GROUND-WATER ASSESSMENT OF SELECTED SHALLOW AQUIFERS IN THE NORTH FLATHEAD VALLEY AND FLATHEAD LAKE PERIMETER AREA, NORTHWEST MONTANA

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CONTENTS

FIGURES

TABLES

Introduction

Flathead Lake is listed as a high priority-303(d)-list water body and nutrient loading from ground water has been identified as a nonpoint source of impairment. Several shallow unconfined and shallow bedrock aquifers discharge into streams and rivers in the north Flathead Valley and directly into Flathead Lake around the lake perimeter. These shallow aquifers are generally more vulnerable to water-quality degradation from point and non-point sources of contamination related to land use, and consequently can contribute to declining surface-water quality. A major concern is that continued growth and development throughout the basin will further impact water quality in and around Flathead Lake. Existing data show that nitrogen and phosphorus levels have reached unacceptable levels in the lake, oxygen is depleted at depth, and algae blooms are common (Stanford and others, 1997).

The Flathead Basin Commission was awarded a U.S. Environmental Protection Agency 319 grant to assess ground-water quality in tributary regions of Flathead Lake. Under the oversight of the Flathead Basin Commission Ground Water Monitoring Committee and the Flathead Basin Volunteer Nutrient Reduction Strategy coordinator, the Montana Bureau of Mines and Geology (MBMG) and the Monitoring Committee developed a ground-water sampling plan that focused on four areas where shallow ground-water discharges directly to Flathead Lake or to the Flathead River, the main tributary to Flathead Lake. The primary goal of the project was to help establish a shallow ground-water monitoring network in the Flathead Basin and to collect water-quality data that can be used in future efforts to address the ground-water component of nutrient loading to Flathead Lake.

Water-quality data for this study were collected by MBMG and the Flathead Lake Biological Station from May 2002 through April 2003. This report presents an overview of the ground-water conditions in the focus areas and summarizes the results of the ground-water analyses performed by the Montana Bureau of Mines and Geology, and stored in the Montana Ground-Water Information Center (GWIC) database; http://mbmggwic.mtech.edu/. As part of the investigation, ground-water samples were also sent to the Flathead Lake Biological Station for low-level nutrient analyses. Those results are summarized in a separate report (Craft and Ellis, 2003).

Previous Investigations

Numerous investigations relating to ground-water resources in the Flathead Basin have been conducted since the early 1940's. These studies have examined various aspects of the hydrology, geology, water quality, and land use throughout the basin. Konizeski and others (1968) provided the first detailed summary of the hydrogeology of the Kalispell valley; the basic data for that study were presented by Brietkrietz (1966). Geographic, geologic, and hydrologic summaries of the Kalispell valley are presented in Kendy and Tresch (1996), Briar and others (1996), Clark and Dutton (1996), and Tuck and others (1996).

The most comprehensive regional investigation of the ground-water resources in the Flathead Basin was completed by the Montana Ground-Water Assessment Program. Major findings of the assessment are summarized in Patton and others (2003), and a comprehensive report will be published in 2004 (LaFave and others, in press). The hydrogeologic framework of the aquifers in the Kalispell valley and Flathead Lake is presented in a series of maps that show the surficial geology (Smith 2000a), the depth to the deep alluvium (Smith 2000c), and depth to the bedrock underlying the valley (Smith 2000b). The ground-water flow system and water quality of the deep alluvial aquifers in the Kalispell and Mission valleys is described in by LaFave (2000a, 2000b, 2000c, 2000d). Data collected during the assessment (Smith and others, 2000) provide baseline water-quality and hydrogeologic data for the major aquifers in the Flathead Lake area. The data for the Flathead Lake ground-water assessment can be accessed through http://mbmggwic.mtech.edu/.

Various aspects of the ground-water resource in the Evergreen aquifer have been evaluated by Morrison-Maierle and others (1977); Spratt (1980); Noble and Stanford (1986); and King (1988). Golder and Associates (1995) evaluated nitrate loading to ground water in the north Flathead Valley, and Uthman and others (2000) conducted a reconnaissance ground-water investigation of the upper Flathead River valley area. Boettcher (1982) evaluated ground-water resources in the central part of the Flathead Indian Reservation. The University of Montana Flathead Lake Biological Station (FLBS) has completed numerous investigation of water-quality in the Flathead Basin (Stanford and others, 1994; Stanford and others, 1997; Ellis and others, 2003). The Natural Resource Department of the Confederated Salish and Kootenai Tribe conducted an investigation assessing nutrient loading from ground-water to Flathead Lake (Makepeace and Mladenich, 1996).

Methods of Investigation

Existing records in GWIC were used to develop a list of potential wells and springs for sampling (Ground-Water Monitoring Work Plan, 2002). In each focus area, wells were selected from locales representing different land-uses (urban, unsewered residential, or agricultural). The main criteria for selection were wells that were less than 75 feet deep, or springs discharging from shallow aquifers. Existing monitoring wells and previously sampled or inventoried wells were included when possible. Potential sites were visited prior to sampling and if a well was unsuitable for sampling or owner permission was not obtained, an alternative sampling site was selected. Shallow wells (< 75 ft) are relatively uncommon around the Flathead Lake perimeter so a number of deeper wells were included when a suitable shallow well could not be located.

Thirty-eight wells and two springs were selected for inventory and water-quality sampling. The well inventory included determination of well location, land-surface altitude (from USGS 1:24,000 topographic maps), water level, aquifer unit, and predominant land-use near the well. Land use was evaluated based on field observations, county plat maps, and the National Land Coverage Dataset (U.S. Geological Survey, 1992). Basic field water-quality parameters (temperature, pH, specific conductance, redox, nitrate, and dissolved oxygen) were measured for each well prior to sample collection using a Hydrolab® Surveyor 4a system.

Water samples for laboratory analysis were collected from the wells and springs in June and September, 2002 and April, 2003. Samples were collected in accordance with the Standard Operating Procedures presented in the Ground-Water Monitoring Work Plan and the QAPP (Quality Assurance Protection Plan) prepared by MBMG; quality-control data were obtained by submitting duplicate field samples from approximately10 percent of the sampling sites. The June 2002 samples were analyzed for major ions, trace elements, and low-level nutrients. The September 2002 and April 2003 samples were analyzed for major ions and low-level nutrients. The major ion and trace element analyses were performed by the MBMG Analytical Laboratory. The low-level nutrient analyses were completed by the Flathead Lake Biological Station Freshwater Research Laboratory.

Where applicable, the water-quality data were compared with U.S. Environmental Protection Agency (1996) primary and secondary drinking-water regulations (MCLs and SDWRs) for drinking water. These standards are the permissible levels allowable in public water supply systems. Constituents for which MCLs have been set may pose a health threat at elevated concentrations. Secondary levels are set for aesthetic reasons—elevated concentrations of these constituents may be a nuisance (bad taste, odor, or staining) but do not normally pose a health risk.

Water samples from the two springs were also tested for selected environmental isotopes (tritium, oxygen-18, and deuterium) to help assess the ground-water sources for the springs. The University of Waterloo Environmental Isotope Lab performed the analyses. Tritium (^{3}H) is the radioactive isotope of hydrogen and has a half-life of 12.3 years. Tritium is produced naturally in the upper atmosphere but the principal source was the atmospheric testing of nuclear weapons between 1952 and 1963. Because of its short half life, tritium is an ideal marker of recent (post 1952) ground-water recharge. Oxygen-18 and deuterium are stable isotopes of oxygen and hydrogen in the water molecule and can be useful in evaluating potential ground-water recharge sources. The ^{18}O and D concentrations are reported as δ values, which represent the difference in parts per thousand (per mill, ‰) between the ratios of $^{18}O/^{16}O$ (or D/H) of the water samples and that of standard mean ocean water.

Descriptions of Focus Areas

This project focused on shallow aquifers in the north Flathead valley that discharge directly to the lower Flathead River or Flathead Lake. Four focus areas were delineated in areas where shallow ground water is vulnerable to contamination from overlying land-use practices. The focus areas are referred to as the Evergreen, Pothole Lakes, Lake Perimeter, and Lake Delta areas (fig. 1).

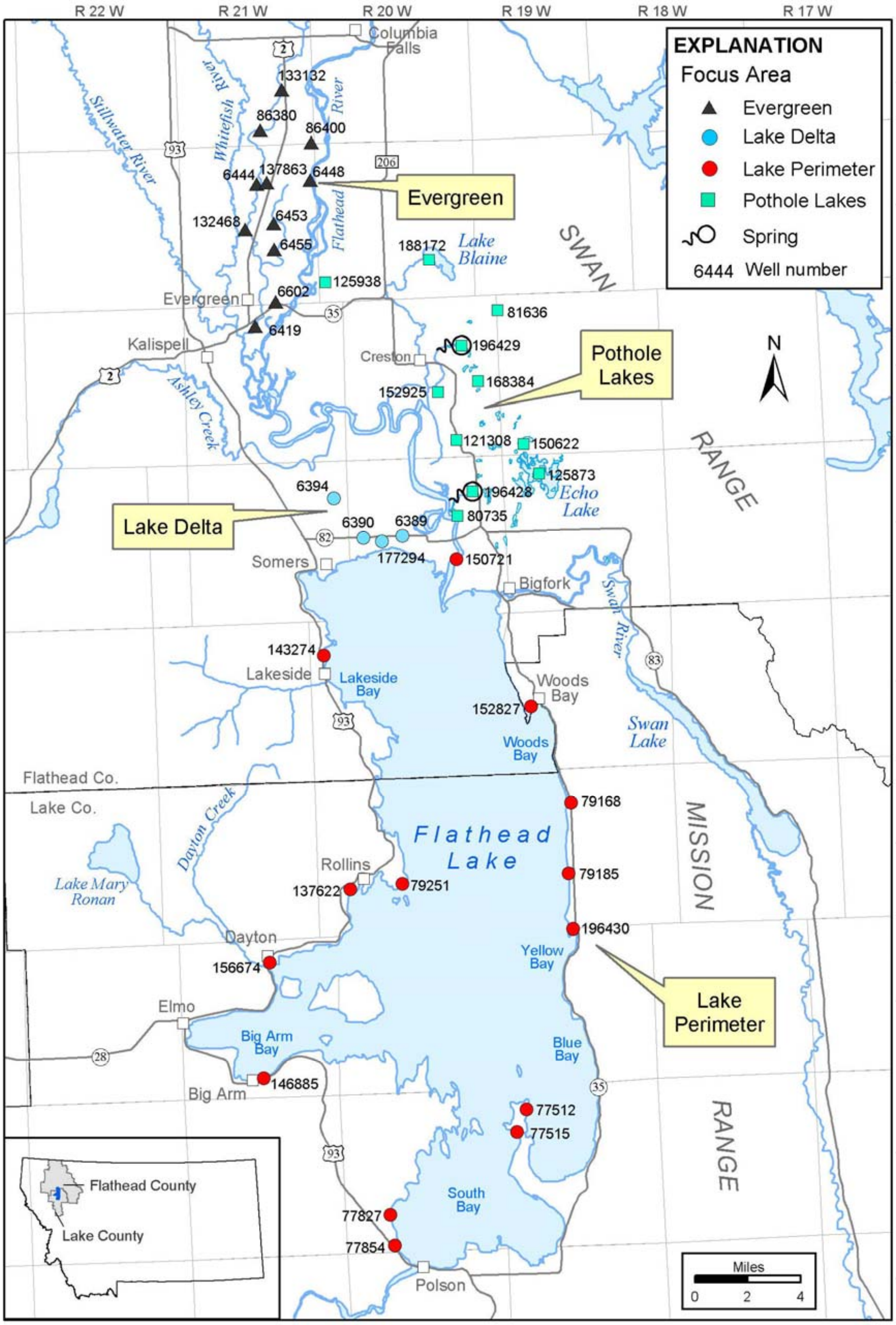

Figure 1. Locations of focus areas and well and spring monitoring sites.

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Evergreen Area

The Evergreen area encompasses the Evergreen aquifer, which is located in the alluvial plain between the Whitefish and Flathead rivers. The unconfined aquifer is about 28 feet thick and consists of unconsolidated gravel containing minor amounts of sand and silt; it is underlain by less permeable glacial till and glaciolacustrine sediments. Ground water flows from north to south and discharges near the confluence of the Stillwater and Flathead rivers. Recharge is primarily from precipitation and surface water losses from the Flathead and Whitefish rivers when river stage is high (Konizeski and others, 1968; Noble and Stanford, 1986).

Approximately 860 wells are completed in the Evergreen aquifer, and have a median reported well depth and static water level of about 25 feet and 12 feet, respectively (GWIC, 2003). The aquifer is very productive with reported yields reaching 1,500 gallons per minute (gpm). The median reported yield is 30 gpm. King (1988), Noble and Stanford (1986), and Konizeski and others (1968) estimated hydraulic transmissivity values in the range of 92,000 to 241,200 feet^2/day. Eleven wells were sampled in this area, including five that were previously sampled by Noble and Stanford (1986). Land use in the area is primarily urban, unsewered residential, and agricultural.

Pothole Lakes Area

The Pothole Lakes area is located east of the Flathead River and encompasses the general area between Echo Lake and Lake Blaine (fig. 1). The primary shallow aquifers are localized sand and gravel layers interbedded with relatively impermeable till and glacial-lake deposits. A few shallow wells are completed in bedrock near the base of the Swan Range. The semi-confined to confined alluvial aquifers are of variable thickness, generally cannot be correlated across large distances, and are usually between 50 and 100 feet below the land surface (LaFave 2000a; Konizeski and others, 1968). Reported well depths are as much as 160 feet, with a median of 35 feet. The median reported static water level is 20 feet below the ground surface. Wells reportedly yield as much as 1,000 gpm with a median yield of 25 gpm (GWIC, 2003).

Ground-water flow is generally from the western front of the Swan Range toward the Flathead River (LaFave and others, in press; LaFave, 2000a; Lorenson, 2003). Several large springs located along the western edge of the Pothole Lakes area are important sources of ground-water discharge. Seasonal water-level fluctuations ranged from 0.8 to 6.7 feet during 2002-2003 and long-term hydrographs indicate that water-level fluctuations display both seasonal and long-term climatic cycles. Water-level and water-quality data suggest that the shallow aquifers east of the Flathead River are hydraulically connected to the deep ground-water flow system and are important recharge sources to that system (LaFave 2000a; LaFave 2000b). Land use is primarily unsewered residential and agricultural. Nine wells and two springs were sampled in this area (fig. 1).

Lake Perimeter Area

The Lake Perimeter area encompasses the east, south, and west shores of Flathead Lake. Shallow ground water occurs in surficial deposits and bedrock aquifers (Makepeace and Mladenich, 1996; LaFave and others, in review). The surficial deposits are various thicknesses of unconsolidated alluvium, discontinuous accumulations of till, and glacial-lake deposits. Shallow wells completed in the alluvium are concentrated in the North Shore, Finley Point, Polson Bay, Dayton, and Woods Bay areas. The median well depth is 41 feet, median reported yield is 25 gpm, and median depth to water is 17 feet below ground surface (GWIC, 2003).

Ground water in the bedrock aquifers occurs primarily in fractures with highly variable spatial distribution and orientation. The median reported well depth for shallow bedrock wells is 74 feet and median depth to water is 23 feet below ground surface. Median reported yield of 15 gpm is lower than for the alluvial aquifers (GWIC, 2003). Water in the alluvial and bedrock aquifers is generally unconfined to confined, and flows toward Flathead Lake (Makepeace and Mladenich, 1996; LaFave and others, in review). Only about 360 of the approximately 2000 wells located around the Flathead Lake perimeter are shallow. Most of these (214) are completed in the alluvium. Land use is predominantly residential and agricultural (mostly cherry orchards along the east shore). Municipal sewer systems are available for the communities of Polson, Lakeside, Big Fork, Elmo, Somers, and for Shelter Bay, near Dayton. Eleven wells were sampled in this area (fig. 1).

Lake Delta Area

The Lake Delta area is located along the north shore of Flathead Lake and encompasses the deltaic sand aquifer delineated by Konizeski and others (1968). The delta aquifer consists of fine- to medium-grained sand, and is bordered by the Flathead River and Flathead Lake. The aquifer’s western extent approximately coincides with Highway 93. Ground-water flow direction is controlled by seasonal stages in the Flathead River and Flathead Lake and generally will be from the aquifer to the river and lake when lake and river levels are low, and from the lake and river into the aquifer when lake and river levels are high (Konizeski and others, 1968).

Depths for about 135 wells completed in the delta aquifer are as much as 75 feet below ground surface, but the median depth is 26 feet. The median reported depth to water is 16 feet (GWIC, 2003). The productivity of the aquifer is generally lower than that for other shallow aquifers; the maximum reported yield is 500 gpm and the median reported yield is 15 gpm. Permeability is generally low with reported transmissivities ranging from 1 to 3,700 $feet^2$/day (Noble and Stanford, 1986). Four wells were sampled in this area (fig. 1), including three that were installed for the Noble and Stanford (1986) study. Land use is primarily agricultural and low density residential development.

Regional Water Quality

Water samples from the 38 wells and 2 springs were analyzed for major cations, anions, and nutrients three times, beginning in June, 2001 and ending in March, 2003. Additionally, the June 2002 samples were analyzed for trace elements. The field data and analytical results for individual wells are given in appendices 1- 4. The laboratory analytical methods used for the water-quality analyses are summarized in appendix 5.

The results of the water-quality sampling show that the shallow ground water is generally of high quality and consistent in chemical composition. The relative chemical water-types are shown in figure 2; and the relative concentrations of major ions and total dissolved solids (TDS) are shown in fig. 3. Water from most of the 40 inventoried sites was a calcium-magnesium-bicarbonate type; 2 sites were mixed calcium-sodium-bicarbonate water (wells 6390 and 156674). In general, ground-water chemistry in the shallow aquifers is very similar to that in the deep alluvial aquifer. The average concentration of major ions is nearly identical between samples from the shallow and deep alluvial aquifer (fig. 2). Trace-element concentrations in ground water were low.

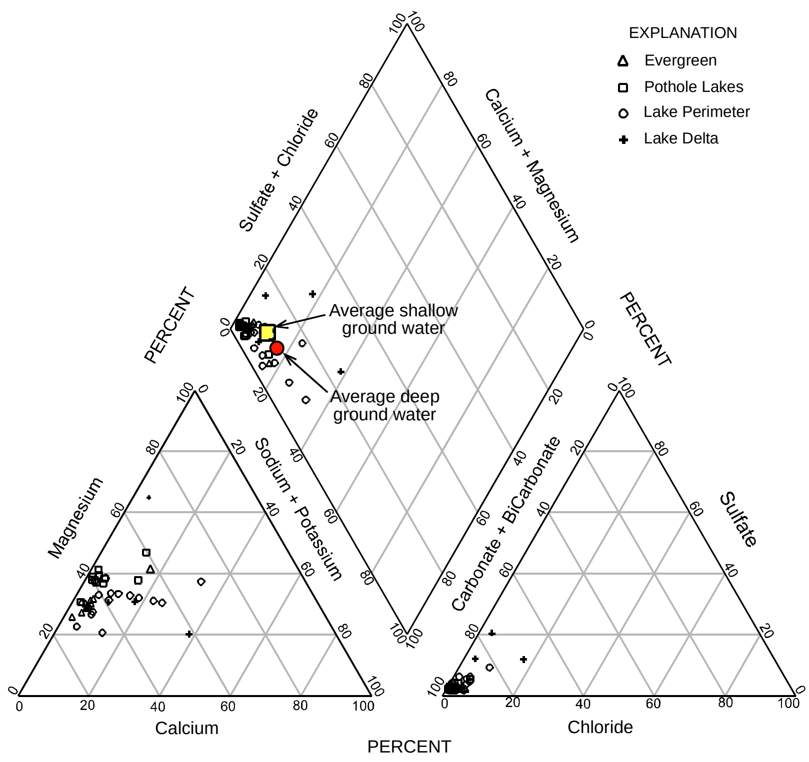

Figure 2. Trilinear diagram showing relative proportion of common ions expressed in milliequivalents per liter.

TDS concentrations were mostly less than 250 mg/L, with a median TDS concentration for all sites of 222 mg/L. The highest TDS values were measured in wells from the Delta aquifer where the median TDS concentration was 599 mg/L. Ground water in the Lake

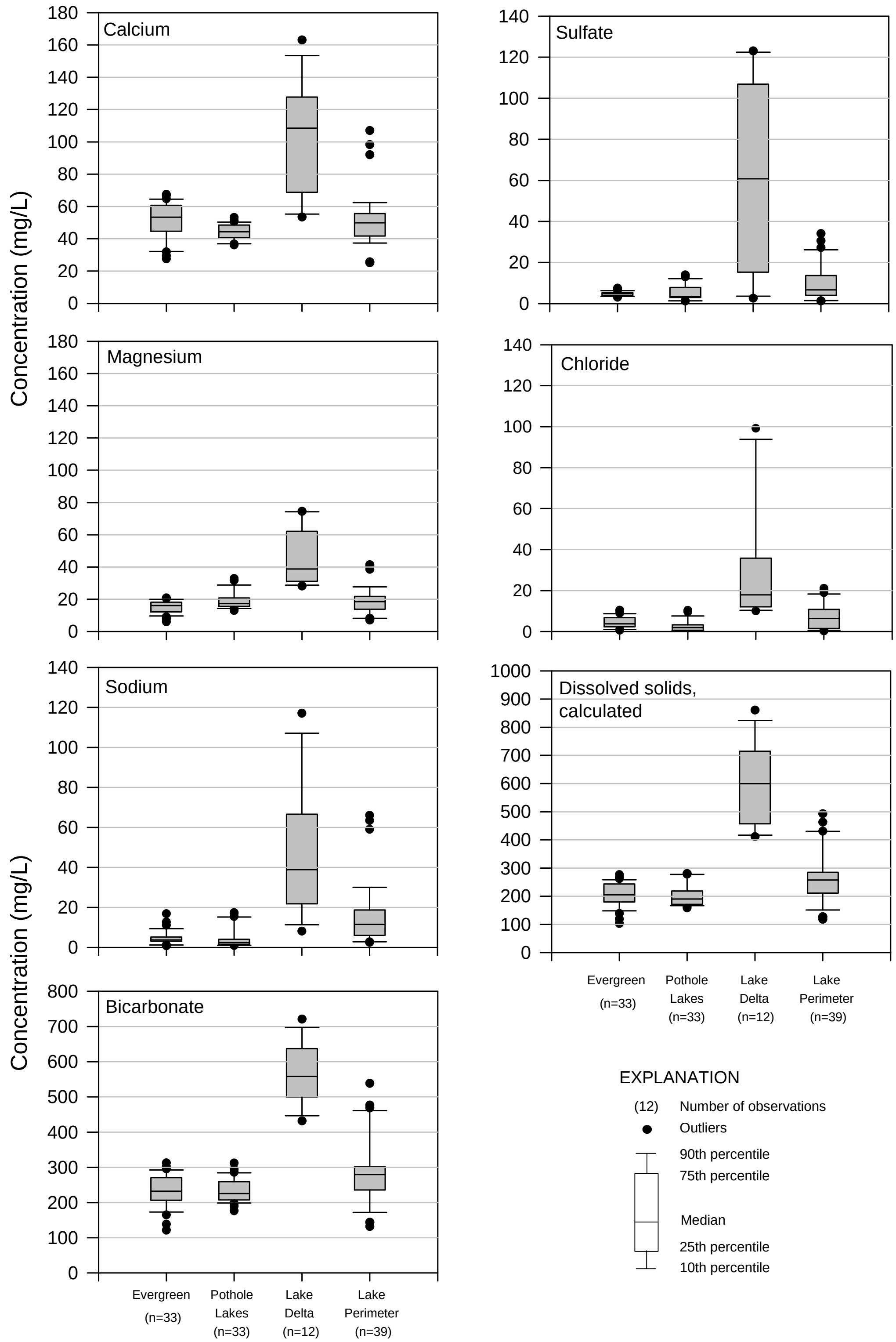

Figure 3. Distribution of concentrations for selected chemical constituents in ground water from the four focus areas.

Delta area is more mineralized than water from the other areas (fig. 3). The difference in water quality probably reflects the finer grained sediments and lower permeability of the aquifer in the Lake Delta area (Noble and Stanford, 1986). The lowest TDS values were measured in wells completed in sand and gravel aquifers in the Pothole Lakes and Evergreen areas where the median concentrations are 190 mg/L and 205 mg/L, respectively. Wells located along the east shore of Flathead Lake had lower average TDS concentrations than those along the west shore. The spatial distribution of TDS concentrations in ground water is shown in figure 4.

There were no exceedences of MCLs for major ions or trace metals, a few samples exceeded SDWRs (appendix 6). Samples from three wells in the delta aquifer exceeded the TDS SDWR of 500 mg/L. The iron SMCL of 0.3 mg/L was exceeded in water from 3 wells, and the manganese SDWR of 0.05 mg/L was exceeded in water from 7 wells. Most of the iron and manganese exceedences were in samples from wells where low (less than 1.0 mg/L) dissolved oxygen concentrations indicate reducing conditions prevail.

Nutrients

One goal of this investigation was to characterize nutrient concentrations in the shallow ground water in each of the focus areas. Nitrate ($NO_{2/3}$ - N) and orthophosphate (PO_4 - P) analyses were completed at the MBMG Laboratory as part of the analytical package for major ions. For the samples analyzed by the MBMG lab, nitrate was below the detection limit (0.5 mg/L) in approximately 43 percent of the samples; orthophosphate was below the detection limit (0.05 mg/L) in all samples. Analyses performed by the Flathead Lake Biological Station included a more comprehensive nutrient analyte list and lower detection limits; the Biological Station will report on those results (Craft and Ellis, 2004).

Nitrate

Each of the 38 wells and 2 springs were sampled three times for nitrate. Table 1 summarizes the results for the four focus areas. Nitrate was detected at least once in 26 of the wells and was not detected in the springs (appendix 3). Concentrations ranged from <0.5 mg/L to 8.5 mg/L. Water from 8 wells had nitrate concentrations that exceeded 2.0 mg/L at least once; water from 6 wells had average nitrate concentrations that exceeded 2.0 mg/L. Nitrate concentrations above 2.0 mg/L are generally considered above typical

Table 1. Summary of basic statistical parameters for nutrients in the four focus areas.

		FOCUS AREA			
Water-quality constituent	Statistic	Evergreen	Pothole Lakes	Lake Delta	Lake Perimeter
Nitrate (mg/L as N)	Mean	0.9	1.4	2.8	1.2
	Median	0.8	<0.5	1.0	0.6
	Range	<0.5 – 1.9	<0.5– 8.5	<0.5 – 7.7	<0.5 – 3.8
	n	33 (7)	33 (20)	12 (5)	39 (18)

[n = number of samples, number in parenthesis is number of samples below the detection limit; concentrations less than the detection limit were set to one-half the detection limit for computing statistics]

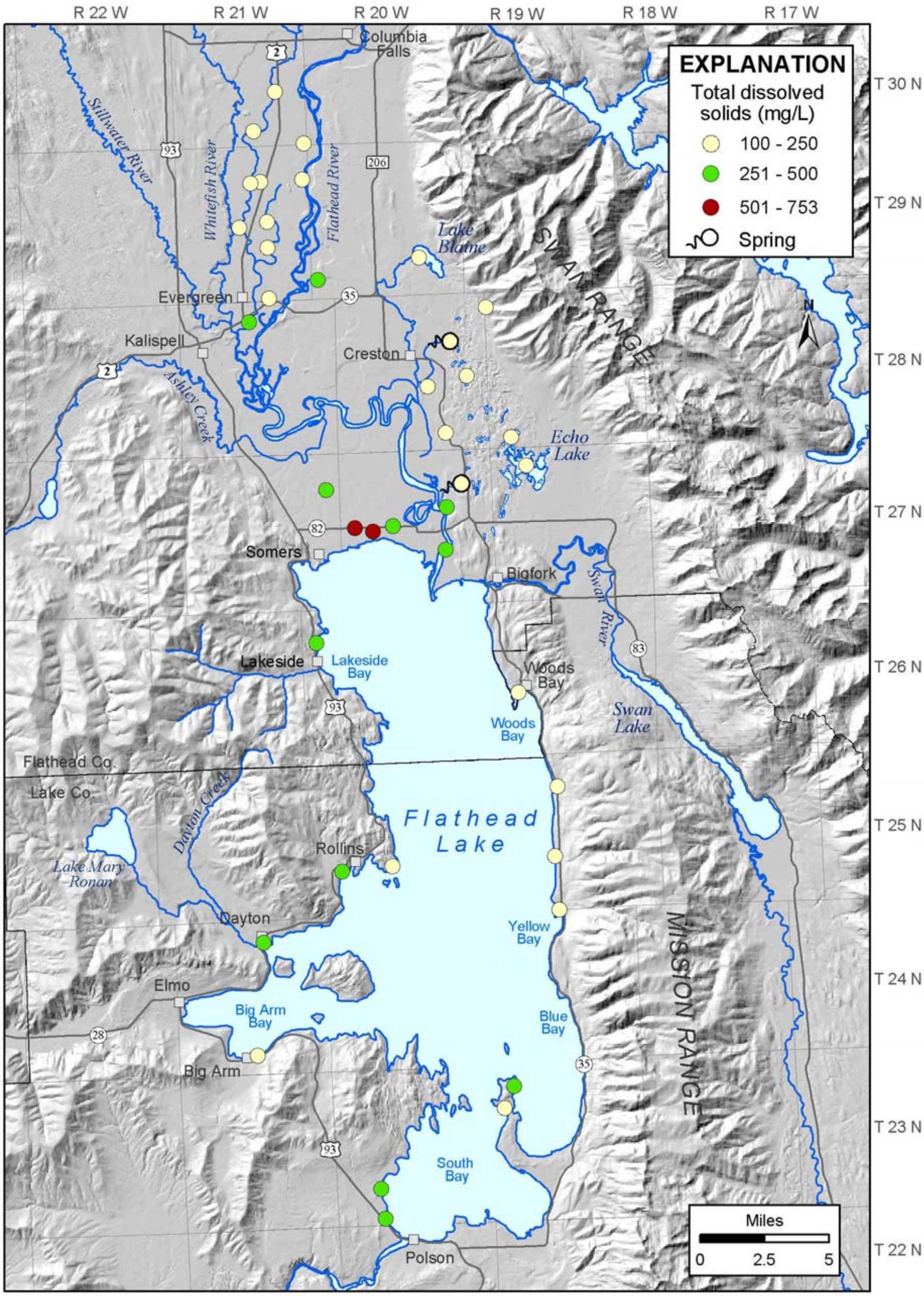

Figure 4. Distribution of average total dissolved solids (calculated) in well and spring samples.

background concentrations for shallow (less than 100 ft deep) ground water in relatively undeveloped areas (Mueller and others, 1995).

The range of nitrate concentrations in the water from the wells and springs in the four focus areas is shown in figure 5. In the Evergreen area, nitrate is pervasive in the gravel aquifer and was detected in 80 percent of the samples. Well 6448 was the only well where nitrate was not detected. Concentrations were generally low and ranged from <0.5 mg/L to 1.9 mg/L, with a mean and median annual concentration of 0.9 mg/L and 0.8 mg/L respectively (table 1). The spatial distribution of nitrate concentrations appears relatively uniform indicating that all parts of the aquifer have been affected by nitrate (fig. 6).

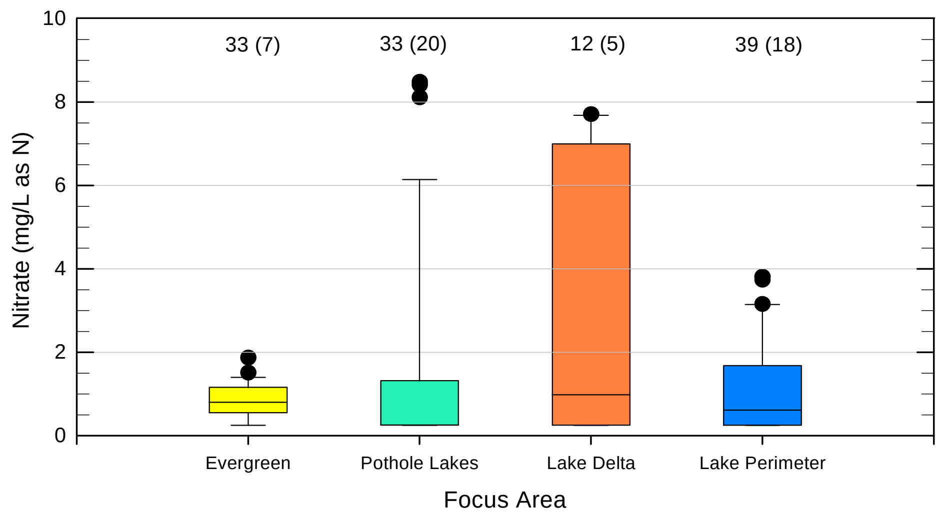

Figure 5. Nitrate concentrations in ground water by focus area. Number in parenthesis is number of analysis that were below the detection limit of 0.5 mg/L.

In the Pothole Lakes area, nitrate concentrations were among the lowest of the four focus areas (figs. 5 and 6). Nine wells and 2 springs were sampled in this area and nitrate concentrations were below the detection limit in all but 3 wells (80735, 125938, and 121308). In these 3 wells, concentrations ranged from 1.1 mg/L to 8.5 mg/L. The average nitrate concentration in well 80735 was 8.3 mg/L which was 4 to 5 times higher than the average concentrations for wells 125938 and 121308. Well 80735 had the highest nitrate concentrations of any of the 40 sites measured for this study.

In the Lake Perimeter focus area, nitrate concentrations ranged from <0.5 mg/L to 3.8 mg/L with a mean and median concentration of 1.2 mg/L and 0.6 mg/L, respectively. Nitrate was detected in 54 percent of the samples and from 8 of the 13 wells. The highest concentrations were measured in bedrock wells in the Rollins, Polson, and Finley Point areas (fig. 6). Bedrock well 77512 in the Finley Point area was the deepest well sampled (180 ft deep) and was one with consistently high nitrate concentrations (mean = 2.2 mg/L).

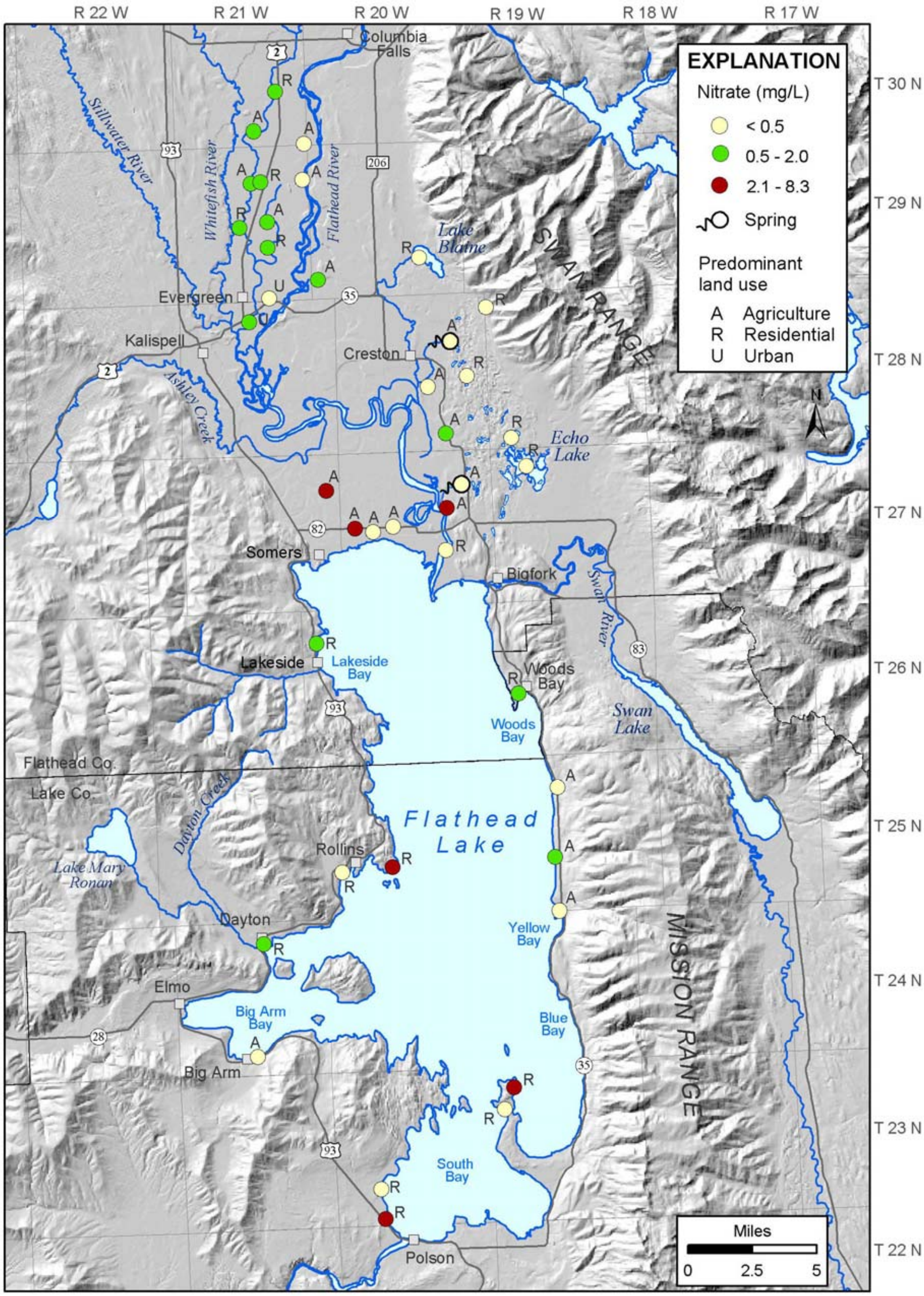

Figure 6. Distribution of average nitrate concentrations in well and spring samples.

In the Lake Delta focus area, 4 wells were sampled and nitrate was detected in all wells except 6389. Concentrations ranged from <0.5 mg/L to 7.7 mg/L, with a median of 1.0 mg/L and a mean of 2.8 mg/L (table 1). Nitrate levels in wells 6390 and 6394 were among the highest of the 40 sites sampled for this study (fig. 6). These two wells were also the shallowest wells sampled, having measured depths of only 13 feet (6390) and 18 feet (6394) below ground surface.

The relationship between nitrate concentration and depth to water is shown in figure 7. The highest nitrate concentrations were measured in wells where ground water was within about 15 feet of ground surface. Four of the 8 wells completed in bedrock had relatively high nitrate concentrations even though the depth to water was generally greater than for wells completed in alluvium. Fractured-rock aquifers can be vulnerable to surface sources of contamination because they typically have little or no soil development and fractures intersecting the surface can provide a direct conduit to the water table.

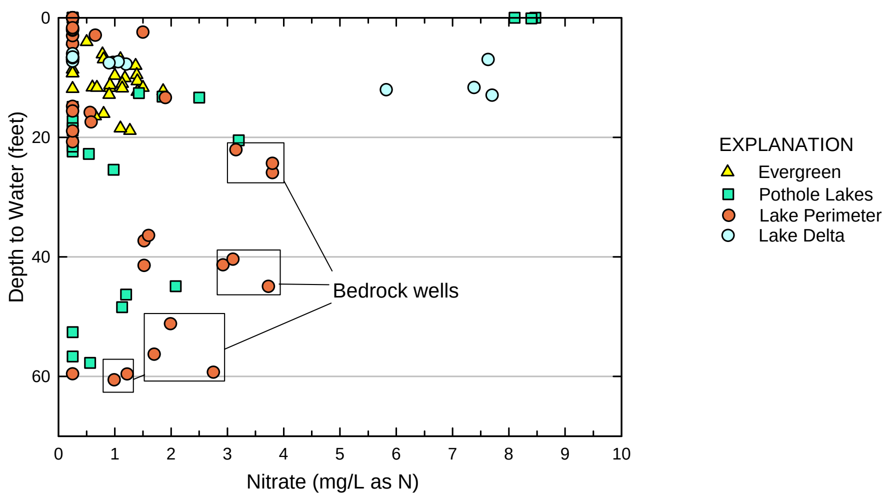

Figure 7. Nitrate concentrations in well water versus depth to water.

Seasonal Fluctuations in Nitrate Concentrations

Samples were collected in March, June, and September to evaluate general temporal changes in nitrate concentrations. In individual wells, temporal variations in nitrate concentration were highly variable (from 2 to 127 percent deviation) compared to the average concentration in each well.

It was not possible to determine if there was a seasonal pattern to the concentration changes because of the infrequent sampling schedule. Seasonal differences for each focus area, based on average nitrate concentration for the months sampled, were lower in the Evergreen and Pothole Lakes areas compared to the Lake Delta and Lake Perimeter areas (table 2).

Table 2. Summary of average nitrate concentration by sampling month for each focus area.

	Average Nitrate Concentration (mg/L as N)			
	Evergreen	Pothole Lakes	Lake Perimeter	Lake Delta
June 2002	0.9	1.3	1.0	3.9
September 2002	0.9	1.3	1.3	2.5
March 2003	0.8	1.3	1.2	1.9

Nitrate Sources

Shallow aquifers are susceptible to potential nitrate contamination from non-point surface and near-surface sources associated with different land-use practices. In residential and urban areas, septic input and residential fertilizers can contribute to loading of an aquifer. In agricultural areas, nitrate loading is primarily from inorganic fertilizers and animal waste (Hallberg, 1986). Determining sources of nitrate loading to ground water was beyond the scope of this investigation, however, wells were selected from all major land uses (urban [sewered], residential [unsewered], and agricultural) in order to evaluate potential differences in nitrate concentrations between the major land-use types. Only general land-use categories were used because of uncertainties in time of ground-water recharge and contributing land-use area for many of the wells.

Three of the wells sampled for this project were in areas where the predominant land use was urban; 19 wells and the 2 springs were from areas where land use was predominantly agricultural; and 18 wells were sampled from unsewered, residential areas (fig. 5). Figure 8 shows a comparison of the nitrate concentrations from the different land uses. In general, there is considerable overlap in concentrations although maximum nitrate concentrations were higher for agricultural and residential areas compared to urban areas. For all land uses, median nitrate concentrations were less than 1.0 mg/L.

The overlap between the different land uses may in part reflect rapidly changing land use in this area, especially the conversion of agricultural land to residential subdivisions. According to the 1997 Census of Agriculture (Montana Department of Agriculture, 2003), the total farm acreage in Flathead County decreased by approximately 22 percent between in 1992 and 1997. In Lake County, the total farm acres decreased by about 5 percent.

The consistently high nitrate level in well 80735 (fig. 1 and fig. 6) may be due to animal waste or local septic influence. This was the only well where boron (associated with waste from laundry and other cleaning products) was detected and concentrations of sodium and chloride, which are potentially good indicators of animal or human waste, were elevated. The average sodium and chloride levels (14.8 mg/L and 10.0 mg/L, respectively) in water from this domestic well were 2 - 4 times higher than values from other wells in this area. The nitrate concentration also showed only minor seasonal

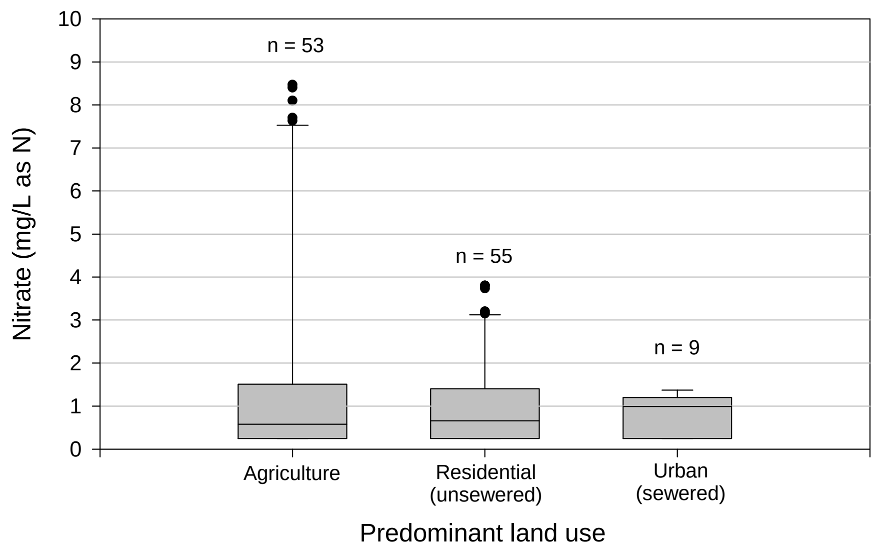

Figure 8. Distribution of nitrate in ground water from different land uses.

fluctuations (0.4 mg/L), consistent with a constant source of nitrate. The well is located in a horse pasture down slope from two private residences. There were no other apparent sources of sodium and chloride, such as road salts.

Historical Nitrate Data

Limited historical nitrate data is available for the Evergreen area and can be used to evaluate changes in ground water-quality over time. Shallow ground-water in this area was first sampled in 1968 and since that time there has been a substantial increase in residential and commercial development. In 1994, a municipal sewer system was completed for the town of Evergreen. These changes in land use can often be associated with changes in water-quality.

Konizeski and others (1968) analyzed samples from 6 wells with nitrate concentrations ranging from below detection (reported as 0 mg/L) to 0.7 mg/L. In 1976, Morrison-Maierle and others (1977) sampled 28 wells, mostly near the town of Evergreen, and reported mean and median concentrations of 0.7 mg/L and 0.7 mg/L, with a range of 0.1 mg/L to 1.6 mg/L. Nitrate data from samples collected from 15 wells in 1984-85 by Noble and Stanford (1986) had concentrations ranging from 0.3 mg/L to 1.3 mg/L, with an annual mean and median concentrations of 0.8 mg/L.

The nitrate concentrations measured during the present study (annual mean = 0.9 mg/L, annual median = 0.8 mg/L, range = <0.5 - 1.9 mg/L) are consistent with and somewhat higher than those measured by previous investigators. However, because the network of wells used for the various investigations has been different, and given the constraints of analytical and seasonal variability, it is not possible to determine if the apparent increase is statistically significant.

Environmental Isotopes – Springs

The two springs located in the Pothole Lakes area were sampled for environmental isotopes (tritium, oxygen-18 ($\delta^{18}O$) and deuterium (δD)) to help assess their source area. The springs, Elliott Spring and Jessup Mill Pond Spring, are located near the base of the elevated terrace on the east side of the valley (fig. 9) and issue from surficial alluvial deposits. Each spring is at the headwater of a tributary drainage to the Flathead River, indicating that the springs are perennial features. A flow rate could not be measured, but discharge appeared to be constant during each sampling event.

The isotope results suggest that the springs represent a discharge point for the shallow aquifer system on the east side of the valley. The tritium content of both springs (11.0 and 12.3 TU, table 3) is consistent with a modern recharge source and distinct from most of the water sampled from the deep aquifer. Of the 24 deep wells sampled for tritium in the Kalispell valley as part of the Ground-Water Assessment study (LaFave and others, in press), only three had tritium concentrations above 10 TU (fig. 9). Each of those wells is located on the east side of the valley and, although each is more than 125 feet deep, they are each completed in a part of the aquifer that probably produces surficial ground water. One well (85592) is completed in alluvium associated with and immediately adjacent to the Flathead River; one (79595) is completed in alluvium associated with, and immediately adjacent to the Swan River; and one (83424) is completed in fractured bedrock at the base of the Swan Range. The tritium values measured in the springs are also consistent with very young (less than five years) alluvial ground water measured in other places in western Montana (LaFave, 2002). Although the tritium values and water chemistry of the springs are similar, the $\delta^{18}O$ and δD values are distinct.

Table 3. Tritium, oxygen-18 ($\delta^{18}O$) and deuterium (δD) results in spring samples.

	$\delta^{18}O$	**δD**	**tritium (TU)**
Elliott Spring (196428)	-14.48	-115.66	11.0 (+/- 1.0)
Jessup Mill Pond Spring (196429)	-16.71	-125.35	12.3 (+/- 1.1)

The $\delta^{18}O$ and δD values from the Jessup Mill Pond Spring sample are enriched relative to the values from Elliott Spring and all the ground-water samples from the deep aquifer (fig. 10). The difference possibly reflects the proximity of the spring to the Swan Range front (less than 2 miles)-the potential main recharge area. The $\delta^{18}O$ and δD values from the Elliott Spring sample are within the range of samples from the deep aquifer obtained from the east part of the valley, however they are enriched relative to most of the deep aquifer samples. The results are consistent with other water chemistry results that

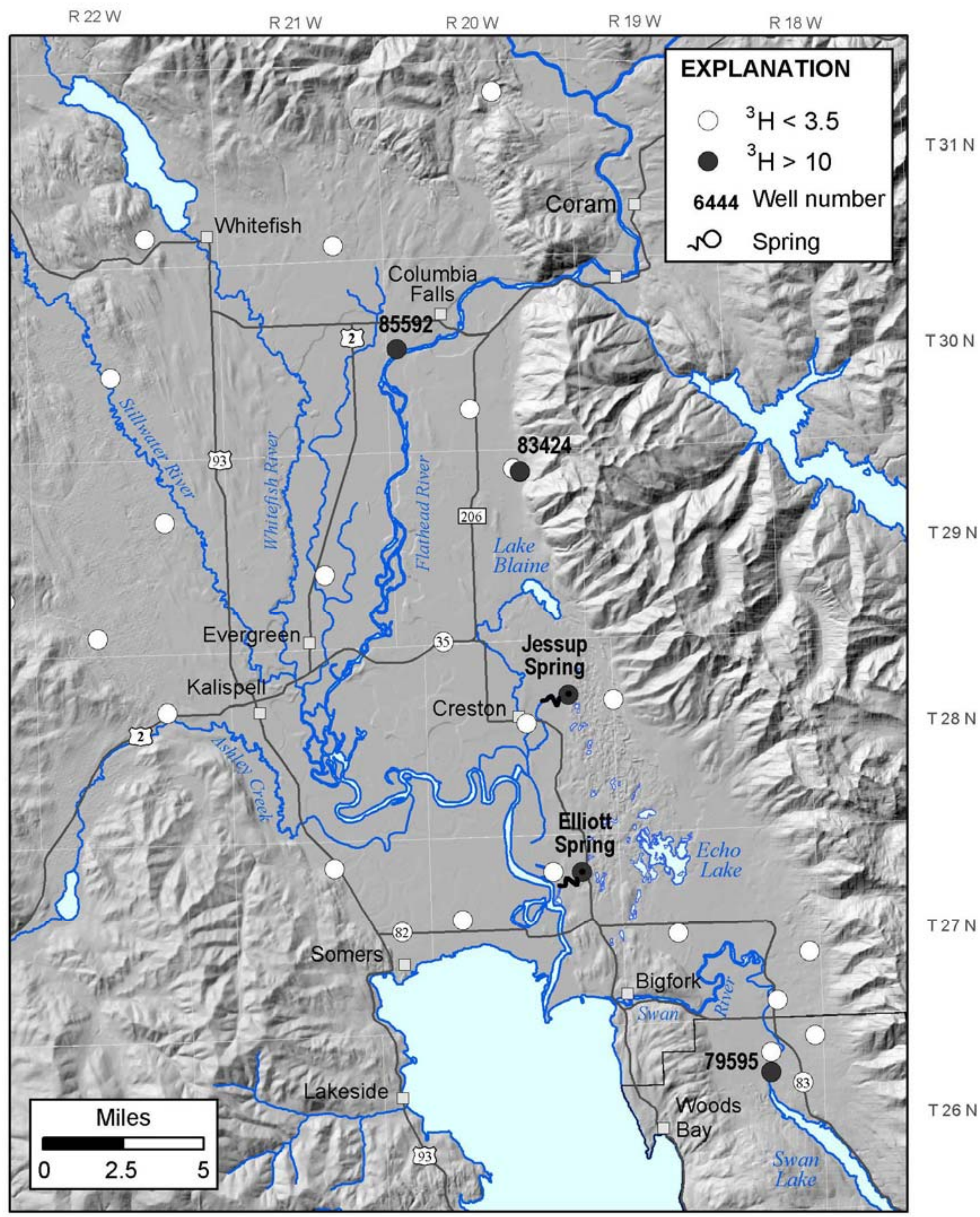

Figure 9. Distribution of tritium concentrations in springs and wells in the north Flathead valley.

indicated that the Pothole Lakes area is an important recharge source for the deep aquifer on the east side of the valley (LaFave 2000b, and LaFave and others 2004).

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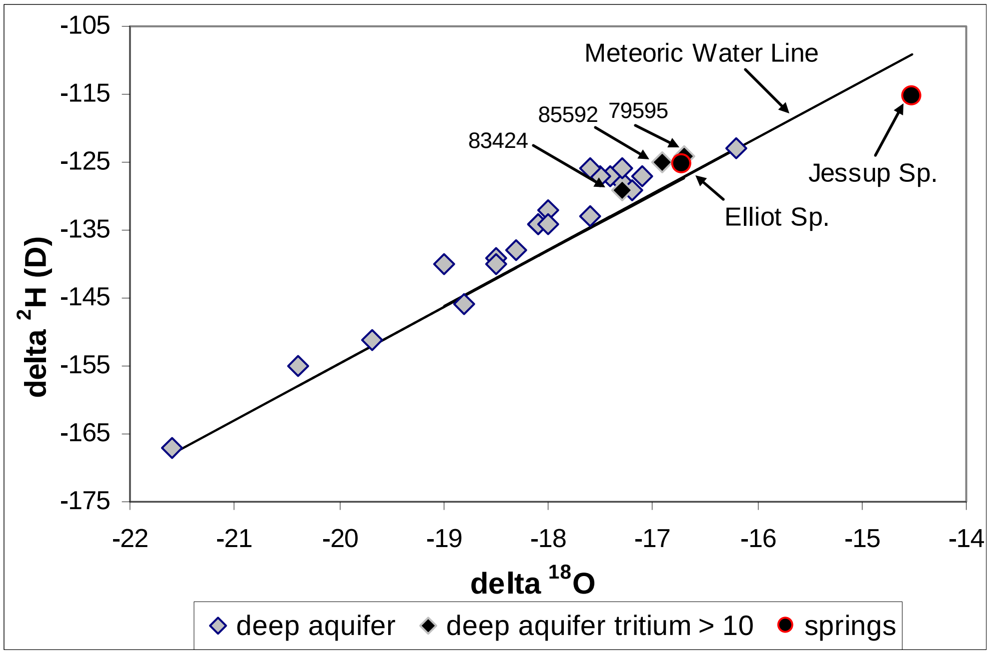

Figure 10. Oxygen-18 and deuterium results for ground-water samples in north Flathead valley.

Discussion/Recommendations

This study was initiated to help establish a ground-water monitoring network in the Flathead Basin and to collect water-quality data necessary to address the ground-water component of nutrient loading to Flathead Lake. The monitoring network established for this project includes 38 shallow wells and 2 springs from 4 areas in the Flathead Basin where shallow ground water likely interacts with surface water. Basic water-quality and nutrient data were collected to evaluate current water-quality conditions and to characterize the spatial distribution, seasonal variability, and relation to general land use for nutrients in shallow ground-water. All data collected by MBMG for this investigation are stored in the Montana Ground-Water Information Center (GWIC) database and can be accessed through http://mbmggwic.mtech.edu/.

Nitrate was the only nutrient detected, and was present in all areas evaluated. The concentrations in bedrock wells around the Flathead Lake perimeter were among the highest although well depths and depth to water was generally deeper suggesting bedrock aquifers may be more vulnerable to contamination. Based on a relatively infrequent sampling schedule, nitrate concentrations in most wells showed some seasonal fluctuations. Although the timing of seasonal changes is not well constrained, the variability needs to be considered when interpreting nitrate data or attempting long-term trend analyses. Nitrate concentrations showed considerable overlap between urban, unsewered residential, and agricultural land uses. Land use is changing rapidly in this area, especially the conversion of agricultural land to residential subdivisions, and the nitrate-concentration data presented in this report may reflect loading from multiple sources.

The focus areas selected for this investigation include areas where shallow aquifers discharge primarily to the Flathead River or directly to Flathead Lake. Determining the relative importance of these areas as sources of nutrient loading to Flathead Lake was beyond the scope of this investigation. However, nutrient concentrations in the Evergreen aquifer area have not changed significantly since nutrient loads were estimated in 1984-1985 (Noble and Stanford, 1986), indicating that ground water discharging from this aquifer remains a component of non-point nutrient loading to Flathead Lake. In the Lake Delta area, nitrate concentrations are also similar to those measured in 1984-1985. Because permeabilities and ground-water movement rates are low, the resulting nutrient load to the lake from this area is probably also minimal. Insufficient data for estimating ground-water flow rates were available for the Pothole Lakes and Lake Perimeter areas but should be collected in the future so potential nutrient loads can be estimated.

The ground-water characterization work completed for this project should be expanded to other tributaries to Flathead Lake where water-quality effects from non-point ground-water sources could be significant. In the Stillwater River drainage, a number of shallow wells have been identified where nitrate concentrations exceed the drinking-water standard of 10.0 mg/L (E. Thamke, oral commun., Montana Department of Environmental Quality, 2003). The wells are located in the Lost Creek Fan area where data collected by Smith and others (2000) suggest that shallow ground water is in hydraulic connection with the underlying deep alluvium and that the deep alluvial aquifer may be locally vulnerable to surface contamination. Other smaller tributaries including Ashley Creek and Stoner Creek are also bordered by shallow aquifers that should be evaluated.

Finally, the monitoring network established for this investigation included 8 monitoring wells, 30 privately-owned wells, and 2 springs. Since there is no guarantee that the privately owned wells will be available for future monitoring, additional permanent monitoring wells should be installed as funding permits. Installation of a permanent monitoring well network will ensure that long-term ground-water monitoring goals can be achieved. Four of the wells (6419, 6455, 81636, and 150622) are part of the MBMG Ground-water Assessment Programs state-wide, long-term monitoring network. The network includes approximately 50 wells in the Flathead Lake and Kalispell valley areas. Water-levels are measured quarterly in most of these wells, water-quality data is collected about every 5 years.

Acknowledgements

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APPENDICES

Appendix 1. Inventoried well and spring information. Wells with bold a GWIC # were wells sampled for the Noble and Stanford (1986) study. Residential land use wells were in unsewered areas.

[GWIC # - Identification number from Montana Ground Water Infromation Center (GWIC). Location: township, range, section, tract. Geologic source: ALVM- Quaternary alluvium, DRFT - Quaternary glacial drift, OTSH - Quaternary glacial outwash, BDRX - undifferentiated MIddle Proterozoic bedrock]

GWIC #	Location	Date	Depth of well (ft)	Altitude of land surface (ft)	Geologic source	Reported yield (gpm)	Predominant land use	Primary use of water	Focus Area
Wells									
6389	27N20W16CCCC	06-11-2002	23	2892	ALVM	3	Agriculture	Monitor	Delta
6390	27N20W19ABBB	06-11-2002	18	2900	ALVM	3	Agriculture	Monitor	Delta
6394	27N21W12BDDD	06-11-2002	20	2901	ALVM	1	Agriculture	Monitor	Delta
6419	28N21W04DCDA	06-10-2002	23	2915	ALVM	40	Urban-sewered	Monitor	Evergreen
6444	29N21W09ADDD	06-10-2002	18	2955	ALVM	18	Agriculture	Monitor	Evergreen
6448	29N21W11ADDA	06-10-2002	23	2953	ALVM	30	Agriculture	Monitor	Evergreen
6453	29N21W22ABBB	06-10-2002	23	2940	ALVM	30	Agriculture	Monitor	Evergreen
6455	29N21W27ABBB	06-10-2002	22	2933	ALVM	28	Residential	Monitor	Evergreen
6602	29N21W34CDDD	06-10-2002	18	2913	ALVM	33	Urban-sewered	Monitor	Evergreen
77512	23N19W06DDCA	06-19-2002	180	2943	BDRX	30	Residential	Domestic	Lake Perimeter
77515	23N19W07CADB	06-20-2002	126	2905	ALVM	17	Residential	Domestic	Lake Perimeter
77827	23N20W29DBCB	06-20-2002	137	2921	BDRX	40	Residential	Domestic	Lake Perimeter
77854	23N20W32DBDC	06-18-2002	50	2928	BDRX	25	Residential	Domestic	Lake Perimeter
79168	25N19W09BBCC	06-14-2002	60	3125	BDRX	15	Agriculture	Domestic	Lake Perimeter
79185	25N19W20DDCD	06-14-2002	60	2920	DRFT	12	Agriculture	Domestic	Lake Perimeter
79251	25N20W27BBAB	06-21-2002	74	2940	BDRX	20	Residential	Domestic	Lake Perimeter
80735	27N20W14BCAC	06-13-2002	48	2898	DRFT	12	Agriculture	Domestic	Pothole Lakes
81636	28N20W01DAAC	06-18-2002	75	3300	BDRX	20	Residential	Domestic	Pothole Lakes
86380	30N21W34ADDD	06-12-2002	25	2967	ALVM	28	Agriculture	Domestic	Evergreen
86400	29N21W36DDDC	06-12-2002	25	2963	ALVM	25	Agriculture	Domestic	Evergreen
121308	28N20W35BCAD	06-17-2002	56	2950	DRFT	24	Agriculture	Domestic	Pothole Lakes
125873	27N19W05CDBD	06-19-2002	40	3020	OTSH	15	Residential	Domestic	Pothole Lakes
125938	29N20W31BDBB	06-13-2002	64	2965	ALVM	20	Agriculture	Domestic	Pothole Lakes
132468	29N21W21BADC	06-12-2002	25	2936	ALVM	20	Residential	Domestic	Evergreen
133132	30N21W23DDCD	06-12-2002	30	2984	OTSH	15	Residential	Domestic	Evergreen
137622	25N20W29BBDB	06-21-2002	150	2900	DRFT	23	Residential	Domestic	Lake Perimeter
137863	29N21W10BDCD	06-10-2002	30	3956	ALVM	60	Residential	Domestic	Evergreen
143274	26N20W07BADD	06-13-2002	86	2960	BDRX	20	Urban-sewered	Domestic	Lake Perimeter
146885	24N21W33ADAC	06-20-2002	56	2910	ALVM	12	Agriculture	Domestic	Lake Perimeter
150622	28N19W31DACC	06-18-2002	43	3020	OTSH	15	Residential	Monitor	Pothole Lakes
150721	27N20W23CCCC	06-13-2002	68	2895	BDRX	20	Residential	Domestic	Lake Perimeter
152827	26N19W19DBAC	06-19-2002	44	2895	DRFT	60	Residential	Commercial	Lake Perimeter
152925	28N20W22DBBD	06-17-2002	158	2910	DRFT	70	Agriculture	Stock	Pothole Lakes
156674	24N21W03CDCA	06-20-2002	40	2900	ALVM	8	Residential	Domestic	Lake Perimeter
168384	28N20W24BBCD	06-13-2002	60	2975	OTSH	30	Residential	Domestic	Pothole Lakes
177294	27N20W20BACB	06-11-2002	40	2900	ALVM	4	Agriculture	Domestic	Delta
188172	29N20W26CABB	06-12-2002	41	2997	OTSH	35	Residential	Domestic	Pothole Lakes
196430	24N19W04AABD	06-14-2002	15	2918	ALVM	25	Agriculture	Monitor	Lake Perimeter
Springs									
196428	27N20W11ACDC	06-19-2002		2950			Agriculture	Irrigation	Pothole Lakes
196429	28N20W11DCCA	06-19-2002		2937			Agriculture	Fish Hatchery	Pothole Lakes

Appendix 2. Physical properties and selected water-quality parameters for well and spring sampling sites.

[GWIC # - Ground Water Information Center (GWIC) well identification number. Abbreviations: mg/L , milligrams/liter; mV, millivolts; ºC, degrees celcius, N/A - not applicable]

GWIC #	Date	Specific conductance, field (µS/cm)	pH, field (standard units)	Temperature, water (°C)	Static water level depth (ft)	Solids, sum of constituents, dissolved (mg/L)	Solids, calculated, dissolved (mg/L)	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Redox, field (mV)	Oxygen, dissolved, field (mg/L)
Wells											
6389	06-11-2002	714	7.6	8.1	6.0	679	428	357	406	107	
	06-11-2002[1]					661	418	354	393		
	09-25-2002	744	7.8	11.2	7.3	745	485	389	421	73	10
	04-01-2003	794	7.8	6.2	6.6	692	448	381	394	74	1
6390	06-11-2002	1200	7.8	7.9	7.0	1058	738	413	517	267	
	09-25-2002	1020	7.8	11.8	7.8	1002	691	424	502	167	9
	04-01-2003	1072	7.8	6.2	7.4	934	651	434	457	125	3
6394	06-11-2002	764	8.1	8.6	11.7	630	411	399	354	314	
	09-25-2002	840	8.2	12.6	13.0	773	507	455	429	281	9
	04-01-2003	979	8.1	7.9	12.1	832	548	453	458	208	3
6419	06-10-2002	492	7.3	9.0	8.1	435	276	251	256	449	
	09-23-2002	457	7.4	10.1	9.7	419	266	246	247	473	7
	03-31-2003	414	7.8	9.2	10.1	412	262	246	242	490	4
6444	06-10-2002	406	7.5	8.2	9.5	358	226	210	213	444	
	09-23-2002	406	7.5	11.4	10.6	346	222	215	200	499	11
	03-31-2003	406	7.8	7.7	11.7	349	220	209	208	446	8
6448	06-10-2002	174	8.0	6.2	4.0	164	103	93	99	425	
	09-23-2002	242	7.9	10.6	8.6	222	138	131	135	474	8
	03-31-2003	222	8.1	5.4	9.3	188	118	113	113	449	7
	03-31-2003[1]					187	117	112	112		
6453	06-10-2002	428	7.6	7.4	11.0	384	244	221	227	429	
	09-23-2002	424	7.4	9.9	11.7	387	246	225	227	479	8
	03-31-2003	461	7.6	7.7	11.8	398	253	232	235	467	7
6455	06-10-2002	343	7.6	8.0	11.3	306	193	178	183	401	
	06-10-2002[1]					307	193	175	185		
	09-23-2002	352	7.5	9.7	12.4	318	202	194	188	489	8
	03-31-2003	377	7.7	7.9	12.9	315	201	190	185	463	7
6602	06-10-2002	321	7.6	7.2	4.1	290	182	167	175	419	
	09-23-2002	303	7.7	10.6	6.2	257	163	158	152	490	9
	03-31-2003	333	7.9	6.4	6.4	280	175	163	171	398	5
77512	06-19-2002	709	6.9	10.2	51.2	632	398	349	378	463	3
	09-30-2002	593	7.2	10.1	56.3	581	367	327	346	353	2
	04-02-2003	784	7.4	9.8	59.3	668	431	382	384	720	2
77515	06-20-2002	273	7.8	10.2	1.8	256	165	123	147	101	0
77827	06-20-2002	449	7.5	11.0		413	267	176	236	342	1
	06-20-2002[1]					409	266	179	232		
	09-30-2002	399	7.7	10.8	20.8	413	268	184	234	257	1
	04-02-2003	446	7.8	10.7	19.0	406	264	178	229	394	1

Appendix 2. Physical properties and selected water-quality parameters for well and spring sampling sites.

GWIC #	Date	Specific conduct-ance, field (µS/cm)	pH, field (stan-dard units	Tem-pera-ture, water (°C)	Static water level depth (ft)	Solids, sum of constituents, dissolved (mg/L)	Solids, cal-culated, dissolved (mg/L)	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Redox, field (mV)	Oxygen, dis-solved, field (mg/L)
77854	06-18-2002	565	7.4	11.3	25.9	482	327	227	251	373	2
	09-30-2002	471	7.7	11.1	24.4	442	297	212	235	278	2
	09-30-2002[1]					435	292	208	231		
	04-03-2003	544	8.0	10.8	22.1	448	303	218	234	526	2
79168	06-14-2002	202	8.0	8.6	14.9	200	127	106	118	438	8
	10-02-2002	185	8.2	8.4	15.6	185	118	108	108	367	8
	04-01-2003	218	8.2	8.0	15.9	198	126	109	117	407	8
79185	06-14-2002	404	7.4	9.9	37.3	378	241	210	221	410	9
	06-14-2002[1]					378	241	209	221		
	10-02-2002	381	7.6	9.7	36.4	379	241	214	223	374	9
	04-03-2003	432	8.1	9.4	41.5	388	248	219	227	424	9
79251	06-21-2002	415	7.6	11.5	41.4	369	244	200	202	69	
	10-01-2002	378	7.6	10.5	40.4	357	236	196	195	259	3
	04-03-2003	443	8.0	10.4	44.9	366	244	203	197	308	3
80735	06-13-2002	514	7.6	9.2	-2.0	425	280	244	234	311	2
	09-27-2002	479	7.7	9.3	-1.0	422	278	245	232	315	2
	04-07-2003	540	7.7	9.1	0.1	422	279	244	231	236	2
81636	06-18-2002	302	7.8	5.5	56.7	279	173	170	171	389	10
	10-08-2002	348	7.9	7.8	52.6	283	175	176	176		
	04-08-2003	363	7.9	6.6	57.7	277	169	161	176		
86380	06-12-2002	386	7.5	8.8	12.3	366	231	207	217	424	
	09-24-2002	371	7.4	10.7	16.1	321	205	204	187	366	7
	04-04-2003	397	7.7	8.3	18.9	334	214	201	195	316	9
86400	06-12-2002	315	7.7	9.0		317	199	158	190	410	
	09-24-2002	338	7.7	9.0	11.6	287	184	161	167	342	1
	04-04-2003	356	8.1	7.6	11.9	313	196	150	190	256	0
121308	06-17-2002	361	7.6	9.4	12.6	347	220	205	207	422	3
	09-26-2002	340	7.7	9.4	13.4	338	216	209	197	432	3
	09-26-2002[1]				13.2	332	212	205	194		
	04-07-2003	398	7.7	9.2		334	213	205	196	269	3
125873	06-19-2002	368	7.4	10.1	17.3	332	207	194	201	239	0
	09-26-2002	289	7.6	10.4	18.8	291	182	175	177	226	0
	04-08-2003	354	7.9	10.3	21.3	304	190	180	185	180	0
125938	06-13-2002	474	7.5	9.7	44.9	434	276	228	256	362	3
	09-26-2002	400	7.6	9.8	46.3	405	256	220	241	427	4
	04-08-2003	448	8.0	9.4	48.4	391	249	203	229	272	2
132468	06-12-2002	292	7.5	8.0	6.1	281	177	156	168	292	7
	09-24-2002	295	7.5	11.2	7.0	280	177	163	166	461	7
	04-03-2003	342	7.8	6.8	6.9	293	186	170	174	318	7
133132	06-12-2002	292	7.5	9.6	9.3	271	170	160	164	391	4
	09-24-2002	395	7.3	11.4	18.5	344	219	207	203	446	6
	09-24-2002[1]					318	205	202	183		
	04-04-2003	379	7.7	7.9	16.5	325	206	196	192	304	9

Appendix 2. Physical properties and selected water-quality parameters for well and spring sampling sites.

GWIC #	Date	Specific conduct-ance, field (µS/cm)	pH, field (stan-dard units	Tem-pera-ture, water (°C)	Static water level depth (ft)	Solids, sum of constituents, dissolved (mg/L)	Solids, cal-culated, dissolved (mg/L)	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Redox, field (mV)	Oxygen, dis-solved, field (mg/L)
137622	06-21-2002	462	7.5	9.2	Flowing	429	270	228	258	78	
	10-01-2002	403	7.6	8.8	Flowing	414	259	221	250	222	3
	04-02-2003	463	7.8	8.6	-32.1	415	262	226	248	339	3
137863	06-10-2002	434	7.4	8.9		395	249	222	236	299	
	09-24-2002	476	7.3	9.8		374	243	244	211	239	0
	04-04-2003	461	7.6	9.0	11.7	387	247	231	227	232	4
143274	06-13-2002	480	7.3	9.8	59.6	438	285	242	247	330	7
	10-01-2002	445	7.5	9.3	59.6	435	284	248	244	274	7
	04-03-2003	504	7.9	9.2	60.6	418	276	246	229	319	7
146885	06-20-2002	347	7.7	10.2	Flowing	358	226	170	212	323	4
	04-02-2003	376	8.1	6.6	Flowing	337	211	170	204		
150622	06-18-2002	323	7.6	6.6	22.8	293	181	170	180	310	8
	10-08-2002	341	7.7	17.2	20.5	248	158	165	145		
	04-08-2003	331	7.7	6.2	25.4	270	169	168	165		
	04-08-2003[1]					274	171	171	166		
150721	06-13-2002	427	7.6	9.5	4.4	402	257	196	234	140	0
	10-01-2002	402	7.7	9.4	3.0	414	263	201	245	81	0
	04-07-2003	442	7.8	9.1	6.9	395	252	196	231	94	0
	04-07-2003[1]					396	252	196	232		
152827	06-19-2002	345	7.2	10.2	2.9	295	191	166	168	351	1
	09-27-2002	366	7.4	11.6	2.4	341	221	195	193	270	3
	04-01-2003	287	7.7	9.3	7.5	246	158	138	141	347	1
	04-01-2003[1]					244	158	138	140		
152925	06-17-2002	311	7.7	9.8	Flowing	261	165	159	155	413	5
	09-27-2002	272	7.8	9.1	Flowing	271	168	159	167	396	5
	04-08-2003	313	8.2	9.6	Flowing	268	166	158	165	286	5
156674	06-20-2002	819	7.3	10.3		765	492	304	441	392	2
	10-01-2002	774	7.5	10.1	13.4	633	430	301	327	274	6
	04-02-2003	829	7.7	9.7	17.5	704	462	291	391	396	2
168384	06-13-2002	378	7.6	9.0	18.5	341	210	196	211	320	5
	09-26-2002	317	7.7	9.2	20.9	329	203	199	203	310	5
	04-08-2003	378	8.0	8.7	22.4	330	205	199	203	290	5
177294	06-11-2002	1411	7.1	9.4	6.7	1226	860	633	591	174	
	09-27-2002	1101	7.0	9.6	7.6	998	674	515	524	115	0
	04-03-2003	1417	7.6	8.6	6.6	1049	723	507	526	103	0
188172	06-12-2002	285	7.8	9.1	15.3	277	172	151	170	164	0
	09-26-2002	257	7.9	8.8	14.9	269	168	152	164	198	1
	04-08-2003	306	8.3	9.0	21.6	268	168	153	162	102	0
196430	06-14-2002	228	7.2	8.8	2.1	253	162	134	148	498	8
	09-25-2002	255	7.4	10.6	2.0	254	161	137	150	564	9
	04-01-2003	268	7.7	5.1	1.7	238	151	131	141	465	8

Appendix 2. Physical properties and selected water-quality parameters for well and spring sampling sites.

GWIC #	Date	Specific conductance, field (μS/cm)	pH, field (standard units	Temperature, water (°C)	Static water level depth (ft)	Solids, sum of constituents, dissolved (mg/L)	Solids, calculated, dissolved (mg/L)	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Redox, field (mV)	Oxygen, dissolved, field (mg/L)
Springs											
196428	06-19-2002	350	7.6	9.7	N/A	297	186	176	178	492	5
	09-25-2002	320	7.4	9.8	N/A	298	186	179	182	426	6
	09-25-2002[1]				N/A	295	185	183	178		
	04-09-2003	350	7.7	9.6	N/A	298	187	180	180		6
196429	06-19-2002	399	7.5	8.3	N/A	364	226	209	224	518	7
	09-25-2002	365	7.5	8.5	N/A	349	217	208	214	491	7
	04-09-2003	397	7.7	8.0	N/A	344	215	208	209		7

[1]Duplicate analyses

Appendix 3. Results of major-ion analyses of ground-water samples from wells and springs.

[GWIC # - Ground Water Information Center (GWIC) well identification number. Abbreviations: mg/L , milligrams/liter; <, less than]

GWIC #	Date	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Iron (mg/L as Fe)	Manganese (mg/L as Mn)	Silica (mg/L as SiO_2)	Bicarbonate, (mg/L as $CaCO_3$)	Carbonate (mg/L as CO_3)	Sulfate (mg/L as SO_4)	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Nitrate (mg/L as N)	Orthophosphate (mg/L as P)
Wells															
6389	06-11-2002	96.3	28.2	19.0	0.65	1.810	0.284	24.2	495	0	2.5	11.1	0.10	<0.50	<0.05
	06-11-2002[1]	95.7	28.0	18.3	0.66	1.090	0.282	23.8	480	0	2.5	11.5	0.12	<0.50	<0.05
	09-25-2002	102.0	32.6	21.6	0.84	1.920	0.292	24.6	513	0	6.1	40.8	1.10	<0.50	<0.50
	04-01-2003	103.0	30.0	22.8	0.71	5.090	0.300	24.7	481	0	6.4	17.9	0.19	<0.50	<0.05
6390	06-11-2002	115.0	30.6	117.0	2.19	0.071	0.563	12.9	630	0	123.0	18.5	0.34	7.63	<0.05
	09-25-2002	114.0	33.9	83.9	2.42	0.124	0.592	13.8	612	0	121.0	17.8	0.36	1.20	<0.05
	04-01-2003	118.0	33.8	71.8	2.28	1.260	0.570	15.1	557	0	115.1	17.3	0.19	1.06	<0.10
6394	06-11-2002	53.4	64.5	8.1	1.67	0.029	0.241	10.7	432	0	42.3	10.0	0.55	7.38	<0.05
	09-25-2002	59.5	74.5	22.3	2.31	0.058	0.309	11.0	523	0	58.0	12.7	0.79	7.70	<0.05
	04-01-2003	59.6	73.8	43.0	2.41	0.081	0.318	11.8	559	0	63.5	11.8	0.75	5.82	<0.05
6419	06-10-2002	66.8	20.5	5.9	1.28	0.017	<0.001	9.8	312	0	6.4	10.4	0.06	1.37	<0.05
	09-23-2002	64.2	20.7	6.7	1.46	0.015	<0.001	9.8	302	0	5.0	8.9	<0.05	1.00	<0.05
	03-31-2003	64.7	20.4	6.3	1.41	0.011	<0.001	10.3	295	0	5.2	7.4	<0.05	1.18	<0.05
6444	06-10-2002	57.7	16.1	3.2	1.18	0.011	<0.001	9.6	259	0	5.1	4.4	0.08	1.39	<0.05
	09-23-2002	59.6	16.1	3.4	1.36	0.013	<0.001	9.6	244	0	5.0	5.9	<0.05	1.40	<0.05
	03-31-2003	56.4	16.5	3.8	1.31	0.010	<0.001	9.8	254	0	3.3	2.5	<0.05	0.91	<0.05
6448	06-10-2002	27.5	6.0	0.8	0.38	<0.005	<0.001	4.5	121	0	3.7	0.6	<0.05	<0.50	<0.05
	09-23-2002	37.7	9.0	1.1	0.54	0.007	0.002	5.0	165	0	3.0	1.0	<0.05	<0.50	<0.05
	03-31-2003	32.5	7.7	1.1	0.45	0.005	<0.001	4.4	138	0	3.8	0.6	<0.05	<0.50	<0.05
	03-31-2003[1]	32.2	7.7	1.1	0.43	0.005	<0.001	4.4	137	0	3.8	0.6	<0.05	<0.50	<0.05
6453	06-10-2002	60.2	17.2	4.9	1.72	0.011	<0.001	8.7	276	0	5.8	7.8	0.06	1.13	<0.05
	09-23-2002	61.8	17.2	4.8	1.87	0.015	<0.001	9.0	277	0	5.0	8.3	<0.05	1.50	<0.05
	03-31-2003	62.5	18.5	5.3	1.87	0.011	<0.001	9.1	286	0	5.1	8.4	<0.05	1.13	<0.05
6455	06-10-2002	49.3	13.3	3.1	1.69	0.009	<0.001	6.8	223	0	5.1	2.8	0.09	0.90	<0.05
	06-10-2002[1]	48.7	13.0	3.1	1.67	0.010	<0.001	6.6	225	0	5.1	2.7	0.07	0.92	<0.05
	09-23-2002	53.4	14.7	3.6	1.99	0.010	<0.001	6.9	229	0	4.0	3.5	<0.05	1.40	<0.05
	03-31-2003	52.0	14.5	4.2	2.01	0.009	<0.001	7.2	226	0	4.2	4.8	<0.05	0.90	<0.05
6602	06-10-2002	47.9	11.6	3.3	0.40	0.021	0.021	5.8	213	0	5.2	2.1	0.07	0.50	<0.05
	09-23-2002	45.8	10.6	3.2	0.43	0.008	<0.001	6.0	186	0	4.0	1.4	<0.05	<0.50	<0.05
	03-31-2003	46.5	11.3	3.2	0.44	0.012	0.011	5.6	208	0	3.8	1.4	<0.05	<0.50	<0.05
77512	06-19-2002	98.2	25.1	12.3	0.87	0.011	<0.001	13.0	460	0	8.7	11.2	<0.05	1.99	<0.05
	09-30-2002	92.0	23.7	11.1	0.83	0.014	<0.001	11.8	422	0	7.0	10.5	<0.05	1.70	<0.05
	04-02-2003	107.0	27.8	17.0	0.96	0.015	0.001	13.8	468	0	9.9	21.0	0.13	2.75	<0.05
77515	06-20-2002	37.4	7.1	8.0	1.34	0.037	0.084	15.3	180	0	6.2	0.6	0.23	<0.50	<0.05
77827	06-20-2002	41.9	17.3	27.2	1.43	0.012	<0.001	18.8	288	0	15.1	2.8	0.31	<0.50	<0.05
	06-20-2002[1]	42.4	17.8	27.3	1.52	0.081	<0.001	19.4	282	0	15.0	3.0	0.34	<0.50	<0.05
	09-30-2002	43.0	18.6	27.5	1.59	0.012	<0.001	18.5	286	0	15.0	2.8	0.19	<0.50	<0.05
	04-02-2003	41.7	17.9	28.4	1.57	0.014	<0.001	19.6	280	0	14.2	2.7	0.27	<0.50	<0.05

Appendix 3. Results of major-ion analyses of ground-water samples from wells and springs.

GWIC #	Date	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Iron (mg/L as Fe)	Manganese (mg/L as Mn)	Silica (mg/L as SiO_2)	Bicarbonate, (mg/L as $CaCO_3$)	Carbonate (mg/L as CO_3)	Sulfate (mg/L as SO_4)	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Nitrate (mg/L as N)	Orthophosphate (mg/L as P)
77854	06-18-2002	54.4	22.2	30.0	1.23	0.010	<0.001	18.3	306	0	27.2	18.9	0.35	3.80	<0.05
	09-30-2002	50.4	20.9	27.3	1.22	0.014	<0.001	17.0	286	0	21.0	15.1	0.25	3.20	<0.05
	09-30-2002[1]	49.7	20.4	26.2	1.16	0.014	<0.001	16.8	281	0	21.0	14.2	0.23	3.80	<0.05
	04-03-2003	52.7	21.0	29.6	1.23	0.014	<0.001	17.8	286	0	18.1	18.3	0.33	3.15	<0.05
79168	06-14-2002	25.2	10.5	2.4	0.69	0.008	<0.001	14.4	144	0	2.8	0.6	0.07	<0.50	<0.05
	10-02-2002	25.1	10.9	2.6	0.76	0.007	<0.001	13.9	131	0	<3.0	<0.50	<0.05	<0.50	<0.05
	04-01-2003	25.6	11.0	2.7	0.79	0.008	<0.001	14.6	143	0	<2.5	<0.50	<0.05	0.56	<0.05
79185	06-14-2002	54.3	18.0	5.9	1.30	0.013	<0.001	17.5	270	0	5.1	4.5	0.15	1.49	<0.05
	06-14-2002[1]	54.3	17.9	5.8	1.26	0.013	<0.001	17.4	270	0	5.2	4.5	0.11	1.52	<0.05
	10-02-2002	54.8	18.7	6.0	1.36	0.012	<0.001	16.9	272	0	4.0	4.1	<0.05	1.60	<0.05
	04-03-2003	55.7	19.5	6.6	1.46	0.012	<0.001	18.4	276	0	4.2	4.4	0.07	1.52	<0.05
79251	06-21-2002	49.9	18.4	11.6	0.93	0.009	<0.001	17.3	246	0	13.6	7.7	0.26	2.92	<0.05
	10-01-2002	49.3	17.6	10.7	0.88	0.012	<0.001	16.1	238	0	13.0	8.2	0.09	3.10	<0.05
	04-03-2003	50.4	18.8	12.7	1.00	0.013	<0.001	17.2	241	0	13.3	8.0	0.15	3.73	<0.05
80735	06-13-2002	45.1	31.9	14.4	3.25	0.022	<0.001	12.6	286	0	13.9	9.6	0.20	8.47	<0.05
	09-27-2002	43.9	32.8	15.4	3.54	0.016	0.002	12.0	282	0	13.0	10.3	0.12	8.10	<0.05
	04-07-2003	45.4	31.7	14.8	3.43	0.020	<0.001	12.6	281	0	13.7	10.2	0.13	8.40	<0.05
81636	06-18-2002	41.7	16.0	1.0	1.05	0.009	0.000	6.8	208	0	3.8	0.6	<0.05	<0.50	<0.05
	10-08-2002	44.0	16.0	1.0	0.63	0.012	<0.001	7.5	214	0	<3.0	<0.50	<0.05	<0.50	<0.05
	04-08-2003	40.4	14.5	1.1	0.54	<0.005	<0.001	3.4	214	0	2.9	<0.50	<0.05	0.56	<0.05
86380	06-12-2002	55.7	16.6	4.0	1.38	0.011	<0.001	9.3	265	0	7.5	4.4	0.09	1.86	<0.05
	09-24-2002	55.0	16.1	2.9	1.47	0.007	<0.001	9.5	228	0	4.0	3.1	<0.05	0.80	<0.05
	04-04-2003	53.5	16.3	3.7	1.52	0.010	<0.001	9.6	238	0	5.5	4.8	0.05	1.27	<0.05
86400	06-12-2002	31.8	19.2	12.7	3.11	0.013	0.001	7.8	232	0	7.1	2.5	0.09	0.58	<0.05
	09-24-2002	33.0	19.2	11.1	3.33	0.008	0.001	7.7	204	0	6.0	2.5	<0.05	0.60	<0.05
	04-04-2003	29.5	18.6	16.8	3.15	0.015	0.004	7.6	231	0	5.2	1.3	0.08	<0.50	<0.05
121308	06-17-2002	48.6	20.3	2.4	1.13	0.008	<0.001	10.7	252	0	8.9	2.1	0.05	1.43	<0.05
	09-26-2002	48.1	21.7	3.0	1.33	0.012	<0.001	10.7	241	0	8.0	2.0	<0.05	2.30	<0.05
	09-26-2002[1]	47.9	20.8	2.6	1.20	0.016	<0.001	10.3	237	0	8.0	2.0	<0.05	2.50	<0.05
	04-07-2003	48.3	20.4	2.6	1.18	0.012	<0.001	10.9	239	0	7.6	2.0	<0.05	1.85	<0.05
125873	06-19-2002	53.2	14.8	1.8	0.59	0.070	0.096	9.9	245	0	3.4	2.8	0.06	<0.50	<0.05
	09-26-2002	48.6	13.0	1.6	0.59	0.020	0.107	9.6	215	0	<3.0	2.0	<0.05	<0.50	<0.05
	04-08-2003	49.3	13.8	1.9	0.63	0.023	0.970	9.6	225	0	<2.5	2.6	<0.05	<0.50	<0.05
125938	06-13-2002	50.6	24.6	17.3	2.09	0.015	<0.001	10.4	312	0	10.9	4.6	0.21	2.08	<0.05
	09-26-2002	48.2	24.2	14.4	2.07	0.012	<0.001	9.8	294	0	8.0	3.4	0.08	1.20	<0.05
	04-08-2003	45.2	21.8	17.0	2.02	0.013	<0.001	10.0	279	0	10.9	3.7	0.12	1.13	<0.05
132468	06-12-2002	43.7	11.5	3.2	0.84	0.008	<0.001	8.1	205	0	4.7	3.0	0.07	0.78	<0.05
	09-24-2002	45.4	12.1	3.2	1.00	0.008	<0.001	8.3	202	0	4.0	3.2	<0.05	0.80	<0.05
	04-03-2003	47.2	12.7	3.7	0.96	0.008	<0.001	8.1	212	0	3.7	3.8	<0.05	1.10	<0.05
133132	06-12-2002	44.0	12.3	1.4	0.98	0.010	<0.001	8.2	200	0	3.4	1.0	0.09	<0.50	<0.05
	09-24-2002	55.5	16.7	3.1	1.47	0.010	<0.001	9.8	247	0	4.0	5.5	<0.05	1.10	<0.05
	09-24-2002[1]	55.7	15.2	2.7	1.31	0.011	<0.001	9.5	223	0	4.0	5.7	<0.05	0.90	<0.05
	04-04-2003	52.5	15.7	3.2	1.10	0.009	<0.001	8.0	234	0	5.5	4.1	<0.05	0.65	<0.05

Appendix 3. Results of major-ion analyses of ground-water samples from wells and springs.

GWIC #	Date	Calcium (mg/L as Ca)	Magne-sium (mg/L as Mg)	Sodium (mg/L as Na)	Potas-sium (mg/L as K)	Iron (mg/L as Fe)	Man-ganese (mg/L as Mn)	Silica (mg/L as SiO_2)	Bicar-bonate, (mg/L as $CaCO_3$)	Car-bonate (mg/L as CO_3)	Sulfate (mg/L as SO_4)	Chlo-ride (mg/L as Cl)	Fluoride (mg/L as F)	Nitrate (mg/L as N)	Ortho-phos-phate (mg/L as P)
137622	06-21-2002	59.5	19.2	11.0	1.11	0.040	0.003	15.4	314	0	7.1	1.6	0.21	<0.50	<0.05
	10-01-2002	58.0	18.6	10.2	1.04	0.064	0.005	13.7	305	0	6.0	1.3	0.09	<0.50	<0.05
	04-02-2003	58.5	19.3	11.5	1.14	0.014	0.040	15.2	302	0	5.9	1.4	0.17	<0.50	<0.05
137863	06-10-2002	61.2	16.8	4.9	1.14	0.032	0.002	9.4	288	0	6.0	6.6	0.08	0.68	<0.05
	09-24-2002	67.5	18.4	5.0	1.26	0.106	0.002	9.8	258	0	4.0	9.2	<0.05	0.80	<0.05
	04-04-2003	63.0	18.0	5.4	1.31	0.034	0.001	10.0	276	0	5.2	6.9	<0.05	0.68	<0.05
143274	06-13-2002	61.0	21.8	10.9	1.11	0.021	<0.001	17.6	301	0	12.3	10.6	0.17	1.22	<0.05
	10-01-2002	61.5	23.0	11.5	1.22	0.016	<0.001	16.9	298	0	12.0	10.8	0.07	<0.50	<0.05
	04-03-2003	62.4	22.0	11.4	1.19	0.017	<0.001	17.9	279	0	11.8	10.8	0.14	0.99	<0.05
146885	06-20-2002	41.7	16.0	13.4	1.05	0.009	0.001	20.6	259	0	4.3	1.5	0.31	<0.50	<0.05
	04-02-2003	40.7	16.7	15.1	1.13	0.093	0.058	13.2	248	0	<2.5	1.5	0.28	<0.50	<0.05
150622	06-18-2002	41.2	16.3	0.9	0.56	0.014	<0.001	7.7	220	0	5.3	0.7	<0.05	0.54	<0.05
	10-08-2002[2]	38.7	16.5	1.1	0.78	0.076	0.005	8.0	176	0	3.0	<0.50	<0.05	3.20	<0.05
	04-08-2003[2]	38.9	17.2	1.0	0.57	0.024	0.002	7.4	201	0	<2.5	<0.50	<0.05	4.33	<0.05
	04-08-2003[1]	42.8	15.7	1.2	0.62	0.015	<0.001	7.0	203	0	3.0	<0.50	<0.05	0.98	<0.05
150721	06-13-2002	47.7	18.6	18.7	2.13	0.139	0.304	15.4	285	0	4.3	9.2	0.26	<0.50	<0.05
	10-01-2002	48.8	19.3	17.9	2.19	0.252	0.502	15.1	298	0	3.0	8.5	0.14	<0.50	<0.05
	04-07-2003	47.0	19.1	18.6	2.17	0.108	0.232	15.9	282	0	2.9	7.1	0.17	<0.50	<0.05
	04-07-2003[1]	47.6	18.7	18.3	2.15	0.109	0.232	15.4	283. 7	0	3.0	7.0	0.18	<0.50	<0.05
152827	06-19-2002	47.4	11.6	5.1	1.66	0.008	<0.001	10.7	205	0	6.7	6.4	0.11	0.66	<0.05
	09-27-2002	55.1	13.9	7.0	1.98	0.010	<0.001	12.1	236	0	6.0	7.4	<0.05	1.50	<0.05
	04-01-2003	40.0	9.2	4.6	1.60	0.007	<0.001	9.8	172	0	4.2	3.5	0.07	0.97	<0.05
	04-01-2003[1]	40.2	9.2	4.6	1.59	0.007	<0.001	9.6	170	0	4.3	3.5	0.07	0.86	<0.05
152925	06-17-2002	37.8	15.6	3.6	0.73	0.008	<0.001	9.9	189	0	3.5	0.5	0.05	<0.50	<0.05
	09-27-2002	36.7	16.4	4.1	0.81	0.009	<0.001	9.5	204	0	<3.0	<0.50	<0.05	<0.50	<0.05
	04-08-2003	37.0	15.9	3.7	0.78	0.020	<0.001	9.9	201	0	<2.5	<0.50	<0.05	<0.50	<0.05
156674	06-20-2002	53.8	41.3	66.0	5.09	0.014	<0.001	19.5	538	0	26.2	14.3	0.59	0.65	<0.05
	10-01-2002	54.2	40.3	59.0	4.64	0.016	<0.001	18.6	399	0	34.0	20.6	0.49	1.90	<0.05
	04-02-2003	52.8	38.6	63.4	4.80	0.023	<0.001	18.9	476	0	30.5	17.6	0.47	0.58	<0.10
168384	06-13-2002	45.5	20.1	1.6	0.64	0.020	<0.001	9.5	258	0	4.3	1.3	<0.05	<0.50	<0.05
	09-26-2002	44.4	21.3	1.6	0.63	0.014	<0.001	9.2	248	0	3.0	1.0	<0.05	<0.50	<0.05
	04-08-2003	45.2	21.0	1.7	0.72	0.014	<0.001	9.9	248	0	3.2	1.0	<0.05	<0.50	<0.05
177294	06-11-2002	163.0	55.0	50.9	19.80	4.540	0.614	29.7	720	0	82.2	99.2	0.66	<0.50	<0.50
	09-27-2002	131.0	45.6	39.5	24.70	3.260	0.577	26.8	639	0	66.0	20.8	<0.05	0.90	<0.05
	04-03-2003	131.0	43.6	38.3	27.80	4.110	0.626	25.7	642	0	54.6	81.2	<0.25	<0.50	<0.25
188172	06-12-2002	37.0	14.3	3.8	0.60	0.044	0.006	9.2	207	0	3.7	1.4	0.10	<0.50	<0.05
	09-26-2002	36.1	15.1	4.1	0.66	0.019	0.003	8.9	200	0	3.0	1.3	<0.05	<0.50	<0.05
	04-08-2003	37.2	14.6	4.2	0.68	0.055	0.005	9.4	198	0	3.1	1.2	<0.05	<0.50	<0.05
196430	06-14-2002	41.0	7.8	2.8	1.02	0.007	<0.001	15.4	180	0	3.5	1.4	0.09	<0.50	<0.05
	09-25-2002	41.5	8.2	2.8	1.23	0.006	<0.001	15.9	183	0	<3.0	1.0	<0.05	<0.50	<0.05
	04-01-2003	39.0	8.2	3.0	1.11	0.005	<0.001	14.8	171	0	<2.5	1.0	<0.05	<0.50	<0.05

Appendix 3. Results of major-ion analyses of ground-water samples from wells and springs.

GWIC #	Date	Calcium (mg/L as Ca)	Magne-sium (mg/L as Mg)	Sodium (mg/L as Na)	Potas-sium (mg/L as K)	Iron (mg/L as Fe)	Man-ganese (mg/L as Mn)	Silica (mg/L as SiO_2)	Bicar-bonate, (mg/L as $CaCO_3$)	Car-bonate (mg/L as CO_3)	Sulfate (mg/L as SO_4)	Chlo-ride (mg/L as Cl)	Fluoride (mg/L as F)	Nitrate (mg/L as N)	Ortho-phos-phate (mg/L as P)
Springs															
196428	06-19-2002	43.4	16.5	2.5	0.74	0.011	<0.001	9.6	217	0	3.3	3.2	0.05	<0.50	<0.05
	09-25-2002	42.8	17.5	2.6	0.83	0.010	<0.001	9.4	222	0	<3.0	3.5	<0.05	<0.50	<0.05
	09-25-2002[1]	44.0	17.8	2.5	0.83	0.011	<0.001	9.5	217	0	<3.0	3.6	<0.05	<0.50	<0.05
	04-09-2003	43.3	17.4	2.7	0.85	0.011	<0.001	10.0	220	0	<2.5	4.0	<0.05	<0.50	<0.05
196429	06-19-2002	51.1	19.7	2.2	0.81	0.008	<0.001	10.9	273	0	4.4	2.0	0.05	<0.50	<0.05
	09-25-2002	49.9	20.2	2.3	0.82	0.012	<0.001	10.4	261	0	3.0	1.6	<0.05	<0.50	<0.05
	04-09-2003	49.7	20.3	2.4	0.87	0.011	<0.001	11.1	255	0	3.4	1.9	<0.05	<0.50	<0.05

[1]Duplicate analyses

[2]Sample for nitrate analysis was contaminated after collection in the field based on comparison with field nitrate test and analysis from FLBS

Appendix 4. Trace-element concentrations for water from wells and springs.

[GWIC # - Identification number from Montana Ground Water Information Center (GWIC). Abbreviations: µg/L, micrograms per liter; <, less than]

GWIC #	Date	Aluminum (µg/L as Al)	Antimony (µg/L as Sb)	Arsenic (µg/L as As)	Barium (µg/L as Ba)	Beryllium (µg/L as Be)	Boron (µg/L as B)	Bromide (µg/L as Br)	Cadmium (µg/L as Cd)	Chromium (µg/L as Cr)	Cobalt (µg/L as Co)	Copper (µg/L as Cu)
Wells												
6389	06-11-2002	<30	<2	<1	740	<2	<30	<50	<2	<2	<2	<2
6389	6-11-2002[1]	<30	<2	<1	729	<2	<30	<50	<2	<2	<2	<2
6390	06-11-2002	<150	<10	<5	209	<10	<150	131	<2	<10	<10	<10
6394	06-11-2002	<30	<2	<1	741	<2	<30	165	<2	<2	<2	<2
6419	06-10-2002	<30	<2	<1	426	<2	<30	<50	<2	<2	<2	<2
6444	06-10-2002	<30	<2	<1	243	<2	<30	<50	<2	<2	<2	<2
6448	06-10-2002	<30	<2	<1	119	<2	<30	<50	<2	<2	<2	<2
6453	06-10-2002	<30	<2	<1	353	<2	<30	<50	<2	<2	<2	<2
6455	06-10-2002	<30	<2	<1	330	<2	<30	<50	<2	<2	<2	<2
6455	6-10-2002[1]	<30	<2	<1	325	<2	<30	<50	<2	<2	<2	<2
6602	06-10-2002	<30	<2	<1	269	<2	<30	<50	<2	<2	<2	<2
77512	06-19-2002	<30	<2	<1	183	<2	<30	60	<2	<2	<2	16
77515	06-20-2002	<30	<2	<1	107	<2	<30	<50	<2	<2	<2	<2
77827	06-20-2002	<30	<2	<1	178	<2	<30	<50	<2	<2	<2	<2
77827	6-20-2002[1]	<30	<2	<1	176	<2	<30	56	<2	<2	<2	<2
77854	06-18-2002	<30	<2	<1	96	<2	<30	70	<2	<2	<2	3
79168	06-14-2002	<30	<2	<1	106	<2	<30	<50	<2	<2	<2	<2
79185	06-14-2002	<30	<2	<1	214	<2	<30	<50	<2	<2	<2	3
79185	6-14-2002[1]	<30	<2	<1	214	<2	<30	<50	<2	<2	<2	3
79251	06-21-2002	<30	<2	<1	52	<2	<30	72	<2	<2	<2	<2
80735	06-13-2002	<30	<2	<1	307	<2	34	<50	<2	<2	<2	<2
81636	06-18-2002	<30	<2	<1	145	<2	<30	<50	<2	<2	<2	<2
86380	06-12-2002	<30	<2	<1	195	<2	<30	<50	<2	<2	<2	37
86400	06-12-2002	<30	<2	<1	302	<2	<30	<50	<2	<2	<2	<2
121308	06-17-2002	<30	<2	<1	463	<2	<30	<50	<2	<2	<2	<2
125873	06-19-2002	<30	<2	<1	142	<2	<30	<50	<2	<2	<2	<2
125938	06-13-2002	<30	<2	<1	282	<2	<30	<50	<2	<2	<2	<2
132468	06-12-2002	<30	<2	<1	185	<2	<30	<50	<2	<2	<2	3
133132	06-12-2002	<30	<2	<1	112	<2	<30	<50	<2	<2	<2	<2
137622	06-21-2002	<30	<2	<1	179	<2	<30	<50	<2	<2	<2	<2
137863	06-10-2002	<30	<2	<1	306	<2	<30	<50	<2	<2	<2	<2
143274	06-13-2002	<30	<2	<1	53	<2	<30	108	<2	<2	<2	<2
146885	06-20-2002	<30	<2	1	284	<2	<30	51	<2	<2	<2	<2
150622	06-18-2002	<30	<2	<1	73	<2	<30	<50	<2	<2	<2	<2
150721	06-13-2002	<30	<2	1	214	<2	<30	86	<2	<2	<2	<2
152827	06-19-2002	<30	<2	<1	135	<2	<30	<50	<2	<2	<2	<2
152925	06-17-2002	<30	<2	<1	377	<2	<30	<50	<2	<2	<2	<2
156674	06-20-2002	<30	<2	5	328	<2	<30	147	<2	<2	<2	4
168384	06-13-2002	<30	<2	<1	189	<2	<30	<50	<2	<2	<2	<2
177294	06-11-2002	<150	<10	<5	700	<10	<150	<500	<2	<10	<10	<10
188172	06-12-2002	<30	<2	<1	305	<2	<30	<50	<2	<2	<2	<2
196430	06-14-2002	<30	<2	<1	171	<2	<30	<50	<2	<2	<2	<2
Springs												
196428	06-19-2002	<30	<2	<1	308	<2	<30	<50	<2	<2	<2	<2
196429	06-19-2002	<30	<2	<1	220	<2	<30	<50	<2	<2	<2	<2

[1]Duplicate analyses

Appendix 4. Trace-element concentrations for water from wells and springs (Continued).

Lead (µg/L as Pb)	Lithium (µg/L as Li)	Molyb-denum (µg/L as Mo)	Nickel (µg/L as Ni)	Selenium (µg/L as Se)	Silver (µg/L as Ag)	Stron-tium (µg/L as Sr)	Titanium (µg/L as Ti)	Vana-dium (µg/L as V)	Zinc (µg/L as Zn)	Zircon-ium (µg/L as Zr)	GWIC #
<2	2	<10	3	<1	<1	174	<1	<5	<2	<2	6389
<2	2	<10	4	<1	<1	174	<1	<5	2	<2	6389
<10	7	<50	<10	<5	<5	193	<1	<25	<10	<2	6390
<2	9	<10	3	1.29	<1	250	<1	<5	3	<2	6394
<2	1	<10	3	<1	<1	104	<1	<5	3	<2	6419
<2	<1	<10	3	<1	<1	72	<1	<5	2	<2	6444
<2	<1	<10	<2	<1	<1	48	<1	<5	<2	<2	6448
<2	<1	<10	3	<1	<1	87	<1	<5	<2	<2	6453
<2	1	<10	2	<1	<1	84	<1	<5	<2	<2	6455
<2	1	<10	<2	<1	<1	83	<1	<5	<2	<2	6455
<2	1	<10	3	<1	<1	86	<1	<5	2	<2	6602
<2	11	<10	3	<1	<1	169	<1	<5	14	<2	77512
<2	3	<10	<2	<1	<1	116	<1	<5	15	<2	77515
<2	4	<10	<2	<1	<1	198	<1	<5	27	<2	77827
<2	5	<10	<2	<1	<1	198	<1	<5	24	<2	77827
<2	6	<10	<2	<1	<1	194	<1	<5	44	<2	77854
<2	1	<10	<2	<1	<1	113	<1	<5	12	<2	79168
<2	4	<10	<2	<1	<1	244	<1	<5	<2	<2	79185
<2	4	<10	<2	<1	<1	245	<1	<5	15	<2	79185
<2	6	<10	<2	<1	<1	132	<1	<5	45	<2	79251
<2	7	<10	<2	<1	<1	274	<1	<5	49	<2	80735
<2	2	<10	<2	<1	<1	53	<1	<5	<2	<2	81636
<2	<1	<10	2	<1	<1	78	<1	<5	18	<2	86380
<2	2	<10	<2	<1	<1	151	<1	<5	4	<2	86400
<2	2	<10	<2	<1	<1	83	<1	<5	21	<2	121308
<2	1	<10	<2	<1	<1	62	<1	<5	6	<2	125873
<2	4	<10	<2	<1	<1	183	<1	<5	31	<2	125938
<2	<1	<10	<2	<1	<1	71	<1	<5	4	<2	132468
<2	1	<10	<2	<1	<1	53	<1	<5	43	<2	133132
<2	2	<10	<2	<1	<1	133	<1	<5	8	<2	137622
<2	1	<10	2	<1	<1	82	<1	<5	109	<2	137863
<2	8	<10	2	<1	<1	196	<1	<5	17	<2	143274
<2	2	<10	<2	<1	<1	204	<1	<5	13	<2	146885
<2	<1	<10	<2	<1	<1	52	<1	<5	3	<2	150622
<2	4	<10	<2	<1	<1	201	<1	<5	34	<2	150721
<2	2	<10	<2	<1	<1	95	<1	<5	35	<2	152827
<2	2	<10	<2	<1	<1	82	<1	<5	4	<2	152925
<2	8	<10	<2	<1	<1	277	<1	<5	22	<2	156674
<2	1	<10	2	<2	<1	69	<1	<5	14	<2	168384
<10	13	<50	<10	<5	<5	246	<1	<25	46	<2	177294
<2	3	<10	<2	<1	<1	84	<1	<5	17	<2	188172
<2	<1	<10	<2	<1	<1	93	<1	<5	4	<2	196430
<2	<1	<10	<2	<1	<1	73	<1	<5	2	<2	196428
<2	2	<10	<2	<1	<1	75	<1	<5	4	<2	196429

Appendix 5. MBMG Laboratory analytical methods for standard water-quality analyses.

[Instruments: ICP - Inductively Coupled Plasma; MS - Mass Spectrometry]

Cations (ICP) EPA Method 200.7

Element	Detection Limit (µg/L)	Element	Detection Limit (µg/L)
boron (B)	80	potassium (K)	20
calcium (Ca)	10	sodium (Na)	20
iron (Fe)	5	silica (SiO_2)	107
lithium (Li)	5	strontium (Sr)	1
magnesium (Mg)	10	titanium (Ti)	2
manganese (Mn)	1	zirconium (Zr)	5

note: Ca, Fe, Mg, Mn, Na, and SiO2 are normally reported in mg/L.

Cation (ICP/MS) EPA Method 200.8/6020-CLPM

Element	Detection Limit (µg/L)	Element	Detection Limit (µg/L)
aluminum (Al)	30	copper (Cu)	2
antimony (Sb)	2	lead (Pb)	2
arsenic (As)	1	molybdenum (Mo)	10
barium (Ba)	2	nickel (Ni)	2
beryllium (Be)	2	selenium (Se)	1
cadmium (Cd)	2	silver (Ag)	1
cobalt (Co)	2	vanadium (V)	5
chromium (Cr)	2	zinc (Zn)	2

Anions EPA Method 300.0A

Parameter	Detection Limit (mg/L)
bromide (Br)	0.05
chloride (Cl)	0.5
fluoride (F)	0.05
nitrate (as N)	0.05
nitrite (as N)	0.05
orthophosphate (as P)	0.1
sulfate	2.5

Other Tests

Parameter	EPA Method
alkalinity	310.1
pH	150.1
specific conductance	120.1

Appendix 6. Drinking-water regulations and guidelines for public water supply.

Parameter	National Primary Drinking-Water Regulation (MCL)*	National Secondary Drinking-Water Regulation (SDWR)*	Montana Drinking-Water Regulation**
		Physical property (standard units)	
pH		6.8-8.5	
		Common constituents (mg/L)	
Dissolved Solids	--	500	--
Chloride	--	250	--
Fluoride	4	2	4.0
Nitrate (as N)	10	--	10.0
Sulfate	500	250	--
		Trace elements (mg/L)	
Aluminum	--	0.05-0.2	--
Arsenic	0.05	--	0.018
Barium	2	--	1
Beryllium	0.004	--	0.04
Cadmium	0.005	--	0.005
Chromium	0.1	--	0.1
Copper	1.3	1	1
Iron	--	0.3	0.3
Lead	0.015	--	0.015
Manganese	--	0.05	0.05
Nickel	0.14	--	0.1
Selenium	0.05	--	0.05
Silver	--	0.1	--
Zinc	--	5	5

* U.S. Environmental Protection Agency, 1996

** Montana Department of Environmental Quality, 1995