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# Use of Tracers and Isotopes to Evaluate Vulnerability of Water in Domestic Wells to Septic Waste

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Ground Water Monitoring&Remediation

# Use of Tracers and Isotopes to Evaluate Vulnerability of Water in Domestic Wells to Septic Waste

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## Abstract

In Nebraska, a large number (>200) of shallow sand-point and cased wells completed in coarse alluvial sediments along rivers and lakes still are used to obtain drinking water for human consumption, even though construction of sand-point wells for consumptive uses has been banned since 1987. The quality of water from shallow domestic wells potentially vulnerable to seepage from septic systems was evaluated by analyzing for the presence of tracers and multiple isotopes. Samples were collected from 26 sand-point and perforated, cased domestic wells and were analyzed for bacteria, coliphages, nitrogen species, nitrogen and boron isotopes, dissolved organic carbon (DOC), prescription and nonprescription drugs, or organic waste water contaminants. At least 13 of the 26 domestic well samples showed some evidence of septic system effects based on the results of several tracers including DOC, coliphages, $NH_4^+$, $NO_3^-$, $N_2$, $\delta^{15}N[NO_3^-]$ and boron isotopes, and antibiotics and other drugs. Sand-point wells within 30 m of a septic system and <14 m deep in a shallow, thin aquifer had the most tracers detected and the highest values, indicating the greatest vulnerability to contamination from septic waste.


## Introduction

More than 100 million people in the United States use ground water as their source of drinking water (Tuthill et al. 1998), and about one-third of rural households including waterfront population (25–30% of the households) use septic systems for waste water disposal (McAvoy et al. 1994; Robertson et al. 1991; U.S. EPA 2000). An estimated trillion liters of sewage from septic systems is released to the subsurface annually (Scandura and Sobsey 1997). This sewage can be a health risk because contaminants from sepic systems may enter the ground water that is used as a drinking water source. Disease outbreaks have been associated with ground water (Moore et al. 1994) contaminated with septic waste and viruses (Scandura and Sobsey 1997). With the increase in urban sprawl, which leads to greater septic system use and high costs of centralized waste water treatment, the problem could intensify in the future (Nizeyimana et al. 1996).

Septic tanks serve primarily as settling chambers, removing solids from the sewage. Contaminants of concern include microorganisms, nutrients, metals, and inorganic and organic chemicals, including endocrine-disrupting compounds such as pharmaceuticals (Roefer et al. 2000; Shore et al. 1993; Kolpin et al. 2002; Verstraeten et al. 2003). Contaminants seeping from septic systems can enter the ground water especially when the water table is shallow and the unsaturated and saturated zones consist mainly of sand and gravel (Robertson et al. 1991; Scandura and Sobsey 1997). Aquifers with these characteristics also typically have high porosity and high hydraulic conductivity, resulting in large infiltration rates and low dispersion in the horizontal plane that may potentially contribute to concentrated plumes from septic systems (Wilhelm et al. 1996) in the shallow part of the aquifer. In addition, if shallow wells are in a flood-prone alluvial setting, contaminants from septic fields and surface water can be transported into the wells with floodwater. Robertson et al. (1991) suggested that current minimum distance-to-well regulations for septic system permits would not adequately protect well water quality in unconfined sandy aquifers with large longitudinal dispersivity. Mobile contaminants such as nitrates, which are sometimes not attenuated by chemical and microbiological processes, are of greatest concern. The potential presence of toxic mobile and persistent compounds in septic systems such as volatile organic compounds and pharmaceuticals from septic systems presents additional concerns (Robertson et al. 1991; Verstraeten et al. 2003). Lowe and Wallace (1999) used a mass-balance approach for nitrogen and determined that lot sizes with adequate minimum septic-to-well distances could vary from as small as 3 acres (clayey and silty aquifer) to as much as 53 acres (sandy aquifer) depending on the aquifer.

In Nebraska, a large number (>200) of shallow sand-point and cased wells completed in coarse alluvial sediments along rivers and lakes still are used to obtain drinking water for human consumption, even though construction of sand-point wells for consumptive uses has been banned since 1987 (Title 178 Department of Health and Human Services Regulation and Licensure Chapter 12, Section 004.01). Nebraska regulations since 1977 (Nebraska Department of Environmental Control 1977) also require a minimum setback distance from domestic wells of 15 m for septic tanks and 31 m for absorption fields. At times water from shallow domestic wells within 5 m of septic systems is used for drinking water. Gosselin et al. (1997) evaluated the presence of nitrates, pesticides, and coliform bacteria in domestic wells in Nebraska. The study indicated that nitrate concentrations (as nitrogen) in water from domestic wells exceeded 10 mg/L, the U.S. EPA maximum contaminant level (MCL), in 39% of the samples. Coliform bacteria were detected in 26% of the samples.

Barrett et al. (1999) identified the need for using multiple tracers to identify contamination by septic waste and its effects on drinking water. Indicators of septic waste impacts include bacteria; coliphages; other viruses; pH; dissolved organic carbon (DOC) ($CH_2O$); ammonium ($NH_4^+$); organic nitrogen; nitrate as nitrogen ($NO_3^-$); isotopes of oxygen ($\delta^{18}O$), carbon ($\delta^{13}C$), nitrogen ($\delta^{15}N$), and sulfur ($\delta^{34}S$); phosphate ($PO_4^{3-}$); chloride (Cl); boron (B); boron isotopes ($\delta^{10}B$ and $\delta^{11}B$); and household chemicals and antibiotics (Aravena and Robertson 1998; Barth 1998; Curry 1999; Francy et al. 2000; Grischek et al. 1994; Harman et al. 1996; Montana HeadWaters Inc. 1998, 1999; Robertson and Blowes 1995; Seiler et al. 1999; Tuthill et al. 1998; Vengosh et al. 1994).

This paper presents the results of a study conducted from 2001 to 2003 by the USGS in cooperation with the Lower Platte River Corridor Alliance with support from the Lower Platte South, Lower Platte North, and Papio-Missouri River Natural Resources Districts (NRDs). The hypotheses were that (1) bacteria and nitrate concentrations are conservative tracers that can indicate contamination of drinking water obtained from domestic wells and (2) multiple tracers are required to assess whether water from domestic wells is impacted by septic systems. The quality of drinking water from shallow domestic wells vulnerable to seepage from septic systems was evaluated through the use of tracers and isotopes.

## Setting

The study area, defined as the 100-year floodplain plus a 1.5-km buffer at both sides of the Platte River, is an area of ~2600 $km^2$ in eastern Nebraska from near Columbus to the Platte River's confluence with the Missouri River (Figure 1). The drainage area of the Platte River in Nebraska is 106,000 $km^2$, with a mean annual flow of ~200 $m^3/s$ at Plattsmouth (Verstraeten et al. 1999a). The river generally is a gaining river except for a small area upgradient. It becomes a losing river near the large wellfields of the cities of Lincoln and Omaha because of induced infiltration (Verstraeten et al. 1999b). The Platte River typically contains concentrations of $NO_3^-$ <2 mg/L (Verstraeten et al. 1998).

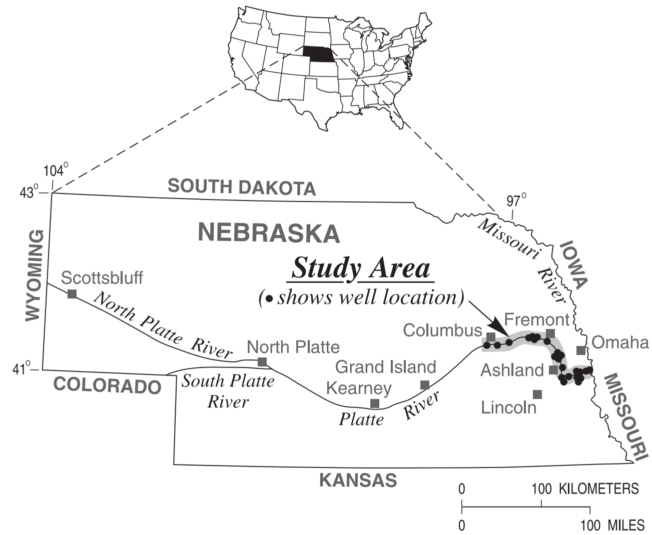


**Figure 1. Study area with generalized locations of wells.**

In the study area, depth to the water table generally is <3 m. Wells generally are completed at depths of <30 m in alluvial material consisting of sand and gravel that contains some silt and clay. Occasionally, during spring melt and after heavy spring rainfall, flooding occurs along the river. The surface water sometimes contains elevated concentrations of nutrients and pesticides, especially during spring runoff events (Verstraeten et al. 1999b). Ground water at times contains concentrations of $NO_3^-$ in excess of 10 mg/L and detectable concentrations of herbicides in some parts of the study area (Verstraeten et al. 1999b).

About 53% of the residents of the study area have domestic wells (Burns and McDonnell Inc. 1999). Thirty-four percent of the wells in eight counties in the study area are sand-point wells, and 61% of the households have their own septic systems (Burns and McDonnell Inc. 1999; Leslie Associates Inc. 1998). In many instances, the septic systems and domestic wells were constructed before the setback distances became subject to regulation. Domestic wells are in developments at sandpit lakes, small towns where all residences have their own water supply, or at farmsteads near cornfields or small (<50 cattle), unconfined animal-feeding operations. Population in the counties in the study area is projected to increase by 10% to as much as 18.4% within 10 years (Bureau of Business Research 1999).

## Methods

All the wells sampled were domestic wells currently or formerly used for drinking water supply. Samples were collected from seven shallow sand-point wells for a preliminary assessment. An additional 19 well sites were selected in the study area that met the following criteria: (1) sand-point or cased wells; (2) wells completed in the Platte River alluvium; (3) wells <30 m deep; and (4) wells within 80 m of a septic tank. Samples were collected from May to October 2001. The well locations were representative of the geologic (completed in a shallow, unconfined alluvial aquifer consisting mainly of sand and silt) and the anthropogenic (surrounded by cornfields, surrounding sandpit lakes, or on the banks of the Platte River) conditions in the study area. Five of the 26 wells were resampled 3 months after initial sample collection because of low dissolved oxygen (D.O.) concentrations, detection of coliphages, or relatively high ammonium or $NO_3^-$ concentrations. Samples were collected from domestic wells before drinking water treatment (e.g., filtration, ion exchange, chlorination) but after (1) the water tank, if present, was emptied; (2) at least three well volumes of water were removed; and (3) field measurements had stabilized within acceptable levels: specific conductance within 5%, pH within 0.1 standard unit, D.O. 0.05 mg/L, and water temperature within 0.2°C.

Samples collected from the initial seven wells were analyzed for total coliform bacteria, $NO_3^-$ reported as N, 60 prescription and nonprescription drugs, and 67 human (waste water related) compounds. Samples collected from the additional 19 wells were analyzed for fecal coliform bacteria, *Escherichia coli*, male-specific and somatic coliphages, DOC, $NO_3^-$ and other nutrients including ammonia, and 26 antibiotics and 60 other prescription and nonprescription drugs in response to the results obtained from the first seven wells (Table 1). A subset of 5 of the 26 samples—four samples containing concentrations of $NO_3^-$ exceeding 10 mg/L and one sample with a low D.O. concentration (0.13 mg/L) and a $NO_3^-$ concentration less than the detection level of 0.05 mg/L—were analyzed for dissolved gases (four samples), other nutrients (five samples), nitrogen isotopes (five samples), boron (five samples), or boron isotopes (five samples) to confirm with additional tracers whether the drinking water has been affected by septic waste and to evaluate whether denitrification might be occurring (Table 1). Two field duplicates and two equipment blanks also were collected. Results of analysis of quality-assurance samples indicated that no contamination occurred during sample collection, and reproducible results (within 5%) were obtained. However, in one duplicate sample obtained from a sand-point well, two nonprescription drugs, ibuprofen and caffeine, were not confirmed.

## Results and Discussion

Data from analyses of microorganisms, inorganic constituents, organic carbon, nitrogen and boron isotopes, and organic compounds such as antibiotics and other prescription and nonprescription drugs were evaluated for use as indicators of vulnerability to septic waste. Data from the 67 waste water–related compounds were inconclusive as indicators because of low concentrations. The evaluation presented herein relates to the geologic and the anthropogenic conditions for the alluvial aquifer adjacent to the

**Table 1**
**Analytical Methods and Sample Size**

| Analytes | Laboratory | Reporting Limit | Number of Samples | Reference |
|---|---|---|---|---|
| Microorganisms | | | | |
| Total coliform bacteria (100 mL) | NDOH | Absence/presence | 7 | Brenner et al. 1993; Clesceri et al. 1998 |
| *E. coli* bacteria (100 mL) | NDOH | Absence/presence | 7 | Brenner et al. 1993; Clesceri et al. 1998 |
| Fecal coliform bacteria (100 mL) | NDOH | Enumeration | 19 | Clesceri et al. 1998 |
| Somatic and male-specific coliphages; U.S. EPA methods 1601 and 1602 (1 L) | Analytical Services Inc. | Absence/presence | 21 | U.S. EPA2001 |
| Inorganic constituents, organic carbon, and isotopes | | | | |
| DOC | USGS NWQL | 0.2 mg/L | 19 | Fishman and Friedman 1989 |
| Nitrate | USGS NWQL | 0.05 mg/L | 26 | Fishman and Friedman 1989 |
| Other nutrients including ammonia | USGS NWQL | 0.006–0.05 mg/L | 19 | Fishman and Friedman 1989 |
| Dissolved gases | USGS Dissolved Gas Laboratory | 0.005–0.005 mg/L | 4 | http://water.usgs.gov/lab/dissolved-gas |
| N isotopes of nitrate | USGS N isotope Laboratory | 0.1 $\delta^{15}N\text{-}NO_3^-$ | 5 | Böhlke and Denver 1995; Böhlke and Coplen 1995 |
| Boron | USGS Menlo Park | 1 μg/L | 5 | Fishman and Friedman 1989 |
| Boron isotopes | USGS Menlo Park | 0.2‰ | 5 | Vengosh et al. 1994 |
| Organic compounds | | | | |
| Selected antibiotics | USGS Lawrence, Kansas | 0.01–2.0 μg/L | 26 | Kolpin et al. 2002 |
| Selected prescription and nonprescription drugs | USGS NWQL | 0.03–0.15 μg/L | 24 | Kolpin et al. 2002 |
| Human (waste water–related compounds) indicators | USGS NWQL | 0.05–5.0 μg/L | 7 | Zaugg et al. 2002 |

NDOH, Nebraska Department of Health; NWQL, National Water Quality Laboratory.

Platte River in eastern Nebraska, and the successful use of the tracers and isotopes will be dependent upon the local conditions.

## Microorganisms

Total coliform bacteria, fecal coliform bacteria, *E. coli*, and coliphages can be indicators of septic waste contamination of drinking water. In this study, bacteria were not detected in any of the domestic well samples, indicating that there may have been sufficient residence time to allow for die-off, as was observed by Whitehead and Geary (2000). Indicator viruses (male-specific coliphages) were detected in 2 of the 19 ground water samples from sand-point wells drilled within 25 m of a septic field, with depths of 8 and 12 m.

Bacterial adsorption in the subsurface may have occurred because of the presence of cations, particularly iron, ammonium from crop fertilization or septic waste (Gerba and Bitton 1984), or clogging. *E. coli* is considered to be an indicator of fecal contamination (U.S. EPA 2000; Shadford et al. 1997). Somatic and F-specific coliphages have been used as indicators of survival and transport of viruses (Deborde et al. 1998; Francy et al. 2000). Total coliform bacteria also appeared to be a good indicator for septic contamination, according to Francy et al. (2000). Scandura and Sobsey (1997) showed that, in sandy aquifers with a shallow water table and pH >7, ground water can be contaminated with viruses from septic systems especially during the winter months. In the current study, the aquifer is sandy, the pH is generally >7, and viruses were detected more frequently than bacteria. The detection of male-specific coliphages suggests the presence of fecal contamination in water from at least 2 of the 21 domestic wells and potentially short transport times from the drainage field to the screens of the wells. Whether the contamination derives from the surface water body nearby, surface applications of manure, domestic septic waste, or a combination of sources remains unresolved on the basis of evidence from microorganisms. Detection of male-specific coliphages may indicate that these viruses can be transported in the aquifer's media because of their small size and negative charge.

### Inorganic Constituents, Organic Carbon, and Isotopes

Nitrogen species and their isotopes, organic carbon, dissolved gases, and boron and its isotopes can be used to identify whether septic waste has affected the source of drinking water and whether denitrification plays a role in the presence of low $NO_3^-$ concentrations. Nitrogen species cannot be considered as conservative tracers because they are actively mediated biologically through nitrification and denitrification reactions during infiltration and movement within the aquifer (Leenhouts et al. 1998). Nevertheless, $NH_4^+$ can sometimes be a distinctive indicator of sewage. However, other sources such as fertilizer and animal wastes also could contribute to $NH_4^+$ concentrations.

Water from 4 of the 26 wells exceeded the EPA MCL of 10 mg/L of $NO_3^-$ as N (U.S. EPA 2000). $NO_3^-$ as N concentrations ranged from <0.05 to 38.7 mg/L (Table 2). $NH_4^+$ as N concentrations ranged from <0.04 to 1.39 mg/L (Table 2).

The presence of $NH_4^+$ appears to be dependent upon well construction type, well depth, and distance to septic field (Figure 2). Sand-point wells of <8 m deep and at a distance of <15 m from the septic field appeared to contain relatively larger concentrations of $NH_4^+$ than cased wells of >8 m deep and at a distance of >30 m from a septic field. Similarly, DOC concentrations appear to be greater in sand-point wells and wells at a distance of <15 m from the septic field than in other wells. Wells closest to septic fields had greater concentrations of $NH_4^+$ and DOC (Figure 3) than those farther away. In general, $NH_4^+$ and DOC decreased with distance from the septic field. Under aerobic conditions (Equation 1), $NH_4^+$ is oxidized easily to $NO_3^-$ within a few hours to a few days and within distances of a few tens of centimeters (Barrett et al. 1999; Leenhouts et al. 1998; Robertson and Blowes 1995; Wilhelm et al. 1994).

$$NH_4^- + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O \quad (1)$$

Similarly, organic carbon will be transformed in an aerobic setting (Equation 2).

$$CH_2O + O_2 \rightarrow CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \quad (2)$$

Equations 1 and 2 illustrate reactions that decrease the pH of ground water (Robertson and Blowes 1995), which may be reflected in association with low pH and high $NO_3^-$ in samples collected from wells between 16 and 29 m away from septic drainage fields.

In cases where vadose zone residence time is relatively short (hours or <1 week), the oxidation process may remain incomplete. Short residence times may result in greater $NH_4^+$, lower $NO_3^-$, greater DOC (above background concentrations from other sources), and lower D.O. concentrations than when residency in the unsaturated zone is relatively long (>7 days) (Robertson et al. 1991). Short residence times may occur at some locations (such as short distances between septic field and domestic well and a shallow water table) sampled during this project. Under anaerobic conditions, denitrification can occur and $NO_3^-$ is transformed to $N_2$ gas (Equation 3).

$$5CH_2O + 4NO_3^- + 4H^+ \rightarrow 2N_2 + 5CO_2 + 7H_2O \quad (3)$$

Anaerobic conditions can develop if substantial amounts of labile organic carbon, possibly derived from septic waste, are present in the aquifer media. Wilhelm et al. (1996) reported that denitrification occurred over distances <2 m and decreased $NO_3^-$ concentrations from 40 to <0.05 mg/L near a river in Ontario, Canada.

Analyses of dissolved gases from four domestic wells in the study area confirmed that denitrification could be a process in the local aquifer causing $NO_3^-$ to be depleted and $N_2$ gas to be produced. For example, water from a 12-m-deep sand-point well located 21 m from a septic field appeared completely denitrified, with <0.05 mg/L $NO_3^-$, 0.13 mg/L D.O., 11.7 mg/L $N_2$ gas in excess of values in equilibration with the atmosphere, and 1.4 mg/L $CH_4$. Other ground water (two wells completed at <10-m depth

**Table 2**
**Statistics for Selected Constituents**

| Constituent | Method Reporting Level | Number of Samples | Minimum | Mean | Median | Maximum |
|---|---|---|---|---|---|---|
| All wells | | | | | | |
| Well depth (m) | —[a] | 26 | 5.0 | 10 | 8.5 | 30 |
| Distance of well to laterals of septic field (m) | —[a] | 26 | 8.0 | 26 | 20 | 76 |
| D.O. | 0.05 | 25 | 0.06 | 1.12 | 0.17 | 12.0 |
| pH (standard units) | 0.10 | 26 | 6.3 | 7.2 | 7.2 | 7.8 |
| Specific conductance (μS/cm at 25°C) | | 26 | 285 | 548 | 572 | 709 |
| DOC | 0.20 | 14 | 0.5 | 2.8 | 3.1 | 4.3 |
| Ammonia as nitrogen (mg/L) | 0.04 | 19 | <0.04 | 0.40 | 0.17 | 1.39 |
| Nitrate as nitrogen (mg/L) | 0.05 | 26 | <0.05 | 4.39 | <0.05 | 38.7 |
| Nitrite as nitrogen (mg/L) | 0.006 | 19 | <0.006 | 0.004 | <0.006 | 0.09 |
| Boron (μg/L) | 0.02 | 5 | 38 | —[a] | —[a] | 193 |
| Boron isotopes (‰) | 0.2 | 5 | −0.2 | —[a] | —[a] | +14.5 |
| Statistics by well type | | | | | | |
| Cased wells | | | | | | |
| Organic carbon | 0.2 | 8 | 0.8 | 2.6 | 2.6 | 4.2 |
| Nitrate ($N0_3^-$) | 0.05 | 12 | <0.05 | 4.77 | <0.05 | 38.7 |
| Ammonia ($NH_4^+$) | 0.04 | 10 | <0.04 | 0.22 | 0.04 | 0.93 |
| Sand-point wells | | | | | | |
| Organic carbon | 0.2 | 6 | 0.54 | 3.1 | 3.4 | 4.3 |
| Nitrate | 0.05 | 14 | <0.05 | 4.06 | <0.05 | 30.2 |
| Ammonia | 0.04 | 10 | <0.04 | 0.60 | 0.43 | 1.39 |
| Statistics by well depth | | | | | | |
| <8 m | | | | | | |
| Organic carbon | 0.2 | 3 | 2.4 | 3.0 | 3.1 | 3.6 |
| Nitrate | 0.05 | 7 | <0.05 | 2.42 | <0.05 | 17.0 |
| Ammonia | 0.04 | 4 | 0.33 | 0.63 | 0.41 | 1.39 |
| 8–14 m | | | | | | |
| Organic carbon | 0.2 | 8 | 0.54 | 3.2 | 3.5 | 4.3 |
| Nitrate | 0.05 | 15 | <0.05 | 3.35 | <0.05 | 30.2 |
| Ammonia | 0.04 | 12 | <0.04 | 0.41 | 0.14 | 1.23 |
| ≥15 m | | | | | | |
| Organic carbon | 0.2 | 3 | 0.77 | 1.7 | 1.7 | 2.7 |
| Nitrate | 0.05 | 4 | <0.05 | 11.7 | 4.12 | 38.7 |
| Ammonia | 0.04 | 3 | <0.04 | NA | <0.04 | 0.07 |
| Statistics by distance of well to laterals of septic field | | | | | | |
| ≤15 m | | | | | | |
| Organic carbon | 0.2 | 5 | 3.1 | 3.7 | 3.6 | 4.3 |
| Nitrate | 0.05 | 9 | <0.05 | 0.02 | <0.05 | 0.09 |
| Ammonia | 0.04 | 6 | 0.17 | 0.71 | 0.58 | 1.39 |
| 16–29 m | | | | | | |
| Organic carbon | 0.2 | 3 | 0.5 | 2.2 | 2.4 | 3.8 |
| Nitrate | 0.05 | 6 | <0.05 | 10.4 | 7.51 | 30.2 |
| Ammonia | 0.04 | 4 | <0.04 | 0.24 | 0.16 | 0.63 |
| ≥30 m | | | | | | |
| Organic carbon | 0.2 | 6 | 0.77 | 2.4 | 2.4 | 4.0 |
| Nitrate | 0.05 | 11 | <0.05 | 4.71 | <0.05 | 38.7 |
| Ammonia | 0.04 | 9 | <0.04 | 0.26 | <0.04 | 1.23 |

All measurements are in milligrams per liter unless otherwise shown.
[a]Not calculated.

at a distance of <13 m from a septic waste field) appeared suboxic, with <1.0 mg/L D.O., $NO_3^-$ and $N_2$ gas present, and methane absent. The generally low (<1.00 mg/L) concentrations of D.O. in water from 20 of the 26 domestic wells (Table 2) indicate reduced conditions that may permit denitrification; therefore, denitrification may be affecting $NO_3^-$ in water from the zone of influence of the domestic wells. Temporal changes in the biogeochemistry

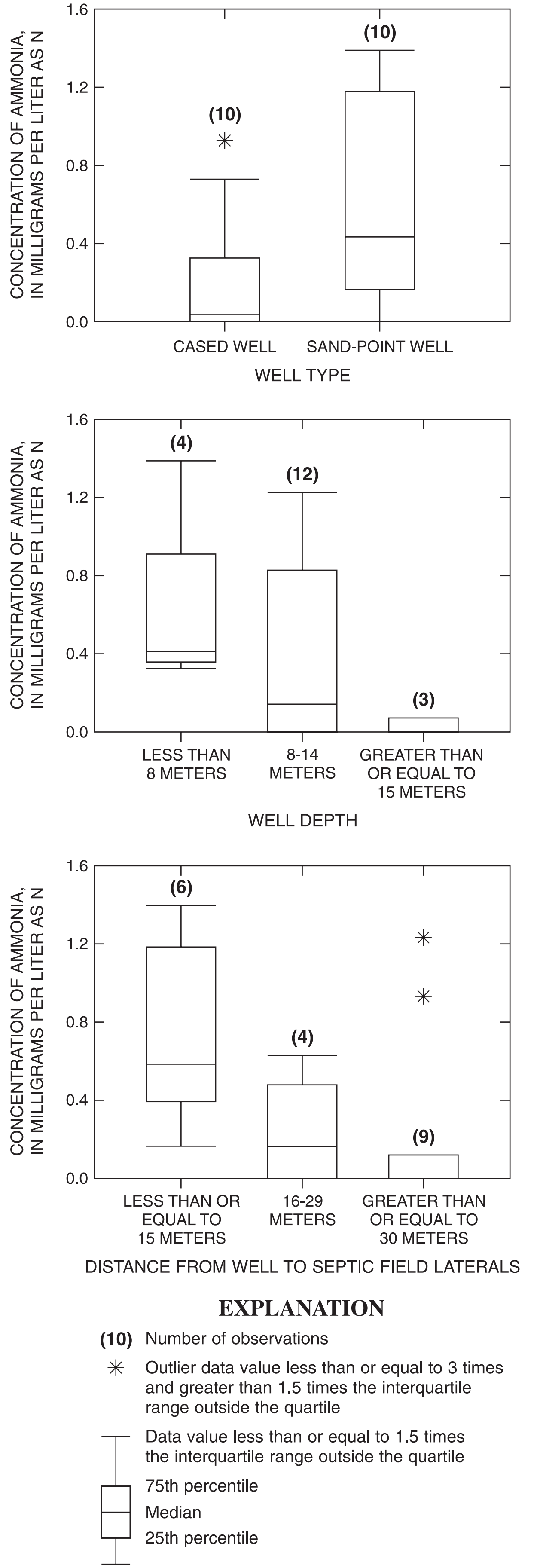


**Figure 2. Ammonia by well construction type, well depth, and distance from septic field laterals.**

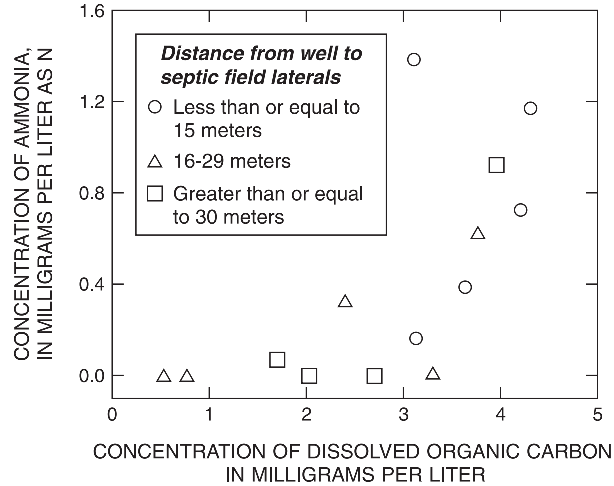


**Figure 3. Relation of ammonia and DOC.**

of the aquifer were indicated in water from a cased well 23 m deep and 46 m from a septic field because nitrate concentrations varied from 39 mg/L collected in September 2001 to 0.08 mg/L collected in December 2001.

Nitrogen isotopes tend to be less conservative than boron isotopes in the study area because nitrogen generally will be in its reduced $NH_4^+$ form when released from a septic system—other sources of $NH_4^+$ are thought to be insignificant based on field observations and interviews with well or land owners. Given the right conditions, $NH_4^+$ easily changes to $NH_3$, which volatilizes and causes a preferential loss of the lighter isotope (resulting in more positive values of $\delta^{15}N$ of $NH_3$) (Leenhouts et al. 1998). During denitrification, $\delta^{15}N[NO_3^-]$ values increase (Aravena and Robertson 1998; Komor and Anderson 1993) as well. Nevertheless, detections of $\delta^{15}N[NO_3^-]$ in conjunction with other tracers can be used to differentiate the sources of nitrogen from soil (0‰ to +4‰) or fertilizer (−2‰ to +4‰), animals (+8‰ to +20‰), and septic tanks (+2‰ to +12‰) (Fogg et al. 1998). Fogg et al. (1998) also determined that it could be difficult to distinguish a geologic N (+3‰ to +9‰) source from septic tank or commercial fertilizer sources using $\delta^{15}N[NO_3^-]$. The low $\delta^{15}N[NO_3^-]$ value (+3.2‰) of water from one domestic well in the study area may indicate influences of fertilizer, soil, or, potentially, septic tanks. Based on the local land use (corn) and distance from the septic field (18 m), fertilizer use may be the primary source of nitrogen (33.6 mg/L $NO_3^-$) in samples from this well. The greater $\delta^{15}N[NO_3^-]$ values of water from two wells (12.26‰ and 7.93‰) could indicate that the water is affected by septic waste. However, these values probably were affected by denitrification because of suboxic conditions at both sites (see discussion of dissolved gases) and therefore are inconclusive in the absence of confirmation of septic contamination by other tracers. The results of the study indicate that nitrogen species did not behave conservatively as tracers of septic waste because of biogeochemical processes present in the aquifer media. It appears that (1) water collected from domestic wells <15 m from a septic system had large concentrations of $NH_4^+$; (2) water from domestic wells 16–29 m from the septic system had lower concentrations of $NH_4^+$ and larger concentrations of $NO_3^-$; and (3) water from domestic wells >30 m from a septic field (or system) had low D.O., low $NH_4^+$, and low $NO_3^-$ (Figure 4), potentially caused by processes such as denitrification and dilution.

On the other hand, the boron data confirm that boron concentrations and boron isotopes could be good indicators of sewage because they are major constituents of detergents (sodium perborate) (Vengosh et al. 1994) and because boron isotopes tend to be a relatively conservative tracer in a hydrogeologic setting with low clay content and neutral pH (Ford and Tellam 1994; Leenhouts et al. 1998). In the study area, the soils are sandy and have low clay content.

Boron concentrations in five water samples from the study area ranged from 38 to 193 μg/L. Boron isotope values varied from −0.2‰ to +14.5‰. Typically, water affected by waste water tends to have a boron isotopic signature of +5‰ or less (Vengosh et al. 1994). Nonmarine borate minerals, which are used to make the perborate additive to detergents, ranged from ~0‰ to +10‰. Boron isotope data collected in February 2002 from drinking water of the city of Lincoln showed a value of +14‰. Water from the wellfield supplying Lincoln's drinking water indirectly receives water from the Platte River through induced infiltration. Two of the five ground water samples suspected to be influenced by septic waste on the basis of nitrogen concentrations, nitrogen isotopes, organic carbon concentrations, general hydrogeologic setting, and well construction had boron values of −0.2‰ and 0.7‰, consistent with waste water effects. The other three samples containing large nitrogen concentrations or detections of coliphages are thought to be contaminated with local fertilizer applications to corn cropland, by a nearby small feedlot, barns, and roaming cattle, or with fertilizer applied to the lawn.

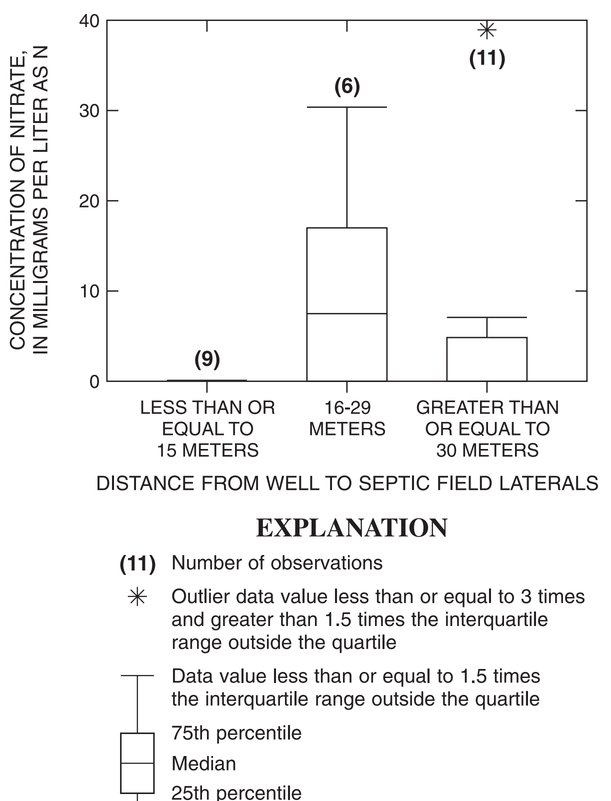


**Figure 4. Relation of nitrate concentrations to distance from septic field laterals.**

### Organic Compounds

The samples collected from the initial seven wells were analyzed for prescription and nonprescription pharmaceuticals, antibiotics, and a variety of household and industrial organic compounds using three analytical methods described in Kolpin et al. (2002). Because none of the household and industrial compounds were detected in these samples, they were not analyzed in the subsequently collected samples.

Antibiotics were detected in water from three sand-point wells (Table 3). These wells are in developments at sandpit lakes or small towns where all residences have their own water supply, and septic systems are far from animal-feeding operations. Trace concentrations (0.05 μg/L) of three fluoroquinolones—ciprofloxacin, enrofloxacin, and sarafloxacin—were detected in a sample from a sand-point well, 6 m deep, at a distance of 30 m from a septic system, with 0.17 mg/L D.O. and <0.05 mg/L $NO_3^-$. One of the seven sulfonamides—0.15 μg/L sulfamethoxazole—was detected in a sample from a sand-point well, 2 m deep, at a distance of 18 m from a septic system, with 0.08 mg/L D.O. and 17 mg/L $NO_3^-$. Trimethoprim and erythromycin-$H_2O$, a metabolite of one of the five macrolides, were detected at concentrations of 0.58 and 0.75 μg/L, respectively, in a sand-point well, 6 m deep, at a distance of ~8 m from a septic system, with 0.11 mg/L D.O. and <0.05 mg/L $NO_3^-$.

Caffeine and other prescription and nonprescription drugs also can be indicators of waste water contamination in water from wells (Seiler et al. 1999). Eight nonprescription or prescription drugs (Table 3) were detected in water from 12 of the 19 domestic wells at concentrations as much as 0.129 μg/L. Although recent studies have shown that a variety of pharmaceutical compounds can be transported into our nation's water resources (e.g., Kolpin et al. 2002), whether these compounds individually or as mixtures have deleterious effects on water quality is not known. In addition, little has been published on the fate and transport of pharmaceuticals in the unsaturated and saturated zones (Drewes et al. 2003; Heberer and Verstraeten in press). Organic compounds can be biodegraded in the subsurface, especially in an aerobic medium, leading to a wide variety of degradates (Drewes et al. 2003; McAvoy et al. 1994; Robertson 1994; Vengosh et al. 1994; Verstraeten et al. 2002a, 2002b, 2003). On the other hand, anaerobic or suboxic conditions, which can exist near septic fields, could prevent or slow down the degradation of organic compounds in ground water. Organic compounds also can be adsorbed to aquifer media. Because people use differing amounts and types of pharmaceuticals, the concentrations of these products or compounds cannot be used as indicators of intensity of contamination in this study.

**Table 3**
**Summary of Detections and Concentrations of Selected Coliphage, Prescription, and Nonprescription Drugs Including Antibiotics, by Well Type.**

| Type of Compound/ Organism | Use | Method Reporting Level (μg/L) | Number of Samples Analyzed | Number of Detects | Detection by Well Type (n/z) | | Maximum Concentration (μg/L) |
|---|---|---|---|---|---|---|---|
| | | | | | Sand-point well | Cased well | |
| Coliphage | Microorganism | NA | 19 | 2 | 2/8 | 0/11 | NA |
| Ciprofloxacin | Antibiotic | 0.020 | 24 | 1 | 1/14 | 0/10 | Trace |
| Enrofloxacin | Antibiotic | 0.020 | 24 | 1 | 1/14 | 0/10 | Trace |
| Sarafloxacin | Antibiotic | 0.020 | 24 | 1 | 1/14 | 0/10 | Trace |
| Sulfamethoxazole | Antibiotic | 0.023 | 25 | 2 | 2/14 | 0/11 | 0.15[a] |
| Trimethoprim | Antibiotic | 0.030 | 24 | 2 | 2/14 | 0/10 | 0.58 |
| Erythromycin-$H_2O$ | Antibiotic metabolite | 0.050 | 22 | 1 | 1/13 | 0/9 | 0.75 |
| Caffeine | Medical, diuretic | 0.014 | 19 | 9 | 4/10 | 5/9 | 0.120 |
| Cotinine | Nicotine metabolite | 0.023 | 19 | 1 | 1/10 | 0/9 | 0.060 |
| Acetaminophen | Analgesic | 0.0086 | 19 | 5 | 2/10 | 3/9 | 0.015[a] |
| 1,7-dimethylxanthine | Caffeine metabolite | 0.019 | 19 | 6 | 2/10 | 4/9 | 0.022 |
| Codeine | Opioid narcotic, cough suppressant | ND | 19 | 1 | 1/10 | 0/9 | 0.080[a] |
| Ibuprofen | Analgesic | 0.018 | 19 | 1 | 1/10 | 0/9 | 0.129 |
| Dehydronifedipine | Antianginal metabolite | ND | 19 | 1 | 1/10 | 0/9 | 0.003[a] |
| Warfarin | Anticoagulant | 0.0061 | 19 | 1 | 1/10 | 0/9 | 0.009[a] |

[a]Concentration is above the detection level but below method reporting level.
n/z, n is the number of detects and z is the number of wells sampled. NA, not applicable.

## Conclusions

Based on the results of analyses of several tracers, including DOC, coliphages, $NH_4^+$, $NO_3^-$, $N_2$, and organic compounds, at least 13 of the 26 domestic wells showed some evidence of septic waste contamination of drinking water. The evidence of septic waste contamination was especially strong when multiple indicators of sewage contamination such as the presence of coliphages, caffeine, and pharmaceuticals were detected in a sample from the same well. Other combinations included a high $NO_3^-$ concentration in combination with a low boron value and several pharmaceuticals in combination with a high $NH_4^+$ concentration. Domestic wells seemed to be more vulnerable to septic waste contamination when they were sand-point wells within 30 m of a septic wellfield and were <15 m deep in the shallow (<3 m), thin (<30 m) alluvial aquifer studied. The study illustrates that the presence or abundance of bacteria and $NO_3^-$ alone is not good indicator of septic waste contamination in an anaerobic setting. Bacterial transport to ground water depends on sediment type, travel times, and clogging. Analyses for smaller organisms, such as coliphages or other indicator viruses, might be a more conservative indicator of waste contamination of ground water from animal or human sources and might be better indicators than bacteria because they are smaller, generally have a lower tendency to adsorb because of their negative charge, and tend to survive longer. The presence of $NO_3^-$ depends on the biogeochemical conditions in the unsaturated and saturated zones. All nitrogen species should be analyzed to assess more fully whether contamination of the aquifer media with nitrogen exists. When suboxic conditions exist, samples may need to be collected multiple times per year from domestic wells since different nitrogen forms, $NH_4^+$, $NO_3^-$, and/or $N_2$, can occur. Using boron isotopes and, to a lesser extent, $\delta^{15}N[NO_3^-]$ isotopes could help to identify the sources of contamination, according to this study and other published studies.

Organic compounds can be used to assess contamination by septic waste in domestic drinking water. However, organic compounds, similar to DOC ($CH_2O$), can degrade during oxidation. Because D.O. generally was low (<0.17 mg/L) in the aquifer materials sampled, oxidation of organic compounds probably did not occur. The presence of pharmaceuticals suggests that they may be used as indicators of septic waste in aquifers under anaerobic conditions.

In conclusion, even though we did not detect bacteria during this study, individual tracers such as bacteria and $NO_3^-$ at times could be good tools to identify whether drinking water is affected by septic waste. However, the use of multiple biological and chemical tracers including isotopes is more informative because it helps scientists to avoid erroneous interpretations when the local hydrology and biochemical processes affect the presence or concentrations of individual tracers such as bacteria and $NO_3^-$. The limited number of wells sampled in this study precluded definitive conclusions on the combinations of chemical constituents and parameters that would best serve as indicators of septic waste contamination in ground water. However, the data from this study indicate that selected combinations of tracers may be useful indicators of septic waste contamination in ground water. To more fully assess the usefulness of these combinations, more comprehensive studies assessing differing contaminant sources need to be conducted.

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**Editor's Note:** The use of brand names in peer-reviewed papers is for identification purposes only and does not constitute endorsement by the authors, their employers, or the National Ground Water Association.

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