Ground Water Quality Technical Report No. 6

An Evaluation of Arsenic in Ground Water in a Portion of Washington County, Idaho

**Idaho Division of Environmental Quality
Southwest Idaho Regional Office
September 1995**

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Prepared by:

Rob Howarth

Idaho Department of Health and Welfare
Division of Environmental Quality
Southwest Idaho Regional Office
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Abstract

The Idaho Division of Environmental Quality, Southwest Idaho Regional Office (DEQ) was notified that high levels of arsenic had been detected in two private wells in Washington County. The arsenic concentrations in these two wells were 240 micrograms per liter (ìg/l) and 950 ìg/l. The arsenic was detected through the Idaho Department of Water Resources' (IDWR) Statewide Ground Water Quality Monitoring Program. These high levels of arsenic led to concern for public health and resulted in an interagency organizational meeting convened for the purpose of developing appropriate follow-up activities. The state's Ground Water Quality Plan directs DEQ to perform activities, including regional and local monitoring, to evaluate areas of ground water contamination.

The project goals outlined at the interagency meeting were:

(1) Assure that immediate public health issues are addressed by contacting homeowners with known elevated arsenic in their drinking water.

(2) Delineate an area of concern with respect to elevated arsenic by sampling ground water from selected domestic wells. This information will also be used as a baseline for evaluating the need for long-term research that will aid in more precisely determining the source of elevated arsenic in the ground water.

(3) Determine appropriate public notification procedures based on the analytical results.

Goal #1 was addressed by IDWR performing follow-up contacts with the two homeowners with the highest arsenic detections. This report presents the findings of this study and addresses goal #2 and a portion of goal #3. A secondary objective of evaluating potential sources of elevated arsenic in the ground water is also briefly discussed.

The study area is located approximately eight miles northeast of Weiser, Idaho, in the lower Mann Creek and Monroe Creek drainages. Agricultural activities constitute the dominant land use. The geology is characterized as Holocene to Pliocene-aged, poorly to well-sorted lacustrine and fluviatile deposits of clay, silt, sand, and some gravel. These sediments exceed 1,500 feet in thickness near Weiser.

Sampling and comprehensive chemical analyses of 14 domestic wells and one surface water location were performed in January, 1995. The distribution of arsenic-rich ground water in the study area was found to be random at the scale of this investigation. Some correlation between elevated arsenic concentrations and the elevation of the water-producing strata may exist. Clay-rich sediments which generally occur below coarser-grained alluvial deposits may produce arsenic-rich ground water. Elevated arsenic also appears to be correlated with higher concentrations of sodium, usually above two milliequivalents per liter or 46 milligrams per liter. No evidence was obtained to suggest that elevated concentrations of arsenic in ground water in the study area are caused by human activity (i.e., the application of arsenic-containing pesticides).

Introduction

In November, 1994, the Idaho Division of Environmental Quality, Southwest Idaho Regional Office (DEQ), was notified that high levels of arsenic had been detected in two private wells in Washington County. Twenty six wells in the County have been sampled since 1990 as part of the Idaho Department of Water Resources' (IDWR) Statewide Ground Water Quality Monitoring Program. This program was established to comply with the requirements of the state's Ground Water Quality Protection Act of 1989. The Statewide Ground Water Quality Program is designed to address three main objectives (Crockett, 1995):

(1) Characterize the ground water quality of the state's aquifers.

(2) Identify potential problem areas.

(3) Identify trends and changes in ground water quality within the state's aquifers.

These objectives are met by sampling a network of wells for a comprehensive chemical analysis (for a description of the network design, see Neely, 1994). The two highest arsenic levels in ground water detected through the Statewide Ground Water Quality Monitoring Program occur within two miles of each other in an area approximately eight miles northeast of Weiser, Idaho in Washington County. The two wells of concern provide water for domestic purposes and contain concentrations of arsenic of 240 micrograms per liter (ìg/l) and 950 ìg/l. The current maximum contaminant level (MCL) allowed in public water systems is 50 ìg/l. The wells are 70 and 75 feet deep, respectively.

The detection of these extreme arsenic levels led to concern that other domestic wells in the area may contain unsafe concentrations of arsenic and that most homeowners would not be aware of the potential health concerns. Upon receiving notification of the elevated arsenic, DEQ organized a meeting of local, state, and federal agencies that could provide assistance in developing the best-possible response to a possible public health problem. The agencies represented at the organizational meeting included:

- DEQ
- IDWR
- Idaho Department of Health and Welfare, Division of Health (DoH)
- Idaho Department of Agriculture (IDA)
- Southwest District Health Department (SWDHD)
- Environmental Protection Agency
- United States Geological Survey (USGS)

Representatives from these groups provided valuable information and expertise on the occurrence of arsenic in the environment and on the associated health risks due to exposure to arsenic. Three main response goals were identified during the meeting. Starting with the most important goal first, they are:

(1) Assure that immediate public health issues are addressed by contacting homeowners with known elevated arsenic in their drinking water.

(2) Delineate an area of concern with respect to elevated arsenic by sampling ground water from selected domestic wells. This information will also be used as a baseline for evaluating the need for long-term research that will aid in more precisely determining the source of elevated arsenic in the ground water.

(3) Determine appropriate public notification procedures based on the analytical results.

To achieve these goals, a course of action for each participating agency was outlined. Goal #1 was addressed by IDWR performing follow-up contacts with the two homeowners with the highest arsenic detections. Health-related issues were discussed and a recommendation was made to have family members visit a physician to assess whether any arsenic-related health effects exist. Toxicologists from IDA and DoH provided technical assistance to IDWR. The DoH also developed an arsenic "fact sheet" to provide environmental and health information to affected homeowners and other interested individuals.

Goal #2 was addressed by DEQ performing sampling and analysis of private domestic wells and surface water. This report presents the findings of that study and thereby addresses a portion of goal #3 as well.

Purpose and Objectives

The purpose of this report is to present the findings of the well and surface water sampling project introduced above. Fourteen private domestic wells ranging in depth from 45 to 325 feet were sampled. In addition, one surface water sample was obtained to determine whether surface water could be directly influencing the quality of the ground water. The objective of the sampling study is to delineate an area with arsenic-rich ground water and to provide baseline data for additional studies. A secondary objective is to provide an evaluation of potential sources of the arsenic-rich ground water, if possible, given the limited data collection associated with this study. This sampling study and report also satisfy DEQ's responsibility to perform follow-up sampling of identified contamination in accordance with the *Idaho Ground Water Quality Plan* (1992).

Literature Review

An abundance of published scientific investigations related to ground water quality in Washington County does not appear to exist. The primary references used in this investigation include a study by Young et. al. (1977) titled *Water Resources of the Weiser River Basin, West-Central Idaho* and more recent ground water quality results from the Statewide Ground Water Quality Monitoring Program. The report by Young et. al. (1977) provides valuable geologic and hydrogeologic information. The study also includes a cursory evaluation of ground water quality in the Weiser River Basin. Within the study area, 11 well sites were sampled as part of the Statewide Ground Water Quality Monitoring Program between the years 1991 and 1994. This information provides comprehensive chemical data for ground water in the study area.

Welch et. al. (1988) present results from a comprehensive literature review and evaluation of databases containing more than 7,000 analyses of ground water samples for arsenic. They conclude that natural occurrences of ground water with arsenic in excess of 50 µg/l is common throughout much of the western United States. They found that elevated arsenic is usually associated with one of four geochemical environments: (1) basin-fill deposits of alluvial-lacustrine origin, particularly in semiarid areas; (2) volcanic deposits; (3) geothermal systems; and (4) uranium and gold-mining areas. In the first two environments, arsenic appears to be associated with sediments derived from volcanic rocks of intermediate to acidic composition.

It is not common to find high arsenic levels in river water without significant contribution from geothermal waters or highly mineralized areas. The Malheur River in southeastern Oregon, for example, contains arsenic concentrations above 50 µg/l during low-flow conditions. Finally, Welch et. al. (1988) state that arsenic concentrations tend to be elevated in volcanic glass, aluminosilicate minerals, and igneous rocks containing iron oxide.

Goldblatt et. al. (1963) describe the occurrence of elevated arsenic in ground water in Lane County, Oregon. They describe the arsenic-rich water as being soft, exhibiting high pH and high boron concentrations. It is postulated that pyroclastic debris deposited on the land contained high arsenic concentrations. Many of the original minerals were subsequently converted to clay due to interaction with circulating ground water. The clays, having a high cation exchange potential, removed calcium and magnesium (elements that contribute to water hardness) from the water system which resulted in increased sodium and arsenic.

A report by the Washington State Department of Health and the Snohomish Health District (Environmental Health Programs, 1991) describes the findings of a 12-month study of ground water near Granite Falls, Washington. Eighteen of 26 wells included in this study contained arsenic over the MCL of 50 µg/l, ranging up to a concentration of 30,000 µg/l. The arsenic concentrations varied with time; the range of variability was from 1.2-fold to 23-fold. The report concluded that in general, the higher the concentration, the greater the variability. Although gold, silver, copper, lead, and zinc mining activities took place in the past, none of the elevated arsenic concentrations found during this investigation were attributed directly to impacts from this activity.

Study Area

The study area is located northeast of Weiser, Idaho, in the lower Mann Creek and Monroe Creek drainages (Figure 1). The numbering system for identifying locations of wells and surface water sampling sites in this report is based on the common subdivision of lands into townships, ranges, and sections (Figure 2). The location based on the township-range system is referenced to the Boise baseline and meridian. The first segment represents the township north of the Boise baseline, the second segment represents the range west of the Boise meridian, and the third is the section number. The three letters following the section number indicate the quarter-quarter-quarter section (10-acre tract) within the section. Quarter sections are labeled A, B, C and D in counterclockwise order starting with the northeast quarter of the section. A numeral following the letters indicates the order in which wells within the 10-acre tract were sampled. An "S" following the numeral indicates that the sampling location is a surface water body rather than a well.

Sampling locations are found in the following townships, ranges, and sections:

- Township 11 north, Range 4 west, Section 6.
- Township 11 north, Range 5 west, Sections 3, 10, and 15.
- Township 12 north, Range 4 west, Sections, 19, 30, and 31.
- Township 12 north, Range 5 west, Sections 24, 25, and 36.

Climate

The climate of the study area is described as semiarid with warm, dry summers and cool, wet winters. Mean annual temperatures are 10.7° C at Weiser. The freeze-free growing season at Weiser is about 150 days. Mean annual precipitation is about 10 inches. Highest mean monthly precipitation occurs in December and January. The lowest mean precipitation occurs in July and August (Young et. al., 1977).

Soils

The soils found in the study area are described in a preliminary Soil Survey of Adams-Washington Area, Idaho, Parts of Adams and Washington Counties (Natural Resources Conservation Service, in press). The discussion of soils below is based on this reference.

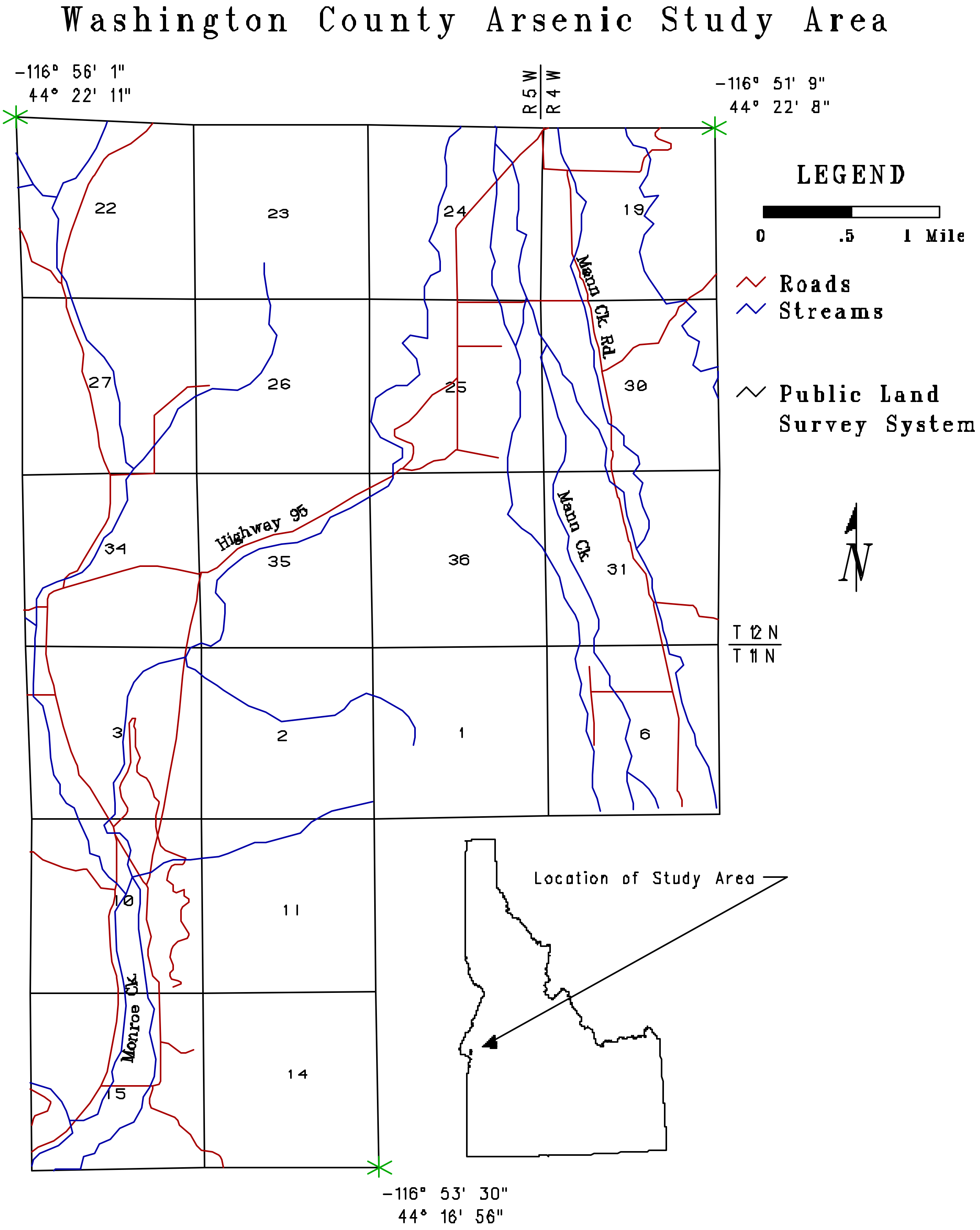


Figure 1. Arsenic Study Area Map

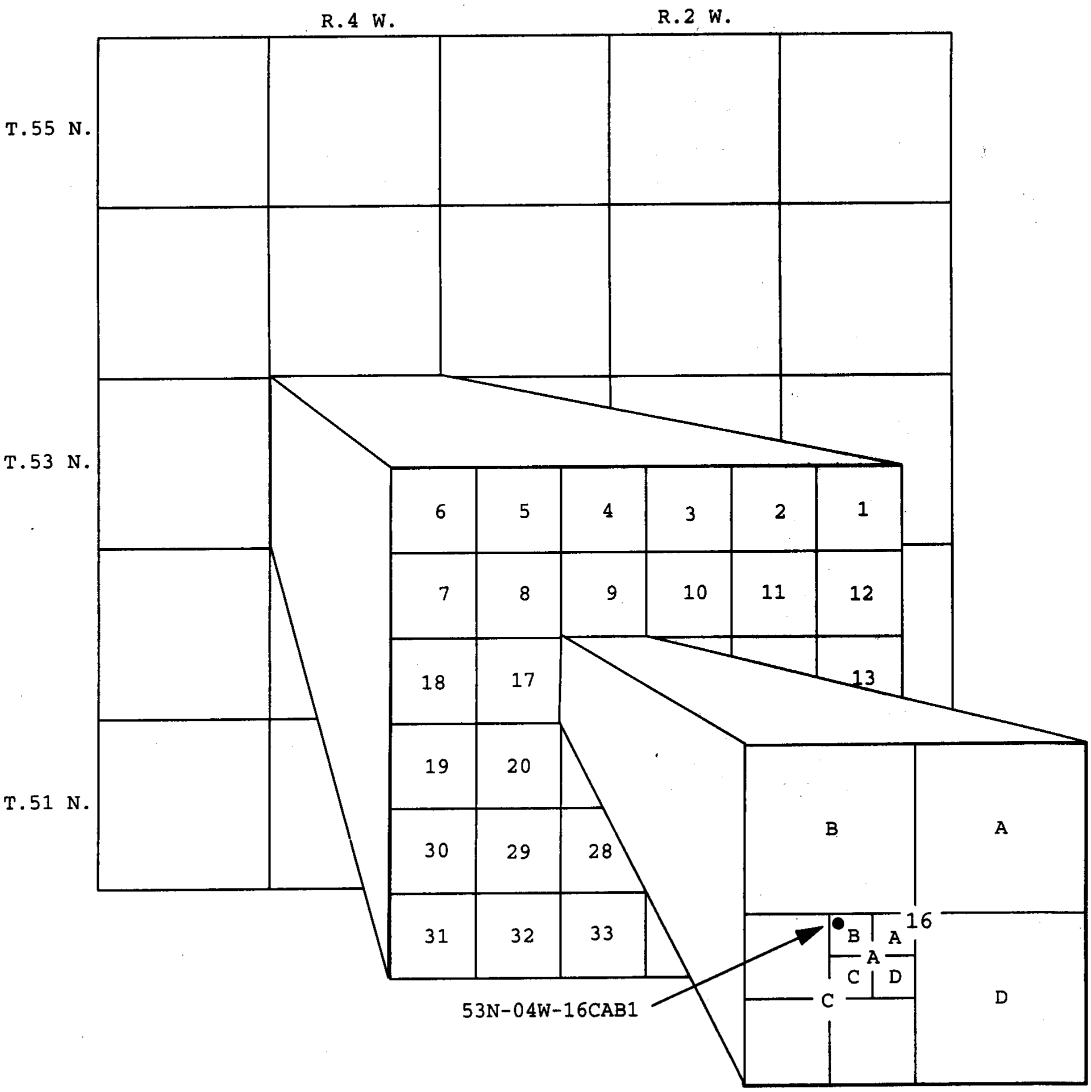


Figure 2. Sample Station Numbering System (modified from the USGS).

The soils associated with the ground water sampling locations are formed on alluvial fans, fan terraces, flood plains, stream terraces, and foothills. Most of the soils are derived from mixed sources of alluvium or lacustrine deposits, or from the residuum of volcanic tuff. A lesser amount of soil in the study area is derived from basaltic alluvium and colluvium. The characteristics of the dominant soils are described as moderately deep to very deep and range from poorly-drained to well-drained. The soils in the area include the Baldock, Bissell, Deshler, Glasgow, Greenleaf, Harpt, Lankbush, Newell, and Shoepeg series.

Geology and Hydrogeology

Geology in the study area is characterized as Holocene to Pliocene-aged, poorly to well-sorted lacustrine and fluviatile deposits of clay, silt, sand, and some gravel. Some surficial deposits of alluvium and colluvium exist. These sediments exceed 1,500 feet in thickness near Weiser. In addition, the region north of the study area contains flood-type basalts of the Pliocene and Miocene Columbia River Basalt Group. These basalts are light to dark gray, dense and include crude columnar jointing in some locations (Young et. al., 1977). A north-south trending fault paralleling the lower reach of Mann Creek with the downthrown side to the east is reported to exist.

Ground water flow direction based on water level measurements in existing wells described by Young et. al. (1977) is generally to the south or southwest. Young et. al. (1977) calculated an average transmissivity of 2,670 ft^2/day based on specific capacity estimated from drillers' logs. Thermal ground water is present in several areas of the Weiser River basin. Thermal springs issue from basalt or from alluvium in proximity to basaltic outcrops. The Weiser Hot Springs and Crane Creek Hot Springs areas are located approximately five miles northwest and 12 miles east of Weiser, respectively.

Land Use

Land use in the area is dominated by agriculture. Farming and ranching activities are both common. Livestock consists mainly of cattle and horses. Both irrigated and non-irrigated farming practices are employed. Sprinkler and surface irrigation are both used with surface and ground water sources supplying water for irrigation. The primary crop types include livestock feed crops such as hay, pasture grasses, and grains. A significant number of the residents who participated in this study had purchased small acreages on which to retire. The owners of these small "ranchettes" commonly maintain small numbers of cattle or horses and other domestic animals as pets.

Historically, orchard rearing was more prevalent in the study area than it is today. An article in *The Weiser Signal-American* (May 15, 1986) describes a commercial apple growing operation on Mann Creek that was begun in 1868. The apple trees were reported to exist until the middle 1920s.

Materials and Methods

A survey of well drillers' logs on-file with IDWR was performed in order to evaluate potential ground water sampling locations. Representatives of DEQ, IDWR, and SWDHD met to make the final determination on the wells to be sampled. Wells were selected based collectively on criteria that included the existence of a driller's log, the reported depth, the detail of the lithologic descriptions, and the location of a particular well with respect to other wells selected. An attempt was made to sample primarily shallow wells in and around the vicinity of previously-detected high arsenic concentrations in ground water. The rationale for this decision was that the two wells known to produce arsenic-contaminated ground water are 70 and 75 feet deep (relatively shallow). A few deeper wells were also selected in an initial effort to compare analytical results between shallow and deeper ground water systems. Three of the wells chosen for sampling have been sampled previously as part of the Statewide Ground Water Quality Monitoring Program. The basis for including these previously-sampled wells was to assess differences in sample collection and analytical techniques.

The names of well owners listed on the drillers' logs were then correlated with county records to determine current property owners. Permission to sample the targeted list of wells was then obtained from the current owners. A list of 18 potential wells for sampling was compiled. Logistical constraints including the denial of access and other physical constraints resulted in the fact that only 14 wells were sampled. One sample was also collected from Mann Creek near one of the sampled wells to assess the possible direct influence on the shallow ground water from surface water.

The samples were collected over a three-day period beginning January 11, 1995. Only wells with existing operable pumps were sampled. Samples were collected as close to the wellhead as feasible from locations not influenced by any water treatment devices. Field water quality parameters (field parameters) were measured at each site using a Horiba U-10 Water Quality Checker. The measured field parameters were temperature, pH, specific conductance, and dissolved oxygen. Prior to collecting samples, each well was purged until the field parameters stabilized to within specified limits. The stabilization criteria used were:

specific conductance................	5%
pH...	0.1 unit
temperature..............................	0.2 degrees Celsius
dissolved oxygen......................	0.1 mg/l

Continuous flow conditions were maintained for the measurement of the field parameters by routing part of the full water flow from the sampling tap into an overflowing plastic bucket. This procedure resulted in good stabilization of all four field parameters after about 25 minutes of purging for most wells. The Mann Creek surface water sample was collected in grab fashion from the middle of the stream. The area chosen for sampling was free from visible debris. Field parameters were also measured at this site by immersing the instrument probe in a relatively slow moving portion of the current.

Each sampling location was plotted on a 7.5-minute USGS topographic map by the field team. In addition, a Trimble Pathfinder Basic global positioning system receiver was used to collect digital location data for mapping purposes.

Quality Assurance and Quality Control

All water samples were collected in clean, one-liter polyethylene containers. Major ion, nutrient, and metals analyses were performed by the Idaho Bureau of Laboratories (State lab). Table 1 lists the analytes and corresponding analytical methods, sample preservation methods, and maximum holding times allowed. Table 2 lists the quality assurance objectives and detection limits for this study.

The following field quality control samples were used in this study:

- One duplicate sample was collected at random by the field team and submitted as a blind sample to the laboratory for analysis.

- One field blank was collected and analyzed. The field blank consisted of analyte-free water that was brought to the field from the laboratory, transferred into sample containers, and transported back to the laboratory for analysis.

- One trip blank was analyzed for each day of sampling (three days). Each trip blank consisted of sample containers containing analyte-free water transported to the field and back to the laboratory for analysis along with all other samples collected that day.

Internal laboratory quality control checks were performed by the State lab in accordance with their standard operating protocols. The State lab has verified that the accuracy goals for all analyses have been achieved. This determination is based on the results of analyses of lab-fortified reagent blanks.

Precision is evaluated by comparing field duplicate analytical results. Calculations of the relative percent difference (RPD) between a field sample and its corresponding duplicate are shown in Table 3. A rough determination of whether the precision criteria are met is accomplished by comparing the RPD values for each parameter with the acceptable precision range. Table 4 indicates that overall precision is acceptable. However, alkalinity and ammonia values in this particular evaluation fell outside of their respective acceptable precision range based on the RPD calculations. A statistical evaluation of a larger population of replicate or duplicate samples would be necessary for a thorough evaluation of precision.

Table 1. Chemical Constituents Evaluated in Washington County Water Samples

Parameter	Method	Container	Preservation	Holding Time
Calcium	EPA 215.1	P	Cool, 4° C	60 days
Magnesium	EPA 242.2	P	Cool, 4° C	60 days
Sodium	EPA 273.1	P	Cool, 4° C	60 days
Potassium	EPA 258.1	P	Cool, 4° C	60 days
Chloride	EPA 325.3	P	Cool, 4° C	28 days
Carbonate	EPA 310.1	P	Cool, 4° C	14 days
Alkalinity	EPA 310.1	P	Cool, 4° C	14 days
Bicarbonate	EPA 310.1	P	Cool, 4° C	14 days
Sulfate	EPA 375.4	P	Cool, 4° C	28 days
Silica	EPA 370.1	P	Cool, 4° C	28 days
Fluoride	EPA 340.3	P	Cool, 4° C	28 days
Ammonia	EPA 350.1	P	2 ml/l conc. H_2SO_4 Cool, 4° C	28 days
Nitrate	EPA 353.2	P	2 ml/l conc. H_2SO_4 Cool, 4° C	28 days
Total Dissolved Solids	EPA 160.1	P	Cool, 4° C	28 days
Arsenic	EPA 200.9	P	3 ml/l 1:1 dil. HNO_3 Cool, 4° C	60 days
Manganese	EPA 243.1	P	3 ml/l 1:1 dil. HNO_3 Cool, 4° C	60 days
Iron	EPA 236.1	P	3 ml/l 1:1 dil. HNO_3 Cool, 4° C	60 days
Selenium	EPA 200.9	P	3 ml/l 1:1 dil. HNO_3 Cool, 4° C	60 days
Lead	EPA 200.9	P	3 ml/l 1:1 dil. HNO_3 Cool, 4° C	60 days

P = Plastic (polyethylene)

Table 2. Quality Assurance Objectives and Detection Limits

Parameter	Detection Limit	Accuracy	Precision	Completeness
Calcium	0.01 mg/l	80-120%	+/-10%	95%
Magnesium	0.01 mg/l	80-120%	+/-5%	95%
Sodium	0.01 mg/l	80-120%	+/-5%	95%
Potassium	0.01 mg/l	80-120%	+/-5%	95%
Chloride	0.9 mg/l	80-120%	+/-15%	95%
Carbonate	1.0 mg/l	80-120%	+/-5%	95%
Alkalinity	1.0 mg/l	80-120%	+/-5%	95%
Bicarbonate	1.0 mg/l	80-120%	+/-5%	95%
Sulfate	4.0 mg/l	80-120%	+/-15%	95%
Silica	0.01 mg/l	80-120%	+/-10%	95%
Fluoride	0.1 mg/l	80-120%	+/-10%	95%
Ammonia	0.005 mg/l	80-120%	+/-10%	95%
Nitrate	0.005 mg/l	80-120%	+/-10%	95%
Total Dissolved Solids	6.0 mg/l	75-125%	+/-20%	95%
Arsenic	0.01 mg/l	80-120%	+/-15%	95%
Manganese	0.01 mg/l	80-120%	+/-10%	95%
Iron	0.01 mg/l	80-120%	+/-15%	95%
Selenium	0.005 mg/l	80-120%	+/-15%	95%
Lead	0.005 mg/l	80-120%	+/-18%	95%

Additional evaluation of analytical accuracy is accomplished by calculating cation-anion balances for each sample (Table 4). The balance errors ranged from zero to 13 percent. The average balance error for the 15 primary samples is four percent. The suggested allowable balance error is generally considered variable depending on the ionic concentration of the samples. A measure of the ionic concentration is considered the filterable residue or total dissolved solids (TDS) concentration. As the ionic concentration increases, the allowable balance error decreases. Acceptable balance errors, given the range of filterable residue concentrations, for this set of data is three to five percent. Therefore, on average, the acceptance criteria are met. However, several samples significantly exceed the acceptable balance error indicating either analytical errors or that certain significant ionic species were not accounted for in the analyses. The analytical results for the field blank and trip blanks do not indicate any adverse affects from field sampling or sample handling and storage protocol.

Table 3. Duplicate Sample Results and Relative Percent Difference Calculations

Parameter	12N-04W-19CAC1 Concentrations	Duplicate Concentrations	Relative Percent Difference	Precision Criteria	Precision Criteria Met?
Calcium	25 mg/l	24 mg/l	4.1%	+/-10%	Yes
Magnesium	8 mg/l	8 mg/l	0%	+/-5%	Yes
Sodium	26 mg/l	26 mg/l	0%	+/-5%	Yes
Potassium	3.7 mg/l	3.5 mg/l	5.6%	+/-5%	Yes
Chloride	5.6 mg/l	4.6 mg/l	19.6%	+/-15%	Yes
Alkalinity	69 mg/l	104 mg/l	40.5%	+/-5%	No
Sulfate	41 mg/l	37 mg/l	10.3%	+/-15%	Yes
Silica	72.9 mg/l	71.8 mg/l	1.5%	+/-10%	Yes
Fluoride	0.71 mg/l	0.73 mg/l	2.8%	+/-10%	Yes
Ammonia	0.124 mg/l	0.155 mg/l	22.2%	+/-10%	No
Nitrate	<0.005 mg/l	<0.005 mg/l	0%	+/-10%	Yes
Total Dissolved Solids	192 mg/l	227 mg/l	16.7%	+/-20%	Yes
Arsenic	42 ìg/l	40 ìg/l	4.9%	+/-15%	Yes
Manganese	240 ìg/l	240 ìg/l	0%	+/-10%	Yes
Iron	2480 ìg/l	2090 ìg/l	17.1%	+/-15%	Yes
Selenium	<5 ìg/l	<5 ìg/l	0%	+/-15%	Yes
Lead	<5 ìg/l	<5 ìg/l	0%	+/-18%	Yes

Table 4. Cation-Anion Balance Errors

Sample Location	Total Cations (meq/l)	Total Anions (meq/l)	Cation-Anion Balance Error (%)
11N-04W-06BCB1	1.47	1.35	4.3
11N-05W-03DCC1	11.74	10.08	7.6
11N-05W-10CDA1	14.51	12.08	9.1
11N-05W-15BDD1	7.86	7.76	0.6
12N-04W-19BAC1	2.58	2.82	4.5
12N-04W-19CAC1	3.13	2.39	13.4
12N-04W-31BAD1	6.81	6.28	4.1
12N-04W-31CAC1	4.76	5.05	3.0
12N-04W-31CBD1S	2.85	2.77	1.4
12N-04W-31DBC1	4.35	4.04	3.7
12N-04W-31DBD1	2.47	2.12	7.6
12N-05W-24ADC2	4.01	3.98	0.4
12N-05W-25ADB1	6.28	6.28	0
12N-05W-25BAD1	7.4	7.52	1.9
12N-05W-36BBA1	4.29	4.13	1.9

Results and Discussion

Analytical results of water samples, sample location information, and well depths are shown in the appendix at the back of this report. Arsenic concentrations are also plotted next to the corresponding sampling locations in map form on Plate 1 also at the back of this report. The analytical results were hydrogeochemically evaluated using a variety of techniques. The purpose of these evaluations was to determine whether correlations exist between elevated arsenic concentrations and any other parameter that could aid in identifying the sources of the arsenic in the ground water system. The following evaluation tools were employed:

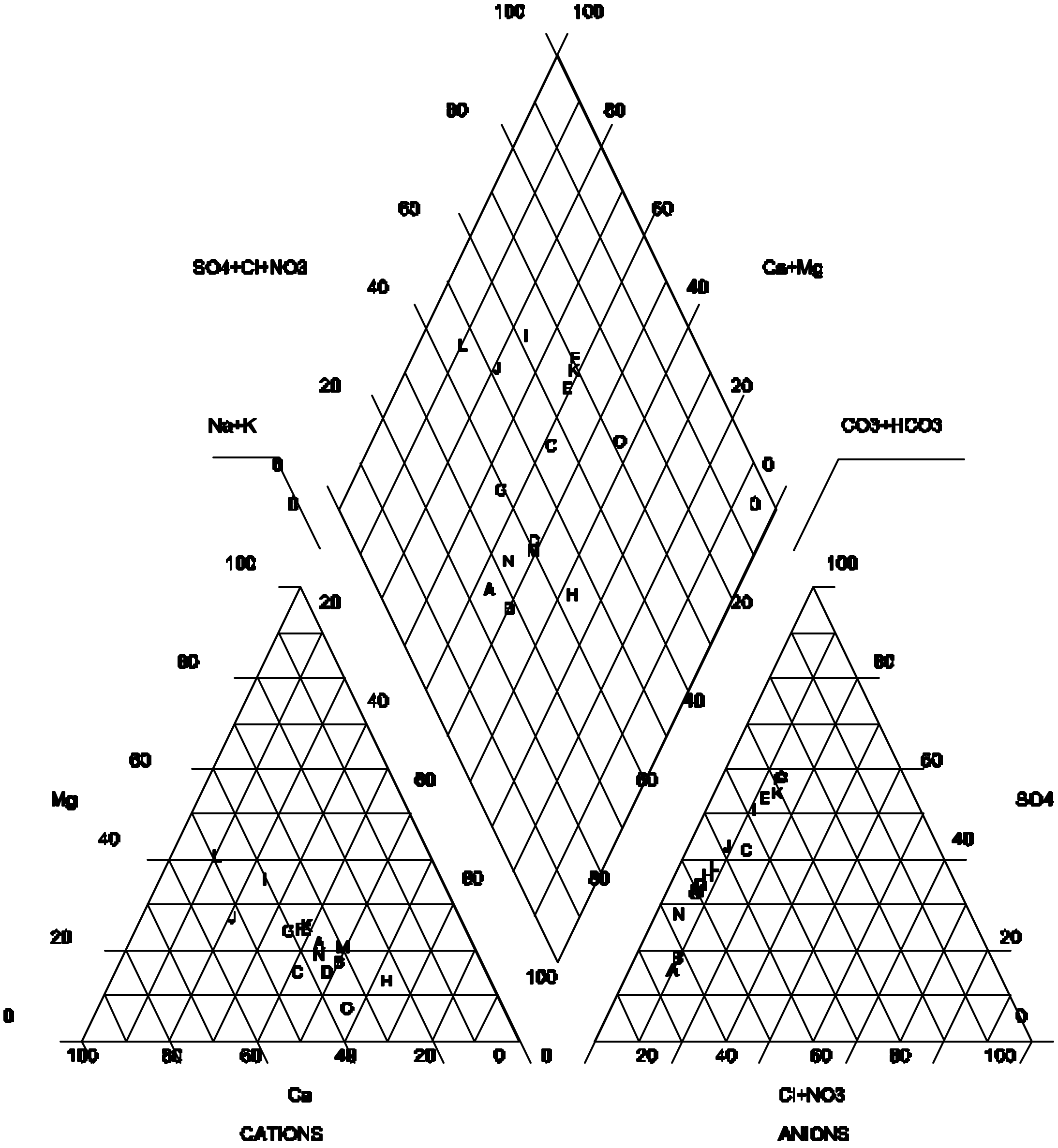
- Trilinear plot
- Composition plots (x-y scatter plots)
- Fingerprint (Schoeller) diagram
- Comparison of arsenic concentrations with field parameters
- Comparison of arsenic concentrations with geologic features
- Comparison of arsenic concentrations with the elevation of the water-producing zone

Each of these methods is used to help identify trends or compositional variations in the water quality data. The data from this specific investigation were also compared to the results of other investigations reported in the literature.

Under natural conditions, the major ion composition of ground water is controlled by the soluble mineral in the aquifer and the residence time of water in the aquifer. A general relationship between the mineral composition of the natural water and the solid minerals with which the water has been in contact is expected. This simple relationship can be complicated by the mixing of water from interconnected aquifers with different compositions. The system may also be affected by chemical reactions such as cation exchange, adsorption of dissolved ions, and biological influences (Hem, 1985).

Trilinear Plot

Figure 3 is a trilinear plot used to display major ion water chemistry (Piper, 1944). The diagram shows concentrations in percent milliequivalents per liter (meq/l) of the major cations and anions for each water sample. The major cations of each water sample (calcium, magnesium, sodium, and potassium) are plotted on the left triangle. The major anions of each water sample (carbonate, bicarbonate, chloride, sulfate, and nitrate) are plotted on the right triangle. The plotted points for each water sample are then projected to the upper diamond-shaped area to show cation and anion groups as a percentage of the sample. Water samples with similar chemistry plot in the same area on the diagram. The trilinear diagram indicates wide variability in the compositions of the water samples. Sodium and calcium



~~Symbol~~	~~Sample Location~~	~~TDS (ppm)~~	~~Arsenic (ppb)~~
A	11N-04W-06BCB1	144	17
B	11N-05W-03DCC1	669	150
C	11N-05W-10CDA1	938	44
D	11N-05W-15BDD1	505	55
E	12N-04W-19BAC1	221	11
F	12N-04W-19CAC1	192	42
G	12N-04W-31BAD1	421	95
H	12N-04W-31CAC1	225	920
I	12N-04W-31CBD1S	180	<10
J	12N-04W-31DBC1	299	17
K	12N-02W-31DBD1	195	13
L	12N-05W-24ADC1	238	<10
M	12N-05W-25ADB1	354	11
N	12N-05W-25BAD1	420	23
O	12N-05W-36BBA1	278	65

Figure 3. Trilinear Diagram.

are the dominant cations. Bicarbonate is the dominant anion although sulfate also constitutes a significant percentage of the anions in some samples. Samples containing elevated arsenic do not plot as a group on the trilinear diagram.

Composition Plots

Figures 4 and 5 present compositional diagrams of the major ions plotted against the total dissolved ions (TDI; the sum of major cations and anions). Figure 4 displays graphs of common cations versus TDI. Figure 5 displays graphs of common anions versus TDI. Both axes represent concentrations in meq/l. This type of diagram is used to determine whether there are compositional differences (water types) in the sample set. Data that plot in linear trends represent mixing of water with low dissolved ion concentrations and water with higher dissolved ion concentrations. Data that plot as one or more clusters indicate separate types of water that are not mixed. A random distribution of data indicate that many individual, unrelated water types exist or that the analytical quality of the data is poor (Mazor, 1991). Weak linear relationships are apparent between calcium-TDI, bicarbonate-TDI, and sodium-TDI. These types of trends show that the water samples vary considerably in their solute concentrations. The linear trends also indicate that water with low solute concentrations is mixing in varying percentages with water of higher solute concentrations. The dominant water type in the overall system is calcium/sodium-bicarbonate, therefore, these ions show the strongest correlation with TDI. The sodium-TDI graph on Figure 4 indicates an apparent grouping of samples into at least two areas of the graph (a group of low sodium concentrations and group of higher sodium concentrations). Two individual samples appear as outliers with high sodium and high TDI concentrations.

Figure 6 is a variation of the sodium-TDI graph in Figure 4. Figure 7 is a comparison of sodium and calcium values plotted on a an x-y graph. Figures 6 and 7 include the arsenic concentration (in ìg/l) as a label next to the corresponding plotting point symbol. Both Figure 6 and 7 portray a potentially useful result. The seven samples that plot near the lower left-hand corner of the graphs have an average arsenic concentration of 17 ìg/l. The other eight samples that plot higher on the graph (i.e., higher sodium concentrations), including the two outliers, have an average arsenic concentration of 170 ìg/l. These graphs reveal that all the samples that contain arsenic above the MCL of 50 ìg/l also contain sodium greater than two meq/l. This fact may indicate that ion exchange processes are taking place that result in increased sodium and arsenic in some samples similar to the hypothesis described by Goldblatt (1963).

Fingerprint Diagram

Figure 8 is a fingerprint diagram of the 15 primary ground water samples. The numbers labeling the lines correspond to the reference number for each sample found in the appendix spreadsheet. Each line on the diagram is a graphical representation of the concentration of the major ionic species of each sample. Water samples containing higher concentrations of ions plot higher on the diagram than those containing lower concentrations. Parallel lines indicate various dilutions of a similar water type.

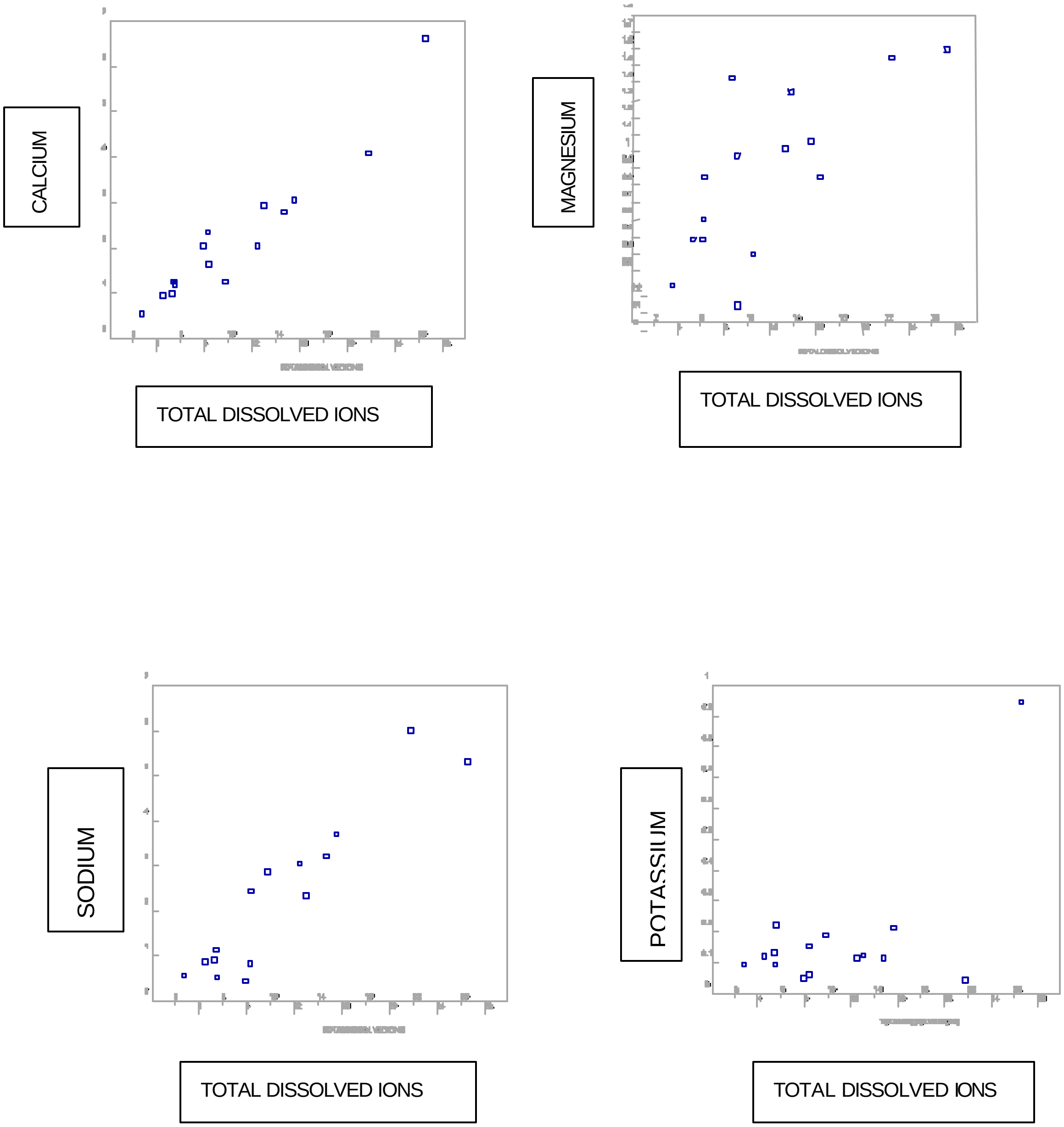


Figure 4. X-Y Plots of Major Cations Versus Total Dissolved Ions (axes represent concentrations in meq/l).

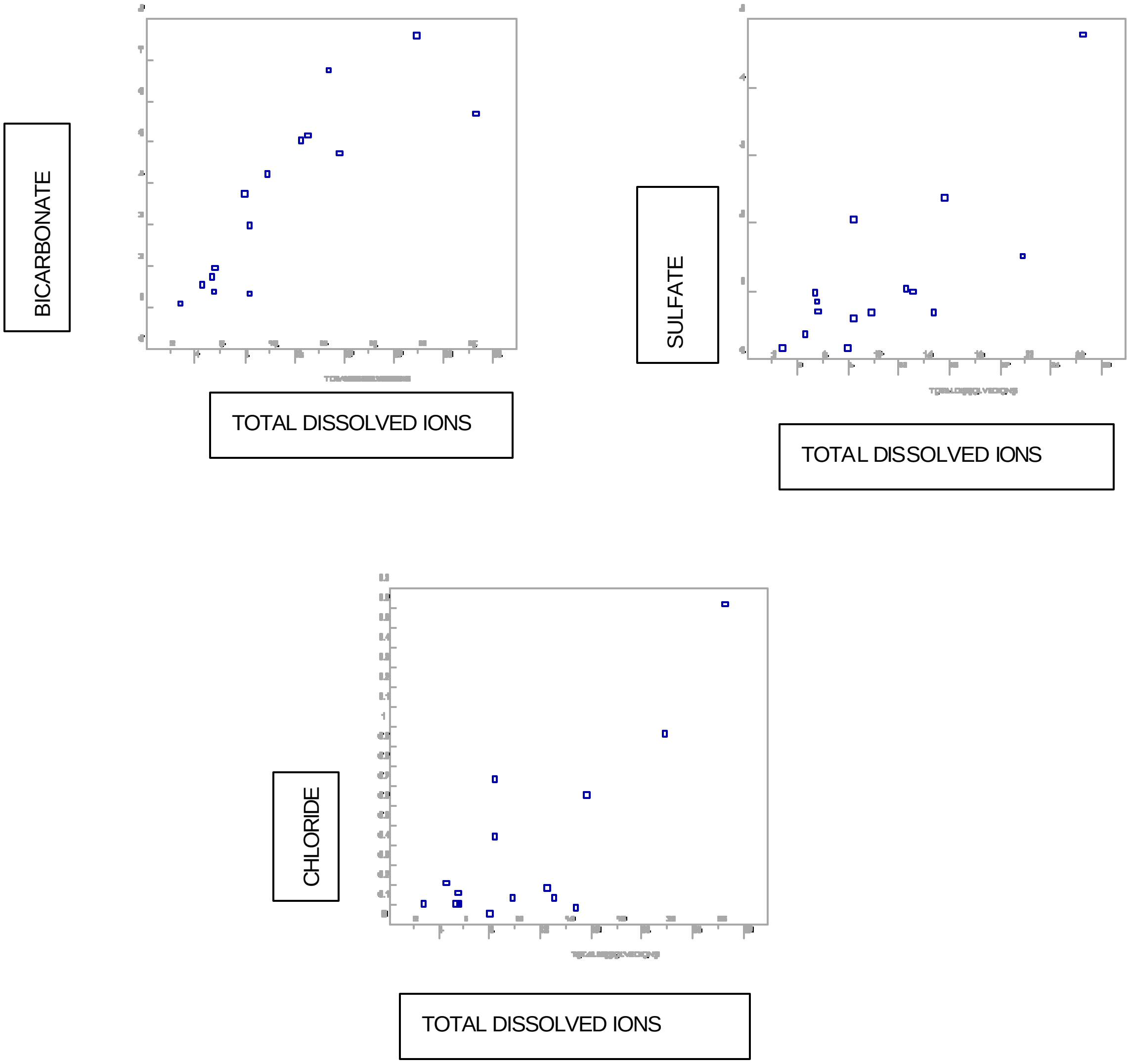


Figure 5. X-Y Plots of Major Anions Versus Total Dissolved Ions (axes represent concentrations in meq/l).

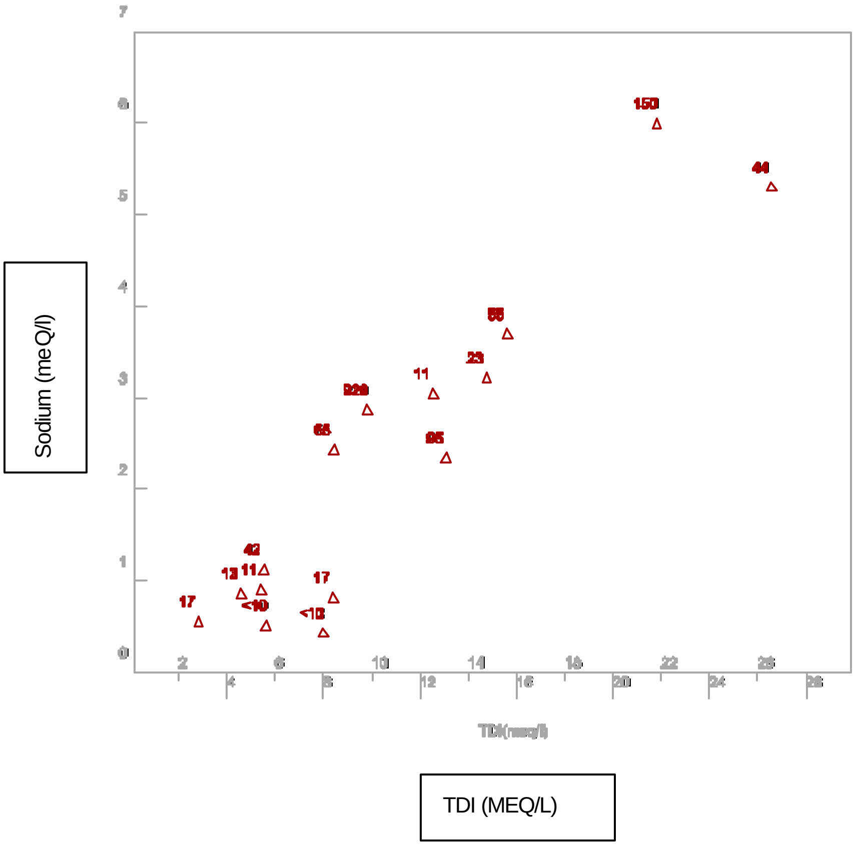


Figure 6. Sodium Versus Total Dissolved Ions (meq/l) with Corresponding Arsenic Concentrations (ìg/l). Arsenic-rich samples occur with sodium greater than two meq/l.

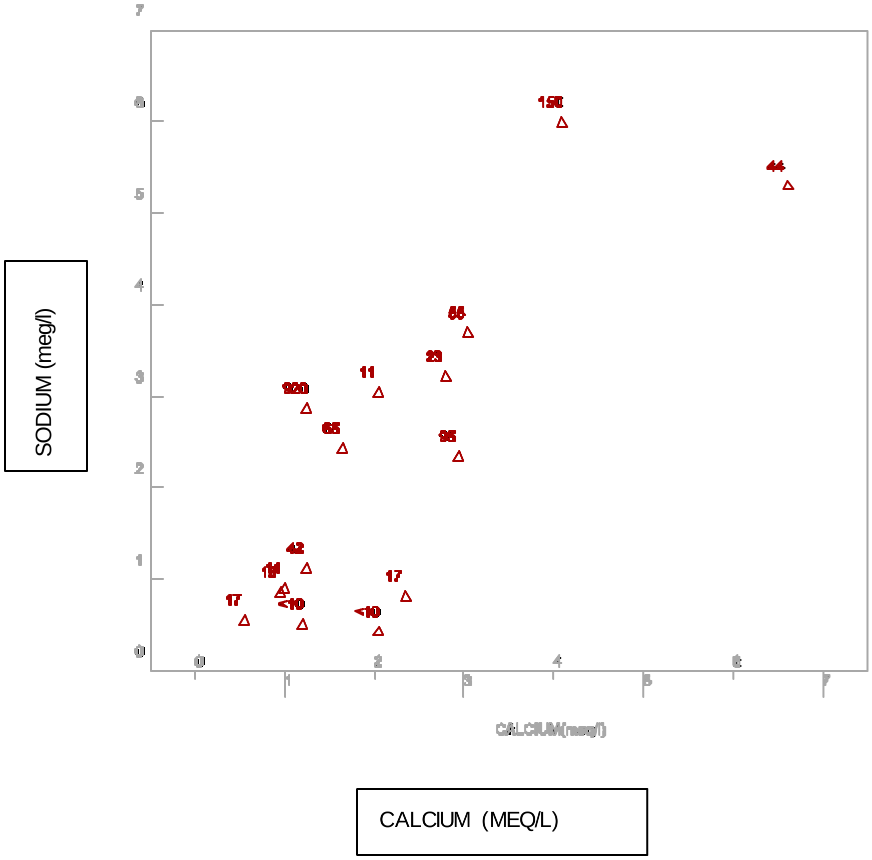


Figure 7. Sodium Versus Calcium (meq/l) with Corresponding Arsenic Concentrations (ìg/l). Arsenic-rich samples occur with sodium greater than two meq/l.

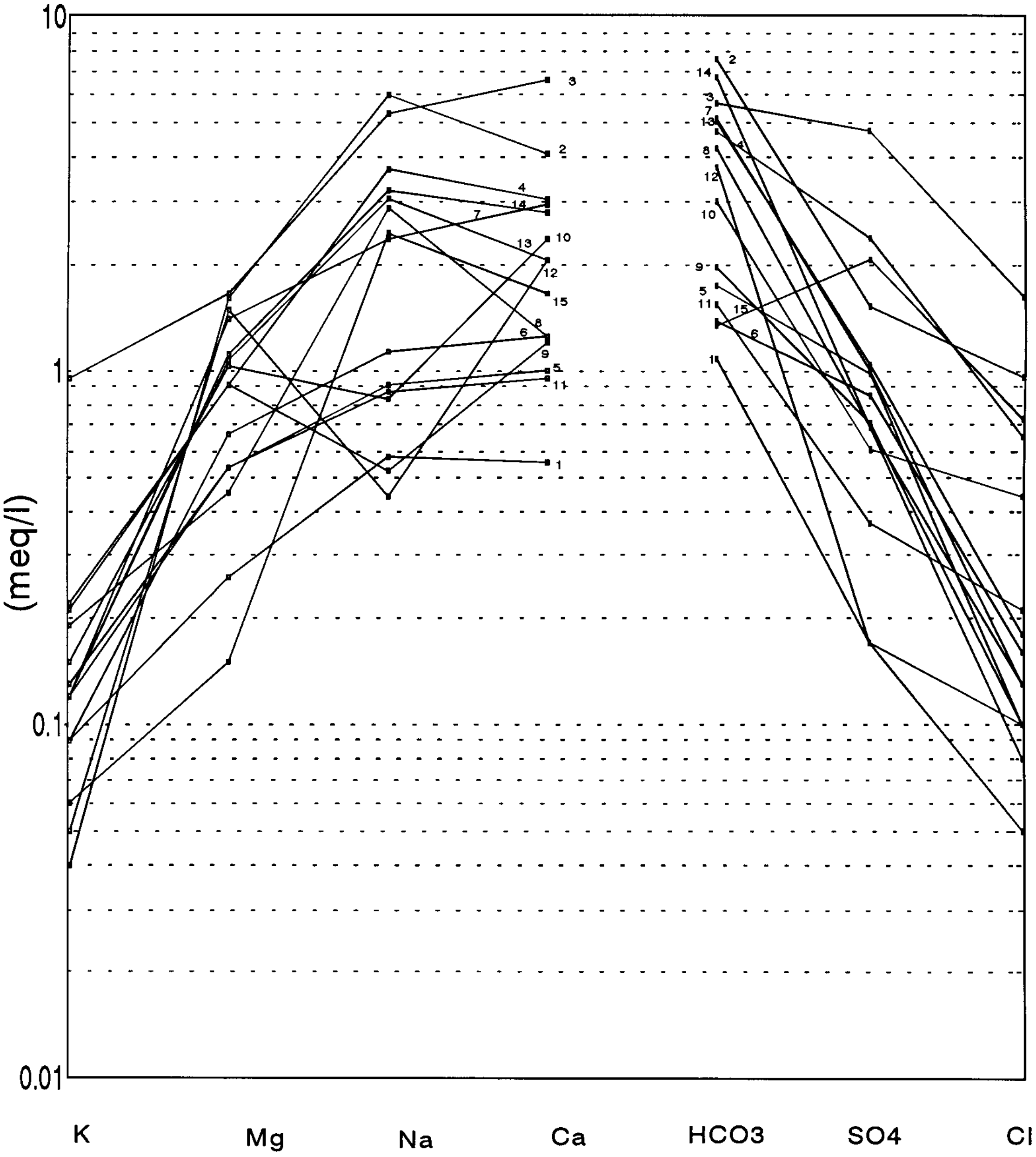


Figure 8. Fingerprint Diagram.

Lines with a fan shape indicate mixing of two distinct water types (Mazor, 1991). The variability in water composition is confirmed by the pattern of the lines on the fingerprint diagram. No clear classifications of sets of parallel lines can be made.

Comparison of Arsenic Concentrations with Field Parameters

Figure 9 is a combination of x-y plots of arsenic concentration versus values of common field parameters including temperature, dissolved oxygen, pH, and specific conductance. A discernable trend in arsenic concentration versus any field parameter would provide a simple means by which to predict the occurrence of elevated arsenic during well installation. Unfortunately, no clear trends exist.

Comparison of Arsenic Concentrations with Geologic Features

Geologic controls on the occurrence of elevated arsenic in ground water in the study area were also evaluated. The north-south trending normal fault that parallels Mann Creek as described by Young et. al. (1977) is a potentially significant feature. However, wells producing elevated arsenic occur on both sides and at varying distances from the mapped surface expression of the fault. There is no discernable correlation with the occurrence of the fault and wells producing water with elevated arsenic.

Comparison of Arsenic Concentrations with the Elevation of the Water-producing Zone

Due to the high degree of variability in topography in the study area, a correlation between well depth and the occurrence of elevated arsenic is not useful. However, when the elevation of the sampled wellheads is considered, a potentially useful correlation becomes apparent. Figure 10 shows the number of wells that produce elevated arsenic (as a percentage of the total number of wells sampled) versus the elevation of the water-producing zone. The elevation axis represents four different elevation ranges: (1) 2,200 to 2,300 feet, (2) 2,300 to 2,400 feet, (3) 2,400 to 2,500 feet, and (4) 2,500 to 2,600 feet. The datum for the elevation used in this comparison is mean sea level. The elevation of each sampled wellhead was estimated by plotting the wells on 7.5-minute USGS topographic quadrangle maps. An evaluation of the driller's log for each well provided an estimate for the elevation of the water-producing zone. The elevation of the center of the screened or open section of the wells was used. When a well contained multiple water producing zones, the shallowest zone was used. Figure 10 shows that wells that obtain water from lower elevations (i.e., the 2,200 to 2,300 range) contain the highest concentrations of arsenic. The drillers' logs of four of the five wells that produce arsenic over the MCL of 50 ìg/l indicate that the water-producing zone contains gray or blue clay or shale. Locally, these fine-grained deposits commonly called "blue clay" are thought to represent fluvial and lacustrine deposits of the

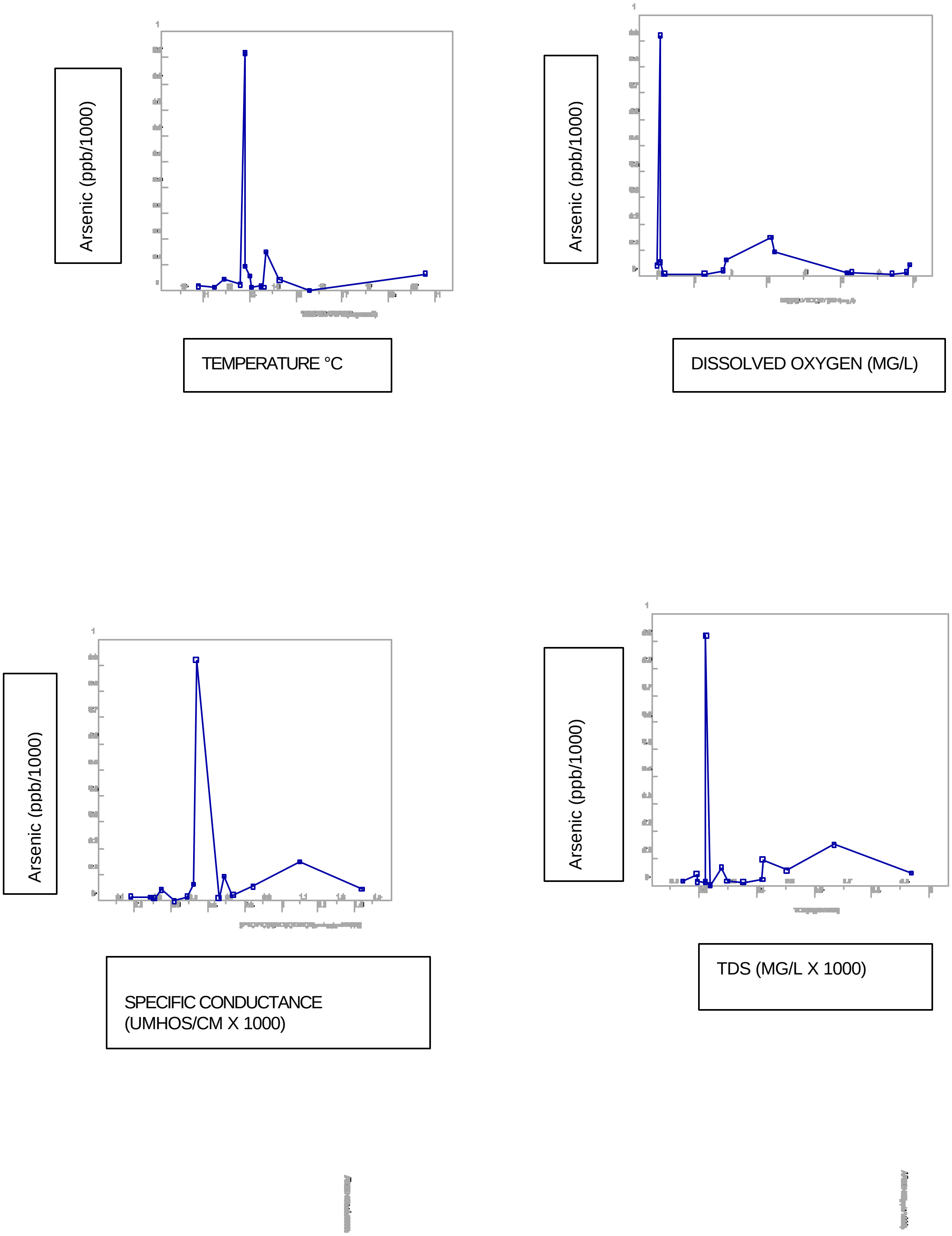


Figure 9. Arsenic Versus Temperature, Dissolved Oxygen, Specific Conductance, and TDS.

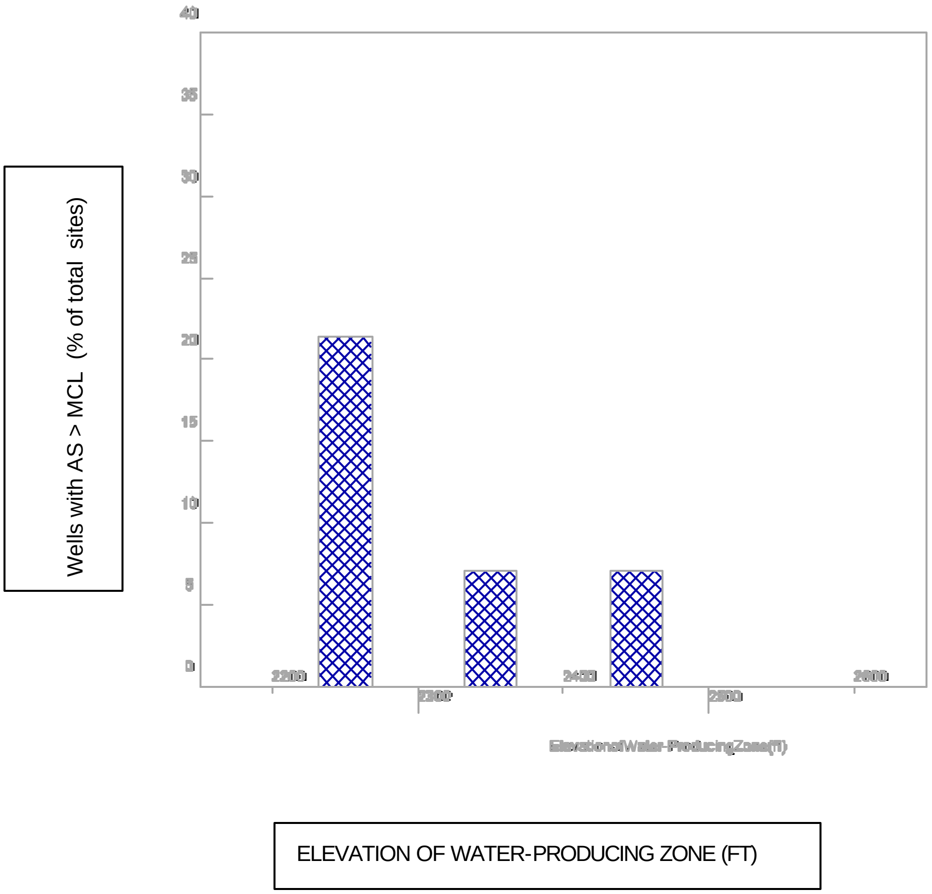


Figure 10. Percentage of Wells Producing Arsenic Concentrations Greater than 50 μg/l Versus Elevation of the Water Producing Zone.

Pliocene Glenns Ferry formation (Kimmel, 1982). The dark color is thought to be a result of deposition in a reducing or oxygen-poor environment.

The occurrence of elevated arsenic in wells that produce water from relatively low topographic elevations may be controlled by the mineralogic, physical, and geochemical characteristics of dark (blue or gray), fine-grained sediments. Additionally, it may follow from Goldblatt's (1963) inference, that the clay-rich deposits provide relatively high ion exchange capacity. This would potentially allow the removal of calcium from circulating ground water and the enrichment of sodium. A simultaneous increase in arsenic content may follow this natural "water softening" as chemical and mineralogical processes alter parent volcanic rocks to clay. Shallower, or topographically higher, aquifer materials representing different sedimentary conditions appear to present a lower risk of producing water with elevated arsenic concentrations. This characteristic tends to support the idea that natural geologic materials control the occurrence of elevated arsenic in ground water in the study area rather than some near-surface anthropogenic source such as the application of arsenic-containing pesticides.

It is worth noting that information obtained from drillers' logs must be considered inexact in most cases. Variations in the quality of the lithologic descriptions found on the logs occurs due to inconsistency in geologic experience and training of drilling professionals. It is also difficult to correlate drillers' logs found on-file at IDWR with physical locations in the study area. A given parcel of land often contains more than one well and the location descriptions found on the logs are often not precise enough to allow correlation with a well. The problem of correlating drillers' logs with wells resulted in well 12N-04W-31DBD1 being sampled even though the corresponding driller's log could not be located.

Conclusion

At the scale of this investigation, the areal distribution of elevated arsenic in ground water in the study area appears to be random. Therefore, the assignment of boundaries around some area of concern cannot be made with certainty. Some correlation between elevated arsenic concentrations and the elevation of the water-producing strata may exist. Estimates of the elevation of the water-producing zones based on drillers' logs and the corresponding arsenic concentrations indicate that lower-elevation (deeper) water-producing zones result in higher arsenic concentrations. This may be a function of the sedimentary stratigraphy. Specifically, clay-rich sediments comprising the Glenns Ferry Formation of the Idaho Group may provide geologic control on the occurrence of arsenic-rich ground water. The clay-rich sediments generally occur stratigraphically below younger coarser-grained alluvial deposits. Ground water users throughout southwest Idaho, especially residents of the western Snake River Plain, should be made aware of the potential for arsenic-rich ground water due to the natural geologic setting.

The apparent correlation between arsenic-rich ground water and relatively deep water producing zones suggests that elevated concentrations of arsenic in ground water may not be caused by human activity (e.g., the application of arsenic-containing pesticides). It must be explicitly noted that this inference is based on limited data collected in a localized study area. More detailed research that includes a drilling and soil sample collection program would be necessary to confirm this opinion.

It does not appear that any field-measured parameter (e.g., dissolved oxygen, specific conductance, temperature, or pH) can be used to predict the occurrence of elevated arsenic in the ground water. However, an apparent correlation between sodium concentrations and arsenic concentrations does exist. Ground water enriched in sodium (roughly over two meq/l or 46 mg/l) tends to also contain higher concentrations of arsenic. This apparent correlation provides little practical usefulness for predicting the occurrence of elevated arsenic since laboratory analyses are required to quantify concentrations of both sodium and arsenic. It does, however, provide a basis for the hypothesis that the alteration of volcanic materials to clay is directly or indirectly related to the occurrence of arsenic-rich ground water. Detailed subsurface geologic characterization coupled with additional geochemical and hydrogeochemical evaluations are needed to assess the validity of this hypothesis.

The results of this investigation will be reported to the appropriate Washington County officials, representatives of the SWDHD, and other water resource agencies. The water resource agencies should investigate whether specialized well completion techniques are needed to avoid the production of arsenic-rich ground water. For instance, water-bearing zones exhibiting high-clay content may need to be isolated from other production zones. Voluntary water testing on the part of citizens living in suspect areas provides the best assurance that long-term adverse health affects are avoided. Also, owners of existing wells that produce arsenic-rich water should be urged to consider the use of effective treatment devices or to use other sources of water for drinking and cooking. A continuing public education process will be required to accomplish this.

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Appendix

						Field Measurements				Laboratory Measurements																	
Reference Number	Sample Location	Latitude (north)	Longitude (west)	Well Depth (feet BGS)	Sample Date	Water Temp. (degrees C)	Specific Conductance (µmhos/cm)	pH (standard units)	Dissolved Oxygen (mg/l)	Alkalinity (total as CaCO3) (mg/l)	Bicarbonate Alkalinity (as CaCO3) (mg/l)	Ammonia (total as N) (mg/l)	Arsenic (µg/l)	Calcium (mg/l)	Chloride (mg/l)	Fluoride (mg/l)	Iron (µg/l)	Lead (µg/l)	Magnesium (mg/l)	Manganese (µg/l)	Nitrate (total as N) (mg/l)	Potasssium (mg/l)	Selenium (µg/l)	Silica (as SiO2) (mg/l)	Sodium (mg/l)	Sulfate (as SO4) (mg/l)	Filterable Residue (TDS) (mg/l)
1	11N-04W-06BCB1	44°19'17"	116°52'06"	85	#######	10.8	178	6.8	5.3	54	54	0.009	17	11.0	3.7	0.24	<20	<5	3.2	<10	3.700	3.7	<5	66.0	13.0	8	144
2	11N-05W-03DCC1	44°18'39"	116°55'22"	70	#######	13.7	1100	7.0	3.1	386	380	<0.005	150	82.0	34.1	0.57	130	<5	19.5	10	16.500	1.7	<5	54.3	138.0	73	669
3	11N-05W-10CDA1	44°17'54"	116°55'29"	155	#######	11.9	1440	7.0	6.9	287	285	<0.005	44	132.5	57.4	0.57	<20	<5	20.0	<10	22.000	37.0	6	51.3	122.0	229	938
4	11N-05W-15BDD1	44°17'24"	116°55'30"	70	#######	13.0	846	7.5	0.1	237	237	1.510	55	61.0	23.1	0.61	710	<5	11.0	400	<0.005	8.3	<5	61.2	85.0	114	505
5	12N-04W-19BAC1	44°22'00"	116°52'00"	161	#######	13.1	308	7.3	1.3	87	87	0.042	11	20.0	3.7	0.57	7840	<5	6.5	160	<0.005	5.2	<5	58.9	21.0	47	221
6	12N-04W-19CAC1	44°21'31"	116°52'08"	100	#######	14.3	345	6.7	0.0	69	69	0.124	42	25.0	5.6	0.71	2480	<5	8.0	240	<0.005	3.7	<5	72.9	26.0	41	192
7	12N-04W-31BAD1	44°20'15"	116°51'50"	85	#######	12.8	691	6.9	3.2	258	258	<0.005	95	59.0	4.6	1.10	<20	<5	17.0	<10	2.780	4.8	<5	67.6	54.0	48	421
8	12N-04W-31CAC1	44°19'50"	116°52'03"	75	#######	12.8	535	7.1	0.1	212	212	2.140	920	25.0	4.6	0.11	2150	<5	5.5	350	<0.005	7.4	<5	33.1	66.0	33	225
9	12N-04W-31CBD1	44°19'48"	116°52'06"	surface wat	#######	2.0	269	7.7	12.7	98	98	0.360	<10	24.0	3.7	0.15	13750	<5	11.0	420	1.090	8.7	<5	26.3	12.0	34	180
10	12N-04W-31DBC1	44°19'43"	116°51'40"	65	#######	13.5	489	6.8	6.8	150	150	<0.005	17	47.0	15.7	0.32	700	<5	12.5	20	2.250	6.0	<5	68.1	19.0	29	299
11	12N-04W-31DBD1	44°19'39"	116°51'31"		#######	13.6	288	6.9	5.2	77	77	<0.005	13	19.0	7.4	0.53	60	<5	6.5	<10	6.130	4.7	<5	70.1	20.0	18	195
12	12N-05W-24ADC1	44°21'46"	116°52'39"	60	#######	15.6	417	6.9	6.4	188	188	<0.005	<10	41.0	1.9	0.17	<20	<5	18.0	<10	0.778	1.9	<5	37.9	10.0	8	238
13	12N-05W-25ADB1	44°21'02"	116°52'42"	45	#######	11.5	659	7.2	0.2	253	253	0.797	11	41.0	6.5	0.56	13150	<5	13.0	240	<0.005	4.5	<5	29.5	70.0	50	354
14	12N-05W-25BAD1	44°21'08"	116°53'02"	65	#######	12.6	736	7.1	1.8	338	338	<0.005	23	56.0	2.8	0.53	<20	<5	13.5	<10	2.550	4.5	<5	32.6	74.0	33	420
15	12N-05W-36BBA1	44°20'21"	116°53'21"	325	#######	20.6	523	8.2	1.9	67	67	0.649	65	33.0	25.9	0.60	100	<5	1.8	90	<0.005	2.4	<5	10.4	56.0	99	278
DUPLICATE	12N-04W-19CAC1	44°21'31"	116°52'08"	100	#######					104	104	0.155	40	24.0	4.6	0.73	2090	<5	8.0	240	<0.005	3.5	<5	71.8	26.0	37	227
FIELD BLAN	11N-05W-15BDD1	44°17'24"	116°55'30"		#######					3	3	0.007	<10	<0.1	0.9	<0.10	<20	<5	<0.1	<10	<0.005	<0.1	<5	<0.2	<0.1	1	10
TRIP BLANK					#######					3	3	0.017	<10	<0.1	0.9	<0.10	<20	<5	<0.1	<10	<0.005	<0.1	<5	<0.2	<0.1	2	11
TRIP BLANK					#######					3	3	0.006	<10	<0.1	0.9	<0.10	<20	<5	<0.1	<10	<0.005	0.1	<5	<0.2	0.1	2	<3
TRIP BLANK					#######					2	2	0.014	<10	<0.1	1.1	<0.10	<20	<5	<0.1	<10	0.046	<0.1	<5	<0.2	<0.1	2	<1

Arsenic Levels
Sampled January
1995

Plate 1

N

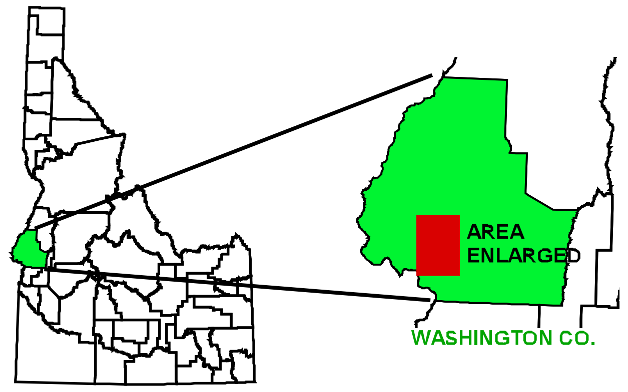
Map Projection: IDTM
SCALE 1:50,000
1 inch represents 0.79 miles

0.5 0 0.5 1 1.5 2 Kilometers

0.5 0 0.5 1 1.5 Miles

◐ arsenic level in microgram/liter
well depth in ft or sw = surface water

+	Arsenic < 25 microgram/liter
◐	Arsenic 25 - 49 microgram/liter
●	Arsenic => 50 microgram/liter
▨	Area Underlain by Aquifers
■	Lakes, Streams, and Rivers
□	Township and Range
□	Section Lines
—	Major Roads
—	Minor Roads



REFERENCE MAP