SICKNESS CAUSED BY SEPTIC DISPOSAL SYSTEMS IN THE BLACK HILLS

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ABSTRACT

More than ten thousand onsite wastewater systems exist in rural areas of the central Black Hills. Numerous septic system failures have been observed; this typically includes effluent reaching the surface caused by bedrock beneath the drainfield. High water table areas may result in effluent backing up into residences. Ground water contamination from septic systems, particularly in dense subdivisions, includes increased nitrate and coliform and other fecal bacteria concentrations. Sickness (gastro-intestinal distress, a form of dysentery) has occurred at several locations in the Black Hills, but firm documentation is available about only two locations. On August 30, 1986, 135 people got sick during a "Volksmarch" after drinking water from the Rockerville Campground well. On June 19, 1995, 35 Girl Scouts got sick at Camp Paha Sapa from the campground well water. Both sickness events occurred from the high use of a well near a septic system where there was a short (~1 day) travel time from the drainfield to the well through fractures in the Precambrian metamorphic bedrock. Both events involved campgrounds where visitors drank untreated well water.

Keywords

Septic systems, bacteria, metamorphic rocks, Black Hills

INTRODUCTION

Analysis of water supplies has demonstrated the presence of harmful organisms whose origin is fecal contamination. These organisms include viruses (e.g., *Hepatitis* A), coliform bacteria (e.g., *Escherichia coli*), and protozoa (e.g., *Giardia lamblia, Entamoeba histolytica* and *Cryptosporidium parvum*). Each of these is known to be capable of causing illnesses when ingested with contaminated drinking water. For example, some strains of *E. coli*, a normal, harmless, inhabitant of the gut flora of warm blooded animals, including humans, produce toxins that cause severe gastroenteritis. *G. lamblia, E. histolytica* and *C. parvum* cause intestinal cramping and diarrhea. Each of these organisms can be ingested with contaminated drinking water.

To prevent illness associated with drinking contaminated water, municipal drinking water supplies are regularly tested. Because identification of specific disease-causing organisms is difficult and time–consuming, *E. coli* has been used to indicate fecal contamination and possible disease-producing organisms. The standard for drinking water is no more than 1 CFU (colony forming unit) per 100 mL (Driscoll 1986). If the water contains up to 50 CFU, chlorine disinfection is used to make the water safe to drink. However, South Dakota does not require chlorination of residential well water, but does require monthly sampling if more than 15 residences are supplied by a common source.

Although surface water can be contaminated with viruses, bacteria and protozoans, ground water, especially in deep aquifers, is generally free of these organisms. However, bacteria can be found in shallow ground water near a source of contamination even though microbiological indicators such as *E. coli* and other fecal coliforms are not very mobile in porous media because they are removed by filtering, die-off, and adsorption (Linsley and Franzini 1979; Canter and Knox 1985). Thus, in fine-grained soils, coliform bacteria do not penetrate more than a few meters (Putnam et al. 2008). However, in coarse-grained alluvium, fractured bedrock, or solution-enhanced rock, ground water velocity can be fast and coliform transport distances can be on the order of a kilometer. In addition, nitrate, chloride, and viruses such as poliovirus, which might escape a drainfield, are known to move freely in the subsurface (Alhajjar et al. 1990). Ground water transport of poliovirus has been observed in sedimentary rocks (Collins et al. 2006). Harvey (1997) observed fast movement of viruses and bacteriophages in sand and gravel deposits; for example, after 90 days only 10% of the poliovirus were inactivated. In the Black Hills, *E. coli* and *G. lamblia* have been found in surface water and E. coli in ground water used for drinking (Putnam et al. 2008).

Meyer (1986) reported that there were 71,743 on-site septic systems and cesspools and 7,913 outhouses serving about 186,000 people in South Dakota. Sawyer and Lindquist (2003) identified approximately 9,000 onsite wastewater systems in the central Black Hills. Because bacteria normally die off within several days after their discharge from a warm-blooded animal (Rahn 1996), the short residence time of bacteria in wastewater infiltrating into the soil below the drain field is generally sufficient to prevent them from reaching a deep water table.

Municipal sewage in U.S. cities is treated by chlorination at sewage-treatment plants, but residences in rural areas typically use unchlorinated onsite wastewater systems. Regulations for the installation and operation of these systems vary by state and county. Meyer (1987) provides background information and regulations of septic systems and their effect on the contamination of ground water in South Dakota and recommends domestic well water should be sampled in areas of concentrated housing which rely on individual septic systems because a major ground water quality problem associated with these systems is nitrate contamination. However, private rural residences generally use untreated well water that is not analyzed for water quality.

Human waste may also contain pharmaceuticals, endocrine-disrupting compounds such as steroids, and antibiotics, all of which may remain active when they end up in wastewater (Stone and Heglund 2005). Putnam et al. (2008) show analyses of organic compounds found in Black Hills water; the most common was "DEET" which showed up in 32% of the analyzed ground water samples.

This paper contains examples of water contamination by onsite wastewater systems in the Black Hills area. The main emphasis is the documentation of actual illness caused by the systems. Documentation for this paper largely stems from records available to the public from the South Dakota Department of Environment and Natural Resources (SD DENR), a result of a recent "open records" law that allows for the release of records to interested parties. These examples are not all-inclusive because data on this subject are difficult to document because there is the perception that if landowners release information on this subject it might contribute to a decline in the value of the real estate.

WATER QUALITY IMPACTS

Recent publications by the US Geological Survey (Putnam et al. 2008) and the South Dakota Geological Survey (Sawyer 2008) contain data on water quality impacts from onsite wastewater systems in the Black Hills. In addition, there are numerous places where septic effluent has been observed surfacing in the Black Hills. Of particular note are houses built on the dip slope of the Minnekahta Limestone in the western part of Rapid City where there is practically no soil for a proper drainfield. For example, in 1979 I saw raw sewage from a Carriage Hills residence in Rapid City surfacing in the adjoining downhill driveway. In 1993, four miles west of Hill City, I saw a "straight pipe" from a septic tank leading to Newton Fork of Spring Creek. In 1990 I saw surfacing sewage effluent within ~20 feet of the Black Hills Playhouse, presumably because of overuse of the onsite system during summer. Minnick (2006) describes surfacing effluent at other places such as the Hisega Lodge, the Cimarron trailer park in Johnson Siding, and a trailer park at the junction of Rt. 44 and 385.

Homes in Green Valley Estates in the lower part of Rapid Valley have been served by private wells. The Rapid Valley area has a long history of wells being contaminated by individual septic systems (Bad Moccasin 1986). According to Scott Hipple (pers. comm. 2008) "there has been a long history of the residents' well water being contaminated by individual septic systems because of the area's high water table." Hovey (1981) found nitrate concentration exceeding 10 mg/L at Green Valley Estates. Coker (1981) found coliform bacteria in 81% of 45 sampled wells, 23% having greater than 1 fecal coliform per 100 ml, the US EPA limit. Mott et al. (2004) have maps showing high coliform, up to 579 CFU/100 ml, and state "…(coliform) bacterial contamination is indicative that the water generally is not safe to drink". Musa (1984) found the nitrate concentration to be 13 mg/L at a test well on the flood plain of Rapid Creek on the campus of South Dakota School of Mines and Technology. Rahn and Davis (1996) suspected this high value could be the result of local lawn fertilizer or the result of upgradient leaking municipal sewer lines combined with early residential onsite systems. Hafi (1983) modeled nitrate concentration in Rapid Valley.

In the Piedmont area north of Rapid City, Bartlett and West Engineering Co. (Royse 1998) studied the area along I-90 in the Red Valley between Blackhawk and Sturgis where ~7,000 people are on individual private septic systems. Tests at 428 wells in this area showed 13% had greater than 5 mg/L nitrate, 28% had coliforms present, and fecal coliforms were present in 4%. The report contains "vulnerability" maps including "sensitivity" (natural occurring fractured aquifers, etc.) and "susceptibility" (man-made factors such as dense septic systems) ratings. In the adjacent Minnelusa Formation area and the Inyan Kara hogback area, Hargrave (2005) and Francisco (2008) used conceptual models to show vulnerability of areas to high density of septic systems. In 2010 at Crooked Creek campground (on the flood plain of Spring Creek above Hill City) the well water had a concentration of greater than 10 mg/L nitrate (Linda Harris, pers. comm. 2010).

In the Spring Creek area above Sheridan Lake, Scott Kenner (pers. comm. 2003) found fecal coliform in Spring Creek below the Hill City sewage lagoon. Palmer Gulch, immediately downstream of the heavily utilized Mt. Rushmore KOA campground, has some of the highest dissolved nitrate values of any Black Hills stream. Schwickerath (2004) showed fecal coliform bacteria in Sheridan Lake exceed swimming standards, and a DNA study indicated that roughly 15% of the bacteria in Spring Creek were from human beings.

Below Sheridan Lake, Spring Creek sinks into the Madison Limestone and recharges ground water. On November 5, 1993, Hazem Shafai got giardia from water from the Copper Oaks well in the Madison Limestone located close to Spring Creek (Hani Shafai, pers. comm. 2011). Kim Taylor (pers. comm. 2008) reported that water from a Madison well (Nonanna) got so dirty during high Spring Creek discharge in 2010 that it couldn't be used; and a new Madison well (Croyle), after hydraulic fracturing, produced 235 gpm, but because the water contained microorganisms and a live worm, they'll need to use membrane filtration to produce drinking quality water. A dye test by Putnam and Long (2007) showed that water moves from Spring Creek to the Nonanna well (10,400 ft away) in only 1.6 days. Long and Putnam (2009) show that flow through the Madison Limestone consists of two domains: a "quick flow" component from sinking streams such as Spring Creek, and a "slow flow" component from infiltration of precipitation falling on the land surface above the Madison Limestone and Minnelusa Formation. Major recharge to the Madison aquifer also occurs from Boxelder Creek (Rahn and Gries 1973; Putnam et al. 2010), and Greene (1999) found dye introduced in Boxelder Creek showed up in Rapid City Madison wells RC-6 in 30 days and RC-10 in 41 days.

Johnson (1975) found fecal bacteria in shallow wells in Keystone in alluvium and attributed these bacteria to septic systems. Sawyer (2006; 2008) studied bacteria in ground water near septic systems in the Black Hills. Putnam et al. (2008) found fecal coliforms most frequently (19%) in Spearfish Formation hydrogeologic settings. In Spearfish Valley they found fecal coliforms up to 6.8 MPN/100 ml, an indication that the subsurface deposits were getting saturated with sewage. The Belle Fourche water infiltration gallery was built in alluvium along lower Spearfish Creek in 1920, and bacteria–free water was produced by gravity flow. Davis (1979) reported that in 1977 bacteria appeared in the gallery water with up to 330 total coliform and 2 fecal coliform per 100 ml. Upgradient residential development in Spearfish Valley with onsite wastewater systems had accelerated in the 1970s, and calculations showed that wastewater could reach the Belle Fourche gallery in ~five days .

Rising nitrate concentrations have occurred in Rapid City's Madison wells (Rahn 2006). Putnam et al. (2008) show nitrate downgradient from septic systems at Silver City and found ground water samples from the Black Hills with up to 24.3 mg/L nitrate. They show wells in the Minnekahta Limestone have the highest mean nitrate concentration (8.62 mg/L) of the five hydrogeologic units studied in the Black Hills. They demonstrated that nitrogen isotope data indicate that warm-blooded animals (presumably from onsite wastewater systems) are the most probable source. Long et al. (2008) found nitrate concentrations greater than 0.4 mg/L in ground water were associated with "conduits" in the Madison Limestone. Because streams typically have low nitrate, they suspect that high nitrate values did not originate as a result of sinking streams, but from infiltration from the land surface.

Gary Stephenson (pers. comm. 2011) formerly worked for the SD DENR and described problem areas where he used dye to confirm movement of septic wastewater to a nearby well. The following are four examples of tests performed 15 to 20 years ago, however the DENR records are incomplete or not available:

- Beaver Lake Campground west of Custer: dye arrived in 22 days,
- Residences in the Homestead Addition in Custer: dye came through in three hours.
- Lead area: dye came to residence wells in four hours.
- Sheridan Lake Heights on Victoria Gulch: dye arrived in less than a day.

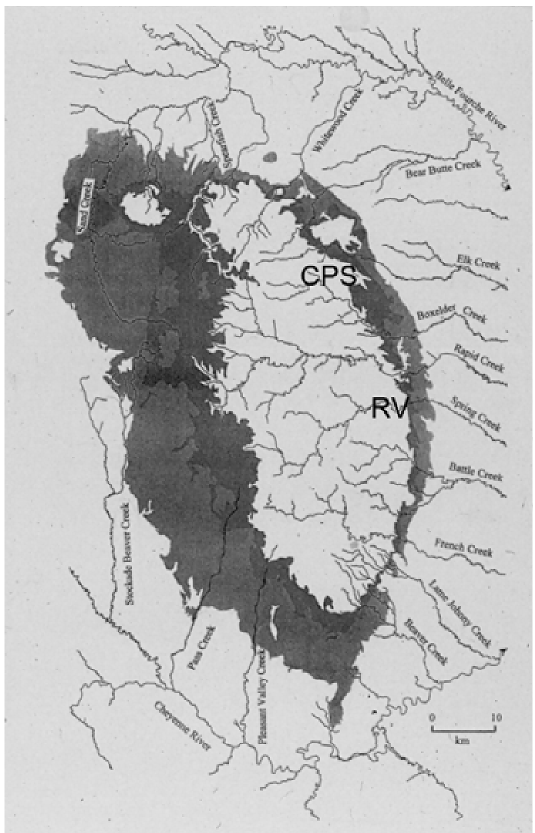

Figure 1. Map of the Black Hills showing major streams. The Madison Limestone is the dark gray color and the Minnelusa Formation is the light gray color. The locations of two sickness events are shown: CPS = Camp Paha Sapa, CG RV = Rockerville Campground.

DOCUMENTED EXAMPLES OF SICKNESS

The following discussion describes two documented sickness events in the Black Hills.

Figure 1 is a geologic map of the Black Hills, and shows the locations of two documented places where people got sick from onsite wastewater systems. Additional sickness events have occurred but are not well documented. For example, in 1993 an intestinal distress outbreak at the Nemo Guest ranch was likely attributed to an onsite wastewater system contaminating the well water (Linda Harris, pers. comm. 11/29/10).

Rockerville ("Wild West") Campground (SE ¼, SE ¼, S 14, T1S, R6E)

Figure 2 is an air photo of the Rockerville Campground area, located about 15 miles southwest of Rapid City. The bedrock in this area is Precambrian schist, specifically a "meta-graywacke" (Redden and DeWitt 2008). The metamorphic bedrock has a prominent foliation, trending approximately north 10 degrees west, and is nearly vertical (Rahn 1987). Lester (2004) found that fractures in this area are typically vertical and strike north 66 degrees east. The surficial deposits include disturbed ground (artificial fill) overlying alluvium. Rockerville Gulch is a small perennial stream and is partially diverted around the camping area. Although the original watercourse most likely extended under the campground, the water from the perennial reach largely sinks into the alluvium under the campground area.

The water table throughout the campground is 10 to 20 ft depth (Figure 3). The campground well has a total depth of 25 ft and a static level of 16 ft.

Figure 2. Air photo from 2008 showing Rockerville Campground (from www.RapidMap.org.). SH = shower house, PH = well house .

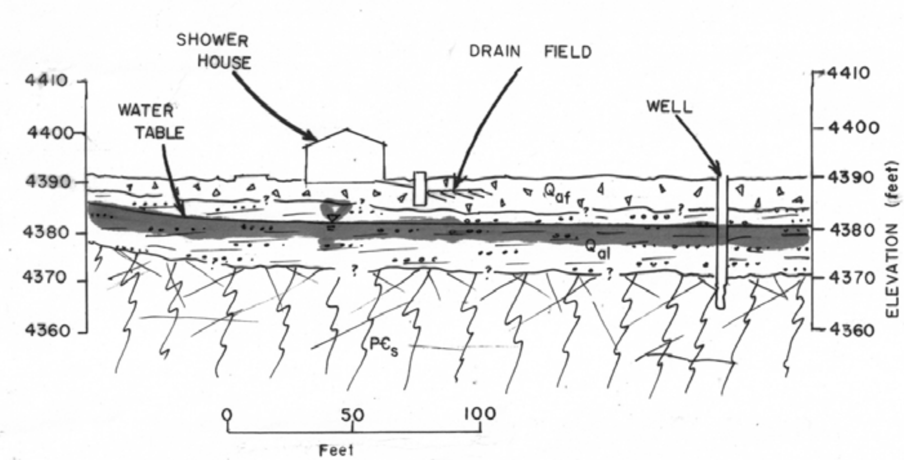

Figure 3. Cross-sectional sketch of the Rockerville Campground area showing geology and ground water conditions. Vertical exaggeration = 2X.

Unfortunately no well log is available. In 2001 an 8-inch steel casing was present at the well in the pump house. According to the owner, the well taps into a "surface stream of the past". This is interpreted to mean the well was drilled into alluvium. But the bottom of the 25 ft well most likely terminates in bedrock. The well is approximately 100 ft downgradient from the dump station and septic drainfield.

On August 30, 1986, 135 out of 181 people on a "Volksmarch" at this campground developed gastrointestinal sickness. The victims were interviewed by the SD Dept. of Health who found that the sickness lasted approximately 33 hours and consisted of diarrhea, explosive vomiting, abdominal cramping, nausea, and fever. The Volksmarch participants drank water from a faucet at the campground that reportedly had not been used for a number of years.

On September 8, 1986, Bill Chalcraft (SD Dept. of Health) and Gary Stephenson (SD DENR) conducted an initial Rhodamine dye test and concluded that the hydraulic connection between the well and the septic system was less than eight days. On October 1, 1986, they conducted a second dye test. They put one pint of fluorescein dye into the 5,000 gal septic tank and collected data as follows. The original dye concentration at the Pump House well was zero.

Date	Location	Fluoroscope units (on 30X scale)
Oct. 1	Dump Station spigot	3
Oct. 1	Pump House	2
Oct. 2	Pump House	10
Oct. 3	Pump House	9
Oct. 4	Pump House	6
Oct. 5	Pump House	2
Oct. 6	Pump House	3
Oct. 7	Pump House	6
Oct. 8	Pump House	4
Oct. 9	Pump House #1	5
Oct. 9	Pump House #2	1

The dye test confirmed that wastewater travelled from the septic system to the well in approximately one day. Because of the results of the dye test and the presence of fecal bacteria in the well water in 1988 and again in 1994, the SD DENR stated: "a dye test conducted in 1986 confirmed that effluent from the septic tank was contaminating the well".

Girl Scout "Camp Paha Sapa" (SW ¼, S 15, T3N, R4E)

This campground, now called "Kamp Kinship", is approximately five miles south of Deadwood. The camp is located on Precambrian metamorphic rocks (Redden and DeWitt 2008). A nearby slate outcrop along the North Fork of Boxelder Creek has a prominent foliation striking north 10 degrees west and dipping 75 degrees east. The 104-ft water well for the camp was drilled in 1978. The static level is reportedly 32 ft, nearly the same as the elevation of the North Fork of Boxelder Creek. The well log shows 13 ft of overburden and schist from 13 to 104 ft. The yield of the well is surprisingly high (40 gpm) because the median yield of Precambrian wells in the Black Hills is only about 10 gpm (Carter et al. 2002). This high yield probably indicates that a fracture contributes abundant water to the well.

Figure 4 is an air photo of Camp Paha Sapa showing a small pond on the North Fork of Boxelder Creek, the septic system location, and the location of the well. The well is 168 ft north of the drainfield. The water table in the Precambrian terrain mimics the topography, hence the static level of the drainfield would be nearly the same as the well (Figure 5), indicating contaminants theoretically might not flow directly to the well. During high use, however, the wastewater would create a mound in the water table under the drainfield, and the pumped well would create a cone of depression, so that wastewater could move from the drainfield to the well. This factor, in addition to the influence of joints and foliation of the bedrock, would explain the contaminant pathway.

Figure 4. Air photo from 2006 of Camp Paha Sapa (from Google Earth "Terra Server"). W = well, WD = wastewater drainfield, L = lake on North Fork of Boxelder Creek.

On June 19, 1995, 35 out of 47 Girl Scouts became sick at Camp Paha Sapa, and some were sent to the hospital. Eight well water samples were collected by the DENR on June 19, and six tested positive for fecal coliform.

In the late summer of 1995, Linda Harris (SD DENR) put dye in the septic system. Her subsequent observations of the well water showed no visible red color, but no fluorescent measurements were made. By late summer there were no campers and little use was being made of the well or shower house. [Note: a complicating factor is that the well is approximately 200 ft downgradient of a septic cleanout for a drain line to a small latrine in the "Settler's Inn" that was inadvertently broken during road construction in 1995 and later repaired (Nancy Clary, pers. comm. 2010). It is possible that this incident also could have contributed to the 1995 well contamination.]

In 1995 the SD DENR was reluctant to relate the Girl Scout sickness to the wastewater system, but in 1997 they concluded there was a connection from the septic system to the well. This sickness incident led to the closure and sale of the camp to a private party.

In 1997 the new owner of Camp Paha Sapa rented the camp to South Dakota School of Mines and Technology for a ten-week summer geology field camp. I was director of the Black Hills Natural Sciences Field Station and was told that the camp had safe water because a chlorinator was installed. Later in the summer I observed that the chlorinator was in the mess hall on the water line from the well to the kitchen, and that the sinks and showers in the bathhouse were

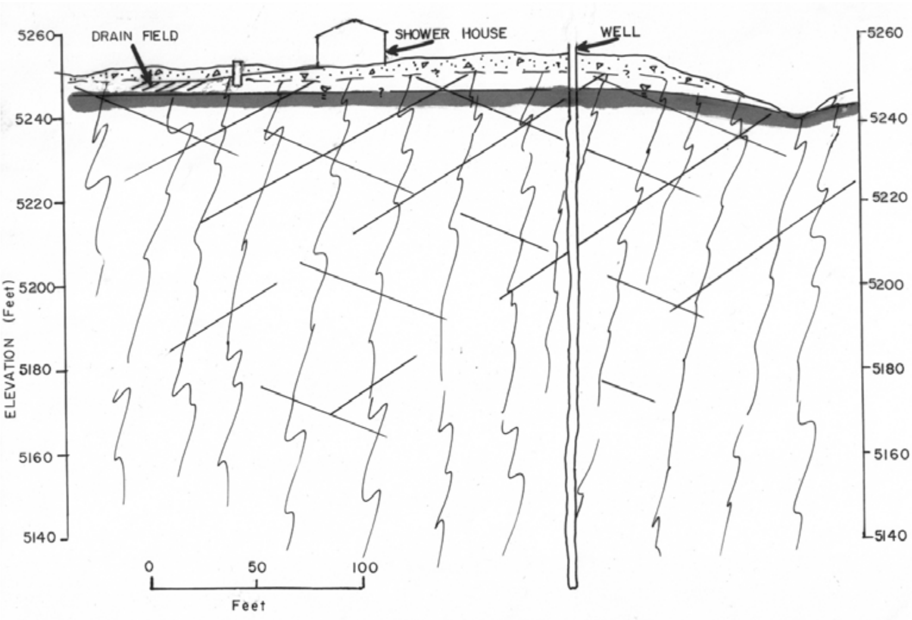

Figure 5. Cross sectional sketch of the Camp Paha Sapa area showing geology and ground water conditions. Vertical exaggeration = 2X.

not included in this circuit. I also noted that the chlorinator to the kitchen did not work all the time. During the early part of the summer season 16 students became sick (fatigue, nausea, diarrhea, and symptoms similar to stomach flu). Students reported that in some mornings the showers smelled like sewage. Students were cautioned about the use of the sink in the bathroom; they began using bottled water, and afterward there were no additional reported incidences of sickness.

According to recent SD DENR files (Barbara Friedeman, letter of Jan. 15, 2004), continuous chlorination of the water at Camp Paha Sapa is required because DENR field investigations show the existing well is vulnerable "…and is likely linked to the wastewater disposal system. Bacteriological analyses confirmed the presence of fecal coliform (sewage related) bacteria, which supports this position. In addition, two Health Department investigations in 1995 and 1997 implicated the drinking water from the existing well as the cause of the water-borne illness experienced by persons staying at the camp. The epidemiological evidence that DENR received from the Health Department indicates that only the drinking water had any commonality with the illnesses reported by those staying at the camp during the summers of 1995 and 1997. Transmission from person to person and transmission by food were both ruled out by the Health Department." In 2004 a new owner redesigned the septic system and in 2006 installed a new 160 ft well. This new water system is carefully regulated by the SD DENR (Linda Harris, pers. comm. 2010).

HYDROGEOLOGIC CONSIDERATIONS

The two examples of onsite wastewater sickness described herein occurred in Precambrian metamorphic rock terrain. Based on nearby outcrops, the bedrock at both locations is schist (which also could contain slate and quartzite). The pathway of contaminant movement is undoubtedly controlled by fractures, i.e., joints. The four problem areas described above provide supporting hydrogeologic evidence of the role of fractures in metamorphic and igneous Precambrian terrain for contaminant pathways. Thus, despite evidence of nitrate buildup and ground-water quality degradation due to onsite wastewater systems in Paleozoic, Mesozoic, and Cenozoic sedimentary rocks, this study shows that the Precambrian terrain is the most critical environment.

The prediction of contaminant pathway using fractured rock depends on the gradient of the potentiometric surface as well as the fracture orientation, width, length, and filling material. Fractures in these metamorphic rocks can include faults, joints (planar features typically in parallel sets), unloading (sheeting) features, and other types of cracks. In general, permeability decreases with depth in metamorphic rocks because overburden pressure tends to seal deeper fractures (Davis and DeWeist 1965; Murdoch et al., in preparation). Using numerous assumptions, Park et al. (2002) modeled the theoretical movement of contaminants in fractured bedrock and found that ground water generally flows directly downgradient, but is affected by bedrock anisotropy. For example, at Nemo, a site a few miles from Camp Paha Sapa, an ethylene dibromide (EDB) contaminant pathway was shown to be strongly influenced by metamorphic rock bedding and foliation (Rahn and Johnson 2002). While analysis of fracture traces or field mapping of fractures would help in the analysis of ground water flow in fractured bedrock, one single fracture could be responsible for contaminant movement at any given site (Paillet and Pedler 1996). However, a single fracture might not be representative of other fractures seen in outcrops, and hence there is no reliable analytical method for predicting overall anisotropy and resulting contaminant movement direction in this hydrogeologic setting.

Although the bedrock at both sickness sites is Precambrian metamorphic rocks, surficial deposits at the Rockerville Campground may have contributed to the contaminant movement because the well is (to some unknown degree) in alluvial deposits along the original channel of Rockerville Gulch.

ONSITE WASTEWATER REGULATIONS

The State of South Dakota requires that, prior to the installation of a septic tank and drainfield, a percolation test must be performed to ensure suitable soil permeability. Another state regulation is that the bedrock and the water table must be at least 4 ft below the bottom of the drain field and the septic tank. Local oversight of septic system installation is usually performed by county and city officials. A major problem for areas of residual soils that are commonly found in the Black Hills is that the boundary between soil and bedrock is not distinct. Nevertheless, onsite wastewater systems continue to be installed in weathered bedrock. Onsite wastewater systems function properly only if they are installed correctly and maintained at regular intervals. Once installed, the State of South Dakota does not have any further regulations unless neighbors complain. In 2009 the City of Rapid City initiated a regulation that, within the city limits (and extending one mile beyond the city limits), a septic tank must be pumped and inspected every three years.

In 2010 the Pennington County Commission passed an ordinance that requires a septic tank be pumped and inspected every six years and that the pumper complete an inspection form. Landowners with 40 or more acres are exempt. Numerous people opposed the Pennington County ordinance, advancing the argument that there is no documented instance of septic systems in the Black Hills causing sickness.

After a septic tank is pumped, the sludge is disposed in a municipal wastewater system or taken to an approved disposal location, typically a field far from houses. Usually lime is applied to the wastes as they are spread. The SD SDENR does not keep records of where septic tank wastes are applied to land. The administrative rules of South Dakota allow for disposal of septage in a municipal wastewater system if the city allows the disposal and the system provides secondary treatment or allows land application under federal guidelines. The U.S. EPA regulates land application of the collected waste. A summary of the US EPA requirements can be found at http://www.denr.sd.gov/des//sw/septagelandapp.aspx.

CONCLUSION

Within the Black Hills a common problem from private onsite wastewater systems is that of surfacing sewage effluent. This is typically a result of shallow bedrock beneath the drainfield. This problem is particularly evident in areas underlain by the Minnekahta Limestone such as the Carriage Hills area of Rapid City. Another handicap to the proper functioning of a septic system is a high water table such as that found beneath the flood plain of Rapid Creek. In these areas, the sewage can back up into a house basement. In addition, the ground water in these areas of high water table develops high nitrate and a buildup of bacteria with a gradual increase in nitrate concentration and bacteria in areas of dense onsite wastewater systems. In some areas the drinking water limit for nitrate of 10 mg/ L is exceeded. Nitrate concentrations were ranked in various hydrogeologic settings and were found to be highest in ground water in the Triassic Spearfish Formation (Putnam and Long 2007).

The only known type of sickness caused by onsite wastewater systems in the Black Hills is gastro-intestinal distress, a variation of "Montezuma's Revenge". Fortunately none of the more serious water-borne diseases such as typhoid or cholera have been observed. Although the specific microbes that caused the illnesses reported herein have not been determined, candidates that are found in the region include *Rotavirus, Cryptosporidium, Salmonella* and *E. coli*.

The two examples of sickness described in this study resulted from hydrogeologic conditions involving fractured schist bedrock and/or alluvium where a water-supply well was within 100 ft of the onsite wastewater disposal system.

The wastewater transit time from the septic system to the well was approximately one day, and hence fecal bacteria survived the journey. High summer use of the septic system and heavy pumping from the nearby well could allow for contamination of a well that under normal use would contain no fecal bacteria.

At both sickness locales, the direction of contaminant movement was approximately downgradient of the general water table, but influenced to some degree by the cone of depression from the well. Predicting a sewage contaminant pathway in fractured rock is complex. Freeze and Cherry (1979) point out that "although there is considerable evidence indicating that bacteria and viruses from sewage have small penetration distances when transported by groundwater through granular material, similar generalizations cannot be made for transport through fractured rocks." Where the water table slope and orientation of metamorphic bedrock fractures are known, it is theoretically possible to predict the direction of ground water flow. At the two sickness sites described in this paper, however, surficial deposits cover the bedrock; the nearest bedrock outcrop is more than 500 ft from the well/septic disposal areas. The number and orientation of fractures is very site-specific, and hence it is not feasible to predict the direction of contaminant movement because a single bedrock fracture, not discernible from the surface, could provide a pathway for pathogens.

Judging from the sickness events and problem areas described in this paper, I predict that any Black Hills well in alluvium, artificial fill, or metamorphic rocks within ~100 ft of a septic system is at risk. The well water should be treated by chlorination or other appropriate methods, especially if the well has high seasonal use by visitors.

The Madison Limestone is the most highly utilized aquifer in the Black Hills. The Madison has large caves and other secondary porosity features with high permeability, yet no incidents of sickness have been documented that can be attributed to onsite wastewater systems operating directly on this unit or on other units above this aquifer. One reason for this is that municipalities and large sanitary districts that utilize this aquifer are required to chlorinate the water before it is delivered to residences. Another reason may be because, in spite of numerous residential septic systems in these areas, the systems are typically situated hundreds of feet above the water table, and hence the wastewater may take weeks or longer to infiltrate to the water table. There are, however, incidents of illness associated with the Madison aquifer that are caused by parasites or microorganisms that gain access to the aquifer from sinking streams such as Spring Creek or Boxelder Creek. In particular, Spring Creek water has contaminants that originate from upstream onsite wastewater systems; this water is carried into sinkholes and can quickly gain access to nearby wells. Upstream onsite septic systems within this watershed contribute to the degradation of surface water, and thereby ultimately affect ground water and wells in the Madison aquifer.

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