Ground Water Quality

Movement of Coliform Bacteria and Nutrients in Ground Water Flowing through Basalt and Sand Aquifers

James A. Entry* and Neal Farmer

ABSTRACT

Large-scale deposition of animal manure can result in contamination of surface and ground water and in potential transfer of disease-causing enteric bacteria to animals or humans. We measured total coliform bacteria (TC), fecal coliform bacteria (FC), NO₃, NH₄, total P, and PO₄ in ground water flowing from basalt and sand aquifers, in wells into basalt and sand aquifers, in irrigation water, and in river water. Samples were collected monthly for 1 yr. Total coliform and FC numbers were always higher in irrigation water than in ground water, indicating that soil and sediment filtered most of these bacteria before they entered the aquifers. Total coliform and FC numbers in ground water were generally higher in the faster flowing basalt aquifer than in the sand aquifer, indicating that the slower flow and finer grain size may filter more TC and FC bacteria from water. At least one coliform bacterium/100 mL of water was found in ground water from both basalt and sand aquifers, indicating that ground water pumped from these aquifers is not necessarily safe for human consumption according to the American Public Health Association and the USEPA. The NO₃ concentrations were usually higher in water flowing from the sand aquifer than in water flowing from the basalt aquifer or in perched water tables in the basalt aquifer. The PO₄ concentrations were usually higher in water flowing from the basalt aquifer than in water flowing from the sand aquifer. The main concern is fecal contamination of these aquifers and health consequences that may arise from human consumption.

Pollution of surface flow and ground water from application of animal waste has been well documented (Mallin et al., 1997; Mawdsley et al., 1995). Liquid-waste discharge onto soil initiates solute and microbe movement that follows natural ground water drainage patterns and may contaminate ground water. Ground water is often used as a source of drinking water. Human consumption of water containing intestinal pathogens may spread disease. Therefore, it is critical to maintain the quality of our lakes and streams by keeping them free of intestinal pathogens and excess nutrients associated with wastewater. Total coliform bacteria (TC) and fecal coliform bacteria (FC) are sensitive and commonly used indicators of bacterial pathogen contamination of natural waters. Their presence implies the potential presence of microorganisms that may cause harmful effects in humans. The total coliform group of bacteria are an aerobic or facultatively anaerobic, gram-negative, non-sporforming, rod-shaped bacteria that ferment lactose with gas production in 24 to 48 h. Total coliform bacteria are discharged in high numbers in animal and human feces, but not all total coliform bacteria are necessarily of fecal origin. These indicator bacteria have been found to be useful for determining safe drinking and recreational waters (Greenberg et al., 1992). The fecal coliform group of bacteria are a subset of the total coliform bacteria. Fecal coliform bacteria are more thermo-tolerant. These bacteria conform to all of the criteria used to define total coliform bacteria plus the requirement that they grow at 44.5°C. Fecal coliform bacteria are bacteria that originate from intestinal tracts of homothermic animals and are used to determine fecal contamination of water. This group of bacteria have been found to have an excellent positive correlation with fecal contamination of water from warm-blooded animals (Greenberg et al., 1992).

Increasing concentrations of N and P in surface runoff and ground water have resulted in concentrations in ground water exceeding the NO₃ and P standards (David and Gentry, 2000; Edwards et al., 2000; Sharpley et al., 2000; Waddell et al., 2000). Nitrogen in drinking water is a concern because concentrations in the range of 10 mg/L can contribute to methemoglobinemia in infants. More recently, it has been linked to non-Hodgkin’s lymphoma (Ward et al., 1996).

Increased N and P concentrations in water can alter the function and stability of many riparian and aquatic ecosystems. In the past few decades, intensive fertilization has contributed to the accumulation of these elements in many wetland and aquatic environments (Koch and Reddy, 1992; Lebo and Sharp, 1993; Vitousek et al., 1997; David and Gentry, 2000; Edwards et al., 2000; Sharpley et al., 2000). Changes in flora and fauna have been attributed to increased input of nutrients (Stevenson et al., 1993; Cooper and Brush, 1993; Koch and Reddy, 1992; Davis, 1991). Most wetland and aquatic ecosystems develop in conditions limited by N and P (Cooper and Brush, 1993; Koch and Reddy, 1992). Nutrients taken up by plants and microbes are made available by nutrient mineralization during the litter decomposition process (Cooper and Brush, 1993; Koch and Reddy, 1992). High concentrations of N in plants can shift allocation of carbon from defense compounds to sugars, lowering the plant defense to insect and disease attack (Entry et al., 1992; Waterman and Mole, 1989). Increased N and P in wetland ecosystems may also cause

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Abbreviations: FC, fecal coliform bacteria; TC, total coliform bacteria.
eutrophication, creating an abnormally high oxygen demand and often resulting in the death of many aquatic organisms (Cooper and Brush, 1993). High concentrations of N in soils are also known to influence soil microbial degradation patterns (Entry, 1999, 2000). High concentrations of N and P are known to be responsible for shifts in species composition in vegetation (Stevenson et al., 1993).

On the Snake River Plain near Hagerman, Idaho, formation of perched ground water systems coincided with a land use change from desert sagebrush to irrigated agriculture (Farmer, 1999; Vector, 1994). Perched water tables and associated ground water flow from basalt and sand aquifers is directly linked to irrigation of agricultural crops and leakage of water from irrigation canals (Farmer, 1999; Vector, 1994). The objective of this study was to determine the movement of TC, FC, N, and P in ground water flowing through basalt and sand aquifers.

MATERIALS AND METHODS

Geologic Setting

The study site lies in Hagerman Fossil Beds National Monument on the Snake River Plain in southern Idaho. The Hagerman Fossil Beds are fossil-bearing sediments that form the western wall of the Hagerman Valley. The bluff is part of the Bruneau Plateau with the Snake River located at the base (Fig. 1). The surface of the bluff has an average elevation of 1100 m, which is 100 m above the Snake River. The deeply incised canyons range from 800 to 1600 m in length with slope angles from 35 to 70 degrees. The Snake River Plain is a major volcanic feature in the northern portion of the Basin and Range geologic region (Bonnichsen and Breckenridge, 1982).

In the area of the sand aquifer, the Idaho Formation is composed of six layers containing three perched aquifers (Fig. 2). Layer 1 is the Tuana Gravel Formation composed of gravel, sand, and subordinate silt and clays. Paleo-stream channels have cut and filled into the Glenns Ferry Formation at 1203 m (Saddler, 1997). The Tuana Formation is underlain by the Glenns Ferry Formation (Layer 2), which overlies a basement volcanic feature in the northern portion of the basin (Farmer, 1999). Since 1970, the Bell Rapids Mutual Irrigation District has operated and maintained an irrigation system that pumps 5.5 x 10^6 L of water from the Snake River to irrigate 7695 ha on the plateau (Vector, 1994). Perched ground water began to discharge on the hillsides during the mid-1970s with slope failures occurring since 1979. Discharge from the basalt aquifer is calculated to be 5.1 x 10^7 L/yr and discharge from the sand aquifer is significantly less than the basalt aquifer and is calculated at 2.5 x 10^7 L/yr (Farmer, 1999). The basalt aquifer lies from 10 m below the soil surface at the northern end and dips at 1 to 3% to 85 m below the soil surface at the southern point, which is the outflow. The sand aquifer lies 50 m below the surface. Tracer studies with fluorescing dye showed that water from the surface percolates into the basalt aquifer in approximately 3 d, moves at an average rate of 30 m/d, and flows a distance of 5100 m. Therefore, irrigation water applied to the soil would flow from the basalt aquifer approximately 6 mo after application. In contrast, water from the surface percolates into the sand aquifer in approximately 90 d, moves at an average rate of 0.3 m/d, and flows a distance of 200 m. Therefore, irrigation water applied to the soil would flow from the basalt aquifer 21 mo after application.

Hydrology

The presence of perched ground water systems coincided with land use change from desert sagebrush to irrigated agriculture (Farmer, 1999). The climate has cool, moist winters and hot, dry summers with annual precipitation of 175 to 305 mm, two-thirds of which occurs during October through March. Average annual temperature ranges from 9 to 10°C. Soils are typically well-drained loams and silt loams derived from loess deposits overlying basalt (Collett, 1980). Vegetation throughout the general area was historically dominated by basin big sagebrush (Artemisia tridentata Nutt.) and perennial bunch grasses.

Experimental Design

The study was arranged in a complete random design consisting of ground water from aquifer type (basalt or sand), wells into aquifer types, irrigation canal water, and Snake River water. In March 1999, three plots were randomly established in each basalt and sand aquifer on the south side of the Snake River Canyon in the Hagerman Fossil Bed National Monument. Plots were spaced 40 to 90 m apart and were 30 m long (across the hillsides) by 10 m wide (downhill) (Fig. 1). Three 10-cm-diameter by 2.0-m-long PVC pipes were randomly set horizontally 1.0 m into the aquifers to reduce possible microbial contamination from wildlife in the area. Wells were located from 3 to 10 m apart in each plot. Water flowed freely from each pipe during all months of the year. In addition, one 20-cm-diameter well was drilled vertically into each aquifer from the top of the plateau. Monthly triplicate samples were taken from 1534 horizontal wells, vertical wells, the irrigation canal, and the Snake River during a 12-mo period (July 1999 through June 2000).
Fig. 1. Infrared air photo of Hagerman sampling area.

Fig. 2. Photographs and geological model of sand aquifer discharge zones.

Fig. 3. Photographs and geological model of basalt aquifer discharge zones.
Table 1. Total coliform bacteria in water from sand and basalt aquifers, wells into sand and basalt formations, the Snake River, and Bell Rapids Irrigation Canal.

<table>
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<tr>
<th>Treatment</th>
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<tbody>
<tr>
<td>Sand aquifer</td>
<td>26c‡</td>
<td>71b</td>
<td>1,598e</td>
<td>1,581f</td>
<td>1,598g</td>
<td>1,581f</td>
<td>1,598g</td>
<td>1,581f</td>
<td>1,598g</td>
<td>1,581f</td>
<td>1,598g</td>
<td>1,581f</td>
</tr>
<tr>
<td>Basalt aquifer</td>
<td>58c</td>
<td>22as</td>
<td>360d</td>
<td>1,033h</td>
<td>218b</td>
<td>1,59b</td>
<td>1,59b</td>
<td>1,59b</td>
<td>1,59b</td>
<td>1,59b</td>
<td>1,59b</td>
<td>1,59b</td>
</tr>
<tr>
<td>Sand well</td>
<td>39c</td>
<td>71b</td>
<td>21e</td>
<td>125d</td>
<td>7d</td>
<td>231b</td>
<td>2,285a</td>
<td>323b</td>
<td>8c</td>
<td>546b</td>
<td>433b</td>
<td>0d</td>
</tr>
<tr>
<td>Basalt well</td>
<td>46c</td>
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<td>9e</td>
<td>2e</td>
<td>0c</td>
<td>0d</td>
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<td>0d</td>
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<td>0d</td>
<td>0d</td>
<td>1d</td>
</tr>
<tr>
<td>Snake River</td>
<td>94b</td>
<td>197a</td>
<td>5,838d</td>
<td>4,525a</td>
<td>2,959g</td>
<td>717a</td>
<td>3,575a</td>
<td>1,392a</td>
<td>1,638a</td>
<td>2,620a</td>
<td>6,580a</td>
<td>6,750a</td>
</tr>
<tr>
<td>Irrigation canal</td>
<td>202a</td>
<td>152a</td>
<td>14,013a</td>
<td>5,037a</td>
<td>NW§</td>
<td>NW</td>
<td>NW</td>
<td>NW</td>
<td>NW</td>
<td>2,390a</td>
<td>5,375a</td>
<td>4,500a</td>
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</tbody>
</table>

† Water flowing from the basalt aquifer was applied to the soil approximately 7 d prior to outflow and collection while water flowing from the sand aquifer was applied to soil approximately 630 d prior to outflow and collection.
‡ In each column, values followed by the same letter are not significantly different as determined by the least square means test (p < 0.05), n = 54.
§ NS§ = not sampled.
¶ NW = no water in the irrigation canal.

Sample Collection

Samples were collected and analyzed for total and fecal coliform bacteria during the second week of each month. Water was collected into sterile 500-mL containers and transported at ambient temperature to the USDA Agricultural Research Service, Northwest Irrigation and Soils Research Laboratory in Kimberly, ID. Samples were stored at ambient temperatures and processed for microbial testing within 24 h of collection (Greenberg et al., 1992). Samples were collected and analyzed for total and fecal coliform bacteria, NO₃, NH₄, PO₄-P, and total P. Subsamples tested for nutrients were stored at 4°C prior to testing (Greenberg et al., 1992).

Coliform and Nutrient Analysis

Total coliform and fecal coliform bacteria were analyzed using the membrane filter technique (Greenberg et al., 1992). Preliminary water samples from test runs taken 1 to 3 d prior to each test were analyzed to determine each dilution before bacteria were counted. One milliliter of water was diluted in 99 mL of sterile distilled phosphate-buffered water (Greenberg et al., 1992). One hundred milliliters of final dilution of each sample was vacuum-filtered through a sterile 0.45-μm filter and placed on Em Endo medium (Difco Laboratories, Detroit, MI) to determine total coliform bacteria. Similarly, FC membranes were used to determine fecal coliform bacteria. Total coliform bacteria were incubated at 39.5 ± 0.02°C for 24 h. Fecal coliform bacteria were incubated at 44.5 ± 0.02°C for 24 h. Nitrate and ammonium were determined using a Lachat autoanalyzer (Lachat Quickchem Systems, Milwaukee, WI) using methods described by Keeney and Nelson (1982). Phosphate and total P were determined using methods described by Olsen and Sommers (1982).

Table 2. Fecal coliform bacteria in water from sand and basalt aquifers, wells into sand and basalt formations in the Snake River, and Bell Rapids Irrigation Canal.

<table>
<thead>
<tr>
<th>Treatment†</th>
<th>July</th>
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<tbody>
<tr>
<td>Sand aquifer</td>
<td>772b‡</td>
<td>329c</td>
<td>113a</td>
<td>1a</td>
<td>1a</td>
<td>0a</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
<td>0c</td>
<td>0b</td>
<td></td>
</tr>
<tr>
<td>Basalt aquifer</td>
<td>13d</td>
<td>3d</td>
<td>0d</td>
<td>1a</td>
<td>0a</td>
<td>0b</td>
<td>0a</td>
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<tr>
<td>Snake River</td>
<td>1812a</td>
<td>1225a</td>
<td>0d</td>
<td>1a</td>
<td>0b</td>
<td>0a</td>
<td>5a</td>
<td>3a</td>
<td>1a</td>
<td>9a</td>
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<td>Irrigation canal</td>
<td>3000a</td>
<td>888b</td>
<td>13b</td>
<td>1a</td>
<td>NW¶</td>
<td>NW</td>
<td>NW</td>
<td>NW</td>
<td>NW</td>
<td>9a</td>
<td>8a</td>
<td>2a</td>
</tr>
</tbody>
</table>

† Water flowing from the basalt aquifer was applied to the soil approximately 7 d prior to outflow and collection while water flowing from the sand aquifer was applied to soil approximately 630 d prior to outflow and collection.
‡ In each column, values followed by the same letter are not significantly different as determined by the least square means test (p < 0.05), n = 54.
§ NS§ = not sampled.
¶ NW = no water in the irrigation canal.

Statistical Analyses

All dependent variables were tested for normal distribution. Number of total and fecal coliform bacteria were transformed using logarithms to achieve normal distributions. Data were then analyzed using general linear model (GLM) procedures for a repeated measures design with Statistical Analysis Systems (SAS Institute, 1996). Statistical comparisons were made of total and fecal coliform bacteria, NH₄, NO₃, total P, and PO₄ in water by aquifer type (Snedecor and Cochran, 1980; Kirk, 1982). In all analyses, residuals were equally distributed with constant variances. Differences reported were significant at p < 0.05, as determined by the least squares means test. Total and fecal coliform bacteria are reported in untransformed numbers.

RESULTS

The number of TC and FC bacteria were always higher in Snake River and irrigation canal water than in ground water from either aquifer (Tables 1 and 2). Most months, the numbers of TC and FC bacteria did not differ between Snake River and irrigation canal water. The number of TC bacteria in ground water discharging from the basalt were higher than from the sand aquifer in August, October, November, December, March, April, and May, while TC numbers were higher in the sand aquifer in September and June. Numbers of TC bacteria in ground water flowing from the basalt and sand aquifer did not differ in July, January, and February. Numbers of FC bacteria were higher in ground water flowing from the basalt than from the sand aquifer.
Table 4. Ammonium concentrations in water from sand and basalt aquifers, wells into sand and basalt formations, the Snake River, and Bell Rapids Irrigation Canal.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>July</th>
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<tr>
<td>Sand aquifer</td>
<td>0.45a</td>
<td>0.45b</td>
<td>0.01b</td>
<td>0.03b</td>
<td>0.042b</td>
<td>0.03b</td>
<td>0.30a</td>
<td>0.03a</td>
<td>0.03a</td>
<td>0.03a</td>
<td>0.03a</td>
<td>0.03a</td>
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<tr>
<td>Basalt aquifer</td>
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<td>0.10b</td>
<td>0.01a</td>
<td>0.04a</td>
<td>0.03b</td>
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<td>0.03a</td>
<td>0.03a</td>
<td>0.03a</td>
<td>0.03a</td>
</tr>
<tr>
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<td>0.02c</td>
<td>0.06c</td>
<td>0.00c</td>
<td>0.00c</td>
<td>0.02b</td>
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<td>0.27a</td>
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<td>0.00b</td>
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<td>0.08a</td>
<td>0.00b</td>
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<td>NW</td>
<td>NW</td>
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<td>NW</td>
</tr>
<tr>
<td>Irrigation canal</td>
<td>0.003c</td>
<td>0.02c</td>
<td>0.02c</td>
<td>0.00c</td>
<td>NW</td>
<td>NW</td>
<td>NW</td>
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</tbody>
</table>

*Water flowing from the basalt aquifer was applied to the soil approximately 7 d prior to outflow and collection while water flowing from the sand aquifer was applied to soil approximately 630 d prior to outflow and collection.*

† In each column, values followed by the same letter are not significantly different as determined by the least square means test (p ≤ 0.05), n = 27.

§ NS = not sampled.

Table 3. Total nitrate concentrations in water from sand and basalt aquifers, wells into sand and basalt formations, the Snake River, and Bell Rapids Irrigation Canal.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>July</th>
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</thead>
<tbody>
<tr>
<td>Sand aquifer</td>
<td>7.0a†</td>
<td>6.9a</td>
<td>6.3a</td>
<td>6.8a</td>
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<td>7.1a</td>
<td>7.0a</td>
<td>6.9a</td>
<td>6.7a</td>
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<td>9.1a</td>
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<td>3.9b</td>
<td>NS§</td>
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<td>NS</td>
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<td>1.3c</td>
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<td>0.6c</td>
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<td>0.6c</td>
<td>0.93c</td>
<td>6.3b</td>
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</tbody>
</table>

† Water flowing from the basalt aquifer was applied to the soil approximately 7 d prior to outflow and collection while water flowing from the sand aquifer was applied to soil approximately 630 d prior to outflow and collection.

§ NS = not sampled.

Table 4. Ammonium concentrations in water from sand and basalt aquifers, wells into sand and basalt formations, the Snake River, and Bell Rapids Irrigation Canal.

<table>
<thead>
<tr>
<th>Treatment</th>
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<tbody>
<tr>
<td>Sand aquifer</td>
<td>0.45a</td>
<td>0.45b</td>
<td>0.01b</td>
<td>0.03b</td>
<td>0.042b</td>
<td>0.03b</td>
<td>0.30a</td>
<td>0.03a</td>
<td>0.03a</td>
<td>0.03a</td>
<td>0.03a</td>
<td>0.03a</td>
</tr>
<tr>
<td>Basalt aquifer</td>
<td>0.10a</td>
<td>0.10b</td>
<td>0.01a</td>
<td>0.04a</td>
<td>0.03b</td>
<td>0.03a</td>
<td>0.30a</td>
<td>0.03a</td>
<td>0.03a</td>
<td>0.03a</td>
<td>0.03a</td>
<td>0.03a</td>
</tr>
<tr>
<td>Sand well</td>
<td>0.02c</td>
<td>0.06c</td>
<td>0.00c</td>
<td>0.00c</td>
<td>0.02b</td>
<td>0.05a</td>
<td>0.27a</td>
<td>0.00b</td>
<td>0.00b</td>
<td>0.00b</td>
<td>0.00b</td>
<td>0.00b</td>
</tr>
<tr>
<td>Basalt well</td>
<td>0.005c</td>
<td>0.03c</td>
<td>0.00b</td>
<td>0.00c</td>
<td>0.05a</td>
<td>0.05a</td>
<td>0.015a</td>
<td>0.02b</td>
<td>0.04a</td>
<td>0.04a</td>
<td>0.01a</td>
<td>0.01b</td>
</tr>
<tr>
<td>Snake River</td>
<td>0.004c</td>
<td>0.15c</td>
<td>0.00c</td>
<td>0.00c</td>
<td>0.08a</td>
<td>0.00b</td>
<td>0.00b</td>
<td>NW</td>
<td>NW</td>
<td>NW</td>
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</tr>
<tr>
<td>Irrigation canal</td>
<td>0.003c</td>
<td>0.02c</td>
<td>0.02c</td>
<td>0.00c</td>
<td>NW</td>
<td>NW</td>
<td>NW</td>
<td>NW</td>
<td>NW</td>
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<td>NW</td>
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</tr>
</tbody>
</table>

† Water flowing from the basalt aquifer was applied to the soil approximately 7 d prior to outflow and collection while water flowing from the sand aquifer was applied to soil approximately 630 d prior to outflow and collection.

‡ In each column, values followed by the same letter are not significantly different as determined by the least square means test (p ≤ 0.05), n = 27.

§ NS = not sampled.

| Water flowing from the basalt aquifer was applied to the soil approximately 7 d prior to outflow and collection while water flowing from the sand aquifer was applied to soil approximately 630 d prior to outflow and collection.

| In each column, values followed by the same letter are not significantly different as determined by the least square means test (p ≤ 0.05), n = 27.

| NW = no water in the irrigation canal.

DISCUSSION

Fecal coliform bacteria are bacteria that originate from intestinal tracts of homothermic animals. Their presence indicates fecal contamination of water. Total and fecal coliform bacteria are sensitive and commonly used indicators of bacterial pathogen contamination of natural waters. Their presence implies the potential presence of microorganisms that are pathogenic to humans. Fecal coliform bacteria have a strong correlation with fecal contamination of water from warm-blooded animals. If 1 fecal coliform per 100 mL of water is detected, the water is considered unsafe to ingest (Greenberg et al., 1992; USEPA, 1998). We found one or more coliform bacteria per 100 mL water in more than 50% of the samples in water that flowed from sand and basalt aquifers, indicating that this ground water is not safe for human consumption.
The concentrations of TC and FC in ground water were generally, but not always, higher in the faster-flowing basalt aquifer than the sand aquifer, indicating that the slower flow in and finer grain size of the sand aquifer generally filter more TC and FC bacteria. Ground water flowing through the basalt aquifer flows through faults and fissures and does not contact as much rock or sediment surface area as water flowing through fine-grained sand. Water flowing through the basalt aquifer is moving in a matter of days while water is flowing through the sand aquifer is moving in a matter of 21 mo. Bacteria flowing through the basalt aquifer have drastically less time and opportunity to contact and adhere to sediment or rock. Fecal coliform bacteria were found in fewer ground water samples than river water samples, showing that the ground water is safer for human consumption than surface water.

Nitrate concentrations in water flowing from the sand aquifer and in the perched water table in the sand aquifer were usually higher than in water flowing from the basalt aquifer or perched water table in the basalt aquifer. Concentrations of NO$_3$–N ranged from a low of 4.1 mg NO$_3$–N/L in the basalt aquifer to a high of 9.1 mg NO$_3$–N/L in water from the sand well. The higher NO$_3$–N concentrations in the sand aquifer could mean that negatively charged NO$_3$–N was previously deposited in this aquifer, adhering to the positively charged sand grains, and then was flushed out during the sampling period. Water flowing from the basalt aquifer contained NO$_3$–N concentrations well below the 10 mg NO$_3$–N/L drinking water limit. Water flowing from the sand aquifer contained higher NO$_3$ concentrations and some samples approached 10 mg NO$_3$–N/L. Wells in this area should be monitored at regular intervals to determine if NO$_3$–N concentrations in ground water are increasing.

Input of N to the Snake River ecosystem may have important effects on eutrophication and ultimately fish survival and species composition as well function and stability of ecosystems. Nitrate concentrations in ground water in southern Idaho agricultural regions are often above background (Rupert, 1996; Rupert et al., 1996; Plummer et al., 2000). Nitrogen fertilizer applications as inorganic and animal manure in southern Idaho range from 8 to more than 20 Mg/km$^2$ and historically are among the highest in the United States (Battaglin and Goolsby, 1994; Wood and Low, 1988; Rupert, 1997). Phosphate concentrations were higher in water flowing from the basalt aquifer than the sand aquifer. The shoes-string basalt in Layer 3 contains high concentrations of hydroxyapatite [Ca$_5$(PO$_4$)$_3$(OH)] which is one of the minerals mined for phosphorus fertilizer. Total P and PO$_4$–P concentrations are not extremely high in water flowing from basalt or sand aquifers and should not alter concentrations in the Snake River system.

Agricultural operations need to be aware of the potential for the spread of disease-causing microorganisms to farm workers when handling and applying solid and liquid waste. Diseases associated with enteric bacteria range from bacteria that cause mild to life-threatening
gastroenteritis, hepatitis, skin infections, wound infections, conjunctivitis, respiratory infections, and generalized infections (Moe, 1997). We suggest a more intense sampling of ground water in areas where recharge is a result of irrigated agriculture.

REFERENCES


