was comparable to a probable background concentration.

Septic seepage tracers measured in the survey included bacteria, nutrients, TOC, DOC, COD, total dissolved solids (TDS), chloride (Cl), sulfate (SO_4), MBAS, detergents, turbidity, and organic wastewater contaminants. Because surface sources (livestock, fertilizers, de-icers, vehicle cleaners, and others) and geology may impart some of these tracers to a well sample, evidence of septic seepage was generally considered only if multiple tracers co-occurred at elevated levels. Another factor that was considered was the quality of well construction since improperly grouted wells are susceptible to the migration of surface contaminants down the annular space of a well bore.

The 10 wells located within 50 ft of septic systems and the nine wells and two spring houses located within 150 ft of known surface sources (livestock) contained water generally of similar quality to wells across the larger survey area. Thirty percent of wells within 50 ft of the septic systems contained total coliform bacteria, a similar frequency to that of the larger survey area. Co-occurrence of multiple tracers was minimal for both groups. Wells completed below grade (with unknown construction quality) and un-grouted wells had similar overall levels of tracer co-occurrence as those of the larger survey area.

Many of the septic effluent-related constituents may have been adequately treated by the surface soils in the unsaturated zone prior to migrating to the groundwater system. The soils tested (n = 20 soil borings) in the survey area generally (with one exception in a low lying, waterlogged area adjacent to Richland Creek) were considered to be highly suitable for septic drainfield installation. Moreover, the thick regolith may dilute constituents by storing and releasing high volumes of groundwater to the underlying fractured bedrock flow system. The soils and regolith also provide additional contaminant treatment through various retention processes.

Although the survey area is typical of others in the Piedmont and mountains of NC, conclusions drawn in this report may or may not hold in other un-sewered mountain watersheds, and no inference is made in this regard.

INTRODUCTION

About two million on-site wastewater treatment systems[1] (septic systems or septics) exist in North Carolina (Hoover and Konsler, 2004), often in rural areas that also are served by private drinking water supply wells. When properly designed, sited, installed, and maintained, septic systems can safely treat most pollutants that are disposed down sink, shower, and toilet drains and are found in domestic wastewater (USEPA, 2002, 1997, 1980). However, septic systems may not adequately treat constituents such NO_3, certain pathogens and viruses, and a host of so-called emerging contaminants such as personal care products, household cleaners, endocrine-disrupters and other pharmaceuticals (Barnes and others, 2008a and 200b; Focazio and others, 2008; Teutsch, 1991; Abu-Ashour, 1994; Gerba and Bitton, 1984; Gerba, 1995).

Septic system leachate is often associated with elevated concentrations of Cl, SO4, various species of nitrogen and phosphorous, TOC, and fecal and total coliform bacteria (Canter and Knox, 1985; Waller and others, 1987; Pitt and others, 1975). These constituents and others are considered to be tracers that help identify septic leachate in groundwater. However, because these constituents may also be found in ambient (uncontaminated) groundwater, researchers often look for evidence of multiple co-occurring tracers at elevated concentrations when assessing septic system impacts (Kendall and others, 2007; Aravena and others, 1993; Komor and Anderson, 1993; Widowry and others, 2004; Seiler, 2005; Verstraeten and others, 2005; Barrett and others, 1999; Aley, 1985).

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[1] Septic tanks serve as settling chambers to remove solids from wastewater effluent which then percolates through drain fields to the unsaturated zone and the groundwater system. A typical septic system consists of a settling tank connected to drain lines in an adsorption field. These lines typically are installed in trenches having suitable soils, a minimum thickness of 3 ft, and a minimum distance of 1 ft to the water table or bedrock. When operating properly, effluent from a septic system consists of liquid leachate that is treated as it percolates through the drain field and unsaturated zone.

The use of multiple tracers is important because some of the septic tracers may also derive from non-septic sources such as livestock and dog waste, organic and inorganic fertilizers, backwash from household drinking water treatment systems, car/equipment washing or maintenance, road de-icers, local soil and rock chemistry, and others. For example, salts like chloride are found in both human and animal waste, and also occur in road de-icers, fertilizers, and in ambient soil in some settings (elevated salts in ambient soils in the survey area are unlikely). Nutrients are found in both human and animal waste, but also occur in organic and inorganic fertilizers, plant decay, and (or) ambient soil[2]. And total and fecal coliform bacteria are found in both human and animal waste[3].

Some septic effluent tracers are not found in ambient groundwater, such as surfactants, optical brighteners found in laundry detergents, and organic wastewater constituents. Organic wastewater constituents include pharmaceuticals, hormones, caffeine, anti-bacterials, flame retardants, and others. These are found in human waste and, in some cases in animal waste (pharmaceuticals, hormones). Taken together, these and the tracers discussed above make up a suite of potential indicators that help identify septic leachate in groundwater.

Septic contaminants can enter the groundwater system where the water table is shallow, in particularly permeable (Robertson, 1991; Scandura and Sobsey, 1997) or thin soils, in flood-prone alluvial settings where storm generated fluxes (increased water table or stream flux-induced groundwater flow reversal) may flush contaminants from the unsaturated zone, and in areas where septic system failure has occurred due to numerous factors (USEPA, 2002; Robertson and Cherry, 1995; Gibbs, 1977; Ellis and Childs, 1973)[4]. If untreated effluent enters the groundwater system, wells drilled in fractured rock may be particularly susceptible to contamination (Sawyer, 2008; Kozar and others, 2001). Well interference and connectivity over hundreds of feet in fractured rock settings has been documented (NC DWR, 2009, written communication; Webb, 2005). Layers of partially weathered bedrock (transition zone), colluvium, alluvium (in historic or active stream channels), relict veins, fractures, rock contacts, and root tunnels can also transmit groundwater quickly[5].

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[2] NO_2 and NO_3 occur naturally, but a combined level above 3 mg/L is generally an indication of human activity (Madison and Burnett, 1985)[2]. Slightly lower values have also been suggested as a threshold above which human sources are suspected (Komor and Anderson, 1993).

[3] Coliform bacteria are a group of microorganisms found in soil and water that typically do not cause illness but may indicate the presence of sewage or other harmful disease causing pathogens. Fecal coliform bacteria are harmful disease causing microorganisms found in human and animal waste.

[4] Factors that may cause a septic system to underperform, fail, or otherwise pose a contaminant threat to downgradient receptors include: 1) inadequate horizontal or vertical spacing/setbacks, 2) pore smear during installation (affects pore size, soil texture, and aerobic conditions), 3) septic field compaction during or after installation (may affect pore size, soil texture, and aerobic conditions), 4) saturated soils (may result in anaerobic conditions over time; saturated flow is faster through pores than unsaturated flow along particle surfaces), 5) position in landscape (foot slope, toe slope, head slope, etc) not optimal, 6) septic installed in a “transition horizon” of rock-soil mixture (between soil and saprolite) that percolates too slowly or too rapidly, 7) septic installed in a mostly sticky or hard saprolite that percolates too slowly, 8) roots may form preferential pathways through the saprolite and into the underlying transition zone, 9) septic installed in “marginal soils” or on a slope, 10) septic installed in less desirable 2nd generation (repair area) or 3rd generation (force fit) location, and (or) 11) septic is old or improperly maintained.

[5] It is recognized that proper septic system installation requires minimum depths of suitable soils, however soil heterogeneities can occur over short distances and highly transmissive conduits may lie just beneath the approved system depths. Highly transmissive layers of partially weathered rock range from 0 to 100 feet below land surface. Highly

Champ and Schroeter (1988) found a strong potential for bacterial transport in fractured crystalline rock. Robertson (1991) suggested that the 100-foot minimum separation distance may be inadequate in protecting downgradient wells and surface waters from dissolved, highly mobile contaminants such as NO_3. Further, in a study of 470 drilled and dug wells in bedrock and glacial till in Maine, Pinette and Noble (1999) found that higher levels of NO_3 were statistically more likely in shallower wells, wells with shorter casings, wells 300 ft or less downgradient of septic systems, and wells in proximity to older septic systems. Seasonal effects, well yield, and a well's proximity to fertilizer use were not correlative. Various researchers have demonstrated the effects of well construction, depth, and setting on contamination occurrence (Hallberg and Keeney, 1993; Panno, 1996; Barnes and others, 2008; Kolpin, 1995; Zimmerman, 2001; and Swartz and others, 2006).

Published findings on ground water quality near septic systems in fractured rock settings are very limited. Monitoring of groundwater quality is not required at most septic system sites, so many well owners have little or no information about the suitability of their drinking supply. Moreover, the state-mandated minimum well-septic separation distance of 100 feet (or 50 feet if lot size precludes 100 feet) is the same across North Carolina despite significant differences in geology and fluid transport properties between the Coastal Plain (granular, porous subsurface) and the Piedmont-Mountains (weathered, fractured regolith material). As part of its continued efforts to understand and protect the State's water quality and to fill a gap in the published record, the NC Division of Water Quality (DWQ) conducted a well-septic survey to determine the potential impacts of septic systems on ground water quality in one fractured rock setting. Additional settings are planned to be evaluated in the future. Partners in this project included NC State University (NCSU), U.S. Geological Survey (USGS), the former Division of Environmental Health's North Carolina Waste Discharge Elimination Program (WaDE), the Haywood Waterways Association (HWWA), and the Pigeon River Fund.

PURPOSE, SCOPE, AND SURVEY AREA SELECTION

Purpose

The purpose of the survey was to assess whether septic systems are contaminating private drinking wells and spring houses in a rural community in Haywood County, NC. The results will help well owners better understand the quality of their ground water drinking supply, and will help county, state and federal agencies better understand potential septic impacts to ground water quality in a rural, mildly sloped fractured rock setting. Results will help DWQ to assess the effectiveness of its well construction and setback rules (2C). While the results obtained in this survey are not considered to be a definitive statement about water quality in other mountain settings, they provide valuable information about the selected survey area and help provide documentation to an otherwise limited published record.

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permeable alluvial material often occurs near surface in historic and active stream channels. Alluvium, saprolite, transition zone material, and fractured crystalline bedrock often are variably thick and interlayered. Layer thickness depends on several factors including the lithology, texture, grain size, and interlayering of parent rock, position in the landscape, and rates of local rainfall.

Scope

Sixty-three private bedrock supply wells and four spring houses were sampled to evaluate groundwater quality. Samples were analyzed for constituents most often associated with septic leachate such as bacteria, nutrients, surfactants, and salts. Organic wastewater constituents also were measured at a small number of wells. Land use in the survey area was evaluated, along with septic violations, owner interviews, well construction quality, well setbacks, and proximity to potential contaminant sources. Topography and stream locations were used to estimate groundwater flow directions.

The scope of the survey was limited in four important ways.

1. Aquifer and borehole testing was not conducted as part of this survey. As a result, little information was available to characterize parcel-scale geology, groundwater flow directions, or aquifer properties. This greatly limited the ability to understand or predict parcel-scale groundwater movement or contaminant transport.

2. Determining contaminant source(s) was difficult due to the nature of groundwater flow in fractured bedrock[6] and the number of potential, overlapping sources including septic systems, fertilizer applications, livestock and other animal sources. Attributing well contamination to septic leachate was not made unless multiple septic-related tracers were observed in a given well at elevated concentrations.

3. Because of funding limitations, samples were not analyzed for pesticides, herbicides, volatile or semi-volatile organic compounds.

4. Well construction information (grouted versus un-grouted*,* depth, casing depth, yield, and age) was not available from wells that were buried or did not contain a well tag.

Survey Area Selection

The selected survey area allowed the team to assess potential impact of septic leachate on groundwater quality in a sloped, fractured rock setting and was particularly suitable for several reasons: 1) private wells and septic systems are in relatively close proximity in parts of the watershed,

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[6] A typical bedrock well draws water from more than one fracture set, and each fracture set is connected to a unique recharge area at the water table. Thus, water in a well is comprised of a mixture of waters of different ages and origins, each having traveled along different three-dimensional flow paths supplied by recharge areas of different locations, sizes, and shapes. This effect is made more complex due to the heterogeneous, anisotropic nature of flow in fractured bedrock systems. Heterogeneities tend to skew drawdown in the direction of predominant (most transmissive) fracture sets in sometimes unpredictable directions, rather than as a uniform cone of depression typical of sand aquifers. In some cases a well may draw more water from a side gradient recharge area than an upgradient recharge area. In short, it is difficult to track the origin of contamination in a well without detailed hydrologic information.

Information needed to identify contaminant inputs to a well includes detailed knowledge of static groundwater levels (to determine local groundwater flow directions), geometry of geologic units, fracture(s) depth, orientation, apperature, and connectivity, areal recharge patterns, stream influences, well, pump, and casing depths, and, of course, the character, size, and location of nearby contaminant sources.

2) most septic systems have been in use for many decades and therefore have had sufficient time to leach constituents to the ground water system, 3) the area is sloped and underlain by regolith and fractured rock, 4) stream quality in the basin has been studied in some detail, but ground water quality is not well understood, 5) septic systems (and septic violations) in the basin have already been identified and mapped by the WaDE program, 6) systematic efforts are underway to improve water quality in the basin, and 7) opportunities exist to strengthen partnerships between local, State, and Federal agencies, Haywood Waterways Association, and well owners.

DESCRIPTION OF SURVEY AREA

The survey area is located in the Richland Creek watershed, a rural mountain community in Haywood County, NC, in the Blue Ridge Province (figs. 1 and 2). The survey also extended into the Hyatt Creek watershed, a sub-basin of Richland Creek. The sampled area covers about two square miles straddling Hyatt Creek in the Hyatt Creek basin and about one square mile on the southern side of Richland Creek in the Richland Creek watershed (figs. 1 and 2). Figure 3 shows a survey “focus area” of 27 homes on 22 acres. Land use is residential intermixed with several small farms and pastures (fig. 4). Slopes are mild (ranging from about 0 to 35 percent, with averages of about five to 15 percent), and elevations range from about 2800 to 3050 ft above mean sea level. House densities range from several mobile homes per acre to a single house on several acres. Most lots are between 0.3 and 1 acre in size. Figure 5 shows an area with especially dense spacing of homes and septic systems. Most homes in the study area were built decades ago and many date from the 1940s. Private bedrock wells are used for drinking water throughout most of the watershed, and most homes rely on septic systems for wastewater treatment and disposal.

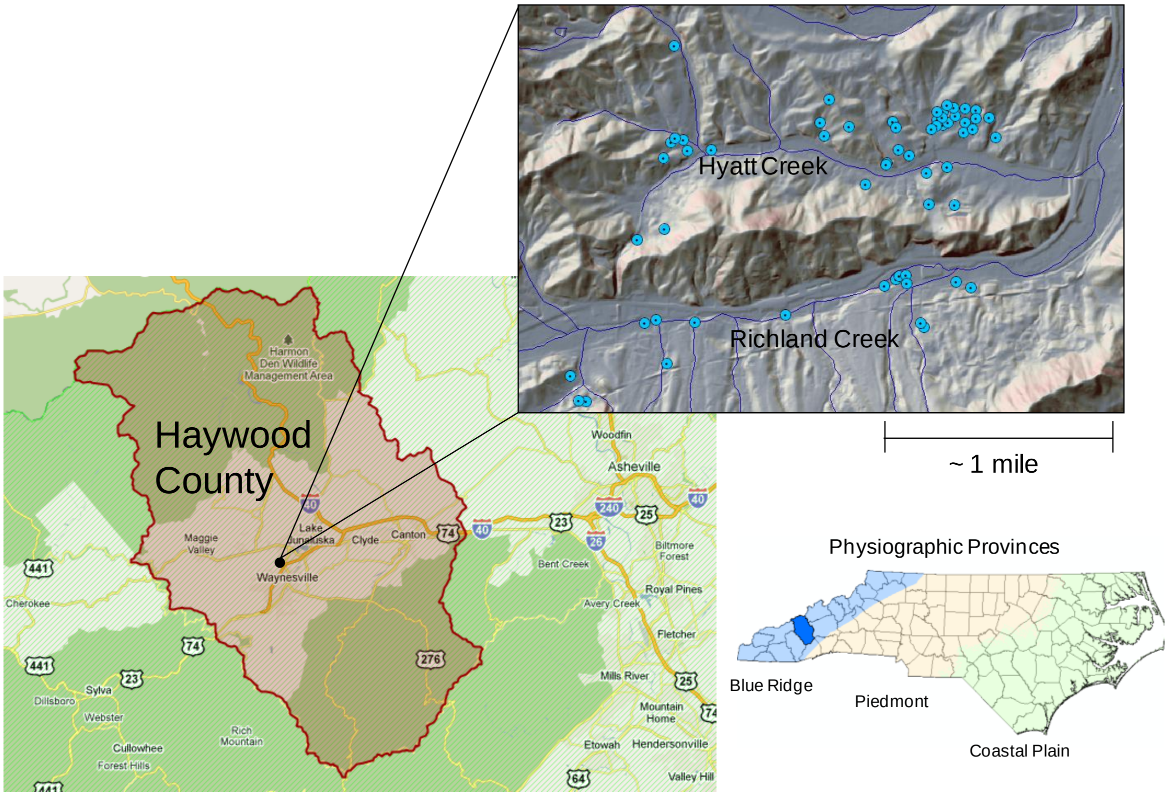

Figure 1. Location of survey area.

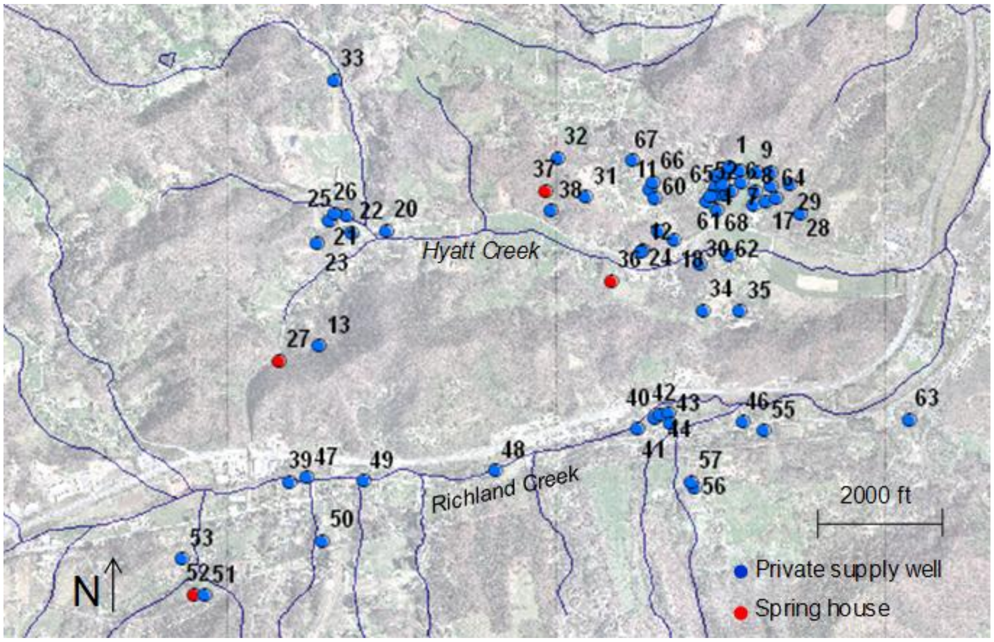

Figure 2. Survey area and sample locations.

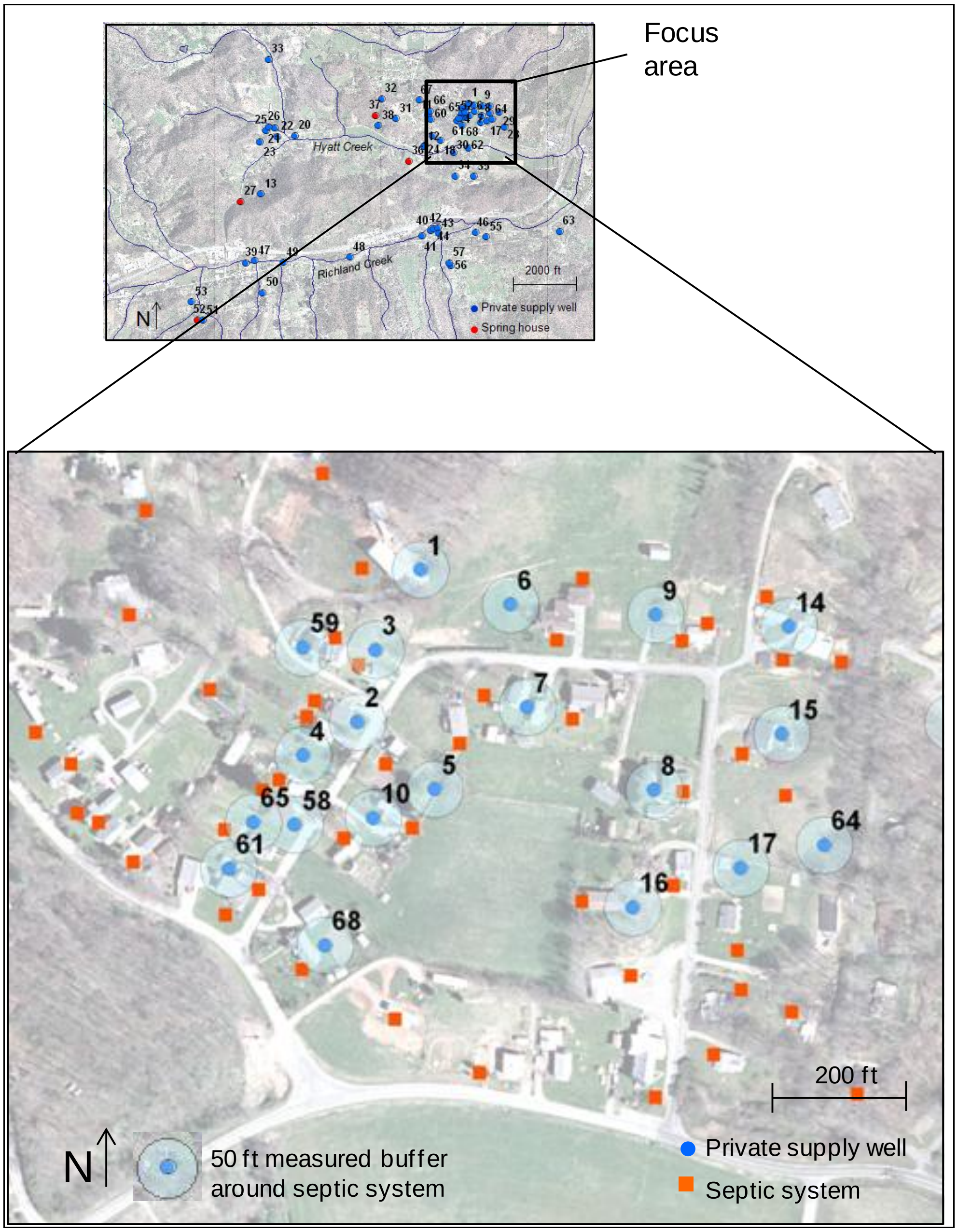

Figure 3. Focus area and sample locations.

Lawns and pastures

Dairy farm

Sloped terrain

Fractured bedrock wells

Figure 4. Examples of land use and setting in survey area.

Figure 5. Densely-spaced homes within survey area.

Groundwater System

The survey area is located in the Blue Ridge Physiographic Province (fig. 1) and is underlain by metamorphosed, fractured bedrock classified as Proterozoic-aged biotite gneiss (ZYbn). Bedrock tends to weather from the surface downward resulting in a variably thick layer of porous saprolite/regolith. Limited data indicate that the layer of soil and saprolite in the survey area is up to 100 feet thick with a typical range of 30 to 80 feet[7]. Bedrock outcrops exist in the watershed but are not prevalent in the vicinity of sampled wells.

Groundwater occurs as a two-part flow system consisting of a shallow porous, variably thick layer of soil/saprolite/regolith that stores and slowly releases water to underlying bedrock fractures. These fractures act as conduits by which water is transported to supply wells. Wells in the survey are open hole bedrock supply wells and range in depth from about 150 to 600 feet (median = 200 feet), with yields of about 0.5 to 30 gallons per minute (gpm) (median = 15 gpm).

Natural, unstressed groundwater flow directions are from higher to lower elevations, toward areas of discharge along Hyatt or Richland Creek or their tributaries. Hyatt Creek, a 2nd order stream, is a tributary to the 3rd order Richland Creek (fig. 1). Richland Creek flows to the Pigeon River, which drains into the French Broad River. Direction of local groundwater flow may vary due to nearby pumping influences and heterogeneities in the groundwater flow system. Water movement in the shallow system is expected to be moderately high, and the water table ranges in depth from about 5 to 20 ft depending on the topographic and geomorphic setting.

Groundwater flow and potential contaminant transport in the basin follows that of other bedrock settings. Rainfall recharges the shallow groundwater system. As the water enters and moves through the flow system it slowly dissolves ions within soil and rock and transports these, along with any soluble contaminants encountered, to discharge areas along springs, streams, or well bores. These contaminants may be sorbed[8], mobilized, and (or) diluted during transport along the flow path.

Because of dispersion and mixing, a contaminant will be diluted as it moves through the groundwater system. The regolith in the survey area is considered to be relatively thick, and dilution is likely a significant factor in contaminant attenuation in the survey area.

Water entering a well may come from numerous recharge areas through complicated flow paths which are further affected by pumping. Contaminant plumes in fractured rock tend to be irregularly shaped (often elongated in the strike direction of principle fracture sets). These factors make it difficult to determine the origin of contaminant(s) to an individual well in bedrock settings without a network of monitor wells installed for this purpose.

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[7] The thickness of the soil and saprolite layer was estimated using the casing depth recorded by the driller at the time of well installation. In many cases, this information was unrecorded or otherwise unavailable.

[8] Whether or not contaminants are sorbed depends on the nature of the compound and the geochemical conditions along the flow path.

Potential Sources of Groundwater Contamination

Potential sources of groundwater contamination in the watershed included the following:

1. Septic system leachate. Sixteen septic violations were noted in the larger survey area by the WaDE program (written communication, S. Brinson, WaDE, Feb 28, 2009), most associated with systems failing to surface.

2. Animal wastes that leach to the subsurface. A dairy farm, an abandoned poultry house, backyard chicken enclosures, and pastures were located in the survey area, including 11 within 150 ft of wells and spring houses sampled during this survey. Free roaming dogs and other animals also were observed in the study area during the survey.

3. Fertilizers that leach to the subsurface. Small farms, pastures, lawns, and backyard gardens were near some wells and spring houses sampled during this survey.

4. Surface contaminants entering the well bore along the annular space (in wells with improperly grouted casing) or through breaches in pipe fittings in wells that are buried.

5. Surface water mixing with groundwater. Very few sampled wells were in close proximity to Richland Creek, Hyatt Creek, or their tributaries, and this potential source was believed to be minimal. Nevertheless, in areas where surface water interacts with groundwater, contamination may occur. Hyatt Creek is a DWQ 303d impaired stream due to elevated bacteria counts along some reaches. Stream restoration efforts are underway by various organizations to remedy this.

6. Pesticides, herbicides, fuels, solvents, and other possible unidentified sources. These potential sources were not the focus of this investigation and were not identified or measured in this survey.

METHODS

Water quality data from 63 private wells and four springhouses were used to assess 1) whether there was evidence of septic effluent contamination in the groundwater drinking supply in the survey area and, 2) if so, whether any observed contaminants exceeded drinking water standards. One duplicate sample was collected and seven wells were re-sampled for quality control purposes. Sampling occurred at various times during the year (rather than a single synoptic round) and therefore reflected various hydrologic and climatologic conditions. Since water in bedrock wells is a composite of ages (reflecting different flow paths) and prior hydrologic conditions, this limitation was considered to be minimal given the survey objectives.

Ground water samples were collected at the wellhead when possible or at an unfiltered, untreated, and sterilized hose bib. Wells were purged for approximately 20 minutes prior to sample collection. Sample water was placed in 500 ml plastic containers, immediately placed in iced coolers, and shipped to the DWQ laboratory to arrive within 48 hours (six hours for the bacteria samples). When available, well depth, casing depth, yield, and depth to water were recorded when available.

Information about land use, septic violations, well construction, setbacks, and proximity to potential contaminant sources in the survey area was gathered via owner interviews. Topography and stream locations were used to estimate groundwater flow directions. Soil information was obtained from county soil maps and area observations. In addition, 4-foot deep soil cores were collected in 20 septic drainfield locations. Physical descriptions are available upon request.

Samples were analyzed for septic-related indicator constituents including total and fecal coliform bacteria, total P, PO_4, NH_3, TKN, NO_2, NO_3, SO_4, Na, Cl, TDS, TOC, DOC, and the detergent-related constituents B and MBAS (table 1). Other major inorganic ions also were analyzed, including Ba, Zn, As, Pb, Cr, Cd, and others. Field parameters were measured including temperature Temp, DO, ORP, pH, and SC.

Following the initial sampling round, locations where potential contamination was suspected were re-sampled for organic wastewater constituents and optical brighteners. Organic wastewater constituents (also commonly referred to as “emerging contaminants”) included certain pharmaceuticals, hormones, viruses, caffeine and triclosan (a recalcitrant anti-bacterial found in hand soaps). These locations were also sampled for isotopes of NO_3 to help determine the source of contamination (human or animal waste, inorganic fertilizer). Naturally occurring constituents unrelated to septic systems - arsenic and radon - also were analyzed. Due to budget constraints, only 11 locations were re-sampled for these additional analytes.

To evaluate sources of potential contamination, the location of sampled wells, septic systems, and land use (digital orthophotos) were mapped using GIS software. These were overlain on a map of topography, hydrography, geology, soils, septic systems, and septic system violations.

Tracers used as potential septic indicators[9] were Cl, SO_4, NO_3, NO_2, NH_3, total P, PO_4, COD, TOC, DOC, TDS, total coliform bacteria, fecal coliform bacteria, MBAS, boron, and organic wastewater constituents. Suspended residue and turbidity also were considered, as well as isotopes of nitrogen (d15) and oxygen (d18) (as NO_3) and relative concentrations of detergent-based optical brighteners. TDS was considered as an aggregate representation of major cations (Ca, Na, Mg, and K) in addition to the anions listed above. Ratios of Na:K (Spruill and others, 2002; Wilhelm and others, 1994; Zublena and others, 1991) were also considered as a possible source indicator.

When multiple tracers were present at abnormally high concentrations, that location was considered an “outlier” and a septic source was considered. For purposes of this assessment, an abnormally high concentration (the term “elevated” is also used in this report) was one that 1) exceeded 95 percent of all current and historic measurements in the local area (Clyde and Waynesville area[9]) (table 2), or 2) clearly exceeded the detection limit and was free of laboratory interferences for those constituents whose most probable source is septic leachate, such as MBAS and organic wastewater constituents.

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[9] These measurements included all data from the current survey of 67 locations as well as historic values available from NC Department of Health and Human Services Public Health laboratory obtained on 1/14/2013.

Table 1. Analytes, field measures, and reporting (detection) limits.

Analyte or measure	Reporting limit	Units	Analyte or measure	Reporting limit	Units
pH	N/A		B	50	ug/L
SC	10	uS/cm	Ag	5	ug/L
Temp	N/A	C	Al	50	ug/L
DO	N/A	mg/L	As	2	ug/L
ORP	N/A	mV	Ba	10	ug/L
TDS	12	mg/L	Cd	1	ug/L
Fecal Coliform	1	col/100 ml	Cr	10	ug/L
Total Coliform	1	col/100 ml	Cu	2	ug/L
Ca	1	mg/L	Fe	50	ug/L
Mg	1	mg/L	Fl	0.4	mg/L
Na	1	mg/L	Hg	0.2	ug/L
K	1	mg/L	Mn	10	ug/L
HCO_3	1	mg/L	Ni	10	ug/L
Cl	1	mg/L	Pb	10	ug/L
SO_4	2	mg/L	Se	5	ug/L
NO_3	0.02	mg/L	Si	2	mg/L
NO_2	0.01	mg/L	Zn	10	ug/L
NH_3	0.02	mg/L	Alk	N/A	mg/L
TKN	0.2	mg/L	Turb	1	NTU
$NO_2 + NO_3$	0.02	mg/L	Susp Res	6.2	mg/L
Total P	0.02	mg/L	Rn-222	100	pCi/L
PO_4	0.02	mg/L	Well Depth	N/A	ft bls
COD	20	mg/L	Casing Depth	N/A	ft bls
TOC	2	mg/L	Yield	N/A	gpm
DOC	2	mg/L	SWL	N/A	ft bls
MBAS	0.1	mg/L	Optical Brighteners	0.4	ug/L

Table 1 continued. Organic wastewater constituents (60 analytes) and reporting (detection) limits.

Analyte or measure	Reporting limit	Units	Analyte or measure	Reporting limit	Units
1,4-dichlorobenzene	0.04	ug/L	diethoxynonylphenol [total)	5	ug/L
1-methylnaphthalene	0.022	ug/L	d-limonene	0.08	ug/L
2,6-dimethylnaphthalene	0.06	ug/L	fluoranthene	0.024	ug/L
2-methylnaphthalene	0.036	ug/L	hexahydrohexamethyl cyclopentabenzopyran (HHCB)	0.052	ug/L
3-beta-coprostanol	1.8	ug/L	indole	0.08	ug/L
3-methyl-1h-indole (skatole)	0.036	ug/L	isoborneol	0.18	ug/L
4-cumylphenol	0.06	ug/L	isophorone	0.08	ug/L
4-n-octylphenol	0.16	ug/L	isopropylbenzene (cumene)	0.3	ug/L
4-octylphenol diethoxylate (op2eo)	1	ug/L	isoquinoline	0.046	ug/L
4-octylphenol monoethoxylate (op1eo)	1	ug/L	menthol	0.32	ug/L
4-tert-octylphenol	0.14	ug/L	metalaxyl	0.12	ug/L
5-methyl-1h-benzotriazole	1.2	ug/L	methyl salicylate	0.044	ug/L
acetophenone	0.4	ug/L	metolachlor	0.08	ug/L
acetyl-hexamethyl-tetrahydro-naphthalene (AHTN)	0.028	ug/L	mix:2-tert-butyl &- 3-tert-butyl-4-hydroxyanisole	8	ug/L
anthracene	0.028	ug/L	n,n-diethyl-meta-toluamide (deet)	0.06	ug/L
anthraquinone	0.16	ug/L	naphthalene	0.04	ug/L
benz[a]pyrene	0.05	ug/L	para-nonylphenol (total) (branched)	2	ug/L
benzophenone	0.08	ug/L	p-cresol	0.08	ug/L
beta-sitosterol	4	ug/L	phenanthrene	0.032	ug/L
beta-stigmastanol	2.6	ug/L	phenol	0.16	ug/L
bromacil	0.36	ug/L	prometon	0.12	ug/L
bromoform	0.1	ug/L	pyrene	0.042	ug/L
caffeine	0.06	ug/L	tetrachloroethylene	0.12	ug/L
camphor	0.044	ug/L	tri(2-butoxyethyl) phosphate	0.8	ug/L
carbaryl	0.38	ug/L	tri(2-chloroethyl) phosphate	0.1	ug/L
carbazole	0.03	ug/L	tri(dichloroisopropyl) phosphate	0.16	ug/L
chlorpyrifos	0.16	ug/L	tributyl phosphate	0.16	ug/L
cholesterol	2	ug/L	triclosan	0.2	ug/L
cotinine	0.6	ug/L	triethyl citrate (ethyl citrate)	0.38	ug/L
diazinon	0.16	ug/L	triphenyl phosphate	0.12	ug/L

Table 2. 95th percentile of selected constituents in private supply wells in Clyde and Waynesville area. [Concentrations in mg/L; Data obtained from current investigation and DHHS, downloaded 1/14/2013; n = 73 to 304, depending on constituent.]

Cl	SO4	NO3	NO2	NH3	total P	PO4	COD	TOC	DOC	B	TDS
7.3	12.5	2.9	DL	0.06	0.1	0.05	DL	DL	DL	DL	126

RESULTS

Soils

Soils in the study area generally are well-drained clayey or sandy loam, with parent material derived from alluvium, colluvium, or bedrock. Predominant soil series include Braddock clay loam, Dellwood cobbly sandy loam, Dellwood urban land complex, Dillsboro loam, Dillsboro urban land complex, Evard stony, Cowee stony, Hayesville clay loam, and Saunook loam (USDA, 2010). Based on the 20 near surface soil borings made during the survey (fig. 6), soils across most parts of the survey area were considered to be highly suitable for installation of septic drainfields (oral communication, Dave Lindbo, NCSU Soil Department, 8/6/2010).

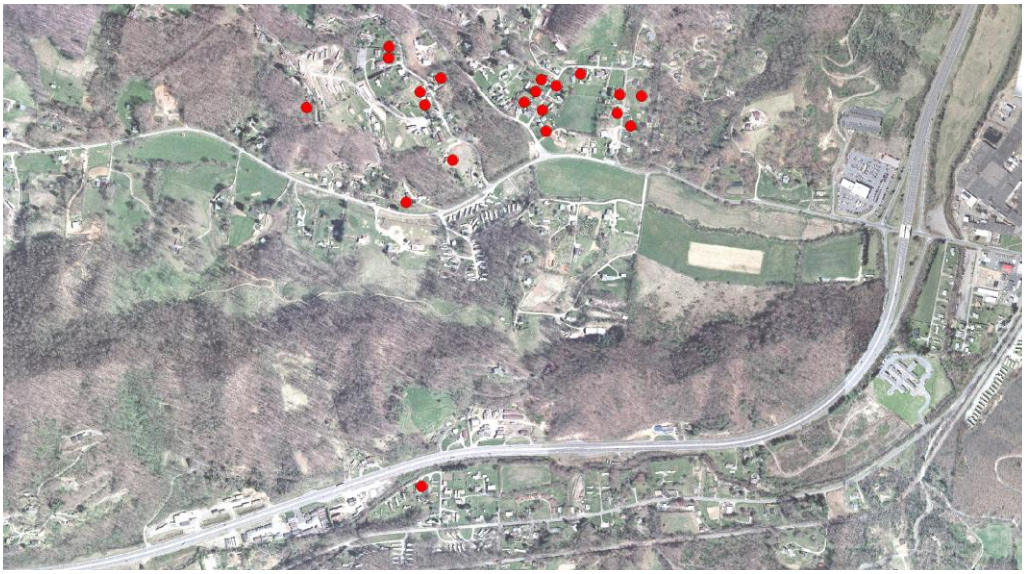

Figure 6. Soil core locations in survey area, Haywood County, NC.

Quality of Well Construction

Fifteen well heads were below grade with unknown quality of construction. Twenty wells were un-grouted[10]. An additional well was buried and un-grouted, and was subsequently repaired. Figure 7 is a photograph showing an example of an improperly constructed, un-grouted well in the survey area (note the cavity and sunken probe rod next to the well head).

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[10] An un-grouted well lacks a cement (grout) seal that is designed to help prevent surface contaminants from migrating along the annular space of the well and entering the well water. The presence of well grout is tested using a probe rod. State well construction rules require the use of well grout.

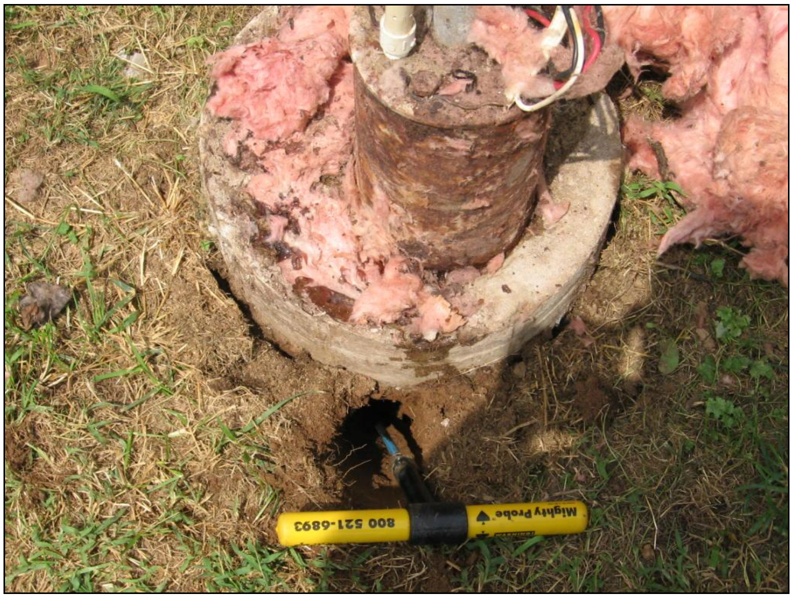

Figure 7. Example of improperly constructed, un-grouted well in survey area.

Ambient (Background) Groundwater Quality

Ambient groundwater in the survey area that is not impacted by anthropogenic contamination generally is of high quality and suitable for drinking purposes. This water is characterized as a calcium-magnesium-bicarbonate type (fig. 8) (a type common to groundwater in the region) and tends to be slightly acidic (median = 6.7), oxic to anoxic, and contains low concentrations of total dissolved solids (median = 80 mg/L) and inorganics. Every well/spring location is recharged by groundwater moving through slightly different soil and rock lithology, so ambient concentrations will vary somewhat from location to location; median levels reflect an approximate midpoint of this range and are shown in table 3. Table 4 shows the minimum, median, 90th percentile, and maximum values obtained for survey samples.

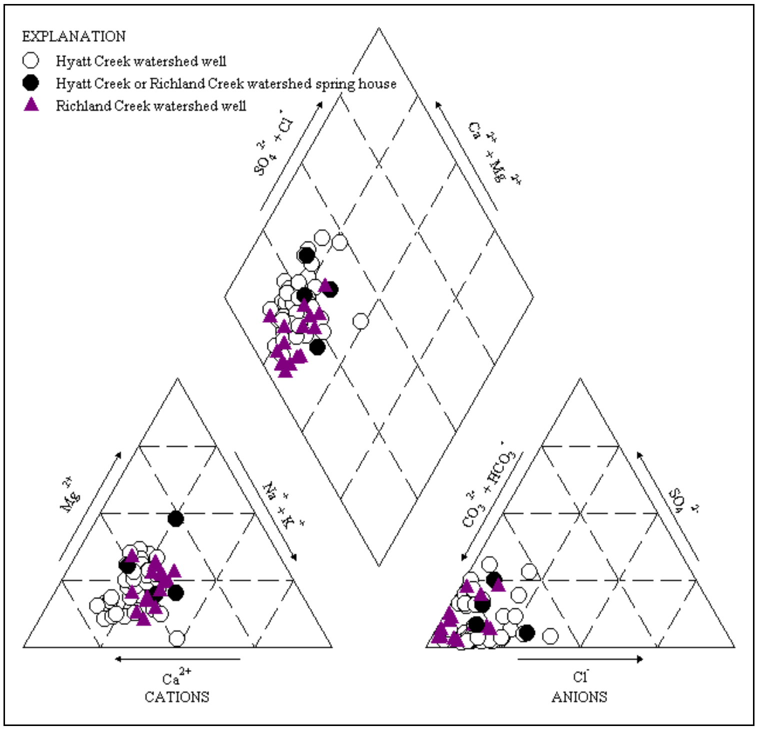

Figure 8. Trilinear (Piper) diagram showing chemistry water type of sample locations.

Table 3. Median values obtained from survey sample locations.

	DL and units	all wells	below grade wells	ungrouted wells	wells in discharge areas	wells in recharge areas	wells within 50 ft of septics	wells 50 to 100 ft from septics	springs	background - representative survey sample	background - local area[a]	background - Blue Ridge Province[b]
n		63	15	20	15	18	10[c]	51[d]	4	1	< or = 325	< or = 571
Field paramters		MEDIAN VALUES										
pH	std units	6.7	6.8	6.7	6.6	6.5	6.5	6.7	5.5	7.3	7.2	6.6
SC	10 uS/cm	99	89	116	89	106	105	100	46	158	91	103
DO	mg/L	5.9	6.5	5.1	5.8	5.4	4.6	6.3	8.6	0.5		6.2
ORP	mV	192	204	182	204	226	212	191	243	92		
TDS	12 mg/L	80	70	90	73	71	78	80	31	123	62	73
Bacteria		MEDIAN VALUES										
Fecal Coliform	1 col/100 ml	BDL	BDL (max = 53)	BDL	BDL	BDL	BDL	BDL	BDL	BDL		
Total Coliform	1 col/100 ml	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL		
% of wells (or springs) with coliform detects		14	20	10	20	17	30	18	25			
Major ions		MEDIAN VALUES										
Ca	1 mg/L	10	9	13	10	12	11	10	4	25	9	8
Mg	1 mg/L	2.7	2.7	3.5	2.5	2.5	2.2	2.7	1.1	4	2	3
Na	1 mg/L	5.4	5.0	5.5	5.3	5.3	5.8	5.4	3.2	6.4	6	5
K	1 mg/L	2.1	2.2	1.9	2.1	2.5	2.5	2.0	1.1	4.3		1
HCO3	1 mg/L	37	36	43	34	41	33	36	14	68	38	32
Cl	1 mg/L	2.9	1.6	3.0	3.1	2.1	1.9	2.8	2.6	1.9	2.5	2
SO4	2 mg/L	BDL	BDL	2.3	BDL	2.3	5.2	2.0	BDL	13	5	5
Hardness	1 mg/L	41	38	45	35	38	39	41	15	79	32	
Nutrients		MEDIAN VALUES										
NO3	0.02 mg/L	0.5	0.4	0.5	0.4	0.1	0.02	0.5	1.0	BDL	<1	0.2[e]
NO2	0.01 mg/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<0.1	
NH3	0.02 mg/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL		0.05
TKN	0.2 mg/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL		
Total P	0.02 mg/L	BDL	0.02	0.03	0.02	0.02	BDL	0.02	0.02	BDL		0.05
PO4	0.02 mg/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL		
Inorganics		MEDIAN VALUES										
B	50 ug/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL		
Ag	5 ug/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<50	
Al	50 ug/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<50	
As	2 ug/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<5	
Ba	10 ug/L	46	50	45	57	46	30	46	32	30	<100	
Cd	1 ug/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<1	
Cr	10 ug/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<10	
Cu	2 ug/L	BDL	3	BDL	BDL	BDL	2.3	BDL	BDL	BDL	<50	
Fe	50 ug/L	BDL	BDL	124	BDL	BDL	BDL	56	BDL	220	60	100
Fl	400 ug/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<200	100
Hg	0.2 ug/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<0.5	
Mn	10 ug/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	89	<30	50
Ni	10 ug/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL		
Pb	10 ug/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<5	
Se	5 ug/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<5	
Si	2 mg/L	25	26	26	24	24	22	25	15	24		16
Zn	10 ug/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	13	BDL	<50	
Other		MEDIAN VALUES										
No. of detected wastewater constituents		0	0	0	0	0	0	0	0			
COD	20 mg/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL		
TOC	2 mg/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL		
DOC	2 mg/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL		
MBAS	0.1 mg/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL		
Alkalinity	1 mg/L	37	36	43	34	41	33	37	14	68	38	32
Turbidity	1 NTU	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	1.5		
Suspended Residue	6.2 mg/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL		
Radon	100 pCi/L	745	890	745	710	540	860	840	BDL	680		
Well construction		MEDIAN VALUES										
Well Depth	ft	200	149	200		294	178	200		150		
Casing Depth	ft	65		80				80				
Well Yield	gpm	15	12	21		14	12	15		60		
SWL	ft bls	20		40				29				

a Local area background based on observations in 325 wells by DHHS (Waynesville and Clyde) and Duncan, 1965 (Clyde).

b Regional background based on observations in 571 wells compiled by Briel and others, 1997.

c 40% of these wells are within 50 ft of a past septic system violation described as "failure to surface"

d 22% of these wells are within 100 ft of a past septic system violation described as "failure to surface"

e value represents combined nitrate + nitrite

Note: blank cells indicate unknown value.

Table 4. Minimum, median, 90th percentile, and maximum values obtained for survey samples.

	DL and units	n	min	median	90th	max
Field Parameters						
pH	std units	65	4.8	6.7	7.8	8.9
SC	10 uS/cm	67	2	99	158	194
DO	mg/L	62	0.2	5.9	8.4	10.7
ORP	mV	66	-248	192	287	508
TDS	12 mg/L	63	16	80	127	142
Bacteria						
Fecal Coliform	1col/100 ml	67	BDL	BDL	48	53
Total Coliform	1col/100 ml	67	BDL	BDL	12	2700
Major ions						
Ca	1mg/L	67	1	10	21	29
Mg	1mg/L	67	1	2.7	5.3	7.6
Na	1mg/L	67	1	5.4	7.0	14.0
K	1mg/L	67	1	2.1	4.0	6.5
HCO3	1mg/L	67	6	37	65	83
Cl	1mg/L	66	1	2.9	6.2	7.6
SO4	2 mg/L	66	BDL	BDL	11.8	17.0
Hardness	1mg/L	67	5	41	71	89
Nutrients						
NO3	0.02 mg/L	67	BDL	0.5	3.6	6.2
NO2	0.01mg/L	67	BDL	BDL	BDL	0.02
NH3	0.02 mg/L	67	BDL	BDL	BDL	BDL
TKN	0.2 mg/L	65	BDL	BDL	BDL	BDL
Total P	0.02 mg/L	67	BDL	BDL	0.05	0.36
PO4	0.02 mg/L	57	BDL	BDL	0.04	0.07
Inorganics						
B	50 ug/L	67	BDL	BDL	BDL	BDL
Ag	5 ug/L	67	BDL	BDL	BDL	BDL
Al	50 ug/L	67	BDL	BDL	51	420
As	2 ug/L	67	BDL	BDL	BDL	BDL
Ba	10 ug/L	67	BDL	46	130	210
Cd	1ug/L	67	BDL	BDL	BDL	BDL
Cr	10 ug/L	67	BDL	BDL	BDL	BDL
Cu	2 ug/L	67	BDL	BDL	12	45
Fe	50 ug/L	67	BDL	BDL	660	2800
Fl	0.4 ug/L	67	BDL	BDL	BDL	BDL
Hg	0.2 ug/L	67	BDL	BDL	BDL	BDL
Mn	10 ug/L	66	BDL	BDL	31	89
Ni	10 ug/L	67	BDL	BDL	BDL	BDL
Pb	10 ug/L	67	BDL	BDL	BDL	BDL
Se	5 ug/L	67	BDL	BDL	BDL	BDL
Si	2 mg/L	61	BDL	25	28	31
Zn	10 ug/L	66	BDL	BDL	41	120
Other						
COD	20 mg/L	64	BDL	BDL	BDL	BDL
TOC	2 mg/L	67	BDL	BDL	BDL	BDL
DOC	2 mg/L	58	BDL	BDL	BDL	BDL
MBAS	0.1mg/L	67	BDL	BDL	0.2	0.6
Alkalinity	mg/L	67	6	37	65	83
Turbidity	1NTU	67	BDL	BDL	6.3	60
Suspended Residue	6.2 mg/L	67	BDL	BDL	BDL	BDL
Radon	100 pCi/L	38	120	745	1650	2150
Well Construction						
Well Depth	ft	21	100	200	365	400
Casing Depth	ft	7	40	65	105	138
Well Yield	gpm	18	3	15	40	100
SWL	ft bls	6	4	20	90	100

Data from the 67 survey locations are presented in box plots (fig. 9) which show the 90th percentile (top whisker), 75th percentile (top of gray box), 50th percentile (median, centerline of gray box), 25th percentile (bottom of gray box), and 10th percentile (bottom whisker) values, as well as values outside these ranges (shown as dots). Data also are presented in a table in Appendix 1.

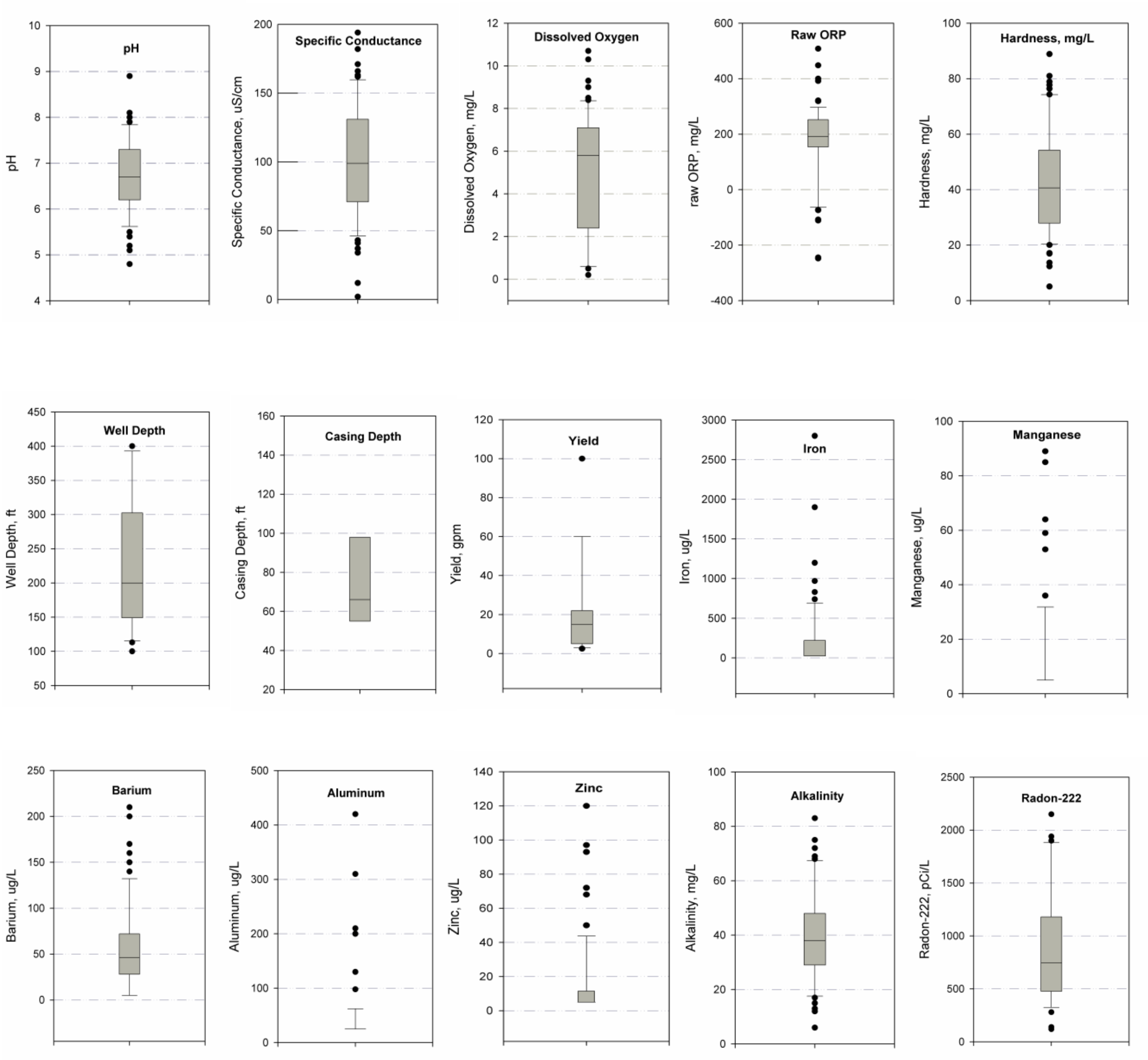

Figure 9. Trilinear (Piper) diagram showing chemistry water type of sample locations.

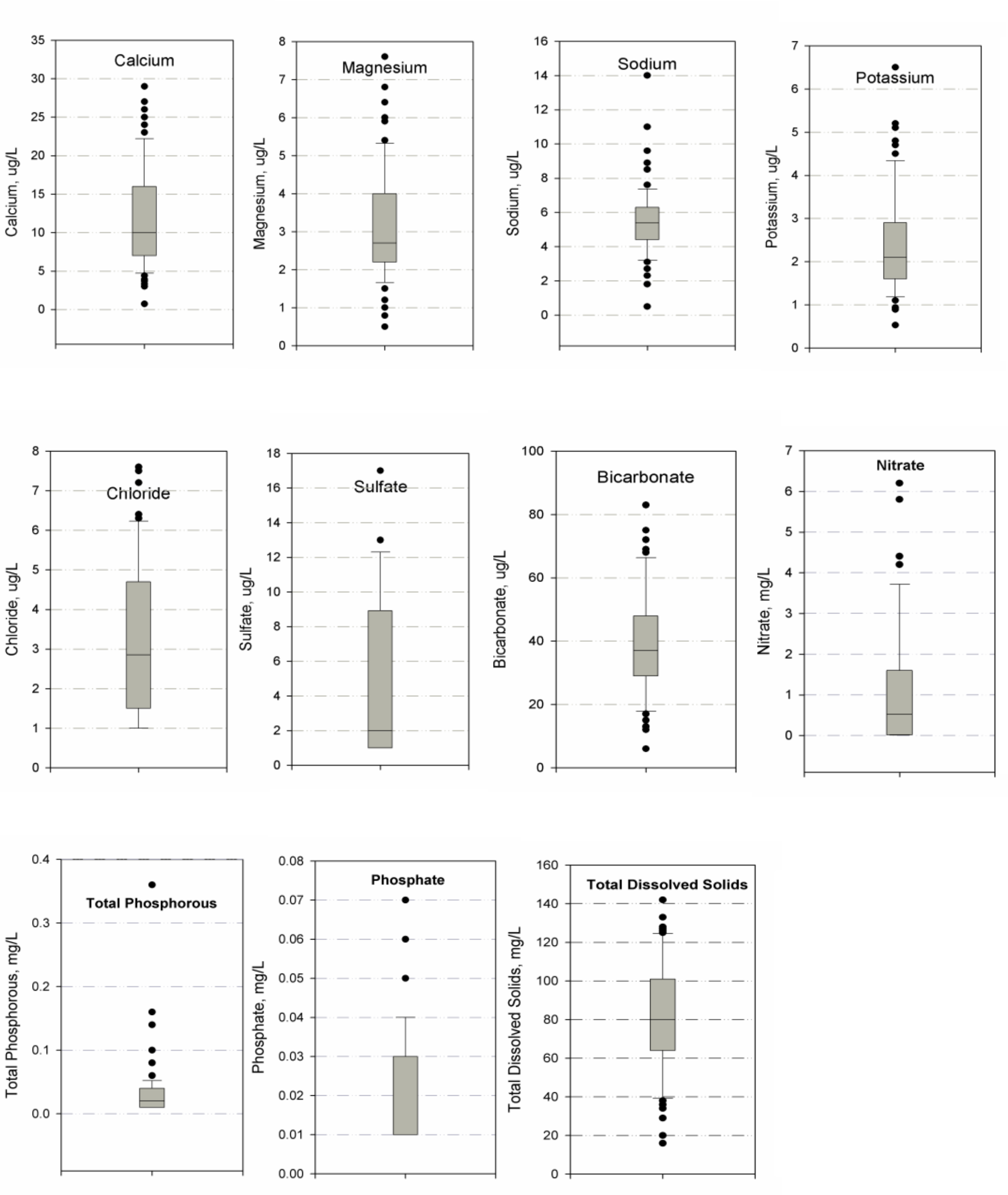

Figure 9 continued. Trilinear (Piper) diagram showing chemistry water type of sample locations.

Naturally occurring contaminants (unrelated to septic seepage) generally were low (median Rn-222 = 750 pCi/L) or not detected (As and Pb), although Fe and Mn exceeded 2L standards in 13 and five samples, respectively (Fe ranged from 53-2800 ug/L and Mn ranged from 11-89 ug/L). These levels of Fe and Mn are not uncommon in regional groundwater and are often attributed to local geology and geochemical conditions (Briel and others, 1997).

Organic Wastewater Constituents (Emerging Contaminants)

A suite of 60 organic wastewater constituents (table 1) was sampled at 11 locations (samples 3, 5, 11, 12, 18, 35, 55, 58, 59, 61, 62) and all were below DL. An occurrence of one or more of these constituents would have been strong evidence of septic effluent contamination. Their complete absence indicates that: 1) wastewater constituents were sorbed, co-precipitated, or degraded along their flow path prior to reaching the well, 2) wastewater constituents were too diluted to be detected once they reached the well, and (or) 3) the well was not positioned to intercept groundwater flow paths from a septic seepage source.

Detergent-Related Constituents

Detergent-related tracers such as boron, MBAS, and optical brighteners are reliable septic seepage indicators if their presence can be positively confirmed and, in the case of boron, occurrences exceed natural background. The use of these tracers for determining septic effluent contamination was inconclusive for reasons explained below.

MBAS was below DL (0.1 mg/L) in 59 locations and only slightly above the DL in eight locations (Appendix 1). While an anthropogenic source cannot be ruled out, the very low MBAS levels may also represent false positive laboratory interferences associated with the analysis of anion-rich water (written communication, M. Ibrahim, Chemist, DWQ Laboratory, 1/18/13). The MBAS detections generally were from samples containing at least moderate anion levels. MBAS co-occurrence with elevated septic seepage tracers generally was minimal and was associated with wells of poor or unknown construction quality (capable of allowing a surface source to enter the well bore along an unsealed casing). MBAS did not co-occur with boron in any survey location.

Boron was below the DL (50 ug/L) in all 67 locations (appendix 1). Five locations were re-sampled using a lower DL (5 ug/L), and of these, 3 contained boron at or just below the DL and one (sample 12) contained boron at 5.9 ug/L. Boron co-occurred with elevated septic tracers at two locations: sample 12 contained B = 5.9 ug/L, CL = 7.6 mg/L, and NO3 = 4.4 mg/L; and sample 55, a buried, un-grouted well with suspected surface contamination issues, contained B = trace, fecal coliform = 53 col/100 ml, and total coliform = 2700 col/100 ml (this well was subsequently repaired, chlorinated, and re-tested and found to be below DL for fecal and total coliform; in the absence of other tracers, septic seepage contamination was believed to be unlikely). Historic ambient dissolved boron data are extremely sparse in the survey area, but results from crystalline bedrock wells in several other counties in the Piedmont-Mountains suggest that boron levels between 2 and 50 ug/L are not uncommon[11]. While an anthropogenic source cannot be ruled out, the observed low boron concentrations are interpreted here as naturally occurring. Additional boron sampling and analyses at the lower DL would help better define background in the survey area.

Optical brighteners were sampled at 20 locations to assess whether the method could be used to identify septic seepage in this setting. Positive interferences may occur for various reasons when analyzing optical brighteners, so relative differences between wells were used to assess the results. Concentrations generally were comparable among the 20 locations, suggesting that optical brighteners were not present or that the method was unsuitable for the very low, diluted concentrations expected in groundwater (written communication, G. Ferrell, 1/25/13).

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[11] Boron concentrations in bedrock wells in various Piedmont-Mountain counties were obtained from USGS National Water Information System database, accessed from the internet on 1/17/13.

Major Inorganic Constituents

Inorganic constituent concentrations generally were typical of uncontaminated groundwater. Some exceptions were noted at levels that, although below 2L standards, may suggest an anthropogenic source. SO_4 and TDS were elevated in six locations (max = 17 and 142 mg/L, respectively), Cl in two (max = 7.6 mg/L), and HCO_3 in one (83 mg/L) (Appendix 1). Maximum values of Ca, Mg, Na, and K were 29, 7.6, 14, and 6.5 mg/L, respectively.

Although co-occurrence of elevated levels of these constituents was minimal, one relationship was noted. Increasing Cl concentrations were associated with increasing NO_3 concentrations (discussed in Nutrients section below), with a correlation coefficient of 0.58 (fig. 10). NO_3 and Cl are both associated with agricultural and (or) septic sources.

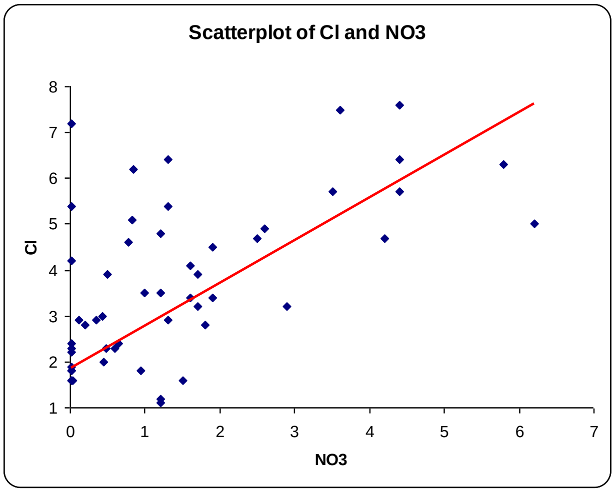

Figure 10. Scatterplot showing relationship between Cl and NO3 in survey samples.

Nutrients

Nutrients are derived from both agricultural and septic sources. The concentrations and extent of co-occurrence with other elevated septic tracers were used to evaluate the likelihood of septic effluent contamination in the survey area. Nutrient concentrations were below 2L in all locations (Appendix 1). NO_2, TKN, and NH_3, were below DL for all locations, with the exception of a single NO_2 value equal to the DL. Concentrations of NO_3, PO_4, and total P were observed in many locations, mostly at very low levels; their co-occurrence with other elevated septic tracers was limited (Appendix 1). In all, nutrient detections in survey samples were inconclusive of septic effluent contamination, as described below.

NO_3 was detected (DL = 0.02 mg/L) in 78% of locations, with a maximum of 6.3, a 90^{th} percentile of 3.5, a 75th percentile of 1.6, and a median of 0.5 mg/L. Background NO_3 in the local area ranges from the DL to about 1.8 mg/L (90th percentile). Elevated NO_3 co-occurred with other elevated tracers in five locations (samples 5, 10, 12, 62, and 67)[12].

PO_4 was detected (DL = 0.02 mg/L) in 43% of locations, but at very low concentrations, with a maximum of 0.07, a 90th percentile of 0.04, a 75th percentile of 0.03, and a median of 0.02 mg/L. Elevated PO_4 co-occurred with other elevated septic tracers in one location (sample 40)[13].

Total P was detected (DL = 0.02 mg/L) in 67% of locations, but at low concentrations with a maximum of 0.36, a 90th percentile of 0.05, a 75th percentile of 0.03, and a median of 0.02 mg/L. Elevated total P co-occurred with other elevated septic tracers in three locations (samples 40, 56, and 67)[14].

Isotopes and Ion Ratios as Source Indicators

Nitrogen (d15N) and oxygen (d18O) isotopes of nitrate were analyzed for 11 samples (samples 2, 5, 6, 7, 8, 9, 10, and 54) to help determine the potential sources of NO_3 such as NO_3 in rainfall, manufactured NO_3, nitrified NH_4 in fertilizer, soil NO_3, or nitrified manure and septic effluent (Kendall, 1998). The results were inconclusive and suggested a NO_3 source from soil, livestock, or human septic waste (figure 11). If the results had fallen distinctly into one category, it may have been possible to classify the source.

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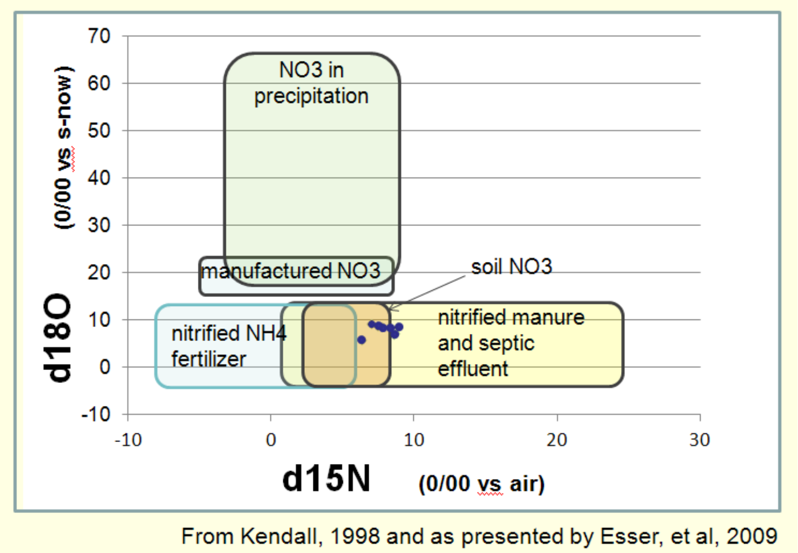
[12] Sample 5, an ungrouted well contained NO3 = 6.2 mg/L, TDS = 133 mg/L, and MBAS = 0.5 mg/L (possibly due to positive laboratory interference); this well also was sampled for organic wastewater indicators and all were below the DL. Sample 10, a buried well with unknown quality of construction, contained NO3 = 5.8 mg/L, TDS = 142 mg/L, and MBAS = 0.5 mg/L (possibly due to positive laboratory interference); this well also was sampled for organic wastewater indicators and all were below the DL. Sample 12 contained NO3 = 4.4 mg/L, Cl = 7.6 mg/L, and boron = 5.9 ug/L (likely a background level). Sample 62, a buried well with unknown quality of construction, contained NO3 = 3.6 mg/L, TDS = 127 mg/L, and Cl = 7.5 mg/L. Sample 67, an ungrouted well, contained NO3 = 4.4 mg/L, total coliform = 6 col/100 ml, total P = 0.14 mg/L, and suspended residue = 6.6 mg/L.

[13] Sample 40, an ungrouted well contained PO_4 = 0.07 mg/L and total P = 0.36 mg/L.

[14] Sample 40, an ungrouted well contained PO_4 = 0.07 mg/L and total P = 0.36 mg/L. Sample 56 contained total P = 0.1 mg/L and total coliform = 66 col/100 ml. Sample 67, an ungrouted well, contained total P = 0.14 mg/L, NO_3 = 4.4 mg/L, total coliform = 6 col/100 ml, and suspended residue = 6.6 mg/L.



From Kendall, 1998 and as presented by Esser, et al, 2009

Figure 11. Oxygen and nitrogen isotope results from selected survey nitrate samples.

A Na:K ratio of greater than 3:1 has been used to distinguish septic waste from animal and fertilizer waste (Spruill and others, 2002; Wilhelm and others, 1994; Zublena and others, 1991). Samples with Na:K ratios as high as 7.8 were found, but results were inconclusive based on the septic tracer signatures in these samples.

Bacteria

Fifteen of 67 locations had total coliform bacteria at or above the 2L standard of 1 col/100 ml (max = 2700 col/100 ml) (Appendix 1). Fecal coliform bacteria was observed in one sample at 53 col/100 ml. The maximum total and fecal coliform concentrations were both obtained in sample 55, a buried, improperly sealed well; this well was subsequently repaired, re-tested, and found to be free of all coliform bacteria. Of the remaining 14 locations containing total coliform bacteria, five were at the DL (1 col/100 ml) and nine ranged from 4 to 170 col/100 ml. Of those nine, two were un-grouted and had well heads less than 6 inches above land surface, three were buried (unknown grout condition), and one was a spring house. Many of these total coliform observations are potentially explainable in terms of poorly constructed wells (surface-borne contaminants migrating down unsealed well bores) and contamination at the well head plumbing itself. Some of these observations may be attributable to septic seepage, but results are inconclusive. Total coliform co-occurred with other elevated septic seepage tracers in four locations (sample 3, 49, 66, and 67)[15]. Any amount of coliform bacteria is considered a 2L exceedance, and wells with any level should be repaired and (or) chlorinated prior to use or re-use.

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[15] Sample 3, an un-grouted well with a well head only 6 inches above land surface, contained total coliform = 11 col/100 ml and TDS = 128 mg/L. Sample 49, a buried well with unknown quality of construction, contained total coliform = 170 col/100 ml and turbidity = 14 NTU. Sample 56 contained total coliform = 66 col/100 ml and total P = 0.1 mg/L. Sample 67, an un-grouted well with a well head only 4 inches above land surface, contained total coliform = 6 col/100 ml, NO3 = 4.4 mg/L, total P = 0.14 mg/L, and suspended residue = 6.6 mg/L.

Analysis of Potential Risk Attributes

Effects of Buried Wells

Fifteen survey wells were buried (well head below grade) and therefore of unknown construction and grout quality (table 5). Thirteen of the 15 wells contained at least detectable concentrations of nutrients, only slightly higher than the frequency of detectable nutrients across all survey locations. Six of the 15 wells, including two within 50 ft of a septic system, contained no elevated septic seepage tracers. Four of the 15 wells contained a single elevated septic tracer (samples 8, 24, 32, 54)[16]. Five of the 15 wells contained two to three elevated septic tracers (samples 6, 7, 40, 49, and 62)[17].

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[16] Sample 8 contained MBAS = 0.4 (possibly laboratory interference. Sample 24 contained total coliform = 88 col/100 ml (this well also contained turbidity above 5 NTU). Sample 32, a well within 50 ft of a septic system, contained PO4 = 0.05 mg/L. Sample 54 contained MBAS = 0.4 mg/L (possibly due to laboratory interference).

[17] Sample 6 contained SO4 = 13 mg/L and MBAS = 0.3 mg/L (possibly due to laboratory interference); this well also was sampled for 60 organic wastewater indicators and all were below DLs. Sample 7 contained SO4 = 13 mg/L and MBAS = 0.3 mg/L (possibly due to laboratory interference); this well also was sampled for 60 organic wastewater indicators and all were below DLs. Sample 40 contained total P = 0.36 mg/L and PO4 = 0.07 mg/L. Sample 49, 75 ft sidegradient to a 5-horse pasture, contained total colif = 170 col/100 ml and turb = 14 NTU. Sample 62 contained TDS = 127 mg/L, Cl = 7.5 mg/L, and NO3 = 3.6 mg/L; this well also contained turbidity above 5 NTU.

Table 5. Results of samples collected in wells of questionable construction quality.

sample number[a]	potential source	constituents above 95th percentile[b] or trace MBAS or turbidity > 5 NTU (in parentheses)	constituents (and result) observed above 2L standards[c]	distance (ft) from proximate source	hydraulic gradient
Below grade wells[d]					
4					
6		SO4 (MBAS, turb)	Fe = 1200 ug/L; Mn = 64 ug/L		
7		SO4 (MBAS)			
8		Cl (MBAS)			
24		total colif (turb)	total colif = 88 col/100 mL; Fe = 680 ug/L		
25	onsite septic system			< 50	upgradient
31	onsite septic system			< 50	sidegradient
32	onsite septic system	PO4		< 50	sidegradient
40		total P, PO4			
42					
44		Total P, PO4			
49	five horse pasture	total colif, turb	total colif = 170 col/100 mL	75	side gradient
54		trace MBAS			
62		TDS, CL, NO3 (turb)			
68					
Ungrouted wells					
2		TDS, SO4 (MBAS)	Mn = 53 ug/L		
3	onsite septic system	TDS, total colif (turb)	total colif = 11 col/100 ml; Fe = 830 ug/L; Mn = 85 ug/L	<50	sidegradient
5		TDS, NO3 (MBAS)			
9	one dog kennel	(MBAS, turb)	Fe = 350 ug/L	30	downgradient
14		(turb)			
16					
17					
19					
26					
28					
39					
46		NO3			
47					
48		turb, susp residue	Fe = 2800 ug/L		
51		total P	Fe = 340 ug/L		
58					
59			Mn = 59 ug/L		
60					
61					
67		total colif, NO3, total P, susp residue	total colif = 6 col/100 ml; Fe = 740 ug/L		
Below grade and ungrouted wells					
55		fecal colif, total colif, turb	fecal colif = 53 col/100 ml; total colif = 2700 col/100 ml; Fe = 970 ug/L		

[a] Unless noted as "springhouse", samples are collected from private wells.

[b] 90th percentile is determined based on all samples collected during survey

[c] 2L standards: Mn = 50 ug/L; Fe = 300 ug/L; total coliform = 1 colony/100 mL

[d] It was not possible to determine whether below grade wells were grouted properly.

Effects of Un-grouted Wells

Twenty survey wells were un-grouted (table 5). Sixteen of the 20 un-grouted wells contained at least detectable concentrations of nutrients, similar to the frequency of detectable nutrients across all survey locations. Twelve of the 20 wells contained no elevated septic seepage tracers. Three of the

20 wells contained a single elevated septic tracer[18]. Five wells contained two or more elevated septic tracers[19].

Effects of Septic Systems within 50 Feet of Sample Locations

Ten survey wells were within 50 ft of septic systems (table 6); eight were sidegradient to the septic system, one was upgradient, and one was side/downgradient. Six of the 10 wells contained detectable concentrations of nutrients which is lower than the 82% frequency of detectable nutrients across all survey locations. Three of the 10 wells contained total coliform (ranging from 11 to 120 col/100 ml), similar to the frequency of total coliform detections of 22% for all locations in the survey. One sample (sample 32), a buried well, contained a slightly elevated level of PO_4 (0.05 mg/L) compared to other locations in the survey but no other elevated tracers. Only two wells, samples 3 and 12, contained more than one elevated septic seepage tracer[20].

Table 6. Results of samples collected within 50 feet of an onsite septic system.

sample number[a]	constituents above 95th percentile[b] or trace MBAS or turbidity > 5 NTU (in parentheses)	constituents (and result) above 2L standards[c]	well construction quality	position relative to septic system
3[d]	TDS, total colif (turb)	total colif = 11 col/100 ml; Fe = 830 ug/L; Mn = 85 ug/L	ungrouted	sidegradient
12	Cl, NO3, B		unknown	sidegradient
21	total colif	total colif = 120 col/100 ml	unknown	sidegradient
25			unknown	upgradient
30			unknown	sidegradient
31			unknown	sidegradient
32	PO4		unknown	sidegradient
38			unknown	side/downgradient
57	(turb)	Fe = 620 ug/L	unknown	sidegradient
63	total colif	total colif = 39 col/100 ml	grouted	sidegradient

[a] Unless noted as "springhouse", samples are collected from private wells.

[b] 95th percentile is determined based on all current and historic samples collected in the Clyde/Waynesville area (DHHD, downloaded 1/14/2013).

[c] 2L standards: Mn = 50 ug/L; Fe = 300 ug/L; total coliform = 1 colony/100 mL

[d] A suite of 60 wastewater constituents was analyzed for this well, and all analytes were below detection limits.

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[18] Sample 9, a well within 30 ft of a one-dog kennel, contained MBAS = 0.6 mg/L (possibly a laboratory interference); this well also was sampled for organic wastewater indicators and all were below DLs. Sample 46 contained NO3 = 2.9 mg/L. Sample 51 contained total P = 0.16 mg/L.

[19] Sample 2 contained TDS = 126 mg/L, SO4 = 13 mg/L, and MBAS = 0.2 mg/L (possibly due to laboratory interference); this well also was sampled for 60 organic wastewater constituents and all were below the DL. Sample 3, a well within 50 ft of a septic system, contained TDS = 128 mg/L and total coliform = 11 col/100 ml; this well also contained turbidity above 5 NTU. Sample 5 contained TDS = 133 mg/L, NO3 = 6.2 mg/L, and MBAS = 0.5 mg/L (possibly due to positive laboratory interference); this well also was sampled for 60 organic wastewater indicators and all were below the DL. Sample 48 contained turbidity = 50 NTU and suspended residue = 10 mg/L. Sample 67 contained total coliform = 6 col/100 ml, NO3 = 4.4 mg/L, total P = 0.14 mg/L, and suspended residue = 6.6 mg/L.

[20] Sample 3, an un-grouted well with a turbidity above 5 NTU, contained total coliform = 11 col/100 ml and TDS = 128 mg/L; this well also was sampled for 60 organic wastewater constituents and all were below DLs. Sample 12, a well of unknown construction quality, contained NO3 = 4.4 mg/L, Cl = 7.6 mg/L, and boron = 5.9 ug/L (likely a background level); this well also contained a very low level of total P (0.03 mg/L).

Effects of Known Surface Contaminants within 150 Feet of Sample Locations

Nine sampled wells and two spring houses were within 150 ft of an identified surface source such as grazing pastures, paddocks, kennels, and poultry houses (table 7); 3 were sidegradient to the source, one was upgradient, and seven were downgradient. Eight of 11 samples contained detectable concentrations of nutrients, only slightly higher than the 82% frequency of detectable nutrients across all survey locations. Four wells and both springhouses contained no elevated septic tracers. Three wells contained a single elevated septic tracer (samples 1, 9, and 66)[21]. Only one sample (sample 49) contained more than one elevated septic tracer[22].

Table 7. Results of samples collected within 150 feet of a known surface source.

sample number[a]	potential source	constituents above 95th percentile[b] or turbidity > 5 NTU (in parentheses)	constituents (and result) above 2L standards[c]	well construction quality	distance (ft) from source	hydraulic gradient
1	currently unused cow pasture	SO4	Mn = 89 ug/L	grouted	90	side gradient
9	one dog kennel	(turb)	Fe = 350 ug/L	ungrouted	30	downgradient
33	commercial dairy cow pasture			unknown	5	downgradient
35	abandoned commercial chicken house	PO4		unknown	100	downgradient
36 -springhouse	small, commercial free range livestock exchange			not applicable	5	downgradient
37 - springhouse	chicken yard			not applicable	70	side gradient
38	chicken yard			unknown	150	downgradient
49	five horse pasture	total colif, turb	total colif = 170 col/100 mL	below grade	75	side gradient
50	one horse pasture		Fe = 1900 ug/L	unknown	50	downgradient
65	chicken yard			unknown	10	downgradient
66	three horse paddock with chickens and dogs	NO3		grouted	40	upgradient

[a] Unless noted as "springhouse", samples are collected from private wells.

[b] 95th percentile is determined based on all current and historic samples collected in the Clyde/Waynesville area (DHHD, downloaded 1/14/2013).

[c] 2L standards: Mn = 50 ug/L; Fe = 300 ug/L; total coliform = 1 colony/100 mL

Statistical Analysis of Potential Risk Attributes

Statistically significant differences were not observed between median total coliform bacteria values (or mean, if values were normally distributed) measured for each of five sample groups. The statistical test used was an analysis of variance (ANOVA) with a 95 percent confidence level, and the five groups tested were: a) samples within 50 ft of a septic system, b) samples within 150 ft of a known surface source, c) samples from buried wells, d) samples from un-grouted wells and e) samples from properly constructed wells. The ANOVA test was also conducted for TDS, Cl, SO_4, NO_3, total P, PO_4, and turbidity. Statistically significant differences were not noted between groups for any of these measures.

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[21] Sample 1 contained SO_4 = 13 mg/L. Sample 9 contained MBAS = 0.6 mg/L (this well was sampled for 60 organic wastewater constituents and all were below the DL). Sample 66 contained NO_3 = 4.2 mg/L.

[22] Sample 49, a buried well with unknown quality of construction, contained total coliform = 170 col/100 ml and turbidity = 14 NTU; this well also contained very low levels of NO3 (0.31 mg/L), total P (0.05 mg/L), and PO4 (0.04 mg/L).

SUMMARY AND CONCLUSIONS

Evidence of septic effluent contamination in the survey area was minimal or inconclusive. While a quarter of samples (63 drilled bedrock wells and four springhouses) contained total coliform bacteria (median = 30 col/100 ml), co-occurrence with other tracers was limited. Coliform bacteria in older, poorly constructed, or poorly maintained wells, is not uncommon. Only one well contained fecal coliform bacteria, and it was a buried, un-grouted well that was subsequently repaired, chlorinated, re-tested and found to be free of all bacteria. Eight samples contained NO_3 above 3 mg/L, a threshold often associated with anthropogenic sources, but co-occurrence with other septic tracers was minimal and nearby agricultural surface sources also was possible. Very low concentrations of total P (max = 0.36 mg/L) and (or) PO_4 (max = 0.07 mg/L) also occurred in about half the samples at levels associated with a relatively ubiquitous, low grade source possibly attributable to the rural agricultural setting. All samples were below DL for NO_2, NH_3, and TKN.

All samples were below DL for TOC, DOC, and COD. Trace levels of MBAS were observed in nine samples, but evidence suggests that these values may be due to laboratory interference (positive interference at these low levels is not uncommon, and co-occurrence with other septic tracers was minimal). Boron was below the DL in all samples except one very low level (5.9 ug/L) comparable to a probable background concentration.

Isotopes of nitrogen and oxygen (as NO3) analyzed for 11 samples were inconclusive source type indicators. It is likely that NO_3 in these samples was derived from soil and (or) nitrified human or animal waste. In addition, eleven locations were sampled for a comprehensive suite of 60 organic wastewater constituents and all were below DLs.

Samples located within 50 ft of septic systems (10 wells) and within 150 ft of known surface sources (livestock) (nine wells plus two spring houses) generally contained water of similar quality to wells across the larger survey area. Thirty percent of wells within 50 ft of the septic systems contained total coliform bacteria, a similar frequency as that of the larger survey area. Co-occurrence of multiple tracers was minimal for both groups. Wells installed below grade (with unknown construction quality) and un-grouted wells had similar overall levels of tracer co-occurrence as those of the larger survey area.

Of the 67 survey samples, 14 exceeded state 2L groundwater standards for total coliform bacteria, one for fecal coliform bacteria, 13 for Fe, and five for Mn. No other constituents exceeded 2L at any sample locations.

Many of the septic effluent-related constituents may have been adequately treated by the surface soils in the unsaturated zone prior to migrating to the groundwater system. The 20 soil cores tested in the survey area generally were considered to be highly suitable for septic drainfield installation (one exception was noted for a core collected in a low lying, waterlogged area adjacent to Richland Creek). The thick shallow regolith groundwater system likely helped to significantly attenuate concentrations in the survey wells through dilution and sorption.

Although the survey area is typical of others in the Piedmont and mountains of NC conclusions drawn in this report may or may not hold in other un-sewered mountain watersheds, and no inference is made in this regard.

ACKNOWLEDGEMENTS

The author would like to thank Eric Romaniszyn (HWWA) who strongly supported this effort in numerous ways and helped to secure grant funding to ensure its success. The Pigeon River Fund deserves a special note of appreciation for their financial grant in support of specialized laboratory analyses that helped to improve data interpretation and overall project value.

This study was made possible by the active collaboration of individuals representing several agencies and organizations. These include Jonathon Stepp (DWQ), Nancy Deal (NCDPH), Gloria Ferrell (USGS, Raleigh), David Lindbo (NCSU Soil Department), Eric Romaniszyn (Haywood Waterways Association), and Stephen Brinson (former WaDE program). Their technical expertise and contributions are greatly appreciated and were invaluable throughout the investigation.

Special thanks are also extended to Gloria Ferrell for her very willing, supportive, and valuable technical input and advice during data interpretation. David Lindbo and Nancy Deal collected and interpreted near-surface soil cores and Deal conducted a thorough literature search on septic effluent tracers, and their assistance is greatly appreciated. Thanks also to Haven Hanford (former WaDE program) for her assistance with GIS mapping and data retrievals. Finally, special thanks are extended to the residents in the Richland Creek watershed who welcomed us into their community and participated in this survey.

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Appendix 1. Survey data, Hyatt and Richland Creek watersheds, Haywood County, NC.

Sample	Type	Watershed	Collection Date	pH	SC	Temp	DO	ORP	TDS	Hardness	Fecal Colif	Total Colif	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3	NO_2	NH_3	TKN	Total P	PO_4
1	well	Hyatt Creek	8/4/2009	7.3	158	13.9	0.5	92	123	79	1 b2	1 b2	25	4	6.4	4.3	68	1.9	13	< 0.02	< 0.01	< 0.02	< 0.2	< 0.02	< 0.02
2	well	Hyatt Creek	8/4/2009	7.5	156	14.2	0.9	-111	126	76	1 b2	1 b2	24	4	5.5	5.2	72	1.8	13	< 0.02	< 0.01	< 0.02	< 0.2	< 0.02	< 0.02
3	well	Hyatt Creek	8/18/2009	6.9	182	14.8	0.8	-60	128	81	1 b2	11	26	3.9	5.7	4.5	32	1.6	12	< 0.02	< 0.01	< 0.02	< 0.2	< 0.02	< 0.02 q2
4	well	Hyatt Creek	8/18/2009	6.6	85	15.8	7.5	93	60	32	1 b2	1 b2	8.4	2.6	5.3	1.3	75	2.3	2	0.59	< 0.01	< 0.02	< 0.2	0.04	0.04
5	well	Hyatt Creek	8/25/2009	6.3	126	14.3	7.2	392	133	47	1 b2	1 b2	11	4.8	5.2	1.9	27	5	<2	6.2	< 0.01	< 0.02	< 0.2	0.02	< 0.02
6	well	Hyatt Creek	8/25/2009	7.1	162	15.2	3.3	-36	122	70	1 b2	1 b2	22	3.6	5.2	4.7	83	1.6	13	< 0.02	< 0.01	< 0.02	< 0.2	< 0.02	< 0.02
7	well	Hyatt Creek	8/25/2009	7.8	194	14.7	0.9	-108	121	89	1 b2	1 b2	29	4	5.9	3.9	65	1.6	13	0.04	< 0.01	< 0.02	< 0.2	0.02	< 0.02
8	well	Hyatt Creek	9/1/2009	6.9	108	15.3	6.8	225	67	42	1 b2	1 b2	10	4.2	4.6	2	38	6.2	<2	0.84	< 0.01	< 0.02	< 0.2	0.02	0.02
9	well	Hyatt Creek	9/1/2009	6.9	94	14.5	7.4	208	77	38	1 b2	1 b2	9.5	3.5	5	1.7	44	3	<2	0.43	< 0.01	< 0.02	< 0.2	0.04	0.03
10	well	Hyatt Creek	9/1/2009	7.2	145	14.8	5.2	169	142	59	1 b2	1 b2	14	5.9	5.5	1.8	41	6.3	<2	5.8	< 0.01	< 0.02	< 0.2	0.02	0.02
11	well	Hyatt Creek	9/29/2009	6.7	115	14.3	6.7	171	94	49	1 b2	1 b2	14	3.5	6.5	3.5	26	5.7	11	3.5	< 0.01	< 0.02	< 0.2	0.03	0.02
12	well	Hyatt Creek	9/29/2009	6	120	14.7	6.9	180	94	55	1 b2	1 b2	12	6	6.3	2.4	37	7.6	2.8	4.4	< 0.01	< 0.02	< 0.2	0.03	0.02
13	well	Hyatt Creek	9/29/2009	5.7	56	12.4	10.3	223	42	25	1 b2	1 b2	6.6	2.1	4.1	1.4	26	2.3	2	0.48	< 0.01	< 0.02	< 0.2	0.04	< 0.02
14	well	Hyatt Creek	9/15/2009	6.5	86	14.2	7.2	229	72	35	1 b2	1 b2	8.9	3.1	4.3	1.7	40	2.8	2	0.2	< 0.02 p	< 0.02	< 0.2	0.04	< 0.02
15	well	Hyatt Creek	9/15/2009	6.3	99	17.2	5.3	219	79	43	1 b2	1 b2	9.4	4.7	4	1.5	42	3.9	2.2	0.49	< 0.02 p	< 0.02	< 0.2	0.04	0.06
16	well	Hyatt Creek	9/15/2009	6.8	125	14.5	5.4	155	111	52	1 b2	1 b2	12	5.3	5.2	2.6	51	3.9	<2	1.7	< 0.02 p	< 0.02	< 0.2	0.03	0.02
17	well	Hyatt Creek	10/6/2009	6.8	118	14.3	4.4	182	78	57	1 b2	1 b2	14	5.3	5.5	2.7	52	6.4	<2	1.3	< 0.01	< 0.02	< 0.2	0.04	0.02
18	well	Hyatt Creek	10/6/2009	7.3	121	13.9	5.3	140	92	54	1 b2	1 b2	13	5.2	5.4	3.6	39	5.7	<2	4.4	< 0.01	< 0.02	< 0.2	0.03	0.02
19	well	Hyatt Creek	10/6/2009	8.9	114	14	1.1	-245	70	35	1 b2	1 b2	13	0.5	14	1.8	36	7.2	9	< 0.02	< 0.01	< 0.02	< 0.2	0.02	< 0.02
20	well	Hyatt Creek	10/13/2009	6.9	89	15.3	4.2	249	62	34	1 b2	4	10	2.2	4.5	2.7	32	5.4	4.2	1.3	< 0.02 p	< 0.02	< 0.2	< 0.02	< 0.02
21	well	Hyatt Creek	10/13/2009	8	135	16.5	2.8	212	99	56	1 b2	120	19	2.1	6.7	5.1	53	4.2	10	< 0.02	< 0.02 p	< 0.02	< 0.2	< 0.02	< 0.02
22	well	Hyatt Creek	10/13/2009	7.9	171	13.7	0.6	186	80	78	1 b2	1 b2	27	2.5	6	6.5	69	5.4	13	< 0.02	< 0.02 p	< 0.02	< 0.2	< 0.02	< 0.02
23	well	Hyatt Creek	10/20/2009	7.9	137	13.1	1.2	-45	96	59	1 b2	1 b2	20	2.1	6.4	3.3	58	2.3	8.9	< 0.02	< 0.02 p	< 0.02	< 0.2	< 0.02	< 0.02
24	well	Hyatt Creek	10/20/2009	7.3	159	13.6	2.7	164	88	74	1 b2	88	17	7.6	4.3	4.8	66	4.8	<2	1.2	< 0.02 p	< 0.02	< 0.2	< 0.02	< 0.02
25	well	Hyatt Creek	11/3/2009	6.5	74	13.2	6.3	226	63	26	1 b2	1 b2	7	2	4.5	2.5	33	2.9	2.3	0.12	< 0.01	< 0.02	< 0.2	< 0.02	< 0.02
26	well	Hyatt Creek	11/3/2009	6.4	67	13.3	7.1	209	88	27	1 b2	1 b2	6.6	2.5	3.8	1.1	29	2.4	<2	0.65	< 0.01	< 0.02	< 0.2	0.03	0.03
27	spring	Hyatt Creek	11/3/2009	6.4	166	11.9	5.8	191	124	71	1 b2	1 b2	18	6.4	6.5	2	57	5.1	17	0.82	< 0.01	< 0.02	< 0.2	0.02	
28	well	Hyatt Creek	11/16/2009	6.2	98	13	6.1	508	83	40	1 b2	1 b2	12	2.4	5.2	1.9	42	1.2	<2	1.2	< 0.01	< 0.02	< 0.2	0.04	0.04
29	well	Hyatt Creek	11/16/2009	6.2	126	13.5	5.8	274	67	53	1 b2	1 b2	15	3.7	5.6	2.7	48	4.5	<2	1.9	< 0.01	< 0.02	< 0.2	< 0.02	< 0.02
30	well	Hyatt Creek	11/16/2009	6.1	90	11.9	6.5	252	<12	34	1 b2	1 b2	9.5	2.5	4.4	1.6	31	2.8	<2	1.8	< 0.01	< 0.02	< 0.2	0.08	0.03
31	well	Hyatt Creek	12/15/2009	5.1	156	12.3	0.5	264		53	1 b2	1 b2	16	3.1	6.9	3.1	47	<1	11	< 0.02	< 0.01	< 0.02	< 0.2	< 0.02	< 0.02
32	well	Hyatt Creek	12/15/2009		34				36	14	1 b2	1 b2	3	1.5	1.8	0.89	17	<1	<2	0.02	< 0.01	< 0.02	< 0.2	0.06	0.05
33	well	Hyatt Creek	12/15/2009	6.8	92	12.6	0.6	191	80	32	1 b2	1 b2	10	1.7	6.8	2.1	28	<1	7.6	0.02	< 0.01	< 0.02	< 0.2	0.03	< 0.02
34	well	Hyatt Creek	1/19/2010	5.7	84	9.1	>5	278	29	32	1 b2	1 b2	8.5	2.6	4.7	1.8	27	4.9	<2	2.6	< 0.01	< 0.02	< 0.2	0.02	0.02

Appendix 1 continued. Survey data, Hyatt and Richland Creek watersheds, Haywood County, NC.

Sample	Type	Watershed	COD	TOC	DOC	MBAS	B	Ag	Al	As	Ba	Cd	Cr	Cu	Fe	Fl	Hg	Mn	Ni	Pb	Se	Si	Zn	Alk
1	well	Hyatt Creek	< 20	< 2	< 2	< 0.1 q2	< 50	< 5	< 50	< 2	30	< 1	< 10	< 2	220	< 0.4	< 0.2	89	< 10	< 10	< 5	24	< 10	68
2	well	Hyatt Creek	< 20	< 2	< 2	0.2 q2	< 50	< 5	< 50	< 2	54	< 1	< 10	< 2	58	< 0.4	< 0.2	53	< 10	< 10	< 5	26	< 10	72
3	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	33	< 1	< 10	< 2	830	< 0.4	< 0.2	85	< 10	< 10	< 5	25	< 10	32
4	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	46	< 1	< 10	3	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	26	< 10	75
5	well	Hyatt Creek	< 20	< 2	< 2	0.5	< 50	< 5	< 50	< 2	43	< 1	< 10	< 2	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	21	< 10	27
6	well	Hyatt Creek	< 20	< 2	< 2	0.3	< 50	< 5	< 50	< 2	51	< 1	< 10	< 2	1200	< 0.4	< 0.2	64	< 10	< 10	< 5	26	120	83
7	well	Hyatt Creek	< 20	< 2	< 2	0.3	< 50	< 5	130	< 2	26	< 1	< 10	< 2	290	< 0.4	< 0.2	36	< 10	< 10	< 5	26	< 10	65
8	well	Hyatt Creek	< 20	< 2	< 2	0.4	< 50	< 5	< 50	< 2	73	< 1	< 10	< 2	91	< 0.4	< 0.2	< 10	< 10	< 10	< 5	28	< 10	38
9	well	Hyatt Creek	< 20	< 2	< 2	0.6	< 50	< 5	210	< 2	38	< 1	< 10	< 2	350	< 0.4	< 0.2	< 10	< 10	< 10	< 5	28	< 10	44
10	well	Hyatt Creek	< 20	< 2	< 2	0.5	< 50	< 5	< 50	< 2	45	< 1	< 10	< 2	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	26	< 10	41
11	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	83	< 1	< 10	6.9	72	< 0.4	< 0.2	16	< 10	< 10	< 5	20	< 10	26
12	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	5.9	< 5	< 50	< 2	130	< 1	< 10	6.1	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	17	< 10	37
13	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	31	< 1	< 10	14	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	23	13	26
14	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	33	< 1	< 10	2.8	640	< 0.4	< 0.2	< 10	< 10	< 10	< 5	25	< 10	40
15	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	70	< 1	< 10	43	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	26	68	42
16	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	170	< 1	< 10	4.1	< 50	< 0.4	< 0.2	10	< 10	< 10	< 5	28	18	51
17	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	98	< 2	200	< 1	< 10	< 2	160	< 0.4	< 0.2	< 10	< 10	< 10	< 5	26	< 10	52
18	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	420	< 2	140	< 1	< 10	4.1	660	< 0.4	< 0.2	< 10	< 10	< 10	< 5	21	< 10	39
19	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	< 10	< 1	< 10	< 2	82	0.5	< 0.2	< 10	< 10	< 10	< 5	18	< 10	43
20	well	Hyatt Creek	< 20	< 2	< 2	0.1	< 50	< 5	< 50	< 2	57	< 1	< 10	7.6	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	18	< 10	32
21	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	36	< 1	< 10	2.5	88	< 0.4	< 0.2	< 10	< 10	< 10	< 5	17	50	53
22	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	58	< 1	< 10	< 2	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	17	< 10	69
23	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	< 10	< 1	< 10	< 2	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	21	< 10	58
24	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	150	< 1	< 10	11	680	< 0.4	< 0.2	30	< 10	< 10	< 5	22	97	66
25	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	55	< 1	< 10	11	53	< 0.4	< 0.2	< 10	< 10	< 10	< 5	25	23	33
26	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	28	< 1	< 10	3.7	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	22	25	29
27	spring	Hyatt Creek	< 20	< 2		< 0.1	< 50	< 5	< 50	< 2	130	< 1	< 10	< 2	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	24	41	57
28	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	160	< 1	< 10	4.7	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	28	93	42
29	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	120	< 1	< 10	< 2	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	28	< 10	48
30	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	87	< 1	< 10	< 2	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	20	< 10	31
31	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	22	< 1	< 10	< 2	< 50	< 0.4	< 0.2	18	< 10	< 10	< 5	22	72	47
32	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	22	< 1	< 10	11	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	17	20	17
33	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	< 10	< 1	< 10	< 2	< 50	< 0.4	< 0.2		< 10	< 10	< 5	24	< 10	36
34	well	Hyatt Creek		< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	45	< 1	< 10	13	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	21	< 10	27

Appendix 1 continued. Survey data, Hyatt and Richland Creek watersheds, Haywood County, NC.

Sample	Type	Watershed	Turbid	Suspended Residue	Radon-222	Hydro Setting	Collection Location	Well Depth	Casing Depth	Yield	Well Condition
1	well	Hyatt Creek	1.5	< 6.2	680	recharge	well head	150		60	surface grouted; unknown sub-surface grouting; assume grouted
2	well	Hyatt Creek	< 1	< 6.2	710	discharge	well head				ungrouted
3	well	Hyatt Creek	6.5	< 6.2	1210	midslope	well head				ungrouted; well head only 6 inches above grade
4	well	Hyatt Creek	< 1	< 6.2	1600	midslope	well head	113			buried
5	well	Hyatt Creek	1	< 6.2	1010	midslope	well head	225	80		ungrouted; channelized beside casing
6	well	Hyatt Creek	12	< 6.2	530	midslope	hose bib	240		2.5	buried
7	well	Hyatt Creek	1 b	6.2 b	890	midslope	hose bib				buried
8	well	Hyatt Creek	< 1	< 6.2	350	midslope	hose bib				buried
9	well	Hyatt Creek	6.1	< 6.2	920	midslope	well head		98	100	ungrouted
10	well	Hyatt Creek	1.1	< 6.2	480	midslope	well head				concrete-floored well house
11	well	Hyatt Creek	2	< 6.2	2150	midslope	well head				concrete-floored well house
12	well	Hyatt Creek	< 1	< 6.2	450	midslope	hose bib			20	
13	well	Hyatt Creek	< 1	< 6.2	560	midslope	hose bib				
14	well	Hyatt Creek	9.5	< 6.2	780	midslope	well head				ungrouted
15	well	Hyatt Creek	< 1	< 6.2	140	midslope	hose bib	157		3	surface grouted; unknown sub-surface grouting; assume grouted
16	well	Hyatt Creek	< 1	< 6.2	500	recharge	well head				ungrouted
17	well	Hyatt Creek	< 1	< 6.2	330	midslope	well head	160		21	ungrouted
18	well	Hyatt Creek	< 1	< 6.2	530	recharge	well head	400			concrete-floored well house; suspected no grout; augered but inconclusive
19	well	Hyatt Creek	< 1	< 6.2	120	recharge	well head				ungrouted
20	well	Hyatt Creek	< 1	< 6.2	1340	discharge	hose bib			8	
21	well	Hyatt Creek	< 1	< 6.2	280	discharge	hose bib				
22	well	Hyatt Creek	< 1	< 6.2	1880	midslope	well head				
23	well	Hyatt Creek	1	< 6.2	540	recharge	well head	300	66		
24	well	Hyatt Creek	6.3	< 6.2	840	midslope	hose bib				buried
25	well	Hyatt Creek	< 1	< 6.2	1410	recharge	hose bib	150		11	buried
26	well	Hyatt Creek	< 1	< 6.2	1900	midslope	well head	200	55	30	ungrouted
27	spring	Hyatt Creek	< 1	< 6.2	400	discharge	spring house	na	na		spring; n/a
28	well	Hyatt Creek	< 1	< 6.2		recharge	hose bib				suspected ungrouted
29	well	Hyatt Creek	< 1	< 6.2		recharge	well head	365	56	16.5	
30	well	Hyatt Creek	< 1	< 6.2		midslope	well head				
31	well	Hyatt Creek	1.4	< 6.2	1140	recharge	hose bib	287		12	buried
32	well	Hyatt Creek	< 1	< 6.2	860	recharge	hose bib	148		15	buried
33	well	Hyatt Creek	< 1	< 6.2	1940	midslope	hose bib				
34	well	Hyatt Creek	< 1	< 6.2	500	recharge	hose bib				concrete-floored well house

Appendix 1 continued. Survey data, Hyatt and Richland Creek watersheds, Haywood County, NC.

Sample	Type	Watershed	Collection Date	pH	SC	Temp	DO	ORP	TDS	Hardness	Fecal Colif	Total Colif	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3	NO_2	NH_3	TKN	Total P	PO_4
35	well	Hyatt Creek	1/19/2010	6.2	92	8.9	6.8	284	34	34	1 b2	1 b2	8.6	3	6	1.6	38	3.5	<2	1.2	< 0.01	< 0.02	< 0.2	0.04	0.04
36	spring	Hyatt Creek	1/19/2010	5.4	51	8.9	9	278	16	17	1 b2	1 b2	4.8	1.2	3.1	1.3	15	4.1	<2	1.6	< 0.01	< 0.02	< 0.2	0.02	< 0.02
37	spring	Hyatt Creek	2/23/2010		12	9.6	10.7	319	20	5	1 b2	1	0.73	0.79	0.5	0.53	6	<1	<2	< 0.02	< 0.01	< 0.02	< 0.2	< 0.02	
38	well	Hyatt Creek	2/23/2010	7.7	119	12.7	0.5	-248	79	44	1 b2	1	14	2.1	11	2.9	44	2.2	9.1	< 0.02	< 0.01	< 0.02	< 0.2	< 0.02	< 0.02
39	well	Richland Creek	2/23/2010	5.7	107	13	4.5	181	61	43	1 b2	1	13	2.6	7.6	2.3	43	3.5	3.5	1	< 0.01	< 0.02	< 0.2	0.04	0.04
40	well	Richland Creek	3/9/2010	6.8	61	10.9	6.8	210	<12	27	1 b2	1 b2	6.5	2.5	4.4	2.1	30	<1	<2	0.43	< 0.01	< 0.02	< 0.2	0.36	0.07
41	well	Richland Creek	3/9/2010	6.7	61	6.1	8	202	<12	27	1 b2	1 b	6.6	2.6	4.4	2.2	31	<1	<2	0.38	< 0.01	< 0.02	< 0.2	0.05	
42	well	Richland Creek	4/6/2010	5.9	81	14.1	7.1	204	73	35	1 b2	1 b	8.6	3.2	5.3	1.6	36	1.8	<2	0.94	< 0.01	< 0.02	< 0.2	0.03	0.03
43	well	Richland Creek	4/6/2010	6.3	58	13.2	8.2	191	50	27	1 b2	1 b	6.3	2.7	3.9	1.2	29	<1	<2	0.3	< 0.01	< 0.02	< 0.2	0.03	0.02
44	well	Richland Creek	4/6/2010	6.8	68	13.5	6.6	166	70	28	1 b2	1 b	6.9	2.7	4.6	2.2	33	<1	<2	0.52	< 0.01	< 0.02	< 0.2	0.05	0.04
46	well	Richland Creek	4/13/2010	6.5	131	13.8	4.8	180	90	68	1 b2	1 b2	16	6.8	5.9	1.8	54	3.2	<2	2.9	< 0.01	< 0.02	< 0.2 j2	< 0.02	< 0.02
47	well	Richland Creek	4/13/2010	8.1	124	13.8	1.4	119	60	47	1 b2	1 b2	16	1.7	9.6	2.6	43	2.9	9	0.35	< 0.01	< 0.02	< 0.2 j2	0.03	< 0.02
48	well	Richland Creek	4/21/2010	6.4	48	12.7	2.1	321	124	17	1 b2	1 b	3.9	1.8	2.3	1.1	15	2	<2	0.44	0.02	< 0.02	< 0.2	< 0.02	< 0.02
49	well	Richland Creek	4/21/2010	6.8	37	13.3	6	212	68	28	1 b2	170	6.9	2.5	5.4	1.7	34	<1	<2	0.31	< 0.01	< 0.02	< 0.2	0.05	0.04
50	well	Richland Creek	4/21/2010	7.4	47	14.3	1.9	162	71	35	1 b2	1 b	9.5	2.7	6.5	2.8	42	<1	2.3	0.04	< 0.01	< 0.02	< 0.2	0.02	< 0.02
51	well	Richland Creek	5/4/2010	6.5	63	12.7	8.3	400	64	22	1 b2	1 b	6.8	1.2	4.7	1.6	27	<1	2.7	0.08	< 0.01	< 0.02	< 0.2	0.16	0.03
52	spring	Richland Creek	5/4/2010	5.5	41	12.1	8.1	208	41	12	1 b2	49	3.3	1	3.2	0.92	12	1.1	<2	1.2	< 0.01	< 0.02	< 0.2	0.03	
53	well	Richland Creek	5/4/2010	7	135	13.6	3.2	191	110	52	1 b2	1 b	17	2.3	8.9	2.6	44	4.6	12	0.77	< 0.01	< 0.02	< 0.2	< 0.02	< 0.02
54	well	Richland Creek	5/18/2010	6.6	43	12.5	6.8	253	45	20	1 b2	1 b	4.4	2.2	1.8	1.2	22			0.2	< 0.01	< 0.02	< 0.2	0.02	0.03
55	well	Richland Creek	6/15/2010	7.5	90			448	80	41	53	2700	12	2.7	5.3	1.9	42	<1	4.7	< 0.02	< 0.01	< 0.02	< 0.2	0.02	< 0.02
56	well	Richland Creek	6/15/2010	7.6	71			147	66	22	1 b2	66	5.6	2	4.6	1.5	27	<1	2.3	0.09	< 0.01	< 0.02	< 0.2	0.1	0.04
57	well	Richland Creek	6/15/2010	7.3	82			43	76	34	1 b2	1 b2	10	2.2	5.9	2.1	33	<1	7.6	< 0.02	< 0.01	< 0.02	< 0.2	0.05	< 0.02
58	well	Hyatt Creek	8/24/2010	6.8	99	15	6.5	152	97	39	1 b2	1	10	3.5	5.5	1.8	35	3.4	2.6	1.6	< 0.01	< 0.02	< 0.2	< 0.02	< 0.02
59	well	Hyatt Creek	8/24/2010	7.5	163	15.3	0.2	-73	125	74	1 b2	1 b2	23	4.1	6.2	3.6	68	2.4	11	< 0.02	< 0.01	< 0.02	< 0.2	< 0.02	< 0.02
60	well	Hyatt Creek	8/25/2010	8.1	130	14.2	0.2	-74	100	52	1 b2	1 b	17	2.3	8.5	2.9	48	1.8	11	< 0.02	< 0.01 q1	< 0.02	< 0.2	< 0.02	< 0.02 q1
61	well	Hyatt Creek	8/26/2010	6.3	100	14.5	6.7	192	101	41	1 b2	1 b2	10	3.8	5.9	1.6	35	3.4	<2	1.9	< 0.01	< 0.02	< 0.2	0.02	0.02
62	well	Hyatt Creek	8/26/2010	6	114	13.5	8.4	186	127	51	1 b2	1 b2	14	3.9	4.7	2.5	19	7.5	<2	3.6	< 0.01	< 0.02	< 0.2	< 0.02	< 0.02
63	well	Richland Creek	11/14/2011	5.2	2	13.1	9.3	272	38	16	1 b2 q1	39 q1	3.7	1.7	3.5	0.94	13	1.6	<2	1.5	< 0.01	< 0.02	< 0.2	0.02	
64	well	Hyatt Creek	11/14/2011	6.4	135	13.9	4	214	119	67	1 b2 q1	1 q1	18	5.4	7.3	3.4	55	4.7	<2	2.5	< 0.01	< 0.02	< 0.2	0.02	
65	well	Hyatt Creek	11/14/2011	5.8	78	14.4	6.8	272	77	33	1 b2 q1	1 b2 q1	8.2	3.1	5.5	1.5	29	3.2	<2	1.7	< 0.01	< 0.02	< 0.2	0.02	
66	well	Hyatt Creek	11/14/2011	4.8	77	13.3	8.5	287	80	36	1 b2 q1	1 b2 q1	9	3.3	2.7	1.8	18	4.7	<2	4.2	< 0.01	< 0.02	< 1 p	0.04	
67	well	Hyatt Creek	11/14/2011	5.4	133	13.8	6.3	252	124	58	1 b2 q1	6 q1	15	5.1	6.2	2.5	31	6.4	4.2	4.4	< 0.01	< 0.02	< 0.2	0.14	
68	well	Hyatt Creek	11/14/2011	7.3	117	13.6	2.4	190	101	57	1 b2 q1	1 b2 q1	19	2.2	6.5	3	47	2.9	7.7	1.3	< 0.01	< 0.02	< 1 p	< 0.02	

Appendix 1 continued. Survey data, Hyatt and Richland Creek watersheds, Haywood County, NC.

Sample	Type	Watershed	COD	TOC	DOC	MBAS	B	Ag	Al	As	Ba	Cd	Cr	Cu	Fe	Fl	Hg	Mn	Ni	Pb	Se	Si	Zn	Alk
35	well	Hyatt Creek		< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	47	< 1	< 10	25	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	30	< 10	38
36	spring	Hyatt Creek		< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	36	< 1	< 10	< 2	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	15	< 10	15
37	spring	Hyatt Creek	< 20	< 2		< 0.1	< 50	< 5	< 50	< 2	15	< 1	< 10	45	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	7.7	< 10	6
38	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	< 10	< 1	< 10	< 2	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	22	< 10	44
39	well	Richland Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	83	< 1	< 10	< 2	260	< 0.4	< 0.2	< 10	< 10	< 10	< 5	22	< 10	44
40	well	Richland Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	66	< 1	< 10	< 2	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	28	< 10	30
41	well	Richland Creek	< 20	< 2		< 0.1	< 50	< 5	< 50	< 2	68	< 1	< 10	2.5	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	28	< 10	31
42	well	Richland Creek	< 20	< 2	< 2	< 0.1 q2	< 50	< 5	< 50	< 2	59	< 1	< 10	20	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	27	< 10	36
43	well	Richland Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	200	< 2	24	< 1	< 10	< 2	480	< 0.4	< 0.2	< 10	< 10	< 10	< 5	23		29
44	well	Richland Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	72	< 1	< 10	3.3	87	< 0.4	< 0.2	< 10	< 10	< 10	< 5	28	< 10	33
46	well	Richland Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	80	< 1	< 10	< 2	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	28	< 10	54
47	well	Richland Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	34	< 1	< 10	< 2	180	< 0.4	< 0.2	< 10	< 10	< 10	< 5	28	14	43
48	well	Richland Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	48	< 1	< 10	6.8	2800	< 0.4	< 0.2	22	< 10	< 10	< 5	11	< 10	15
49	well	Richland Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	49	< 1	< 10	< 2	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	29	< 10	34
50	well	Richland Creek	< 20 j6	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	57	< 1	< 10	< 2	1900	< 0.4	< 0.2	< 10	< 10	< 10	< 5	26	< 10	42
51	well	Richland Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	46	< 1	< 10	< 2	340	< 0.4	< 0.2	< 10	< 10	< 10	< 5	28	11	27
52	spring	Richland Creek	< 20	< 2		< 0.1	< 50	< 5	< 50	< 2	28	< 1	< 10	< 2	< 50	< 0.4	< 0.2	16	< 10	< 10	< 5	15	15	12
53	well	Richland Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	< 10	< 1	< 10	< 2	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	26	< 10	44
54	well	Richland Creek	< 20	< 2	< 2	0.4	< 50	< 5	< 50	< 2	39	< 1	< 10	6	< 50		< 0.2	< 10	< 10	< 10	< 5	19	< 10	22
55	well	Richland Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	< 10	< 1	< 10	< 2	970	< 0.4	< 0.2	13	< 10	< 10	< 5	25	< 10	42
56	well	Richland Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	42	< 1	< 10	< 2	61	< 0.4	< 0.2	< 10	< 10	< 10	< 5	27	< 10	27
57	well	Richland Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	< 10	< 1	< 10	< 2	620	< 0.4	< 0.2	11	< 10	< 10	< 5	24	< 10	33
58	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	42	< 1	< 10	3.5	75	< 0.4	< 0.2	< 10	< 10	< 10	< 5	31	< 10	35
59	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	29	< 1	< 10	2.5	270	< 0.4	< 0.2	59	< 10	< 10	< 5	27	< 10	68
60	well	Hyatt Creek	< 20	< 2	< 2	< 0.1 q1	< 50	< 5	< 50	< 2	< 10	< 1	< 10	< 2	< 50	< 0.4	< 0.2	< 10	< 10	< 10	< 5	23	< 10	48
61	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	46	< 1	< 10	2.9	88	< 0.4	< 0.2	< 10	< 10	< 10	< 5	31	< 10	35
62	well	Hyatt Creek	< 20	< 2	< 2	< 0.1	< 50	< 5	< 50	< 2	110	< 1	< 10	13	120	< 0.4	< 0.2	< 10	< 10	< 10	< 5	23	< 10	19
63	well	Richland Creek	< 20	< 2		< 0.1 q1	< 50	< 5	< 50	< 2	27	< 1	< 10	4.3	< 50	< 0.4	< 0.2	< 10	< 2	< 2	< 5		< 10	13
64	well	Hyatt Creek	< 20	< 2		< 0.1 q2	< 50	< 5	53	< 2	210	< 1	< 10	< 2	81	< 0.4	< 0.2	< 10	< 2	< 2	< 5		< 10	55
65	well	Hyatt Creek	< 20	< 2		< 0.1	< 50	< 5	< 50	< 2	40	< 1	< 10	14	< 50	< 0.4	< 0.2	< 10	< 2	< 2	< 5		< 10	29
66	well	Hyatt Creek	< 20	< 2		< 0.1	< 50	< 5	< 50	< 2	110	< 1	< 10	< 2	< 50	< 0.4	< 0.2	< 10	< 2	< 2	< 5		< 10	18
67	well	Hyatt Creek	< 20	< 2		< 0.1	< 50	< 5	310	< 2	60	< 1	< 10	9.5	740	< 0.4	< 0.2	23	< 2	< 2	< 5		24	31
68	well	Hyatt Creek	< 20	< 2		< 0.1	< 50	< 5	< 50	< 2	19	< 1	< 10	< 2	< 50	< 0.4	< 0.2	< 10	< 2	< 2	< 5		30	47

Appendix 1 continued. Survey data, Hyatt and Richland Creek watersheds, Haywood County, NC.

Sample	Type	Watershed	Turbid	Suspended Residue	Radon-222	Hydro Setting	Collection Location	Well Depth	Casing Depth	Yield	Well Condition
35	well	Hyatt Creek	< 1	< 6.2	460	midslope	hose bib	125	40	35	concrete-floored well house
36	spring	Hyatt Creek	< 1	< 6.2		discharge	hose bib	na	na		spring; n/a
37	spring	Hyatt Creek	< 1	< 6.2		midslope	kitchen tap	na	na		spring; n/a
38	well	Hyatt Creek	< 1	< 6.2	470	midslope	well head				
39	well	Richland Creek	< 1	< 6.2	710	discharge	well head				ungrouted
40	well	Richland Creek	< 1	< 6.2	1600	discharge	hose bib				buried
41	well	Richland Creek	< 1	< 6.2		discharge	kitchen tap				concrete-floored well house
42	well	Richland Creek	< 1	< 6.2	1170	discharge	hose bib	125			buried
43	well	Richland Creek	2.3	< 6.2	990	midslope	hose bib				
44	well	Richland Creek	1.1	< 6.2	840	midslope	hose bib			< 10	buried
46	well	Richland Creek	< 1	< 6.2		discharge	well head				ungrouted
47	well	Richland Creek	2.9	< 6.2		discharge	well head	200			thin surface grouting; ungrouted below surface
48	well	Richland Creek	50	10		discharge	well head				ungrouted
49	well	Richland Creek	14	< 6.2		discharge	hose bib				buried
50	well	Richland Creek	< 1	< 6.2		recharge	well head				concrete-floored well house
51	well	Richland Creek	3.4	< 6.2		recharge	well head				thin surface grouting; ungrouted below surface
52	spring	Richland Creek	1.2	< 6.2		midslope	spring house	na	na		spring; n/a
53	well	Richland Creek	< 1	< 6.2		midslope	well head	400		22	
54	well	Richland Creek	< 1	< 6.2		discharge	hose bib				buried
55	well	Richland Creek	60	< 6.2		midslope	hose bib				buried; suspected ungrouted
56	well	Richland Creek	< 1	< 6.2		recharge	well head				
57	well	Richland Creek	5.8	< 6.2		midslope	well head	205		5	
58	well	Hyatt Creek	< 1	< 6.2		midslope	well head				ungrouted; channelized beside casing
59	well	Hyatt Creek	1.3	< 6.2		midslope	hose bib				ungrouted
60	well	Hyatt Creek	< 1	< 6.2		recharge	well head	326		3	ungrouted
61	well	Hyatt Creek	< 1	< 6.2		midslope	well head	100		15	ungrouted; erosion channeling beside casing
62	well	Hyatt Creek	5.1	< 6.2		discharge	hose bib				buried
63	well	Richland Creek	< 1	< 6.2		recharge	hose bib				surface grouted; unknown sub-surface grouting; assume grouted
64	well	Hyatt Creek	< 1	< 6.2		midslope	well head	305	138	4	grouted
65	well	Hyatt Creek	< 1	< 6.2		midslope	well head				concrete-floored well house
66	well	Hyatt Creek	1.1	< 6.2		recharge	hose bib				surface grouted; unknown sub-surface grouting; assume grouted
67	well	Hyatt Creek	< 1	6.6		recharge	hose bib				ungrouted; stick up is only 4" instead of 12"
68	well	Hyatt Creek	4.9	< 6.2		midslope	hose bib				buried