Ground Water Quality Technical Report No. 21

Evaluation Of Water Quality Impacts Associated With FMC And Simplot Phosphate Ore Processing Facilities, Pocatello, Idaho

Department of Environmental Quality
Technical Services Division
January 2004

Cover photo: stream gaging at transect T-3 facing south, with the Simplot facility in the background.

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EXECUTIVE SUMMARY

A study was undertaken to evaluate the potential phosphorus and nitrogen loading contributions from ground water emanating from beneath two phosphate ore processing facilities, as well as other local potential contaminant sources, to the lower Portneuf River. The primary objective was to provide information that may be used in the development of a TMDL for the lower Portneuf River.

Numerous data sources were utilized to evaluate orthophosphate trends over time and space, geochemical controls on contaminant transport, and loading of various sources in the study area to the lower Portneuf River. These data sources included ground water monitoring data from the FMC and Simplot (Don Plant) facilities, ground water quality data from the Idaho Department of Water Resources statewide ground water monitoring network, ground water monitoring data from the Simplot wastewater land application site, water quality and stream discharge data from the Portneuf River and springs discharging to the river collected by DEQ personnel, water quality data from the Batiste Spring channel collected by DEQ personnel, ground water quality data from monitoring wells at the City of Pocatello wastewater treatment plant and sludge treatment facility, and discharge effluent data for the City of Pocatello wastewater treatment plant.

Five potential sources of nitrate and phosphorus contribution to the river were evaluated including regional ground water discharge, Batiste Spring, the City of Pocatello wastewater treatment plant, the Simplot wastewater land application site and ground water underflow from the FMC and Simplot facility areas. Nitrogen and phosphorus loading estimates and calculations show that ground water underflow from the FMC and Simplot facility areas contributes between 35 and 55 percent and possibly as much as 80 percent of the nutrient load to the river.

Historical and current production operations associated with both facilities have significantly impacted the shallow ground water system with elevated levels of phosphorus and nitrogen. The discharge of this impacted ground water to the lower Portneuf River occurs over a very short stretch of river and contributes the vast majority of the large increase in phosphorus loading to the river measured below Batiste Road. With the closure of the FMC facility, current loading to ground water and the river is dominated by the Simplot facility. The likely accumulation of phosphorus on aquifer sediments from historical loading combined with aquifer conditions which maximize phosphorus solubility may contribute to elevated phosphorus levels in ground water and surface water for extended periods of time, despite the reduction or elimination of current sources.

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INTRODUCTION

PROBLEM STATEMENT

The lower Portneuf River flows north-northwest from the City of Pocatello to its discharge point in American Falls Reservoir. The Department of Environmental Quality (DEQ) has currently developed a Total Maximum Daily Load (TMDL) for the river. A TMDL allocates loading of contaminants from various sources to the river to ensure that the designated beneficial uses of the river, such as cold water biota, etc., are supported. The TMDL target for total phosphorus in the lower Portneuf River, which is currently out of attainment, is 0.075 mg/L.

As the river leaves the City of Pocatello its discharge relationship with the local ground water system changes from a losing to a gaining condition. Sources that discharge to the river include numerous natural springs, shallow ground water and municipal wastewater treatment effluent. This transition also coincides with a significant increase in phosphorus concentration and loading in the river. Two of the most potentially significant sources of phosphorus to the river in this reach are two phosphate ore processing facilities (FMC Corporation [FMC], which was Astaris during this study[1], and J. R. Simplot Company [Simplot]) and the Pocatello wastewater treatment plant (WWTP).

PURPOSE AND OBJECTIVES

The DEQ Technical Services Division performed the study documented here at the request of the DEQ Pocatello Regional Office. The purpose of the study was to evaluate the potential contribution from ground water emanating from beneath the ore processing facilities, as well as other local potential contaminant sources, to phosphorus and nitrogen loading in the lower Portneuf River. The objective was to provide information that may be used to refine wasteload and load allocations for the TMDL for the lower Portneuf River.

The tasks that have been completed to achieve this purpose and objective fall into two general categories: evaluation of contaminant loading to the river, and analysis of ground water chemical concentration trends and site geochemistry beneath the facilities. The specific tasks included the following:

- Conduct a background review of the hydrogeological assessments completed by FMC and Simplot, including associated monitoring data, well construction/lithological logs, ground water flow models, and Portneuf River data including flow volumes and associated analytical data.

[1] This facility was historically owned and operated by FMC Corporation. From 2000 to 2002 it was owned and operated by Astaris. When Astaris ceased operations and closed the plant, ownership reverted to FMC. Throughout this report it will be referred to as the FMC site or facility, except when reports or maps already generated by others refer to it as the Astaris site or facility.

- Collect surface water samples for selected analytes, and collect surface water flow information to document areas of ground water inflow and delineate areas of nutrient contribution to the river.
- Perform statistical trend analysis of ground water quality data for selected facility wells, from both upgradient and downgradient locations, using the existing well data.
- Evaluate ground water geochemistry at selected well locations across the facilities to 1) examine the connection between ground water quality beneath the facilities and in the Portneuf River and 2) evaluate geochemical controls on phosphorus fate and transport.
- Based on all the work described above, summarize results as to the potential impacts on local ground water and the Portneuf River, and develop technical recommendations regarding identified data gaps and additional monitoring/remediation that may be needed related to TMDL development and implementation.
- Evaluate areas where remedial activities could reduce nutrient loads to the Portneuf River.

DATA SOURCES

Numerous sources of information and data were utilized in this study. These sources include:

- Database of historical monitoring results for the study area associated with the Eastern Michaud Flats Superfund investigations, generated by Bechtel Environmental, Inc.
- Database of historical monitoring data associated with Resource Conservation and Recovery Act (RCRA) monitoring at the FMC facility, generated by FMC.
- Database of monitoring well locations and historical monitoring data for selected constituents from the 300 to 500 series ground water monitoring wells. The database was supplied by the J. R. Simplot Company.
- Portneuf River transect data and Batiste Springs channel monitoring data collected by DEQ Pocatello Regional Office, and the City of Pocatello, respectively.
- City of Pocatello wastewater treatment plant discharge data and sludge pond monitoring well data.
- Statewide ground water monitoring well network data from the Idaho Department of Water Resources. Throughout this report, these wells will be termed statewide monitoring wells.
- Reports prepared by consultants, state and federal agencies, and graduate students containing geological and hydrogeological data and interpretations of these data, which are listed in the References section.

STUDY AREA DESCRIPTION

The study area, illustrated in figure 1, is located immediately northwest of the City of Pocatello and east and west of the lower Portneuf River in the areas known as Michaud Flats and the Fort Hall Bottoms. The FMC and Simplot facilities are approximately in the middle of the study area. They share a common boundary and fenceline, with FMC west of the boundary and Simplot east of it (figure 2). This area is generally referred to as the Joint Fenceline area. The Bannock Range rises directly south of the FMC and Simplot facilities.

DESCRIPTION OF FACILITIES AND SITE HISTORY

The FMC and Simplot facilities have processed phosphate ore since the 1940s. The products, processes, and waste products of the two facilities are very different. The FMC plant utilizes an electric arc furnace method to produce elemental phosphorus while the Simplot facility uses sulfuric acid to produce phosphoric acid. Waste products associated with FMC are kiln slag and liquids, formerly deposited in numerous unlined ponds, resulting from calcining and other processes. Simplot primarily produces phosphogypsum as a waste product, initially placed as a slurry in ponds and then redeposited in extensive "stacks." At the Simplot facility these are often collectively referred to as the gyp stack and will be so called in this report. Phosphogypsum, as its name implies, is primarily gypsum along with numerous impurities resulting from the ore processing. Phosphorus is found in all of these potential source areas, primarily in the orthophosphate form. Other contaminants associated with these sources include arsenic, selenium, zinc, cadmium, vanadium, and fluoride, as well as major ions such as sodium, potassium, chloride, nitrate, ammonia, and sulfate.

As a result of contamination releases from the source areas described above both facilities were included in the Eastern Michaud Flats (EMF) Superfund site. The site was listed on the National Priorities List (NPL) in August 1990, and FMC and Simplot agreed to conduct a Remedial Investigation/Feasibility Study (RI/FS) for the site, starting in 1992. As a result of these RI/FS activities numerous wells were installed. The location of these wells is shown in figure 2. A Record of Decision (ROD) was issued in 1998.

The original remedy, as described in the ROD, addressed two Operable Units (OUs), the FMC plant and the Simplot lant. Each OU included Off-Plant Areas. The major components of the selected remedy are described below.

The remedy for the FMC OU included: capping the old Phossy Waste Ponds and Calciner Solids Storage area and lining the Railroad Swale to reduce or eliminate infiltration of rainwater to ground water and prevent exposure to contaminants, and monitoring ground water and implementing institutional controls (ICs) to prevent the use of contaminated ground water for drinking purposes under current and future ownership. Ground water monitoring and ICs were to continue until site contaminants of concern (COCs) in ground water declined to below maximum contaminant levels (MCLs) or risk-based concentrations (RBCs) for those contaminants. Other facets of the remedy included additional ICs to prevent potential future residential use and control potential worker exposures under future ownership, and implementation of a contingent ground water extraction/treatment system if contaminated ground water was found to migrate beyond company owned property and into adjoining springs or the Portneuf River. Containment of contamination was to be achieved by hydrodynamic controls provided by low level pumping. Extracted ground water would be treated and recycled by using it within the plant instead of using unaffected ground water that would have been extracted for use in plant operations.

The remedy for the Simplot OU included: implementation of a ground water extraction system to contain contaminants associated with the phosphogypsum stack and operation and maintenance of that system, implementation of ICs to prevent potential future residential use of the Simplot property and to control potential worker exposures under current and future ownership, excavation of contaminated soils from the dewatering pit and east overflow pond, and monitoring of ground water and implementation of ICs to prevent the use of contaminated ground water for drinking purposes under current and future ownership. Ground water monitoring and enforceable controls were planned to continue until site concentrations of COCs in ground water declined to below MCLs or RBCs for those contaminants.

The remedy for the Off-Plant Area (actions common to both Simplot and FMC OUs included: implement ICs and monitoring in the Off-Plant area to restrict property use due to potential exposure to radionuclides in soils and inform future property owners of the potential risks associated with consumption of homegrown fruits and vegetables, and monitoring of fluoride levels around the site in order to determine the levels of fluoride present and to evaluate the potential risk to ecological receptors.

Since the signing of the ROD, ground water monitoring has continued to the present time as part of RCRA ground water monitoring requirements involving nine waste management units. Proposals for capping of the FMC calciner ponds are currently being evaluated. Simplot has entered into a consent decree to design and implement the pump-and-treat system described above.

REGIONAL HYDROGEOLOGY

The Portneuf River from north of Interstate 86 (I-86) to American Falls Reservoir is a gaining reach and serves as a discharge area for aquifers on both the east and west sides of the river. To the east, ground water in the Michaud Gravel moves out of the valley of the Portneuf River at Pocatello and flows west to discharge to the river. On the west, regional ground water flow moves radially outward to the north, west and east from a broad area between I-86 and American Falls Reservoir (figure 3). Ground water on the eastern part of this area discharges to the Portneuf River.

The ground water flux to the river from the east is probably large compared to flux to the river from the west. On the west, regional ground water flow is generally to the north, toward American Falls reservoir, with a small component of flow discharging to the river (figure 4).

LOCAL HYDROGEOLOGY

Michaud Flats, including the FMC-Simplot complex, is underlain by the following units, youngest to oldest and shallow to deep:

Quaternary loess or silt, and gravels (surface cover) – underlies the facilities and surrounding area, mostly disturbed due to past construction activities and presence of structures, ponds (some closed), roads, and other site activities. Much of this layer constitutes the vadose (unsaturated) zone.

Upper gravel aquifer zone – includes the Michaud Gravel and Aberdeen Terrace deposits, the latter essentially reworked Michaud Gravel. The Michaud Gravel can include boulders up to four feet in diameter in the East Michaud Flats study area (Trimble, 1976).

American Falls Lake Beds (AFLB) – the regional aquitard, which locally appears to pinch out near the Portneuf River. Most often noted on logs as silty clay and clay.

AFLB Fluvial Facies – Sunbeam Formation and underlying basalt – comprises a thick, high transmissivity reservoir composed predominantly of coarse gravels, and fractured and vesicular basalt flows.

Where the AFLB appears to pinch out or disappear near the Portneuf River, the result is a relatively thick and unconfined aquifer, especially in the vicinity of Batiste Springs. The "pinch out" may be a result of erosion of the AFLB by the Bonneville flood, rather than a true stratigraphic change, or a combination of both. Ground water flowing into Batiste Springs then reflects both the ground water chemistry and contaminant loading from both the shallow (Michaud Gravels) and deep (section underlying the AFLB) aquifers.

An examination of the Simplot and FMC monitoring wells verifies that the lithology in the site area is predominantly gravel, silty and sandy gravel, and gravelly sand in wells nearest the Portneuf River. South and southwest of the river and within the facility boundaries, there is a marked increase in silt, clay and silty clay at depth, in zones both above (eolian and alluvial deposits) and below (alluvial and lacustrine deposits) the AFLB.

Figure 5 shows potentiometric contours on the shallow water table for the area around the FMC and Simplot facilities (from Bechtel Environmental, 1994). Ground water flow in both the shallow and deep aquifers exhibits a northward component of flow in the southern part of the FMC and Simplot facilities. Near I-86, the predominant flow direction in both aquifers is to the east-northeast, towards the Portneuf River. This flow direction was demonstrated in both earlier work and more recent work at the site

(Bechtel, 1994; Astaris Idaho LLC, 2001). In the western part of the FMC area the potentiometric surface has a uniform slope toward the river.

North of the Joint Fenceline area (an area surrounding the facilities' common boundary), a trough in the water table concentrates shallow ground water flow toward the Batiste Spring and Spring at Swanson Road discharge areas (the location of these springs can be seen in figure 2). The trough is believed to be a reflection of a highly transmissive zone in the Michaud Gravel, a unit that was deposited during the Bonneville Flood event. Trimble (1976) mapped a zone with boulders ranging from three to four feet in size extending to the west along I-86 from the Joint Fenceline area that coincides with the trough in the shallow water table (figure 6, adapted from Trimble, 1976, figure 13). Trimble (page 58) describes the Michaud Gravel as a composite sand and gravel deposit that was dumped into the American Falls Lake.

Othburg (2002) describes the Michaud Gravel as a "large Bonneville Flood expansion bar" and indicates there is "clear evidence of reworking and channeling of the bar by later, reduced flow regimes of the flood." Features described as "channeled-flow pathways" were mapped by Othburg, one of which corresponds to the boulder zone along I-86 mapped by Trimble. It is believed that this paleochannel provides a conduit for ground water movement to the east, where it discharges to Batiste Spring and the Spring at Swanson Road. The trough in the potentiometric surface reflects this concentration of ground water flow towards the spring discharge areas.

A component of ground water flow moves from northwest to southeast to discharge at Batiste Spring. This ground water flow component is unaffected by site activities, as will be shown in following sections of the report, and represents regional ground water quality. On the east side of the area, north of the Simplot gyp stack (the dark gray to black area of the Simplot facility as seen in figure 1), some ground water moves under the river from east to west and then flows northward, parallel to the river.

This component of ground water underflow seems counterintuitive since the river has been assumed to serve as a discharge area for shallow and deep ground water both on the east and west sides of the river. However, Source Water Assessment work conducted for the Simplot drinking water wells (which also are used as a water supply source for the industrial process) indicates that near the Bannock range hills there must be some underflow from the east in order to supply the approximately 4,500 gallon per minute pumping rate at the three Simplot production wells (Washington Group International, Inc., December 2001). The Portneuf River north of the study area to American Falls Reservoir most likely receives ground water discharge from both the east and west.

RIVER SAMPLING

DEQ began a monitoring program for the lower Portneuf River in 1999 in conjunction with the implementation of the Portneuf River TMDL for total phosphorus. The purpose of this data collection program was to document recharge/discharge relationships and nutrient loading between ground water and the river. Specific objectives included collection of synoptic discharge measurements and nutrient samples from the river during low flow periods when surface water contribution to the river was at a minimum. Flow measurements from springs discharging to the river were collected where possible and nutrient samples were collected from all major springs discharging to the river. The data collection program was conducted over a four-year period to evaluate flow and water quality variability of the ground water and surface water systems.

The data collection program began in 1999 with an investigation of water quality at Batiste Spring and the spring channel. This water quality investigation, funded by the City of Pocatello, included collection of field parameters and laboratory analysis of water samples. These data will be presented in a later section. In September 2000, DEQ conducted water quality monitoring and discharge measurements at nine river transects located on the two-mile reach of river downstream of the I-86 bridge. Intermediate, intensive river transects were added in 2001 after evaluation of the initial monitoring results. Detailed investigations were conducted at these additional locations. Tables 1 through 6 and table 8 show sampling dates, locations, and parameters collected for all sample events.

Discharge trends and distribution of nutrient loads in the river are discussed in the following section, followed by an evaluation of nutrient sources and loads to the river. Nutrient sources include area-wide ground water that discharges to the river, Batiste Spring, the City of Pocatello WWTP, ground water underflow from the Simplot wastewater land application site and ground water underflow from the Simplot and FMC facilities.

INITIAL PORTNEUF RIVER TRANSECT DATA COLLECTION

During September 12, 13, and 14, 2000, nine transects were sampled on the Portneuf River, from just upstream of the I-86 crossing (Transect 1 or T-1) to just below or downstream of Papoose Springs (T-10). Figure 7 shows the location of the initial transects. No T-5 transect was installed. At each transect, discharge was measured and samples were collected for analysis of total ammonia, total nitrite/nitrate, total Kjeldahl nitrogen, dissolved orthophosphate, and total phosphorus. Stream discharge was measured using a Marsh McBirney current meter. Samples were collected every two to three feet across the stream for each segment using a depth-integrated sampler. Samples were composited in a churn splitter prior to collection in sample containers. Concentrations for the above parameters are shown in table 1 and plotted in figure 8 (with the exception of total Kjeldahl nitrogen). At transects T-6 through T-10 pH, conductivity, and temperature information were collected.

The stretch of river downstream of I-86 has historically been known to be a gaining reach due to the numerous springs discharging along the banks and bottom of the streambed. This stream flow gain is demonstrated in the transect data, which shows a flow of 77.91 cubic feet per second (ft^3/sec) at T-1, increasing to as much as 276 ft^3/sec at T-9 (figure 8), an almost four-fold increase in flow. Equally notable is the increase in contaminant concentrations through this stretch, also shown in figure 8 and documented for the first time in this study**.**

ADDITIONAL RIVER TRANSECT DATA

Following a review of the September 2000 transect data, additional flow measurements and samples were collected during the period August 20-22, 2001. The east, middle and west thirds of the stream at transect T-2 and the east and west halves of the stream at transect T-7 were sampled separately during this event.

For transect T-2, analytical results showed that the nitrogen load in the western third of the stream was 590 pounds per day, compared to a nitrogen load of 330 pounds per day for the eastern two thirds of the stream. Total phosphorus loads were 956 pounds per day in the western third of the stream compared to a phosphorus load of 234 pounds per day in the eastern two thirds of the stream.

Nitrogen and total phosphorus concentrations and loads were more evenly distributed across the stream channel at T-7. The nitrogen load for the western half of the stream was 1,166 pounds per day compared to a nitrogen load of 1,533 pounds per day for the eastern half. The total phosphorous load for the western half of the stream was 455 pounds per day compared to a total phosphorous load of 875 pounds per day for the eastern half. These loads were calculated based on discharge and nutrient concentrations listed in Table 2.

Based on these August 2001 sample results, additional transects, here termed intensive transects, were established in the area of greatest stream flow gain and nutrient loading, namely the reach between transects T-1 and T-3. The purpose of the intensive transects was to determine if water quality and nutrient loading characteristics identified at T-2 during the August 2001 sample event were present at other river locations.

The locations for the intensive transects were established by first conducting reconnaissance transects R-1 through R-5 at the locations shown on figure 9. Dissolved oxygen, pH, and specific conductance were recorded at these transects. Field parameter information was collected with the instrument probe at the bottom of the channel so the data were representative of ground water quality in gaining stretches of the river.

The evaluation of reconnaissance transect data led to the establishment of intensive transects T-1A, T-1B, T-2A and T-2B. During October 2001, field parameters, water samples, and discharge data were collected where possible from these transects and five springs that discharge to the river along the same stretch: East Spring, Spring at Swanson Road, T-1B Spring, Batiste Spring and Spring E-4. The intensive transects and spring locations are shown on figure 9. Analytes at the intensive transects and springs included field parameters (pH, specific conductance and dissolved oxygen), common ions (calcium, magnesium, sodium, potassium, bicarbonate, chloride, and sulfate), ammonia, Total Kjeldahl Nitrogen, total phosphorus and fluoride. Discharge, nitrogen and phosphorous data are shown in table 3 and laboratory analytical sample results are shown in table 4. Separate samples were collected from the east and west halves of the river using a depth-integrated sampler and composited in a churn splitter. The stream bottom profile, dissolved oxygen, temperature, pH, and specific conductance values were recorded at two- to three-foot intervals across the channel. Composite samples also were collected for analysis of the stable isotopes of hydrogen (^{2}H), oxygen (^{18}O), nitrogen (^{15}N) and sulfur (^{34}S) from transects and springs listed in table 6.

RIVER TRANSECT SAMPLING RESULTS

Discharge and water quality data from transects demonstrated a large increase in discharge and nutrient loading to the river along the reach from transects T-1 to T-10. Flow in the river, from discrete spring sources and from diffuse ground water discharge in the channel bottom, increased by about 189 ft^3/sec from transect T-1 through T-10 during the September 2000 sample event and about 198 ft^3/sec during the August 2001 and September 2002 sample events (tables 1, 2 and 5). The three measurement events were conducted during low flow periods, when ground water discharge accounted for all of the inflow to the river below I-86 excepting the Pocatello WWTP.

A stream flow loss of about 90 ft^3/sec between transects T-4 and T-6 was recorded for the September 2000 sampling event (table 1 and figure 8). Discharge measurements conducted during August 2001 and September 2002 at the same transects do not show this pronounced stream flow loss, although a loss of approximately 20 ft^3/sec was measured during August 2001. The reason for the 90 ft^3 loss is unknown.

The stream flow gain between transects T-1 and T-2 averaged about 36 ft^3/sec for flow measurements made during the fall of 2000, 2001 and 2002 (tables 1, 2, and 5). Shallow aquifer discharge to the river from the west side along the same reach is estimated to be about 2.9 ft^3/sec or about eight percent of the total gain (see flow net analysis in the Flow and Loading Calculations section, page 12). Estimates of the volume of ground water contribution to the river from the deep aquifer on the west side and from aquifers on the east side were not possible due to limited information on aquifer properties.

Plots of specific conductance, pH, and dissolved oxygen data for the five transects T-1A through T-2B reveal that the west side of the river generally has lower pH, lower dissolved oxygen, and higher specific conductance than the east side (figures 10 through 15). At some transects the transition to higher pH, higher dissolved oxygen, and lower specific conductance occurs over a short distance across the channel (transect T-1A) while at other transects there is a gradual transition in water quality across the channel (transect T-2B).

At transect T-2A the specific conductance information indicates that ground water discharge enters the stream in the central part of the channel. Ground water discharge zones in the channel bottom may be controlled by subsurface geology. The jagged nature of the stream bed profile at transects T-1B and T-2 reflects boulder zones that are remnants of the Bonneville flood event; these areas are likely highly permeable and provide favorable areas for ground water discharge. The intensive transects provide further evidence that contaminated ground water enters the river from the west between transects T-1A and T-3.

CONTAMINANT LOADING ANALYSIS

The above data demonstrate a large increase in nitrogen and phosphorus loading to the river in the two-mile reach below the I-86 bridge. Five potential sources of nutrient loading to the river within this reach were evaluated: 1) regional ground water discharge to the river, 2) Batiste Spring and the spring channel, 3) the City of Pocatello WWTP, 4) the Simplot wastewater land application site on the east side of the river, and 5) ground water that flows beneath the FMC/Simplot facilities and discharges to the river downstream of the I-86 bridge. These five sources account for all flow and nutrient inputs to the river within this reach.

In the following sections, nitrogen and total phosphorus data for each of the sources is evaluated and the volume of discharge to the river from the combined five sources estimated. Loads are then calculated based on concentration and volume of the discharge.

REGIONAL GROUND WATER

Potentiometric data show that ground water discharges to the river below the I-86 bridge (figures 3, 4, and 5). Nitrogen and phosphorus in regional ground water that discharges to the river is one possible source of nutrient loading. Water quality data from statewide monitoring wells on the east and west sides of the Portneuf River were used to characterize the quality of regional water discharging to the river.

For a statistically valid characterization of regional ground water quality, data from the statewide ground water monitoring network wells were used. This statewide ambient monitoring program was established in 1991 with the following objectives: characterize the ground water quality of the state's aquifers; identify trends and changes and identify potential problem areas in ground water quality within the state's aquifers (Neely, 1994). Only wells that had well logs and were open to a single cold water aquifer ($\leq 26^{o}$ C) were selected for inclusion in the network, which currently consists of about 1,600 wells located in the major aquifers throughout the state. The wells were selected using a stratified random sampling statistical method for the network design.

Thirteen wells in the statewide monitoring network are located near the study area (figure 16). Among them, individual wells have been sampled from one to eight times during the period 1991 through 2001, the most recent year that data are available, and the results provide a long-term record of regional ground water quality near the study area. Table 7 lists mean nitrate-N and total phosphorus concentrations from the 13 wells. The only phosphorus data available from statewide monitoring wells is total phosphorus.

Mean nitrate-N concentrations range from 1.1 to 5.4 mg/L for eight statewide wells on the east side of the Portneuf River and from 1.1 to 3.1 mg/L for five statewide wells on the west side of the Portneuf River (table 7). Mean total phosphorus concentrations ranged from 0.01 mg/L to 0.06 mg/L for east side wells and from 0.009 to 0.011 mg/L for west side wells. This total phosphorus concentration is lower than the "background" total phosphorus concentration of 0.27 mg/L presented by Bechtel (1994) in the remedial investigation (RI) of the two facilities. It is likely that the RI background phosphorus concentration was determined using wells that were impacted by site activities.

BATISTE SPRING AND CHANNEL

Water that discharges from Batiste Spring flows into a channel that runs parallel to the Portneuf River for a distance of approximately one mile. The spring itself is adjacent to the west bank of the river at a point between T-2 and T-2A (figure 9). At the lower end of the channel, part or all of the spring flow is diverted through the Batiste Spring Trout Farm. After flowing through the trout farm facility, the water discharges to the Portneuf River, just upstream of transect location T-7 (figure 7).

During the period May 4, 1999 through December 7, 2000 the City of Pocatello collected monthly samples at five locations along the Batiste Spring channel. These locations were sampled for chloride, sulfate, alkalinity, total dissolved solids (TDS), ammonia, Total Kjeldahl Nitrogen, nitrite plus nitrate as N (NO_2+NO_3-N), total nitrogen, total phosphorus and orthophosphate, total suspended solids, and turbidity. These sample data are included in table 8. The five sample locations, as shown on figure 7 are the springhouse, loading dock (Meadow Gold/Rowlands Dairy), culvert, spillway (above Batiste Springs Trout Farm), and the Batiste Springs Trout Farm discharge (marked as Hatchery Effluent on figure 7). Analytical results for all sample parameters were similar for all sample events. Figure 17 shows plots of total nitrogen, total phosphorus, chloride, sulfate, alkalinity and total dissolved solids for the November 8, 2000, a representative channel sample event.

CITY OF POCATELLO WASTEWATER TREATMENT PLANT

The City of Pocatello WWTP discharges treated effluent to the Portneuf River at a point located between transects T-3 and T-4. This discharge is regulated under an EPA National Pollutant Discharge Elimination System (NPDES) permit. The permit requires the city to analyze treated effluent several times per week for average daily flow, ammonia, Total Kjeldahl Nitrogen, total phosphorus and orthophosphate, and nitrite plus nitrate as N (NO_2+NO_3-N). Data for the period January 2000 through March 2001, shown in table 9, were reviewed for this project. Nitrogen and phosphorus analytical data for the treated discharge are available for September 13 and 14, 2000 when the Portneuf River transect data were collected. Data for September 12, 2000 are also included for further comparison. Nitrogen and phosphorus loading estimates derived from these data are included with the September 2000 stream data (table 1).

SIMPLOT WASTEWATER LAND APPLICATION SITE

Industrial wastewater from the Simplot facility is land applied during the growing season to approximately 328 acres on the east side of the Portneuf River, in accordance with DEQ wastewater land application permit LA-000104-01. The acreage is divided among three fields, shown on figure 18**,** and wastewater applications are reported to be uniform at all three acreages. Three ground water monitoring wells (513, 509, and 511) around the Swanson acreage have been sampled since 1992 for constituents including nitrate-N and orthophosphate; the Spanbauer and BAPCO/Carlsen acreages do not have ground water monitoring systems. Well 513 is an upgradient well, and wells 509 and 511 are downgradient wells for the Swanson acreage (figure 18). Table 10 shows average nitrate-N and orthophosphate concentrations at these monitoring wells.

FMC/SIMPLOT FACILITY GROUND WATER

Quality

Phosphorus and nitrogen concentrations in ground water beneath the two phosphate ore processing facilities differ dramatically from that seen in the regional aquifer. Figures 19 and 20 show orthophosphate and nitrate concentrations in shallow ground water from selected wells at the two sites. These concentrations are taken from a December 1993 sampling event, a time period when both facilities were operating. Orthophosphate concentrations in ground water ranged from several hundred mg/L to less than 0.1 mg/L. Nitrate concentrations in wells in the shallow aquifer range from more than 40 mg/L to less than 0.1 mg/L.

Flow and Loading Calculations

Ground water discharge to the Portneuf River from the FMC/Simplot area in the shallow aquifer was evaluated for the shallow system prior to mixing with the deep aquifer. A flow net analysis was conducted for the shallow aquifer system in the FMC/Simplot area. Figure 21 (adapted from Bechtel, 1996, figure 2.2.3) shows the area that was evaluated using the flow net analysis. Ground water flux through a cross-sectional area of six flow tubes was estimated and the resulting volumes were multiplied by nitrate-N and orthophosphate concentrations to arrive at a mass load from the shallow aquifer. These loading results are presented in a later section.

The first step in the evaluation was to construct a series of ground water flow path lines on the June 1994 potentiometric map (figure 5) for the shallow aquifer (figure 21). Next, the saturated thickness of the shallow aquifer within the resulting flow tubes was calculated by subtracting the elevation of the top of the American Falls Lake Bed from the appropriate water table elevation. For this calculation the elevation of the American Falls Lake Bed was subtracted from the 4,384-foot water table contour to calculate the cross-sectional area for each flow tube. The ground water flux through each flow tube at the 4,384-foot water table contour was then estimated using the Darcy equation:

$$\mathbf{Q = KiA,} \text{ where}$$

Q = ground water flow volume (ft^3/day)
K = hydraulic conductivity of the shallow aquifer (ft/day) (K data from Bechtel, 1994),
i = hydraulic gradient (ft/ft), from potentiometric map, and
A = cross sectional area of the aquifer (ft^2).

Hydraulic conductivity values were summarized from a ground water flow model of the FMC and Simplot areas (Bechtel, 1994). For each flow tube, recent nitrate-N and orthophosphate concentrations in monitoring wells nearest to the 4,384 foot contour line were used to represent ground water quality at the 4,384-foot contour. From north to south, representative wells included 502, 517, 331, 335S, 327 and 318.

Finally, the ground water flow volume was multiplied by the orthophosphate and nitrate-N concentrations at each well to estimate a constituent load moving through the cross-sectional area at the 4,384-foot contour. The results, summed for a total load to the river, are listed in table 11.

PHOSPHORUS AND NITRATE CONCENTRATIONS AND LOADS IN THE PORTNEUF RIVER

Nitrate-N and total and orthophosphate concentrations and load in the river increase dramatically between transect T-1 and T-3. Downstream of T-3, nitrate-N concentrations in the river remain in the range of 2.6-2.7 mg/L, reflecting inflow of ground water with a similar nitrate-N concentration (figure 8). The nitrate-N concentration in the river can not decrease below this concentration range because ground water discharging to the river has a similar nitrate-N concentration. However, nitrogen loads in the river continue to increase due to the increase in the volume of stream flow (figure 22).

Phosphorus concentrations gradually decrease downstream of transect T-3, reflecting the influx of ground water with lower phosphorus concentrations, in the range of 0.03 to 0.04 mg/L (figure 8). Phosphorus loads in the river are more or less constant, since the increase in stream flow is offset by decreasing phosphorus concentrations. This trend is evident for the September 2000, August 2001 and September 2002 data (tables 1, 2, and 5).

Estimates of nutrient loading from the five potential sources are presented in the following sections. The discussion is focused mainly on the reach of the river between transects T-1 and T-2, where most of the nutrient loading occurs.

REGIONAL GROUND WATER DISCHARGE AND LOADING

The total stream flow increase between transects T-1 and T-2 averaged about 36 ft^3/sec for 2000 through 2002. Shallow aquifer discharge to the river from the west side is estimated to be about 2.9 ft^3/sec for this same reach, leaving a discharge of about 33 ft^3/sec from deep ground water on the east and west sides of the river. Nutrient loads to the river from regional ground water are estimated using the range of nitrate-N and phosphorus concentrations recorded in regional ground water from statewide monitoring wells in the area. Using the range of 1.1 to 5.4 mg/L nitrate-N in statewide wells, nitrate-N loads to the river could range from 190 to 930 pounds per day. A loading estimate of 200 to 300 pounds per day of nitrate-N is probably more reasonable since most statewide wells had nitrate-N concentrations in the range of 1 to 4 mg/L (table 7).

Phosphorus loading from the same regional ground water discharge volume is on the order of 100 times less than calculated phosphorus loads in the river, 1 to 10 pounds per day versus 800 to 1,000 pounds per day at T-2, showing that the regional ground water does not contribute significant phosphorus to the river between transects T-1 and T-2.

Nitrogen loads in the river continue to increase downstream of T-2, at transects T-3 and T-4. This additional load may be from intergravel flow contributions to the water column downstream of where ground water first flows into the river channel. In this context, intergravel flow is defined as ground water that moves through the substrate pores in the channel bottom. Phosphorous loads in the river increase between transects T-3 and T-4, and remain more or less constant downstream of T-4 (figure 22).

As previously noted, the phosphorus concentration in regional ground water entering the river below transect T-2 is low, and the impact of this source to the river can be evaluated. Using a regional ground water phosphorus concentration of 0.04 mg/L and a stream flow gain of about 71 ft^3/sec between transects T-2 and T-4, the phosphorus load to the river from regional ground water would be about 15 lbs/day, compared to a phosphorus load of about 2,000 lbs/day based on stream flow and water quality data from the river. In a similar fashion, nitrate-N loads to the river between transect T-2 and T-4 from ground water are estimated to be about 1,155 lbs/day (3.0 mg/L nitrate-N and 71 ft^3/sec river gain).

BATISTE SPRING DISCHARGE AND LOADING

Discharge at Batiste Spring varies in response to the water level elevation in aquifers that contribute water to the spring. A discharge of as much as 46 ft^3/sec has been recorded at the spring (Perry, 1981); a large discharge of 38 ft^3/sec was also recorded on April 2, 1978 (Goldstein, 1981). Discharge at the spring on October 4, 2001 was 0.2 ft^3/sec, as measured by DEQ, and an August 2002 site visit indicated that discharge at the spring was comparable to that measured in October 2001.

The unusual low flow at Batiste Spring recently may be due to lower than normal precipitation in the area. The mean annual precipitation at the Pocatello Airport National Weather Service station for the period 1939 through 2001 was 11.64 inches; during 2001 it was 7.09 inches, an almost 40 percent decrease from the long-term average. Precipitation during the first four months of 2002 was about 63 percent of the long-term average for the same period.

Water quality data indicate that the source of water to the spring has changed, perhaps in response to declining water table elevations. Concentrations of some constituents in spring discharge appear to have peaked in 1996 and have been declining since that time. Isotope data, presented in table 6 and figure 23, confirm this observation.

Figure 17 shows total nitrogen, total phosphorus, alkalinity (as $CaCO_3$), total dissolved solids, chloride, and sulfate trends at the five spring channel sample locations for November 8, 2000, a representative spring channel sample event. Concentrations of total nitrogen, total phosphorus, total dissolved solids, chloride, and sulfate decreased dramatically between the spring house and the loading dock, which is about 350 feet downstream from the spring house (figure 7). Concentrations of most constituents remained low downstream of the loading dock. Similar trends exist for these constituents on other sampling dates. These concentration decreases are believed to result from the influx of regional ground water into the spring channel, resulting in dilution of the contaminated water that discharges from the spring. Ground water that discharges to the spring channel would have water quality characteristics of the regional aquifer in the Michaud Flats area, with nitrate concentrations in the range of 1 to 3 mg/L and total phosphorus concentrations in the range of 0.01 mg/L.

The concentrating effect of the trough in the shallow water table (figure 5) results in significant water quality changes over short distances north or south of the axis of the trough. Ground water originating from areas north of the axis of the trough has water quality similar to ambient water quality shown in table 7.

Changes in water quality along the Batiste Spring channel confirm the above observations. Chloride, sulfate, nitrate and phosphorus concentrations decrease by approximately one half over the distance of about 350 feet between the spring house and the loading dock. Although decreases in phosphorus concentration could be attributed to uptake by aquatic growth, concentration decreases of conservative tracers such as chloride and nitrate show the most likely explanation to be dilution of contaminated water discharging from the spring by an influx of regional ground water originating from the north.

CITY OF POCATELLO WASTEWATER TREATMENT PLANT DISCHARGE AND LOADING

Discharge from the Pocatello wastewater treatment plant accounted for less than one percent of the stream flow gain between transects T-3 and T-4 during the September 2000 sample event (table 1). Discharge from the wastewater treatment plant to the river is probably similar from year to year.

Loading calculations show that the phosphorus load from the wastewater treatment plant to the river is very small compared to the total load in the river (table 12). During some periods nitrogen loading to the river from the wastewater treatment plant may be a significant percentage of the nitrogen load in the river at T-4. For example, for the month of January 2001 the daily ammonia plus nitrite/nitrate-N load from the wastewater treatment plant was estimated to be about 1,250 pounds per day (table 9). Ammonia plus nitrite/nitrate-N loads at T-4 ranged from about 2,360 to about 2,980 pounds per day for the 2000, 2001 and 2002 DEQ sample events (table 12). Although the load estimates were generated for different times of the year, there may be periods when the wastewater treatment load could account for 40 to 50 percent of the nitrogen load in the river.

SIMPLOT WASTEWATER LAND APPLICATION SITE DISCHARGE AND LOADING

Average nitrate-N concentrations at monitoring wells 509, 511 and 513 of 3.23 mg/L, 2.30 mg/L and 3.40 mg/L, respectively (table 10)**,** are similar to nitrate-N concentrations in statewide monitoring wells. Average orthophosphorus concentrations in wells 509, 511 and 513 (0.11 mg/L, 0.045 mg/L and 0.037 mg/L, respectively, table 10) are similar to total phosphorus concentrations in statewide monitoring wells (which range from 0.010 to 0.042 mg/L, table 7) with the exception of well 509, where the average orthophosphate includes one sample result of 0.8 mg/L; if this value were excluded the average orthophosphate concentration at this well would be 0.038 mg/L, similar to orthophosphate concentrations in statewide monitoring wells.

Nutrient and phosphorus loading to the river from ground water underflow beneath the land application site is similar to loading in regional ground water, based on the above ground water quality information. Therefore, the wastewater land application site does not contribute significant nitrate-N and phosphorus loading to the Portneuf River.

FMC/SIMPLOT FACILITIES DISCHARGE AND LOADING

The estimated shallow aquifer nutrient loads discharging to the river between transects T-1 and T-2 are shown in table 11. These estimated nutrient loads can be compared to stream flow gains and contaminant loading between the same river transects. Ground water discharge from flow tubes represented by wells 502, 517, 331, 335S, 327, and 318 is estimated to be about 2.9 ft^3/sec, compared to the river gain of about 36 ft^3/sec between transects T-1 and T-2. The difference in stream flow gain between T-1 and T-2, about 33 ft^3/sec, must come from a combination of ground water discharge from the aquifer on the east side of the river and ground water discharge from the deep aquifer underlying the FMC/Simplot facilities on the west side of the river.

Orthophosphate loading from the same shallow aquifer region is estimated to be about 432 lbs/day (Table 11). Calculated river phosphorus loads at transect T-2 range from about 771 lbs/day to about 1,191 lbs/day (Table 12, September 2000 and September 2002). By these estimates, from 36 to 56 percent of the phosphorus load to the river at transect T-2 originates from the FMC/Simplot area.

The phosphorous load in the river between transects T-2 and T-4 increased by about 1,200 lbs/day for September 2000 and by about 300 lbs/day for September 2002. This increased load is believed to enter the water column from intergravel flow that originated upstream of T-4. The phosphorous load from regional ground water influx to the river between transects T-2 and T-4 is quite small, on the order of a few pounds per day, and no additional phosphorous sources were identified, so the majority of the additional phosphorous load between transects T-2 and T-4 probably originates from the FMC/Simplot area. If this is the case, then as much as 80 percent of the phosphorous load at transect T-4 could originate from the FMC/Simplot area.

From 70 to 95 percent of the nitrogen load to the river at T-2 is estimated to originate from the FMC/Simplot area (707 lbs/day from the shallow aquifer versus 744 to 1003 lbs per day in the river, tables 11 and 12 respectively).

LOADING ESTIMATE ACCURACY

The relative accuracy of the shallow aquifer loading estimates and the stream loading calculations can be evaluated as follows. The aquifer loading estimates were based on saturated thickness, hydraulic gradient and ground water concentration data from six discrete sample points (wells 502, 517, 331, 335S, 327 and 318) representing approximately 4,000 feet of aquifer cross section. The stream loading estimates were based on 15 to 20 width- and depth-integrated flow and water quality samples collected across a 40- to 50-foot stream channel width. Stream discharge and loading estimates are probably accurate to within 10 to 20 percent. The ground water loading estimate may only be accurate within an order of magnitude.

ANALYSIS OF GEOCHEMICAL DATA

The results of Portneuf River sampling presented earlier suggest higher concentrations of phosphorus and other constituents in ground water discharge to the river from the west than from the east. The objective of this section is to further examine the connection between Portneuf River water quality and spring and ground water quality, both directly adjacent to the river and further upgradient in the vicinity of potential sources at the two phosphate facilities.

GEOCHEMICAL DATA SOURCES

Since about 1990, both facilities have undertaken extensive site characterization and ground water monitoring activities as part of the Superfund remedial investigation and feasibility study process. Over 100 monitoring wells were installed and sampled, primarily during the period 1990-1994. Subsequent to the ROD being finalized in 1996, the FMC facility has continued monitoring a select group of wells as part of RCRA waste management unit monitoring. Since 1994, ground water monitoring and new well installation has also taken place at the Simplot facility as part of remedial design activities.

The data for the geochemical evaluation were selected from the water quality database comprised of data from these monitoring wells. Data from the December 1993 sampling event undertaken as part of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site investigation were chosen because of the widespread coverage of wells sampled, the relatively extensive nature of the constituents analyzed, and the timing of the event with respect to the onset of remedial activities, such as pond closures, at the site.

RIVER/NEAR RIVER GEOCHEMISTRY

Figure 25 presents a Piper diagram illustrating the general water chemical composition of a group of water samples taken from east and west sides of the river channel and springs east and west of the river in October 2001, ground water monitoring wells immediately adjacent to the west side of the river channel, and regional wells. The monitoring wells included shallow (503, 505, 518, 525, 527, and TW-12S) monitoring wells. Regional wells were comprised of domestic wells from the local area completed in the regional aquifer on both sides of the river. The diagram indicates similarity in cation composition among most samples from all groups with a dominance of calcium and magnesium. Greater differences are seen in anion composition with a differentiation primarily between sulfate and bicarbonate. East side river channel, east side spring, and regional ground water samples are generally similar and cluster with bicarbonate percentages of 60 to 80 percent. Samples from the west side of the river channel, springs discharging from the west side of the river bank and shallow monitoring wells from the west side contain a lower percentage of bicarbonate (40 to 60 percent) and a correspondingly greater percentage of sulfate. The shallow west side monitoring wells are seen to be most similar in anion composition to two west-side springs. These west-side springs (Spring at Swanson Road and T-1B spring) contained the highest concentrations of phosphorus of all water samples gathered during the October 2001 sampling event. Though not shown in the Piper diagram the same associations and trends seen with sulfate are also observed for pH. That is, water samples from west side, shallow wells adjacent to the river, and west-side channel and spring locations have lower pH and higher phosphorus concentrations than samples from the east side channel, east side springs and regional ground water. The west side monitoring wells and springs selected above, possessing elevated sulfate and phosphorus and lower pH, are located adjacent to the river in an area where numerous ground water flowpaths, whose origins are on the FMC and Simplot facilities, converge, as illustrated in figure 21.

STABLE ISOTOPES

Stable isotope data collected during the October 2002 sample event provide additional lines of evidence for defining sources and areas of ground water contribution to the river, the degree of ground water/surface water mixing in the river, and the source of water to Batiste Spring. As noted above, stable isotopes of oxygen (^{18}O), deuterium (^{2}H), nitrogen (^{14}N), and sulfur (^{34}S) were collected for analysis.

The environmental isotopes of oxygen, hydrogen, nitrogen and sulfur can be used as tracers of water, nutrient, and sulfur cycling. Oxygen and deuterium are useful indicators of processes affecting ground water prior to recharge. As water evaporates, the lighter isotopes, ^{16}O and ^{1}H, are removed and delta values shift to less negative values. Oxygen and deuterium become more negative with an increase in altitude and latitude, and more negative with decreasing air temperature.

Isotope Abundance

Absolute isotope abundance is difficult to measure with the precision needed for interpretation of results so isotope variations are analyzed relative to an arbitrary standard. Standard mean ocean water (SMOW) is the reference used for the analysis of isotopic concentrations of oxygen ($^{18}O/^{16}O$) and deuterium-hydrogen ($^{2}H/^{1}H$) for this study. The international standard for ^{34}S values is the troilite (FeS) phase of the Cãnon Diablo meteorite (CDT). The results are expressed in delta notation (δ):

$$\delta = [(\text{R-sample}/\text{R-standard})-1] \cdot 1000$$

where R is the ratio of the heavy to the light element ($^{2}H/^{1}H$ for hydrogen/deuterium, $^{18}O/^{16}O$ for oxygen and $^{34}S/^{32}S$ for sulfur). Results are expressed as parts per thousand or permil (‰) rather than parts per hundred (%) because there are only slight differences in the isotope concentrations. The analytical precision for $\delta^{18}O$ values is usually better than ± 0.2 ‰, the analytical error for deuterium is usually ± 1.0 ‰, and the analytical error for sulfur is usually about ± 0.3 ‰ (Clark and Fritz, 1997). For this project, differences between initial and repeat laboratory isotope analyses (in permil) were as follows: $\delta^{18}O$, -0.21 to 0.72 (n=2); ^{2}H, -0.37 to 1.39 (n=15); ^{34}S, -0.63 to -0.04 (n=5).

Oxygen and Deuterium

Craig (1961) determined that $\delta^{18}O$ and $\delta^{2}H$ in fresh waters correlate on a global scale and developed a “global meteoric water line” (GMWL) that defines the relationship between ^{18}O and ^{2}H in worldwide fresh waters:

$$\delta^{2}H = 8\ \delta^{18}O + 10\ ‰ \quad \text{SMOW}$$

where SMOW is the standard used in the determination.

Sulfur

Sulfur from different sources can have different isotopic signatures. Sources of sulfur include atmospheric sulfur compounds, soil sulfur compounds, sulfur minerals in rocks, sulfur in hydrocarbon deposits and sulfur in fertilizers such as ammonium sulfate ($(NH_4)_2SO_4$) (Krouse and Grinenko, 1991). Industrial processes can contribute sulfur to the atmosphere, soils and ground water. In the East Michaud Flats area, elemental sulfur is imported to the Simplot facility to make sulfuric acid which is then used to process phosphorus ore. The elemental sulfur is a byproduct of natural gas processing, and has been imported from natural gas fields in Canada. At the time of this study (2001), the source of elemental sulfur was from sour gas plants associated with natural gas production in Wyoming (Ward Wolleson, J.R. Simplot Company, personal communication, 2002).

Oxygen associated with the sulfate ion can be analyzed for its $^{18}O/^{16}O$ ratio and the information can be used in conjunction with sulfur isotope data to infer sources of sulfur in ground water. According to Krouse and Grinenko (1991, p. 240):

The isotope geochemistry of sulphur compounds in ground water depends strongly on existing redox regimes. When oxidizing conditions prevail, the oxygen and sulphur isotopic compositions of sulphate in ground waters are diagnostic of the origin of the sulphate. It is usually possible to distinguish between sulphates added through the oxidation of reduced sulphur and contributions from marine evaporates.

Regional ground water outside the FMC and Simplot facilities is believed to exist under aerobic or oxidizing conditions. Flow paths are relatively short and ground water recharge is from local precipitation and irrigation infiltration; these sources of recharge should contain adequate dissolved oxygen to maintain aerobic conditions. Dissolved oxygen concentrations measurements from Statewide monitoring well samples confirm this scenario; dissolved oxygen ranged from 3.7 to 9.5 mg/L with a mean concentration of 5.79 and a median of 5.8 mg/L for 14 measurements from 10 wells. Within the FMC and Simplot facilities, redox values from 109 sample locations collected during 1993 ranged from 442 to –213 millivolts, with a mean of 96 millivolts and a median of 92 millivolts. Geochemists have identified a sequence of oxidation-reduction reactions that occur in ground water at successively lower redox values. Nitrate reduction (denitrification) occurs under mild reducing conditions while sulfate reduction occurs under strongly reducing conditions. Information presented in a later section indicates denitrification has occurred in ground water beneath some closed FMC ponds. The redox measurements do not provide sufficient information to determine if sulfate reduction is possible within the FMC and Simplot boundaries.

For all environmental isotopes, positive δ-values from samples can be described as “enriched” or “heavy” while negative δ-values are described as “depleted” or “light.” Sample results of an isotope can be compared and described as enriched or depleted relative to each other.

Evaluation Of Isotope Data

Figure 23 shows a plot of $\delta^{18}O$ versus $\delta^{2}H$ for samples collected from the Portneuf River, springs discharging to the river, and regional ground water and springs sampled by Jacobson (1984). Several observations can be made from the figure.

First, oxygen and deuterium values from Portneuf River transects T-1A, T-1B, T-2, T-2A and T-2B plot in a cluster that is enriched relative to regional ground water. (Jacobson (1984) indicated that the two regional ground water isotope values that plotted above the meteoric water line probably were the result of either sample contamination or analytical error.) The difference between regional and Portneuf River oxygen and deuterium isotopic results is significant when compared to the laboratory analytical error discussed above. The enriched isotope values indicate that ground water discharging from springs and to the river from the west has undergone significant evaporation prior to recharge.

A major hydrologic feature in the area is the Simplot gyp stack ponds. Water balance estimates indicate that at present (2002), approximately 3,065 acre-feet per year is discharged to the ponds, approximately 390 acre-feet per year leaves the ponds as seepage (approximately 2,740 acre-feet per year of seepage prior to 1996), approximately 800 acre-feet per year of evaporation occurs from the ponds and the remainder is returned to the plant to be used as process water (MFG, Inc., 2002). MFG, Inc. (2002) note that evaporation from the ponds is enhanced because water entering the ponds is warm and the dark color of the stack material absorbs radiant energy. A water budget is not available for the former FMC operations, but during operations the ground water pumping rate at this facility was approximately 1,200 gallons per minute, approximately one quarter of the current Simplot ground water pumping rate of 4,300 gallons per minute. Unlined ponds at the FMC facility were closed during the mid-1990s and replaced with lined ponds.

Other than evaporation, no other isotope fractionation process acts to alter oxygen and deuterium values of water entering the aquifer in the area. Thus, oxygen and deuterium isotopes can serve as direct tracers of water that infiltrates the gypsum stack and discharges to the Portneuf River. Oxygen and deuterium values for the Simplot equalization pond (now closed) and the gypsum decant pond (1980 sample results) plot in the same region as the 2002 Portneuf River samples, indicating that similar evaporative processes have continued at the facility throughout at least the past 20 years and that equilibrium conditions with respect to isotopes in ground water have long been established. An oxygen/deuterium result from a 2001 Simplot wastewater sample (LA-104WW) plots in the same area as the 2001 Portneuf River and 1980 pond samples, showing that this source of plant process water undergoes similar evaporative processes.

Second, Batiste Spring oxygen and deuterium results for 1982 are more depleted in oxygen and deuterium isotopes than 2001 results (Figure 23). The 1982 results indicate mixing between regional ground water and water from facility sources. The 2001 Batiste Spring result, depleted relative to the 1980 value, plots in the area of regional ground water isotope values. These data indicate that the proportion of sources of water to Batiste Spring has changed during the period of 1980 to 2001, most likely in response to decreased shallow ground water recharge from precipitation, as discussed above. Plots of orthophosphate, potassium, and nitrate-N indicate an improvement in water quality at the spring during this period. This water quality improvement most likely reflects the influx of regional ground water moving from the north to discharge at the spring, rather than an improvement in quality of ground water moving from the facilities to the spring.

This point has important implications for using Batiste Spring as a downgradient compliance point to monitor water quality improvements and treatment efficiency at the facilities. The spring would not be useful as a compliance point under current ground water flow conditions; a return to historical precipitation patterns could result in changes in ground water flow conditions. Changes in ground water flow paths and sources of water to the spring should be confirmed by comparing isotope sample results to historical values before using the spring as a compliance point.

Figure 23 shows a plot of $\delta^{34}S$ versus one over the sulfate concentration for October 2001 Portneuf River transect and spring samples, a city of Pocatello municipal well, and a wastewater equalization pond at the Simplot facility. Also plotted on the figure is a $\delta^{34}S$ isotope sample result from a solid sample of elemental sulfur provided by Simplot. Data points that plot in the upper right part of the figure (Pocatello Airport well #35, T-1A river transect, and east side data points) are believed to represent regional ground water whose sulfur isotope signature is unaffected by elemental sulfur used at the Simplot facility. The Batiste Spring $\delta^{34}S$ value most closely resembles regional ground water, and provides another line of evidence that the spring currently is supplied by ground water flowing from the north. Sulfur isotope values for east and west halves of the river plot in separate clusters, indicating there is limited mixing within the river channel of water entering from the east and west sides. Spring at Swanson Road and T-1B Spring have $\delta^{34}S$ values similar to the equalization pond and the elemental sulfur sample, indicating a common source.

FACILITY-WIDE GEOCHEMISTRY

The orthophosphate concentrations in ground water associated with source areas at both facilities are illustrated in figure 19. Figure 26 illustrates the ground water orthophosphate concentration trends observed over time at some of these locations. The significant phosphorus source areas on the FMC property appear to be ponds used for the storage of waste byproducts of elemental phosphorus production. Of these, pond 8S, located in the west central portion of the site (associated with wells 150, 152, 156, and 157), and the calciner ponds area (associated with wells 136 and 145 and located in the Joint Fenceline area, along the common boundary with Simplot), are the most important.

At the Simplot facility, significant phosphorus sources include the gyp stack that occupies the southwestern portion of the property (wells 307, 308, 333, 300, 316, and 326) and hotspots in the plant area in the vicinity of phosphoric acid production and storage (wells 335S, 340). Orthophosphate concentrations for the latter two wells are not shown in Figure 19 but have been measured at over 1000 mg/liter as recently as 1999-2000.

Orthophosphate concentrations in FMC source areas, particularly the Pond 8S area, have historically been higher than at Simplot, but are more limited in areal extent. These time series plots seem to indicate that over time orthophosphate concentrations in FMC source areas have declined, while those associated with Simplot have remained stable or are increasing.

These visual observations of trends are supported by statistical analysis of time series data. Tables 13 and 14 present the results of Mann-Kendall analysis of nitrate and orthophosphate time series data for selected wells at both facilities. The Mann-Kendall test for trend (Mann, 1945; Kendall, 1975) is a nonparametric test that is useful when the data set has missing values or when the data do not conform to a particular distribution. The Mann-Kendall test uses only the relative magnitudes of the data rather than their measured values. After performing the calculations for the Mann-Kendall statistic, hypothesis testing was performed. With each run, the null hypothesis, H_0, of no trend was tested against the alternative hypothesis, H_A, of either an upward or downward trend. Using statistical tables, the level of significance at which the null hypothesis can be rejected in favor of the alternative hypothesis was determined. Tables 13 and 14 list whether there is a positive, negative, or zero trend, the level of significance for the trend, and the final measurement date and value used in the analysis. A zero trend was determined if the level of significance for the test was less than 80 percent. Some of the wells tested have as few as four sampling events (usually in 1992 and 1993). Others have as many as 39 sampling events (1990 to 2000). As more data becomes available on all the wells, the trends can be re-analyzed to determine whether cleanup methods are reducing the values of nitrate and orthophosphate in the ground water.

Figure 27 is a Piper diagram, similar to Figure 25 but with source area wells and wells in identified ground water flowpaths from source areas at both facilities toward the river added to the river/spring and near river ground water sample locations. It can be seen that the same differentiation along a sulfate-bicarbonate mixing line is present and is accentuated. The sulfate end member is composed of wells predominantly from Simplot source areas and the Joint Fenceline area. Another mixing line of samples, exhibiting an end member composition dominated by chloride rather than sulfate, is also present. This line represents a flowpath beginning in the vicinity of former pond 8S and extending to downgradient well TW-9S.

Given these trends in general water chemistry the relationship between sulfate, chloride and orthophosphate was examined further. Figures 28, 29, and 30 are scatter plots of orthophosphate versus the ratio of sulfate to chloride concentration, sulfate, and chloride, respectively, for the same group of samples as in figure 27. Several features of figure 28 can be noted. Samples from the east channel and springs, while varying more in phosphate concentration, have low SO_4/Cl ratios similar to regional ground water and lower than those of the west channel and springs. The FMC samples associated with Pond 8S have similar, uniformly low SO_4/Cl ratios which do not change dramatically as orthophosphate concentrations decrease and are aligned parallel to the Y-axis of the plot. This relationship may indicate uniform dilution of sulfate and chloride with unimpacted ground water from the west and north and adsorption/precipitation of orthophosphate. The offset location of these wells relative to those of the west springs and river channel data and the fact that orthophosphate concentrations at the downgradient end of the flowpath from the source area, at TW-9S, are below concentrations measured at the springs and channel seem to indicate that this source is not a significant one with respect to the load seen in the Portneuf River.

Samples associated with Simplot and several FMC wells from the Joint Fenceline area (wells 110, 123, 136, 143, and 145) exhibit a different behavior. A trend is seen of decreasing SO_4/Cl ratios as orthophosphate concentrations decrease from source areas to downgradient locations. This relationship indicates a greater rate of change in sulfate compared to chloride and may reflect precipitation of the initially high sulfate concentrations as gypsum. Plots of orthophosphate versus sulfate concentration and chloride concentration, figures 28 and 29 respectively, indicate that changes in orthophosphate concentration for these wells appear to be greater than changes in sulfate or chloride. Two order of magnitude reductions in phosphate are occurring compared to a one order of magnitude or smaller reduction in sulfate and chloride. This relationship may reflect greater adsorption or precipitation of orthophosphate compared to sulfate as ground water moves towards the river. It also appears to indicate that mechanisms other than simple dilution of orthophosphate may be occurring, although, as contaminated ground water approaches the river mixing with upwelling deeper ground water or shallow Portneuf aquifer ground water from the south may be significant.

JOINT FENCELINE AREA GEOCHEMISTRY

In the Joint Fenceline area , two potential sources of phosphorus are co-located; the calciner ponds and pond solids area on FMC property, and directly adjacent to them the gyp stack on Simplot property. The relative significance of these two sources with respect to phosphorus loading to ground water in this vicinity is difficult to assess for several reasons. The history of activities at the sources is complex. The calciner ponds were originally unlined ponds. They were replaced with the current lined ponds over the period 1986 to 1993. The concentrations of constituents measured in water recovered from each pond's leak detection system show variable composition and strength of leachate. Leachate volumes collected from leak detection systems also vary from each of the ponds. Wastewater application practices on the gyp stack have also changed from the early 1990s to the present, both in terms of volumes and location on the stack.

The hydrogeology of the area is complex. The general direction of ground water flow, inferred from numerous sitewide and facility-specific sampling events, indicates a general southeast to northwest direction of flow in the vicinity of the ponds with a significant shift to the northwest and the river between wells 145 and 110. A relict channel carved in the volcanic bedrock surface, with an orientation similar to the direction of ground water flow, has also been delineated which may influence the direction of ground water flow (MFG, 2002).

Figures 27-30 showed several wells on FMC property in proximity to and hydraulically downgradient of the calciner ponds (wells 145, 136, 110, 143) to have general water chemistry similar to nearby Simplot wells 307, 308, 333, 310, and 312. While the general chemistry of these wells is similar, certain trace constituents may assist in differentiating sources. For example, figure 31 illustrates the selenium concentration in shallow Joint Fenceline area wells (wells 142, 333, 307, 308, 143, 136, 123, 145, TW-7S, 310, 312, 110, 331 and 517) from a December 1993 sampling event. It can be seen that a plume of selenium, elevated above the background concentration of approximately 0.007 mg/L, extends from the northeast edge of the calciner ponds on FMC property and extends northwest to the vicinity of well 331. The local high selenium concentration is seen away from the ponds themselves at well 123, possibly indicating several source areas for selenium. All wells to the east on the Simplot facility have much lower concentrations. A similar plot for orthophosphate concentrations (Figure 32) indicates a different pattern. The plume for orthophosphate has it's highest concentrations in wells on the eastern edge of the calciner ponds on the Simplot facility (wells 307, 308, and 333) and extends downgradient to the north and northeast, indicating the phosphogypsum stack as the primary source of phosphorus in this vicinity. Examination of trends in these two constituents over time illustrates differing plume dynamics. Figures 33 and 34 show temporal trends in selenium and orthophosphate for wells in the Joint Fenceline area. For selenium, only FMC wells are shown because Simplot wells showed no change from generally low background values over time. No recent data is available for well 145. All wells in the plume with high selenium show declining concentrations, reflecting reduction of source area concentrations. A more variable situation exists for orthophosphate. Source area wells (wells 307, 308, 333, and 323) show stable or slightly decreasing concentrations while downgradient wells (wells 310, 312, and 331) show stable or increasing concentrations. Wells on the western margin of the calciner ponds (143 and 123) show stable or declining low concentrations while the eastern margin well 136 appears to be steadily declining in concentration..

Two other constituents, which may assist in evaluating the sources in this vicinity, are potassium and chloride. Plots and concentration time trends for potassium are presented in Figures 35 and 36, while those for chloride are presented in Figures 37 and 38. Potassium concentration distributions show highs in wells 145 and 136 surrounded by much lower concentrations, indications of a source associated with the calciner ponds. FMC wells show stable or decreasing concentrations over time, while Simplot wells show stable or increasing concentrations. Chloride concentration distributions show significant highs, similar to those seen for selenium, in FMC wells 143 and 123 with high concentrations extending to the northeast downgradient to wells 312 and 331. FMC wells show interesting chloride concentration trends over time. The high source area (wells 123 and 143) has shown significant increases over time while other wells associated with the calciner ponds have shown decreases or have remained stable. Simplot wells downgradient of the high chloride source areas (wells 312 and 331) also show increases over time while other Simplot wells associated with the gyp stack (wells 307, 308, and 333) have shown relatively stable concentrations since about 1995.

These spatial trends would indicate that, while the calciner ponds historically may have contributed a phosphorus load to the ground water, their contribution has declined since the installation of a pond liner, while phosphogypsum stack contributions have remained relatively stable. The spatial variability of ground water concentrations for individual constituents and their variation over time also illustrates the complex nature of releases to ground water in this area and the likelihood that the composition and flux of leachate from each of the ponds vary considerably.

FLOWPATH GEOCHEMICAL ANALYSIS

The evaluation of major ion chemical data described above has illustrated the connection between ground water under the facilities and water discharging to the Portneuf River and the chemical similarities and differences that exist in ground water underneath the facility. A more detailed geochemical evaluation was undertaken to attempt to explain the changes in orthophosphate concentration that occur between source areas and the river and to identify the dominant controls on orthophosphate concentration in the shallow aquifer.

Selection of Flowpaths

To this end a ground water flowpath, described by a series of monitoring wells, was identified on each facility. Each flowpath began at significant phosphorus source areas and ended at a specified downgradient location. The flowpaths and wells selected along the flowpaths are shown in Figure 39. Data considered in the selection of wells to describe a flowpath included:

- historical maps of the ground water potentiometric surface,
- spatial distributions of orthophosphate concentration,
- sitewide chemical distributions of ground water parameters which may impact phosphorus transport (such as aluminum, fluoride, iron, manganese, pH, redox, and temperature), and
- availability of other chemical data neccesary for the analysis.

The FMC flowpath selected is based on recent (June 2000) ground water elevation data (Astaris Idaho LLC, 2001). A different flowpath might have been selected if earlier ground water flow conditions were used. Changes in the potentiometric surface appear to have occurred between the early 1990s and 2001, resulting in a more rapid turn in the flowlines to the east as shallow ground water from the facilities encounters regional ground water. These changes may be the result of reduced ground water recharge associated with closure of the unlined ponds on the facility. Since the cessation of site characterization activities in 1994, ground water level measurements have been facility-specific and sitewide potentiometric maps showing ground water flow direction have not been available.

For the Simplot facility it was difficult to identify flowpaths for which only a single source of contamination could be identified. Typically, additional contaminant sources occurred, sometimes introducing significant changes in geochemical conditions along a given flowpath (such as a dramatic change in ground water temperature). As a result of the complexities associated with the Joint Fenceline area that area was avoided.

These flowpaths are not the only ones which could have been chosen, but are considered representative of conditions at the facilities.

As described earlier, the data selected for the analysis was from the December 1993 sitewide sampling event. Ground water data from the selected wells were evaluated using the geochemical speciation model MINTEQ, Version 4.0 (USEPA, 2000). MINTEQ was used to calculate estimates of dominant chemical species present and SIs for selected minerals. While several geochemical models are available, MINTEQ was chosen because of the completeness of its thermodynamic database with respect to the numerous calcium phosphate minerals that appear to significantly influence phosphorus solubility at the site. It was assumed, for the purposes of this analysis, that given the large inputs of phosphorus into the aquifer, precipitation-dissolution reactions of solid phases are the dominant controls on phosphate solubility although it is acknowledged that sorption of phosphates to surface coatings such as hydrous iron oxides also occurs.

Ground water parameters utilized as input to MINTEQ included total aluminum, iron, and manganese; the cations calcium, magnesium, sodium, and potassium; the anions chloride, fluoride, nitrate, and sulfate; orthophosphate; the field parameters pH, temperature, and oxidation-reduction potential; and ammonia. The adequacy of the data for the purposes of comparative geochemical analysis is limited by several factors. These include:

- Variability in analytical parameters measured over time. The ability to conduct sitewide historical comparison and facility to facility comparisons was constrained by the fact that in recent years only a limited set of parameters, many of which do not facilitate evaluation of geochemical conditions, were typically measured. For example, monitoring data obtained for Simplot facility wells for the period after December 1994 was limited in scope and did not contain critical parameters, such as pH, temperature, or redox potential necessary for a geochemical evaluation.

- Analysis of total concentrations rather than filtered, dissolved concentrations.

- Elevated detection limits for total concentrations for selected constituents such as aluminum and iron.

- Uncertainty as to the reliability of difficult measurements such as oxidation-reduction potential.

The vast majority of analyses for trace elements and major ions were for total concentrations. At various times, but primarily early in the site characterization process, analyses for both dissolved and total concentrations were performed during the same sampling event. These data were examined for three elements; aluminum, manganese, and iron, to evaluate the impact of using total instead of dissolved concentrations.
For aluminum, the dissolved/total concentration ratio (in percent) for 42 samples ranged from nearly zero to 130 with the 50th percentile value being 5 percent. For manganese, this range for 49 samples was from nearly zero to over 100; the 50th percentile value was 66 percent. For iron, the range was nearly zero to 250 with a 50th percentile value of 9 percent. Twenty of the 47 sampled dissolved iron concentrations were less than the typical detection limit for total iron concentration (0.0549 mg/L). The primary impact of these low ratios is the introduction of inaccuracy into the calculation of SIs of minerals containing these compounds. The wrong minerals may be identified as controlling constituent solubilities.

General Chemistry

Table 15 presents a summary of the field parameters and chemical constituents of ground water from wells located in the selected flowpaths that were used in the analysis. In this table, wells for a given facility are listed from top to bottom, generally representing the downgradient flow direction from major source area to discharge point. Below these wells are results for wells representing background water quality of the shallow aquifers (wells TW-10S and 514 for FMC and 301 and 328 for Simplot). Results for Batiste Spring, one of several ground water discharge points to the river, is also included.

As noted earlier, ground water associated with the two facilities possesses differences in geochemical characteristics. Ground water from wells along the FMC flowpath is characterized by lower concentrations of calcium, sulfate, and alkalinity, higher concentrations of potassium, chloride, nitrate + ammonia, iron and manganese, higher temperature and pH, lower oxidation-reduction potential, and similar levels of orthophosphate levels compared to the Simplot flowpath. These relationships reflect the different processes used to treat the phosphate ore at each plant. Orthophosphate concentrations in the FMC source area (well 152), while initially higher, appear to be attenuated to a greater degree as ground water travels toward the discharge area. Concentrations at TW-9S are lower than the concentrations seen in spring discharge on the west side of the river. This may partially reflect the greater opportunity for mixing and dilution with uncontaminated ground water of the Bannock Range and Michaud Flats aquifer to the west and north that are also flowing toward spring discharge points and the river. Another interesting trend perhaps related to mixing is the dramatic decrease in concentrations of most constituents in the Simplot flowpath between wells 326 and 327. This decrease may reflect mixing with either the Portneuf aquifer system, ground water from the deeper system, or both.

Chemical Speciation

The following general observations can be made with respect to the speciation computations:

- Ground water from background wells possessed high percentages of free ions such as Ca^{+2}, F^-, Fe^{+2}, SO_4^{-2}, etc., typically constituting > 90 percent of total concentrations. By contrast, ground water within the facility plumes had reduced percentages of these species (56 to 83 percent on Simplot and 70 to 87 percent on FMC). The difference was commonly made up by neutral aqueous complex species such as $CaSO_4$ or charged complexes such as $CaHCO_3^+$. The percentage of calcium in solution as $CaSO_4$ was higher at Simplot than at FMC (13 to 41 percent vs. 5 to 9 percent).
- Aluminum in ground water from background wells and most FMC wells (with the exception of the source well 152) was typically present as $Al(OH)_4^-$ or $Al(OH)_2^+$ while throughout all of the Simplot ground water it was present as aluminofluoride complexes such as AlF^{+2}, AlF_2^+, or AlF_3.
- The most dramatic changes in speciation along the FMC flowpath occur immediately downgradient of the source area between wells 152 and 141. Here, the predominance of sodium and potassium in orthophosphate complexes decreases substantially. This behavior may be due to source area ground water immediately being influenced by relatively unimpacted ground water that has very low concentrations of these constituents. Along the Simplot flowpath changes occur both downgradient of the gyp stack source area, between wells 300 and 316, and further down the flowpath, between wells 326 and 327. The changes from the source area coincide with an increase in pH while the change further down the flowpath may be due to dilution or mixing with unimpacted ground water.

- Dissolved phosphate occurred predominantly as the orthophosphate ion (72 to 90 percent) with the relative percentages of $H_2PO_4^-$ and HPO_4^{-2} varying predictably in response to differences in pH. Complexes such as $CaHPO_4$ and $MgHPO_4$, or $CaPO_4^+$ contributed the remainder of the total orthophosphate concentration. An exception to this relationship occurred in the FMC source area where manganese and potassium complexes with orthophosphate compose a significant amount (10 percent) of the total. This is likely due to highly reducing conditions measured in this area while potassium complexes are due to high source area concentrations.

Saturation Indices

Presented in Tables 16 and 17 are summaries of the MINTEQ calculated SIs for selected mineral phases. The SI is the potential for a given water to dissolve or precipitate a given mineral species, such as calcite or gypsum. For the purposes of this discussion and given the uncertainties and data limitations previously mentioned, SI values between -0.5 and 0.5 for a given mineral phase are considered to represent equilibrium with that phase, while SI values greater than 0.5 are considered oversaturated and values less than -0.5 are considered undersaturated.

Along the FMC flowpath the ground water appears to be generally in equilibrium with respect to calcite and undersaturated with respect to gypsum. Along the Simplot flowpath conditions with respect to these two minerals were more variable. Ground water was in equilibrium with gypsum until the vicinity of well 327 where undersaturated conditions were calculated. Calcite was estimated to be undersaturated in the source area wells 300 and 327 and in equilibrium elsewhere. If a measured redox potential (Eh) of +150 millivolts (mV) is used as a general guide as a cutoff between oxidizing and reducing conditions, the redox conditions found along this flowpath appear to be variable, alternating between oxidizing and reducing. The exception is the highly reduced source area associated with well 152. The location of well 152 is shown on Figures 19 and 20. Levels of manganese, iron, ammonia, and nitrate also varied significantly, often corresponding with changes in redox conditions. As a result of these conditions ground water was calculated to be oversaturated with respect to $MnHPO_4$ and generally close to equilibrium with rhodocrosite, a manganese mineral that may act to control manganese concentrations in solution. The ground water from wells 152, TW-5S, and TW-9S were also estimated to be oversaturated with vivianite, an iron phosphate mineral. Ground water associated with the Simplot facility possessed a more uniformly oxidizing redox condition.

Ground water was consistently oversaturated with respect to the aluminum oxide mineral phases, very likely an artifact of the high analytical detection limits and the measurement of total instead of dissolved concentrations. This condition may apply to iron as well, there being no iron mineral phases identified which were in equilibrium with the ground water, except as noted above for vivianite.

The precipitation-dissolution relationships and mineral phase equilibria for phosphate minerals are extremely complex and will not be examined in detail here. Lindsay (1979) provides an excellent review of the subject. Generally, there are a suite of calcium phosphate minerals, varying in degrees of crystallinity and solubility, which may be present in calcareous aquifers of circumneutral pH, similar to conditions measured at this site, that may act to control phosphate solubility, albeit at relatively high concentrations. These minerals include, presented in order with respect to solubility and stability:

- $Ca_5(PO_4)3OH$ (hydroxyapatite or HAP)—least soluble and most stable
- $Ca_3(PO_4)2$ (BETA-TCP)
- $Ca_4H(PO_4)2{:}3H_20$ (OCP)
- $CaHPO_4$ (DCP)
- $CaHPO_4{:}2H_20$ (DCPD)—most soluble and least stable.

In the FMC flowpath it appears that in the source area the ground water is in equilibrium with respect to DCPD, DCP, and OCP and oversaturated with respect to BETA-TCP, HAP, and fluorapatite. The solubilities of DCPD, DCP, and OCP at the pH and calcium concentrations present indicate that all these minerals can coexist. As ground water travels downgradient the equilibrium shifts to BETA-TCP as the more soluble minerals are transformed to more stable minerals of lower solubility. BETA-TCP then becomes undersaturated leaving HAP, fluorapatite, and manganese phosphate minerals as the only possible minerals controlling phosphorus solubility. The manganese phosphate mineral $MnHPO_4$ is consistently oversaturated. HAP and fluorapatite remain oversaturated but progressively less so along the flowpath. This oversaturated condition for HAP also occurs in background well 514 but not in background well TW-10S where it is at equilibrium. The type of transition observed, from more soluble to less soluble mineral phases with time or in this case ground water travel along a flowpath, is also commonly observed in studies of phosphate fertilizer fate and availability in agricultural soils. The consistent excess saturation of HAP is also commonly observed and may be due to several factors. It may represent a lack of true equilibrium of the mineral with respect to the ground water solution. That is, the kinetics of HAP formation compared to ground water flow rates may be slow. The form of the mineral present in the aquifer, in terms of its purity and degree of crystallinity, may also not match that used to generate the K values used in the MINTEQ database and may have higher solubility. Solid solution series very likely exist whereby hydroxyapatite forms in combination with other minerals such as the manganese phosphate minerals or with calcite. These types of mixed mineral phases will often have solubilities higher than the pure mineral phases by themselves.

A trend in the SI for the calcium phosphate mineral phases similar to that seen at FMC is also seen along the Simplot flowpath. The minerals DCPD, DCP, and BETA-TCP are in equilibrium throughout the upper portions of the flowpath. Downgradient of well 326 these minerals are undersaturated. The same trends for HAP and fluorapatite as in the FMC flowpath are also observed here.

For manganese the mineral $MnHPO_4$ is at equilibrium or oversaturated. Since the pH in well 327 is very similar to that seen in the upgradient wells some other factor is controlling the mineral phases at this location.

Several factors have been identified which act to control the solubility of the calcium phosphate minerals. These factors include the calcium ion activity, pH, and redox.

Calcium ion activity is affected primarily by the presence and solubility of calcite, the carbon dioxide concentration, amounts of exchangeable calcium, and the presence of other cations or anions. It has been observed that phosphate mineral solubility decreases dramatically with increasing pH until the area of pH 7-8 when solubility begins to increase again. This relationship is illustrated in Figure 12.9 of Lindsay (1979), reproduced here as figure 40. The average pH in the FMC and Simplot flowpaths are 6.83 and 6.31, respectively.

Figure 41 presents a graph of calcium activity and pH versus orthophosphate concentration for Simplot and FMC ground water along the selected flowpaths. The plot attempts to capture the effect of two major factors responsible for phosphate mineral solubility. For both FMC and Simplot flowpaths orthophosphate concentrations appear to decrease in a predictable linear manner with increasing pH and/or calcium ion activity, similar to that described by Lindsay (1979). The pH has a greater influence on the solubility than calcium activity. The persistence of lower pH, compared to background, in both the Simplot and FMC areas, results in higher solubility of the calcium phosphate minerals and may be responsible for the persistent, elevated phosphate concentrations observed. Figure 42 is a plot of pH trends over time in ground water from selected wells at both facilities. It can be seen that the lower pH conditions established under the facilities as a result of operations, compared to background, have changed little over time.

Geochemical Data Conclusions

The analysis presented above documents the geochemical similarities between phosphate contaminated ground water under both facilities and significant increases in phosphorus measured over a relatively short stretch of the lower Portneuf River. Phosphate concentrations in most FMC wells have declined since 1993 and at downgradient locations are lower than those observed in the Portneuf River and at spring discharge locations. Simplot area phosphate ground water concentrations have generally been stable or increasing since 1994.

Phosphate concentrations appear to decrease as ground water moves downgradient from source areas to discharge locations at rates greater than would be expected due to dilution alone. This indicates other attenuation processes, such as sorption and/or precipitation, are operative. However, concentrations of orthophosphate in ground water adjacent to the river and at ground water discharge points remain elevated one to two orders of magnitude above the designated TMDL total phosphorus concentration in the Portneuf River despite the closure of most unlined ponds on both facilities. This type of behavior for phosphate was observed in a sewage-contaminated ground water plume in Massachusetts (Stollenwerk, 1996). At that site the large reservoir of sorbed phosphorus on sediment coupled with slow phosphorus desorption rates resulted in predictions that phosphate contamination could continue for decades despite control of the source. At the Simplot/FMC phosphate ore processing facilities natural geochemical mechanisms to control phosphate concentrations at background or near background levels appear to be ineffective. In addition, significant source areas of phosphate loading to ground water still remain at both facilities. Simplot is currently in the initial stages of implementation of remedial actions to control phosphate loading from the gypstacks. FMC is proposing actions to control releases from the ponds located in the Joint Fenceline area. Until monitoring data documenting the effectiveness of these remedies is collected it is unclear whether these actions will be sufficient to adequately control phosphate concentrations in the river or if additional measures that would modify subsurface geochemical conditions to enhance mineral phase geochemical controls on phosphate concentrations, such as pH adjustment, will be needed.

CONCLUSIONS

- Releases of phosphorus and nitrogen to the environment associated with operations of the FMC and Simplot phosphate ore processing facilities have significantly impacted the shallow aquifer system underlying these facilities. Nearly all shallow wells associated with both of these facilities exceed the TMDL target of 0.075 mg/L total phosphorus. Total phosphorus concentrations in regional ground water are at or below the Portneuf River TMDL target.

- Discharge of phosphorus and nitrogen from these impacted aquifer systems to the Portneuf River represents a significant portion of the total load measured in the river. Conversely, the Simplot wastewater land application area, the City of Pocatello wastewater treatment plant effluent and sludge lagoon facility, and regional ground water discharging to the river do not contribute significant phosphorus loads to the river.

- The zone of ground water contribution from the FMC and Simplot area is controlled by hydrogeological conditions. Data indicate this zone extends about 200 to 300 feet along the west side of the river, between transects T-1A and T-2.

- Downstream of the zone where facility phosphorus loads enter the river, phosphorus concentrations in the river gradually decrease in response to influx of regional ground water containing low phosphorus concentrations. Nitrogen loads in the river downstream of the facilities continue to increase in response to elevated nitrogen concentrations in regional ground water.

- Evaluation of water quality data illustrates the geochemical connection between impacted shallow ground water beneath both facilities and the river. While several sources of phosphorus to shallow ground water are present at each facility the primary sources at the present time appear to be associated with Simplot facility operations.

- Concentrations of orthophosphate in the shallow aquifer associated with source areas at the Simplot facility have remained stable or are increasing with time. These trends in concentration over time are supported by non-parametric statistical analysis of trends.

- Stable isotopes of oxygen, hydrogen, and sulfur can be used as tracers for delineation of facility impacts to ground water. Oxygen and deuterium ratios in water are affected by evaporative processes and can be used to delineate impacts of gyp stack seepage.

- The source of water to Batiste Spring has changed over time, based on water quality and stable isotope data. Discharge at the spring currently appears to be from regional ground water, whereas underflow from the FMC and Simplot facilities supplied much of the water to the spring in the past. A significant decrease in area wide precipitation over the past several years may have caused this change in the ground water flow system.

- Across both facilities, the ground water concentrations of phosphorus have generally changed little during the time period in which intensive monitoring has taken place (1990 to the present). The large historical and ongoing input of phosphorus to the ground water system by these facilities has likely resulted in a large reservoir of phosphorus in the subsurface. Continued, slow desorption of phosphorus and the maintenance of existing geochemical conditions maximizes the solubility of phosphorus minerals. These conditions limit the ability of the ground water system to naturally attenuate orthophosphate concentrations to TMDL target levels in the river without additional active remedial measures.

RECOMMENDATIONS

Based on the results and conclusions of the analysis detailed above, the following recommendations are presented:

- With new remedial efforts either planned or underway at both facilities, coordination of ground water monitoring across facilities to document the effectiveness of these actions is needed. A sitewide map of ground water elevations in both the shallow and deep aquifers is needed to document the nature of changes in the flow field since the implementation of remedial measures. Measuring of sitewide ground water elevation should be renewed. A subset of existing monitoring wells should be selected for comprehensive water quality sampling.

- Studies should be undertaken to better understand the nature and occurrence of phosphorus associated with aquifer sediments beneath the facilities and along ground water flowpaths to the river. The potential for desorption of phosphorus from these sediments and implications for achieving remedial goals should also be investigated. These studies would assist in the design of additional remedial measures if the currently planned strategies prove ineffective.

- A systematic monitoring program to better characterize the interaction of the ground water system with the Batiste Spring channel and the river, with respect to water quality and water balance, should be implemented.

- Given the finding that the estimated large contribution to phosphorus and nitrogen loading to the river from the two facilities occurs over a relatively short reach of the river, additional efforts to better characterize the spatial location, amount, and mode of this discharge should be initiated. These characterization efforts would facilitate the implementation of more focused remedial measures. These characterization activities could include additional, multi-level, monitoring wells adjacent to the river, sampling at additional, more closely spaced, river transect locations, measurement of additional parameters such as temperature, and installation of piezometer nests in the bank and river bed to document rates of ground water seepage and mass flux.

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TABLES

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Table 1. Discharge and water quality data from Portneuf River sampling, September 13 and 14, 2000, and City of Pocatello wastewater treatment plant September 12, 13, and 14, 2000.

Site	Description	Stream Wetted Width (ft)	Flow (ft^3/sec)	Total Suspended Solids (mg/l)	Total Ammonia (mg/l)	Total nitrite/nitrate (mg/l)	Total Kjeldahl nitrogen (mg N/l)	Total phosphorous (mg P/l)	Dissolved Ortho-phosphorous (mg P/l)	Percent of stream occluded*	Percentage of transect points with aquatic macrophytes or filamentous algae
T-1	Above Interstate (above FMC & Spring at Swanson Road complex)	43	77.91	10	0.014	0.014		0.044	0.008	0.00%	14.30%
T-2	Below FMC & Swanson Springs complex, above STP	62	109.98	170	0.114	1.14		1.3	0.893	18.40%	17.90%
T-3	Above Pocatello STP	81.7	139.59	4	0.417	2.53		2.07	1.93	7.70%	75.00%
T-4	Below Pocatello STP	85.7	181.3	2	0.377	2.6		2.06	1.88	31.00%	70.00%
T-6	Above Batiste Springs Trout Farm discharge	62.2	91.78	2	0.382	2.71	0.49	1.9	1.8	34.20%	85.00%
T-7	Below Batiste Springs Trout Farm discharge	97	160.62	2	0.292	2.62	0.44	1.47	1.36	38.90%	52.20%
T-8	Between Batiste and Papoose Springs	94.3	254.11	5	0.23	2.7	0.42	1.45	1.33	1.30%	60.90%
T-9	Above Papoose Springs	86.1	276.25	2	0.275	2.71	0.4	1.44	1.35	5.50%	100.00%
T-10	Below Papoose Springs	105.8	266.5	2	0.167	2.71	0.24	1.21	1.18	20.10%	72.00%
	STP (9/12/00 - flow = 5.02mgd)		0.129		5.14	9.3	6.3	0.8	0.54		
	STP (9/1300 - flow = 1.66mgd)		0.043		1.82	9					
	STP (9/14/00 - flow = 1.97mgd)		0.051		1.83	7.9					

* percent of stream which has emergent vegetation from each streambank

STP = City of Pocatello Wastewater Treatment Plant discharge to Portneuf River

Table 2. Discharge and water quality data from Portneuf River sampling, August 20, 21 and 22, 2001.

Site	Descriptions	Discharge (ft^3/sec)	Total Discharge (ft^3/sec)	Total ammonia (mg/l)	Total nitrite/nitrate (mg/l)	Total Kjeldahl nitrogen (mg N/l)	Total phosphorous (mg P/l)	Dissolved ortho phosphorous (mg P/l)	Chlorophyll as MG/M2 (ug/L)
T-1	Above Interstate (above FMC & Spring at Swanson Road complex)	45.22	45.22	0.076	0.019	0.55	0.232	0.01	0.01
T-2	Below FMC & Spring at Swanson Road complex, above STP; east	2.15		0.01	2.66	0.07	1.07	1.07	
T-2	Below FMC & Spring at Swanson Road complex, above STP; middle	41.95		0.021	1.32	0.24	0.98	0.997	
T-2	Below FMC & Spring at Swanson Road complex, above STP; west	35.60	79.69	0.411	3.07	0.64	4.98	5.24	
T-3	Above Pocatello STP	103.18	103.18	0.37	2.79	0.58	2.2	2.22	
T-4	Below Pocatello STP	166.25	167.01	0.302	3.02	0.6	2.01	2.06	0.01
T-6	Above Batiste Springs Trout Farm discharge	145.98	145.98	0.3	3.24	0.6	1.83	1.8	
T-7	Below Batiste Sp Trout Farm discharge; east bank to middle	91.648		0.301	3.1	0.67	1.77	1.8	
T-7	Below Batiste Sp Trout Farm discharge; middle to west bank	80.346	171.99	0.203	2.69	0.39	1.05	1.04	
T-8	Between Batiste and Papoose Springs	214.18	214.18	0.185	3.05	0.34	1.43	1.38	0.02
T-9	Above Papoose Springs	190.42	190.42	0.173	3.13	0.36	1.42	1.38	
T-10	Below Papoose Springs	219.29	243.69	0.145	3.11	1.17	1.21	1.19	

Table 3. Discharge and water quality data from Portneuf River sampling, October 3, 4, and 5, 2001.

Site	Description	Discharge (ft^3/sec)	Total Discharge (ft^3/sec)	Total ammonia (mg/L)	Total nitrite/nitrate (mg/L)	Total Kjeldahl nitrogen (mg N/L)	Total phosphorous (mg P/L)
East Sp.	Grab sample in spring discharge pool (No discharge estimate)			0.009	3.3	0.09	0.046
T-1A	100 meters below Interstate Bridge	28.75	28.75	0.014	1.01	0.23	0.082
T-1B-E	Below confluence of Portneuf R and Spring at Swanson Road, east ½	29.703		0.009	1.24	0.22	0.83
T-1B-W	Below confluence of Portneuf R and Spring at Swanson Road, west ½	29.162	58.865	0.013	1.7	0.19	2.91
T-2-E	Below FMC & Spring at Swanson Road complex, above STP, east 1/2	23.27		0.011	1.53	0.15	1.07
T-2-W	Below FMC & Spring at Swanson Roadcomplex, above STP, west 1/2	54.27	77.54	0.18	2.3	0.4	2.89
T-2A-E	200 meters below T-2, east ½	51.17		0.073	1.94	0.23	1.5
T-2A-W	200 meters below T-2, west ½	42.76	93.93	1.05	4.74	1.39	5.14
T-2B-E	300 meters below T-2; above confluence with Sp E-4, east 1/2	44.69		0.216	2.43	0.31	1.81
T-2B-W	300 meters below T-2; above confluence with Sp E-4, west 1/2	96.67	141.36	0.533	3.37	0.68	3.13
T-3	Above STP (NO3 and Total-P data from 08/21/01 sample date)	140.29	140.29		2.79		2.2
Batiste Sp	Grab sample at spring weir	0.2	0.2	0.007	3.61	0.1	0.373
T-1B Sp.	Grab sample from spring discharge pool (Est 20 gpm)	0.0446	0.0446	0.007	5.36	0.35	17.5
Sp. Batiste Rd	Spring channel downstream of pool area	5.1	5.1	0.046	3.46	0.14	6.69
Sp E-4	Spring channel, just above confluence with Portneuf River	35.60	35.60	0.019	3.88	0.11	0.066

Table 4. Concentrations of selected constituents from Portneuf River surface water and spring samples, October 3, 4 and 5, 2001.

Sample ID	Sample Date	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO_4 (mg/L)	CL (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	HCO_3 (mg/L)	Sp Cond umho/cm	Total Ammonia (mg/L)	NO_2+NO_3 (mg/L)	TKN-N (mg/L)	TDS (mg/L)	F (mg/L)	Total P (mg/L)
Batiste Spring	10/4/2001	55	20.7	42	5.2	62.7	30.8	196	239	551	0.007	3.61	0.1	369	0.32	0.373
East Spring	10/4/2001	79.1	29.6	40	6.5	55.2	41.5	281	343	740	0.009	3.3	0.09	498	0.26	0.046
Spring E-4	10/4/2001	71	28.6	49	7	68	30.4	282	344	735	0.019	3.88	0.11	460	0.25	0.066
Spring at Swanson Road	10/4/2001	125	48.9	82	8.9	228	55.6	367	447	1148	0.046	3.46	0.14	675	0.39	6.69
T-1A	10/4/2001	65.1	30.4	43	7.9	49.2	50.7	268	327	764	0.014	1.01	0.23	424	0.37	0.082
T-1B-E	10/4/2001	70.3	31.8	47	8.2	67.6	51.8	279	340	842	0.009	1.24	0.22	545	0.27	0.83
T-1B-Spring	10/5/2001	145	79.2	138	10.8	433	60.1	432	527	1807	0.007	5.36	0.35	1064	0.43	17.5
T-1B-W	10/4/2001	81.6	37.7	58	8.2	115	51.4	294	358	871	0.013	1.7	0.19	544	0.29	2.91
T-2A-E	10/4/2001	74	32.2	49	7.7	79.9	43.8	280	341	799	0.073	1.94	0.23	531	0.27	1.5
T-2A-W	10/4/2001	83	36.1	61	9.7	136	47.1	279	340	918	1.05	4.74	1.39	566	0.34	5.14
T-2B-E	10/4/2001	73.2	31.7	50	7.9	84	44.7	278	339	849	0.216	2.43	0.31	475	0.29	1.81
T-2B-W	10/4/2001	77.4	33.6	54	8	106	42.4	275	335	771	0.533	3.37	0.68	482	0.69	3.13
T-2-E	10/5/2001	72.1	31.6	46	7.4	71	44.4	275	335	750	0.011	1.53	0.15	470	0.26	1.07
T-2-W	10/5/2001	80	36.8	56	8.1	113	46.5	295	360	822	0.18	2.3	0.4	515	0.29	2.89

Notes: Ca = calcium; Mg = magnesium; Na = sodium; K = potassium; SO_4 = sulfate; HCO_3 = bicarbonate; Sp Cond = specific conductance; NO_2+NO_3 = nitrite plus nitrate as N; TKN = total Kjeldahl nitrogen; TDS = total dissolved solids; F = fluoride; Total P = total phosphorous.

Table 5. Discharge and water quality data from Portneuf River sampling, September 2002. Samples collected by DEQ, Idaho State University, and the City of Pocatello.

Site	Description	Discharge (ft^3/sec)	Alkalinity as $CaCO_3$ (mg/L)	Cl (mg/L)	Ammonia (mg/L)	NO_2+NO_3 (mg/L)	TKN (mg/L)	Ortho-P (mg/L)	Total P (mg/L)	SO_4 (mg/L)
T-1	In back of Simplot Frontier building	54.2	249	54.5	0.05	0.027	0.55	0.017	0.049	56.9
T-2 east	Upstream of FMC boat ramp, east half of river	95.38[a]	265	49.1	0.027	0.855	0.42	0.338	0.389	62
T-2 west	Upstream of FMC boat ramp, west half of river		293	49.5	0.123	1.57	0.42	3.18	3.14	120
T-3	Upstream of Pocatello STP	122.03	276	44.4	0.339	2.14	0.71	1.82	1.83	87.8
T-4	Downstream of Pocatello STP	168.69	269	54.4		2.59	0.63	1.64	1.66	80.9
T-6	Upstream of Batise Springs Fish Hatchery outlet	173.98	272	57.7		2.65	0.63	1.59	1.59	81.8
T-7	Downstream of Batise Springs Fish Hatchery outlet	196.96	260	53		2.7	0.65	1.22	1.24	72
T-8	Between Batise and Papoose springs	205.28	259	49.7		2.57	0.71	1.27	1.28	71.7
T-9	Upstream of Papoose Springs outlet	220.79	257	46	0.338	2.68	0.61	1.03	1.17	65.1
T-10	Downstream of Papoose Springs outlet	252.68	247	41.5	0.309	2.64	0.56	1.01	1	61.6

a. Flow of 95.38 ft3/sec is combined flow for east and west halves of the river.

Table 6. Isotope results from Portneuf River surface water, springs, ground water, and Simplot equalization pond samples collected during October 3, 4 and 5, 2001, and November 9 and 11, 2001.

Sample ID	East or West half of river	Sample Date	^{18}O Result (per mil)	^{18}O Repeat (per mil)	^{2}H Result (per mil)	^{2}H Repeat (per mil)	^{34}S Result (per mil)	^{34}S Repeat (per mil)	^{18}O of SO_4 Result (per mil)	^{18}O of SO_4 Repeat (per mil)
Batiste Spring	W	10/4/2001	-17.05		-131.43	-132.64	13.95	14.58	5.37	5.28
East Spring	E	10/4/2001	-15.87		-123.16	123.77	13.08		5.29	5.19
Spring E-4	E	10/4/2001	-15.44		-123.32	-122.95	12.94		5.96	5.87
Spring at Swanson Road	W	10/4/2001	-15.38		-125.22	-125.28	10.5	10.58		
T-1A		10/4/2001	-15.17		-122.99	-124.13	13.79			
T-1B-E	E	10/4/2001	-16.04		-123.04	-123.63	12.88			
T-1B-Spring	W	10/5/2001	-15.51		-126.65	-126.87	10.95		5.29	5.21
T-1B-W	W	10/4/2001	-15.46	-16.18	-125.41	-125.97	11.84	11.8		
T-2A-E	E	10/4/2001	-15.33		-124.86	-125.84	12.7			
T-2A-W	W	10/4/2001	-15.06		-125.96	-126.51	12.18			
T-2B-E	E	10/4/2001	-15.37		-123.39	-123.78	12.62		4.33	4.77
T-2B-W	W	10/4/2001	-15.56		-127.09	-128.48	12.29	12.39	5.26	5.31
T-2-E	E	10/5/2001	-15.7	-15.49	-125.44	-126.04	12.15			
T-2-W	W	10/5/2001	-15.52		-127.2	-127.12	11.99			
Pocatello Airport well 35	W	11/9/2001	-17.55		-133.44	-134.03	15.45	15.99		
LA-104 WW *	W	11/28/2001	-15.84		-126.43	-127.34	10.93		8.36	8.13

* Equalization pond at JR Simplot plant

Table 7. Ambient nitrate-N and total phosphorous concentrations in ground water from the East Michaud Flats area, statewide monitoring wells.

Statewide Wells	Mean Concentrations NO_3-N(mg/L)	Total P (mg/L)	Number of Observations
East Side Wells			
5.33.36ADA1[a]	2.6	**0.011**[b]	4
5.34.20DCBB1	1.1	0.030	2
5.34.31DCA1	2.1	0.010	1
5.34.34BAA1	1.3	0.06	1
6.34.07ADA2	2.7	0.022	4
6.34.09BCB1	5.4	0.021	7
6.34.10CCD1	4.4	0.042	3
6.34.16BAB1	3.5	**0.023**[b]	3
West Side Wells			
5.33.34CBC1	1.1	**0.010**[b]	3
6.33.02AAA1	1.3	**0.01**[b]	4
6.34.06CBD1	3.1	0.014	3
6.34.07ABD1	1.6	0.016	3
6.34.07BBC1	1.7	**0.013**[b]	8

a. 5.33.36ADA1 = T05S R33E Section 6ADA1.

b. P values in **Bold** indicate some individual sample results were below laboratory detection limit of 0.01 mg/L.

Table 8. Batiste Spring channel analytical data for the period May 4, 1999 through December 7, 2000.

Sample Date	Site Name	Cl (mg/L)	SO_4 (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	TDS (mg/L)	Ammonia (mg/L)	TKN (mg/L)	NO_2+NO_3 (mg/L)	Total N (mg/L)	Total P (mg/L)	ortho-P (mg/L)	Turbidity (NTU)	ortho-P nf (mg/L)	Hardness as $CaCO_3$ (mg/L)
12/07/2000	Springhouse	48	119	225	na	1.2	1.3	5.05	6.35	5.85	6.1	0.238		322
12/07/2000	Loading dock	27	52	199	na	<0.1	<0.5	2.27	2.27	0.39	0.79	0.098		229
12/07/2000	Culvert	29	54	216	na	<0.1	<0.5	2.59	2.59	0.63	0.91	0.202		248
12/07/2000	Spillway	28	53	218	na	<0.1	<0.5	2.54	2.54		0.9	0.46		249
12/07/2000	Hatchery	28	53	216	na	0.2	<0.5	2.55	2.55	0.55	0.92	0.429		246
12/07/2000	Hatchery 2	28	51	217	na	0.1	<0.5	2.59	2.59	0.53	0.67	1.02		252
11/08/2000	Springhouse	51	126	217	534	1.3	1.3	5.46	6.8	7.44	6.55	0.212		
11/08/2000	Loading dock	28	51	198	339	<0.1	<0.5	2.28	2.3	0.41	0.79	0.293		
11/08/2000	Culvert	32	57	217	372	<0.1	<0.5	2.68	2.7	0.83	0.85	0.287		
11/08/2000	Spillway	30	56	206	362	<0.1	<0.5	2.64	2.6	0.86	0.95	0.455		
11/08/2000	Hatchery	27	51	221	367	0.2	1.1	2.63	3.7	0.86	1.1	0.731		
10/10/2000	Springhouse A	49	124	229	535	1.3	1.6	6.02	7.6	7.24	5.95	0.192		
10/10/2000	Springhouse B	26	<1	<1	121	4.4	4.5	15.5	20	4.09				
10/10/2000	Loading dock	25	47	201	331	<0.1	0.6	2.17	2.2	0.21	0.27	0.124		
10/10/2000	Culvert	28	54	219	365	<0.1	<0.5	2.91	2.9	0.88	1.05	0.351		
10/10/2000	Spillway	28	53	223	366	<0.1	<0.5	2.84	2.8	0.81	0.87	0.392		
10/10/2000	Hatchery	28	52	219	367	0.2	0.5	2.82	2.9	0.82	0.85	0.792		
09/06/2000	Springhouse	38	83	214	425	0.2	<0.5	3.82	3.8	3.24	0.64	0.32		
09/06/2000	Loading dock	24	44	223	333	<0.1	<0.5	2.39	2.4	0.04	0.42	0.39		
09/06/2000	Culvert	26	47	227	343	<0.1	<0.5	2.43	2.4	0.21	0.44	0.24		
09/06/2000	Spillway	25	47	229	342	<0.1	<0.5	2.37	2.4	0.18	0.41	0.46		
09/06/2000	Hatchery	26	47	230	347	0.2	0.5	2.33	2.83	0.24	0.48	0.93		
08/08/2000	Springhouse	35	69	209	374	<0.1	<0.5	2.85	2.9	1.78	0.38	1.17		
08/08/2000	Loading dock	24	44	210	309	<0.1	<0.5	2.19	2.2	0.03	0.27	0.253		
08/08/2000	Culvert	25	45	225	325	<0.1	<0.5	1.61	1.6	0.06	0.41	0.149		
08/08/2000	Spillway	26	45	225	347	<0.1	<0.5	2.1	2.1	0.07	0.73	0.674		
08/08/2000	Hatchery	25	45	228	331	0.2	0.6	2	2.6	0.17	0.37	0.81		
07/12/2000	Springhouse	36	78	210	420	<0.1	<0.5	2.67	2.7	2.15	2.4	0.278		
07/12/2000	Loading dock	22	40	187	321	<0.1	<0.5	1.97	2	0.02	0.24	0.238		
07/12/2000	Culvert	24	42	200	341	<0.1	<0.5	1.88	1.9	0.07	0.25	0.458		
07/12/2000	Spillway	24	42	215	348	<0.1	<0.5	1.85	1.9	0.07	0.25	0.404		
07/12/2000	Hatchery	24	42	210	349	0.2	0.5	1.82	2.3	0.14	0.45	0.396		
06/14/2000	Springhouse	46	124	224	507	<0.1	0.8	4.35	5.15	4.7	4	0.389		
06/14/2000	Loading dock	24	45	190	305	<0.1	0.6	1.67	2.27	0.13	0.4	0.689		
06/14/2000	Culvert	26	49	210	326	<0.1	<0.5	2.15	2.2	0.3	0.45	0.571		
06/14/2000	Hatchery	26	49	221	339	1.4	2.6	1.89	4.49	0.63	0.65	3.76		

Table 8 (continued). Batiste Spring channel analytical data for the period May 4, 1999 through December 7, 2000.

Sample Date	Site Name	Cl (mg/L)	SO_4 (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	TDS (mg/L)	Ammonia (mg/L)	TKN (mg/L)	NO_2+NO_3 (mg/L)	Total N (mg/L)	Total P (mg/L)	ortho-P (mg/L)	Turbidity (NTU)	ortho-P nf (mg/L)	Hardness as $CaCO_3$ (mg/L)
04/04/2000	Springhouse										7.4			
04/04/2000	Loading dock										0.18			
04/04/2000	Culvert										5.8			
04/04/2000	Spillway	34	74	230	409	0.2	<0.5	3.6	3.6	2	5.7			
04/04/2000	Hatchery	35	72	229	407	0.3	<0.5	3.6	3.6	2.17	4.9			
03/03/2000	Springhouse										10.8	0.524		
03/03/2000	Loading dock										2.2	0.513		
03/03/2000	Culvert										2.4	0.404		
03/03/2000	Spillway	34	76	228	422	0.4	<0.5	3.76	3.8	2.64	2.1	0.462		
03/03/2000	Hatchery	34	77	231	423	0.5	0.5	3.79	4.29	2.51	2.2	0.667		
02/09/2000	Springhouse										1.44	1		
02/09/2000	Loading dock										0.21	0.2		
02/09/2000	Culvert										0.92	0.3		
02/09/2000	Spillway	30	61	221	381	0.1	<0.5	2.94	2.9	1.05	0.85	1		
02/09/2000	Hatchery	31	61	221	380	0.2	<0.5	2.92	2.9	1.09	1.1	1.3		
01/11/2000	Springhouse										8.1	0.67		
01/11/2000	Loading dock										0.1	0.52		
01/11/2000	Culvert										0.96	0.44		
01/11/2000	Spillway	33	62	222	379	0.2	<0.5	2.98	3	1.09	0.96	0.6		
01/11/2000	Hatchery	31	62	223	380	0.3	<0.5	2.99	3	1.04	1	1.16		
12/01/1999	Springhouse	56	188	262	671	3.8	3.8	8.67	12.5	9.4	10.4	0.6		
12/01/1999	Loading dock	26	45	203	300	<0.1	<0.5	2.09	2.1	0.02	0.09	0.2		
12/01/1999	Culvert a	33	65	222	371	0.3	<0.5	3.19	3.2	1.25	1.2	0.5		
12/01/1999	Culvert b	33	66	227	366	0.3	<0.5	3.17	3.2	1.14	1.15			
12/01/1999	Spillway	33	65	228	365	0.2	<0.5	3.17	3.2	1.1	1.1	0.8		
12/01/1999	Hatchery	34	66	229	355	0.3	0.6	3.18	3.8	1.28	1.06	1.3		
11/03/1999	Springhouse	53	185	280	702	3.7	3.8	8.54	12.3	8.36	7.4	0.22		
11/03/1999	Loading dock	22	43	206	312	<0.1	<0.5	2.1	2.1	0.02	0.06	0.38		
11/03/1999	Culvert	29	65	228	388	0.2	<0.5	3.17	3.2	1.13	0.96	0.16		
11/03/1999	Spillway	29	63	230	385	0.2	<0.5	3.14	3.1	1.1	0.98	0.47		
11/03/1999	Hatchery	29	63	231	387	0.3	<0.5	3.14	3.1	1.05	0.96	0.69		
10/19/1999	Springhouse	56	191	283	716	3.7	3.8	8.59	12.39	8.72	0.8	0.3		
10/19/1999	Loading dock	24	47	204	321	<0.1	<0.5	2.07	2.07	0.37	0.22	0.49		
10/19/1999	Culvert	30	64	231	373	0.3	<0.5	3.09	3.09	1.1	0.94	0.25		
10/19/1999	Spillway	29	63	228	383	0.2	<0.5	3.03	3.03	0.97	0.44	0.71		
10/19/1999	Hatchery	30	63	231	372	0.3	<0.5	3.01	3.01	0.98	0.46	0.76		
09/23/1999	Springhouse	47	149	271	640	2.7	3.5	7.41	10.9	7.48	6	0.15		
09/23/1999	Loading dock	23	44	205	314	<0.1	<0.5	2.09	2.1	0.02	0.06	0.28		

Table 8 (concluded). Batiste Spring channel analytical data for the period May 4, 1999 through December 7, 2000.

Sample Date	Site Name	Cl (mg/L)	SO_4 (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	TDS (mg/L)	Ammonia (mg/L)	TKN (mg/L)	NO_2+NO_3 (mg/L)	Total N (mg/L)	Total P (mg/L)	ortho-P (mg/L)	Turbidity (NTU)	ortho-P nf (mg/L)	Hardness as $CaCO_3$ (mg/L)
09/23/1999	Spillway	27	57	230	376	0.2	<0.5	2.76	2.8	0.7	0.63	0.4		
09/23/1999	Hatchery	27	57	231	375	0.3	<0.1	2.66	2.7	0.86	0.64	0.74		
08/10/1999	Springhouse	na	na	218	468	0.5	0.5	4.3	4.8	2.8	3	0.01		
08/10/1999	Loading dock	na	na	185	311	<0.1	<0.5	1.82	1.8	0.02	0.06	0.07		
08/10/1999	Culvert	na	na	209	350	<0.1	<0.5	2.18	2.2	0.15	0.21	0.15		
08/10/1999	Spillway	na	na	198	353	<0.1	<0.5	2.09	2.1	0.17	0.23	0.27		
08/10/1999	Hatchery	na	na	218	344	0.1	<0.5	2.01	2	0.2	0.23	0.56		
07/15/1999	Springhouse	na	na	240	585	<0.1	<0.5	0.21	0.21	4.87	4.4	0.24		
07/15/1999	Loading dock	na	na	189	321	<0.1	<0.5	1.81	1.81	0.04	0.08	0.11		
07/15/1999	Culvert	na	na	211	357	<0.1	<0.5	2.34	2.34	0.25	0.32	0.36		
07/15/1999	Spillway	na	na	na	na	<0.1	<0.5	2.28	2.28	0.25	0.26	0.26		
07/15/1999	Hatchery	na	na	216	364	0.2	0.6	2.25	2.85	0.31	0.31	0.85		
06/03/1999	Springhouse	77	325	377	1020	6.3	6.5	11.9	18.4	14.7		0.18	12.4	
06/03/1999	Loading dock	40	121	238	514	0.9	1.1	5.81	6.9	3.58		0.15	3.2	
06/03/1999	Culvert	41	133	267	549	1.2	1.3	5.45	6.8	4.3		0.17	3.8	
06/03/1999	Spillway	41	129	262	549	1.0	1.3	5.4	6.7	4.08		0.24	3.6	
06/03/1999	Hatchery	40	128	256	552	1.1	1.3	5.44	6.7	4.28		0.33	3.5	
05/04/1999	Springhouse	63	274	353	1000	2.22	5.09	9.68	14.77	16.1	13.4	0.1		
05/04/1999	Loading dock	31	73	195	400	<0.04	0.36	3	3.36	1.02	1.4	0.19		
05/04/1999	Culvert	38	123	248	532	<0.04	0.58	3.78	4.36	3.44	3.9	0.12		
05/04/1999	Spillway	37	117	242	522	0.38	0.37	4.33	4.7	3.32	3.7	0.23		
05/04/1999	Hatchery	37	117	245	522	1.13	1.27	4.42	5.69	3.44	3.8	0.45		

Notes: Cl = chloride, SO_4 = sulfate; TDS = total dissolved solids; TKN = total Kjeldahl nitrogen; NO_2+NO_3 = nitrite plus nitrate as N; Total N = total nitrogen; Total P = total phosphorous; ortho-P = orthophosphorous; ortho-P nf = nonfiltered orthophosphorous; $CaCO_3$ hardness given in mg/L.

Table 9. Daily loading calculations[a] for nitrogen and phosphorous from City of Pocatello wastewater treatment plant.

Month	Nitrogen loading Ammonia (lbs/day)	TKN (lbs/day)	Nitrite+nitrate (lbs/day)	TKN +NO_2/NO_3 loading (lbs/day)	Total P loading (lbs/day)
March-01	16	119	395	514	44
February-01	430	608	364	972	86
January-01	1018	1979	231	2210	45
December-00	504	602	416	1018	58
November-00	300	331	589	920	58
October-00	254	340	755	1095	50
September-00[a]					
August-00	320	340	386	726	39
July-00	35	1636	694	2330	80
June-00	18	69	309	379	16
May-00	25	146	651	797	89
April-00	15	82	810	892	266
March-00	10	105	531	636	47
February-00	12	103	419	522	53
January-00	77	196	510	706	127

a. Loadings calculated from average daily flow and average daily nutrient concentration

b. Data are available for only three days during September 2000; therefore, loads could not be calculated.

Table 10. Average nitrate-N and orthophosphate concentrations for three monitoring wells at Simplot Swanson wastewater land application acreage.

Well Number	Upgradient/ Downgradient	Avg. NO_3-N (mg/L)	Ave. Ortho-P (mg/L)	Number of Observations
509	Downgradient	3.23	0.11	9
511	Downgradient	2.30	0.045	5
513	Upgradient	3.40	0.037	5

Table 11. Flow, orthophosphate and nitrate-N loading calculations from the shallow aquifer, FMC/Simplot facilities, to the Portneuf River between transects T-1 and T-2.

Representative Well	Model K (ft/day)	i (ft/ft)	Area (ft^2)	Q (ft^3/day)	Concentration O-P (mg/L)	Concentration NO_3-N (mg/L)	Load O-P (lbs/day)	Load NO_3-N (lbs/day)
502	1,700	5.24e-4	1.44e4	12,827	0.1	3.3	.09	2.9
517	9,940	6.45e-4	1.28e4	82,064	1	9.73	5.6	54.4
331	9,940	7.14e-4	1.60e4	113,554	29	31.8	224	245.9
335S	1,700	8.13e-4	2.20e4	30,406	95	194	197	401.7
327	1,700	1.47e-4	3.28e4	8,197	5	3.14	2.8	1.8
318	1,700	1.47e-4	4.05e3	1,012	47	2.1	3.2	.1
Totals				**248,060**			**432**	**707**

Notes: Model K = hydraulic conductivity from ground water flow model (Bechtel 1994); area = cross sectional area of aquifer; i = hydraulic gradient; Q = discharge; NO_3-N = nitrate as nitrogen; O-P = orthophosphate.

Table 12. Portneuf River transect nutrient loading calculations for data collected September 13 and 14, 2000, August 20, 21, and 22, 2001, and September 2002.

	September 2000		August 2001		September 2002	
Sample Location	Nitrogen (NH_4 + NO_2/NO_3) loading (lbs/day)	Total phosphorous loading (lbs/day)	Nitrogen (NH_4 + NO_2/NO_3) loading (lbs/day)	Total phosphorous loading (lbs/day)	Nitrogen (NH_4 + NO_2/NO_3) loading (lbs/day)	Total phosphorous loading (lbs/day)
T-1	12	18	23	57	23	14
T-2	744	771	1003	1190	746	1191
T-3	2219	1559	1759	1224	1632	1205
T-4	2911	2015	2979	1803	2357	1510
T-6	1531	941	2788	1441	2487	1492
T-7	2523	1274	2935	1330	2869	1317
T-8	4016	1988	3737	1652	2846	1417
T-9	4448	2146	3393	1459	3594	1393
T-10	4136	1739	3850	1431	4019	1363
WWTP 9/12/00	10	1				
WWTP 9/13/00	3	NA				
WWTP 9/14/00	3	NA				

NA – Total phosphorous data from WWTP not available for 9/13/2000 and 9/14/2000.

Table 13. Trend Analysis for time series nitrate data from selected wells.

Label						
Well Trend	134	TW-5S	111	TW-9S	122	146
Significance (%)	Positive	Positive	Positive	Negative	Positive	Negative
Last Value (mg/L)	99.8	80	92	78	97	99.8
Date of Last	16.2	21.4	14.7	3.91	28	5.5
	May 2000	Dec. 1993	May 2000	Dec. '94	Aug. 2000	May 2000
Well Trend	145	136	312	331	110	Batiste
Significance (%)	Zero	Negative	Positive	Positive	Positive	Positive
Last Value (mg/L)	89	87	28	72	85	100
Date of Last	3.97	2.3	4.26	31.8	3.1	8.0
	Dec. 1993	May 2000	Mar. 1998	Mar. 1998	May 2000	Nov. 1996
Well Trend	306	316	326	327	503	TW-12S
Significance (%)	Negative	Positive	Positive	Positive	Positive	Zero
Last Value (mg/L)	94	100	44	78	94	100
Date of Last	1.42	25.1	14.7	3.14	5.26	6.9
	Dec. 1994	Mar. 1998	Mar. 1998	Mar. 1998	Mar. 1998	Nov. 2000
Well Trend	320	323	325	TW-12S	517	
Significance (%)	Positive	Positive	Positive	Zero	Negative	
Last Value (mg/L)	45	100	52	100	64	
Date of Last	194	3.90	180[1]	6.9	9.73	
	Mar. 1998	Mar. 1998	Mar. 1998	Nov. 2000	Mar. 1998	

[1] From Dec. 1992 to Dec. 1995 nitrate in Well 325 fluctuated from about 20 mg/L to about 45 mg/L. There was no monitoring in 1996. Then, in March 1997 the nitrate value was 166 mg/L. The March 1998 value was 180 mg/L. No further nitrate monitoring was recorded.

Table 14. Trend Analysis for time series orthophosphate data from selected wells.

Label						
Well	123	143	136	110	122	145
Trend	Negative	Negative	Negative	Positive	Negative	Zero
Significance (%)	100	100	90	85	94	62
Last Value (mg/L)	2.9	6.3	85.2	3.9	5.9	86.9
Date of Last	Aug 2000	May 2000	May 2000	May 2000	Mar. 2000	Dec. 1993
Well	333	307	308	323	312	331
Trend	Zero	Zero	Zero	Positive	Positive	Positive
Significance (%)	50	40	78	99.4	91	99.3
Last Value (mg/L)	93	132	113	167	36.7	28.5
Date of Last	Aug. 2001	Aug 2001	Aug 2001	Mar. 2000	Mar. 2000	Mar. 2000
Well	300	316	326	327	503	
Trend	Positive	Positive	Positive	Zero	Zero	
Significance (%)	98.5	99.6	95	83	75	
Last Value (mg/L)	206	118	238	5.04	5.67	
Date of Last	Dec. 1994	Mar. 2000	Mar. 2000	Mar. 2000	Mar. 2000	
Well	152	141	134	TW-5S	111	TW-9S
Trend	Zero	Zero	Negative	Zero	Negative	Negative
Significance (%)	64	50	99.6	100	80	100
Last Value (mg/L)	211	20.2	20.2	7.84	8.2	2.0
Date of Last	Sept. 1995	Jan. 1998	May 2000	Dec. '93	May 2000	Nov. 2000
Well	306	310	325	320	TW-12S	Batiste
Trend	Zero	Zero	Positive	Positive	Zero	Positive
Significance (%)	45	64	100	99	35	99.8
Last Value (mg/L)	24.8	18	13.5	94.8	16.1	12.6
Date of Last	Dec. 1994	Aug. 2001	Mar. 2000	Mar. 2000	Nov. 2000	Mar. 2000

Table 15. Analytical results for selected wells in FMC and Simplot areas used for flowpath evaluation

Well	Al (mg/L)	Ammonia (mg/L)	HCO3 (mg/L)	Ca (mg/L)	Cl (mg/L)	F (mg/L)	Total Fe (mg/L)	Total Mg (mg/L)	Total Mn (mg/L)
FMC									
152	0.0222	10.5	1660	42.2	400	12.5	0.795	104.9	1.422
141	0.0222	1.7	514	145.3	253	0.2	0.0549	66.7	8.87928
134	0.0222	0.5	510	116.4	322	0.2	0.0549	75.0	3.16035
TW-5S	0.0222	0.5	326	87.7	271	0.2	0.38775	50.8	0.40383
111	0.0222	0.5	374	107.8	305	0.2	0.0648	63.7	1.14615
TW-9S	0.0222	0.5	342	98.4	246	0.2	0.80705	49.3	1.03993
TW-10S	0.0222	0.5	150	79.8	332	0.4	0.2386	24.9	0.00121
514	0.0222	0.5	138	43.3	29	0.7	0.0549	14.4	0.0008
Simplot									
300	0.0222	0.5	360	395.8	90	0.2	0.0549	82.9	0.0008
316	0.0222	0.5	1380	462.2	125	0.2	0.1008	266.2	0.00907
326	0.0222	0.5	1350	426.7	125	0.2	0.0549	289.6	0.00228
327	0.0222	0.5	364	131.5	66	1.2	0.0549	51.5	0.0008
503	0.0222	4.82	328	125.2	62	1.8	0.0549	39.6	0.04491
Batiste Spring	0.0222	2.7	236	86.9	73	0.4	0.0549	31.9	0.01197
301	0.0264	0.5	144	48.1	41	0.4	0.0549	12.1	0.0008
328	0.0222	0.5	298	84.1	33	0.2	0.0549	33.0	0.0008

Table 15 (concluded). Analytical results for selected wells in FMC and Simplot areas used for flowpath evaluation.

Well	NO3-N (mg/L)	ortho-P (mg/L)	pH S.U.	K (mg/L)	Redox (mV)	Se (mg/L)	Na (mg/L)	SO4 (mg/L)	T (degrees Celsius)
FMC									
152	0.05	333	6.94	1219.3	-228	0.0008	449.1	254	14.8
141	0.05	23.6	6.71	32.4	-14	0.01147	197.3	195	16.8
134	7.69	31.8	6.7	185.1	155	0.00243	190.5	224	17.5
TW-5S	21.4	7.84	6.89	186.7	-78	0.00357	110.7	133	19.6
111	19.3	10.9	6.82	139.9	134	0.00409	159.7	203	16
TW-9S	14	2.66	6.89	127.9	-109	0.00243	130.7	178	16.9
TW-10S	3.95	0.02	7.33	8.7	83	0.00516	48.2	36	14.6
514	0.82	0.033	7.73	4.4	168	0.00275	21.2	42	11.6
Simplot									
300	0.61	208	5.72	14.8	177	0.00553	652.4	2750	16.6
316	13.7	51.2	6.33	30.8	165	0.02786	462.7	1970	16.2
326	19.1	77.1	6.26	22.5	152	0.01433	550.4	2130	16.1
327	3.52	6.84	6.52	13.0	-8	0.00273	92.3	272	13.9
503	5.29	4.39	6.7	9.0	210	0.0036	79.5	286	13.9
Batiste Spring	6.38	4.09	6.74	12.2	135	0.01017	64.9	192	12.6
301	0.17	0.081	7.72	5.7	170	0.00154	13.5	15	14.4
328	3.13	0.037	7.14	7.5	180	0.0008	45.0	50	13.1

Concentration units are mg/L unless noted.

Notes: Al = aluminum; HCO_3 = bicarbonate; Ca = calcium; Cl = chloride; F = fluoride; Ttoal Fe = total iron; Total Mg = total; magnesium; Total Mn = total magnesium; NO_3-N = nitrate as nitrogen; ortho-P = ortho phosphorous; K = potassium; Se = selenium; Na = sodium; SO_4 = sulfate.

Table 16. Saturation indices for selected minerals and wells in Simplot area and background shallow wells.

	Saturation Index = [Log (Ion Activity Product/Solubility Product)]							
Mineral	**300**	**316**	**326**	**327**	**503**	**Batiste Spring**	**301**	**328**
$Al(OH)_3$ (am)	-3.547	-1.734	-1.973	-2.276	-2.185	-1.058	-1.481	-0.982
$Al(OH)_3$ (Soil)	-1.006	0.808	0.57	0.274	0.366	1.498	1.068	1.572
Al_2O_3	-5.33	-1.714	-2.193	-2.853	-2.67	-0.445	-1.25	-0.283
$Al_4(OH)_{10}SO_4$	-4.923	1.013	0.258	-1.536	-1.492	3.172	-2.009	1.953
$AlOHF_2$	-14.3	-13.824	-13.926	-12.806	-12.693	-12.849	-15.267	-14.183
$AlOHSO_4$	-2.443	-2.029	-2.088	-3.433	-3.664	-2.657	-6.187	-3.995
Anhydrite	-0.381	-0.465	-0.481	-1.383	-1.364	-1.62	-2.774	-2.158
Aragonite	-1.391	-0.091	-0.222	-0.726	-0.608	-0.841	-0.173	-0.291
Boehmite	-1.358	0.453	0.214	-0.1	-0.008	1.114	0.698	1.191
$Ca_3(PO_4)_2$ (beta)	-0.895	0.373	0.343	-1.214	-1.039	-1.253	-2.313	-4.056
$Ca_4H(PO_4)3{:}3H_2O$	-2.45	-1.239	-1.195	-3.792	-3.7	-4.07	-6.475	-8.667
$CaCO_3xH_2O$	-2.591	-1.292	-1.422	-1.926	-1.808	-2.041	-1.373	-1.491
$CaHPO_4$	-0.006	-0.043	0.037	-0.887	-0.97	-1.055	-2.498	-2.877
$CaHPO_4{:}2H_2O$	-0.328	-0.366	-0.288	-1.222	-1.305	-1.396	-2.83	-3.215
Calcite	-1.251	0.049	-0.082	-0.586	-0.468	-0.701	-0.033	-0.151
Diaspore	0.421	2.236	1.998	1.705	1.796	2.93	2.497	3.003
Dolomite (disordered)	-3.506	-0.481	-0.672	-1.979	-1.834	-2.263	-1.063	-1.129
Dolomite (ordered)	-2.921	0.106	-0.085	-1.382	-1.237	-1.66	-0.469	-0.529
FCO_3-Apatite	15.182	19.76	19.507	16.922	17.9	15.393	13.298	8.589
$Fe(OH)_2$	-8.862	-7.266	-7.693	-6.851	-6.488	-6.365	-4.286	-5.506
Fluorite	-2.384	-2.402	-2.46	-0.876	-0.514	-1.919	-1.98	-2.458
Gibbsite (C)	-0.456	1.358	1.12	0.824	0.916	2.048	1.618	2.122
Gypsum	-0.091	-0.173	-0.188	-1.078	-1.059	-1.308	-2.472	-1.849
Hercynite	-4.15	1.049	0.14	0.245	0.792	3.092	4.43	4.132
Hydroxyapatite	3.591	6.146	6.002	3.706	4.139	3.732	3.143	-0.028
Magnesite	-2.558	-0.818	-0.875	-1.597	-1.57	-1.718	-1.253	-1.153
$Mg_3(PO_4)_2$	-8.099	-5.542	-5.361	-7.76	-7.861	-7.931	-9.443	-10.646
$MgHPO_4{:}3H_2O$	-1.695	-1.305	-1.157	-2.378	-2.553	-2.6	-4.179	-4.388
$Mn_3(PO_4)_2$	-23.617	-19.511	-21.214	-22.689	-17.202	-18.696	-22.627	-25.049
$MnCl_2{:}4H_2O$	-16.629	-15.282	-15.89	-16.53	-14.829	-15.213	-16.783	-17.041
$MnCO_3$ (am)	-4.99	-2.739	-3.426	-3.871	-1.982	-2.623	-2.938	-3.263
$MnHPO_4$	0.162	1.067	0.588	-0.331	1.357	0.832	-1.55	-2.168
$MnSO_4$	-13.417	-12.566	-13.142	-14.075	-12.286	-13.004	-15.066	-14.712
Rhodochrosite	-4.5	-2.249	-2.936	-3.384	-1.494	-2.137	-2.45	-2.777
Vivianite	-4.561	-2.548	-3.297	-3.302	-3.058	-2.835	-3.048	-5.556

Values shown in red indicate oversaturation. Values shown in blue indicate equilibrium.

Table 17. Saturation indices for selected minerals and wells in FMC area and background shallow wells.

	Saturation Index = [Log (Ion Activity Product/Solubility Product)]								
Mineral	**152**	**141**	**134**	**TW-5S**	**111**	**TW-9S**	**TW-10S**	**514**	**503**
$Al(OH)_3$ (am)	-3.585	-1.003	-1.03	-1.036	-0.915	-0.955	-1.21	-1.46	-2.185
$Al(OH)_3$ (Soil)	-1.038	1.537	1.507	1.493	1.628	1.584	1.338	1.1	0.366
Al_2O_3	-5.448	-0.239	-0.278	-0.242	-0.081	-0.141	-0.703	-1.274	-2.67
$Al_4(OH)_{10}SO_4$	-8.016	2.179	1.958	0.802	2.574	1.99	0.098	-0.703	-1.492
$AlOHF_2$	-13.043	-13.698	-13.763	-14.244	-13.759	-13.973	-14.285	-14.585	-12.693
$AlOHSO_4$	-5.796	-2.931	-2.926	-3.636	-2.968	-3.244	-4.852	-5.538	-3.664
Anhydrite	-2.256	-1.539	-1.588	-1.832	-1.623	-1.675	-2.329	-2.396	-1.364
Aragonite	-0.084	-0.331	-0.447	-0.481	-0.488	-0.459	-0.412	-0.286	-0.608
Boehmite	-1.404	1.186	1.161	1.165	1.271	1.234	0.97	0.707	-0.008
$Ca_3(PO_4)_2$ (beta)	1.147	0.411	0.306	-0.504	-1.445	-1.279	-4.2	-3.189	-1.039
$Ca_4H(PO_4)3{:}3H_2O$	-0.264	-1.408	-1.464	-2.729	-4.283	-4.046	-8.978	-7.916	-3.7
$CaCO_3xH_2O$	-1.285	-1.532	-1.647	-1.681	-1.688	-1.659	-1.613	-1.486	-1.808
$CaHPO_4$	0.233	-0.282	-0.27	-0.834	-1.258	-1.236	-3.125	-2.91	-0.97
$CaHPO_4{:}2H_2O$	-0.098	-0.602	-0.587	-1.141	-1.582	-1.556	-3.456	-3.257	-1.305
Calcite	0.056	-0.191	-0.307	-0.341	-0.348	-0.319	-0.272	-0.146	-0.468
Diaspore	0.392	2.963	2.933	2.917	3.056	3.011	2.768	2.533	1.796
Dolomite (disordered)	0.107	-1.067	-1.137	-1.212	-1.284	-1.281	-1.443	-1.221	-1.834
Dolomite (ordered)	0.7	-0.483	-0.556	-0.64	-0.696	-0.697	-0.85	-0.614	-1.237
FCO_3-Apatite	25.354	19.397	18.871	16.723	14.651	15.032	8.771	11.765	17.9
$Fe(OH)_2$	-5.271	-6.51	-6.555	-5.251	-6.255	-4.932	-4.494	-4.278	-6.488
Fluorite	0.368	-2.454	-2.579	-2.614	-2.555	-2.553	-1.889	-1.54	-0.514
Gibbsite (C)	-0.488	2.087	2.057	2.043	2.178	2.134	1.888	1.65	0.916
Gypsum	-1.957	-1.249	-1.301	-1.555	-1.329	-1.385	-2.028	-2.078	-1.059
Hercynite	-0.738	3.3	3.241	4.651	3.686	4.98	4.776	4.316	0.792
Hydroxyapatite	7.35	6.491	6.302	5.345	3.716	4.07	0.006	1.665	4.139
Magnesite	-0.186	-1.186	-1.166	-1.283	-1.218	-1.276	-1.401	-1.193	-1.57
$Mg_3(PO_4)_2$	-3.015	-5.838	-5.476	-6.356	-7.387	-7.405	-11.04	-10.049	-7.861
$MgHPO_4{:}3H_2O$	-0.457	-1.65	-1.477	-2.048	-2.53	-2.562	-4.708	-4.524	-2.553
$Mn_3(PO_4)_2$	-9.739	-9.049	-10.198	-13.228	-13.15	-12.981	-24.512	-23.421	-17.202
$MnCl_2{:}4H_2O$	-12.245	-11.365	-11.623	-12.571	-12.064	-12.265	-14.854	-17.108	-14.829
$MnCO_3$ (am)	0.287	0.487	0.013	-0.79	-0.406	-0.389	-3.18	-2.983	-1.982
$MnHPO_4$	4.328	4.308	3.979	2.695	2.576	2.608	-2.174	-1.963	1.357
$MnSO_4$	-11.395	-10.149	-10.527	-11.456	-11.002	-11.03	-14.615	-14.736	-12.286
Rhodochrosite	0.776	0.978	0.505	-0.296	0.084	0.101	-2.691	-2.498	-1.494
Vivianite	3.48	-1.765	-1.585	0.654	-3.181	0.628	-3.653	-3.876	-3.058

Values shown in red indicate oversaturation. Values shown in blue indicate equilibrium.

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FIGURES

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Figure 1. Air photo showing features in the East Michaud Flat and FMC/Simplot study area.

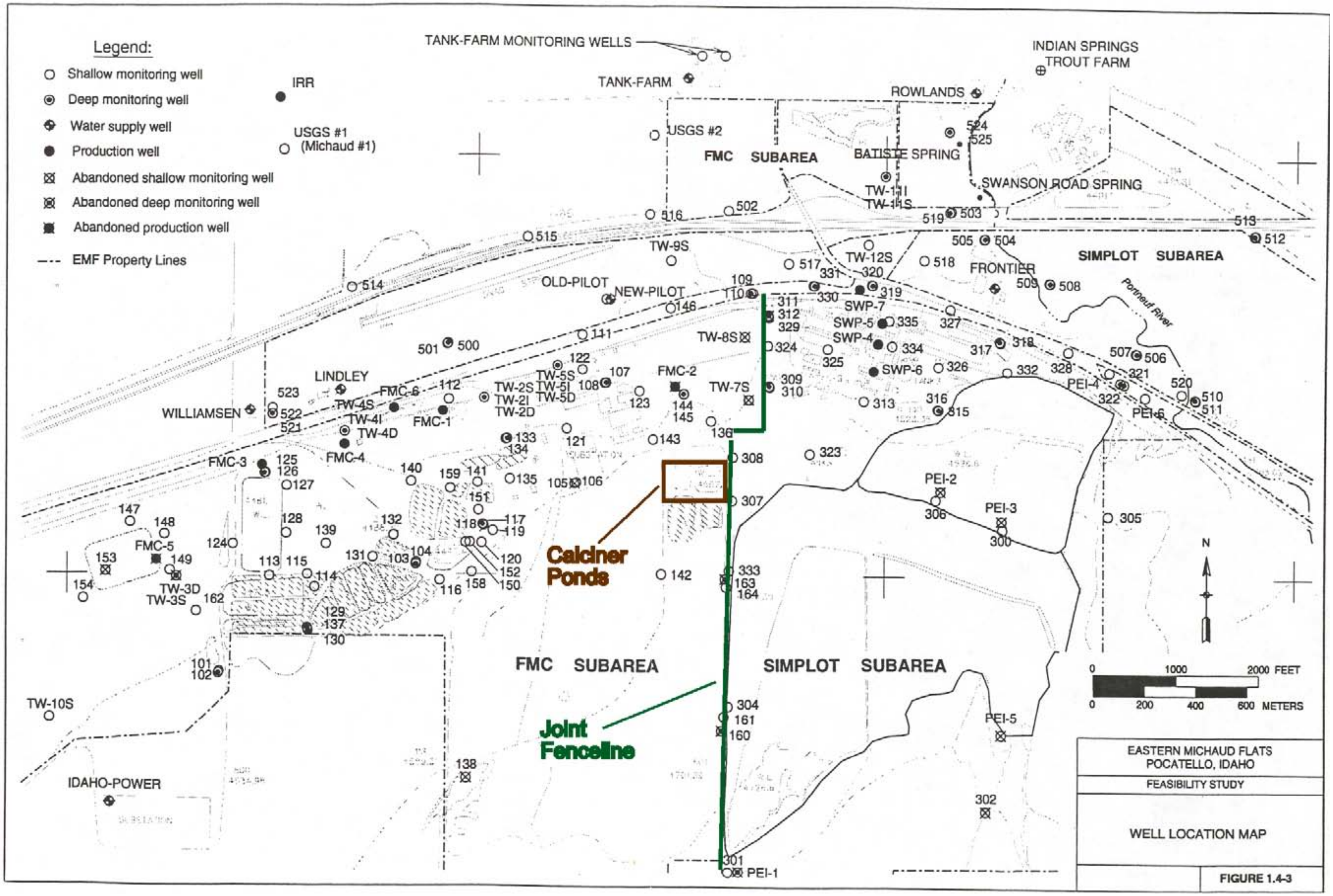


Figure 2. Locations of deep and shallow monitoring wells and production wells at the FMC/Simplot site. (Adapted from Bechtel Environmental Inc., June 1994.)

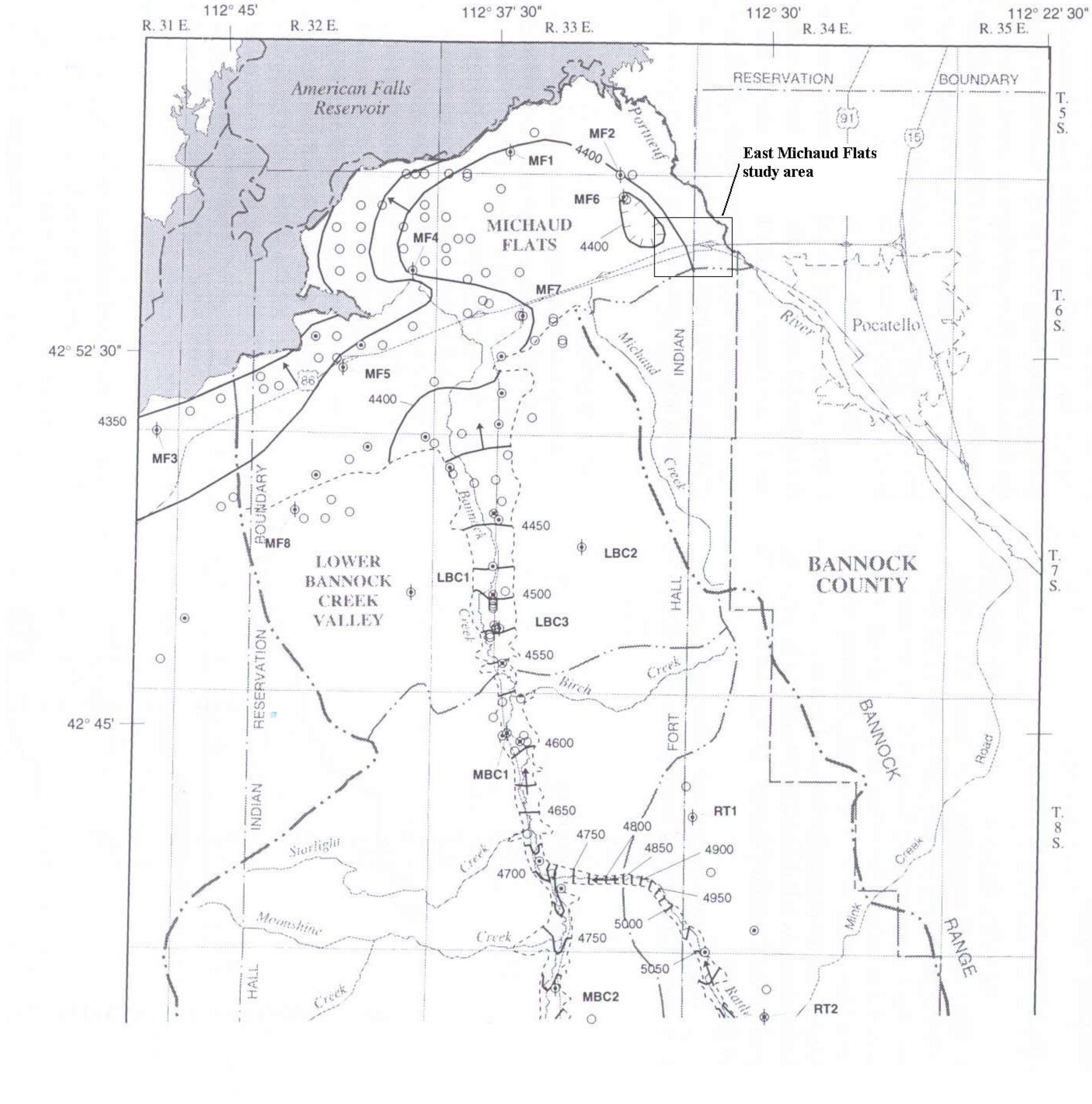


Figure 3. Potentiometric map of the lower Bannock Creek and Michaud Flats areas, showing location of the East Michaud Flats study area (modified from Spinazola and Higgs, 1998, figure 11).

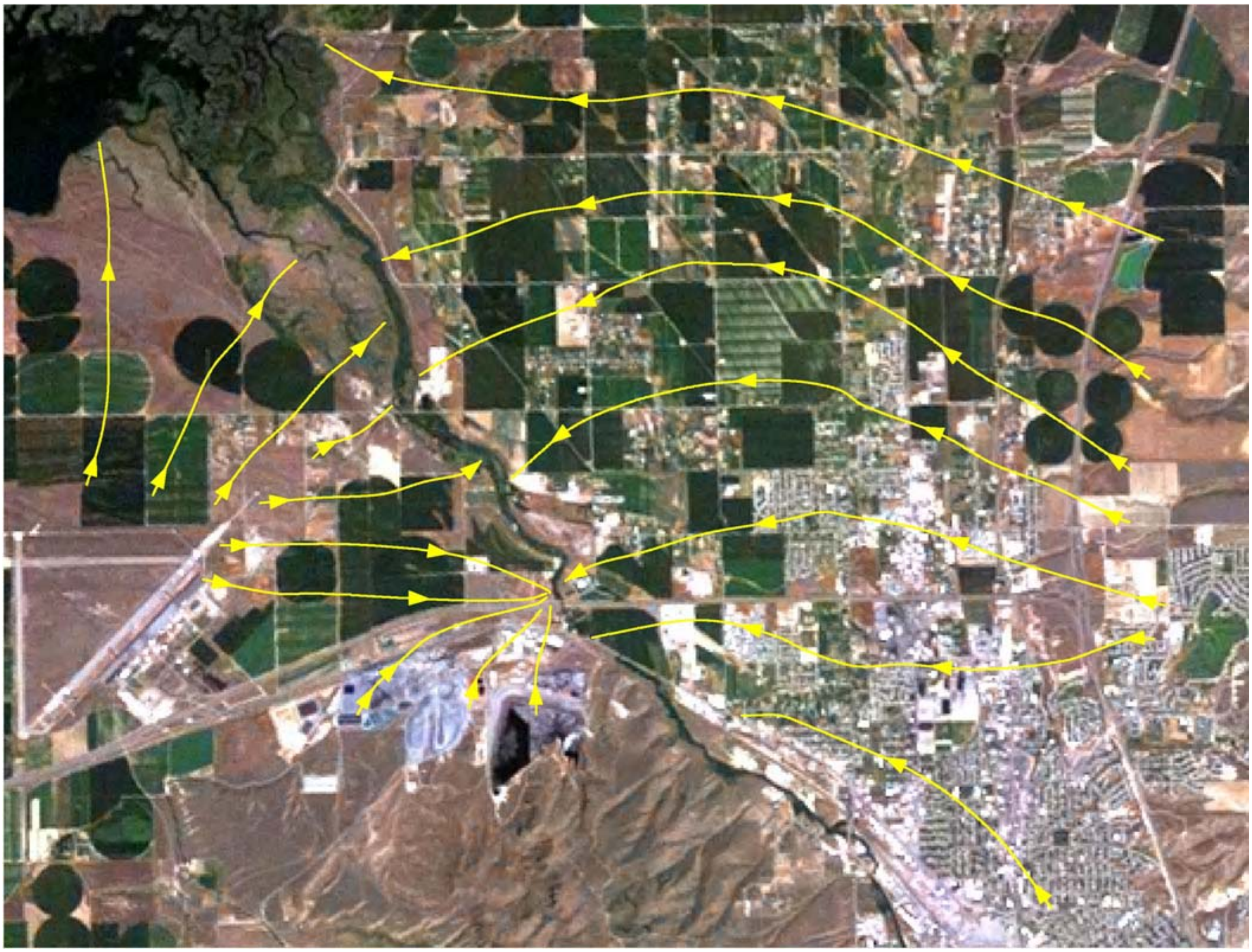


Figure 4. Ground water flow directions for aquifers east and west of the Portneuf River. Flow directions based on potentiometric maps from West and Kilburn, 1976, Plate 1, Jacobson, 1982, and Bechtel Environmental, Inc., June 1994.

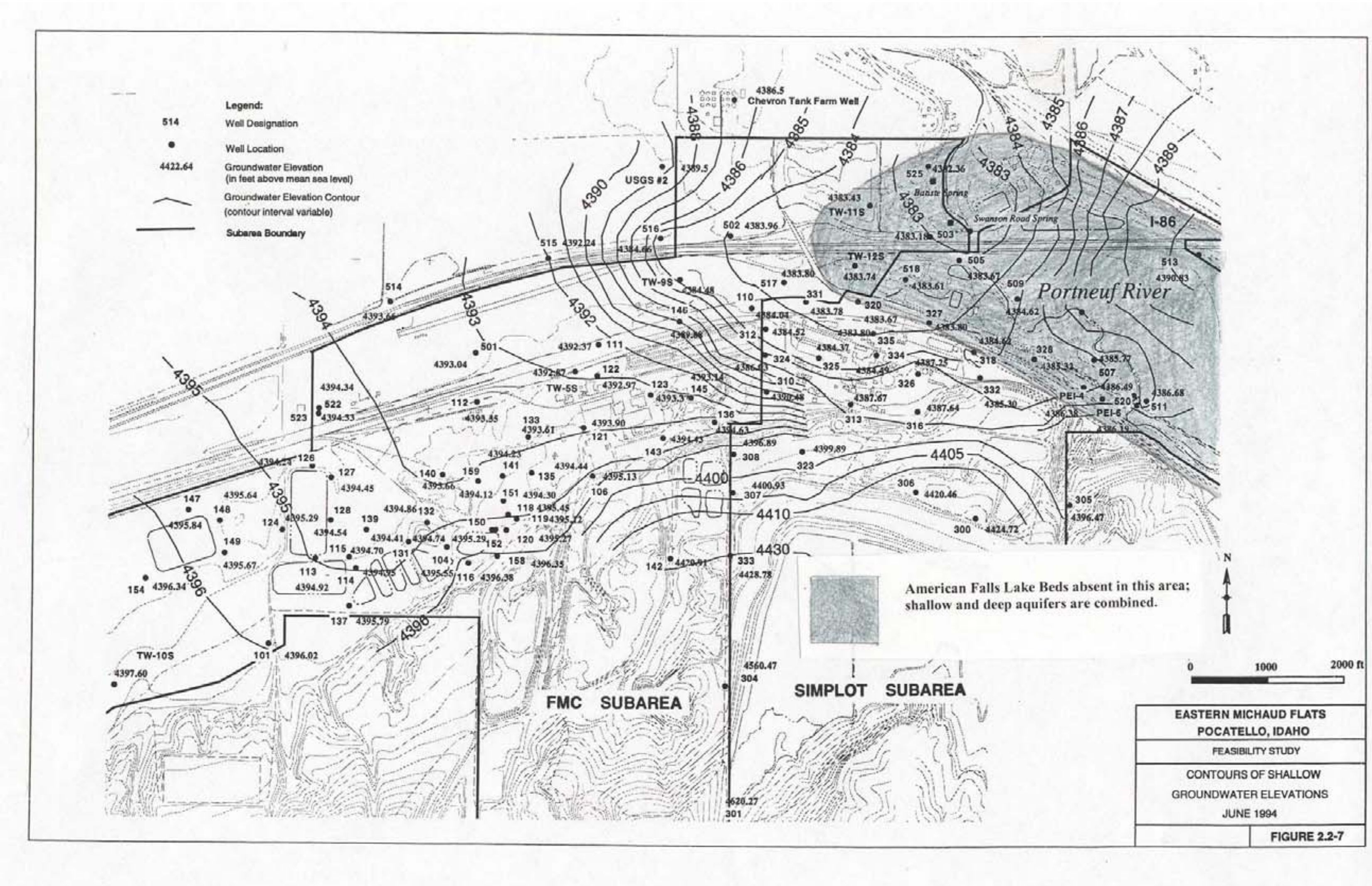


Figure 5. Potentiometric map for the shallow aquifer for the FMC/Simplot site. Shaded region represents area where American Falls Lake Beds are absent. Shallow and deep aquifers are combined in shaded area. (Adapted from Bechtel Environmental Inc., 1994.)

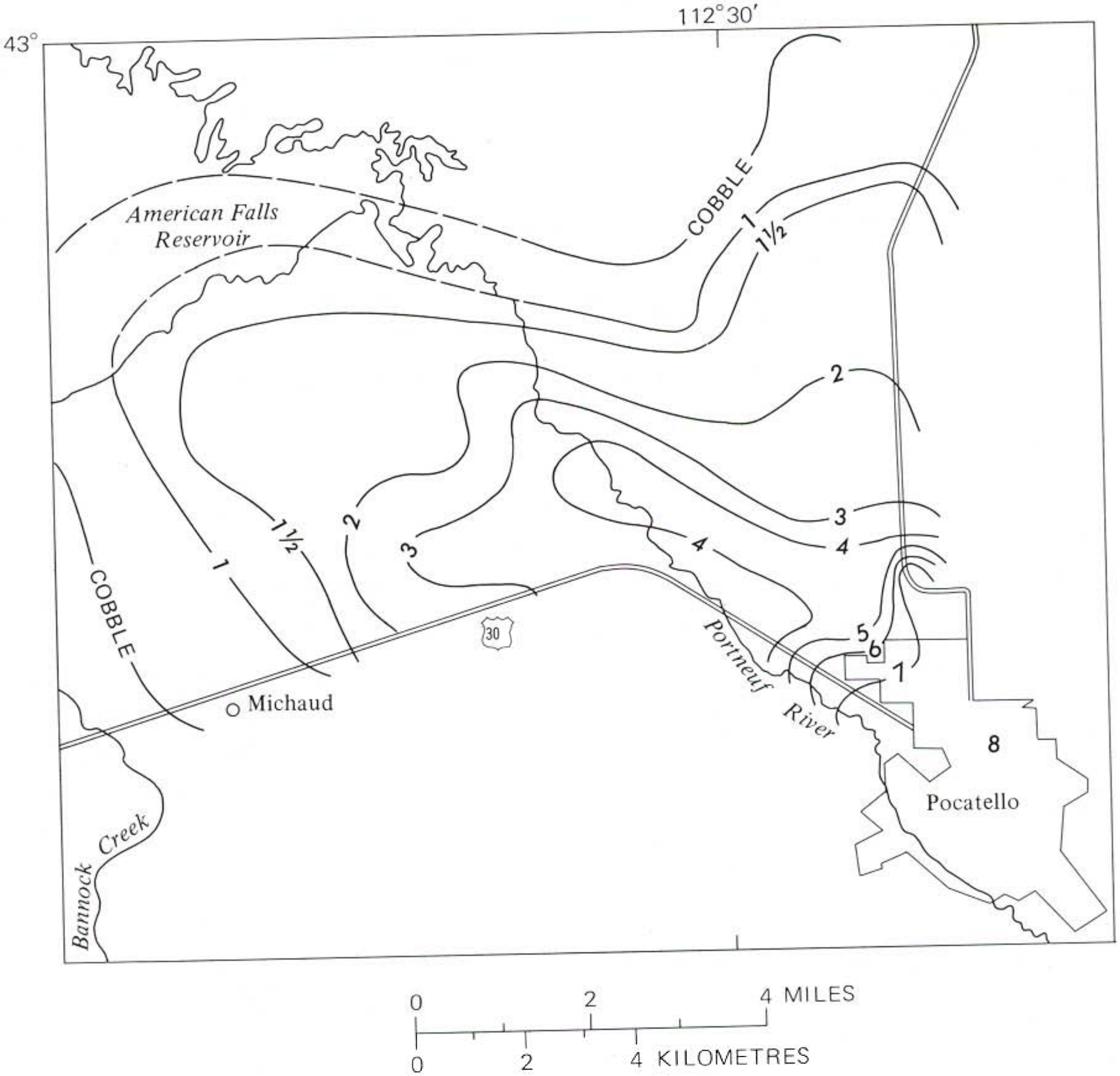


Figure 6. Areal variation in maximum boulder size in the Michaud gravels with contours in feet of longest dimension of largest boulders. (Adapted from Trimble, 1976, figure 13.)

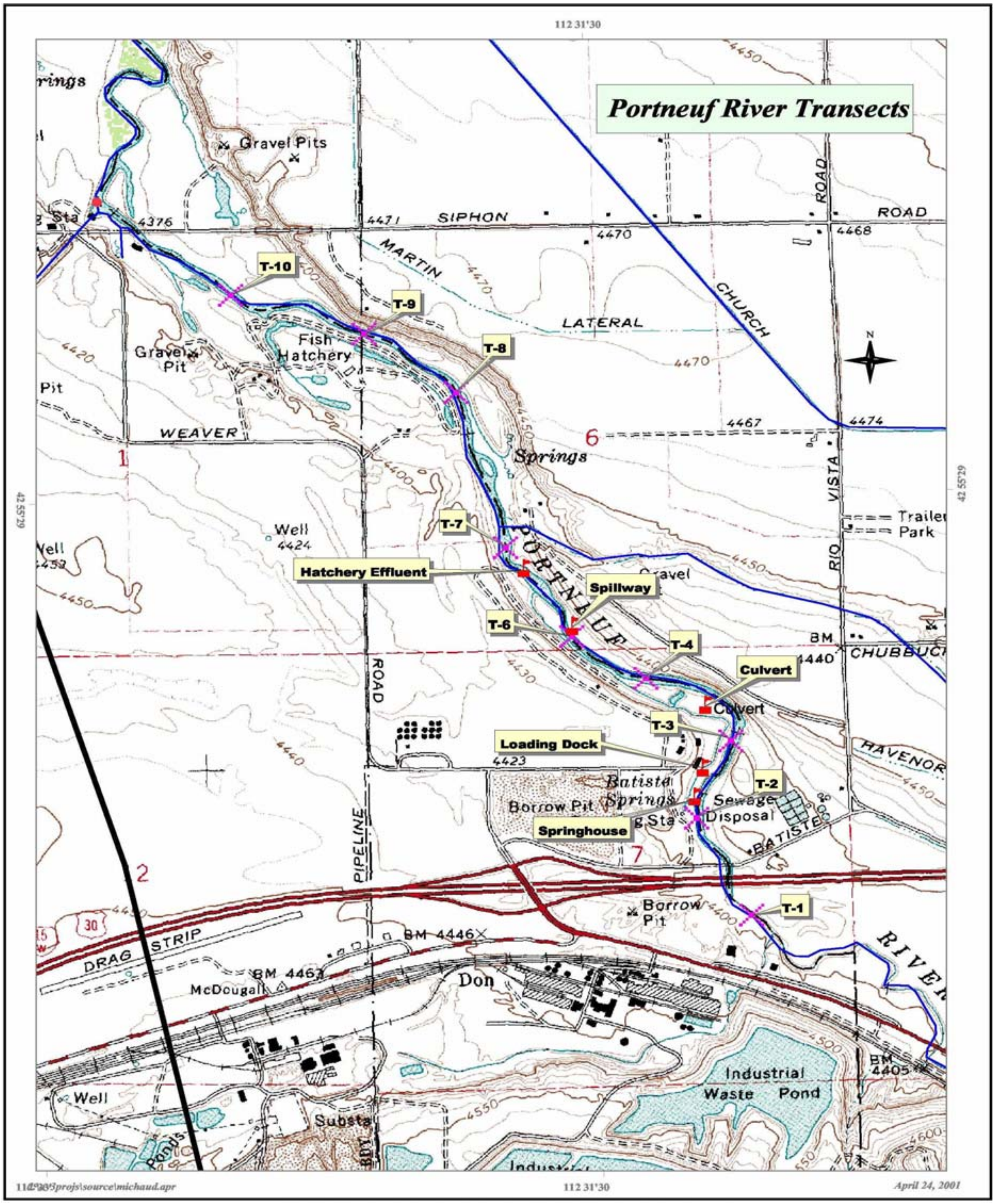
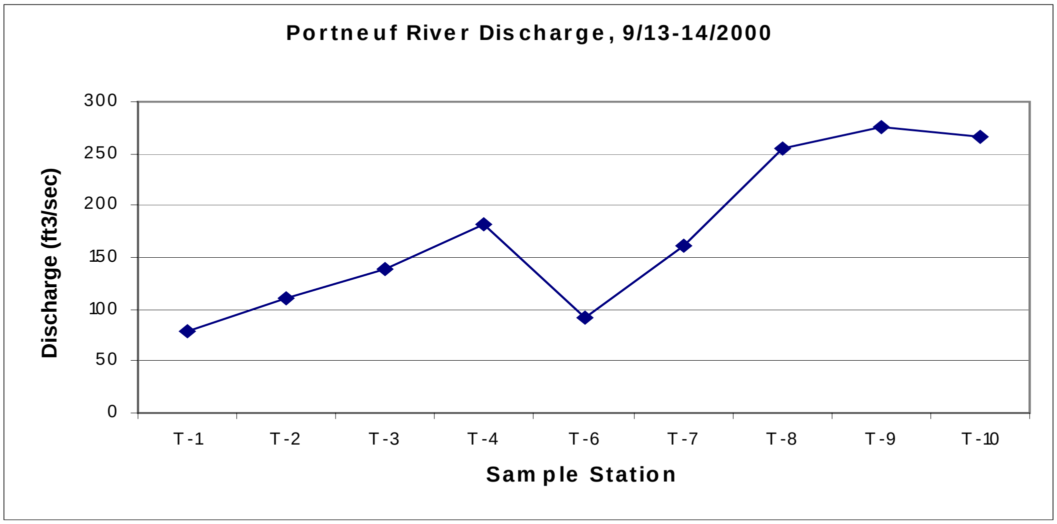
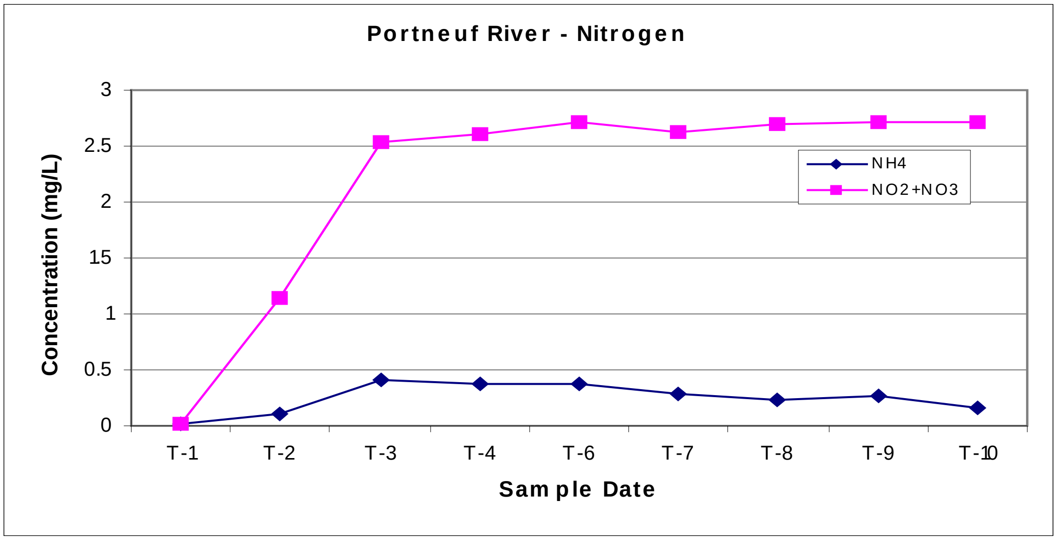


Figure 7. Transect locations sampled along the Portneuf River on September 13 and 14, 2000. Also shown are five Batiste Spring channel locations sampled from May 4, 1999 through December 7, 2000.





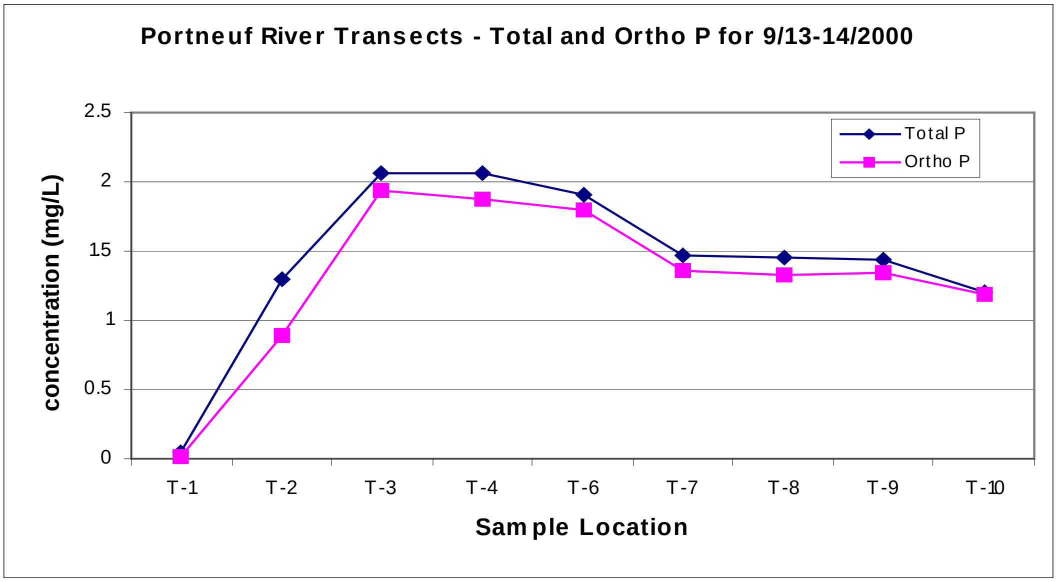


Figure 8. Discharge, ammonia, nitrite/nitrate, total phosphorus, and orthophosphate concentrations for Portneuf River transects sampled September 13-14, 2000.

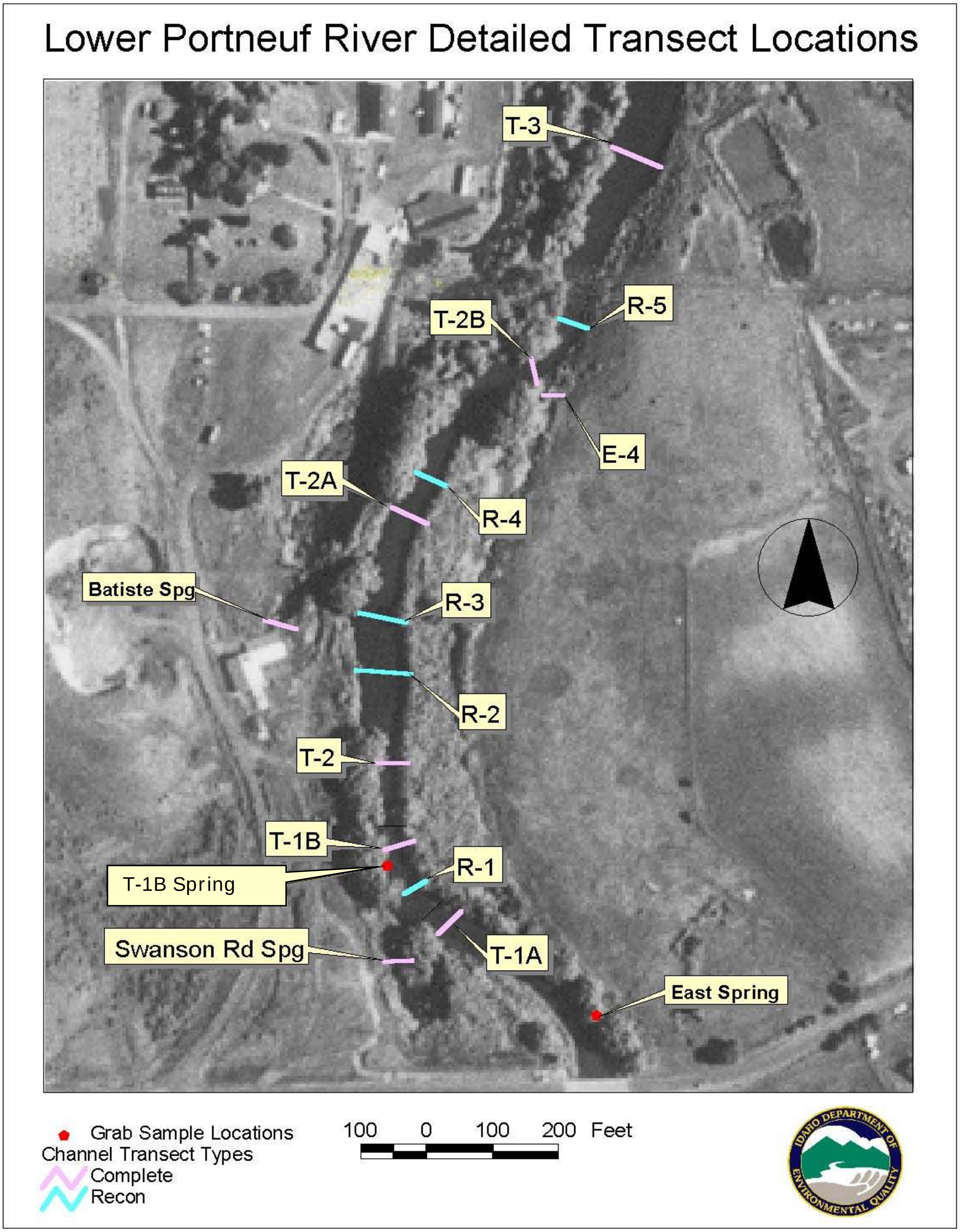
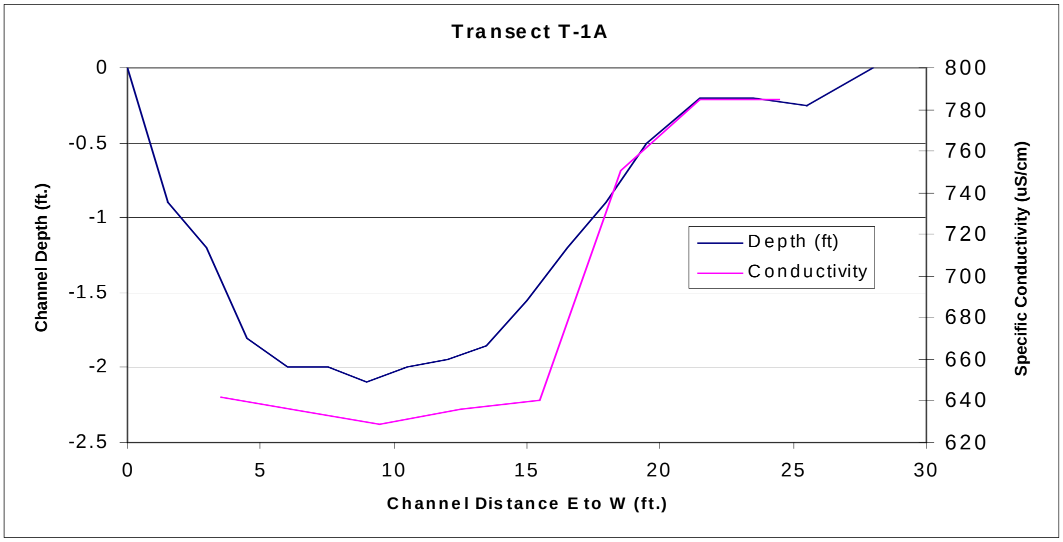
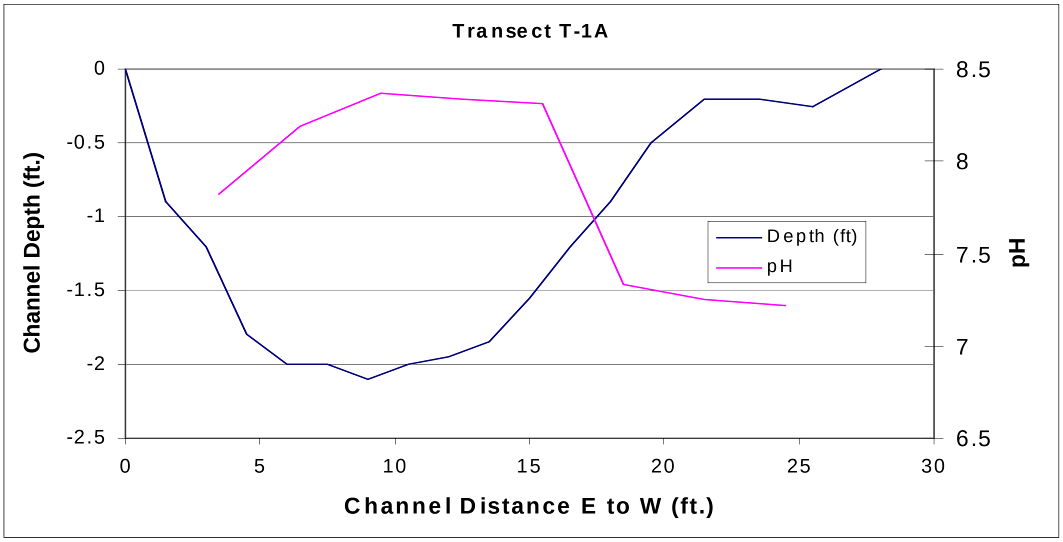


Figure 9. Location of reconnaissance transects R-1 through R-4 and additional transects T-1A through T-2B established along the Portneuf River during October 2001.





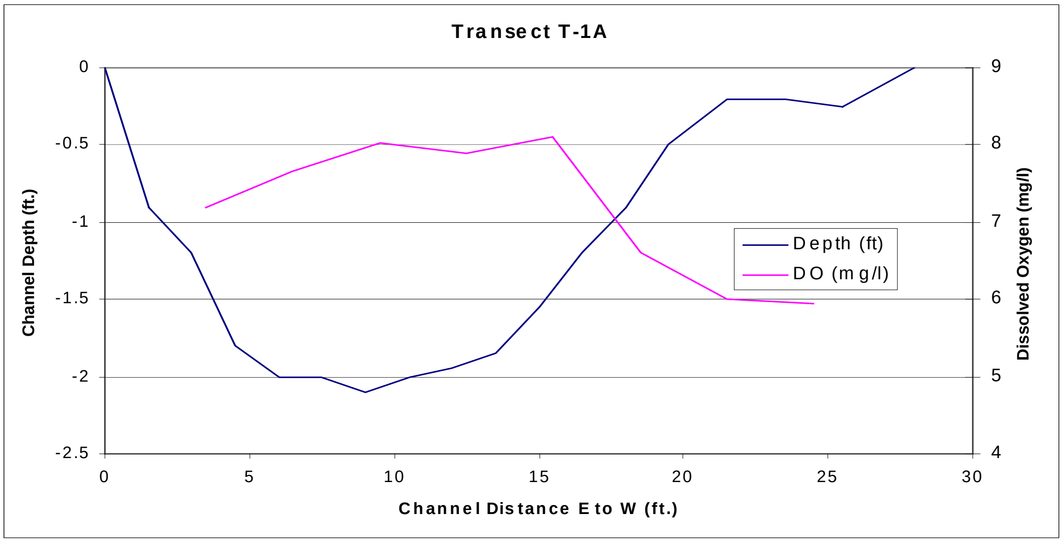
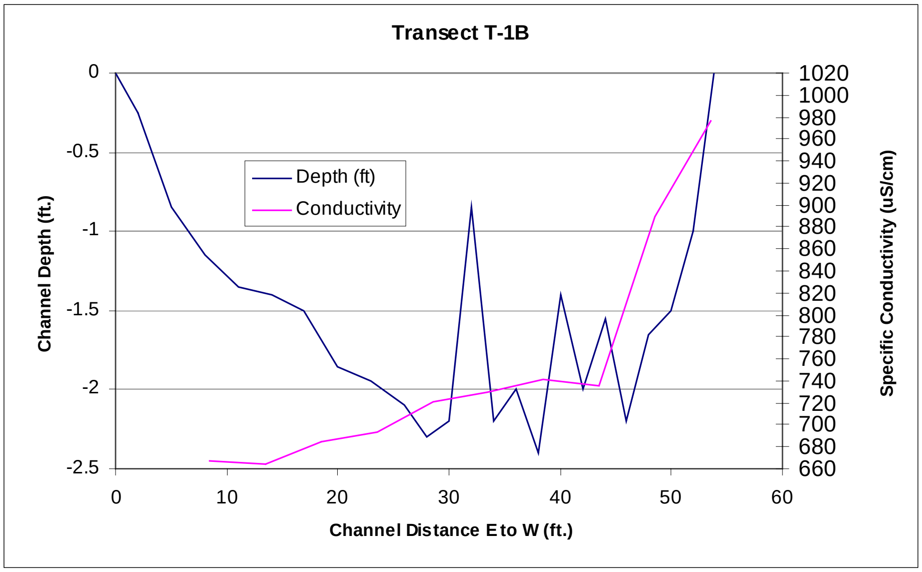
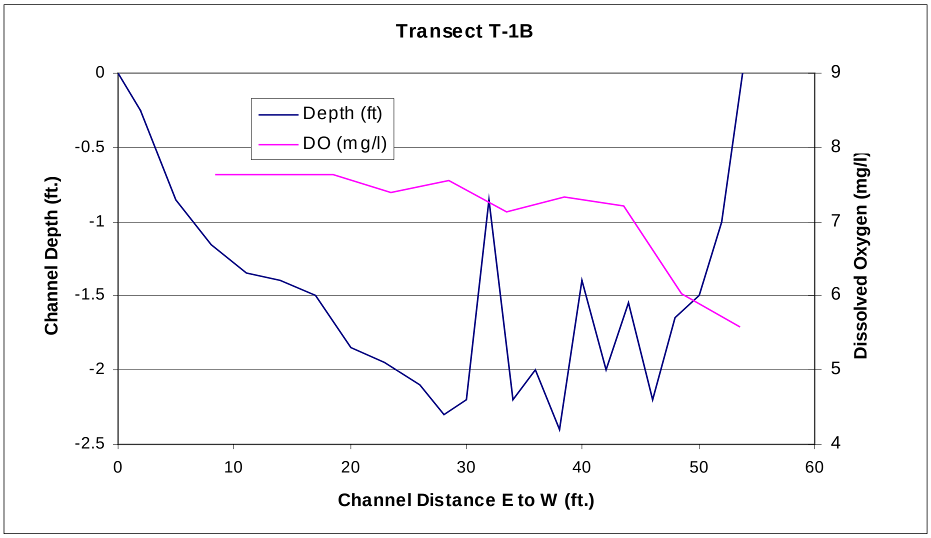


Figure 10. Portneuf River transect T-1A showing Specific Conductivity, pH, and dissolved oxygen measurements versus east to west channel distance.





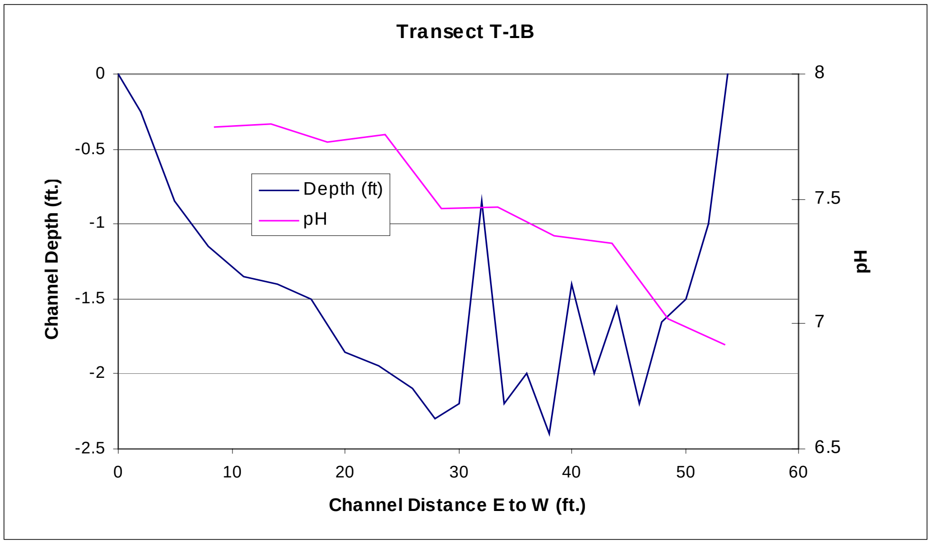


Figure 11. Portneuf River transect T-1B showing Specific Conductivity, pH, and dissolved oxygen versus east to west channel distance.

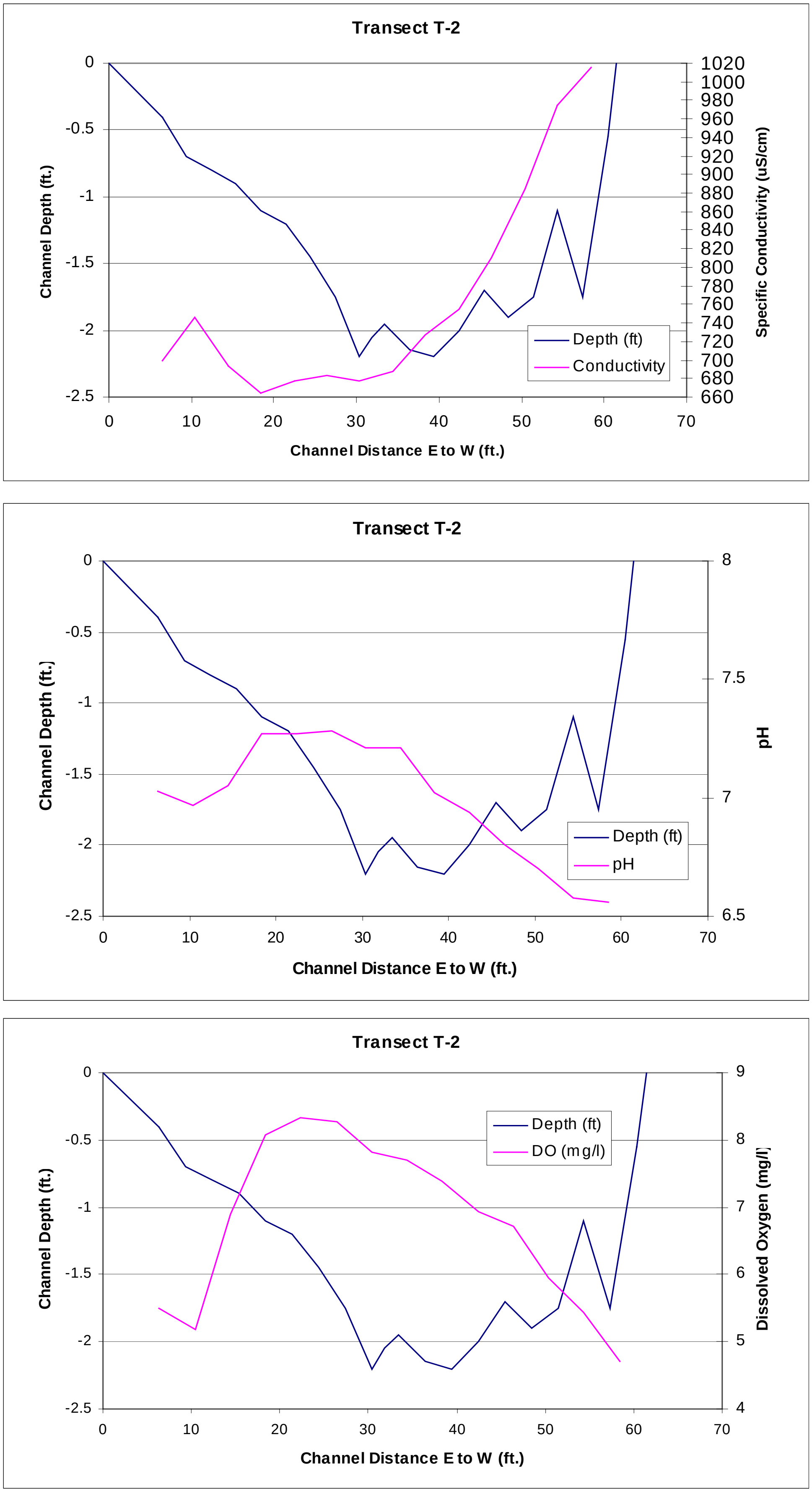


Figure 12. Portneuf River transect T-2 showing Specific Conductivity, pH, and dissolved oxygen versus east to west channel distance.

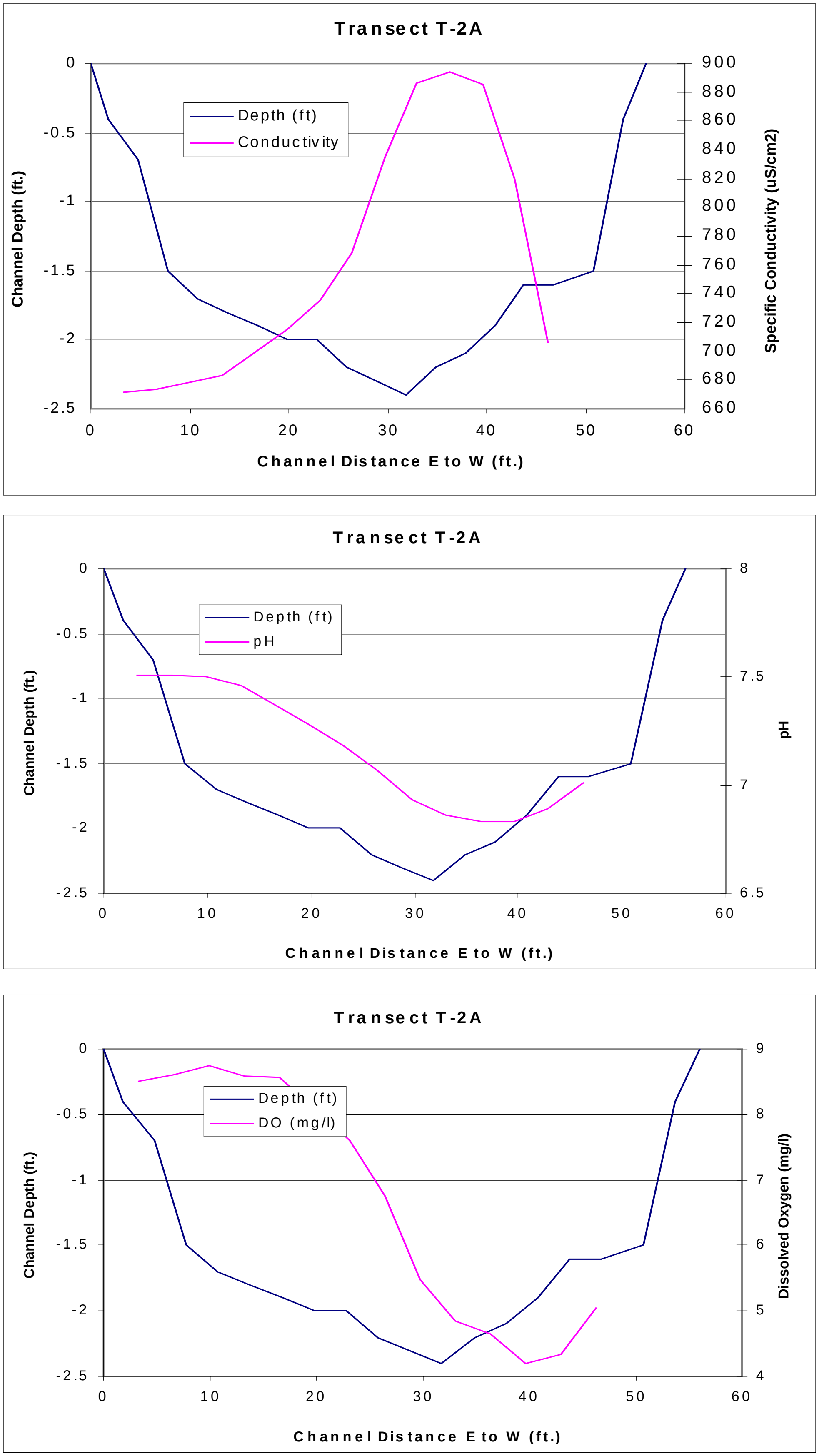
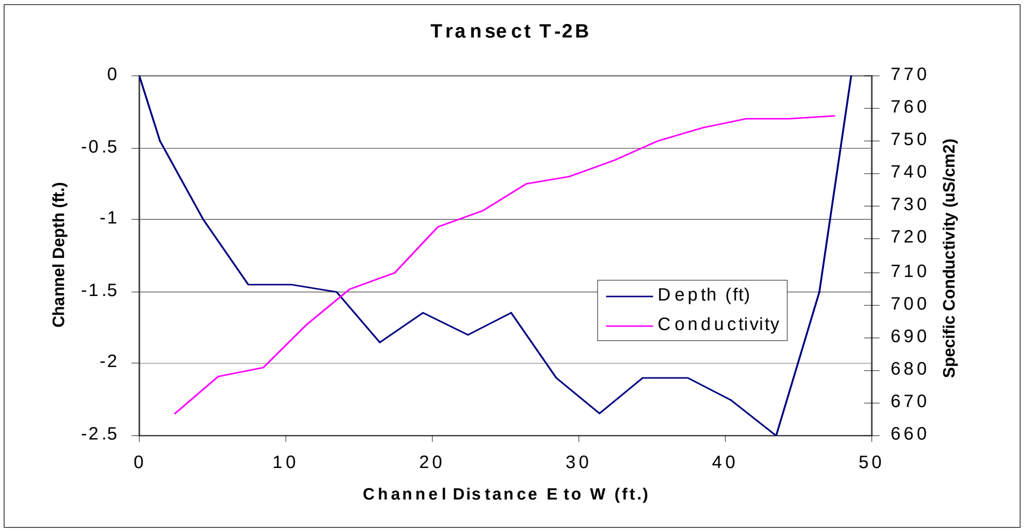
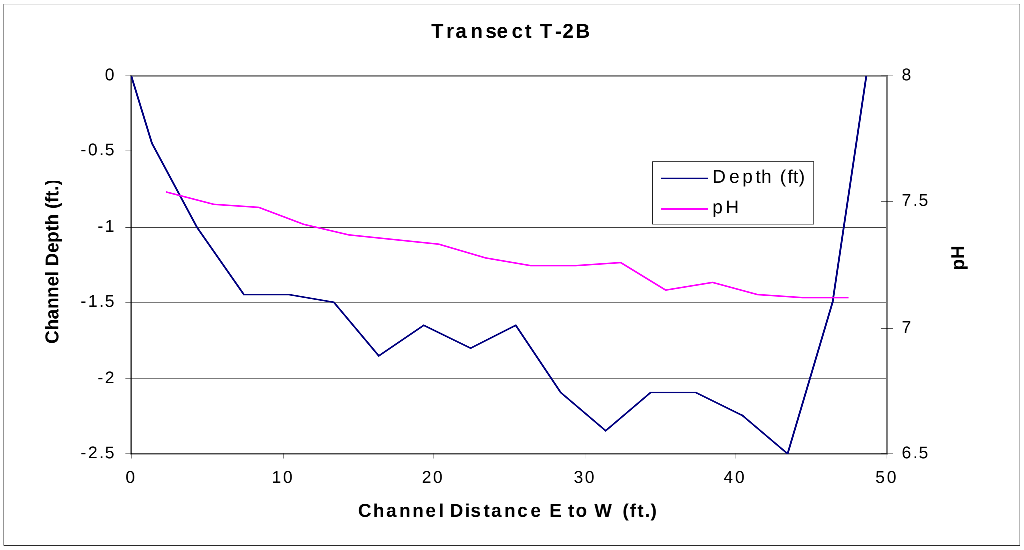


Figure 13. Portneuf River transect T-2A showing Specific Conductivity, pH, and dissolved oxygen versus east to west channel distance.





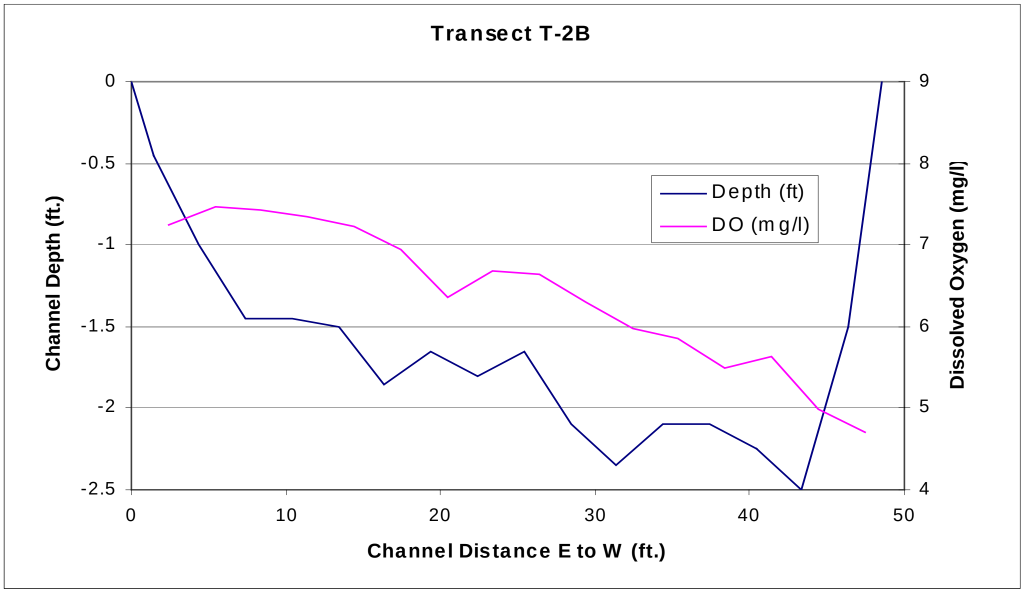


Figure 14. Portneuf River transect T-2B showing Specific Conductivity, pH, and dissolved oxygen versus east to west channel distance.

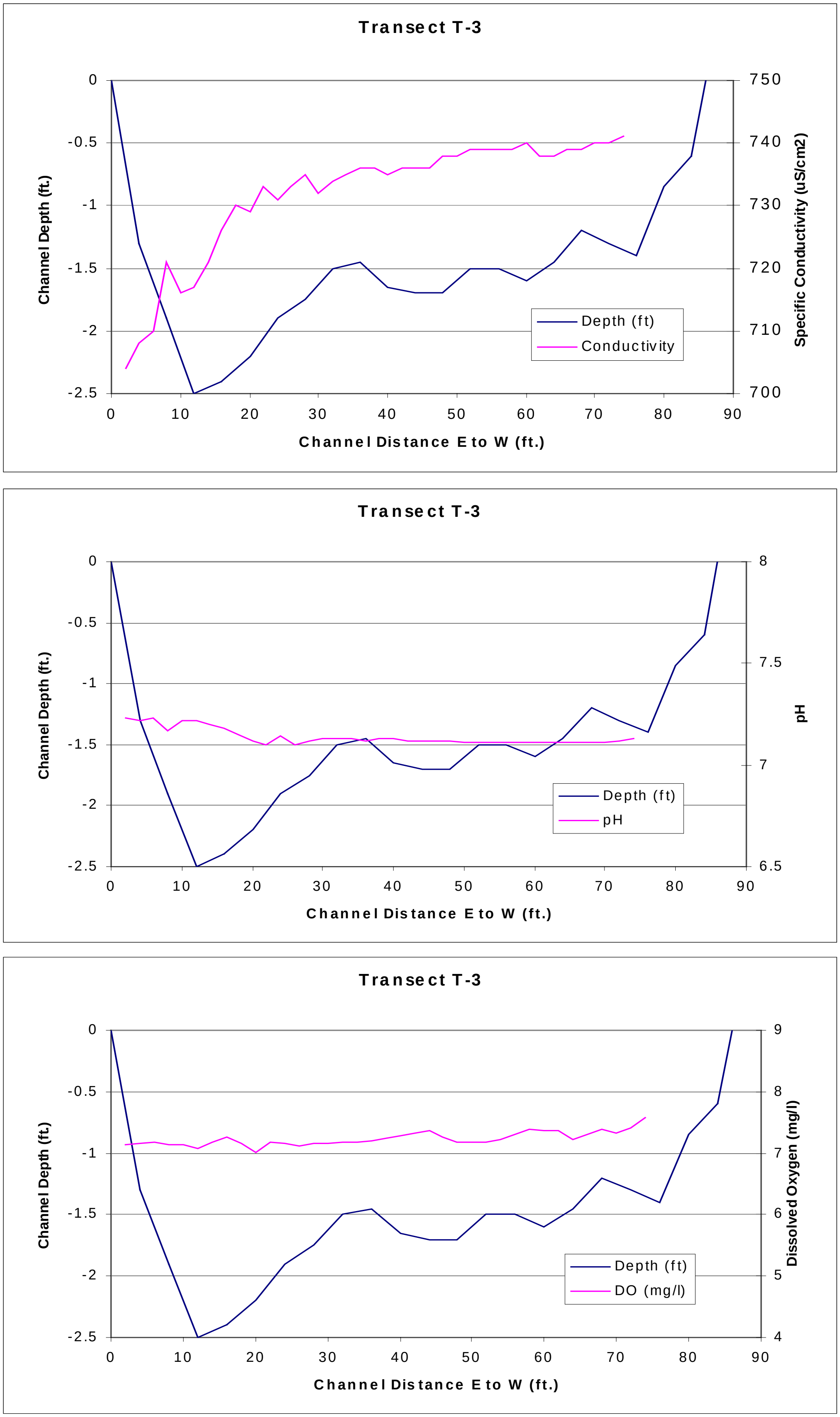


Figure 15. Portneuf River transect T-3 showing Specific Conductivity, pH, and dissolved oxygen versus east to west channel distance.

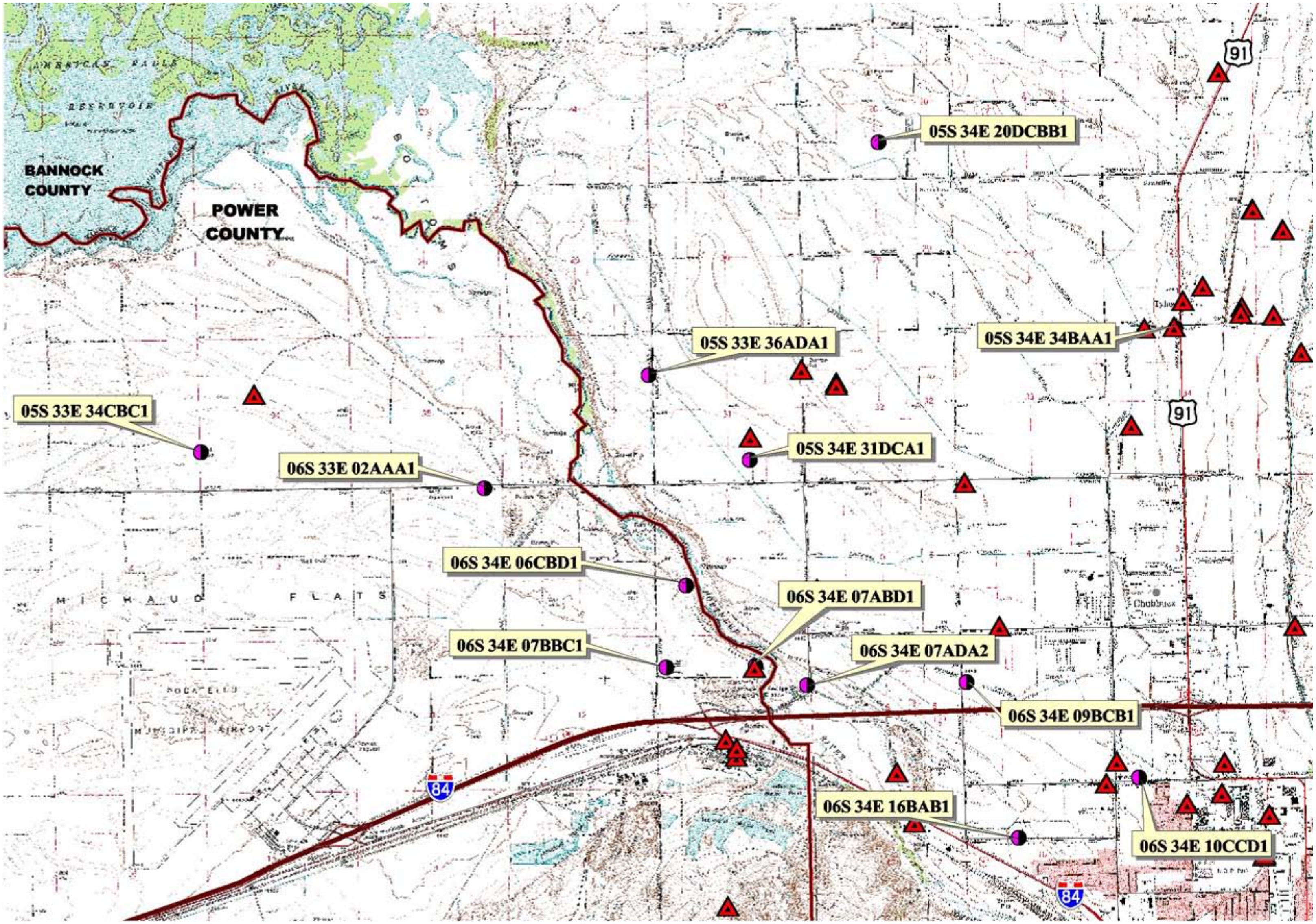
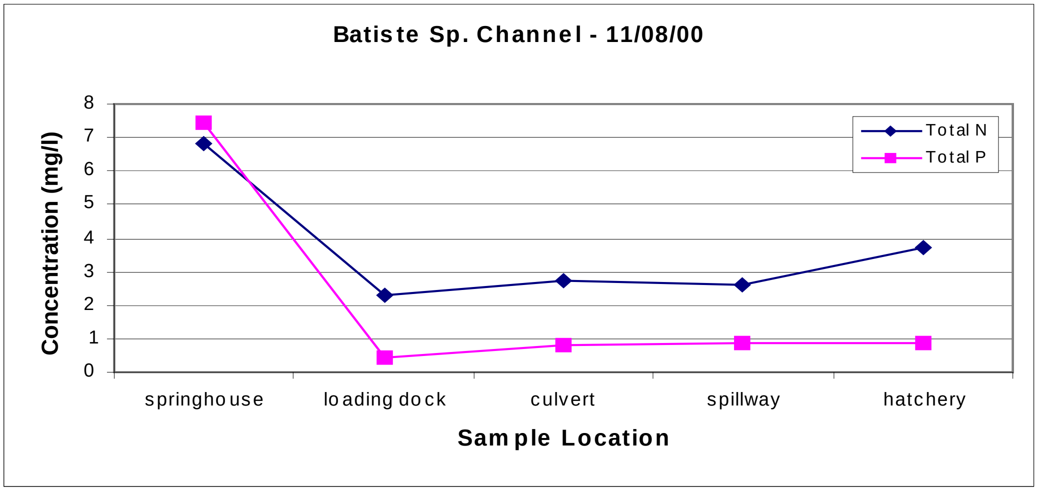
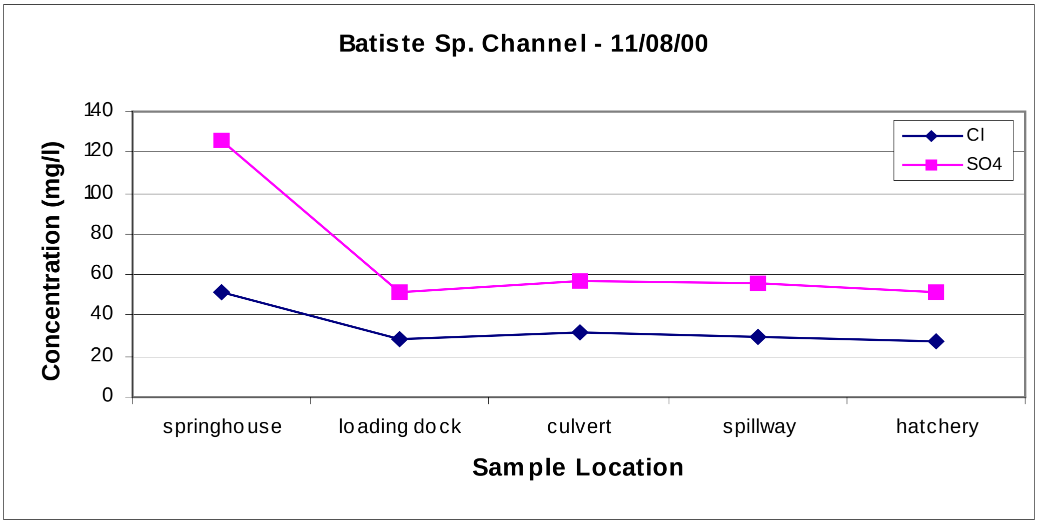


Figure 16. Station ID (Township, Range and Section) for 13 statewide monitoring wells in the vicinity of the Eastern Michaud Flats area. Triangles show locations of public water supply system (PWS) wells.





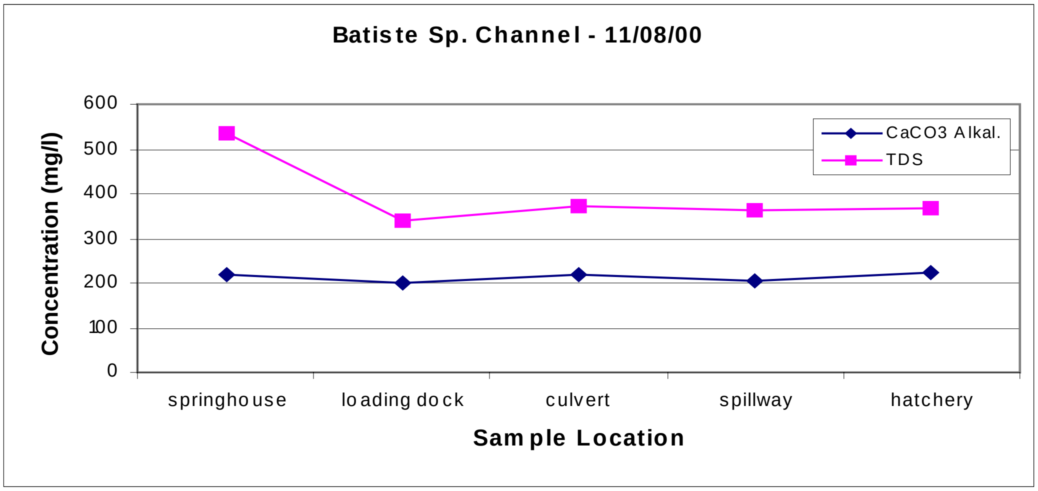


Figure 17. Water quality parameters for five sample locations along Batiste Spring channel, November 8, 2000.

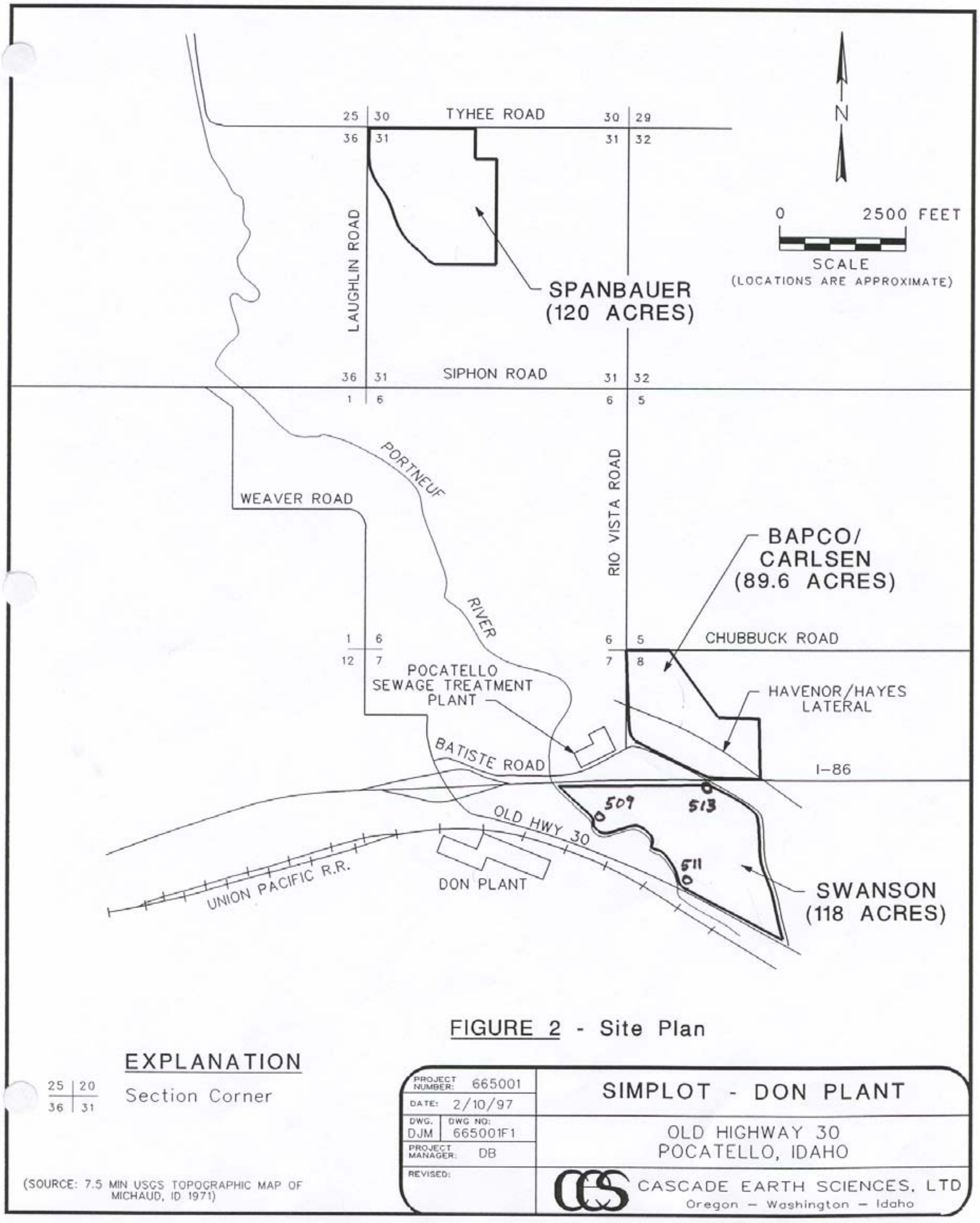


Figure 18. Location of Simplot Don Plant wastewater land application acreage on east side of Portneuf River. Locations for monitoring wells 509, 511 and 513 are shown for Swanson acreage. (Adapted from Cascade Earth Sciences, May 20, 1998.)

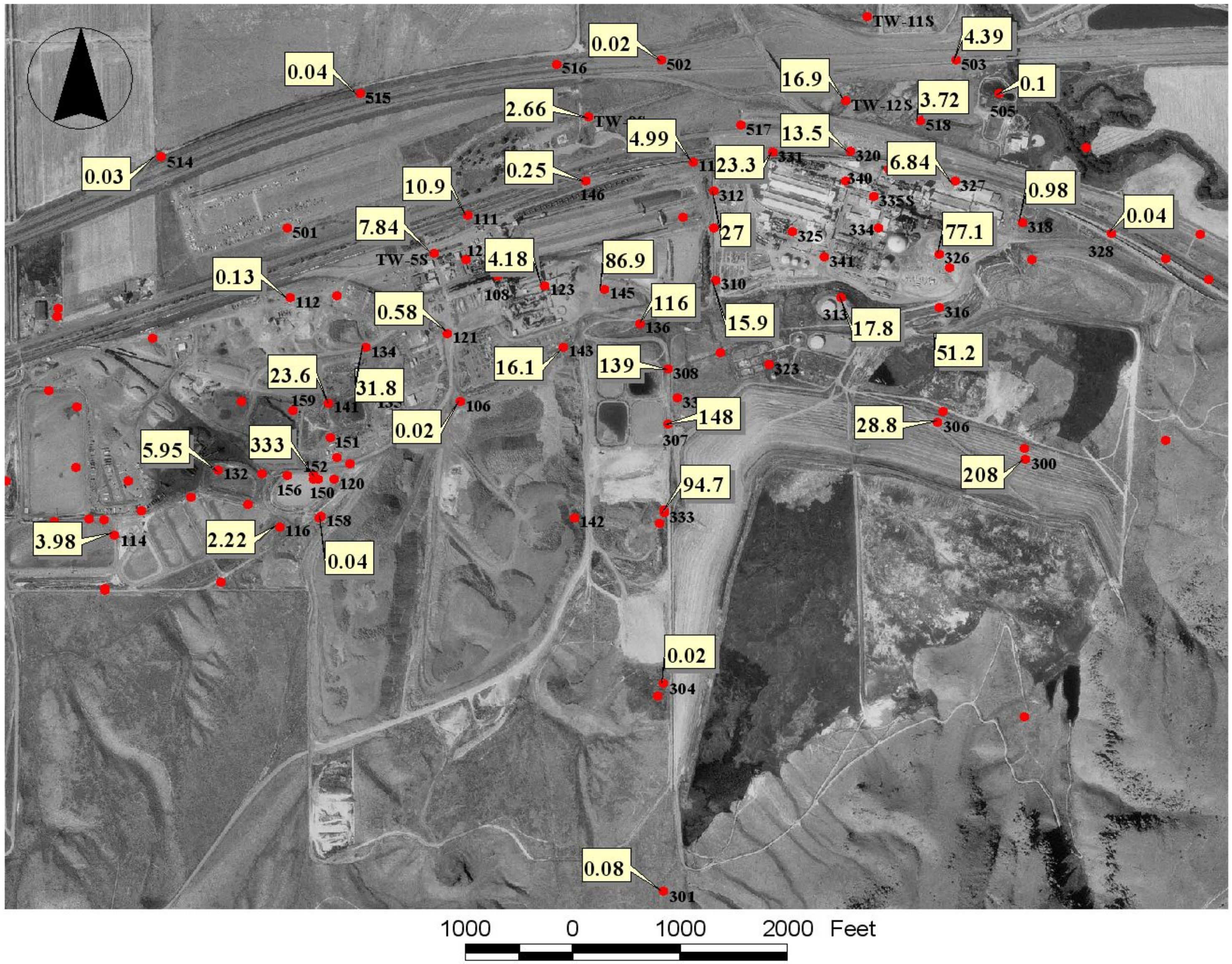


Figure 19. Site-wide orthophosphate concentrations in the shallow aquifer based on sampling conducted in December 1993.

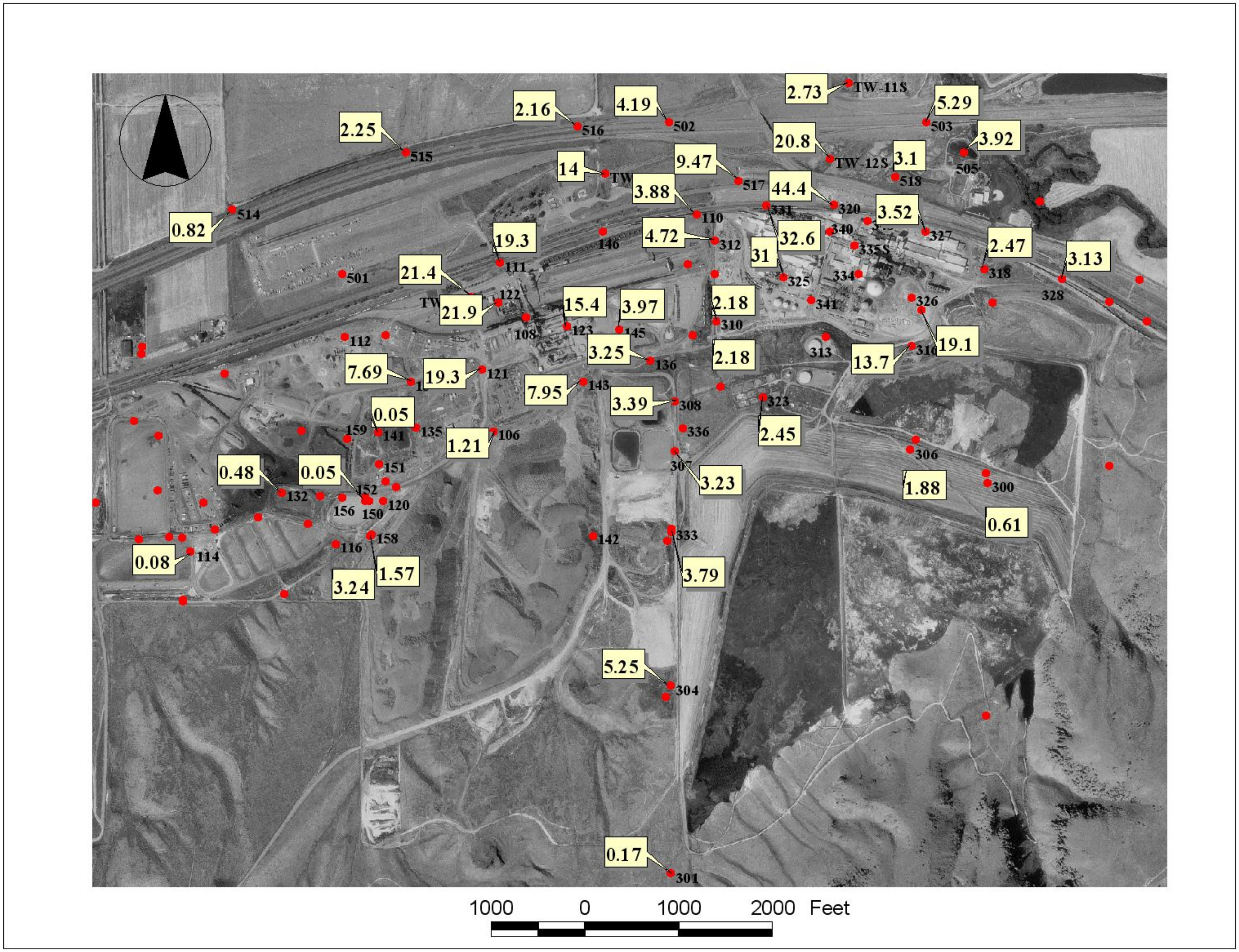


Figure 20. Site-wide nitrate concentrations in the shallow aquifer based on sampling conducted in December 1993.

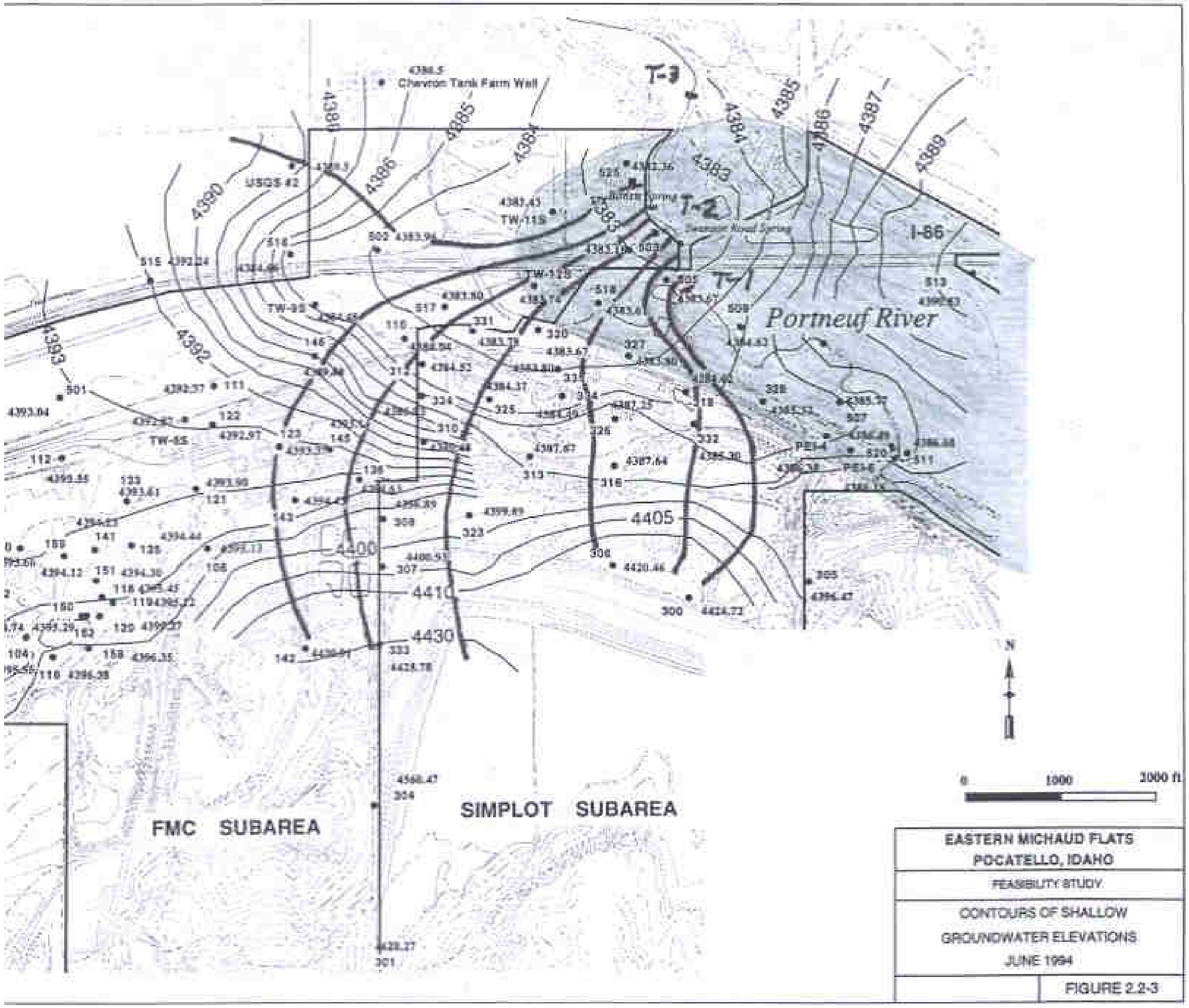
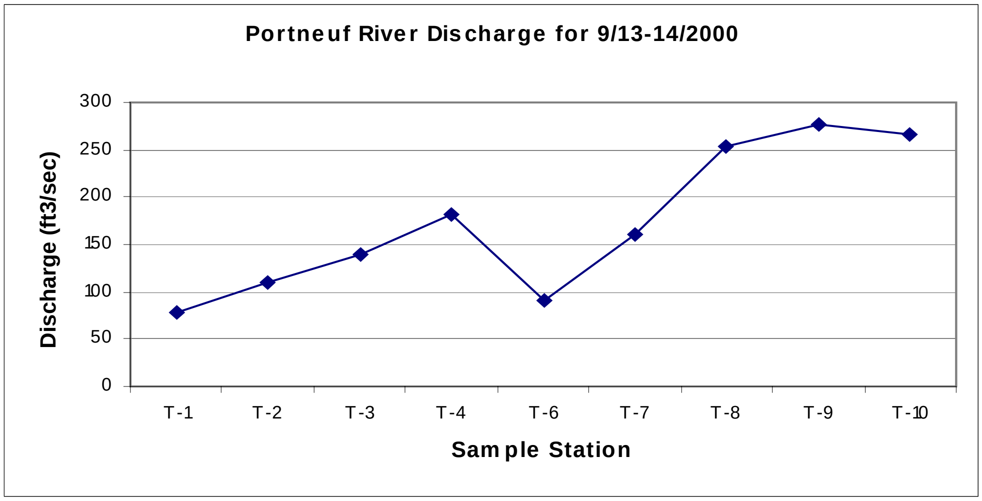
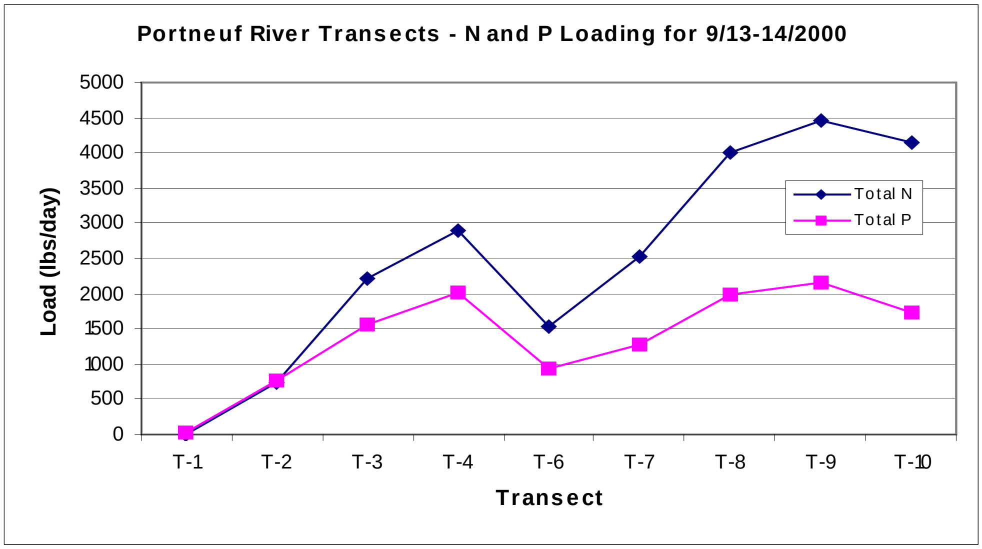


Figure 21. Ground water flowpaths for phosphorous loading calculations. American Falls Lake Beds are absent and shallow and deep aquifers are combined in the shaded area. (Adapted from Bechtel Environmental, Inc., 1994.)





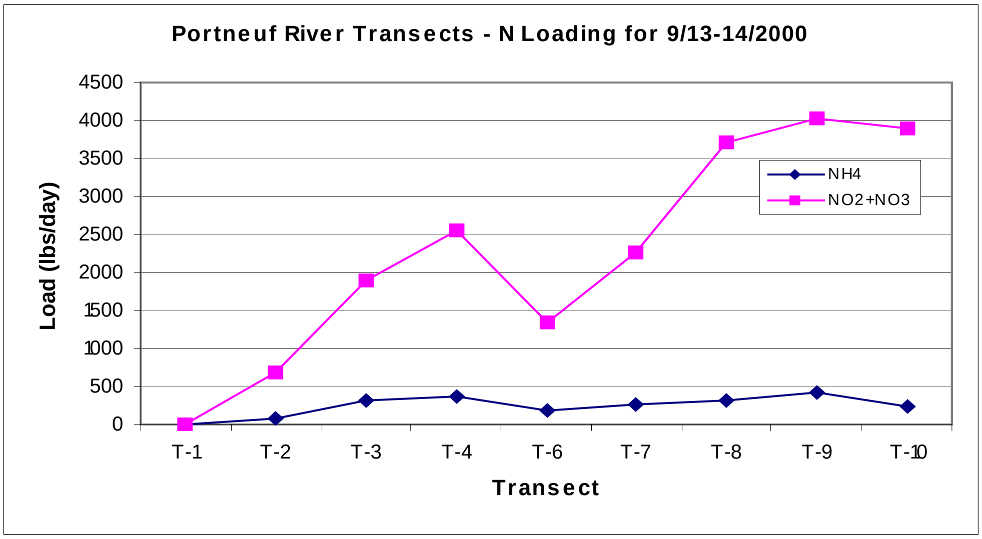


Figure 22. Discharge and loading, in pounds per day, for total nitrogen, total phosphorous, ammonia, and nitrite/nitrate for Portneuf River transects sampled September 13-14, 2000.

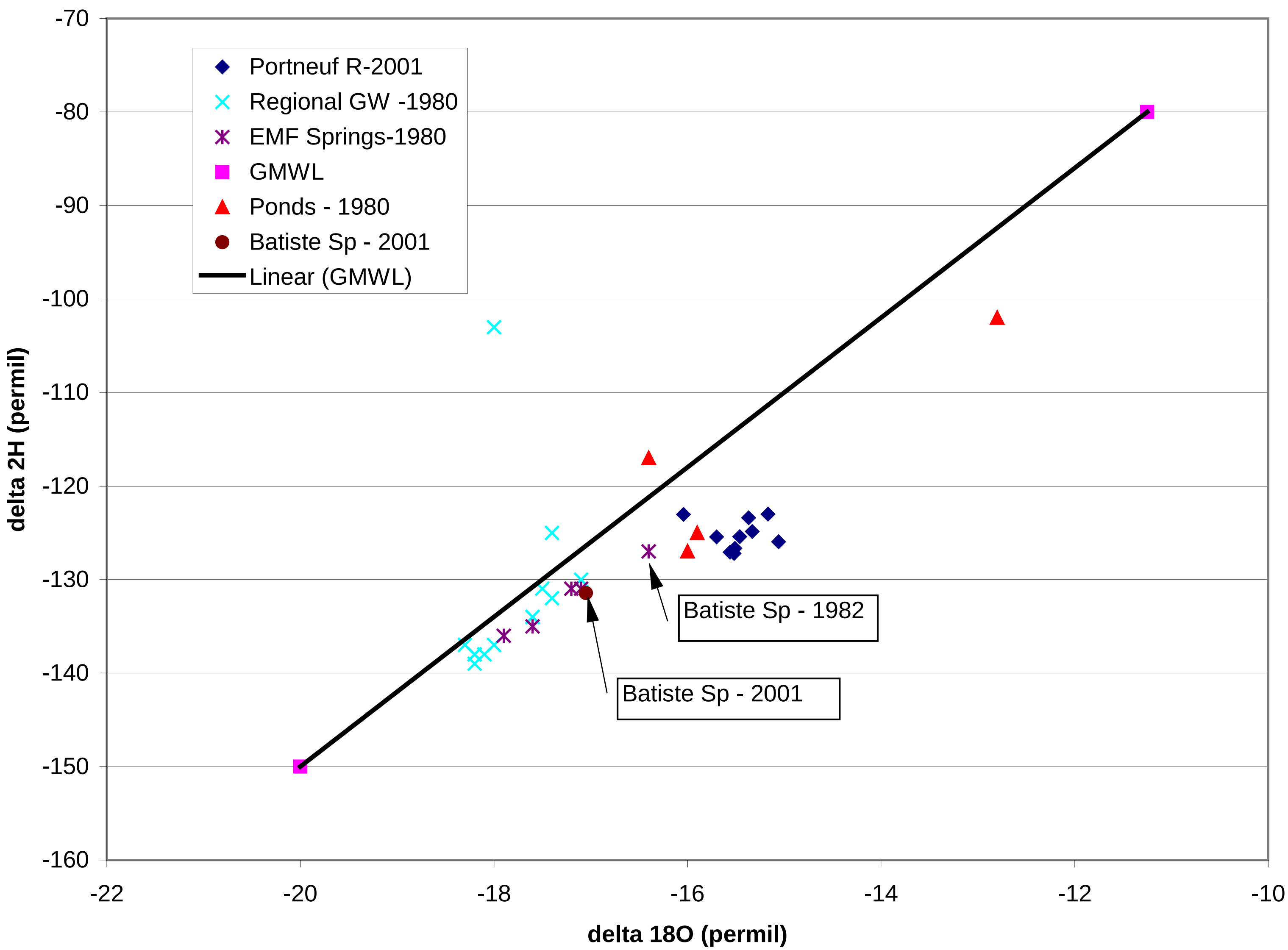


Figure 23. δ ^{18}O versus δ ^{2}H for samples collected from springs and the Portneuf River, and from industrial ponds. (Portneuf R-2001 includes transects T-1A, T-1B, T-2, T-2A and T-2B.)

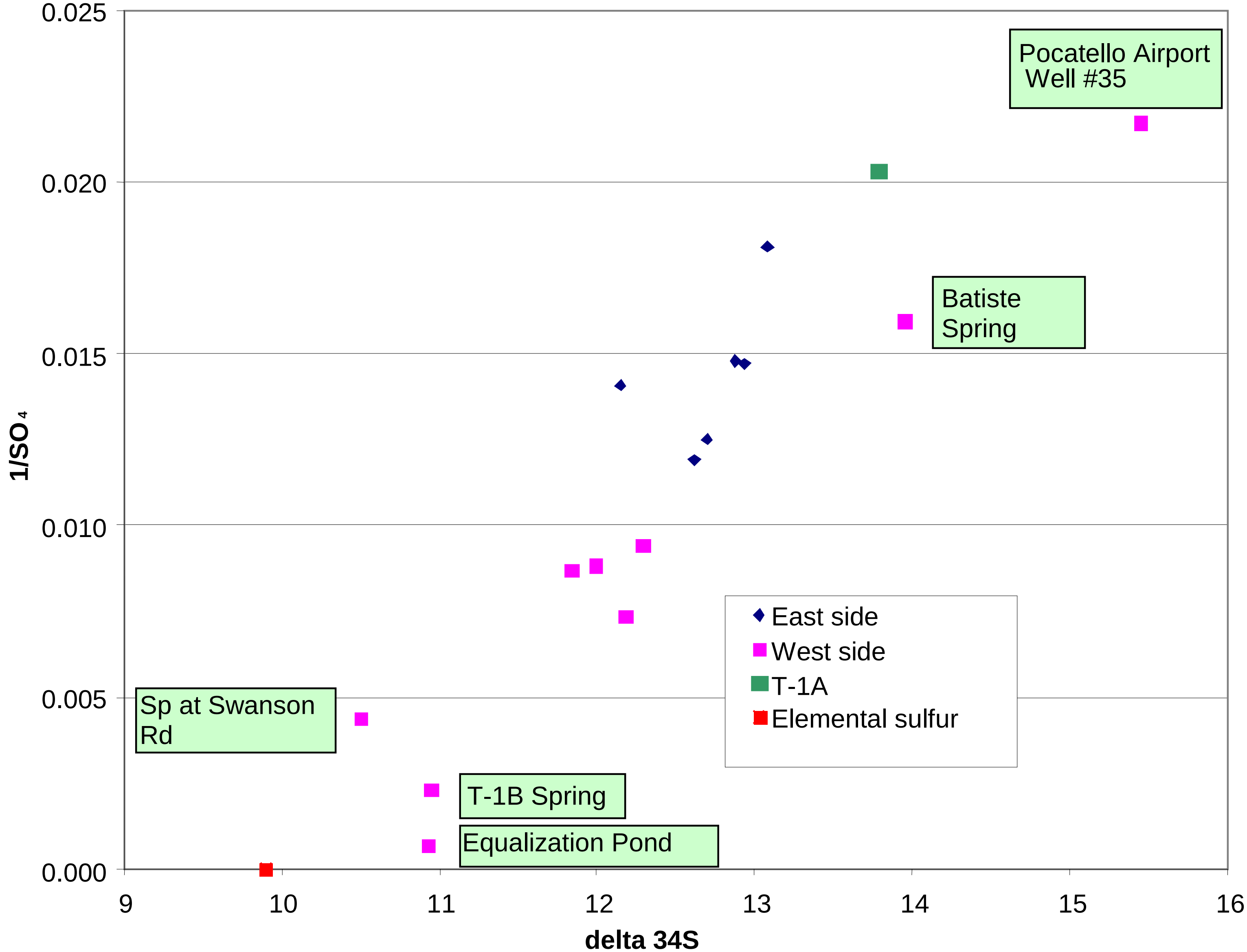


Figure 24. δ [34]S versus sulfate concentration for samples from the Portneuf River, springs and a City of Pocatello well.

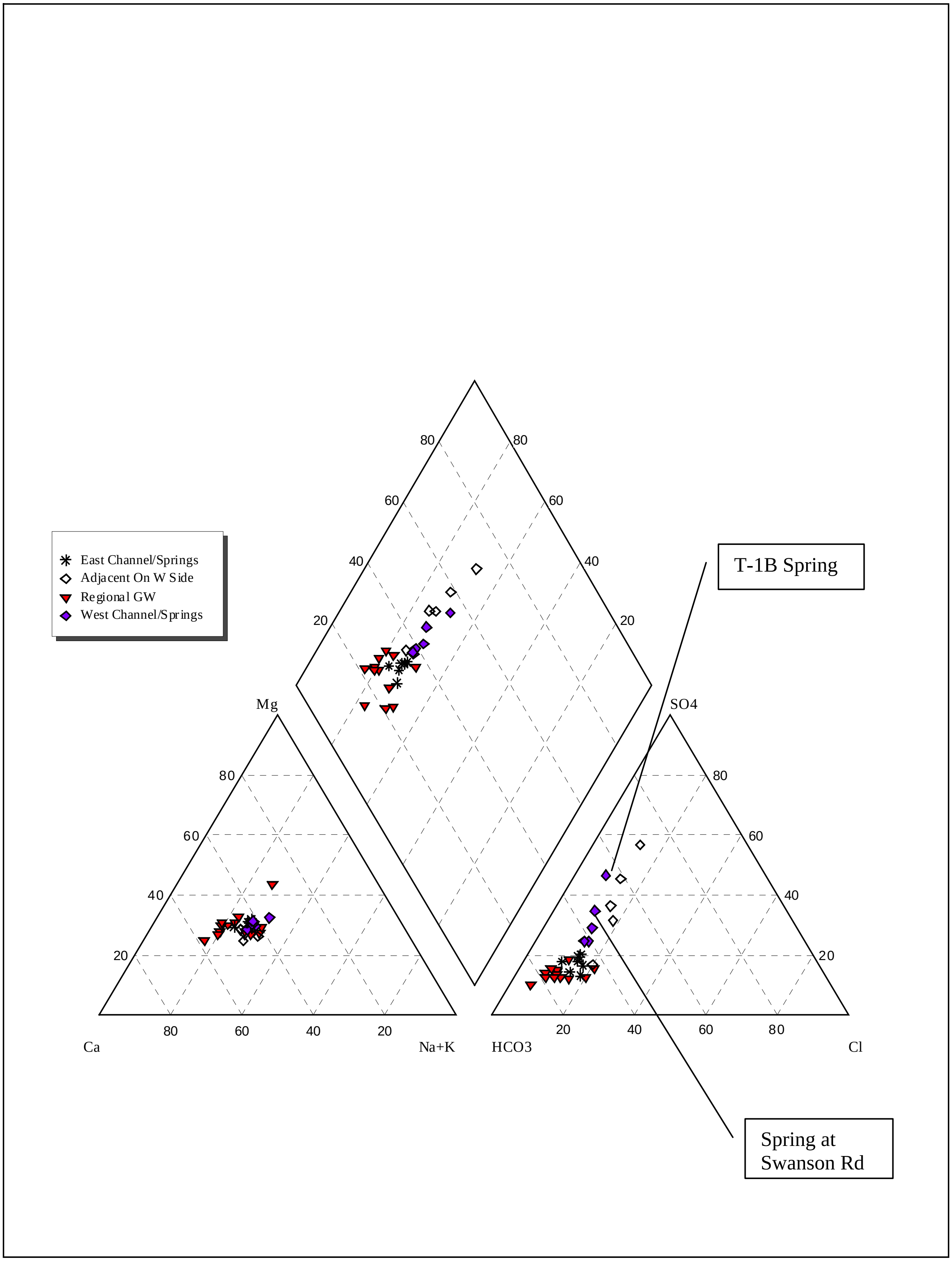
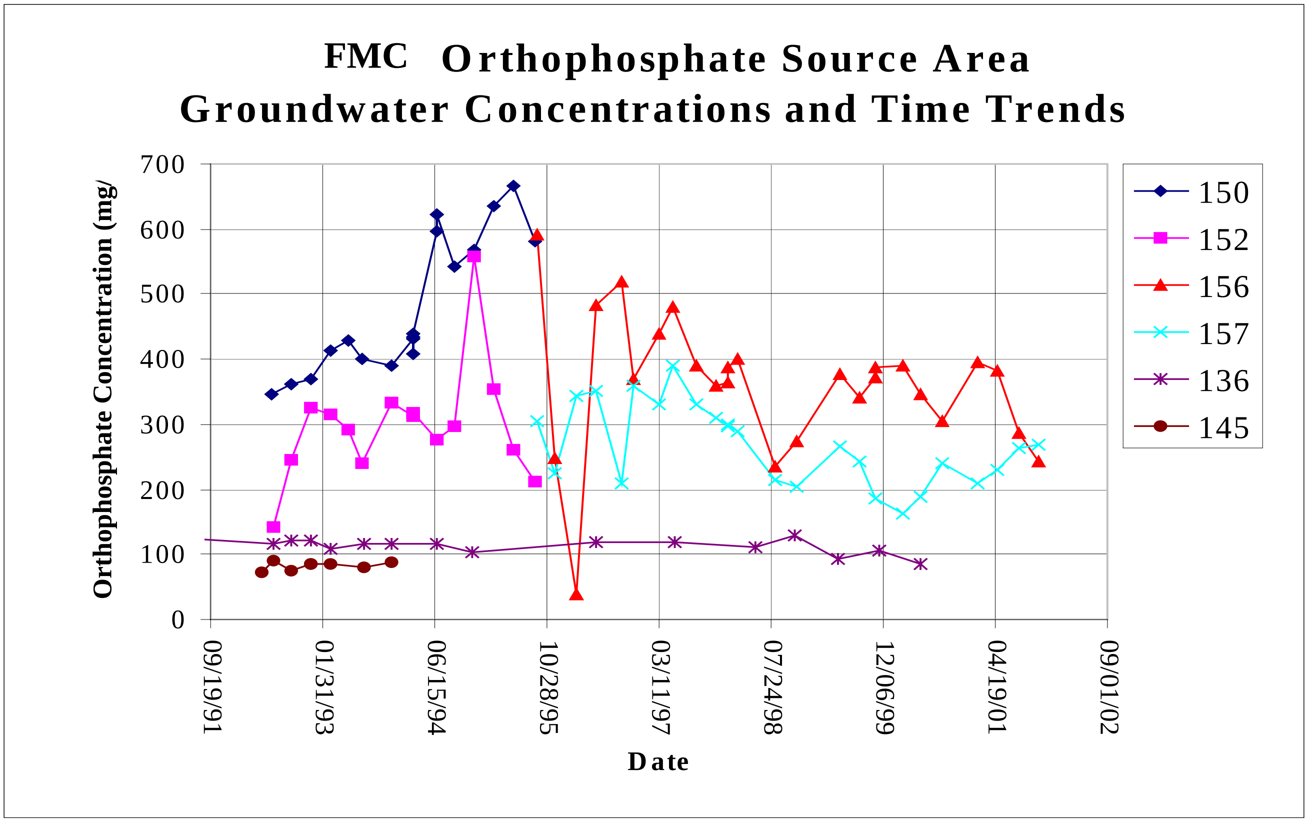


Figure 25. Major ion composition of water from Portneuf River, springs, adjacent shallow ground water, and regional ground water.



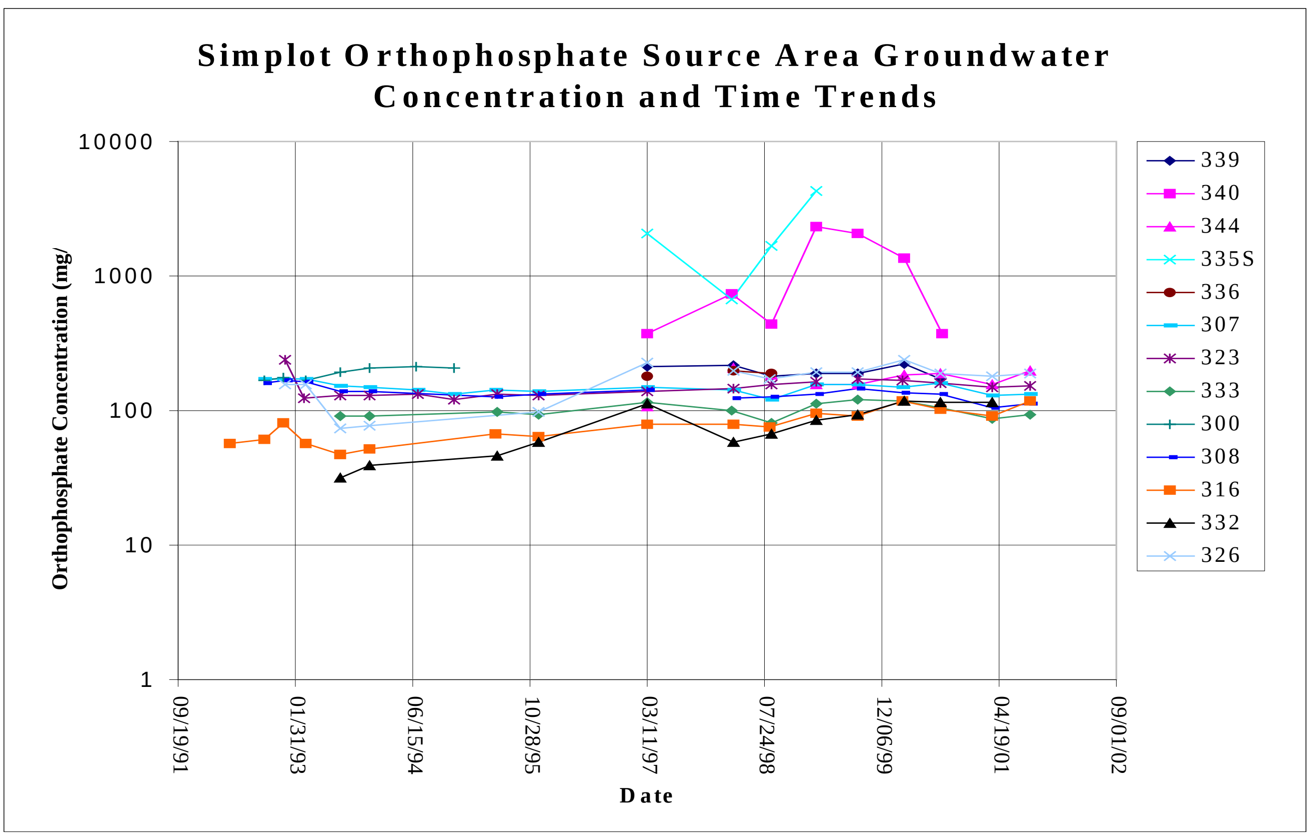


Figure 26. FMC and Simplot orthophosphate source area ground water concentrations and time trends.

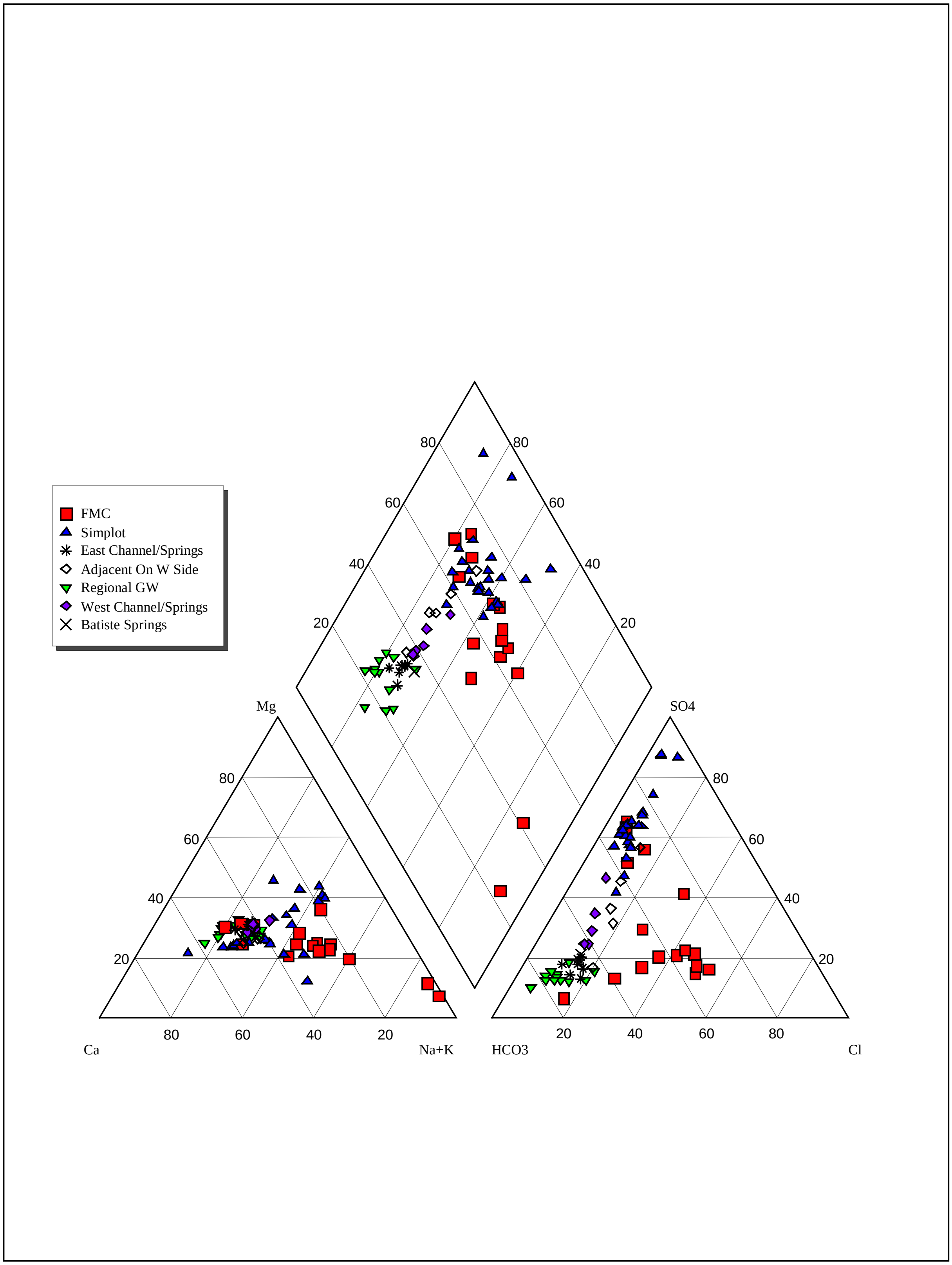


Figure 27. Major ion composition of water samples from Portneuf River, springs, and selected wells from beneath FMC and Simplot facilities.

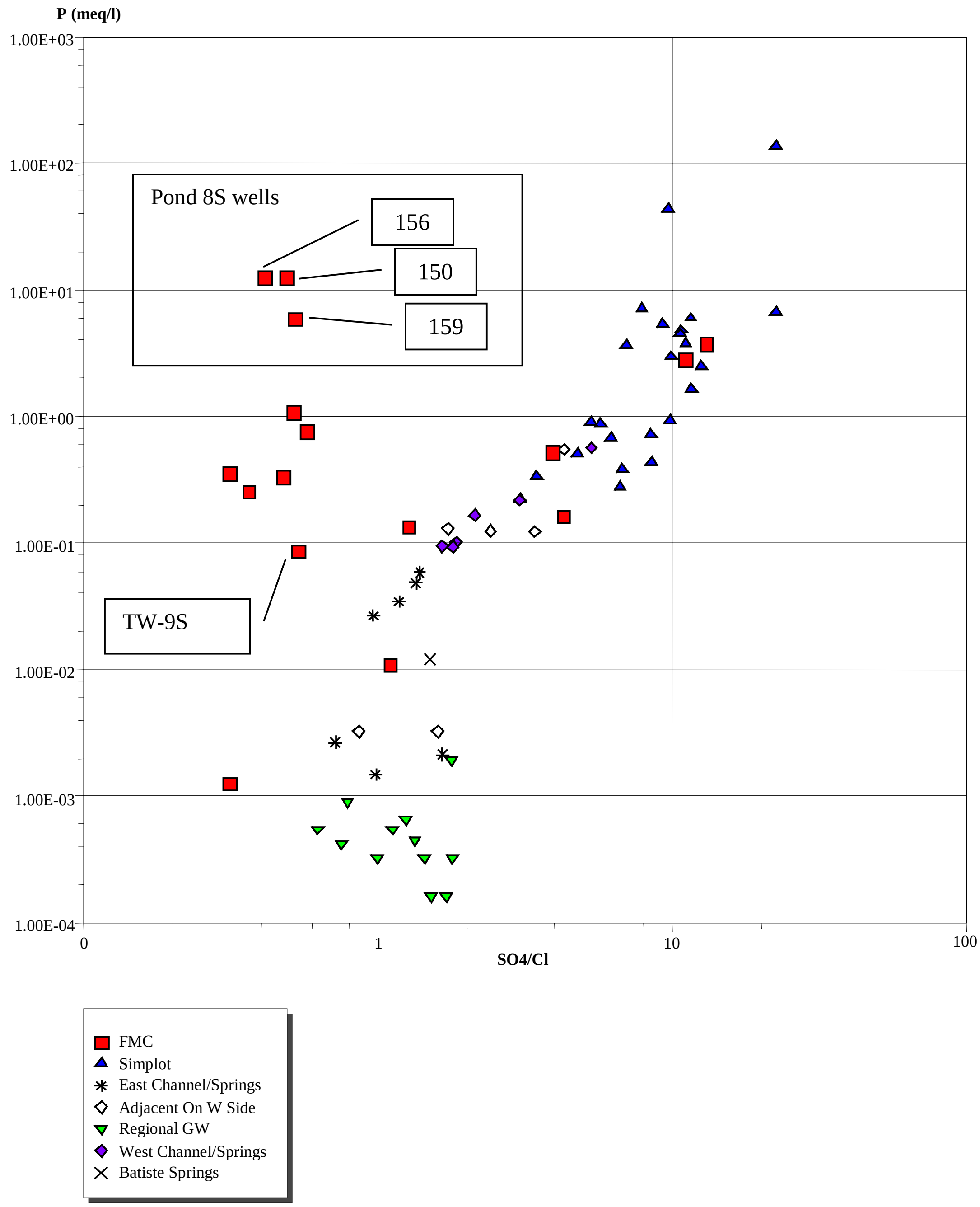


Figure 28. Orthophosphate concentration vs. sulfate/chloride ratio in water from Portneuf River, springs, and selected wells on FMC and Simplot facilities.

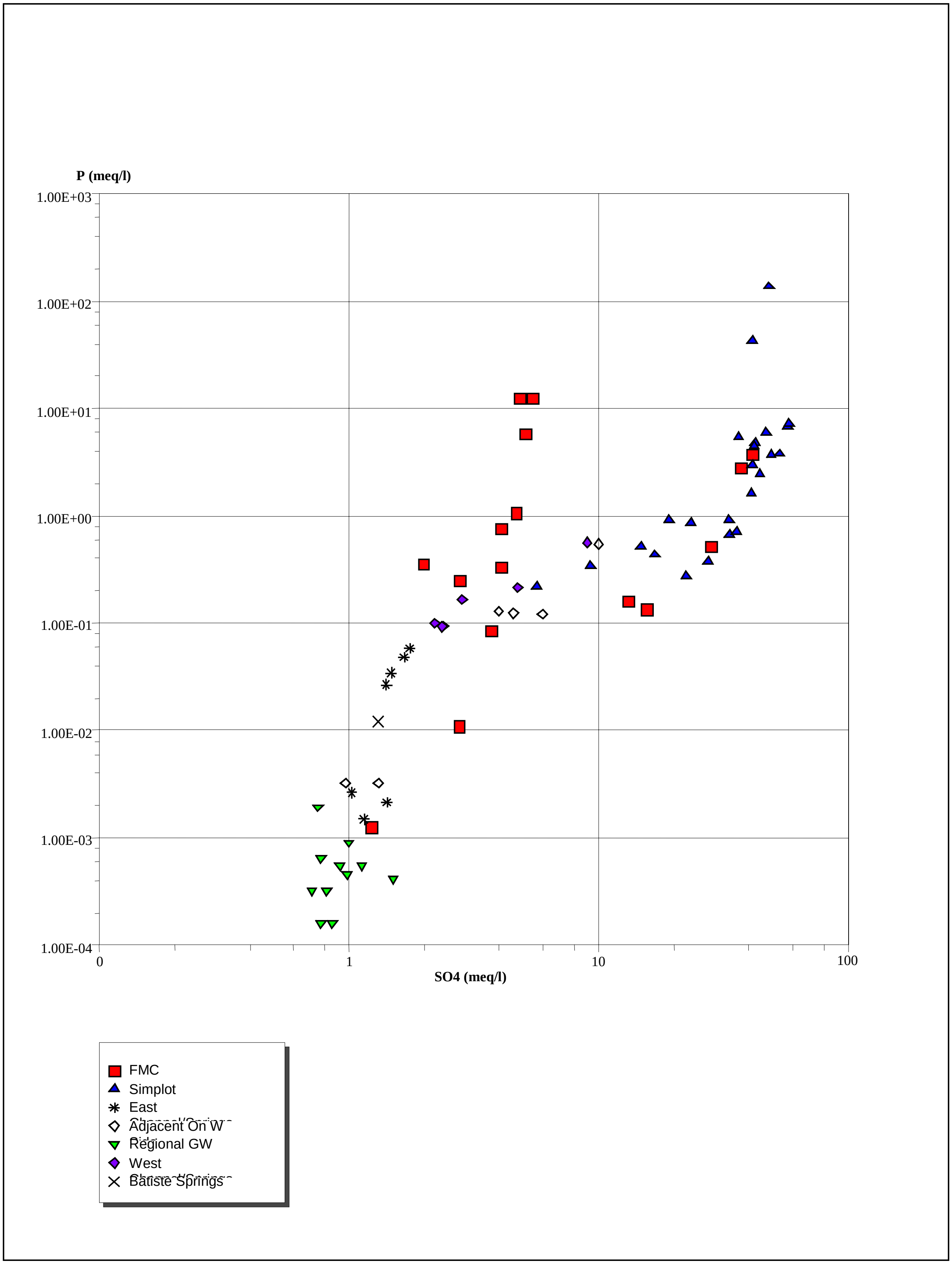


Figure 29. Orthophosphate vs. sulfate concentration in water from Portneuf River, springs, and selected wells on FMC and Simplot facilities.

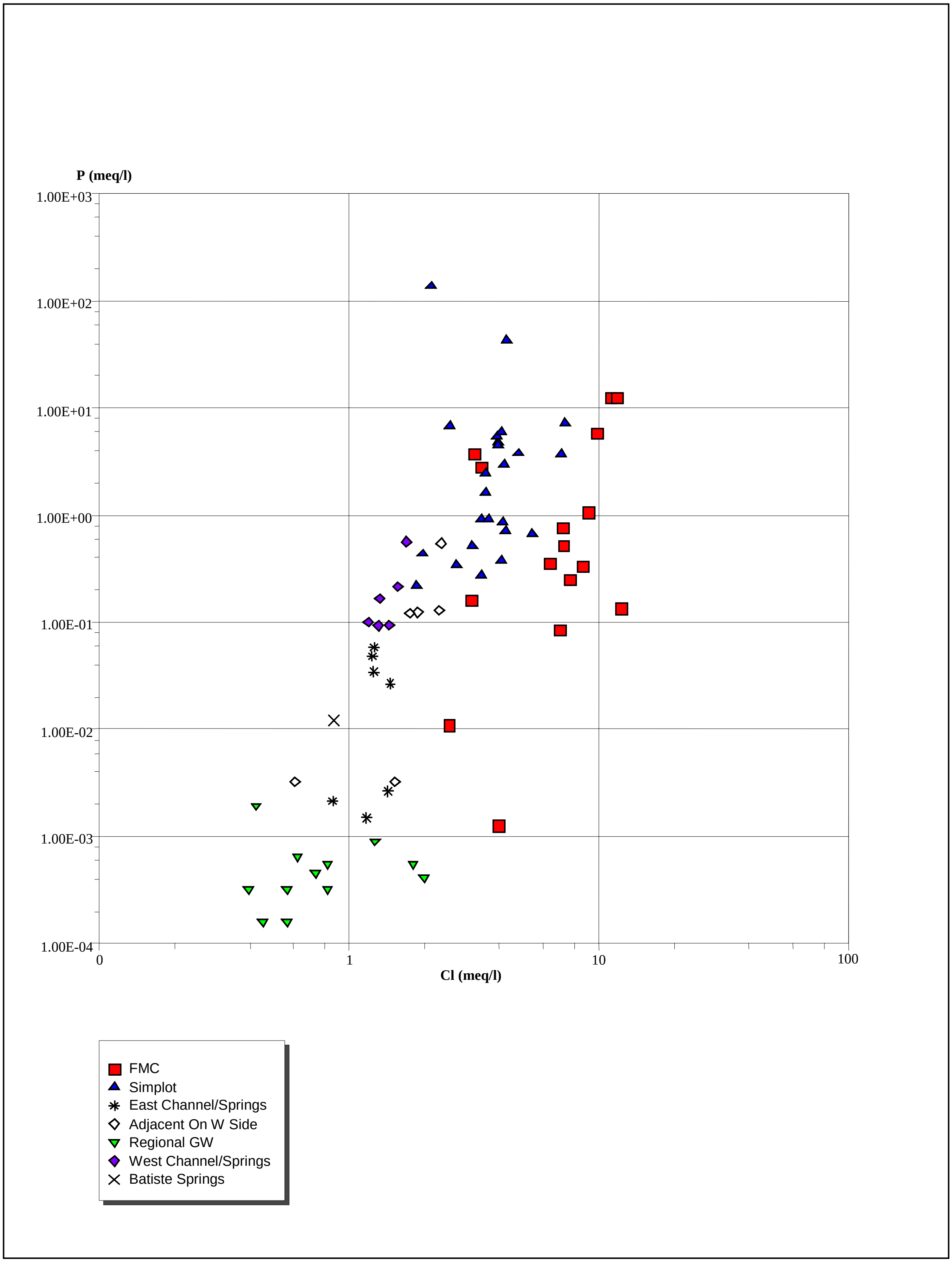
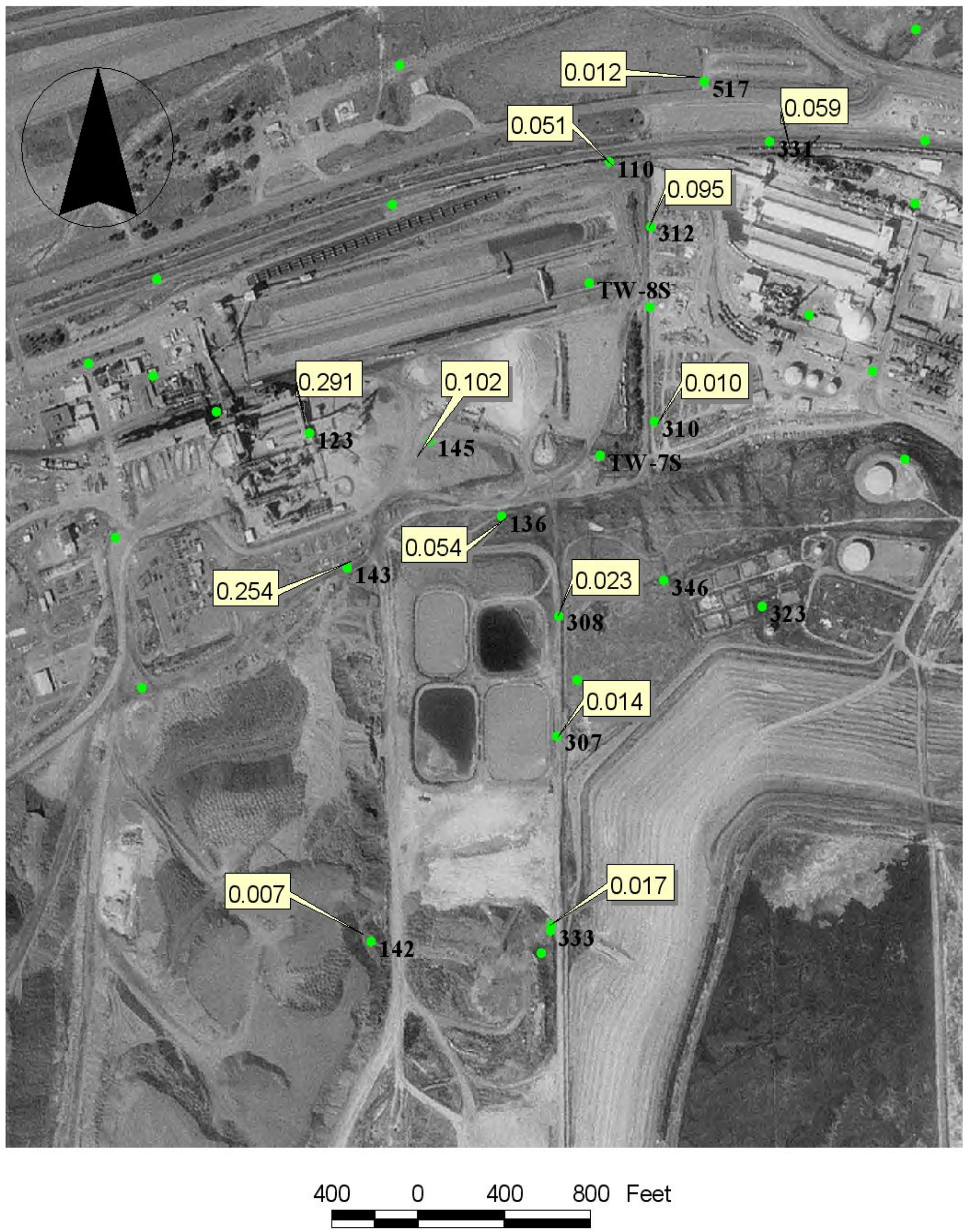
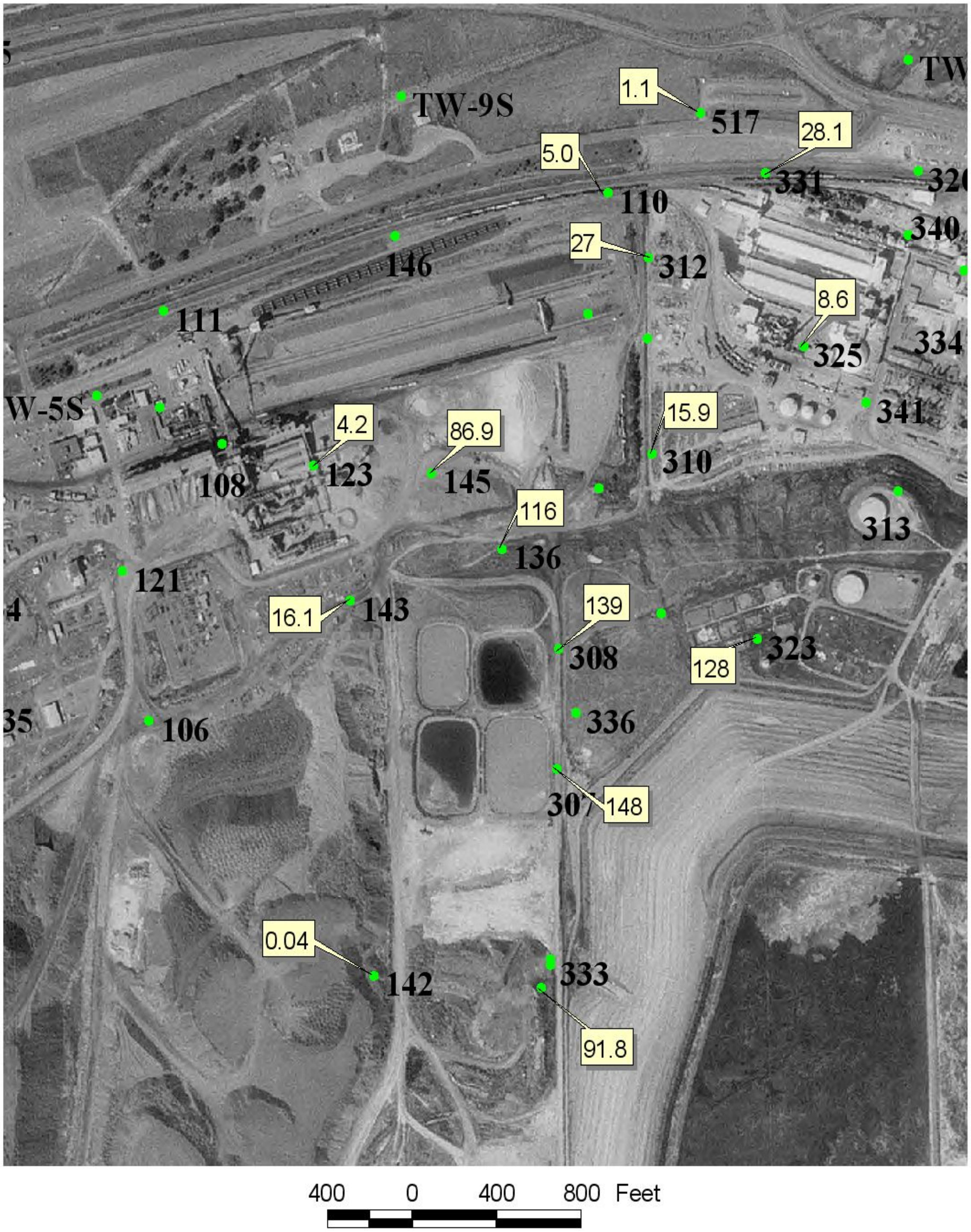


Figure 30. Orthophosphate vs. chloride concentration in water from Portneuf River, springs, and selected wells on FMC and Simplot facilities.



Note: Selenium Concentrations are taken from 12/1993 and are expressed as mg/l.

Figure 31. Selenium concentration in ground water in the Joint Fenceline area.



Note: Orthophosphate Concentrations are taken from 12/1993 and are expressed as mg/l.

Figure 32. Orthophosphate concentration in ground water in the Joint Fenceline area.

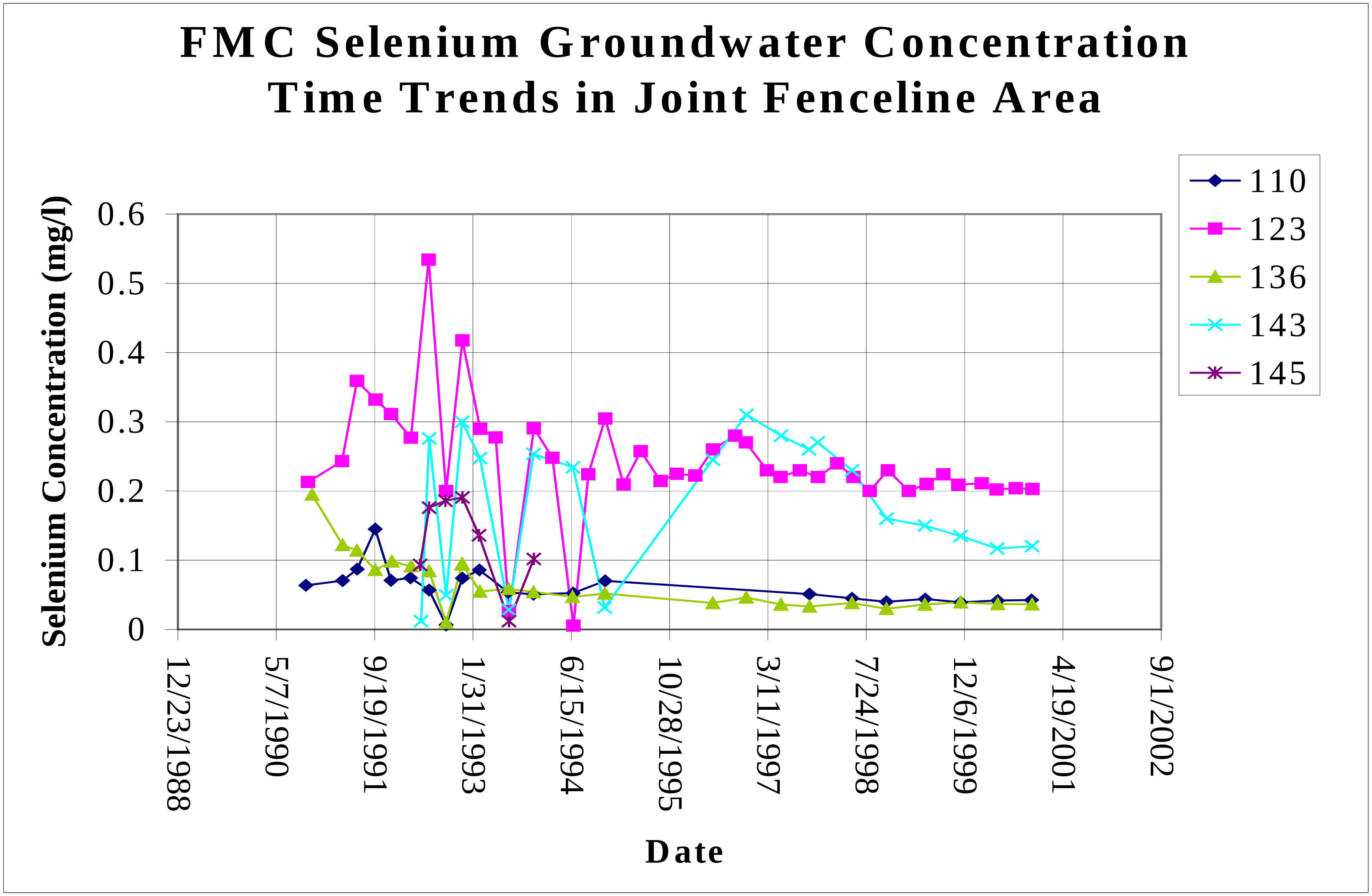
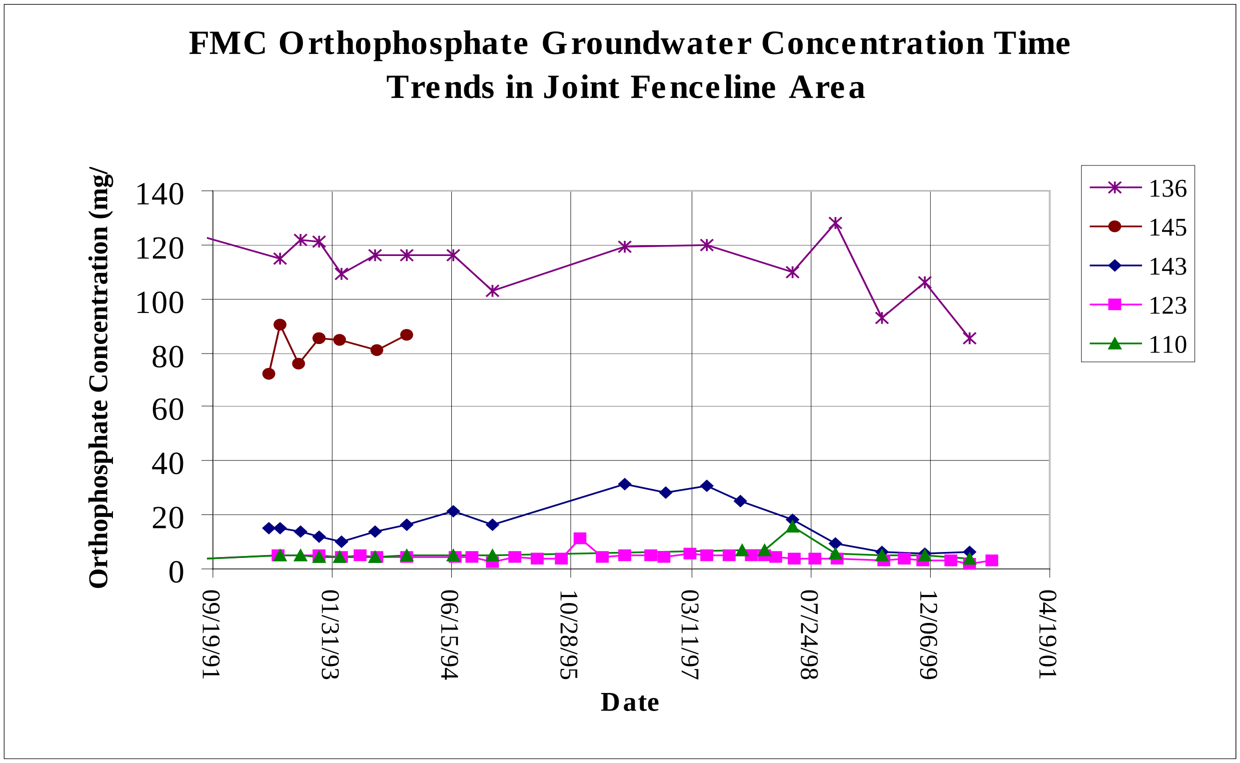


Figure 33. Selenium Concentration Time Trends in Groundwater from Selected FMC Wells in the Joint Fenceline Area.



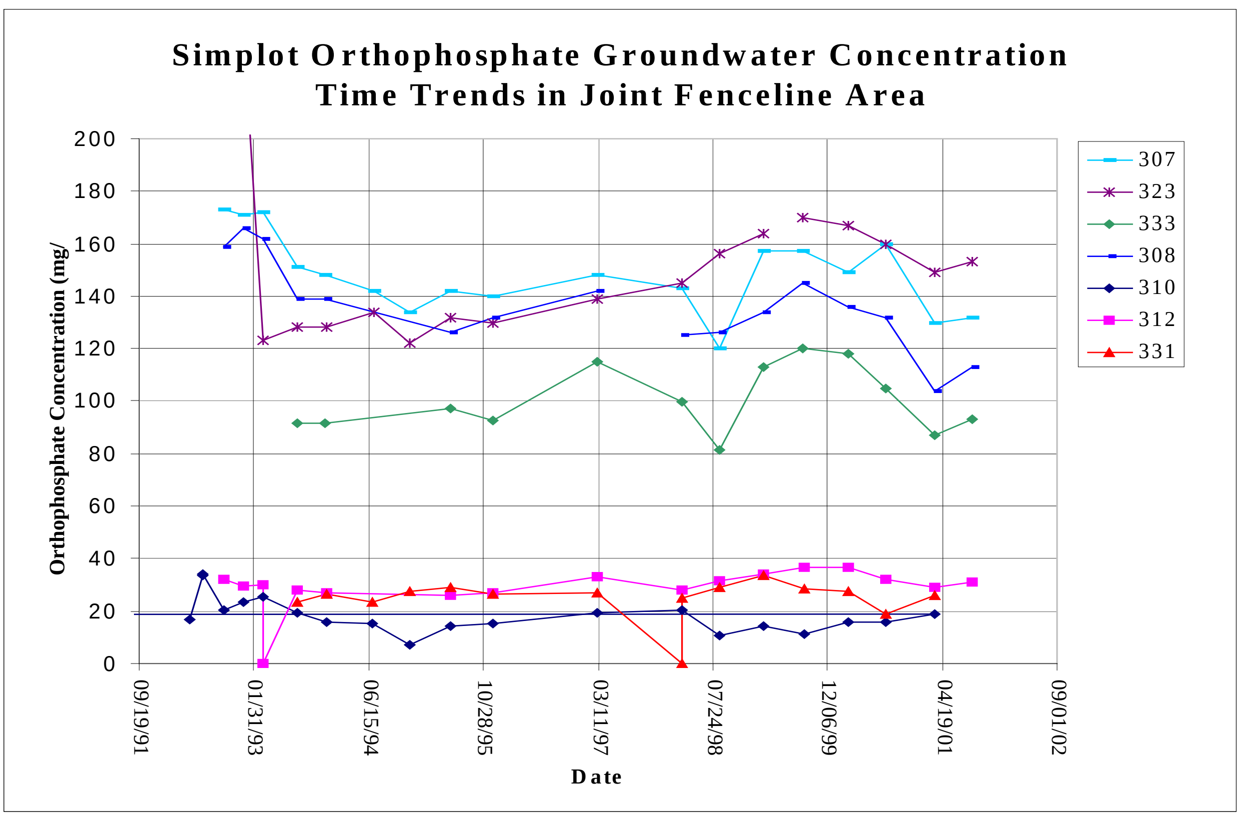
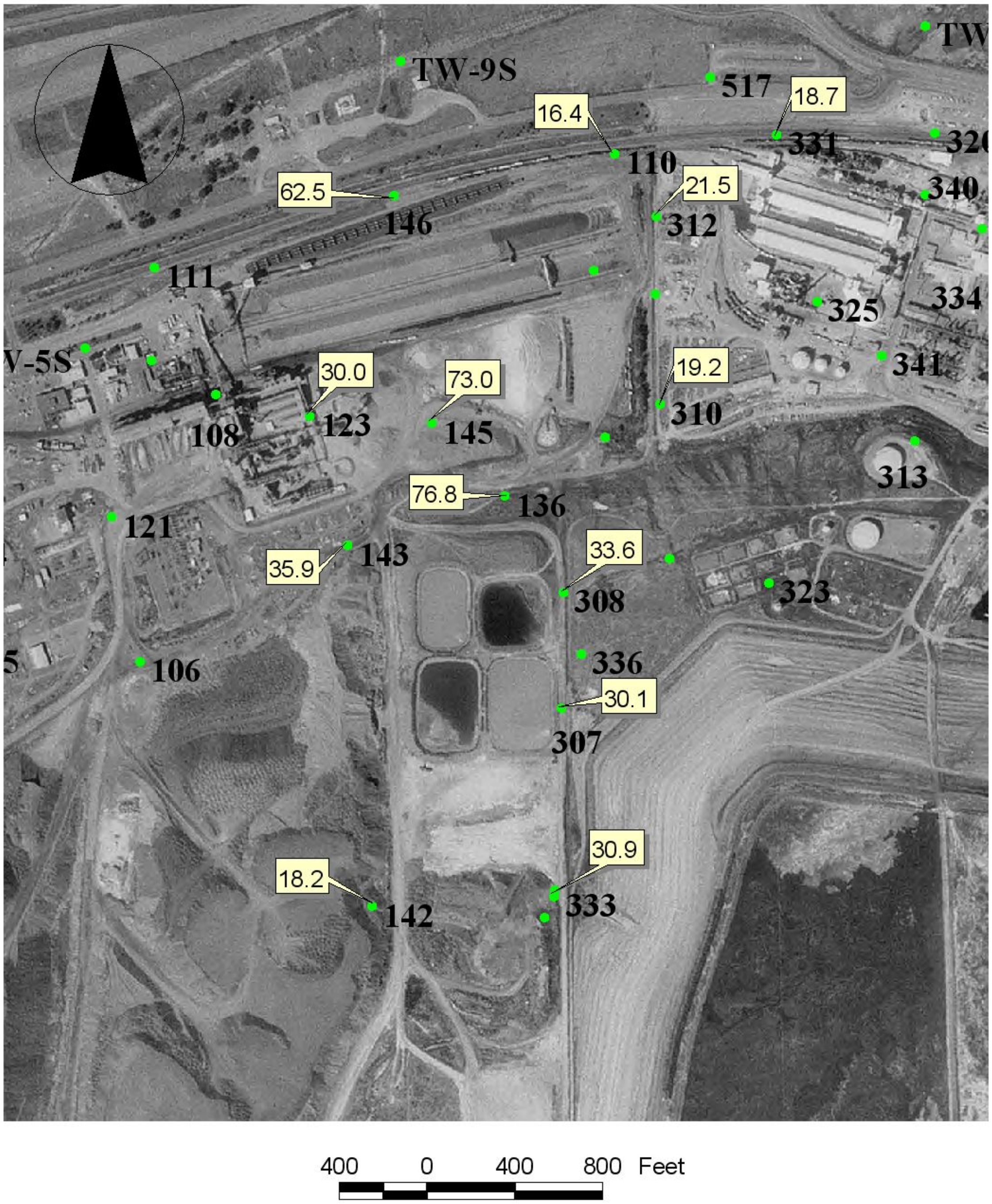
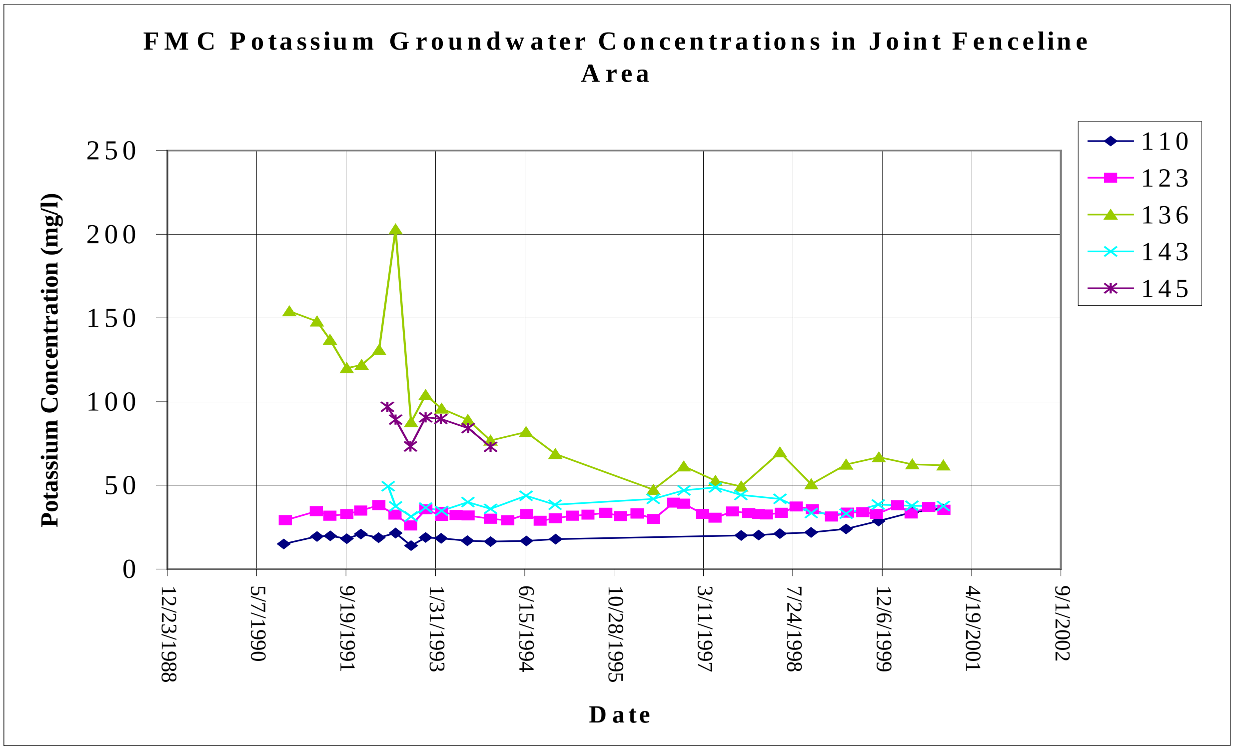


Figure 34. Orthophosphate concentration time trends in ground water from selected FMC and Simplot wells in the Joint Fenceline area.



Note: Potassium Concentrations are taken from 12/1993 and are expressed as mg/l.

Figure 35. Potassium concentration in ground water in the Joint Fenceline area.



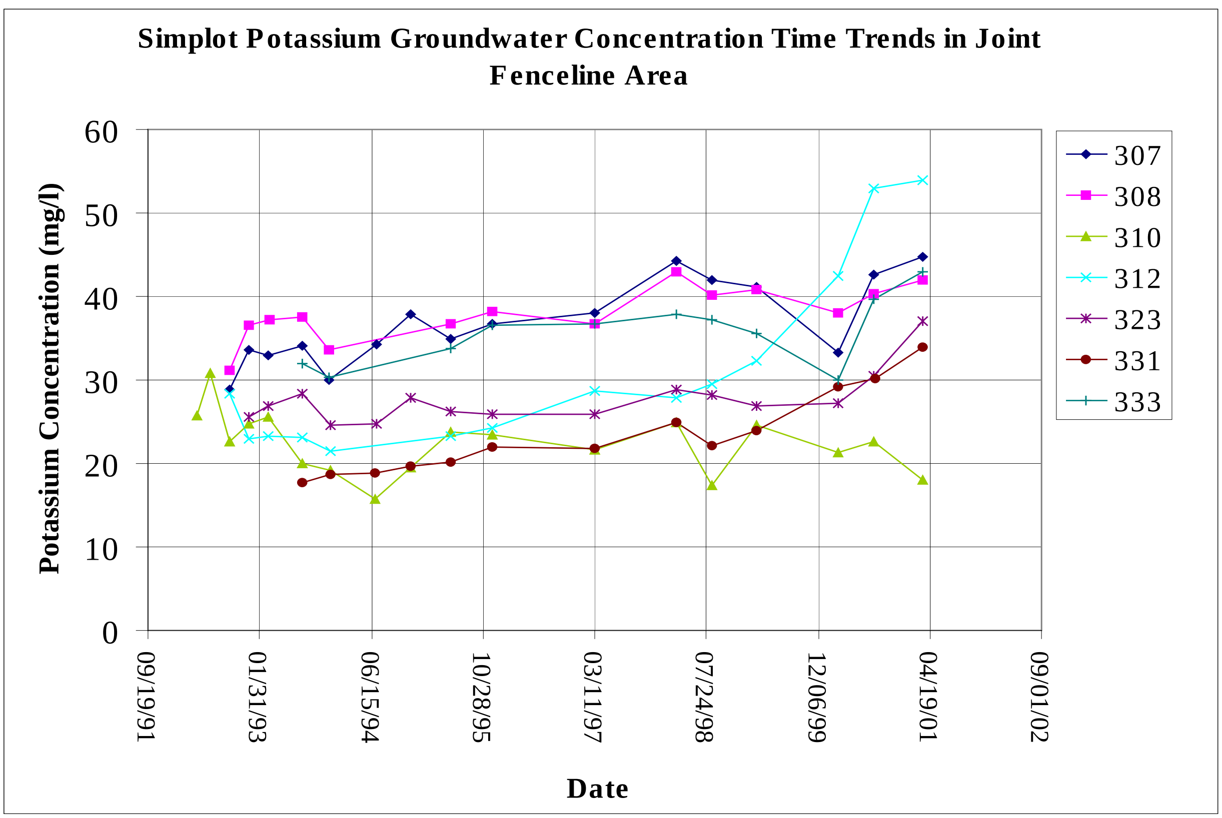
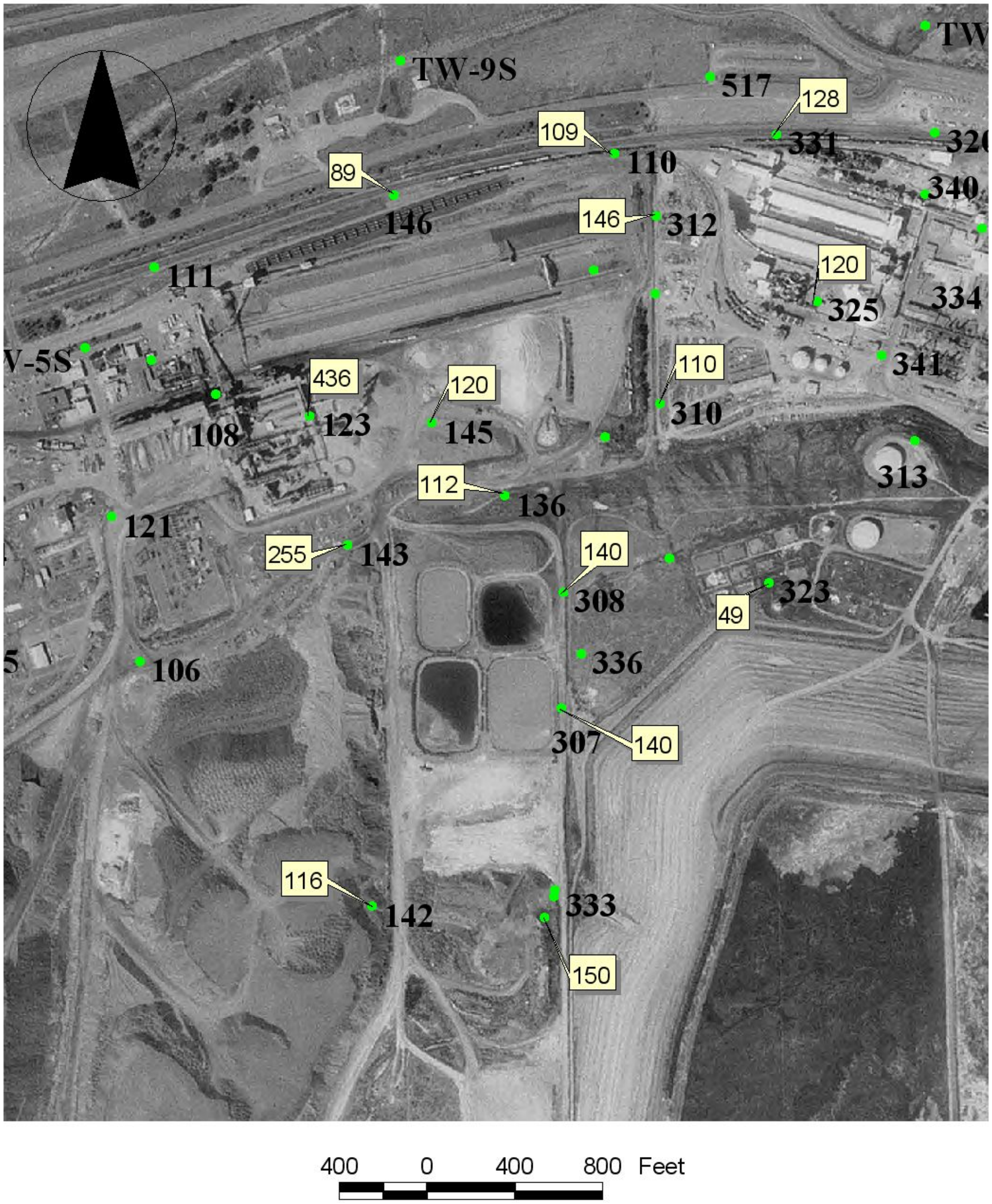
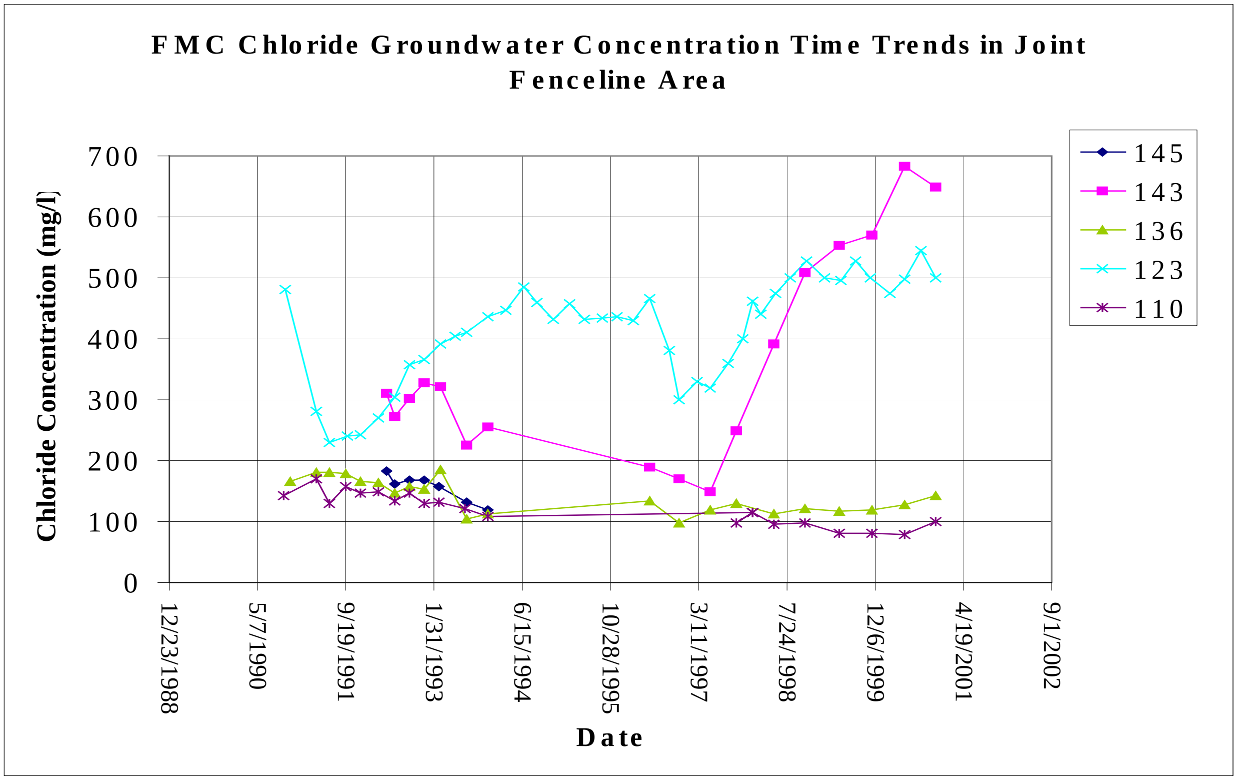


Figure 36. Potassium concentration time trends in ground water from selected FMC and Simplot wells in the Joint Fenceline area.



Note: Chloride Concentrations are taken from 12/1993 and are expressed as mg/l.

Figure 37. Chloride concentration in ground water in the Joint Fenceline area.



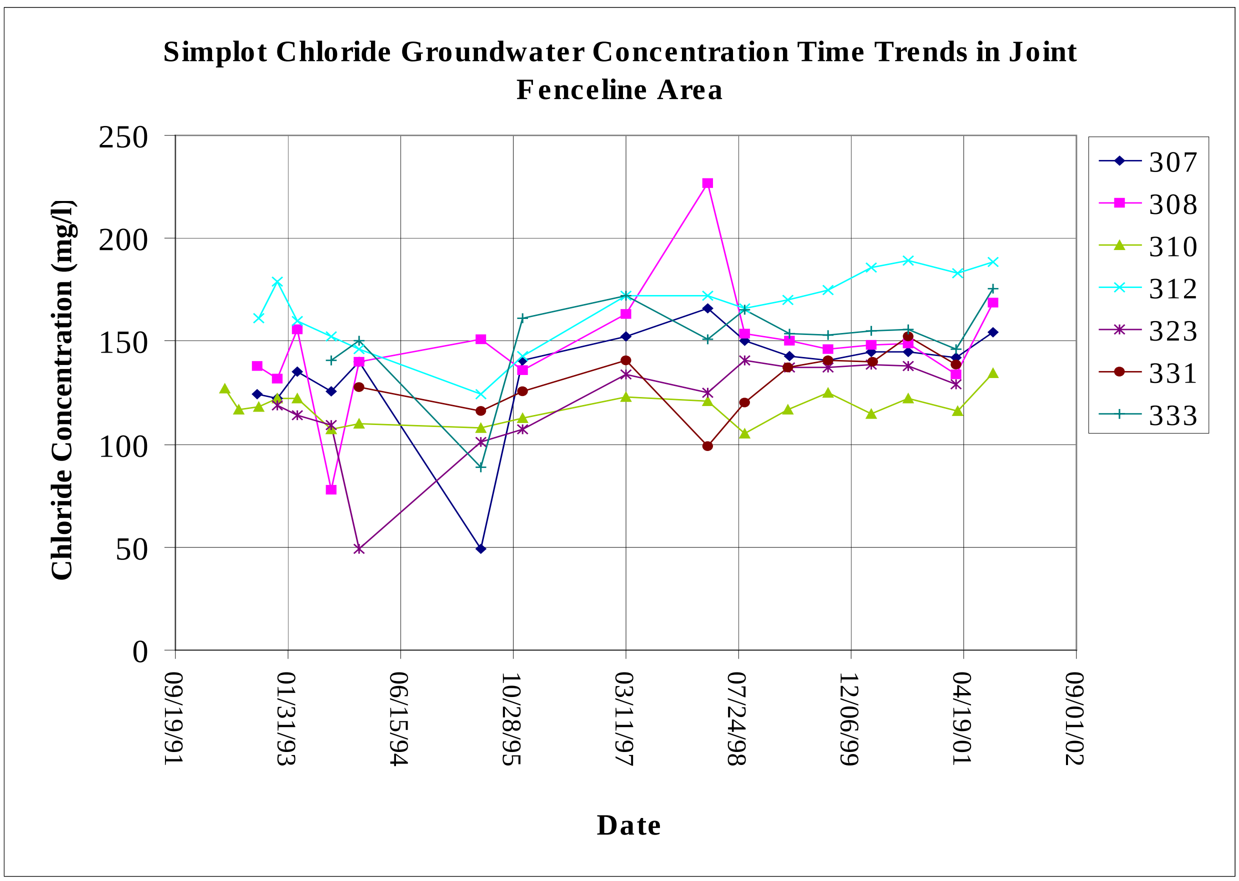


Figure 38. Potassium concentration time trends in ground water from selected FMC and Simplot wells in the Joint Fenceline area.

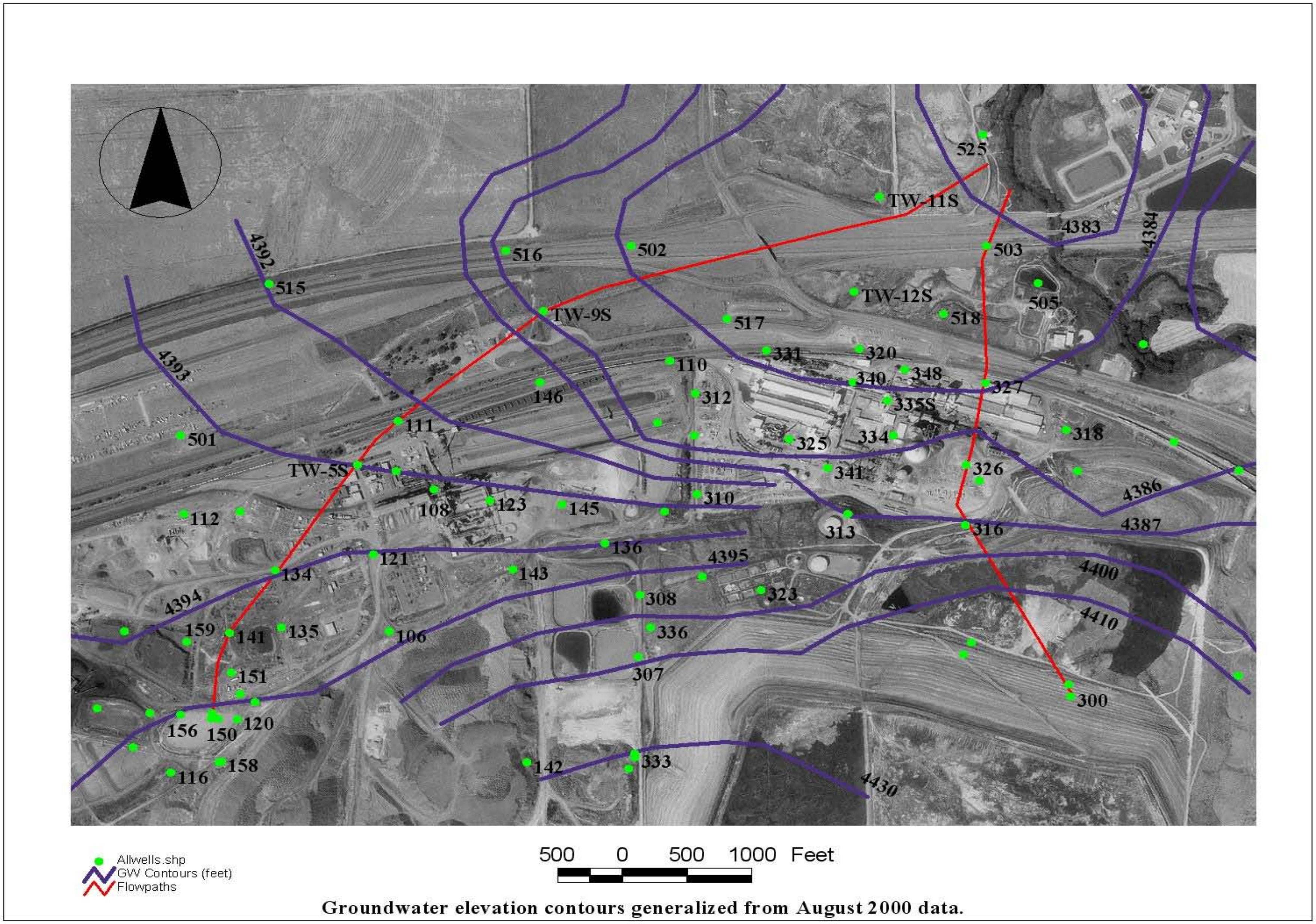


Figure 39. Monitoring wells, generalized shallow ground water contours, and locations of example flowpaths.

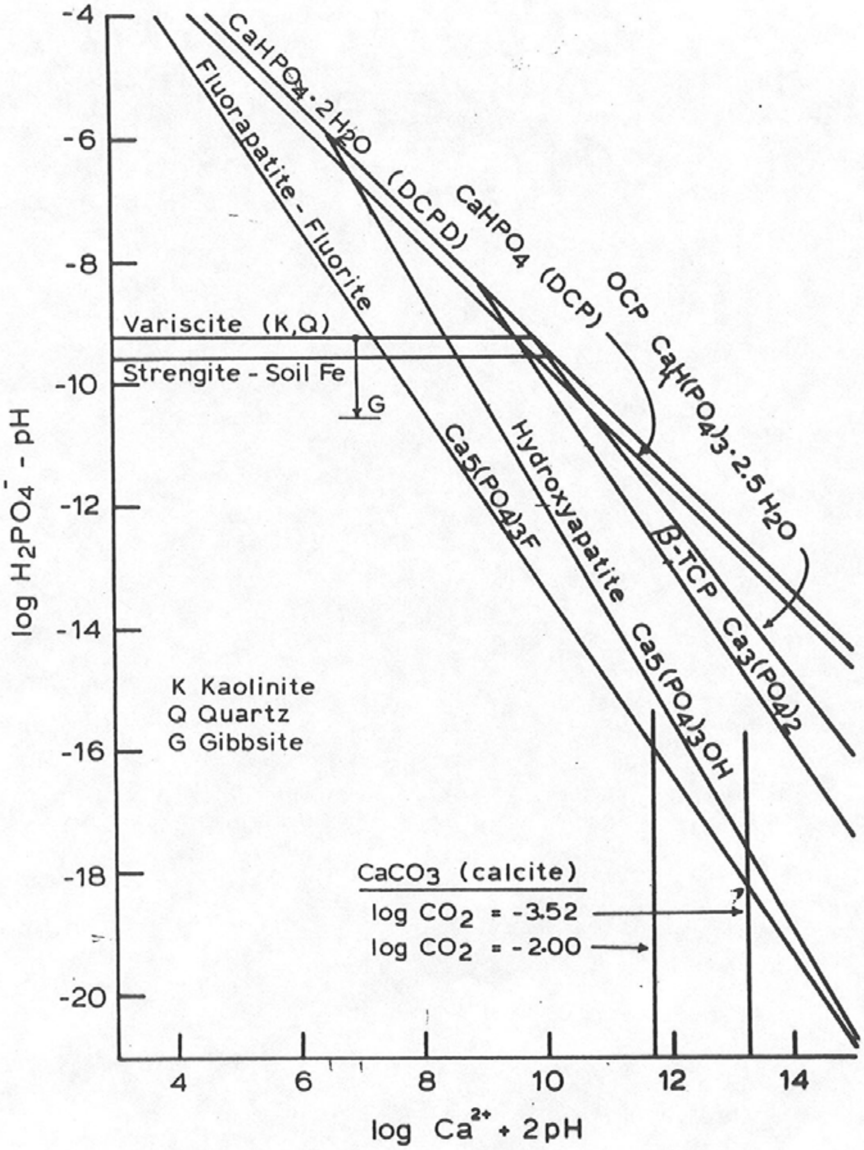


Fig. 12.9 The solubility of calcium, iron, and aluminum phosphates showing limits imposed by calcite and CO_2(g).

Figure 40. Solubility diagram of calcium phosphate minerals. Reproduction of Figure 12.9 from Lindsay (1979).

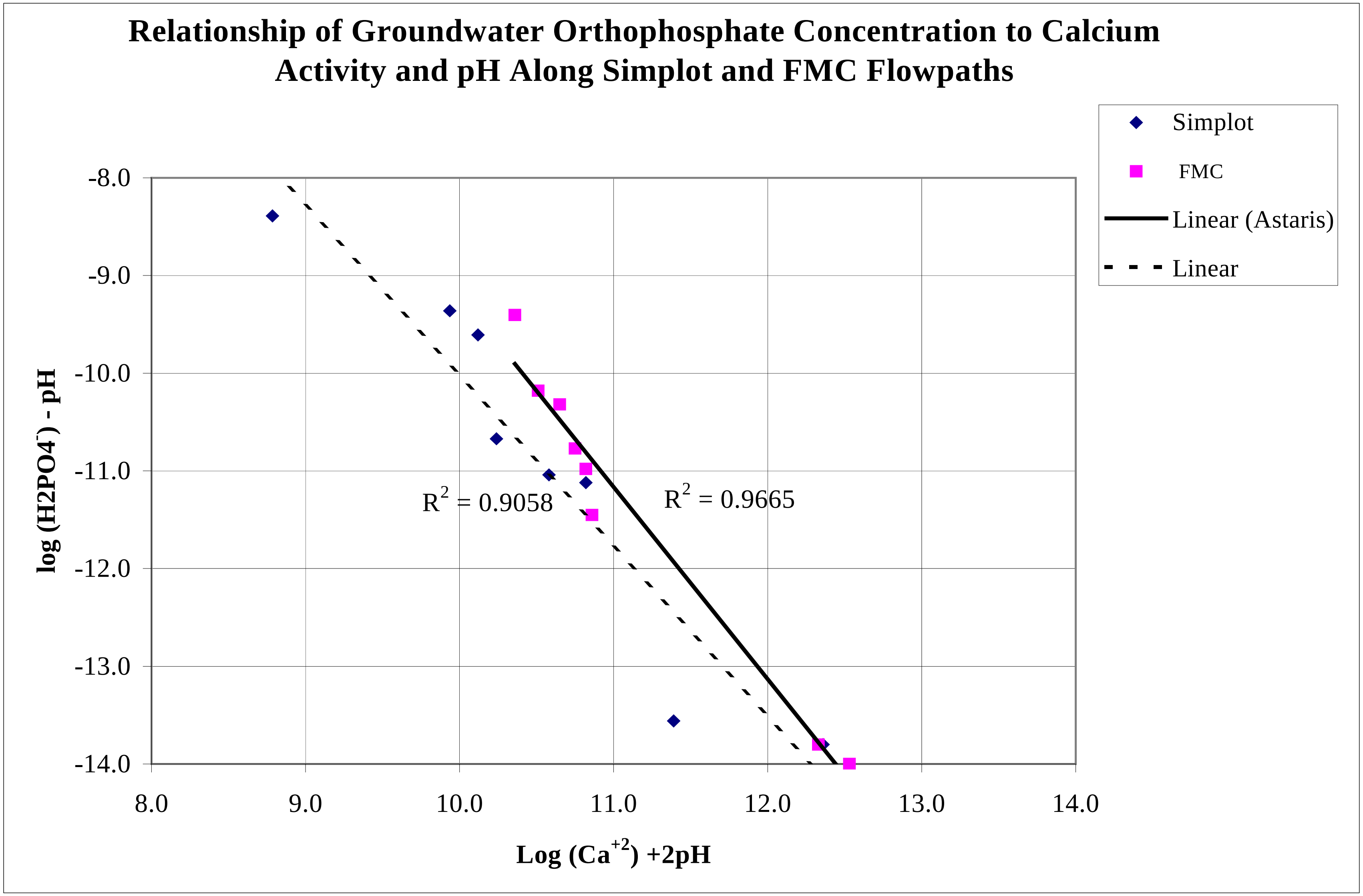
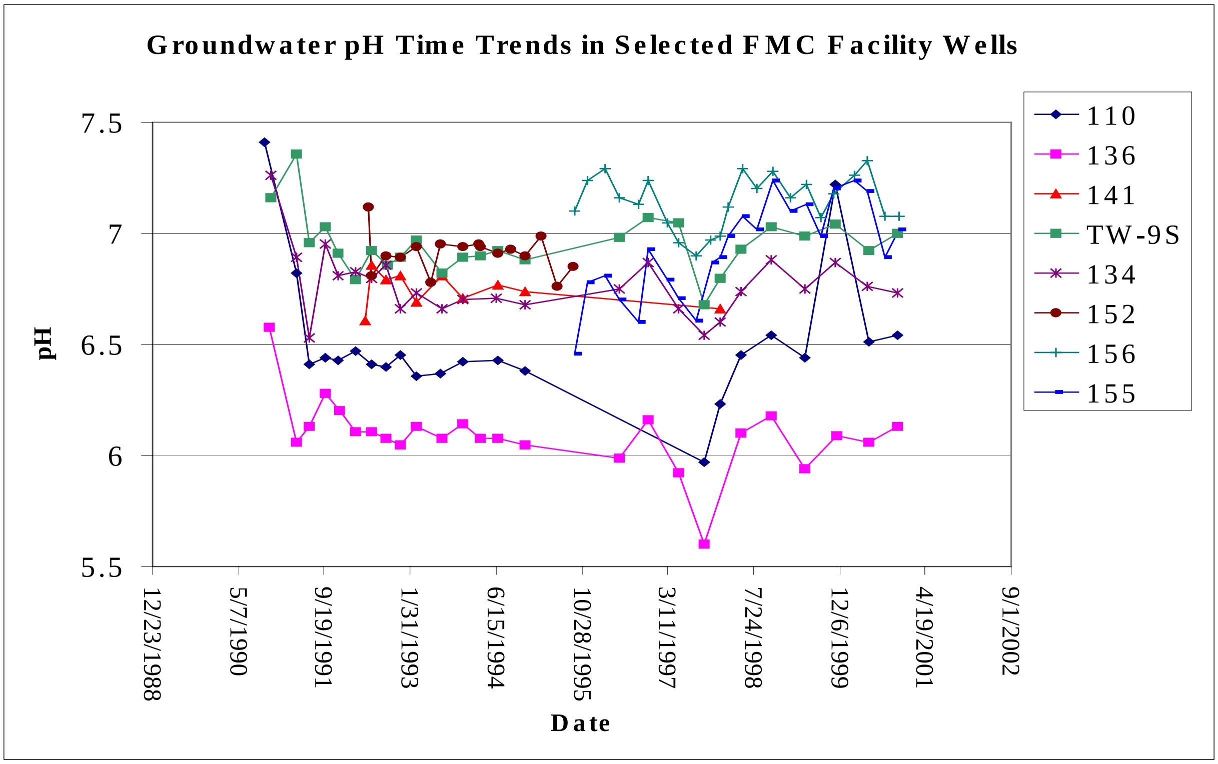


Figure 41. Relationship of groundwater orthophosphate concentration to calcium activity and pH along simplot and FMC flowpaths.



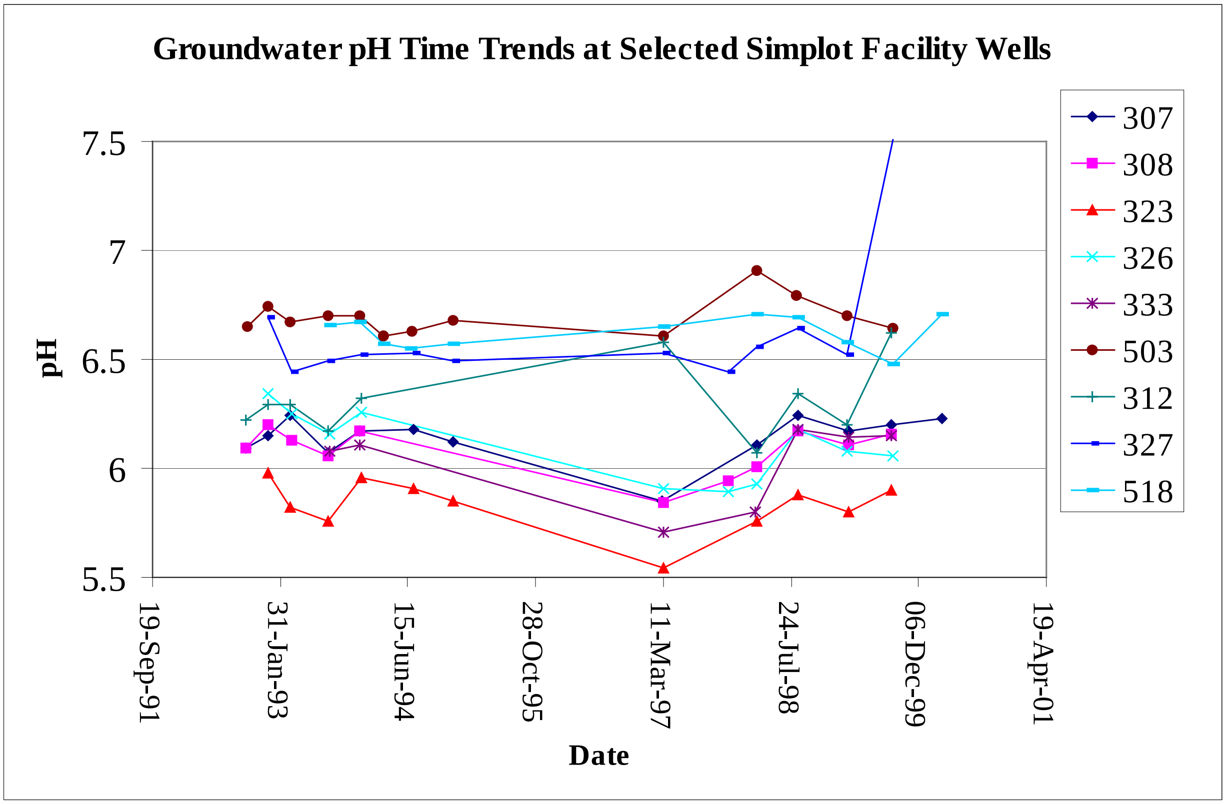


Figure 42. Groundwater pH time trends in selected FMC and Simplot facility wells.