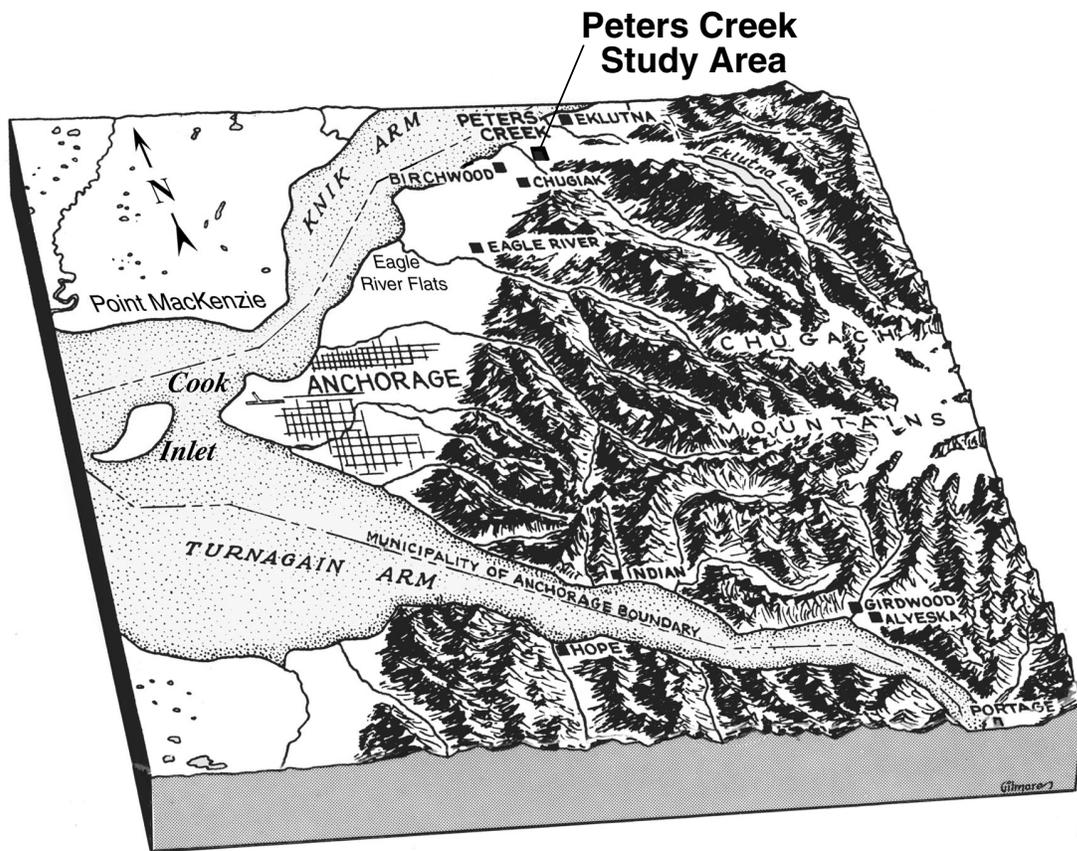![USGS logo - science for a changing world]

Prepared in cooperation with the Municipality of Anchorage

Nitrate Source Indicators in Ground Water of the Scimitar Subdivision, Peters Creek Area, Anchorage, Alaska

Water-Resources Investigations Report 00-4137

U.S. Department of the Interior
U.S. Geological Survey

Nitrate Source Indicators in Ground Water of the Scimitar Subdivision, Peters Creek Area, Anchorage, Alaska

By Bronwen Wang, Pat M. Strelakos, and Brett Jokela

_____

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, WATER-QUALITY ABBREVIATIONS, AND VERTICAL DATUM

Multiply	by	To obtain
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
liter per second (L/s)	15.85	gallon per minute

In this report, temperature is reported in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8 \ (°C) + 32$$

WATER-QUALITY ABBREVIATIONS

mg/L, milligram per liter
µg/L, microgram per liter
µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius
µL, microliter
µm, micrometer
ng, nanogram
pg/kg, picogram per kilogram
pptv, part per trillion by volume

VERTICAL DATUM

Vertical datum is an ellipsoid height determined by GPS observations and referenced to NAD83. For National Geodetic Survey data see *http://www.ngs.noaa.gov/*

Nitrate Source Indicators in Ground Water of the Scimitar Subdivision, Peters Creek Area, Anchorage, Alaska

By Bronwen Wang[1], Pat M. Strelakos[1], and Brett Jokela[2]

ABSTRACT

A combination of aqueous chemistry, isotopic measurement, and *in situ* tracers were used to study the possible nitrate sources, the factors contributing to the spatial distribution of nitrate, and possible septic system influence in the ground water in the Scimitar Subdivision, Municipality of Anchorage, Alaska. Two water types were distinguished on the basis of the major ion chemistry: (1) a calcium sodium carbonate water, which was associated with isotopically heavier boron and with chlorofluorocarbons (CFC's) that were in the range expected from equilibration with the atmosphere (group A water) and (2) a calcium magnesium carbonate water, which was associated with elevated nitrate, chloride, and magnesium concentrations, generally isotopically lighter boron, and CFC's concentrations that were generally in excess of that expected from equilibration with the atmosphere (group B water). Water from wells in group B had nitrate concentrations that were greater than 3 milligrams per liter, whereas those in group A had nitrate concentrations of 0.2 milligram per liter or less. Nitrate does not appear to be undergoing extensive transformation in the ground-water system and behaves as a conservative ion. The major ion chemistry trends and the presence of CFC's in excess of an atmospheric source for group B wells are consistent with waste-water influ-

ences. The spatial distribution of the nitrate among wells is likely due to the magnitude of this influence on any given well. Using an expanded data set composed of 16 wells sampled only for nitrate concentration, a significant difference in the static water level relative to bedrock was found. Well water samples with less than 1 milligram per liter nitrate had static water levels within the bedrock, whereas those samples with greater than 1 milligram per liter nitrate had static water levels near or above the top of the bedrock. This observation would be consistent with a conceptual model of a low-nitrate fractured bedrock aquifer that receives slow recharge from an overlying nitrate-enriched surficial aquifer.

INTRODUCTION

Background and Problem

Nitrate is essential for plant growth and nourishment, but an overabundance can cause a number of adverse health and ecological effects. Public health issues linked to high nitrate intake are cancers, hypertension, and rare cases of methemoglobinemia in newborn infants. Because of these health concerns, the maximum concentration level for nitrate in drinking water is 10 mg/L nitrate (as nitrogen). Nitrate concentrations in uncontaminated ground water generally are less than 2 mg/L (as nitrogen) and are derived primarily from decomposition of soil organic matter (Mueller

[1]U.S. Geological Survey, Anchorage, Alaska
[2]Montgomery Watson, Anchorage, Alaska

and Helsel, 1996). Human activities can influence the nitrate concentration in ground-water systems, and the principal sources of enhanced nitrate are (1) animal waste, (2) waste water effluent, (3) nitrogen fertilizers, and (4) municipal wastes.

Elevated nitrate concentrations in well water from the hillside areas of Anchorage have been a concern of the Municipality of Anchorage, Alaska, for years. Contractors for the municipality have analyzed the distribution of nitrate-containing wells (Bristol Environmental, 1997; Montgomery Watson, 2000) and have attempted to correlate the occurrence of nitrate with environmental factors such as depth of well, depth to bedrock, land-surface slope, and depth to water table. They have been unable, however, to reliably explain the distribution of the nitrate concentration in the wells on the basis of any of the factors evaluated.

The Municipality of Anchorage, Montgomery Watson, and the U.S. Geological Survey (USGS) agreed to focus intensively on the aqueous chemistry and hydrology of one subdivision in which wells commonly contain nitrate. Scimitar Subdivision near Peters Creek (fig. 1) was selected for this study.

Wells in the Scimitar Subdivision have a spotty distribution of nitrate concentration. Water from several wells has exceeded the 10 mg/L standard. Both on-site wells and septic systems are used throughout the subdivision, and the likely source of the nitrate is waste water effluent. However, nitrate concentrations throughout the subdivision did not correlate with the depth of well, nor with the duration of septic-system operation (Montgomery Watson, 2000).

Purpose and Scope

The objectives of this study were to obtain a better understanding of factors contributing to the spatial distribution of nitrate, and to evaluate possible nitrate sources and septic-system influence in the ground water in the Scimitar Subdivision. A combination of stable isotopic analysis, chemical analysis, and *in situ* tracers was used in this evaluation.

Eight wells in the Scimitar Subdivision were sampled for chemical analysis (table 1; fig. 1). In addition to these eight wells, 18 additional wells were surveyed for well-head elevation and location (appendix 1).

Table 1. Wells sampled for chemical constituents, Scimitar Subdivision

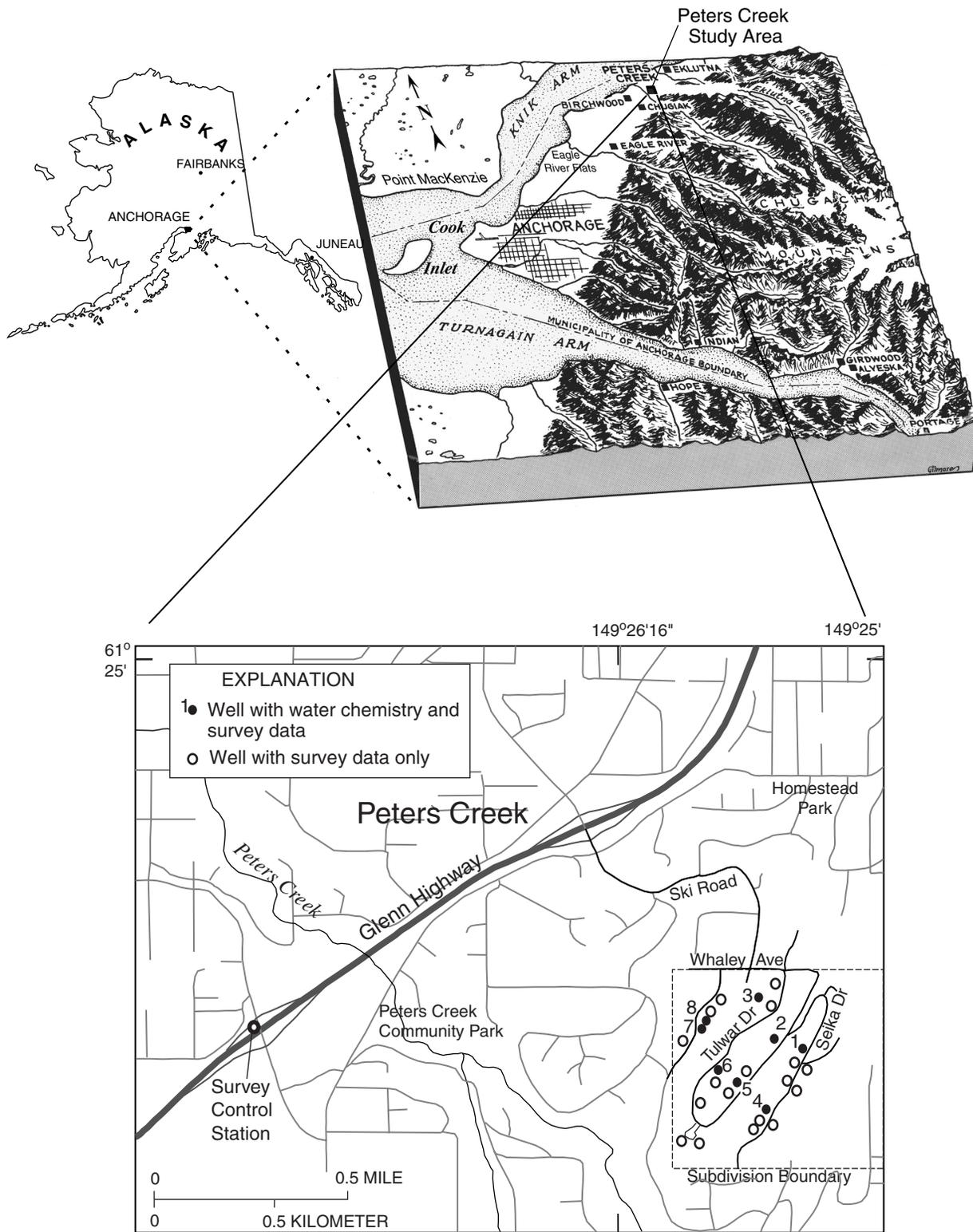| Well number (fig. 1)	Location			USGS site ID
	Subdivision	Block	Lot	
1	3	1	1	612408149252001
2	2	3	18	612411149252601
3	1	2	9	612417149253303
4	3	1	6	612359149253201
5	2	3	15	612404149253402
6	1	3	7	612404149254301
7	1	2	2	612409149254901
8	1	2	3	612411149254201

Figure 1. Location of wells studied in the Scimitar Subdivision, Peters Creek area, Anchorage, Alaska (see table 1 for information about wells 1-8).

Hydrogeology of the Study Area

The hydrogeology of the Peters Creek area was previously described by Brunett and Lee (1983). Alluvium, glacial alluvium, and morainal deposits overlie the bedrock in the vicinity of the Scimitar Subdivision. Brunett and Lee (1983) reported that bedrock in the Peters Creek region is composed of both metamorphic and igneous rocks in a complex lithology that includes the following:

• the Cretaceous McHugh Complex composed of metamorphosed siltstone, graywacke, arkose, conglomeratic sandstone, and greenstone associated with chert and argillite;

• a Mesozoic ultramafic complex composed of pyroxenite, peridotite, and serpentinized dunite and associated gabbro;

• the Jurassic Knik River schist composed of marble, argillite, metachert, metasandstone, and metavolcanic rocks;

• a Jurassic age granodiorite, diorite, quartz diorite formation; and

• the Tertiary Kenai Group composed of siltstone, sandstone, and coal.

Wells in the Peters Creek area draw water either from the bedrock aquifer or from the unconsolidated sediments. Weathered zones and fractures are the primary conduits for water flow in the bedrock. Wells in this region that derive waters from the bedrock have an average water yield of 0.38 L/s as opposed to 1.2 L/s for the unconsolidated sediments (Brunett and Lee, 1983).

NITRATE

Nitrate is one of the primary forms of dissolved nitrogen in natural waters. It is generally the dominant form in waters containing dissolved oxygen, is highly soluble, and is readily transported in ground water. Dissolved nitrogen may also be present as ammonium (NH_4^+),

nitrite (NO_2^-), nitrogen (N_2), nitrous oxide (N_2O), and organic nitrogen. Nitrogen is converted to these nitrogen-containing compounds through the various processes of the nitrogen cycle (fig. 2). Organic nitrogen is converted to nitrate through the combined processes of ammonification (the decomposition of organic matter into ammonium ion) and nitrification (the oxidation of ammonium to nitrate). These are aerobic processes (meaning they occur when oxygen is present) and can lead to an accumulation of nitrate in the ground water (Burt and Trudgill, 1993; Chapelle,1993). Nitrate may be lost from ground water by denitrification, a process whereby nitrate is reduced to nitrogen gas (fig. 2). Denitrification occurs when oxygen is depleted in the water (a condition known as "anaerobic") and when sufficient dissolved organic carbon exists to stimulate the microorganisms that carry out the process. Denitrification, along with dilution, advection, and dispersion, is a mechanism by which nitrate concentration can be lowered in ground water and may be important in the spatial distribution of nitrate in the Scimitar Subdivision. To address the potential for denitrification to occur in wells in the Scimitar Subdivision, the oxidation-reduction (redox) status of the well water was inferred from the dissolved-oxygen concentration, and from the presence of dissolved iron and sulfide.

WASTE-WATER INDICATORS

Septic-system influence in a ground-water system can be inferred from the presence of analytes typical of septic systems. Several researchers have used major and minor ion concentrations to delineate septic-system plumes in ground water (Robertson and others, 1991; Thurman and others, 1984). The utility of a specific ion in distinguishing waste water influence will depend on the chemical characteristic of the ambient ground water. Concentrations of the major ions chloride, calcium, magnesium,
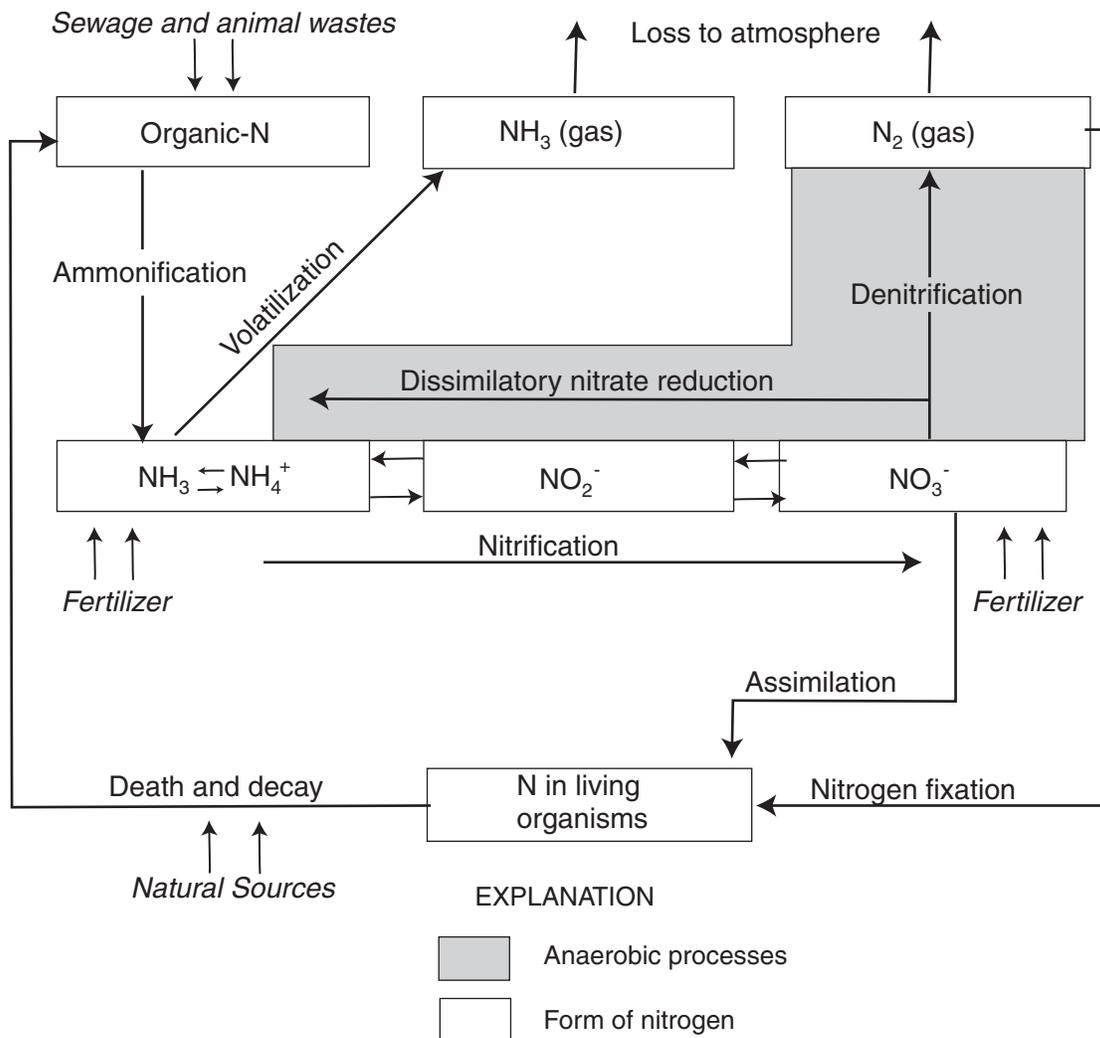
Figure 2. Simplified nitrogen cycle, showing sources of nitrogen contamination of ground water (from Seiler, 1996).

carbonate, sodium, sulfate, and boron all have been useful in delimiting septic-system contamination (Robertson and others 1991; Thurman and others, 1984; Thomas and others, 1999; Seiler, 1996, 1999).

Vengosh and Keren (1996) found that chloride from waste water behaves conservatively. A conservative element, such as chloride, remains in solution and is not removed by processes such as sorption, volatilization, or chemical reaction. Ground water receiving waste water can reflect the chloride concentra-

tion of the effluent. Similarly, the concentration of boron, a common component in household detergents that usually moves through septic systems, has been used to identify waste-water plumes (Thurman and others, 1984). Boron may behave conservatively in aqueous systems but it sorbs both on clay and oxyhydroxide surfaces and sorption is a mechanism of removing boron from surface water and ground water (Bassett and others, 1995; Goldberg and Glaubig, 1988, 1986a, 1986b; Vengosh and Keren, 1996; Leenhouts and others, 1998).

Other changes in the major ion composition of water receiving waste water effluent arise from salt addition during household use, ion-exchange processes involving these salts, and carbonate mineral dissolution caused by the increased acidity associated with septic effluent (Seiler, 1999). The result of these reactions is an evolution of the ground water receiving the effluent toward a decreased sodium/chloride ratio and increased calcium/(bicarbonate + sulfate) ratio (Seiler, 1999; Vengosh and Keren, 1996).

In addition to the ion concentration, stable isotopic ratios have been used to detect waste-water effluent in ground-water systems. Leenhouts and others (1998) and Bassett and others (1995) have found that boron isotopes are useful as an intrinsic tracer in identifying potential nitrate sources. The isotopic composition of boron in natural waters depends on the isotopic composition of the boron in the geologic framework with which the water is in contact. Natural waters can have an isotopic composition of boron ranging from about -10 to greater than +40 per mil depending on the geologic source. The boron isotope ratios for various aqueous systems are given in table 2.

Stable isotopic measurements determine the ratio of the heavier isotope to the lighter isotope. All isotopic measurements are made relative to an accepted standard and are reported in the delta notation. For example, the delta notation for boron is given as:

$$\delta^{11}B \;=\; 1,000\left[\frac{(^{11}B/^{10}B)_{sample}}{(^{11}B/^{10}B)_{standard}} - 1\right].$$

These values may be positive or negative and represent the isotopic distribution in the sample relative to the standard. The boron used in detergents is obtained from perborates, which are isotopically light relative to other geologic materials. Consequently, the boron in waste water is typically isotopically lighter (has a greater abundance of the light ^{10}B isotope) than that found in most ground water. Therefore, the isotopic composition of the boron in the well water may provide a good tracer for waste-water effluent (Vengosh and others, 1999; Bassett and others, 1995; Leenhouts and others, 1998).

Table 2. Boron isotope ratios for several aqueous systems

Possible boron source	$\delta^{11}B$ (per mil)	Reference
Seawater	39.5	Spivack and Edmond, 1987
Brackish ground water	24.8 to 49.9	Vengosh and others, 1999
Ambient ground water	13.3 to 16.7	Bassett and others, 1995
	27.4	Leenhouts and others, 1998
	21.2 to 32.4	Vengosh and others, 1999
Geothermal fluids	-9.3 to 4.4	Palmer and Sturchio, 1990
Treated waste water	6.0 to 10.1	Bassett and others, 1995
	2.2	Leenhouts and others, 1998
	-2.2	Seiler, 1999

Anthropogenic compounds such as methylene blue active substances (MBAS) and chlorofluorocarbons (CFC's) may also serve as waste-water indicators (Thomas and others, 1999; Seiler, 1996). MBAS are anionic surfactants that are common in sewage effluent because they are used in common household products, such as detergents. CFC's are stable, synthetic organic compounds used worldwide in industrial and refrigerant applications. Dichlorodifluoromethane (CFC-12) was first introduced in 1931, followed by trichlorofluoromethane (CFC-11), and trichlorotrifluoroethane (CFC-113). Their extensive use has resulted in a global atmospheric distribution and subsequent introduction into the hydrologic cycle through gas-liquid exchange equilibria. Atmospheric concentrations increased from the time of introduction until a production moratorium in 1996. Atmospheric mixing ratios peaked in the mid- to late 1990's, but have been declining since then (Plummer and Busenberg, 1999).

In addition to the atmospheric source, other potential sources of CFC's in ground water are runoff or leaching from urban and industrial areas, and sewage effluent (Plummer and Busenberg, 1999; Thomas and others, 1999). The concentrations of CFC's in ground water receiving water from these sources are greater than those attributable to the atmospheric source. CFC's were used extensively in household products, such as propellants in aerosol cans and solvents, and they appear to be retained and slowly released from the septic system (Thomas and others, 1999; Seiler, 1996).

METHODS

A combination of chemical analysis and stable isotopic analysis was used to determine the best procedures for evaluating the nitrate distribution and fingerprinting the nitrate source in the Scimitar Subdivision. In addition, 26 wells in the Scimitar Subdivision were surveyed for the well-head elevation and locations; eight of these wells were sampled for chemical analysis (fig. 1).

Elevation Survey

Latitude, longitude, and well-head elevations for the 26 wells were established in August 1999 using a Global Positioning System (GPS) survey. The survey control station is located on the overpass structure for North Birchwood exit on the Glenn Highway (Alaska State Highway 1), approximately 1.6 km southeast of Peters Creek (fig. 1). The monument was established in 1985 by the Municipality of Anchorage and R&M Consultants. The horizontal coordinates were established by GPS observations and adjusted by the National Geodetic Survey in September 1992. The vertical component is an ellipsoidal height determined by GPS observations and is referenced to NAD 83. The ellipsoidal height of the survey monument is 110.95 m. Prior to 1992, the vertical datum of the monument was referenced to NGVD 29 at 100.30 m. This is the mean sea level datum and the difference between it and the ellipsoidal height is 10.65 m. Data were collected over a point on the top of the well cap or sanitary seal, with elevations expressed as heights above the ellipsoid. In order to obtain elevations above sea level that would correspond to elevations on USGS topographic maps of the area, 10.65 m was subtracted from the ellipsoidal heights. Horizontal data were collected and processed in degrees, minutes, and decimal equivalents of seconds. Vertical data referenced to the ellipsoid were collected and processed in meters. Survey data for all 26 wells are given in appendix 1.

Water Chemistry

Ground-water samples from the Scimitar Subdivision were collected using the homeowner's submersible pump. The pump was lifted from the pitless-tee and a galvanized-

steel pipe fitted with a brass hose-bib was attached. Teflon sampling lines were attached to the hose-bib. This process allowed the samples to be taken from the pump discharge and before any pressure or in-house treatment tanks. Prior to collection, the well water was passed through a flow-through chamber attached to a multiparameter probe. Samples were collected when pH, temperature, and specific conductance stabilized. The multiparameter probe was then removed prior to sample collection. Samples for dissolved oxygen (DO) were collected in glass DO bottles. The bottle volume was exchanged three times with well water before the bottles were stoppered. The DO concentration was determined using the Winkler titration method (Hach Company, 1998).

Field measurements and samples for major-ion, trace-element, nutrient, and MBAS concentrations were collected according to published procedures (Wilde and Radtke, 1998; Koterba and others, 1995). Filtered samples were passed through a 0.45 μm capsule filter and these samples are considered to represent the dissolved fraction. Unfiltered samples were collected for the MBAS analysis. Sulfide analysis was done in the field using the methods of the Hach Company (1998). Major ions, trace elements, nutrients, and MBAS were analyzed using methods described by Struzeski and others (1996), Burkhardt and others (1995), and Fishman and Friedman (1989).

Samples for boron isotopic analysis were filtered and collected in a polycarbonate bottle. Prior to analysis, the samples were acidified with boron-free acid. Boron isotopes were analyzed by the negative ion thermal mass spectrometry technique at the USGS laboratories in Menlo Park, Calif. For each analysis, sufficient sample containing approximately 2 ng of boron was evaporated in a Teflon beaker and treated with 100 μL H_2O_2 to oxidize organics. The dried sample was loaded onto a rhenium filament ribbon and placed into the high vacuum source of the mass spectrometer. Filaments were heated to approximately 950 °C, and data were collected when ion beams stabilized in their growth characteristics. Ion beams were measured simultaneously at mass 42 ($^{10}BO_2$) and 43 ($^{11}BO_2$) for approximately 30 minutes. The reported $\delta^{11}B$ is the per mil difference of the ratio of the measured $^{11}BO_2$ to $^{10}BO_2$ beams, relative to the reference standard, the National Institute of Standards and Technology (NIST) 951 boric acid. The correction for oxygen isotope composition is negligible. On this mass spectrometer, NIST 951 gives a $^{11}B/^{10}B$ value of 4.004; seawater gives a value of 4.161 which corresponds to a $\delta^{11}B$ of +39.2 relative to NIST 951. Precision is ±0.5 per mil.

Waters for CFC analysis were collected using specialized sampling equipment designed to isolate the water sample from the atmosphere. The samples were collected in borosilicate glass vials and sealed under ultra-pure nitrogen. Detailed sampling procedures and the analytical methods are described by Busenberg and Plummer (1992). Concentrations expected from atmospheric sources were calculated using the model of Plummer and Busenberg (1999). The calculation was made using a recharge temperature of 0 °C and recharge elevations of sea level and 1525 m.

WATER CHEMISTRY DATA

To understand the distribution and potential sources of nitrate in ground-water systems, it is generally necessary to evaluate the chemical characteristics of the water, in addition to determining the nitrate concentration, for two reasons. (1) The potential source of nitrate in ground water can lead to differences in water chemistry and (2) naturally occurring processes, such as denitrification, can transform nitrate into other nitrogen-containing compounds. Physical-chemical data, major and minor ion concentrations, nutrients concentrations, anthropogenic compounds, and isotopic data were collected in eight wells in the Scimitar Subdivision (table 3sd).

Table 3. Field measurements, major and minor ions, nutrients, and isotope data for ground-water samples from the Scimitar Subdivision

[°C, degree Celsius; mg/L, milligram per liter; µg/L, microgram per liter; µS/cm, microsiemen per centimeter; pg/kg, picogram per kilogram; <, value is less than value shown; --, no data]

Property or constituent	Unit	Well (Group A, unshaded; Group B, shaded)							
		1	2	3	4	5	6	7	8
Water temperature	°C	4.18	6.68	4.4	5.22	4.58	4.49	4.78	7.19
pH		8.3	9.1	7.4	7.1	8.1	7.4	7.9	7.3
Specific conductance	µS/cm	303	273	400	538	383	309	342	382
Dissolved oxygen	mg/L	<0.1	2.4	4.6	0.6[a]	4.7	5.7	4.8	6.0
Alkalinity	mg/L as $CaCO_3$	116	110	142	155	97	117	152	150
Bicarbonate	mg/L as HCO_3^-	141	102	173	189	118	143	185	183
Carbonate	mg/L as CO_3^{2-}	--	14.6		--			--	
Sulfide	mg/L as S	< 0.01	< 0.01	< 0.01	--	< 0.01	< 0.01	< 0.01	< 0.01
Orthophosphate, dissolved	mg/L as P	< 0.01	0.02	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Ammonia + organic nitrogen, dissolved	mg/L as N	0.1	0.1	<0.1	0.1	<0.1	<0.1	0.4	0.1
Nitrite, dissolved	mg/L as N	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Ammonia, dissolved	mg/L as N	0.03	0.09	< 0.02	0.09	< 0.02	< 0.02	< 0.02	< 0.02
Nitrate, dissolved	mg/L as N	< 0.05	0.22	5.9	< 0.05	11	3.3	0.1	5.4
Calcium, dissolved	mg/L as Ca	17	15	53	47	43	34	36	46
Sodium, dissolved	mg/L as Na	43	26	5.7	46	4	4.5	34	5.1
Magnesium, dissolved	mg/L as Mg	6.8	10	17	12	18	14	5.5	16
Potassium, dissolved	mg/L as K	0.6	0.5	0.8	1.2	0.8	0.6	< 0.1	0.7
Chloride, dissolved	mg/L as Cl	4.7	4.2	16	2.8	21	7.5	4.9	14
Fluoride, dissolved	mg/L as F	0.3	0.8	< 0.1	0.2	< 0.1	< 0.1	< 0.1	< 0.1
Sulfate, dissolved	mg/L as SO_4	40	31	19	120	18	18	32	18
MBAS[b]	mg/L	< 0.02	< 0.02	0.03	< 0.02	0.03	< 0.08[c]	< 0.02	< 0.02
Boron, dissolved	µg/L as B	820	2780	80	730	55	49	1090	64
Iron, dissolved	µg/L as Fe	<10	< 10	45	< 10	< 10	50	< 10	< 10
Manganese, dissolved	µg/L as Mn	40	5	2[d]	90	< 3	9	49	10
Dissolved organic carbon	mg/L as C	1	1.3	1.2	1.6	0.9	1.7	0.4	1.4
Silica, dissolved	mg/L as SiO_2	12	16	17	9.5	15	20	13	17
CFC-11	pg/kg	10	657	2817	70	450	1644	642	2206
CFC-12	pg/kg	32	391	748	60	333	515	425	2700
CFC-113	pg/kg	7	122	287	16	97	344	182	541
$\delta^{11}B$	per mil	6.5	5.7	4.7	1.5	-1.2	-1.2	22.2	4

[a]Value from multiparameter probe

[b]Methylene blue activated substance, unfiltered sample

[c]The laboratory reported a higher detection limit for this sample than the method detection limit of 0.02 mg/L. This can arise from interference in a given sample.

[d]Estimated

Major and Minor Ions, and Nitrate Concentrations

Major ion data indicate that two water types are present in the Scimitar Subdivision. This is illustrated by the separation of the wells into two groups when the major ion data are plotted on a trilinear diagram (fig. 3). Wells 1, 2, 4, and 7 compose one group (group A) and wells 3, 5, 6, and 8 compose the other (group B) (fig. 4). Sodium accounts for greater than 40 percent of the cationic charge in water from wells in group A as opposed to less than 10 percent in group B (fig. 3). Waters from group A classify as calcium sodium carbonate type

waters, whereas those from group B are calcium magnesium carbonate type waters.

In addition to sodium, significant differences in chloride, magnesium, boron, and nitrate concentrations were found between the two groups (table 4, fig. 5). Nitrate, chloride, and magnesium concentrations are higher in group B, whereas boron and sodium concentrations are higher in group A (fig. 5). The increased chloride and magnesium shifts the water of group B slightly more toward a calcium magnesium chloride water relative to the water of group A. A plot of the calcium/(bicarbonate + sulfate) versus the sodium/chloride ratio clearly separates the two groups: group B
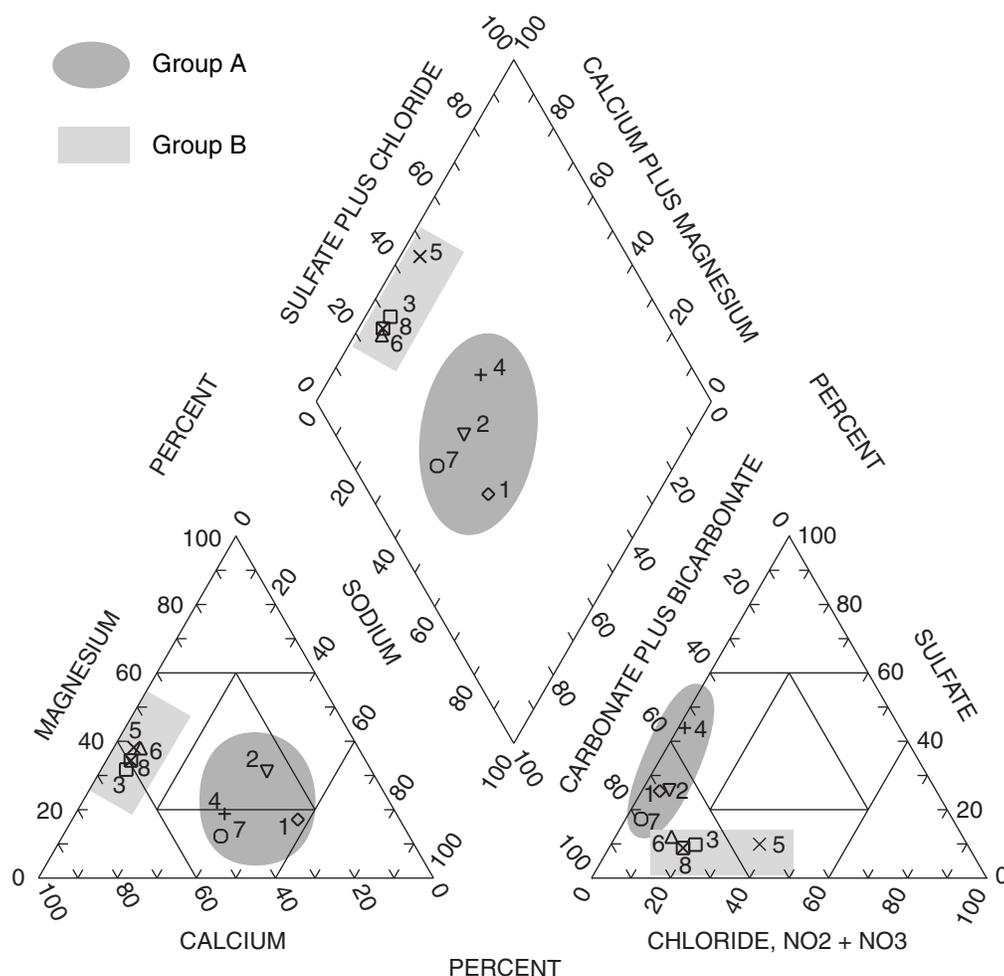
Figure 3. Trilinear diagram for well water samples taken from the Scimitar Subdivision. Numbers refer to well number given in table 1.
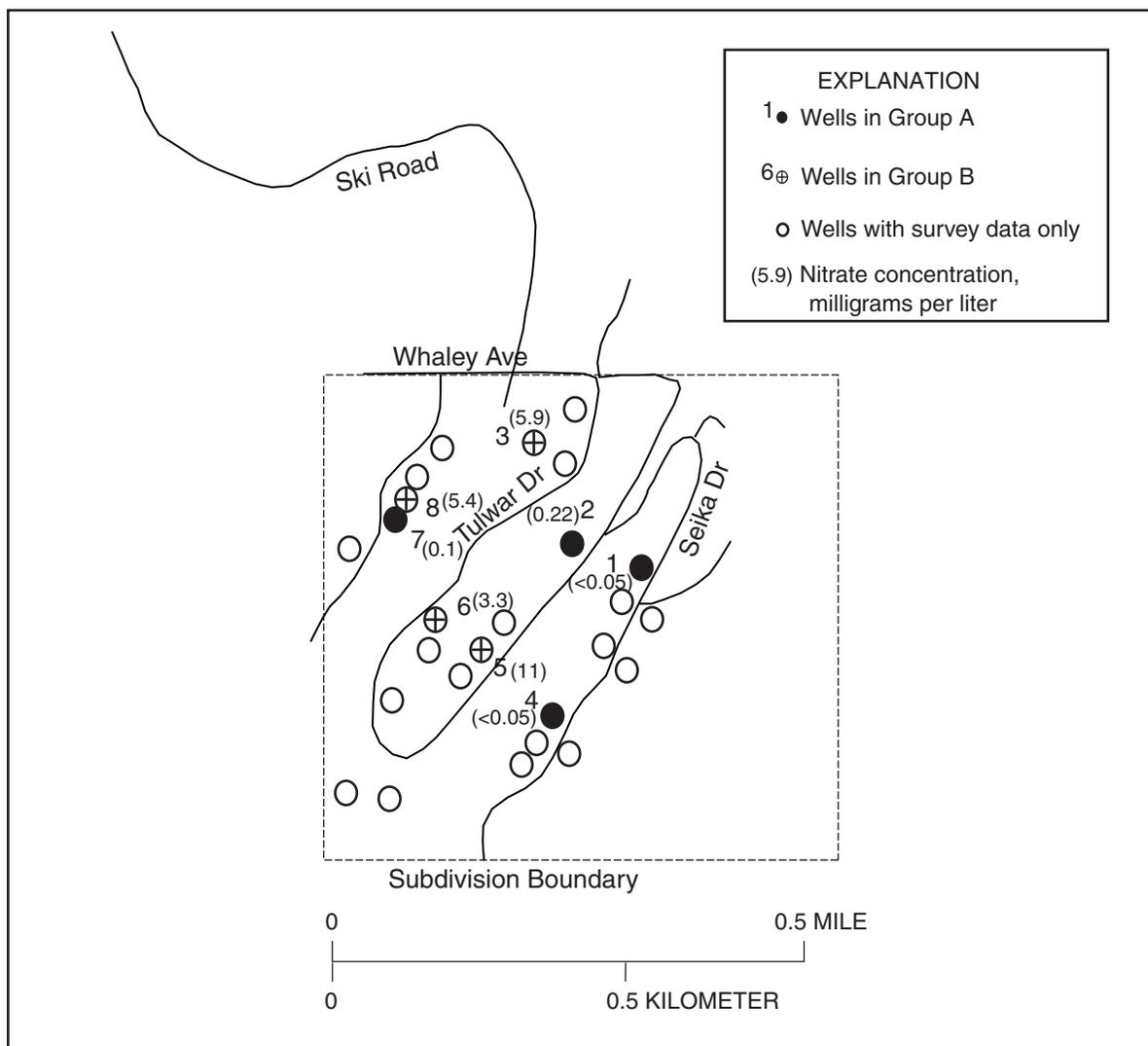
Figure 4. Spatial distribution of wells in group A and group B and nitrate distribution in the Scimitar Subdivision.

has a lower sodium/chloride ratio and a higher calcium/(bicarbonate + sulfate) ratio relative to group A (fig. 6A). For this trend to represent the evolution of group A type water to group B, boron must be removed from the native ground water during the septic processes and/or subsequent waste-water release.

Boron may behave as a conservative ion but it also sorbs both on clay and oxyhydroxide surfaces and sorption is a mechanism of remov-

ing boron from surface water and ground water (Bassett and others, 1995; Goldberg and Glaubig, 1988, 1986a, 1986b; Vengosh and Keren, 1996). Iron oxide floc was noted when the pumps were pulled from wells 6 and 3. Peak sorption of boron onto iron oxide occurs over the pH range from 7 to 8 (Goldberg and Glaubig, 1985). This is the pH range found in the ground-water system in the Scimitar area and sorption of boron by iron oxide may remove boron from this system. If boron is not

Table 4. Summary statistics for selected major and minor ions for well water samples from the Scimitar Subdivision

(mg/L, milligram per liter; µg/L, microgram per liter; SD, standard deviation; p-value, attained significance level[a])

Constituent	Unit	Group A			Group B			p-value
		Mean	Median	SD	Mean	Median	SD	
Nitrate	mg/L as N	0.1	0.08	0.08	6.4	5.7	3.26	0.008
pH		8.1	8.1	0.8	7.5	7.4	0.37	0.27
Calcium	mg/L as Ca	29	27	15	44	45	7	0.13
Sodium	mg/L as Na	37	39	9	4.8	4.8	0.7	0.0004
Magnesium	mg/L as Mg	8.6	8.4	2.9	16	16	1.7	0.004
Alkalinity	mg/L as $CaCO_3$	140	146	21	161	162	37	0.36
Chloride	mg/L as Cl	4.2	4.5	0.95	15	15	5.6	0.01
Sulfate	mg/L as SO_4	56	36	43	18	18	0.5	0.13
Boron	µg/L as B	1350	950	960	61	59	13	0.036

[a]significance determined to an α-value of 0.05, where α is the level of significance. Values less than the reporting limit were set equal to the reporting limit for purposes of the analysis. This may bias the mean high relative to the true mean concentration.

removed, these waters simply represent two distinct systems. However, within group B, there is a trend toward a decreased sodium/chloride ratio and an increased calcium/(bicarbonate + sulfate) ratio as the nitrate concentration increases (fig. 6B). This trend is consistent with waste-water influence in the wells of group B.

Nitrate and chloride concentrations in the wells in group B vary linearly (fig. 7). The linearity between the nitrate and the chloride suggests that they are derived from the same source, and that the nitrate is behaving conservatively and is not sorbed or transformed in the system. Elevated chloride could be indicative of waste-water influence in wells of group B.

Redox and Nitrate Concentrations

Water from wells in group B have nitrate concentrations that are greater than 3 mg/L, whereas those in group A have nitrate concentrations of 0.2 mg/L or less (table 3). A possible mechanism that influenced the nitrate spatial distribution is the removal of nitrate through denitrification. Denitrification occurs under anaerobic conditions. Redox indicators include dissolved oxygen, iron, and sulfide concentrations. Dissolved-oxygen concentrations in most of the wells are between 2.4 and 6.0 mg/L indicating that water in most wells is oxygenated. The exceptions are wells 1 and 4, which

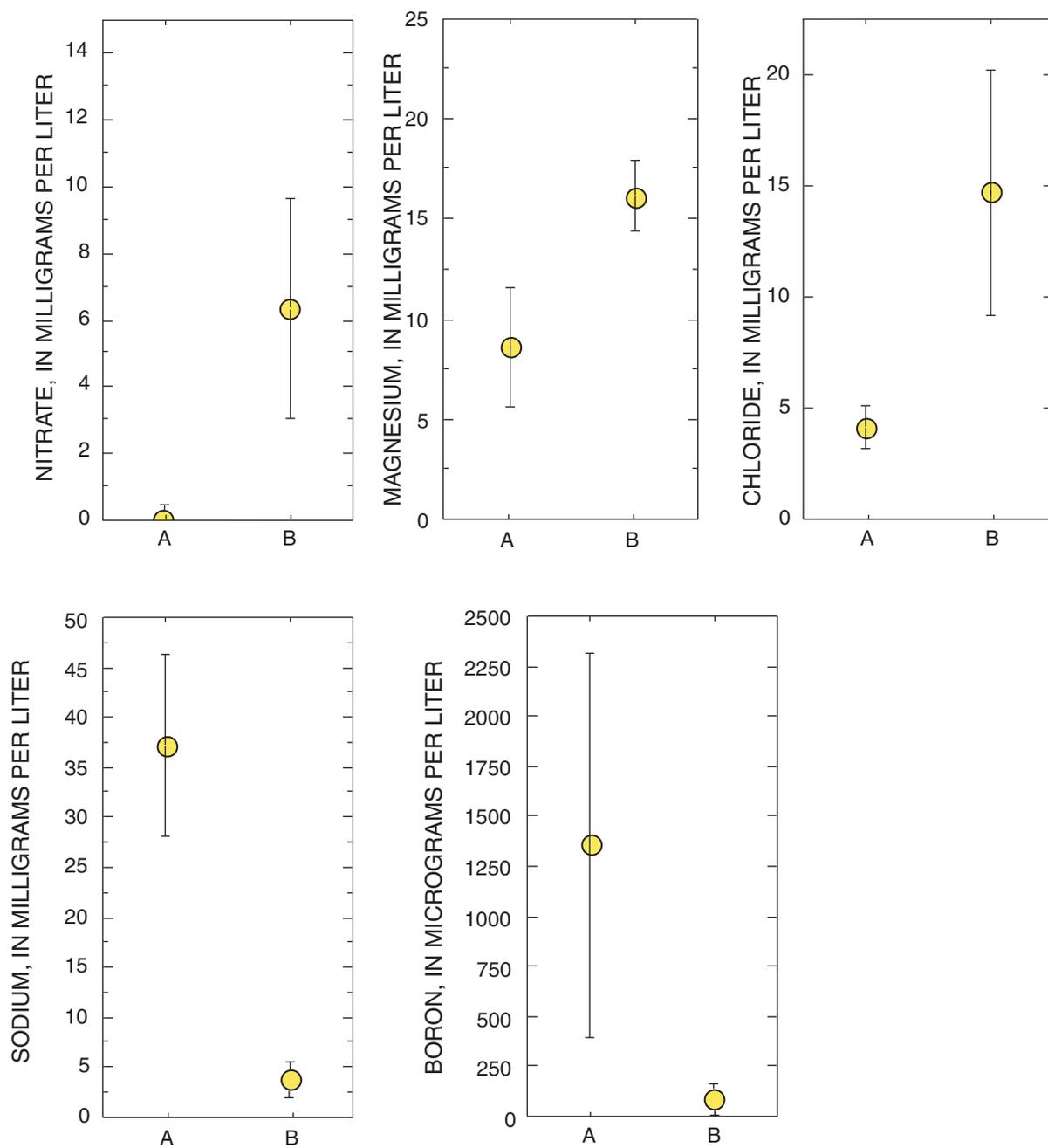**Figure 5.** Mean and standard deviation for nitrate, magnesium, chloride, sodium, and boron concentrations for well water samples taken from the Scimitar Subdivision.
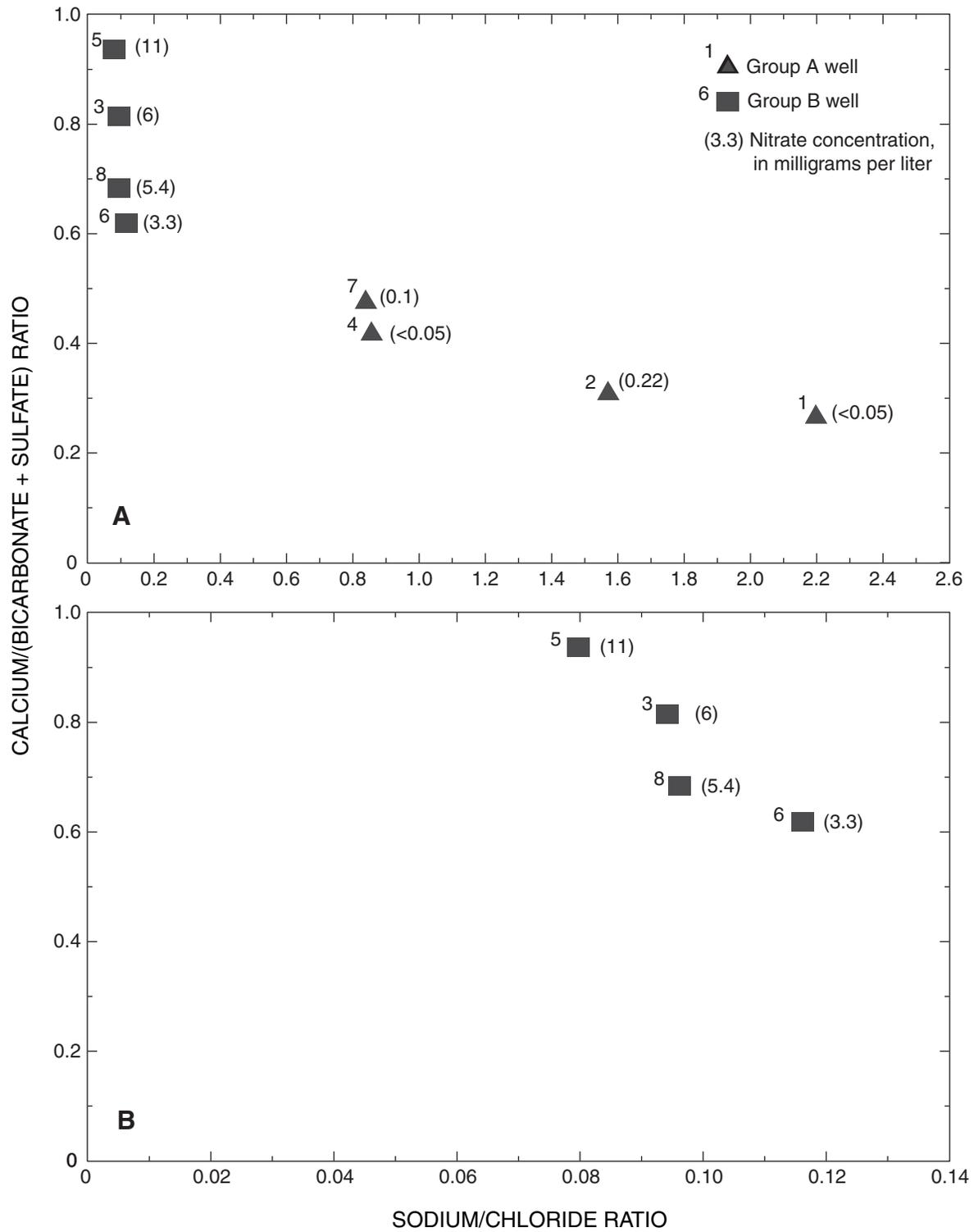
Figure 6. Calcium/(bicarbonate + sulfate) ratio plotted against the sodium/chloride ratio for (A) all water samples taken from the Scimitar Subdivision and (B) group B water samples. Ratios are calculated using milliequivalent per liter concentration units.
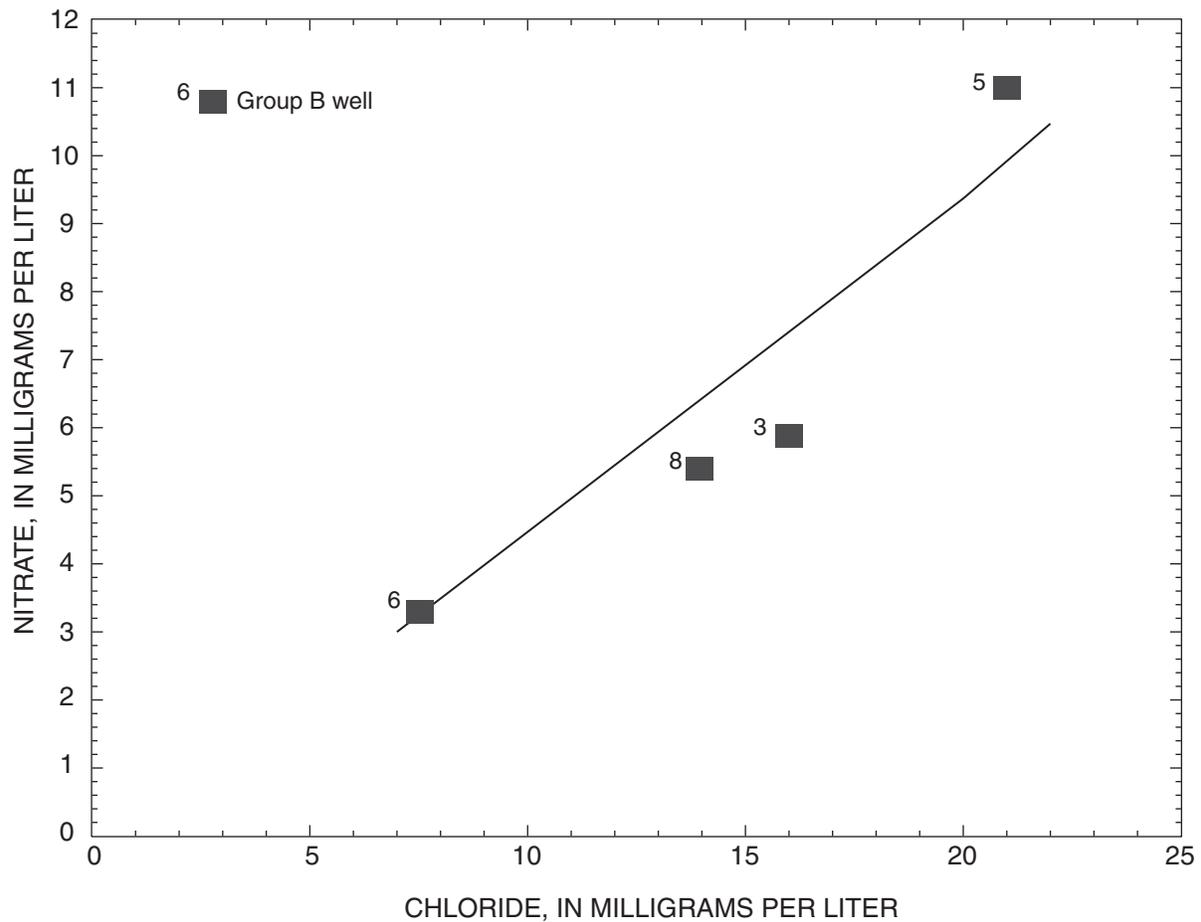
Figure 7. Nitrate concentration plotted against chloride concentration for group B well water samples from the Scimitar Subdivision. Least squares regression gives the relation between nitrate and chloride in these wells as [nitrate] = 0.5496 [chloride] - 1.6124 with an r^2 = 0.89.

have dissolved-oxygen concentrations of < 0.1 and 0.6 mg/L, respectively. Iron and sulfide concentrations in these two wells were below the reporting limit (table 3), indicating that the wells do not reflect strongly reducing conditions.

The presence of oxygen in most wells indicates that denitrification may not be an important mechanism controlling the nitrate concentrations in Scimitar Subdivision. Nitrate is the nitrogen-containing species that is expected to dominate under aerobic conditions. Nitrate is the dominant nitrogen-containing species in the ground water from wells in group B and well 2. Ammonia was the dominant nitrogen-containing species in well 4 and organic nitrogen was dominant in wells 1 and 7. Nitrite was below the detection limit in all wells.

Boron Isotopes and Chlorofluorocarbons

The isotopic signature of treated waste water ranges from -2.2 to 10 per mil (table 2). The $\delta^{11}B$ values ranged from -1.2 to 4.7 per mil for wells in group B and from 1.5 to 22.2 for wells in group A (table 3). The generally lighter isotopic values for group B are consistent with the expected range for waters receiving waste water. If boron is sorbed by the iron oxide, isotopic fractionation could alter the isotopic signature. The wide $\delta^{11}B$ range for group A indicates a complex geologic signature in the area.

The concentrations in water samples of the three CFC's analyzed, CFC-11, CFC-12, and CFC-113, are given in table 3. These concentrations are compared with the maximum expected aqueous concentration from air-water equilibration with atmospheric sources alone (table 5, fig. 8). The expected concentration depends on the recharge temperature, recharge elevation, salinity, and relative humidity. The temperature of the water recharging to the ground water was assumed to be 0 °C. Because gases are more soluble at a lower temperature if the actual recharge temperature is greater than zero, the expected concentration would be lower than the calculated one. Expected concentrations were calculated using both sea level and 1525 m (the elevation of the highest ridge line above Scimitar). The relative humidity was assumed to be 100 percent and, because the waters are dilute, the salinity was assumed to be 0 part per thousand. The maximum expected aqueous concentrations of the three CFC's are given in table 5.

Generally the wells in group B had higher concentrations of all three CFC's than those in group A, and were generally at or above the concentrations expected from atmospheric input during recharge (fig. 8). The exception was well 5 in group B. This well had concentrations of all three CFC's consistent with an atmospheric source. Group A wells had CFC concentrations at or within the concentration range expected from an atmospheric source.

MBAS was detected in wells 3 and 5 at low concentrations, but was not detected in the other wells (table 3). Consequently, MBAS may have been removed from the effluent by sorption on organic matter in the soil or diluted with ground water (Thomas and others, 1999).

Table 5. Maximum expected aqueous concentrations of CFC-11, CFC-12, and CFC-113 for recharge elevations of sea level and 1525 meters, a recharge temperature of 0 degrees Celsius, and 100 percent relative humidity.

(m, meter; pptv, part per trillion by volume; pg/kg, picogram per kilogram)

CFC	Maximum atmospheric concentration[a], partial pressure (pptv)	Maximum expected aqueous concentration for recharge at sea level (pg/kg)	Maximum expected aqueous concentration for recharge at 1525 m (pg/kg)
CFC -11	280	1479	1230
CFC-12	560	634	527
CFC-113	90	212	176

[a]Concentrations from Plummer and Busenberg (1999)
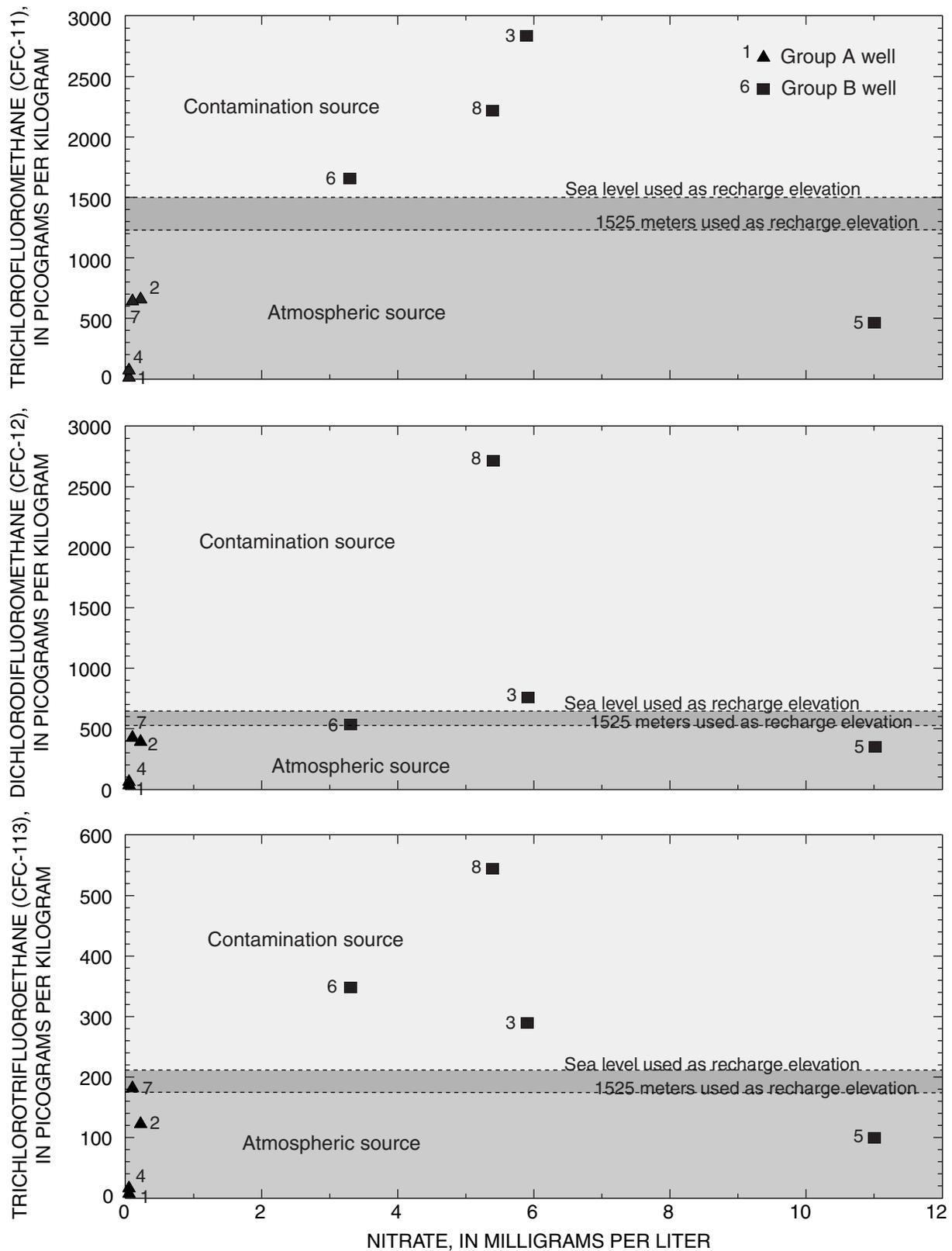
Figure 8. Chlorofluorocarbon plotted against nitrate concentrations for well water samples taken from the Scimitar Subdivision.

NITRATE AND THE GROUND-WATER SYSTEM

In order to evaluate the nitrate concentrations in relation to the ground-water system in the Scimitar Subdivision, the difference between the static water level and the top-of-bedrock elevation was calculated for the wells in groups A and B. The result of this computation will be negative if the static water level is within the bedrock and positive if the static water level is above the bedrock. Groups A and B were not statistically different (p = 0.4) due to a small sample size relative to the variation in the difference. However, the computation indicated that group B wells (those with higher nitrate) had a water-level elevation near or above the bedrock and that group A wells generally had a water-level elevation within the bedrock (fig. 9). To explore this possibility fur-

Figure 9. Boxplots of the difference between the static water levels and the bedrock elevation for group A and B wells sampled by the USGS and for wells with less than 1 mg/L nitrate (group L) and greater than 1 mg/L nitrate (group G) sampled by Montgomery Watson for the Scimitar Subdivision.

ther, additional nitrate and water table data from wells sampled by Montgomery Watson (2000, appendix 1) were compiled. Sampling by Montgomery Watson 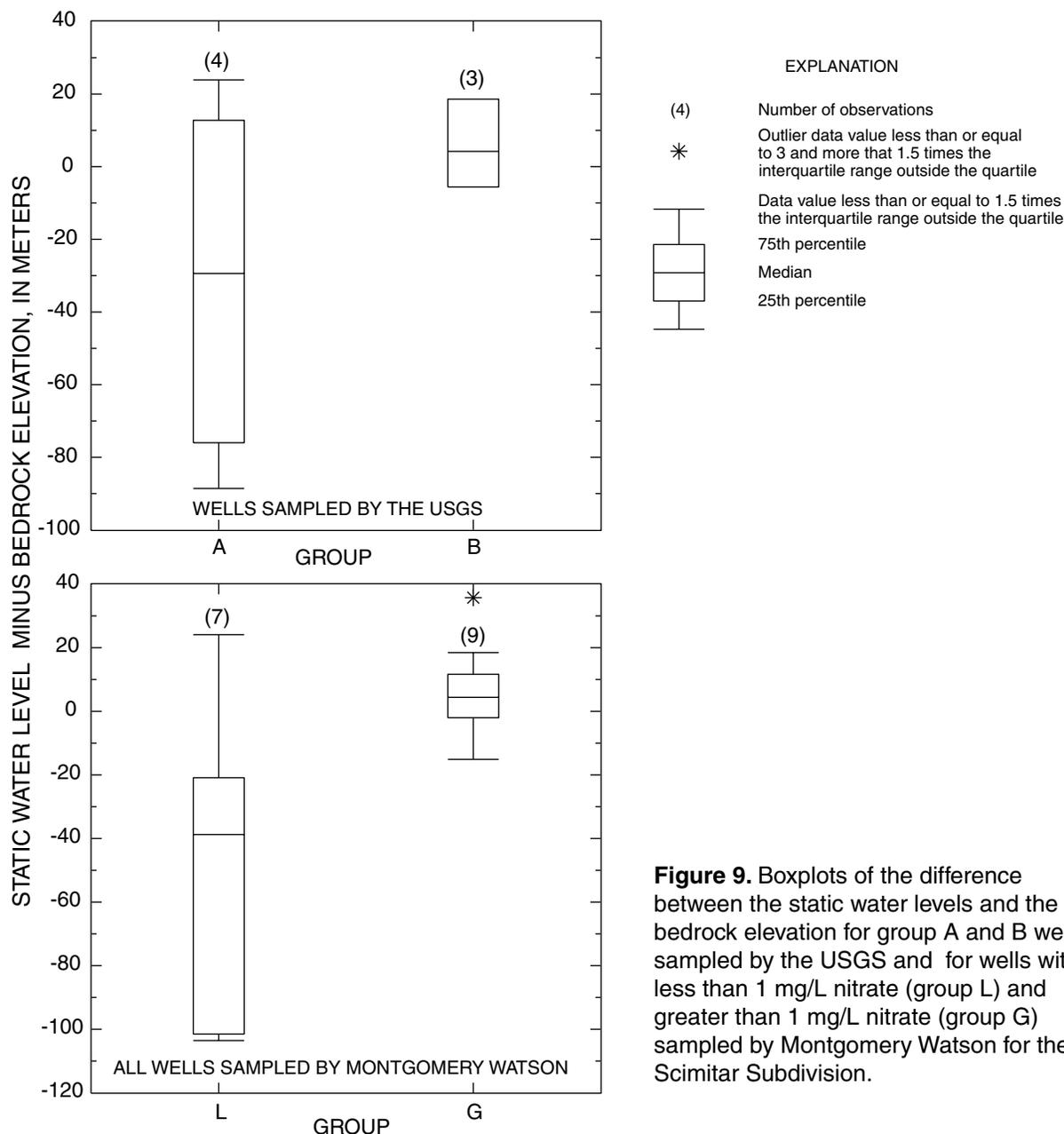was concurrent with the USGS field work but was limited to nitrate analysis. The samples were grouped into wells with nitrate concentrations less than 1 mg/L (group L) and those with nitrate concentrations greater than 1 mg/L (group G). A significant difference ($p = 0.01$) was found between groups L and G in the static water level relative to the bedrock elevation (fig. 9). Group G wells have static water levels near or above the top of the bedrock and group L wells have static water levels within the bedrock. This observation would be consistent with a conceptual model of a low-nitrate fractured bedrock aquifer that receives slow recharge from an overlying nitrate-enriched surficial aquifer.

A detailed analysis of the ground-water system was not within the scope of the current study. However, the observations indicate a ground-water system that almost certainly has the following characteristics:

• The water table aquifer is a thin layer of saturated unconsolidated materials through which ground water flows in a direction parallel to the bedrock surface. In much of the area, this aquifer is too thin to produce water for wells.

• Septic effluent and infiltration of precipitation recharge the unconfined aquifer.

• Water levels that are generally lower in the bedrock aquifer than those in the water-table aquifer indicate downward movement of water between the aquifers

SUMMARY AND CONCLUSIONS

Two distinct water types were found in wells sampled in the Scimitar Subdivision. Of the eight wells sampled, four were classified as calcium sodium carbonate (group A) and four were calcium magnesium carbonate (group B). Wells in group B have significantly higher nitrate, chloride, and magnesium concentrations than those in group A, whereas wells in group A have higher sodium and boron concentrations. The trends in the major ion chemistry within group B are consistent with those expected from waste-water effluent. Aerobic conditions are typical in the aquifer and there is no evidence of significant denitrification. Consequently, nitrate behaves as a conservative ion. The boron in group A wells is generally heavier than that in group B wells. CFC concentrations in group B wells were generally in excess of those expected from an atmospheric source alone, indicating an additional source for these compounds. Urban and industrial areas, and waste water effluent are common sources of these compounds. In this instance, waste-water effluent is the most likely source.

Using an expanded nitrate concentration data set provided by Montgomery Watson, a significant difference in the static water level relative to bedrock was found. Samples with nitrate concentrations less than 1 mg/L had static water levels within the bedrock, whereas those with nitrate concentrations greater than 1 mg/L had static water levels near or above the top of the bedrock. This observation would be consistent with a conceptual model of a low-nitrate fractured bedrock aquifer that receives slow recharge from an overlying nitrate-enriched surficial aquifer.

On the basis of the major ion chemistry of the water and the presence of CFC's in excess of an atmospheric source, group B wells appear to have some waste-water influence. The spatial distribution of the nitrate among wells is likely due to the magnitude of this influence on any given well.

REFERENCES CITED

Bassett, R.L., Buszka, P.M., Davidson, G.R., and Chong-Diaz, D., 1995, Identification of groundwater solute sources using boron isotopic composition: Environmental Science and Technology, v. 29, no. 12, p. 2915-2921.

Bristol Environmental, 1997, An evaluation of nitrate in drinking water and development of a groundwater protection program—Anchorage hillside area: Available from the Municipality of Anchorage Department of Health and Human Services, Anchorage, Alaska, 44 p.

Brunett, J., and Lee, M., 1983, Hydrogeology for land-use planning—The Peters Creek area, Municipality of Anchorage, Alaska: U.S. Geological Survey Water-Resources Investigations 82-4120, 6 sheets.

Burkhardt, M.R., Cinotto, P.J., Frahm, G.W., Woodworth, M.T., and Pritt, J.W., 1995, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of methylene blue active substances by spectrophotometry: U.S. Geological Survey Open-File Report 95-189, 16 p.

Burt, T.P., and Trudgill, S.T., 1993, Nitrate in groundwater, chap. 8 in Burt, T.P., Heathwaite, A.L., and Trudgill, S.T., eds., Nitrate—Processes, patterns, and management: Chichester, England, John Wiley and Sons, p. 213-238.

Busenberg, E., and Plummer, L.N., 1992, Use of chlorofluorocarbons (CCl_3F and CCl_2F) as hydrologic tracers and age-dating tools—The alluvium and terrace system of central Oklahoma: Water Resources Research, v. 48, no. 9, p. 2257-2283.

Chapelle, F.H., 1993, Ground-water microbiology and geochemistry: New York, John Wiley and Sons, 424 p.

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Goldberg, Sabine, and Glaubig, R.A., 1985, Boron adsorption on aluminum and iron oxide minerals: Soil Science Society of America Journal, v. 49, no. 6, p. 1374-1379.

Goldberg, Sabine, and Glaubig, R.A., 1986a, Boron adsorption on California soils: Soil Science Society of America Journal, v. 50, no. 5, p. 1173-1176.

Goldberg, Sabine, and Glaubig, R.A., 1986b, Boron adsorption and silicon release by the clay minerals kaolinite, montmorillonite, and illite: Soil Science Society of America Journal, v. 50, no. 6, p. 1442-1448.

Goldberg, Sabine, and Glaubig, R.A., 1988, Boron and silicon adsorption on an aluminum oxide: Soil Science Society of America Journal, v. 52, no. 1, p. 87-91.

Hach Company, 1998, DR/2010 Spectrophotometer—Procedures manual: Information available from <http://www.hach.thomasregister.com/olc/hach>.

Koterba, M.T., Wilde, F.D., and Lapham, W.W., 1995, Ground water data-collection protocols and procedures for the National Water-Quality Assessment program—Collection and documentation of water-quality samples and related data: U.S. Geological Survey Open-File Report 95-399, 113 p.

Leenhouts, J.M., Bassett, R.L., and Maddock, T., 1998, Utilization of intrinsic boron isotopes as co-migrating tracers for identifying potential nitrate contamination sources: Ground Water, v. 36, no. 2, p. 240-250.

Montgomery Watson, 2000, Local wellhead and aquifer protection study—Phase II: Available from the Municipality of Anchorage Department of Health and Human Services, Anchorage, Alaska, variously paged.

Mueller, D.K., and Helsel, D.R., 1996, Nutrients in the Nation's waters—Too much of a good thing?: U.S. Geological Survey Circular 1136, 24 p.

Palmer, M.R., and Sturchio, N.C., 1990, The boron isotope systematics of the Yellowstone National Park (Wyoming) hydrothermal system—A reconnaissance: Geochimica et Cosmochimica Acta, v. 54, p. 2811-2815.

Plummer, L.N., and Busenberg, E., 1999, Chlorofluorocarbons, chap. 15 in Cook, P.G., and Herczeg, A.L., eds., Environmental tracers in subsurface hydrology: Boston, Kluwer Academic Publishers, 552 p.

Robertson, W.D., Cherry, J.A., and Sudicky, E.A., 1991, Ground water contamination from two small septic systems on sand aquifers: Ground Water, v. 29, no. 1, p. 82-92.

Seiler, R.L., 1996, Method for identifying sources of nitrogen contamination of ground water in valleys in Washoe County, Nevada: U.S. Geological Survey Open-File Report 96-461, 20 p.

Seiler, R.L., 1999, A chemical signature for ground water contaminated by domestic wastewater: Reno, Nev., University of Nevada Reno, Ph.D. dissertation, 125 p.

Spivack, A.J., and Edmond, J.M., 1987, Boron isotope exchange between seawater and the oceanic crust: Geochimica et Cosmochimica Acta, v. 51, p. 1033-1043

Struzeski, T.M., DeGiacimi, E.W.J., and Zayhowski, E.J., 1996, Methods of analysis by the U.S.Geological Survey National Water Quality Laboratory— Determination of dissolved aluminum and boron in water by inductively coupled plasma-atomic emission spectrometry: U.S. Geological Survey Open-File Report 96-149, 17 p.

Thomas, J.M., Thodal, C.E., and Seiler, R.L., 1999, Identification of nitrate source contributing to ground water in the Indian Hills area of Douglas County, Nevada: U.S. Geological Survey Water-Resources Investigations Report 99-4042, 22 p.

Thurman, E.M., Barber II, L.B., Ceazan, M.L., Smith, R.L., Brooks, M.G., Schoeder, M.P., Keck, R.J., Driscoll, A.J., LeBlanc, D.R., and Nichols, Jr., W.J., 1984, Movement and fate of solutes in a plume of sewage-contaminated ground water, Cape Cod, Massachusetts: U.S. Geological Survey Open-File Report 84-475, 64 p.

Vengosh, A., and Keren, R., 1996, Chemical modifications of groundwater contaminated by recharge of treated sewage effluent: Journal of Contaminant Hydrology, v. 23, no. 4, p. 347-360.

Vengosh, A., Spivack, A.J., Artzi, Y., and Ayalon, A., 1999, Geochemical and boron, strontium, and oxygen isotopic constraints on the origin of the salinity in groundwater from the Mediterranean coast of Israel: Water Resources Research, v. 35, no. 6, p. 1877-1894.

Wilde, F.D., and Radtke, D.B., (eds.), 1998, National field manual for the collection of water-quality data—Field measurements: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6, variously paginated.

APPENDIX 1

Well-Elevation Data and Characteristics for Selected Wells in the Scimitar Subdivision

Appendix 1. Well-elevation data and characteristics for selected wells in the Scimitar Subdivision

[**Bold** wells on shaded rows are those with chemical analyses; mg/L, milligram per liter; --, no data]

| Well No. (fig. 1) | Scimitar location | | | USGS site ID | Latitude | Longitude | Elevation: Top of well above sea level (meters) | [a]Static water elevation (meters) | [a]Bedrock elevation (meters) | [a]Static elevation minus bedrock elevation (meters) | [a]Nitrate concentration (mg/L) |
	Sub	Blk	Lot								
	1	1	1	612406149252601	61°24'06.11"	149°2604.37"	148.83	138.2	134.8	3.4	5.13
7	**1**	**2**	**2**	**612409149254901**	**61°24'07.35"**	**149°26559.96"**	**148.84**	**134.2**	**110.1**	**24.1**	**0.68**
8	**1**	**2**	**3**	**612411149254201**	**61°24'09.38"**	**149°25'59.48"**	**149.86**	**130.5**	**125.8**	**4.7**	**5.65-5.42**
	1	2	4	612411149255601	61°24'09.10"	149°25'54.42"	150.54	127.5	142.7	-15.1	1.07
	1	2	5	612415149255501	61°24'12.31"	149°25'53.23"	149.98	--	135.4	--	2.93
	1	2	8	612416149254101	61°24'13.87"	149°25'39.98"	166.71	--	148.2	--	--
3	**1**	**2**	**9**	**612417149253303**	**61°24'12.53"**	**149°25'39.86"**	**169.70**	**147.4**	**153.0**	**-5.6**	**5.71-5.63**
	1	2	10	612414149254001	61°24'11.58"	149°25'38.71"	174.42	147.1	142.5	4.6	4.27
6	**1**	**3**	**7**	**612404149254301**	**61°24'01.93"**	**149°25'52.04"**	**189.34**	**189.6**	**171.1**	**18.5**	**3.37**
	1	3	8	612404149255601	61°24'01.13"	149°25'54.91"	188.63	190.0	154.2	35.8	12.7
	1	3	10	612401149260201	61°23'59.11"	149°2600.08"	189.55	149.7	162.4	-12.7	--
	1	3	24	612353149260501	61°23'50.78"	149°2603.87"	189.58	184.3	151.5	32.8	--
	2	2	25	612354149260201	61°23'52.14"	149°2600.81"	188.75	179.7	174.3	5.4	--
	2	3	14	612403149254901	61°24'01.10"	149°25'47.95"	190.09	181.1	179.5	1.6	5.95
5	**2**	**3**	**15**	**612404149253402**	**61°24'03.62"**	**149°25'46.94"**	**189.65**	**--**	**169.7**	**--**	**12.2**
	2	3	16	612407149254501	61°24'05.02"	149°25'43.43"	191.33	179.4	175.0	4.4	13.2

Appendix 1. Well-elevation data and characteristics for selected wells in the Scimitar Subdivision—Continued

[**Bold** wells on shaded rows are those with chemical analyses; mg/L, milligram per liter; --, no data]

Well No. (fig. 1)	Scimitar location			USGS site ID	Latitude	Longitude	Elevation: Top of well above sea level (meters)	[a]Static water elevation (meters)	[a]Bedrock elevation (meters)	[a]Static elevation minus bedrock elevation (meters)	[a]Nitrate concentration (mg/L)
	Sub	Blk	Lot								
2	**2**	**3**	**18**	**612411149252601**	**61°24'06.96"**	**149°25'37.01"**	**191.63**	**134.8**	**173.0**	**-38.2**	**0.78**
1	**3**	**1**	**1**	**612408149252001**	**61°24'04.62"**	**149°25'30.34"**	**232.81**	**193.4**	**214**	**-20.6**	**0.62**
	3	1	2	612406149253201	61°24'04.11"	149°25'30.86"	232.77	113.2	214.7	-101.5	0.72
	3	1	3	612404149253601	61°24'01.22"	149°25'34.95"	232.34	195.1	217.0	-21.9	--
4	**3**	**1**	**6**	**612359149253201**	**61°23'57.69"**	**149°25'39.16"**	**233.01**	**131.4**	**220.3**	**-88.9**	**0.634**
	3	1	7	612358149254201	61°23'55.60"	149°25'40.81"	232.26	154.6	219.6	-65.0	--
	3	1	8	612356149254501	61°23'53.50"	149°25'43.62"	235.87	--	197.9	--	--
	3	1	16	612359149254001	61°23'56.29"	149°25'38.18"	233.07	129.6	233.2	-103.4	0.71
	3	2	1	612404149253101	61°24'01.85"	149°25'29.18"	235.52	243.0	237.1	5.88	--
	3	2	2	612402149253401	61°23'59.99"	149°25'33.07"	235.49	201.9	240.7	-38.8	0.70

[a]Selected data from Montgomery Watson, 2000