GEOLOGIC INFLUENCES ON SALINITY IN THE SOUTH PLATTE RIVER BASIN

Prepared for:

Colorado Water Conservation Board

Prepared by:

NEIRBO Hydrogeology
316 W Olive Street
Fort Collins, Colorado 80521

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Grady O'Brien
Owner/Principal
NEIRBO HYDROGEOLOGY

EXECUTIVE SUMMARY

Salinity is a concern for irrigated agriculture and municipal water supplies. Emerging evidence reveals that Colorado's South Platte River Basin, like many other intensively irrigated agricultural regions worldwide, suffers from salinization. Salinity can decrease crop yields, decrease crop diversity, and if not managed it can lead to the loss of agricultural cropland. Municipalities are also challenged to find suitable water supplies for growing populations. Costly water treatment and conveyance can be required to provide new or expanded potable water sources to communities.

This study is a follow-up to the 2020 report that investigated salinity trends in the South Platte River (Neirbo, 2020). Salinity was found to be gradually increasing from 1995 to 2018, particularly along the Colorado Front Range. Trends in the lower basin were less clear due to the paucity of data, both spatially and temporally.

There are many salt sources that can contribute to salinity. Anthropogenic sources include wastewater effluent, irrigated agriculture, livestock, road de-icing salts, urban runoff, oil and gas produced water, and industrial sources. Geologic formations and their derived soils are natural sources of minerals that contribute to groundwater and surface-water quality. This study investigated the South Platte Basin geology as a potential salinity source.

Hyporheic zone groundwater and surface water samples were collected from the South Platte River and the Saint Vrain, Big Thompson, and Cache la Poudre tributaries (Figure ES-1). The South Platte River was sampled from Denver to Julesburg. The tributaries were sampled from where the rivers exited the mountains to their confluences with the South Platte. Samples were collected during the 2021 irrigation season (August) and prior to spring runoff in March-April 2022. The suite of analyses included the major ions, total dissolved solids, and several trace elements (boron, barium, bromide, iron, manganese, selenium, and uranium).

After exiting the mountains, the South Platte River flows along the western edge of the Denver Basin, which is a bowl-shaped geologic structural syncline. There are four principal bedrock aquifers, the Laramie-Fox Hills, Arapahoe, Denver, and Dawson, have generally good water quality and do not contribute significantly to salinity. The exception may be the Laramie-Fox Hills aquifer that consists of the Laramie Formation, Fox Hills Sandstone, and upper Pierre shale. Further downstream near, the White River formation and the Ogallala formation outcrop from Hillrose to past Julesburg and they tend to have good water quality.

The South Platte River streambed alluvium overlies the bedrock formations and forms the alluvial aquifer. Groundwater flows through the alluvial aquifer and supplies water to the South Platte River. This groundwater occurs largely due to irrigation water infiltrating through agricultural soils to the water table where it flows laterally to the river.

The South Platte has a sodium-chloride type water in the Denver metro area, likely due to the influence of wastewater effluent (Figure ES-2). The bedrock aquifers in this area have calcium bicarbonate and sodium bicarbonate water and have a lesser influence on water quality. The South Platte water evolves into a mixed calcium-sodium sulfate type water as it flows downstream. The tributaries changed from calcium bicarbonate to mixed calcium-sodium sulfate water with downstream distance (Figure ES-3).

Salinity (i.e. Total Dissolved Solids) in the South Platte was about 700 mg/l as the river exited the Denver metro area and it steadily increased downstream to about 1,440 mg/l near Julesburg (Figure ES-4). These concentrations require treatment to be used as drinking water or industrial water. Irrigated agriculture can experience reduced crop yields, soil salination, and loss of crop diversity. An instantaneous South Platte River total salt load of 1,000 tons per day was calculated from the streamflow and TDS concentration near Kersey. This river reach had a salt load of 448,500 tons per year in 2018 and a long-term average of 636,600 tons per year (Neirbo, 2020).

The major tributaries flow out of the mountains, across the Pierre shale, and through Front Range cities before joining the South Platte. The dissolution of gypsum and thenardite in the Pierre shale are suspected to contribute salinity in the form of sulfate, calcium, and sodium (Figure ES-5). The sulfate percentage of TDS increased from 10-20-percent to about 60-percent in each of the rivers sampled. Sulfate concentrations increased from less than 100 mg/l to as high as 780 mg/l along the Cache la Poudre River as it flowed through the Pierre shale. The South Platte River flows across the Pierre shale in the lower basin and it had sulfate concentrations as high as 800 mg/l. Groundwater typically had higher TDS and sulfate concentrations than surface water.

The sulfate, calcium, and sodium increases in the South Platte and the tributaries were too large to be solely due to dissolution of gypsum and thenardite in the Pierre shale. Each of these rivers also flow through irrigated agriculture areas. Soil amendments and fertilizers used for agricultural purposes are potential sources that could account for these higher-than-expected concentrations.

Trace elements, boron, barium, bromide, and selenium were generally found in low concentrations. However, eight manganese samples were 1-3 mg/l, which exceeded the 0.05 mg/L secondary drinking water standard.

There were several samples that exceeded the iron secondary drinking water standard of 0.3 mg/L. During the irrigation season (August) 15 samples exceeded the standard with 13 groundwater samples exceeding during the spring. These samples were generally collected in areas with the Pierre shale, Fox Hills, and Laramie formations.

Uranium concentrations gradually increase downstream and start to exceed the drinking water standard of 30 µg/l in the reach between Weldona and Snyder, where Bijou and Beaver Creeks join the South Platte River. South Platte River uranium concentrations continue to increase downstream reaching a maximum of about 55 µg/l near Julesburg. The gradual uranium concentration increase suggests that the geologic formations are a non-point source.

This study has found evidence that the South Platte Basin geology plays a significant role in the basin’s water quality. Geologic units are a far reaching, non-point source of salts and trace elements that create a water-quality baseline upon which other sources are added. Wastewater and runoff in the Denver metro area and Front Range cities contribute to salinity.

Irrigated agriculture in the tributaries and lower basin also impact water quality. Agricultural return flows dominate the hydrologic system. These return flows contribute to streamflow and transport chemicals leached from farmland soils into the underlying groundwater. The expansive network of ditches, recharge basins, and reservoirs also play a role in the basin’s water quality. Interactions between geology, irrigated agriculture, water storage, and water conveyance add to the hydrologic-system complexity.

Parsing the salinity contributions or loading due to geology, wastewater, irrigated agriculture, livestock, urban runoff, and industrial sources will require many years of detailed study. It is safe to say that each of these sources plays a role in the basin's salinization and overall water quality. There are mitigating measures that can be implemented today to reduce the impact of each of these sources. It will require commitment and resources from all the basin's water users to improve the basin's water quality.

Figure ES-1. South Platte Basin geology, irrigated lands, and sampling locations

Figure ES-2. Downstream changes in South Platte River major ions

Figure ES-3. Major ions in the South Platte River and major tributaries

Figure ES-4. Total dissolved solids concentrations in the South Platte River and tributaries with downstream distance

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1. INTRODUCTION

The South Platte River and its major tributaries have headwaters in the Rocky Mountains. The South Platte River flows out of the mountains, through the Denver metropolitan area, along the northern Front Range, through urban communities, rural agricultural areas, and east to the Nebraska state line. The South Platte Basin's (Basin) water is used and reused many times along this path to support municipal and industrial water supplies, irrigated agriculture, livestock, and ecological systems.

Salinity has been investigated since the development of irrigated agriculture in the Basin. Salinity studies in the past 20 years have been completed by Northern Water (2002, 2005, 2009); Flynn (2003), Haby and Loftis (2004), Otton and others (2005), Haby (2011), Bauder and others (2014), Neirbo (2020), and Hocking (2021). Earlier water-quality studies included Code (1943), Bjorklund and Brown (1957), Boberg and Runnells (1971), Robson (1987), Dennehy and others (1998), and Litke and Kimbrough (1998). These studies have presented surface water and groundwater salinity data, including Total Dissolved Solids (TDS), Electrical Conductivity (EC_w), salt loading, trends, and water chemistry.

This study has collected surface water and hyporheic-zone water-quality data to investigate the role of natural, geologic salinity sources in the Basin (Figure 1-1). As water flows over and through geologic formations and soil it leaches elements that contribute to salinity. This geology based, non-point source salinity contribution creates the background or baseline salinity upon which anthropogenic salinity sources are added. There are many salinity sources in addition to geologic units and distinguishing the contributions and location of these sources is challenging.

Figure 1-1. The South Platte Basin and major rivers

This report presents supporting background information and water-quality sampling results. The study methodology, including sampling and analyses are presented. The geologic and hydrologic settings are discussed to provide context for the results. Historical water-quality reports were reviewed and summarized as a reference and context for current findings. Previous work assisted the interpretation of water-quality data collected for this study.

Tabular information and figures, including maps, graphs, and diagrams are provided at the end of the report text. Laboratory water-quality analyses are provided as appendices.

2. STUDY METHODS

This study collected surface water and hyporheic-zone groundwater samples during two hydrologic seasons. Sampling sites were along the South Platte River and tributaries, including Saint Vrain Creek, Big Thompson River, and the Cache la Poudre River. The water-sampling events were during the irrigation season (August 9-25, 2021) and before the start of irrigation season and spring runoff (March 14 to April 7, 2022). A pre-runoff sampling event was also attempted in April 2021. However, sampling was aborted after three days when river stages rose dramatically due to spring runoff caused by warm temperatures and rapid snow melt.

The sampling sites were selected based on geologic formation contacts, river and drainage confluences, near wastewater treatment plants, along the South Platte River, and at lower basin drainages (Figure 2-1). The sampling was completed over short periods with similar streamflow conditions along each river.

In most cases, the sampling sites were the same for both sampling events. However, tributary sites were added to improve coverage in the April 2022 event. Other sites had to be slightly altered due to access or streambed conditions that were unfavorable to hyporheic-zone sampling.

Figure 2-1. Water-quality sampling sites

Hyporheic zone groundwater samples were a scoping-level method for identifying the influence of the underlying geologic units on water quality. The hyporheic zone is the saturated sediment layer immediately beneath and beside the active stream or river channel (Figure 2-2). Groundwater can enter the stream through the hyporheic zone and stream flow can be lost to the groundwater system through this zone. These dynamics can result in shallow groundwater and surface water mixing as hydraulic gradients change from gaining to losing conditions (Figure 2-3).

Figure 2-2. Hyporheic zone groundwaterflow (Hayashi and Donald Rosenberry, 2017)

Figure 2-3. Pierre shale and alluvial aquifer interaction with (A) gaining and (B) losing stream condition measured by mini-piezometer

In most cases, groundwater and surface-water samples were collected at each site. At some sites, only a surface-water sample was collected. The groundwater samples were collected using a temporary "mini-piezometer." A 1-inch diameter pipe was hand driven into the streambed to a depth of about 3 feet. Tygon tubing with a 6-inch sediment filter screen on the bottom was inserted into the pipe. The pipe was removed, leaving the tubing in the streambed. Water would fill the piezometer tubing and the water level was compared to the stream stage. An upward hydraulic gradient or gaining stream conditions, when groundwater flows from the hyporheic zone into the stream, was indicated when the piezometer water level was higher than the stream stage. Conversely, losing stream conditions were indicated when the piezometer water level was lower than the stream stage.

Hyporheic zone groundwater samples were collected using a peristaltic pump to withdraw water from the piezometer. Low pumping rates indicated that the piezometers were within low permeability sediments and the piezometer was isolated from the streamflow. The piezometer tubing was removed at the end of sampling.

The surface water was collected as grab samples while wading or from bridges. Field parameters (temperature, pH, specific conductance, TDS, dissolved oxygen, oxidation-reduction potential, and turbidity) were obtained for all samples. Samples were collected, preserved, filtered, chilled, and shipped as required by the specific analytical laboratory analysis. The laboratory parameter analysis list is provided as Table 2-1.

Table 2-1. Water-quality laboratory analyses

Groundwater is in contact with rocks and soils much longer than surface water, so there is more time for minerals to leach out of the subsurface materials. As a result, groundwater concentrations tend to be higher than surface water concentrations. The influx of precipitation runoff, effluent, and irrigation canal return flow can also dilute or decrease surface-water concentrations. Gaining stream conditions were also indicated when groundwater concentrations were greater than surface-water concentrations. The South Platte River and the tributaries tend to be gaining streams. Direct streamflow measurements that would confirm gaining or losing conditions, were beyond the scope of this study.

Total dissolved solids (TDS) is the sum of all the major dissolved constituents in water and was directly measured by evaporating a sample of water and weighing the residue. Dissolved-solids concentrations are directly related to specific conductance because dissolved solids in the ionic form cause increased specific conductance. Standard conversion factors can be used to convert specific conductance to an approximate TDS (Table 2-2).

Table 2-2. Salinity measurement units and conversion factors for water-quality analyses

3. GEOLOGIC SETTING

The South Platte River flows out of the Rocky Mountain's Precambrian crystalline rocks and into the foothills of the Colorado Front Range. These Precambrian rocks are exposed in the Front Range mountains but are at depth and form the basement upon which younger sedimentary rocks were deposited in the South Platte Basin (Knepper, 2002). The younger Paleozoic to Tertiary age rocks that overlie the basement rock include sandstone, shale, siltstone, conglomerate, and limestone (). The Fountain Formation and Dakota Group form prominent sandstone hogbacks that are parallel to the mountain front at the western basin margin. A summary of the Basin's geologic units is provided in Table 3-1

Table 3-1. Generalized geologic units in the northern Front Range and Denver Basin areas

The Early Cretaceous Dakota Group was deposited as the Cretaceous Sea expanded (i.e. transgressed) into eastern Colorado (Berman and others, 1980). Overlying the western basin hogback units are Late Cretaceous marine shales and limestones with minor amounts of sandstone, that were also deposited by the Cretaceous sea (Scott, 1963; Berman and others, 1980).

The Late Cretaceous Pierre Formation (Pierre or Pierre shale), is a marine shale formed by the Cretaceous inland sea and it can be 8,000 feet thick. The Pierre is the uppermost Cretaceous shale in the Denver Basin (Scott, 1963; Weimer, 1973) This pervasive marine shale deposit is a potential salinity contributor throughout the Basin. The Pierre is considered the base of the Denver Basin aquifer system because of its low permeability and great thickness (Romero, 1976). Late

Cretaceous to Tertiary-age sandstone aquifers and intervening claystone confining units overlying the Pierre shale form the Denver Basin aquifer system (Scott, 1963, Weimer, 1973; Romero, 1976).

The Pierre shale is exposed in Morgan County and in Logan County on the north side of the South Platte River as far east as Illif (Bjorklund and Brown, 1957). The Pierre shale lacks resistant beds and erodes, for the most part, into gentle slopes, which generally are overlain by thin deposits of loess. Good exposures are found only where severe gullying has taken place or in excavations.

Oil and gas drilling indicates that the Pierre is 7,000 to 8,000 feet thick in fields south of Greeley (Higley and Cox, 2005). East of Kersey, the Pierre has been reported to be 6,500 feet thick and it thins toward the east with a thickness of about 2,500 feet along the South Platte River in western Nebraska (Bjorklund and Brown, 1957).

The Denver Basin, east of the Front Range, is a bowl-shaped, double-plunging syncline (Anderman and Ackman, 1963). The basin axis is oriented approximately north-south and parallel to the Front Range. The basin is deepest near the western margin and the Front Range sedimentary rocks dip steeply (as much as 70°) toward the basin axis (Anderman and Anderson, 1963; Nwangwu, 1977; Robson, 1987). Further east, the sedimentary rock dip flattens and is generally less than 5° toward the basin axis (Nwangwu, 1977; Tweto, 1980). On the eastern margin the Denver Basin these sedimentary rocks dip gently toward the west (Tweto, 1980).

The Denver Basin has four principal bedrock aquifers (Robson and others, 1998). The Laramie-Fox Hills aquifer (Cretaceous) is the deepest of these and consists of the Laramie Formation, Fox Hills Sandstone, and upper Pierre shale. Overlying the Laramie-Fox Hills aquifer are the Arapahoe (Cretaceous), Denver (Cretaceous-Tertiary), and Dawson (Tertiary) aquifers. These bedrock aquifers are recharged in outcrop areas along the western edge of the basin.

The South Platte Basin geologic map with sampling locations is presented as Figure 3-1. The Pierre formation outcrops along the Front Range are shown with a green outline. The base of the Denver Basin aquifer units are also highlighted.

Figure 3-1. South Platte Basin geology with Denver Basin Aquifer and Pierre shale (Tweto, 1979)

As the Cretaceous Seaway gradually retreated from what is now central Colorado, the Fox Hills Sandstone, which is a marine beach sand, was deposited as a series of interbedded layers within the upper Pierre shale (Weimer, 1973; Raynolds, 2002). As the seaway regressed farther, the Cretaceous Laramie Formation was deposited in a backswamp and deltaic environment with mostly overbank claystone and coal interbedded with fluvial channel sandstones (Weimer, 1973; Raynolds, 2002).

The Fox Hills sandstone and the Laramie formation underlie the South Platte River in the northern part of the Denver Basin (Figure 3-1). The Fox Hills sandstone consists predominantly of medium-grained buff to yellowish-brown poorly consolidated calcareous sandstone interbedded with dark-gray to black gritty shale and some massive white sandstone (Bjorklund and Brown, 1957). The Laramie formation consists of gray to yellowish-brown sand, dark clay and shale, and coal, interstratified with irregularly bedded gray to cream or buff sandstone. The Laramie Formation marine shale beds and coal beds are potential salinity contributors. The Fox Hills sandstone and the Laramie formation range in thickness from zero to nearly 200 feet in the lower South Platte River reaches (Bjorklund and Brown, 1957).

The White River group, consisting of the Chadron and Brule formations, and the Ogallala formation occur in the eastern part of the Basin. The Chadron formation consists of white to light-gray silty clay that is overlain by medium-grained to very coarse-grained siliceous sandstone. The Chadron formation contains many channel deposits of sand and gravel, which are present at all horizons within the formation but are more abundant near its upper and lower boundaries (Bjorklund and Brown, 1957).

The Brule formation is predominantly silt but contains small quantities of clay and fine sand. In eastern Colorado the Brule formation is relatively impermeable and wells drilled into the formation yield very little water. However, in southeastern Wyoming the Brule can produce abundant water if wells intersect fracture zones (Bjorklund and Brown, 1957).

The Ogallala formation consists of alternating hard and soft layers of sandstone, in part cemented with calcium carbonate, interbedded and intermixed with buff to gray or pinkish structureless clay, silt, and fine sand. Coarse gravel and pebbles are present throughout the formation but are most common in the middle part (Bjorklund and Brown, 1957). The formation ranges in thickness from zero near Sedgwick to 350 feet or more in western Nebraska.

Alluvium underlies the valleys of the South Platte River and its tributaries. The alluvium consists mainly of heterogeneous mixtures of clay, sand, and gravel, or lenses of these materials (Bjorklund and Brown, 1957). The lenses of silt, sand, and gravel were deposited by braided streams as they aggraded their channels. The materials in the South Platte River valley generally are coarser than those in the tributary valleys and contain fewer clay lenses. Extensive lenses of clay are most prevalent in the tributary valleys and probably represent shallow-lake deposits (Bjorklund and Brown, 1957). The alluvium thickness is highly variable and can be less than a foot at valley edges to as much as 400 feet.

4. HYDROLOGIC SETTING

Agricultural irrigation in the South Platte Basin began in the early 1860's and initiated changes to the basin's hydrology that continues today. Parshall (1922) stated that "It is known that before the development of irrigation in this valley, the flow of the (South Platte) river at times during the summer months was exceedingly small; and at places the stream would sink beneath the sands of the riverbed". It was clear that agriculture would need to rely on irrigation systems to be successful. At first, irrigation ditches from the river were short, low capacity, and served relatively small areas along the river bottom. However, these small, irrigated areas began saturating the soil and raising the water-table, which resulted in groundwater flow to the South Platte River. As development continued, the ditches became larger and longer, reservoirs were constructed, and the available water supply became more abundant (Parshall, 1922). Groundwater discharging into the South Platte River is called "return flow", on the assumption that most of it is derived from seepage from canals, reservoirs, and irrigated land (Bjorklund and Brown, 1957).

Agricultural development resulted in increasing irrigation return flow that, over time, provided a significant contribution to the South Platte River's flow. Parshall (1922) opined that the South

Platte River, especially between the mouth of the Cache la Poudre River and the Nebraska State line, accumulated more return flow water than any other stream in Colorado. The return flows from irrigation system development resulted in the river having “ample supply during the growing season even during average (precipitation) years” (Parshall, 1922).

These hydrologic conditions described by Parshall in 1922 still exist today. Canals, reservoirs, recharge basins, augmentation structures, and expanded irrigated agriculture have increased the hydrologic interactions between surface water and groundwater. Irrigated croplands are focused near the South Platte River and its tributaries (Figure 4-1). The water table generally slopes diagonally downstream and toward the South Platte River (Figure 4-2). Groundwater tends to discharge into the river, making it a gaining stream. During periods of low flow, all or almost all the river flow is derived from groundwater (Bjorklund and Brown, 1957).

Figure 4-1. Irrigated land in the South Platte River basin

Figure 4-2. Map and section showing groundwater flow to the South Platte River (Bjorklund and Brown, 1957)

These hydrologic conditions result in groundwater flowing downstream through the South Platte River and tributary river alluvium. Groundwater also flows into the alluvium from the surrounding formations and deposits. The Ogallala formation occurs in the lower basin and it was identified as a substantial groundwater source to the South Platte River by Bjorklund and Brown (1957). Groundwater discharge to streams occurs throughout the basin including Lodgepole Creek, and in the lower reaches of Bijou, Beaver, Wildcat, and Pawnee Creeks (Bjorklund and Brown, 1957).

The South Platte River’s gaining conditions have been directly measured and they indicate that return flows vary with time at the same location and vary with distance along the river. The differences were attributed in part to differences in augmentation. Ditches divert water from the river and discharge water back into the river, so the gains and losses are not solely due to groundwater return flow. In 1982, streamflow gain-and-loss investigations were conducted on a 25.8-mile reach of the South Platte River from the Masters streamflow-gaging station (USGS 06756995) to the mouth of Bijou Creek (Ruddy, 1984). These investigations indicated an average downstream discharge gain in this reach of 150 cubic feet per second (cfs) during the irrigation season (Ruddy, 1984). The average gains in discharge per mile in the three subreaches were 10.0 cfs, 2.6 cfs, and 2.0 cfs. Measured gains for the total reach ranged from 112 cfs on July 20, 1982 to 194 cfs on August 13, 1982. The streamflow measurements indicated that streamflow gain increased as the saturated aquifer thickness increased (Ruddy, 1984).

5. WATER-QUALITY INFLUENCES

Naturally occurring contributions of major ions to groundwater generally are the result of interactions between the water and the soil and aquifer material through which the water has passed. Evaporation of shallow groundwater and irrigation water applied to lawns and crops can concentrate major ions (Bruce and McMahon, 1998). Human activities like agriculture, wastewater (municipal and industrial), road de-icing, and industrial processes can also affect water quality.

Most natural water contains calcium, magnesium, sodium, bicarbonate, sulfate, and chloride. The amount and the composition of the dissolved minerals are influenced by the length of time the water has been in contact with the rocks or soils. Groundwater usually is more highly concentrated than direct surface runoff since it is in contact with the rocks and soils for much longer periods.

Historical water-quality studies were reviewed to gain insights into the Basin's groundwater characteristics. This section summarizes groundwater characteristics of the shallow alluvial aquifer, the bedrock aquifers, and areas with differing land use.

5.1 ALLUVIAL AQUIFER

The alluvial aquifer occurs in the South Platte River valley and the principal tributary streams. The alluvium consists mainly of heterogeneous mixtures or lenses of clay, sand, and gravel. The silt, sand, and gravel lenses were deposited by braided streams as they aggraded their channels (Bjorklund and Brown, 1957). The materials in the South Platte River valley generally are coarser than those in the tributary valleys and contain fewer clay lenses. Extensive lenses of clay are most prevalent in the tributary valleys and probably represent shallow-lake deposits (Bjorklund and Brown, 1957).

Although the alluvial aquifer area is only 28 percent of the basin and has only 3 percent of the stored groundwater, Robson (1989) estimated that it supplied 91 percent of the water pumped from wells. Most irrigation wells obtain their entire yield from the alluvium (Bjorklund and Brown, 1957). Alluvial wells were reported to yield 500 to 1,000 gpm in most places and yields as high as 2,000 gpm were considered possible in thick saturated alluvium sections along the South Platte River (Bjorklund and Brown, 1957).

5.1.1 Salinity

The general term "salinity" can be used when discussing Total Dissolved Solids (TDS) concentrations, which is a measure of all salt forms in water. Specific conductance and electrical conductivity are indirect measures of salinity and are often measured due to low cost and simplicity. Specific conductance measurements can be converted to provide approximate TDS concentrations. TDS can be determined directly by evaporating a volume of water and measuring the solid minerals that remain. TDS can also be estimated by summing the individual water constituents.

Dissolved-solids concentrations were found to be largest at agricultural sites by Litke and Kimbrough (1998). Alluvial groundwater in heavily irrigated areas becomes progressively more mineralized downstream due to return flows (Swenson, 1957). These return flows become highly mineralized because the groundwater flows relatively slowly through the unconsolidated alluvial materials where it picks up minerals that are further concentrated as shallow groundwater evaporates. It has been estimated that about one-half of the surface water diverted for irrigation is lost to evaporation and transpiration (Robson, 1989). This process repeats itself as river water is used and reused in subsequent irrigation diversions (Swenson, 1957). These have been considered the primary processes responsible for the downstream increase in total dissolved-solids concentrations in the South Platte River (Robson, 1989).

Alluvial aquifer dissolved-solids concentrations have been reported to range from less than 500 mg/l in local areas to more than 3,000 mg/l (Figure 5-1, Robson, 1989). Alluvial groundwater in the Box Elder Creek and Lone Tree Creek drainages were identified as having TDS of 2,000 to 4,000 mg/l (Figure 5-1). Similar alluvial groundwater Total Dissolved Solids concentrations ranging from 212 to 3,580 mg/l and averaging 1,170 mg/l were reported by Swenson (1957). Calcium and sulfate were the most prevalent dissolved solids in alluvial groundwater downgradient of Hardin, Colorado (Swenson, 1957).

Figure 5-1. Total dissolved solids concentrations in the alluvial aquifer (Robson, 1989)

Along the Front Range, shallow alluvial groundwater was reported to have specific conductance between 1,000 and 5,000 µS/cm Flynn (2003), which is approximately equivalent to TDS of 640 to 3,200 mg/l.

5.1.2 Land Use

Past studies have investigated the influence of land use on water quality in the Basin (Litke and Kimbrough, 1998; Bruce and McMahon, 1998, Bruce and McMahon, 1996; Swenson, 1957). These studies investigated generally "undeveloped" areas, urban areas, and agricultural areas. Undeveloped areas were in the mountains and dominated by crystalline bedrock, woodland forests, or rangeland. The urban land use represented the greater Denver-metro area, but other urban areas with less influence were included. Agricultural areas occur from north of Denver to Julesburg, but agriculture dominates from Kersey to Julesburg.

In general, major-ion data indicated an increase from small concentrations of dissolved solids in the upstream crystalline and undeveloped areas to large concentrations in the downstream agricultural areas. A large downstream increase in dissolved-solids concentrations was generally correlated with a change from bicarbonate to sulfate as the dominant anion and by increasing concentrations of calcium, sodium, and sulfate (Bruce and McMahon, 1998).

The proportions of major ions in rivers and streams at different land use areas are illustrated with Piper diagram in Figure 5-2. The major ions in groundwater in different land-use areas is provided in Figure 5-3. Land use sites that were not influenced by agriculture, including crystalline, forested, and rangeland sites had predominantly calcium bicarbonate type water. Urban area water tended to have less sulfate and more sodium than agricultural areas. Calcium and magnesium were the predominate cations in undeveloped and agricultural areas. Swenson (1957) reported that, on average calcium and magnesium were 70 percent of the cations with sodium and potassium about 30 percent in agricultural areas.

Figure 5-2. Piper diagram with major-ion composition of rivers and streams at land use sites (Litke and Kimbrough, 1998).

Figure 5-3. Piper diagram with major-ion composition in groundwater at three land use areas (Bruce and McMahon, 1998).

Urban areas tended to have more sodium than the undeveloped and agricultural areas (Figure 5-2; Figure 5-3). Calcium was typically the dominate cation with appreciable sodium and minor magnesium in agricultural groundwater and surface water. The urban area groundwater anions were highly variable (Figure 5-3), while surface water had roughly equal percentages of bicarbonate and sulfate, with less chloride (Figure 5-2). Agricultural area surface water was dominated by sulfate as were most groundwater samples. Bicarbonate was the predominate anion in undeveloped areas (Figure 5-3).

The increase in the proportion of sulfate in lower South Platte reaches has been attributed to the carbonate precipitation from water used for irrigation (Smith, Schneider, and Petri, 1964). Large sulfate concentrations in agricultural areas may be due to application of fertilizers with sulfur and sulfate that can be transported to surface water through irrigation return flows (Litke and Kimbrough, 1998). The gypsiferous character, with calcium and sulfate as the most prevalent dissolved solids, has also been attributed to the aquifer material being derived from gypsiferous shales in the underlying Pierre shale (Swenson, 1957). However, gypsum ($CaSO_4$-$2H_2O$) was only found in small amounts in the Pierre shale.

A detailed study of shallow groundwater quality in the unconsolidated alluvial aquifer beneath the Denver urban center was conducted in 1993 (Bruce and McMahon, 1996). This study indicated that water quality was highly variable in residential, commercial, and industrial land-use settings (Bruce and McMahon, 1996). Sulfate was the predominant anion in most samples from the residential and commercial land-use settings, whereas bicarbonate was the predominant anion in samples from the industrial land-use setting.

An analysis of water-quality data from 2,138 wells in shallow aquifers in the Front Range Urban Corridor (Denver to Fort Collins and east to Greeley) was conducted by Flynn (2003) Most wells were completed in alluvium and the geologic unit was unknown in many wells. Calcium tended to be the dominate cation but sodium could exceed 50 percent (Figure 5-4). The groundwater bicarbonate and sulfate were highly variable (10 to 90 percent), with chloride usually less than 20 percent, although higher chloride was observed in some samples. Areas north of the Cache la Poudre River was identified as an area with elevated sulfate concentrations. Pierre shale and Laramie Formation shales were suspected contributors to the elevated sulfate concentrations. However, agricultural land use also occurs in this area.

Figure 5-4. Piper diagram with major-ion composition in groundwater samples along the Frong Range (Flynn, 2003)

If agriculture was a significant land use in an area, it tended to dominate the water chemistry. For example, a mix of undeveloped and agriculture or a mix of urban and agriculture, tended to have agriculture type water that was predominately calcium and sulfate (Figure 5-2; Figure 5-3).

Alluvial groundwater was hard with more than 90 percent of the 89 samples having hardness greater than 200 mg/l and 50 percent with hardness exceeding 600 mg/l (Swenson, 1957). Hardness in alluvial groundwater did not appear to be influenced by the well depth or location.

Sulfate sources can be geologic or anthropogenic. Anthropogenic sources can include fertilizer, gypsum soil amendments, road treatments, and organic contamination. Geologic sulfate sources include gypsum (evaporites), coal beds, and marine shales (Hem, 1992). Rocks submerged by a marine sea can become impregnated with soluble salts that include sulfate, chloride, and sodium (Hem, 1985). However, areas of elevated sulfate along the Front Range were not coincident with areas of elevated chloride (Flynn, 2003). Chloride concentrations reported by Flynn (2003) were generally less than 100 mg/l with a median of 44.0 mg/l. These relatively low concentrations may be due to chloride leaching from weathered shale that occurs in near-surface exposures (Billings and Williams, 1967).

5.2 BEDROCK AQUIFER

The Denver Basin is a bowl-shaped geologic structural syncline. There are four principal bedrock aquifers in the Denver Basin (Robson and others, 1998). The individual aquifers from deepest to shallowest are the Laramie-Fox Hills aquifer (Cretaceous), the Arapahoe (Cretaceous), Denver (Cretaceous-Tertiary), and Dawson (Tertiary) aquifers. These bedrock aquifers have been considered as individual aquifers or as a combined “bedrock aquifer.”

The South Platte River flows over this structural basin from the Denver Metro area to near Riverside Reservoir (about 18 miles east of Kersey; Figure 3-1). In the upper reaches the river flows over the Denver, Arapahoe, and Dawson aquifers. Near Platteville the underlying bedrock changes to the Laramie Formation.

The Laramie-Fox Hills aquifer (Cretaceous) is the deepest aquifer in the Denver Basin and consists of the Laramie Formation, Fox Hills Sandstone, and upper Pierre shale. The Fox Hills Formation occurs near Masters with upper Pierre shale outcrops near Fort Morgan. The White River and Ogalalla formations begin outcropping near Hillrose and continue past Julesburg (Figure 3-1).

The South Platte River streambed consists of modern alluvium that overlies the bedrock formations and other Quaternary alluvial deposits throughout the Basin (Figure 3-1). The near river geologic units for the river’s course in Colorado consists of Quaternary gravels, alluvium, and eolian deposits made up of dune sands, silt, and loess (Figure 3-1). These Quaternary units overlie and obscure the bedrock units that outcrop further from the riverbed.

The dissolved-solids concentrations of water in the bedrock aquifer generally are less than 200 milligrams per liter in the upper part of the bedrock aquifer, such as the Dawson Arkose (Robson 1989). The Dawson Aquifer occurs south of Denver and is unlikely to have any impact on the South Platte River. Its calcium bicarbonate type water generally has excellent chemical quality in most areas (Robson, 1984). Dissolved-solids concentrations are less than 100 mg/l with sulfate concentrations from 4 to 10 mg/L in the central and south-central part of the aquifer. However, an isolated area at the northern margin of the aquifer has TDS exceeding 1,000 mg/l with sulfate concentrations greater than 700 mg/l.

The Denver Aquifer occurs in the Denver Metro area. TDS is 25-250 mg/l near the South Platte River (Robson, 1984). The water is calcium bicarbonate type in the central part and a sodium bicarbonate or sodium sulfate type near the margins of the aquifer. Downward hydraulic gradients would prevent the Denver Aquifer from influencing alluvial groundwater or South Platte River water (Robson, 1984).

Arapahoe aquifer water is classified as sodium bicarbonate type (Robson, 1984). Arapahoe aquifer water is generally similar in type to that found in the overlying Denver aquifer, due in part to the downward movement of water from the Denver aquifer to the Arapahoe aquifer. TDS is low in the central part of the aquifer but increases to more than 2,000 mg/l near aquifer margins (Robson, 1984). The South Platte River traverses the Arapahoe aquifer north of Denver.

The Laramie-Fox Hills aquifer forms the boundary of the Denver basin. The South Platte River flows along the west and northern boundary and is the most likely Denver basin aquifer to influence South Platte River water quality (Figure 3-1).

Lower Laramie Formation sandstones were deposited in freshwater delta-front fluvial channels after the Cretaceous sea regression (Weimer, 1973). The Laramie Formation sandstones generally are composed of clean, well-sorted, very fine- to medium grained sandstones with minor amounts of silt and clay and are nearly white (Scott, 1963). A 10- to 20-foot-thick shale bed may separate the Laramie sandstones into two units, and a shale bed 5 to 20 feet thick generally separates the Laramie and Fox Hills sandstones (Robson, 1987). These Laramie formation shale layers have a marine origin that could be the source of high mineral content water. Swenson (1957) reported a Weld County Laramie formation well, 190 feet deep, that produced brackish water consisting largely of sodium chloride. This well's TDS was 2,150 mg/l with chloride accounting for almost one-half by weight (Swenson, 1957).

The Laramie-Fox Hills aquifer generally is not used as a source of irrigation water. Near the margins of the aquifer, water can have large dissolved-solids concentrations and sodium bicarbonate or sodium sulfate type water, which has a high salinity hazard (Robson, 1989). Sodium sulfate water was reported along the northern and eastern margins of the aquifer (Robson, 1984).

The Laramie Formation and Fox Hills Sandstone occurs along the basin margin and has dissolved-solids concentrations from 800 to 1,200 milligrams per liter with 25 to more than 250 milligrams per liter of sulfate (Robson, 1989). These large dissolved-solids concentrations could be due to evaporation, transpiration, and leaching of soluble minerals from the soil into the aquifer (Robson, 1989). Laramie-Fox hills aquifer water is very hard with hardness exceeding 180 mg/l.

In areas where TDS concentrations exceed 1,200 mg/l the Laramie-Fox Hills aquifer is overlain by the shaly upper part of the Laramie Formation and is beyond the edge of the overlying Arapahoe aquifer (Robson, 1984). The poor water quality in these areas could be the result of surface water or upper Laramie Formation groundwater transporting soluble minerals into the aquifer (Robson, 1984). This implies downward hydraulic gradients and losing stream conditions that would preclude the Laramie-Fox Hills aquifer from influencing alluvial groundwater and South Platte River water quality. However, the upper Laramie Formation may have some influence on water quality.

The Ogallala formation occurs east of the Denver basin formations and underlies the lower South Platte River starting near river mile 190 (Figure 2-1; Figure 3-1). Ogallala groundwater samples collected from six (6) wells with depths from 60 to 225 feet were identified as calcium bicarbonate water potentially due to the calcium carbonate cementing material (Swenson, 1957). Total Dissolved Solids for these samples ranged from 152 to 396 mg/l. The Ogallala aquifer has been speculated to discharge higher quality, lower TDS groundwater into the South Platte River, which could create a dilution affect lowering TDS concentrations in the lower basin (Bjorklund and Brown, 1957, Dennehy and others, 1998).

5.3 PIERRE SHALE

The Pierre Formation is a marine shale that occurs across the entire basin and it is a potential contributor to salinity in soils, surface water, and groundwater. It has a thickness of up to 8,000 feet, and either outcrops, underlays near-surface deposits, or occurs at depth. Shale and coal beds in the Laramie formation are also potential salinity contributors.

The Pierre shale extends along the Front Range from the southern part of the basin where the South Platte River exits the mountains to near the Colorado-Wyoming state line in the north. It outcrops in a belt as much as 20 miles wide in the northern areas (Scott and Cobban, 1965) and narrows to a thin band in the Denver Metro area. The Cache la Poudre River, Big Thompson River, Saint Vrain Creek, and Big Dry Creek drainages cross wide swaths of the Pierre shale. Conversely, the more southern drainages like Clear Creek and the South Platte River itself have little contact with the Pierre shale.

A study on the geologic origins of saline soils in the northern Front Range concluded that the Pierre shale was the primary source of salts in the study area. (Otton and others, 2005). The saline soils were mapped, sampled, and analyzed for sulfur-isotope geochemistry and mineralogy (Figure 5-5). The saline soils are most prevalent from the city of Loveland southeastward to the northern Denver suburbs. The northwest part of the study area is underlain by the Pierre shale and saline soils tend to form in the numerous depressions. Saline soils also occur on upland areas underlain by residual soils formed on shale (Otton and others, 2005).

Figure 5-5. Saline soils mapped in the northern Front Range area (Otton and others, 2005)

The saline soil salt crusts were dominated by sodium-, magnesium-, and calcium-sulfate minerals (Otton and others, 2005). The sodium-sulfate salt, thenardite, dominated most soil samples. In contrast, soils near oil and gas tanks that may have had saline produced water spills and leaks, contained chloride-dominant salts (Figure 5-6). Natural non-saline soil leachates were dominated by carbonate and bicarbonate anions, whereas the saline soils were dominated by sulfate (Figure 5-6; Otton and others, 2005).

Figure 5-6. Anion percentages from saline soil leacheates in the Front Range (Otton and others, 2005)

Studies on Colorado's western slope found that the Mancos Shale, which is equivalent to the Pierre shale, has gypsum and highly soluble thenardite (Na_2SO_4) as common weathering products (Tuttle and Grauch, 2009). Both salts are found in soils derived from the shale. Gypsum is also found along fractures and bedding planes in the unsaturated zone. Deeper gypsum is thought to be related to historic weathering of the shale when the water table was higher and/or the climate wetter (Tuttle and others, 2008). Gypsum and thenardite in the Mancos Shale were the dominant sulfate sources.

Sulfur isotopic composition of dissolved sulfate and of sulfate salts in soils near Pierre shale bedrock is mimicked in saline soils closer to the Denver suburbs despite a transition to other bedrock units. Wind appears to transport the salts downwind with the clay and fine sediment that erodes from the weathered Pierre shale (Otton and others, 2005).

Sulfur isotopes ($\delta^{34}S$) were found to vary between Pierre shale derived soils and leachates from coalmine waste piles consisting mostly of shale and coal from the Laramie Formation (Otton and others, 2005). This suggests that sulfate in surface water and groundwater originating in the Pierre shale, Laramie Formation shale and coal beds, and agricultural sources could be distinguished by sulfur isotopes.

The chemical composition of the saline soils derived from the Pierre shale reported by Otton and others (2005) differ significantly from Pierre shale groundwater sampled by Swenson (1957). Eight (8) wells, 220 to 650 feet deep, that monitored the Pierre shale were analyzed for water chemistry (Swenson, 1957). The groundwater typically had Total Dissolved Solids concentrations exceeding 1,000 mg/l, low hardness, several hundred mg/l chloride, and was sodium bicarbonate type water (Swenson, 1957). Sulfate was not a major component of the Pierre shale groundwater samples reported by Swenson (1957). Groundwater chloride concentrations ranged from 24 to 658 mg/l. One groundwater sample had 1,074 mg/l sulfate, but 6 of 10 samples were 22 mg/l or less and 3 of 10 were 103 to 256 mg/l (Swenson, 1957).

Calcium-sulfate type water can be due to dissolution of gypsum ($CaSO_4$-$2H_2O$). Alluvial groundwater has been noted to have a gypsiferous character thought to be derived from gypsiferous shales in the underlying Pierre shale (Swenson, 1957). However, Pierre shale groundwater samples analyzed by Swenson (1957) had minor sulfate concentrations and did not have a gypsiferous character. Gypsum was found in minor to trace amounts in the Pierre shale and northern Front Range saline soil samples derived from the Pierre shale (Swenson, 1957; Otton and others, 2005).

Low hardness was considered a characteristic property of Pierre groundwater by Swenson (1957). Total hardness ranged from 19 to 128 mg/l in wells that monitored the Pierre shale. The low hardness, due to relatively small amounts of calcium and magnesium, was interpreted as possibly caused by cation exchange reactions. The Pierre shale was reported to have bentonite, which is a highly absorbent, micaceous clay mineral capable of readily exchanging its bases. Calcium and magnesium originally in the water could be replaced by alkalis in the bentonite (Swenson, 1957).

5.4 URANIUM

Uranium concentrations in the South Platte River were investigated by Boberg and Runnells (1971). The river water uranium ranged from 5 to 67 micrograms/liter (µg/l or parts per billion) during the winter of 1969-1970. These concentrations were anomalously rich in uranium in comparison with most other rivers around the world that were reported to have an average uranium concentration of 1 µg/l (Livingstone, 1963). The South Platte River contains higher uranium concentrations than the Colorado and North Platte rivers, despite these rivers draining uranium ore-producing areas. An additional finding was that the uranium concentrations increased downstream in the South Platte River. Rivers that drain areas with known uranium deposits tend to have decreasing uranium concentrations with downstream distance from the deposit (Boberg and Runnells, 1971).

An "incremental areal uranium-load" parameter was used by Boberg and Runnells (1971) to compare changes in loading rates in the South Platte River. Drainage areas and measured uranium concentrations were used in the calculation which identifies reaches with anomalously large amounts of uranium being added to the river. In the headwaters of the South Platte River the incremental areal uranium-load was 0.00018 kilogram uranium per day per square kilometer (kg U/day/km^2). The incremental areal uranium-load between Henderson and Fort Lupton, which is underlain chiefly by the Tertiary Dawson Arkose and the Laramie Formation, rises to 0.0119 kg U/day/km^2. Between Weldona and Balzac the incremental areal uranium-load was a high of 0.016 kg U/day/km^2 (Boberg and Runnells, 1971). In this reach flow is across the Dawson Arkose, Laramie, Fox Hills, and Pierre Formations. The uriniferous coal found locally in the Laramie Formation and uranium-rich black shales in the Pierre Formation were suggested as the possible uranium source (Boberg and Runnells, 1971). Approximately 38 percent of the drainage area of the South Platte River is in the Laramie and Pierre formations.

In 1969-1970, the uranium concentrations in Saint Vrain Creek, Big Thompson River, and Cache La Poudre River, near their confluences with the South Platte, were 26, 40, and 34 µg/l. These similar uranium concentrations suggested that the underlying bedrock is a major control on the uranium content (Boberg and Runnells, 1971). Fluvial or sedimentological processes including sediment leaching, was considered of secondary importance.

An alluvial groundwater study in the Denver Metro area found that dissolved-uranium concentrations ranged from less than 1.0 to 80 ug/l with a median concentration of 15 ug/l (Bruce and McMahon, 1996). The highest uranium concentrations (greater than 40 ug/l) were collected from wells in the Clear Creek drainage, which was attributed primarily to mining activities in the upper reaches of the stream. The alluvial deposits consist of igneous and metamorphic minerals, and they were considered a likely source of the relatively high levels of uranium in the Denver metro urban land-use area.

6. FINDINGS

This scoping-level study was investigating the role of geologic formations on the Basin's water quality. The scope was limited to obtaining hyporheic zone groundwater samples and stream samples. Water-quality sampling was completed at multiple locations along the South Platte River and the Saint Vrain River, Big Thompson River, and Cache la Poudre River tributaries.

6.1 SALINITY

Total dissolved solids (TDS) is the amount of organic and inorganic materials, such as metals, minerals, salts, and ions, dissolved in water and is measure of the overall salinity. TDS concentrations have been shown to increase downstream throughout the Basin (Neirbo, 2020) and this study had similar results.

In the Denver metro area, surface water TDS concentrations were about 600 mg/l in the spring and 410 mg/l in the summer (Figure 6-1). Groundwater concentrations were about 800 to 900 mg/l. As the South Platte River exited the Denver Metro area (mile 40) TDS stabilized at about 700 mg/l (Figure 6-1). Further downstream the tributaries were contributing 900-1,000 mg/l of TDS, which contributed to the South Platte River TDS increase to about 800 mg/l.

Figure 6-1. Total dissolved solids concentrations along the South Platte River

As the South Platte flowed through the Pierre shale reach (Figure 3-1) TDS increased to over 1,000 mg/l at river mile 145 (Figure 6-1). Groundwater TDS at this location exceeded the river concentrations and was about 1,300 mg/l. The South Platte TDS continued to increase downstream to Julesburg at river mile 245 and the summer sample exceeded 1,400 mg/l. For reference, these graphs also provide geologic formations, wastewater treatment facilities, and diversion points along the river.

In addition to sampling along the South Platte River three (3) tributaries in the lower Basin were sampled. Surface water and groundwater samples were collected during the spring 2022 event from Box Elder Creek (BEC), Bijou Creek (BJC), and Beaver Creek (BVC). Sampling locations were upstream from the drainage confluence with the South Platte River. The TDS and general water quality concentrations in these lower basin tributaries was similar or slightly higher than the nearby South Platte River samples. TDS in the Beaver Creek groundwater sample was about 1,360 mg/l (Figure 6-1). These samples were collected near the drainage confluences with the South Platte River. It is unclear whether the samples represent alluvial aquifer concentrations or water from further upstream in these lower basin tributaries.

Concentrations of all major ions tend to increase downstream with sulfate having the largest increases as shown on Figure 6-2. Sulfate consistently increases, while bicarbonate concentrations stabilize in the lower basin. Calcium and sodium were the dominant cations. Chloride and magnesium occur at minor concentrations. The sulfate percentage of TDS increased from 10-20-percent to about 60-percent in each of the rivers sampled (Figure 6-3).

Figure 6-2. Increasing Total Dissolved Solids and major ion concentrations

Figure 6-3. The sulfate percentage of Total Dissolved Solids with downstream distance

Although the overall trends are for ions concentrations to increase downstream, there can be variability due to the numerous influences affecting water quality. Agricultural return flows, geology diversions, and wastewater effluent influence water quality in most of the Basin’s rivers and streams.

Figure 6-4. Total Dissolved Solids concentrations along the Saint Vrain River

Figure 6-5. Total Dissolved Solids concentrations along the Big Thompson River

Figure 6-6. Total Dissolved Solids concentrations along the Cache la Poudre River

The major tributaries contribute flow and chemical loads to the South Platte River (Figure 6-4, Figure 6-5, Figure 6-6, and Figure 6-1). TDS concentrations in the most upstream tributary sampling locations were typically less than 100 mg/l, although the spring sample in Saint Vrain River was 280 mg/l. The groundwater samples at these upstream locations were 260 to 440 mg/l. As the tributaries flowed over the Pierre shale the TDS concentrations increased to 1,100 to 1,200 mg/l. In most locations, the groundwater concentrations exceeded the surface water concentrations. Surface water concentrations tend to be more variable due to the streamflow influence. This results in pre-spring runoff concentrations being higher than summer concentrations because flows were lower.

The highest groundwater concentrations tended to occur during summer and at the most downstream location. The samples were collected in August, after several months of crop irrigation. Return flows could be reaching the streams and elevating concentrations. Groundwater is also flowing downstream through the alluvium that forms the streambed deposits.

In most cases, surface-water concentrations decreased immediately downstream of the wastewater treatment facilities. The effluent appears to have lower TDS than the streamflow, which would create a dilution effect. After this initial decrease in concentration, they tended to resume their gradual downstream increase.

The South Platte River total salt load at the time of sampling was about 300 tons per day (t/d) in the Denver Metro area (Figure 6-7). As the river exited the metro area the salt load had increased to 600 to 700 t/d. Even though TDS concentrations increase downstream the largest loads were near Kersey (1,000 t/d) and the smallest was near Iliff (<200 t/d). At Julesburg the spring sample total salt load was 460 t/d. The downstream loads were highly variable due to the influence of diversions on streamflow (Figure 6-7). Diversions were active during the spring and summer sampling periods. During the non-irrigation season diversions are actively filling reservoirs.

Figure 6-7. Total salt load at sampling locations along South Platte River and at tributary confluences

Total salt loads in the major tributaries are shown on Figure 6-8. Salt loads increased downstream, and the largest salt load was 280 t/d in the Saint Vrain, with 225 t/d in the Cache la Poudre and 160 t/d in the Big Thompson. Salt loads were consistently larger in the spring samples.

Figure 6-8. Total salt load at sampling locations along the major tributaries

The salt load was calculated as the product of TDS concentration and streamflow at the nearest gaging station. These loads are approximate due to the potential for error in streamflow estimates at the sampling locations. Streamflow can vary dramatically over short distances due to numerous diversions, wastewater discharge, and changing groundwater contributions to the rivers. Salt loads vary with concentrations and streamflow and these measurements represent a snapshot in time. However, these estimates illustrate the loading magnitudes and relative contributions of each river.

6.2 WATER QUALITY

Piper or trilinear diagrams illustrate the dissolved constituents in water. Downstream changes in the dominant constituents can be seen since water samples were collected from long reaches of the major upper basin tributaries and the South Platte River. Tabulated water-quality data are provided in Attachment A.

The most upstream South Platte River samples were in the Denver Metro area and there was a strong municipal wastewater effluent influence with sodium and chloride being the dominate ions (Figure 6-9). Chloride can be used in municipal wastewater treatment processes. The chloride percentage decreased with distance from the metro area wastewater contributions. The dominate anion changed as chloride decreased from 50 to 10 percent and sulfate increased from 20 to 70 percent. At the most downstream site near Julesburg calcium and sodium were about 40 percent each with about 20 percent magnesium (Figure 6-9). Bicarbonate concentrations were consistent at about 30 percent for most of the river's length before decreasing to 20 percent near Julesburg.

Figure 6-9. Piper diagram illustrating major ion evolution with downstream distance in the South Platte River

A Durov diagram, that includes pH and TDS, in addition to the major ions is provided as Figure 6-10. The Durov diagram illustrates that with distance downstream pH becomes increasingly alkaline and TDS increases. The groundwater sample from site SPR-2, near Crook (river mile 220), had the highest TDS of 1,745 mg/l. There was variability in pH values, with the highest pH of 9.7 being measured at three (3) sites (SPR-4, SPR-7, SPR-11) located in the upper and lower basin. The South Platte River samples had pH of about 8. Groundwater samples commonly had pH 7 to 8. A few samples had pH exceeding 9.5.

Figure 6-10. Durov diagram illustrating water-quality evolution with downstream distance in the South Platte River and its major tributaries

The most upstream samples in the upper basin tributaries reflected their crystalline bedrock origin. Each of these rivers initially had calcium-bicarbonate type water as they exited the mountains (Figure 6-11; Figure 6-12; Figure 6-13). The Saint Vrain River sodium and magnesium percentages increased, and sulfate became the dominate anion near its confluence with the South Platte River (Figure 6-11). In the Big Thompson River magnesium increased and sulfate became the dominant anion as it evolved into mixed calcium-magnesium-sulfate type water (Figure 6-12). The Cache la Poudre River became a mixed cation-sulfate type water (Figure 6-13). The downstream most tributary samples had calcium, magnesium, and sodium cations in similar percentages ranging from 30 to 35 percent. Sulfate accounted for 60-65 percent of the anions in each of the tributaries.

Figure 6-11. Piper diagram illustrating major ion evolution with downstream distance in the Saint Vrain River

Figure 6-12. Piper diagram illustrating major ion evolution with downstream distance in the Big Thompson River

Figure 6-13. Piper diagram illustrating major ion evolution with downstream distance in the Cache la Poudre River

A piper diagram combining the South Platte and the tributaries categorized by river is provided as Figure 6-14. The downstream South Platte River water reflects the mixing and contributions of the upper basin tributaries. There is a downstream shift from calcium to sodium with each about 40 percent and magnesium about 20 percent, resulting in a mixed cation-sulfate type water (Figure 6-15).

Figure 6-14. Piper diagram illustrating major ion evolution in the South Platte River and its major tributaries

Figure 6-15. Piper diagram illustrating major ion evolution with downstream distance in the South Platte River and its major tributaries

Individual constituent concentrations for surface water and groundwater in the South Platte River and its major tributaries are presented graphically relative to downstream distance in Appendix B. These graphs present concentrations at each sampling location with geologic formation, wastewater treatment facilities, and diversion locations. Constituents included in this detailed analysis include total dissolved solids, calcium, sodium, sulfate, bicarbonate, chloride, iron, selenium, and uranium. These major cations, major anions, and trace elements were selected to gain insights into water-quality changes as the rivers flow through geologic units.

The South Platte River concentrations were less variable than the tributary data (Appendix B). There was also generally less difference between the South Platte groundwater and surface water samples. This may indicate water mixing or that the piezometer wasn't deep enough into the hyporheic zone to obtain discrete water samples.

The spring and summer South Platte River data were also more consistent than the tributary data (Appendix A). This may indicate that agricultural return flows continue throughout the year.

Water-quality analyses included trace elements boron, barium, bromide, iron, manganese, selenium, and uranium. In general, these elements were found in low concentrations with the most variability in the Saint Vrain, Big Thompson, and Cache la Poudre tributaries (Appendix B). Uranium concentrations exceeded the drinking water standard of 30 µg/l in the lower basin.

Boron and bromide concentrations were less than 1 mg/l in all areas. Bromide had increasing concentrations with downstream distance in the South Platte River, but concentrations did not exceed 1 mg/l. Upper basin barium concentrations were typically less than 200 µg/l and lower basin concentrations were consistent and less than 100 µg/l.

The manganese secondary drinking water standard is 0.05 mg/L. While most sites had concentrations less than these standards, there were several samples that exceeded the standards, with the highest concentrations in the upper basin. The highest manganese samples were 1-3 mg/l with eight (8) samples in this range.

There were several samples that exceeded the iron secondary drinking water standard of 0.3 mg/L. During the irrigation season (August samples) 15 samples exceeded the standard with five (5) in the Saint Vrain and four (4) in the Cache la Poudre. Surface water (6) and groundwater samples (9) exceeded with the highest concentrations being 7.2 and 3.39 mg/l. No surface water samples exceeded in the spring event, but 13 groundwater samples exceeded 0.3 mg/l. Saint Vrain (3), Cache la Poudre (4), Big Thompson (1), South Platte (1), Box Elder (1), and Bijou Creek (1) samples exceeded the standard. These samples were generally collected in areas with the Pierre shale, Fox Hills, and Laramie formations.

All selenium samples were less than 16 µg/l, which are below the 50 µg/l drinking water standard. One sample each in the Big Thompson and Cache la Poudre rivers were between 10 and 14 µg/l. The highest selenium concentrations of 15 and 16 µg/l were observed in Bijou Creek and Beaver Creek groundwater samples. Most selenium samples were less than 5 µg/l.

Uranium concentrations start to exceed the drinking water standard of 30 µg/l in the reach between Weldona and Snyder, where Bijou and Beaver Creeks join the South Platte River. South Platte River uranium concentrations continue to increase downstream reaching a maximum of about 55 µg/l near Julesburg. The largest uranium concentration was in Beaver Creek groundwater at about 68 µg/l. The South Platte groundwater sample at SPR-5 near Snyder and the confluence with Beaver Creek was about 50 µg/l. The nearby river concentrations were about 30 µg/l. These uranium concentrations are consistent with the 40 µg/l at Weldona and 67 µg/l at Balzac reported by Boberg and Runnells (1971).

Boberg and Runnells (1971) postulated several possible uranium sources, including leaching of uranium and dissolution of detrital silicates carried by the river from the mountains, uraniferous coals and black shales in the sedimentary rocks traversed by the South Platte, and man-made pollution. Although not all groundwater samples from areas underlain by the Pierre shale had relatively elevated uranium and selenium concentrations, the elevated samples were all from areas underlain by Pierre shale. In particular, Big Thompson, Cache la Poudre, Bijou Creek, and Beaver Creek drainages have Pierre outcrops. Wildcat Creek, on the north side of the South Platte River, was not sampled, but it also has Pierre outcrops and its confluence with the river is in the area with elevated concentrations (Figure 3-1). This suggests that parts of the Pierre shale could be contributing uranium in concentrations that exceed the drinking water standard.

6.3 SALINITY INFLUENCES AND SOURCES

This study investigated the role of geologic formations on the Basin's water quality. Geologic materials like rocks and soils are a naturally occurring salinity source. Chemical weathering can mobilize the minerals in rocks and soils. The salt types and concentrations the rocks and soils contribute depend largely on the mineral composition, the mineral solubility, and the exposure to water. The Pierre shale was considered a potentially significant formation due to its marine origin and widespread occurrence in the Basin.

In addition to the Pierre shale, there are also agricultural activities, municipal wastewater effluent discharges, and other factors that can influence water quality. Agricultural lands occur in areas underlain by the Pierre shale in the upper basin tributary drainages, along the South Platte River, and in the lower basin drainages (e.g. Bijou Creek, Beaver Creek, Wildcat Creek). Agricultural irrigation and ditches can transport soluble elements from fertilizer and soil amendments into the shallow groundwater system. This groundwater can interact with soils derived from the Pierre and transport elements contributed from agriculture and natural geologic conditions into the tributaries and the South Platte River.

The mineral content and the leaching potential of the Pierre shale, or any other formations, has not been determined. Parsing a river's mineral and salt loading into its individual components was not possible in this reconnaissance level study. A detailed salt balance that geology, agriculture, wastewater, road de-icing salts, industrial source, oil and gas produced water was beyond the scope of this study.

Surface water exiting the mountains has low Total Dissolved Solids concentrations, which means the concentration of common salt-forming elements were also low. The Pierre shale is one of the first and certainly the most extensive geologic unit that the Saint Vrain, Big Thompson, and Cache la Poudre rivers flow through when they exit the crystalline mountain terrain. Sampling results show that TDS in these tributaries increases significantly as they flow through the Pierre shale.

Most element concentrations increase through the Pierre reaches in the upper tributaries. Cations calcium, sodium, and magnesium increase while potassium occurs at consistently low concentrations. Upstream sulfate groundwater concentrations dramatically increased from less than 50 to 400-680 mg/l. Bicarbonate was initially around 150 mg/l and increased gradually to 250-300 mg/l. Chloride concentrations did not appear to be influenced by the Pierre and they were consistently in the 100-150 mg/l range with three (3) Cache la Poudre samples at 150-300 mg/l.

The dissolution of gypsum ($CaSO_4$), thenardite (Na_2SO_4), and pyrite ($FeSO_4$) are possible geologic-based sulfate (SO_4), calcium, and sodium sources. Halite (NaCl) is also soluble and could influence water quality. The Pierre shale and other geologic units have been reported to contain gypsum, thenardite, halite, and pyrite minerals (Tuttle and Grauch, 2009; Otton and others, 2005; Flynn, 2003; Bruce and McMahon, 1989; Bjorklund and Brown, 1957; Swenson, 1957). Thenardite (Na_2SO_4) was the dominant salt-crust assemblage found by Otton and others (2005) along the Front Range drained by the major tributaries. However, agricultural soil amendments are also possible sulfate (SO_4), sodium (Na), and chloride (Cl) contributors.

Scoping-level analyses were used to inform whether geologic formations were the primary sources of sulfate, calcium, sodium, and chloride. Element ratios ($Ca:SO_4$, $Na_2:SO_4$, Na:Cl, $Fe:SO_4$) were calculated on a molar basis. A ratio of 1 suggests that the elements were derived from dissolution of geologic minerals (Tuttle and Grauch, 2009). Ratios greater than 1 or less than 1 suggests that there were other sources of the element that causes the ratio imbalance. Molar ratio tabular data are provided in Appendix A and graphs are provided in Appendix B.

This molar-ratio analysis is not definitive and is used as an indicator of possible agricultural sources. The ratios can be influenced by calcium and sodium exchange in marine clays and there are several geologic minerals that can contribute calcium, sodium, and sulfate. Sulfur isotopes have been used to distinguish sulfate sources (Tuttle and Grauch, 2009). Rock core and chemical analyses of geologic formations in the South Platte Basin could confirm the presence of soluble minerals contributing to the water's composition.

The South Platte River downstream of the Denver metro area and the major tributaries downstream of the crystalline mountain rock influence had similar molar ratios. The most upstream samples in the tributaries have higher bicarbonate concentrations representative of crystalline mountain rocks. Downstream of these influences, the $Ca:SO_4$ ratios were consistently less than 1, suggesting an additional sulfate source. The Na:Cl ratios were consistently greater than 1, suggesting an additional sodium source. The $Na_2:SO_4$ ratios were greater than 1, but not excessively and were in the 1.5 to 2 range.

Collectively, these molar ratios suggest that there is excess sodium and sulfate than would be expected if geology was the only contributor. The moderate $Na_2:SO_4$ ratios may suggest that thenardite is a significant influence on water quality. Thenardite is an evaporite that has been identified in Pierre shale derived salt crusts (Otton and others, 2005). Additionally, alluvium in the lower basin tributaries have lake and playa deposits that may contain thenardite. However, the molar ratios also suggest additional sources of sodium and sulfate, which could be due to irrigated agriculture. Further investigation and the use of sulfur isotopes may help distinguish the sulfate sources and their relative contribution to water quality. The source distinction is important because the mediation measures would be different for natural geologic sources compared to agricultural soil amendments.

Pyrite ($Fe:SO_4$) is a potential geologic sulfate source, but iron was found in very low concentrations and the $Fe:SO_4$ ratios were 0.1 or less (Appendix B). This suggests that pyrite is not present in significant quantities in the geologic formations underlying the South Platte River and its major tributaries.

Several historical groundwater studies were discussed in Section 5. Water quality from mountain, urban, and agricultural land use areas in addition to Pierre shale groundwater wells have been previously studied. A piper diagram illustrating the water types from these settings and the water samples collected for this study are presented as Figure 6-16. The samples from this study were classified as from shale and non-shale river reaches.

Figure 6-16. Piper diagram comparing geology, land use, and historical Pierre shale groundwater water types

Deep Pierre shale wells, located downstream of Sterling, were sampled by Swenson (1957). These Pierre shale groundwater samples are dramatically different from the other samples (Figure 6-16). The Pierre groundwater was reported to have nearly 100-percent sodium and chloride or bicarbonate type water (Figure 6-16). The other samples throughout the basin tend to be a sodium-calcium cation mix and dominantly sulfate anion type water. The nature of Pierre shale groundwater and its leachable minerals need further characterization to confirm the Pierre shale influence on the basin's water resources. If the Swenson (1957) analyses are confirmed and the Pierre does not contribute sulfate, then agriculture is the likely dominant source.

The historical samples focused on urban and agricultural land use but did consider the difference between mountain bedrock and basin alluvium geology. The mountain urban-crystalline land use water was consistent with the most upstream tributary waters before they were influenced by the sedimentary geologic units (Figure 6-16). The urban-alluvium water was equivalent to this study's Denver metro area water. The agriculture-alluvium water was consistent with the lower basin water samples in this study (Figure 6-16). Swenson (1957) was the only study to consider the underlying geology as an influence on the South Platte Rivers water quality.

A correlation matrix was used to investigate the dependence between multiple variables at the same time. The correlation coefficients between each variable and the others are provided in Figure 6-17. The concentrations of several elements were well correlated. The largest sulfate correlations were with calcium (0.91) and magnesium (0.88), uranium (0.81), and sodium (0.71). Sulfate was also correlated with downstream distance (0.68) and bicarbonate (0.69). Uranium was also correlated with bicarbonate (0.65), calcium (0.73), magnesium (0.69), sodium (0.69), and downstream distance (0.77). The low iron-sulfate correlation (0.16) also indicates that pyrite dissolution is not a significant influence on South Platte Basin water quality.

Figure 6-17. Water-quality correlation matrix showing the dependence between all variables.

These correlations suggest that dissolution of several geologic minerals may be contributing to salinity and overall water quality in the basin. The large sulfate concentrations could be due to several evaporite minerals and salt compounds. Gypsum (calcium sulfate), magnesium-sulfate salt, thenardite (sodium sulfate), and uranium-based salts have been identified in the basin's geologic units, which are likely sources (Otton and others, 2005; Boberg and Runnells, 1971; Swenson, 1957).

The major tributaries' water quality changed dramatically as the rivers entered and flowed through reaches underlain by the Pierre shale. Water-quality concentrations in the South Platte River stabilized after flowing through the Denver metro area and then had consistent increases as the river flowed through Laramie and Pierre formation reaches. The geologic influence on water quality is supported by formation correlations, molar ratios, and element correlations.

6.3.1 AGRICULTURAL INFLUENCE

Irrigated agriculture occurs along and near the sampled tributaries and the South Platte River (Figure 4-1). Soil amendments applied to croplands can contain sulfate, calcium, sodium, and chloride. These elements can migrate through the soils and into the groundwater where they migrate to the South Platte River and its tributaries. Distinguishing agriculture's influence from geologic, wastewater, and other water-quality influences is challenging. Agriculture is a source of nutrients, whereas the basin's geologic formations are not considered significant sources of nitrogen and phosphate. Phosphate minerals like apatite, which is a naturally occurring calcium phosphate mineral, could be investigated as geologic source.

There are several non-irrigated agriculture potential nutrient sources including sewage treatment plants, landscape fertilizer, animal waste, urban stormwater runoff, and faulty septic systems (CSU, 2023a). In this study area, agriculture and wastewater are likely the most significant nutrient sources. Nutrient pollution is considered excess nitrogen and phosphorus (CSU, 2023a). Wastewater could be a significant nutrient source in the Denver metro area. Wastewater contributions decrease downstream of the metro area and tributary confluences as the population density dramatically decreases.

Nitrogen is a critical plant nutrient, and most nitrogen is used and reused by plants within an ecosystem (Vitousek and others, 2002), so in undisturbed ecosystems little nitrogen migrates into groundwater, and concentrations are very low. When nitrogen fertilizers are applied in amounts greater than can be incorporated into crops or lost to the atmosphere, nitrate concentrations in groundwater can increase. The federal nitrate drinking water standard is 10 mg/L, which is EPA's Maximum Contaminant Level (MCL) to prevent methemoglobinemia (U.S. EPA, 2006).

There is considerable nitrate as nitrogen groundwater concentration variation in agricultural areas along the South Platte River and concentrations can exceed 5 mg/l (CSU, 2023c). The median groundwater nitrate concentration in an agricultural-alluvium study area was reported as 9.35 mg/l by Bruce and McMahon (1998). The nitrate as nitrogen concentrations in this study were generally less than 5 mg/l. The generally low nitrogen concentrations may indicate that applied nitrogen was being incorporated into crops or lost to the atmosphere, rather than reaching the hydrologic system as agricultural return flows.

Nitrate as nitrogen concentrations were low, less than 1 mg/l, in upper tributary reaches. A noticeable nitrogen increase to 2-5 mg/l was observed immediately downstream of wastewater treatment facilities in the Big Thompson and Saint Vrain rivers. Nitrogen concentrations were consistent in the tributaries after the urban influence occurred. Additionally, groundwater nitrogen was typically noticeably lower than the surface-water samples. This suggests that wastewater was the primary nitrogen source.

The South Platte River nitrogen increased in the Denver metro area, potentially due to wastewater facilities, and was generally less than 3 mg/l upstream of the tributary confluences. Downstream of the confluences, from Kersey to Snyder (SPR-7 to SPR-5; river miles 70 to 145) nitrogen increased to 3-8 mg/l. In this reach groundwater concentrations were typically greater than surface water. This may suggest an increase in agricultural return flow. Nitrogen concentrations tended to decrease downstream of Snyder, with about 2 mg/l at Julesburg (SPR-1).

6.3.2 SEASONALITY

The South Platte River and its tributaries flow in response to snow-melt runoff, storm-water runoff, wastewater effluent, groundwater, and irrigation return flow. The contribution from each of these sources can vary by season and by year. Fresh-water runoff from snowmelt and summer storms can temporarily reduce water-quality concentrations. Wastewater effluent is a relatively constant discharge throughout the year. Groundwater is also a significant component of streamflow throughout the year. As the term suggests, “irrigation return flow” is irrigation water that infiltrates through the unsaturated zone, reaches the groundwater system, and discharges into the South Platte River and its tributaries.

Water samples were collected during the irrigation season (August) and during the spring, pre-irrigation, pre-snowmelt runoff season (March-April). These sampling periods were selected to minimize the potential influence of temporary fresh-water sources like snowmelt and stormwater runoff. Differences between these seasonal samples could aid in distinguishing the influence of geologic formations and agricultural return flows on water quality.

River baseflow is the groundwater component of streamflow. During periods with no precipitation groundwater seepage into riverbeds can maintain perennial streams. During baseflow conditions the geologic influence on water quality should be most apparent.

Baseflow is most likely to occur prior to spring snowmelt runoff and after most of the previous irrigation season return flows have left the stream-alluvial aquifer system. However, the Basin’s rivers are highly managed with numerous ditch diversions, reservoirs, recharge basins, and augmentation methods. These water management measures occur during the irrigation and non-irrigation seasons. The travel time for irrigation return flows reaching the rivers can vary from days to months to years due to differences in groundwater flow-path distance and aquifer properties.

Groundwater and surface water-quality concentrations were generally higher during the spring sampling event. This was most evident in the tributary samples and less so in the South Platte River samples. The tributaries are more likely to have true baseflow conditions during the spring due to fewer water-management diversions and less agricultural return flow.

Long-term monitoring would be required to define baseflow conditions in the Basin's rivers. Water-level and water-quality data from alluvial groundwater monitoring wells can characterize groundwater baseflow.

Another seasonal influence is the impact of road deicing compounds and related runoff on water quality. Two samples of what is termed "road muck" were analyzed. These Fort Collins vehicle ice samples were collected from two March 2022 snowstorms. The samples were predominately sodium chloride with 20 and 28 percent magnesium. These road muck samples had more sodium and more chloride than any of the water samples and about the same percentage of magnesium. (Figure 6-18).

Figure 6-18. Road de-icing runoff ions compared to groundwater and surface water samples

7. SUMMARY

The geologic influences on water quality in the South Platte River and its major tributaries, the Saint Vrain, Big Thompson, and Cache la Poudre rivers were investigated in this study. Hyporheic zone samples were also collected to gain insight into the groundwater contribution to stream water quality. Water samples were collected during the summer irrigation season (August 2021) and during the spring, pre-runoff season (March-April, 2022). Laboratory water analyses included the major ions and several trace elements (boron, barium, bromide, iron, manganese, selenium, and uranium).

After exiting the mountains, the South Platte River flows along the western edge of the Denver Basin, which is a bowl-shaped geologic structural syncline (Figure 3-1). There are four principal bedrock aquifers, the Laramie-Fox Hills, Arapahoe, Denver, and Dawson, have generally good water quality and do not contribute significantly to salinity. The exception may be the Laramie-Fox Hills aquifer that consists of the Laramie Formation, Fox Hills Sandstone, and upper Pierre shale. Further downstream near, the White River formation and the Ogallala formation outcrop from Hillrose to past Julesburg and they tend to have good water quality.

The South Platte River streambed alluvium overlies the bedrock formations and forms the alluvial aquifer. Groundwater flows through the alluvial aquifer and supplies water to the South Platte River. This groundwater occurs largely due to irrigation water infiltrating through agricultural soils to the water table where it moves laterally to the river.

The South Platte has a sodium-chloride type water in the Denver metro area, likely due to the influence of wastewater effluent. The bedrock aquifers in this area have calcium bicarbonate and sodium bicarbonate water. The water evolves into a mixed calcium-sodium sulfate type water as it flows downstream.

Salinity (TDS) in the South Platte was about 700 mg/l as the river exited the Denver metro area and it steadily increased downstream to about 1,440 mg/l near Julesburg. An instantaneous South Platte River total salt load of 1,000 tons per day was calculated from the streamflow and TDS concentration near Kersey. The water pH ranged from about 7 to about 9.7 and generally increased downstream.

The major tributaries flow out of the mountains, across the Pierre shale, and through Front Range cities before joining the South Platte. Other studies have found that gypsum and thenardite were present in the Pierre shale, and the Mancos Shale, its western slope equivalent (Tuttle and Grauch, 2009; Otton and others, 2005). These salts were the dominant sulfate sources in soils and surface water derived from the Pierre.

The dissolution of gypsum and thenardite in the Pierre shale are suspected to be sulfate, calcium, and sodium contributors. Sulfate concentrations increased from less than 100 mg/l to as high as 780 mg/l along the Cache la Poudre River as it flowed through the Pierre shale. Sulfate increases were also seen in the Saint Vrain and Big Thompson rivers. Groundwater typically had higher sulfate than the surface water. Sulfate concentrations continued to increase in the South Platte River after the tributary confluences as the river flowed across the Pierre shale again with a maximum of 800 mg/l. The sulfate percentage of TDS increased from 10-20-percent to about 60-percent in each of the rivers sampled.

The sulfate, calcium, and sodium increase in the South Platte and the tributaries were too large to be solely due to dissolution of gypsum and thenardite in the Pierre shale. Each of these rivers also flow through irrigated agriculture areas. Soil amendments and fertilizers used for agricultural purposes are potential sources that could account for these higher-than-expected concentrations.

Trace elements, boron, barium, bromide, and selenium were generally found in low concentrations. However, eight manganese samples were 1-3 mg/l, which exceeded the 0.05 mg/L secondary drinking water standard.

There were several samples that exceeded the iron secondary drinking water standard of 0.3 mg/L. During the irrigation season (August) 15 samples exceeded the standard with 13 groundwater samples exceeding during the spring. The high concentrations occurred in the Saint Vrain (8), Cache la Poudre (9), Big Thompson (3), South Platte (2), Box Elder (3), and Bijou Creek (1). These samples were generally collected in areas with the Pierre shale, Fox Hills, and Laramie formations.

Uranium concentrations gradually increase downstream and start to exceed the drinking water standard of 30 µg/l in the reach between Weldona and Snyder, where Bijou and Beaver Creeks join the South Platte River. South Platte River uranium concentrations continue to increase downstream reaching a maximum of about 55 µg/l near Julesburg. The largest uranium concentration was in Beaver Creek groundwater at about 68 µg/l. These uranium concentrations are consistent with the 40 µg/l at Weldona and 67 µg/l at Balzac reported by Boberg and Runnells (1971).

This study has found evidence that the South Platte Basin geology plays a significant role in the basin's water quality. Geologic units are a far reaching, non-point source of salts and trace elements that create a water-quality baseline upon which other sources are added. Wastewater in the Denver metro area and Front Range cities contribute constituents, but some of these constituents are likely at lower concentrations than are present in the rivers.

Irrigated agriculture in the tributaries and lower basin also impact water quality. Agricultural return flows dominate the hydrologic system. These return flows contribute to streamflow and transport chemicals leached from farmland soils into the underlying groundwater. The expansive network of ditches, recharge basins, and reservoirs also play a role in the basin's water quality. Interactions between geology, irrigated agriculture, water storage, and water conveyance add to the hydrologic-system complexity.

Parsing the contributions or loading due to geology, wastewater, irrigated agriculture, livestock, urban runoff, and industrial sources will require many years of detailed study. It is safe to say that each of these sources plays a role in the basin's salinization and overall water quality. However, there are mitigating measures that can be implemented today to reduce the impact of each of these sources. It will require commitment and resources from all the basin's water users to improve the basin's water quality.

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TABLES

Table 8-1. Water-quality laboratory analyses

Ward Laboratories		Eurofins Laboratory
Laboratory pH	Magnesium (Mg)	Barium (Ba), Dissolved (ug/L)
Sodium Adsorption Ratio (SAR)	Chloride (Cl)	Selenium (Se), Dissolved (ug/L)
Adjusted Sodium Adsorption Ratio (SAR)	Bicarbonate (HCO_3)	Uranium (U), Dissolved (ug/L)
Electrical Conductivity (mmho/cm)	Carbonate (CO_3)	Chloride (Cl)
Total Dissolved Solids (TDS) Estimated	Sulfate as S (SO_4-S)	Bromide (Br)
Total Dissolved Solids (TDS)-Gravimetric	Sulfate (SO_4)	Cl/Br Ratio
Cations (me/L)	Fluoride (F)	Na/Br Ratio
Anions (me/L)	NO_3-N	
Total Alkalinity ($CaCO_3$)	Ortho Phosphorus (P)	
Total Hardness ($CaCO_3$)	Boron (B)	
Sodium (Na)	Total Iron (Fe)	
Potassium (K)	Manganese (Mn)	
Calcium (Ca)		

Units in milligrams per liter unless otherwise noted; me/L: milliequivalent per liter; ug/L: microgram per liter; mmho/cm: millimho per centimeter

Table 8-2. Salinity measurement units and conversion factors for water-quality analyses

To Convert	Multiply By	To Obtain
mg/l	1.0	ppm
TDS, ppm	~2.72	TDS, lb/ac-ft
dS/m	100	mS/m
dS/m	1,000	µS/cm
dS/m	1.0	1 mmho/cm
mmho/cm	1,000	1 µmho/cm
µmho/cm	0.001	dS/m
µmho/cm	0.001	mmhos/cm
Electrical Conductivity (water) <5 dS/m (approximate)		
dS/m	640	TDS, mg/l
mS/cm	640	TDS, mg/l
mS/m	6.4	TDS, mg/l
µS/cm	0.64	TDS, mg/l
Electrical Conductivity (water) >5 dS/m (approximate)		
dS/m	800	TDS, mg/l
mS/cm	800	TDS, mg/l
mS/m	8.0	TDS, mg/l
µS/cm	0.8	TDS, mg/l

dS/m: deciSiemen per meter; mS/m: milliSieman per meter; µS/cm: microSieman per centimeter; mg/l: milligram per liter; ppm: parts per million; mmho/cm: millimho per centimeter; µmho/cm: micromho per centimeter; TDS: Total Dissolved Solids

Table 8-3. Generalized stratigraphy in the northern Front Range and Denver Basin areas

[from Scott and Cobban, 1965; Colton, 1978; and Trimble and Machette, 1979]

Formation	Age	Comments
Alluvium	Pleistocene and Holocene	Occupies modern stream valleys.
Eolian sand and loess	Pleistocene and Holocene	Covers most upland areas and older stream-valley terrace deposits.
Older gravel deposits on uplands	Pleistocene	Occurs irregularly in upland areas.
Denver and Arapahoe Formations	Upper Cretaceous and lower Tertiary	Claystone, siltstone, tuffaceous sandstone and conglomerate. Nonmarine.
Laramie Formation	Upper Cretaceous	Claystone, shale, sandy shale, sandstone, coal near base, lignite near top. Mostly nonmarine.
Fox Hills Sandstone	Upper Cretaceous	Coarsening upward sequence of shale, silty sandstone, and sandstone; local thin coal. Nonmarine.
Pierre shale—upper transition member	Upper Cretaceous	Sandstone, shaly sandstone, sandy shale. Marine.
Pierre shale—lower shale and sandstone members	Upper Cretaceous	Silty shale, shale, claystone, sandy siltstone, sandstone. Marine.
Dakota Sandstone	Early Cretaceous	Sandstone, mudstone, claystone, shale
Fountain Formation	Pennsylvanian	Conglomerate and sandstone

FIGURES

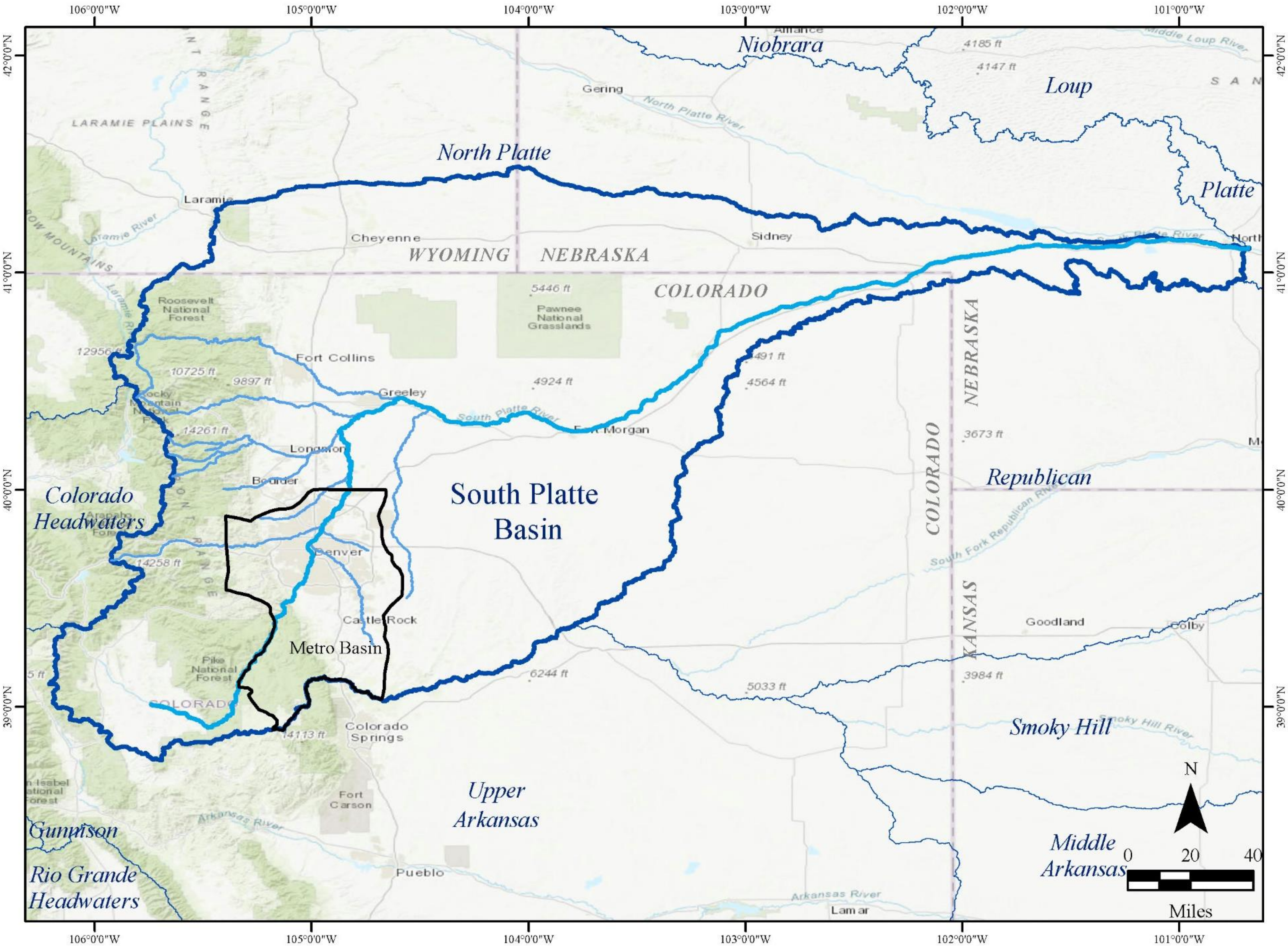

Figure 1-1. South Platte Basin and major tributaries

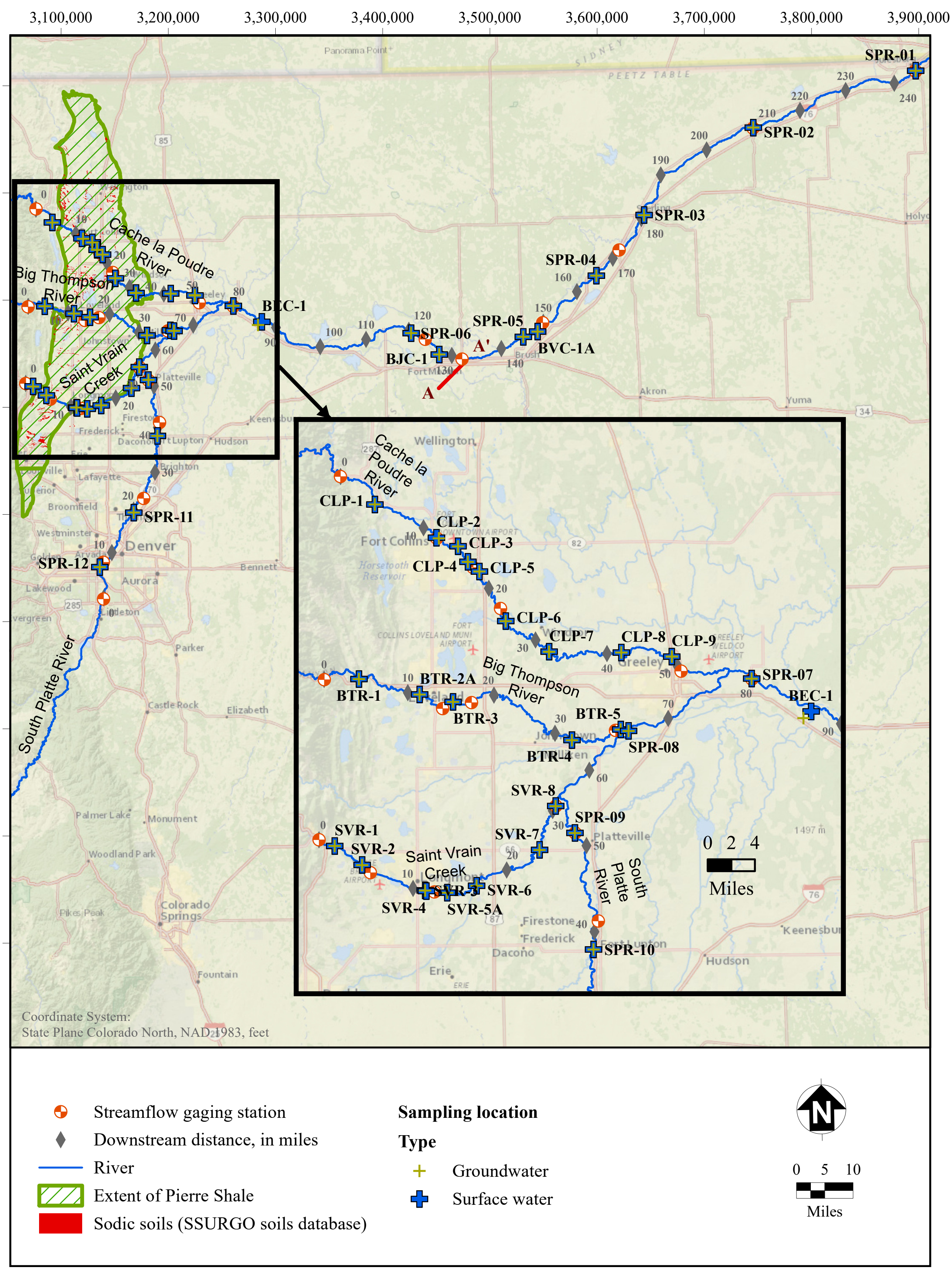

Figure 2-1. Water-quality sampling sites

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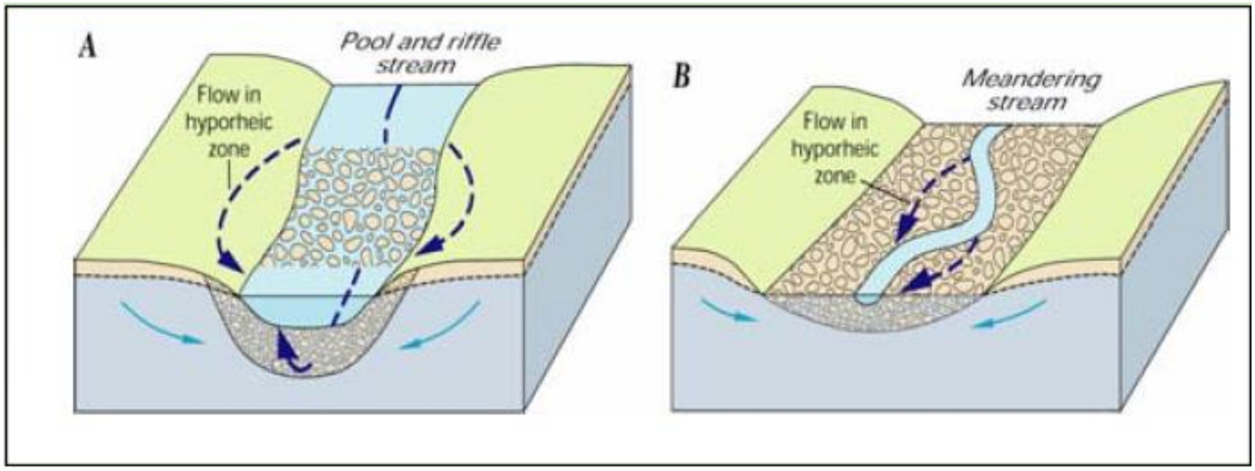


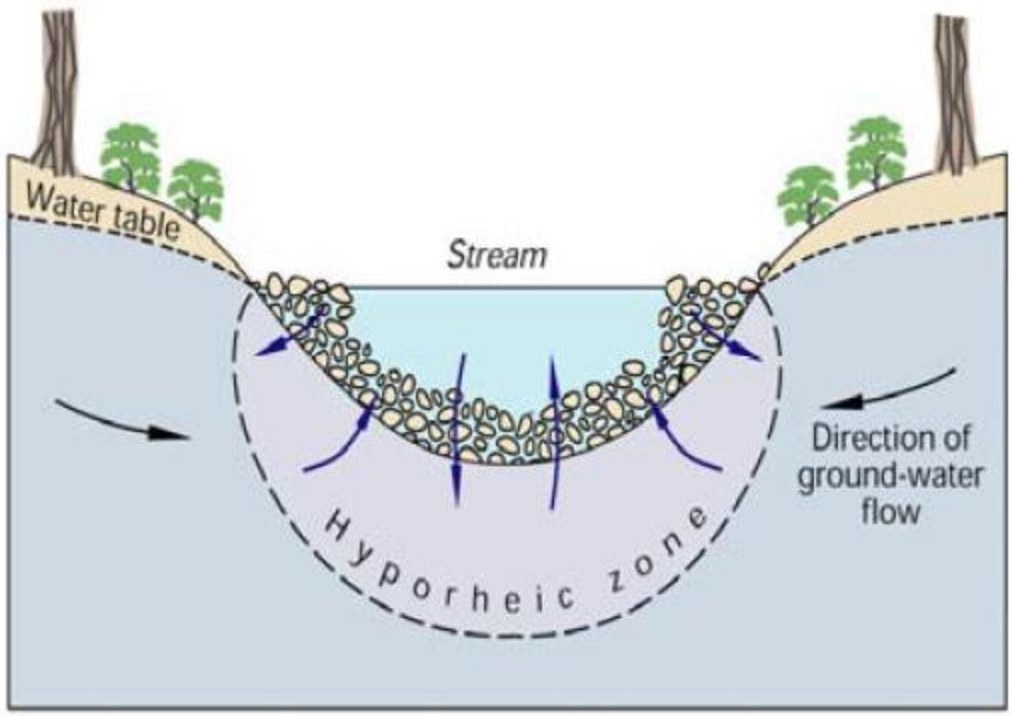


Figure 2-2. Hyporheic zone groundwater flow (Hayashi and Donald Rosenberry, 2017)

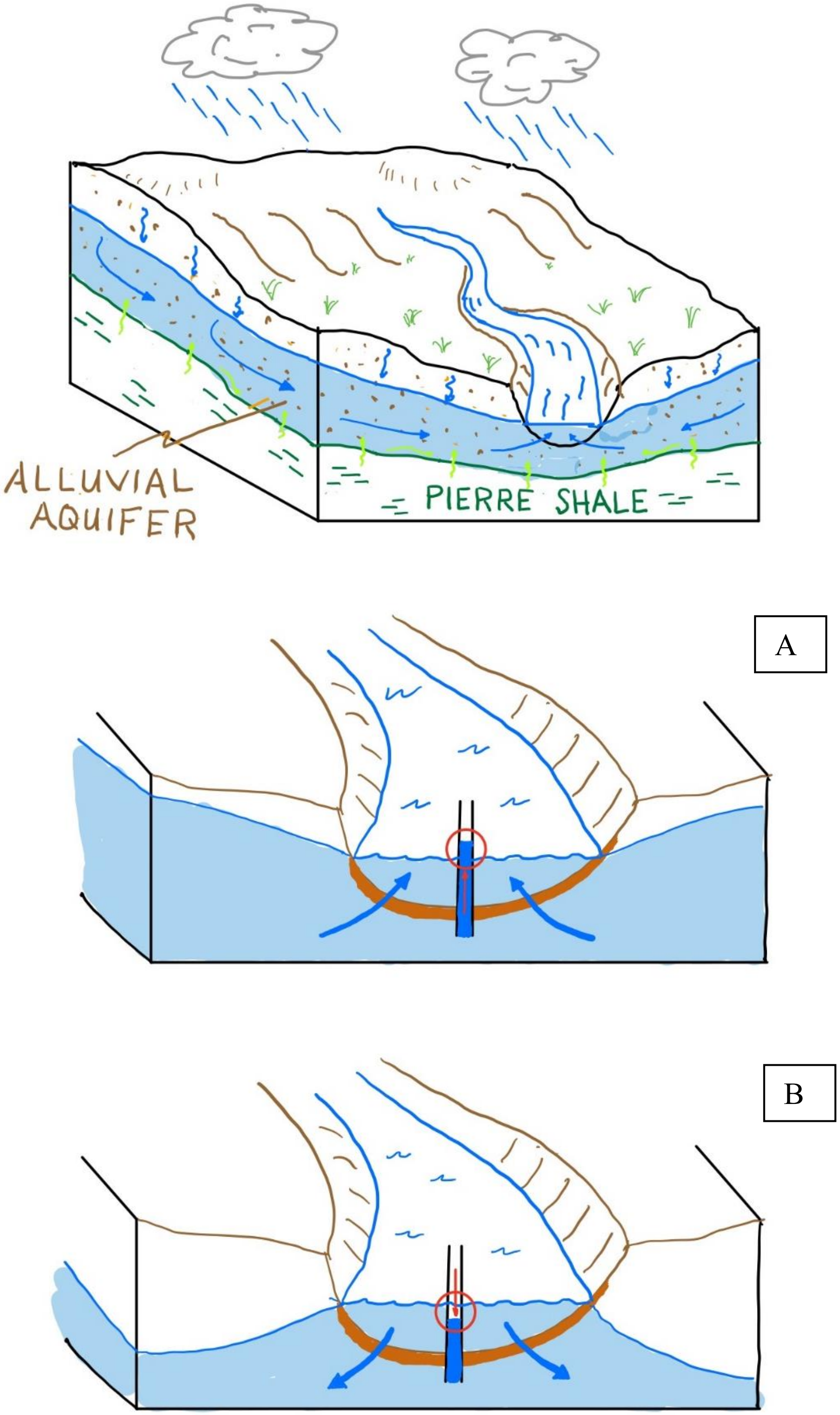


Figure 2-3. Pierre shale and alluvial aquifer interaction with (A) gaining and (B) losing stream conditions measured by mini-piezometers

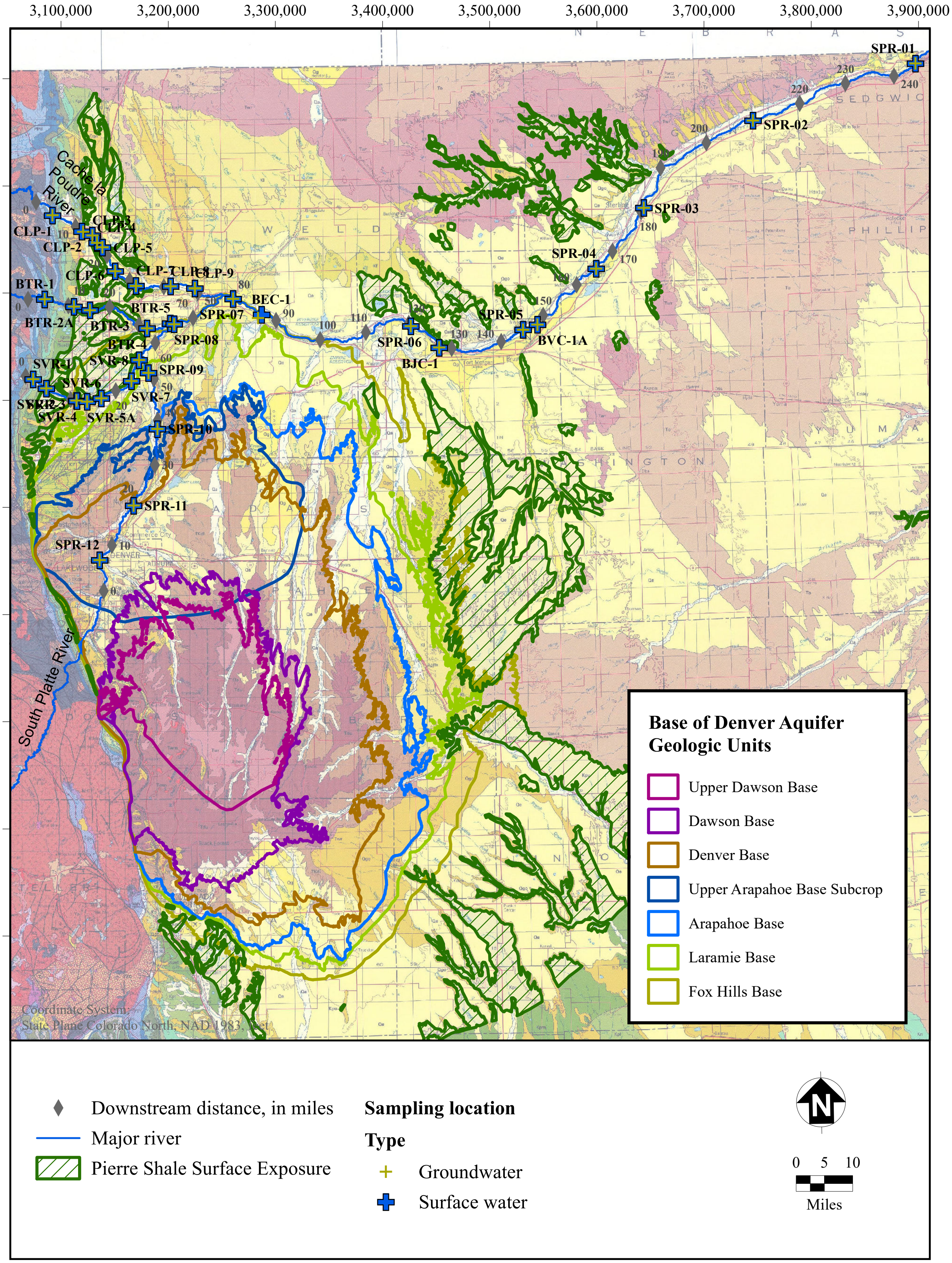
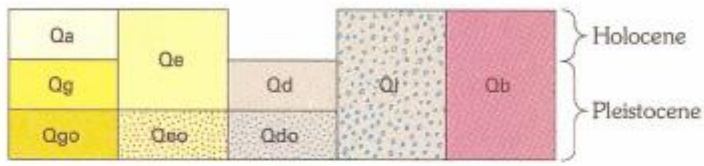


Figure 3-1. South Platte Basin geology with Denver Basin Aquifer and Pierre shale (Tweto, 1979)

Figure 3-1. CONTINUTED-South Platte Basin geologic map with major formations highlighted and sampling locations

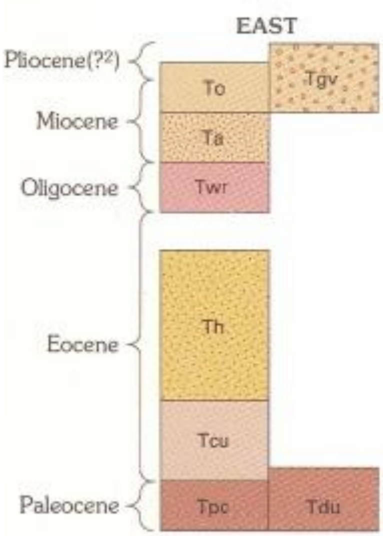
Geologic Map of Colorado Explanation (Tweto, 1979)



UNCONSOLIDATED SURFICIAL DEPOSITS AND ROCKS OF QUATERNARY AGE

Qa	MODERN ALLUVIUM—Includes Piney Creek Alluvium and younger deposits
Qg	GRAVELS AND ALLUVIUMS (PINEDALE AND BULL LAKE AGE)—Includes Broadway and Louviers Alluviums
Qgo	OLDER GRAVELS AND ALLUVIUMS (PRE-BULL LAKE AGE)—Includes Slocum, Verdos, Rocky Flats, and Nussbaum Alluviums in east, and Florida, Bridgetimber, and Bayfield Gravels in southwest
Qe	EOLIAN DEPOSITS—Includes dune sand and silt and Peoria Loess
Qeo	OLDER EOLIAN DEPOSITS—Includes Loveland Loess
Qd	GLACIAL DRIFT OF PINEDALE AND BULL LAKE GLACIATIONS—Includes some unclassified glacial deposits
Qdo	OLDER GLACIAL DRIFT (PRE-BULL LAKE AGE)
Ql	LANDSLIDE DEPOSITS—Locally includes talus, rock-glacier, and thick colluvial deposits
Qb	BASALT FLOWS (AGE <1.8 M.Y.[1])

SEDIMENTARY ROCKS OF TERTIARY AGE



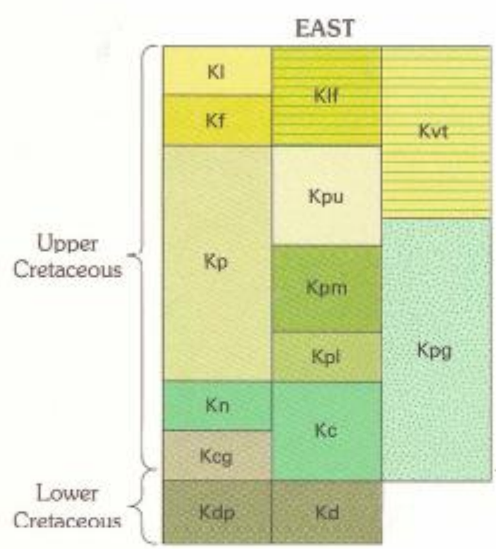
EAST

To	OGALLALA FORMATION—Loose to well-cemented sand and gravel
Tgv	BOULDERY GRAVEL ON OLD EROSION SURFACES IN FRONT RANGE AND NEVER SUMMER MOUNTAINS
Ta	ARIKAREE FORMATION—Sandstone; contains abundant volcanically derived material
Twr	WHITE RIVER FORMATION OR GROUP—Ashy claystone and sandstone. Includes Castle Rock Conglomerate in region southeast of Denver
Th	HUERFANO FORMATION—Shale and sandstone. Includes Farisita Conglomerate in northwestern Huerfano County
Tcu	CUCHARA FORMATION—Sandstone and shale
Tpc	POISON CANYON FORMATION—Arkosic conglomerate, sandstone, and shale
Tdu	UPPER PART OF DAWSON ARKOSE—Arkosic sandstone, conglomerate, and shale. Includes Green Mountain Conglomerate south of Golden

Figure 3-1. CONTINUTED-South Platte Basin geologic map with major formations highlighted and sampling locations

Geologic Map of Colorado Explanation (Tweto, 1979)

SEDIMENTARY ROCKS OF CRETACEOUS AGE



EAST

Kl	LARAMIE FORMATION—Shale, claystone, sandstone, and major coal beds
Kf	FOX HILLS SANDSTONE
Klf	LARAMIE FORMATION AND FOX HILLS SANDSTONE
Kvt	VERMEJO FORMATION (SHALE, SANDSTONE, AND MAJOR COAL BEDS) AND TRINIDAD SANDSTONE
Kp	PIERRE SHALE, UNDIVIDED
Kpu	Upper unit
Kpm	Middle unit—In Boulder-Fort Collins area, contains Richard, Larimer, Rocky Ridge, Terry, and Hygiene Sandstone Members; elsewhere, shale between zones of *Baculites reesidei* and *B. scotti*
Kpl	Lower unit—Sharon Springs Member (organic-rich shale and numerous bentonite beds) in lower part
Kn	NIOBRARA FORMATION—Calcareous shale and limestone
Kcg	CARLILE SHALE, GREENHORN LIMESTONE, AND GRANEROS SHALE
Kc	COLORADO GROUP—Consists of Niobrara Formation (Kn) and either Benton Shale or Carlile, Greenhorn, and Graneros Formations (Kcg)
Kpg	PIERRE SHALE (Kp), NIOBRARA (Kn), AND CARLILE, GREENHORN, AND GRANEROS (Kcg) FORMATIONS, UNDIVIDED
Kdp	DAKOTA SANDSTONE AND PURGATOIRE FORMATION—Sandstone and shale
Kd	DAKOTA SANDSTONE OR GROUP

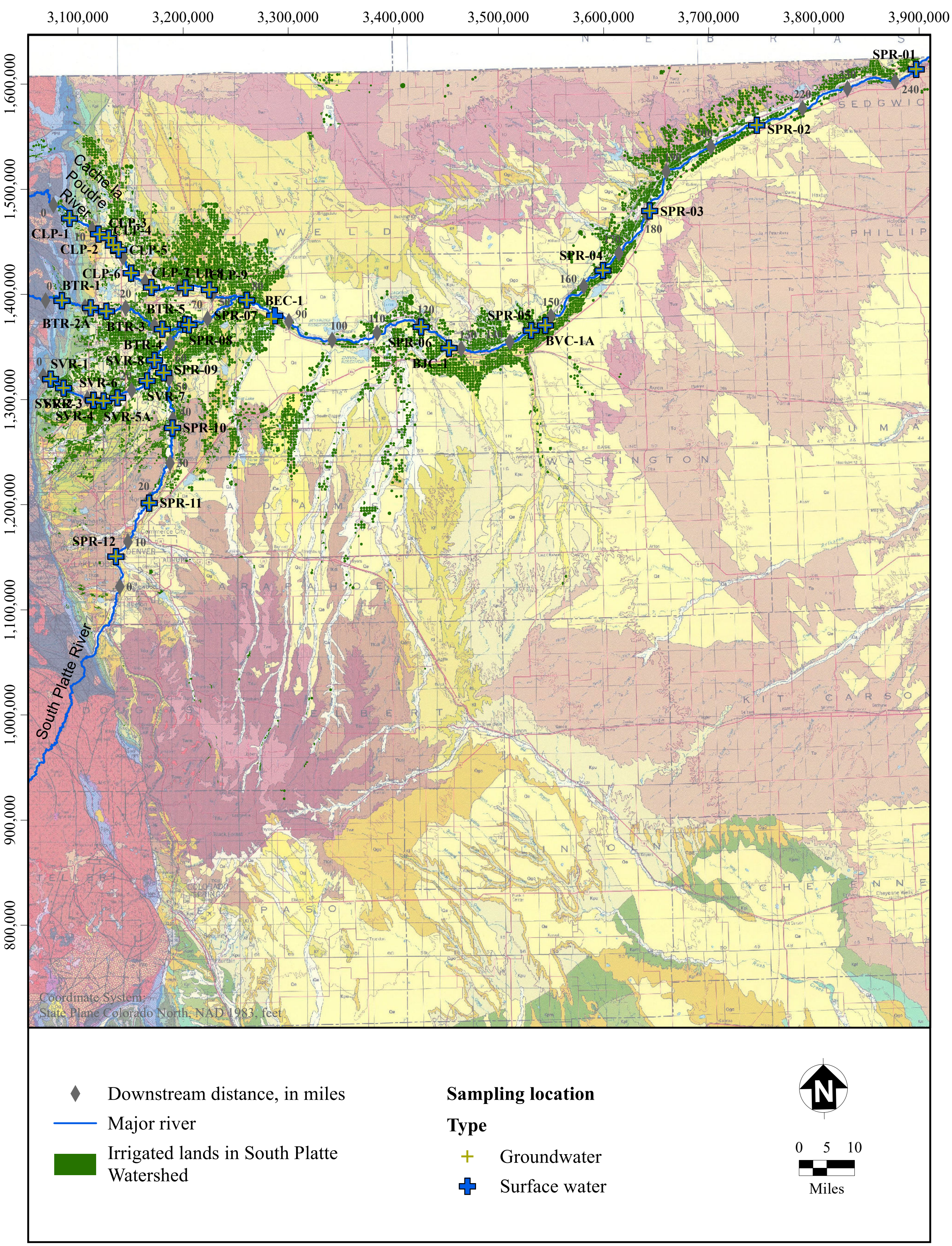


Figure 4-1. Irrigated land in the South Platte River basin

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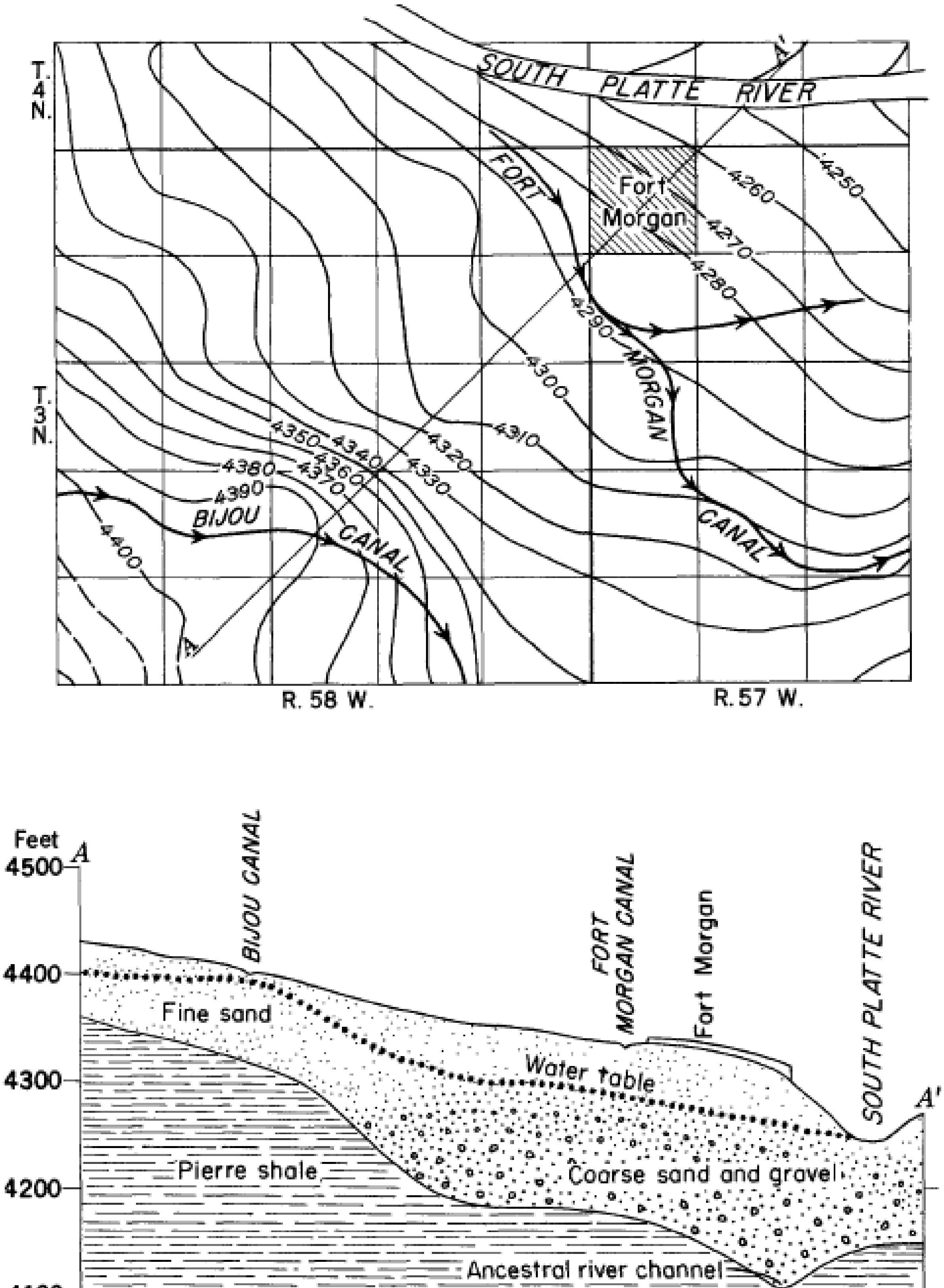


Figure 4-2. Map and section showing groundwater flow to the South Platte River (Bjorklund and Brown, 1957)

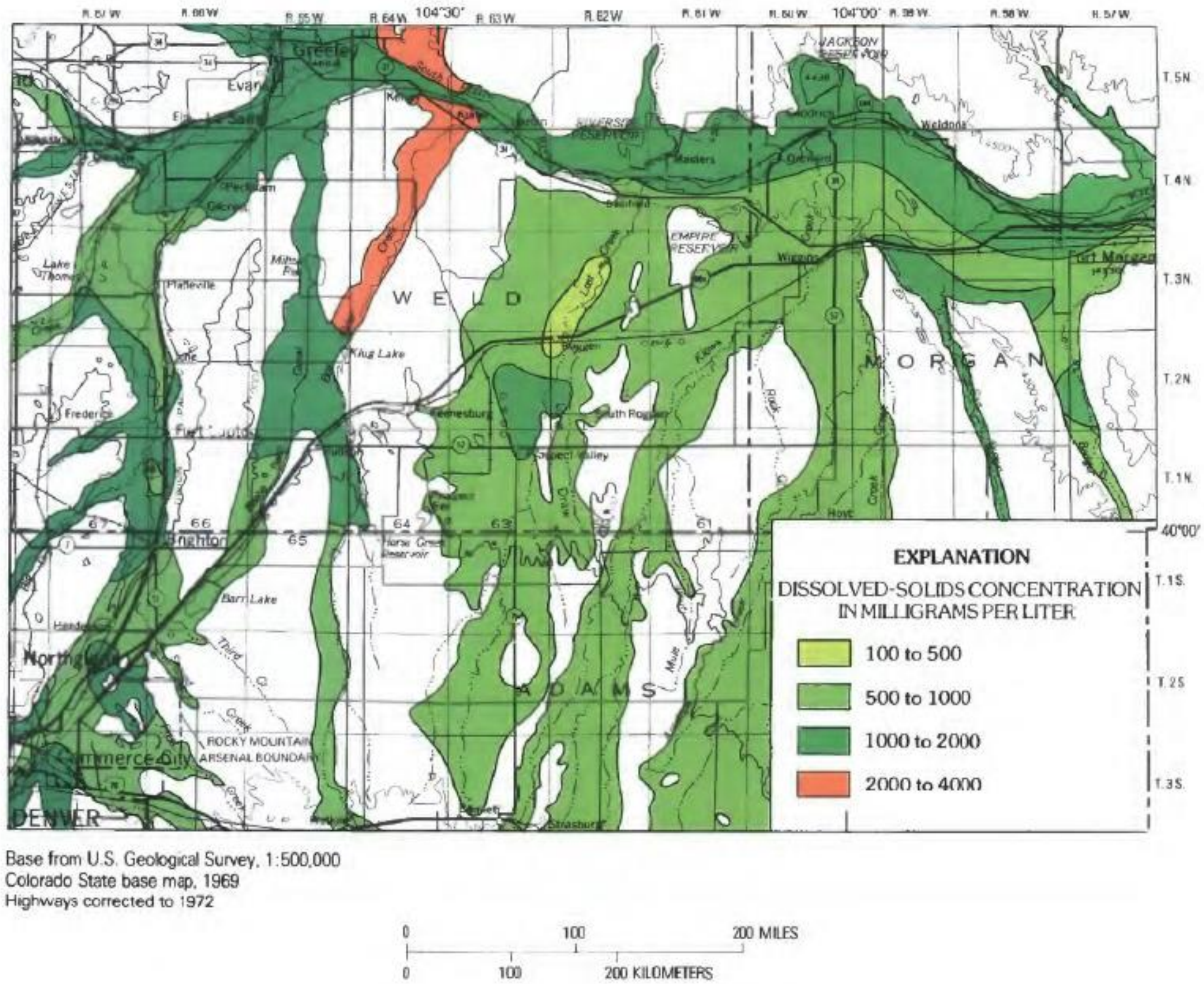


Figure 5-1. Total Dissolved Solids concentrations in the alluvial aquifer (Robson, 1989)

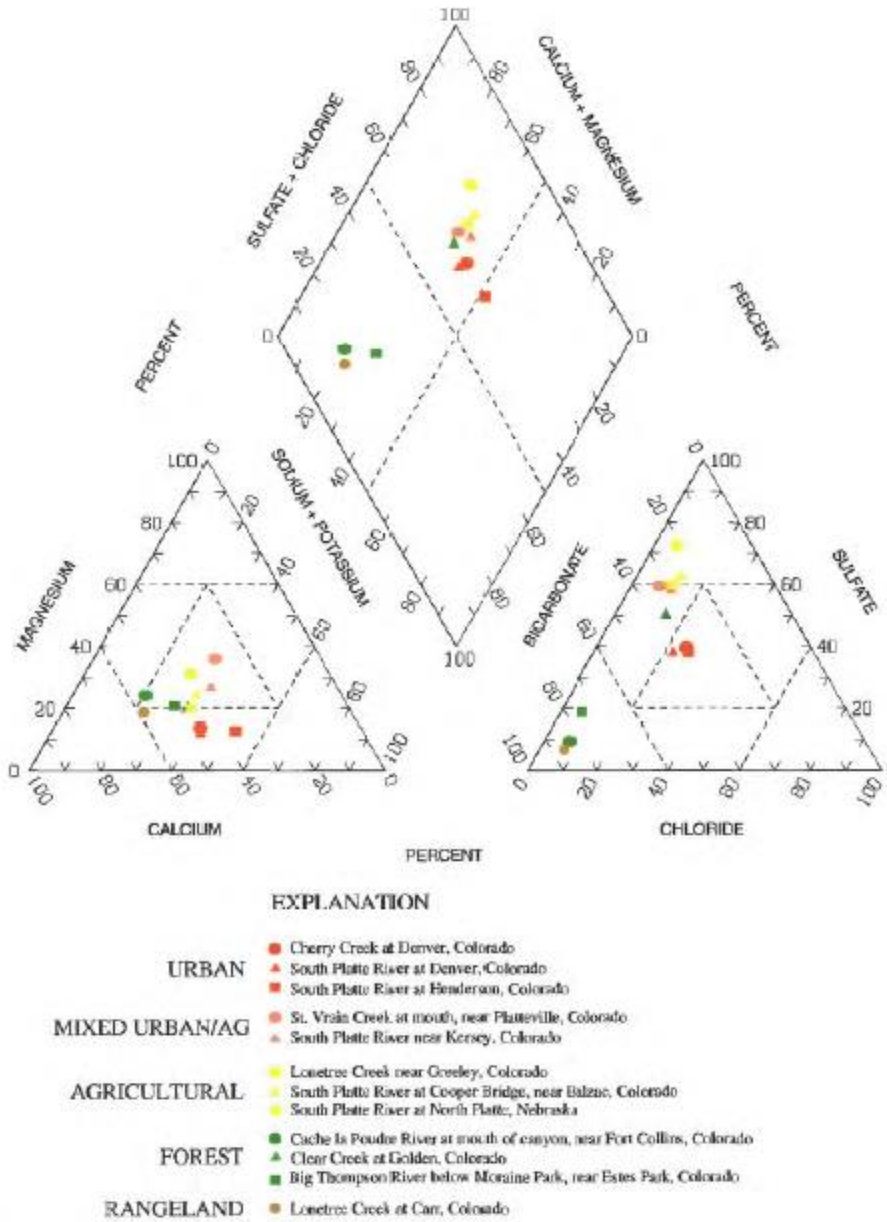


Figure 5-2. Piper diagram with major-ion composition of rivers and streams at land-use study sites (Litke and Kimbrough, 1998)

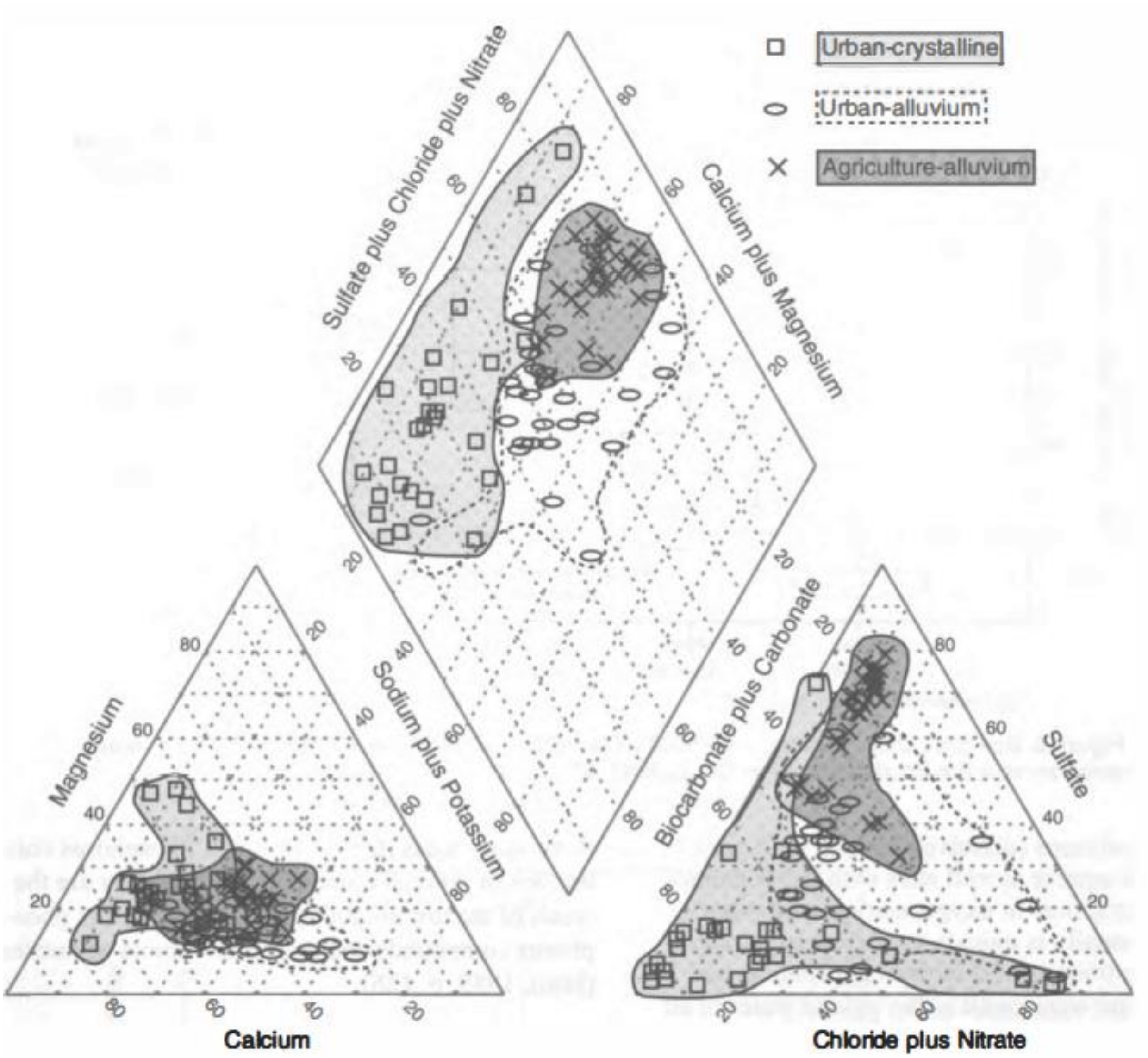


Figure 5-3. Piper diagram with major-ion composition in groundwater at three land-use areas (Bruce and McMahon, 1998)

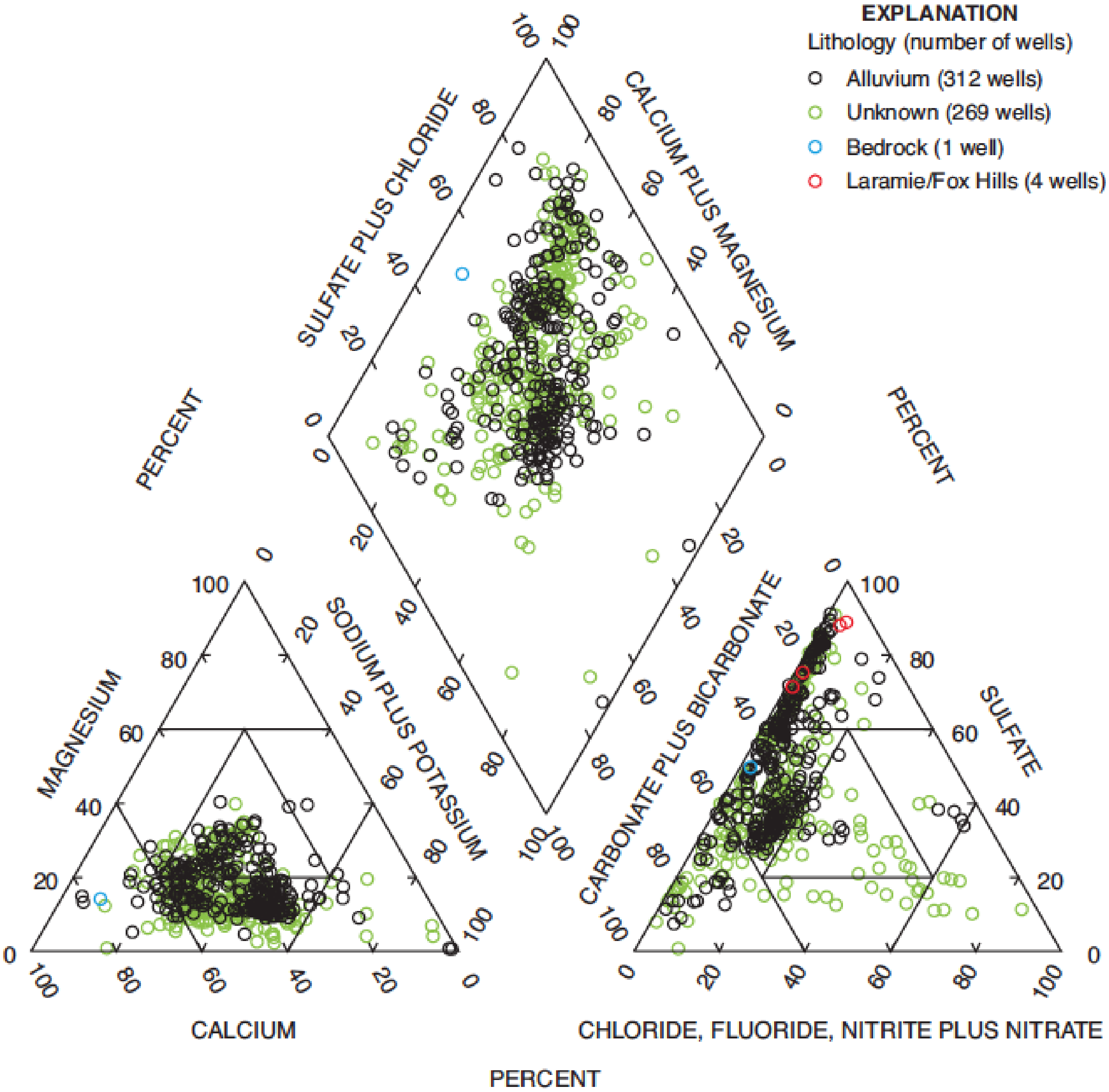
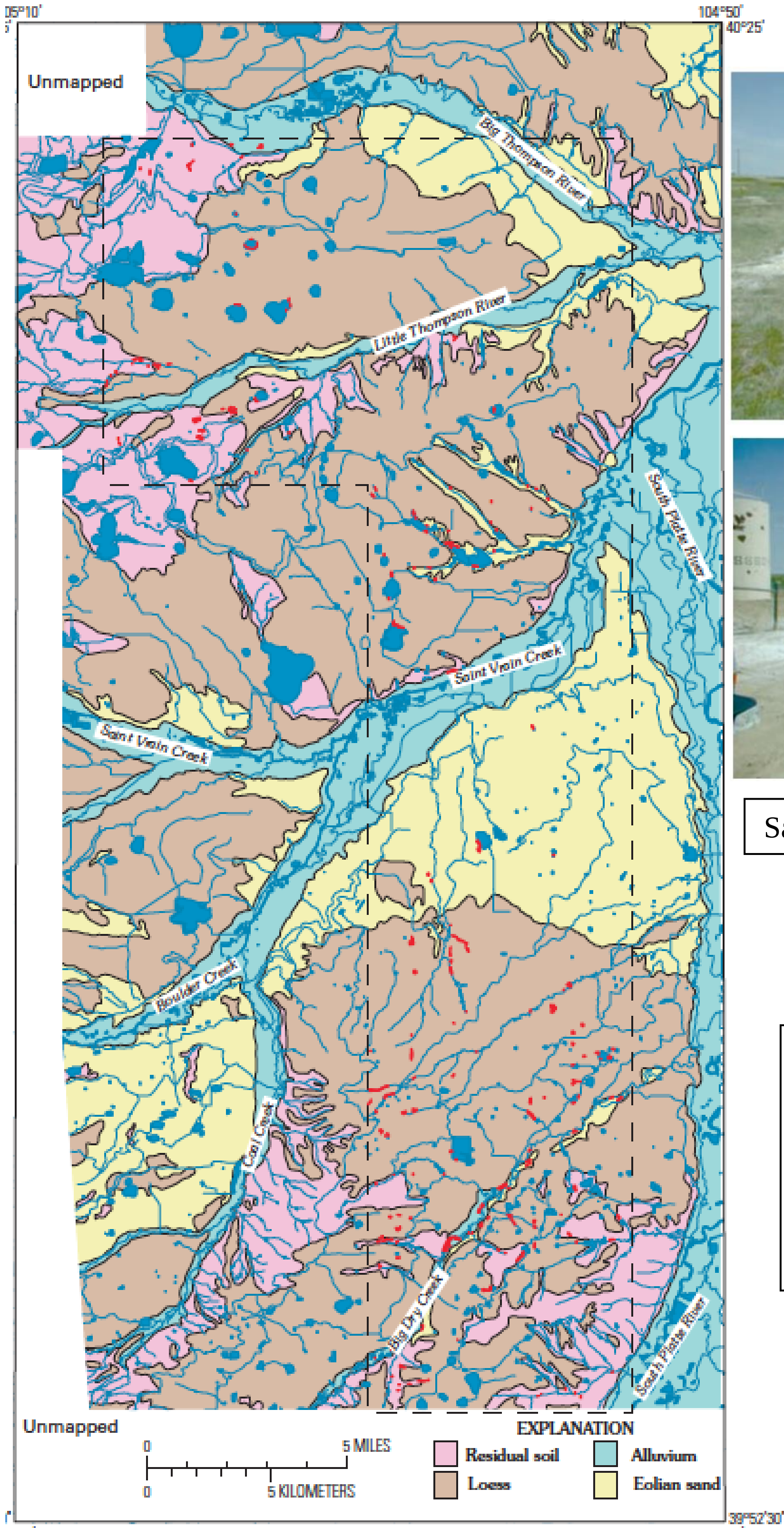


Figure 5-4. Piper diagram with major-ion composition in groundwater samples along the Front Range (Flynn, 2003)



Saline soils in the mapped area

Residual soil and loess areas are underlain by the Pierre Shale, which is a primary source of saline soils that contribute salts to the South Platte River tributaries along the Front Range.

Figure 5-5. Saline soils mapped in the northern Front Range area (Otton and others, 2005)

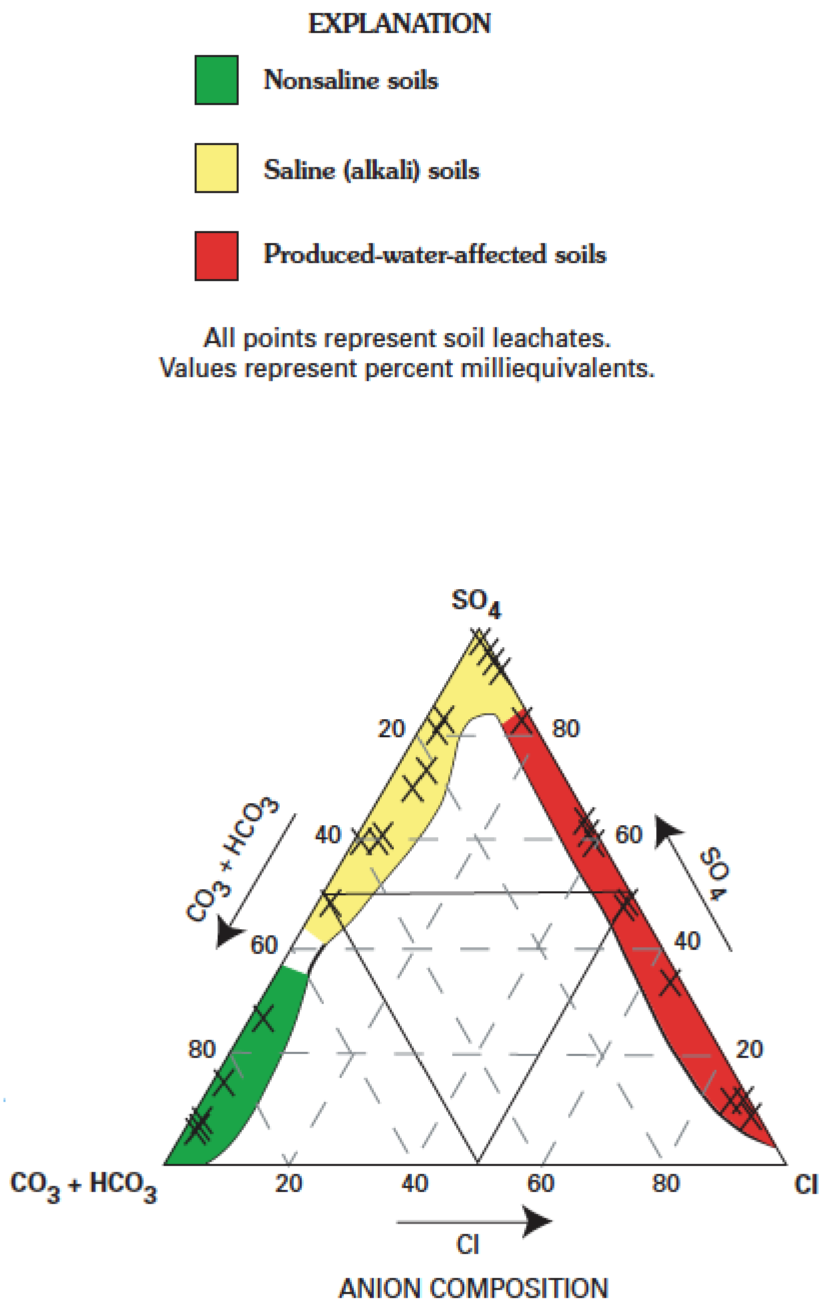


Figure 5-6. Anion percentages from saline soil leacheates in the Front Range (Otton and others, 2005)

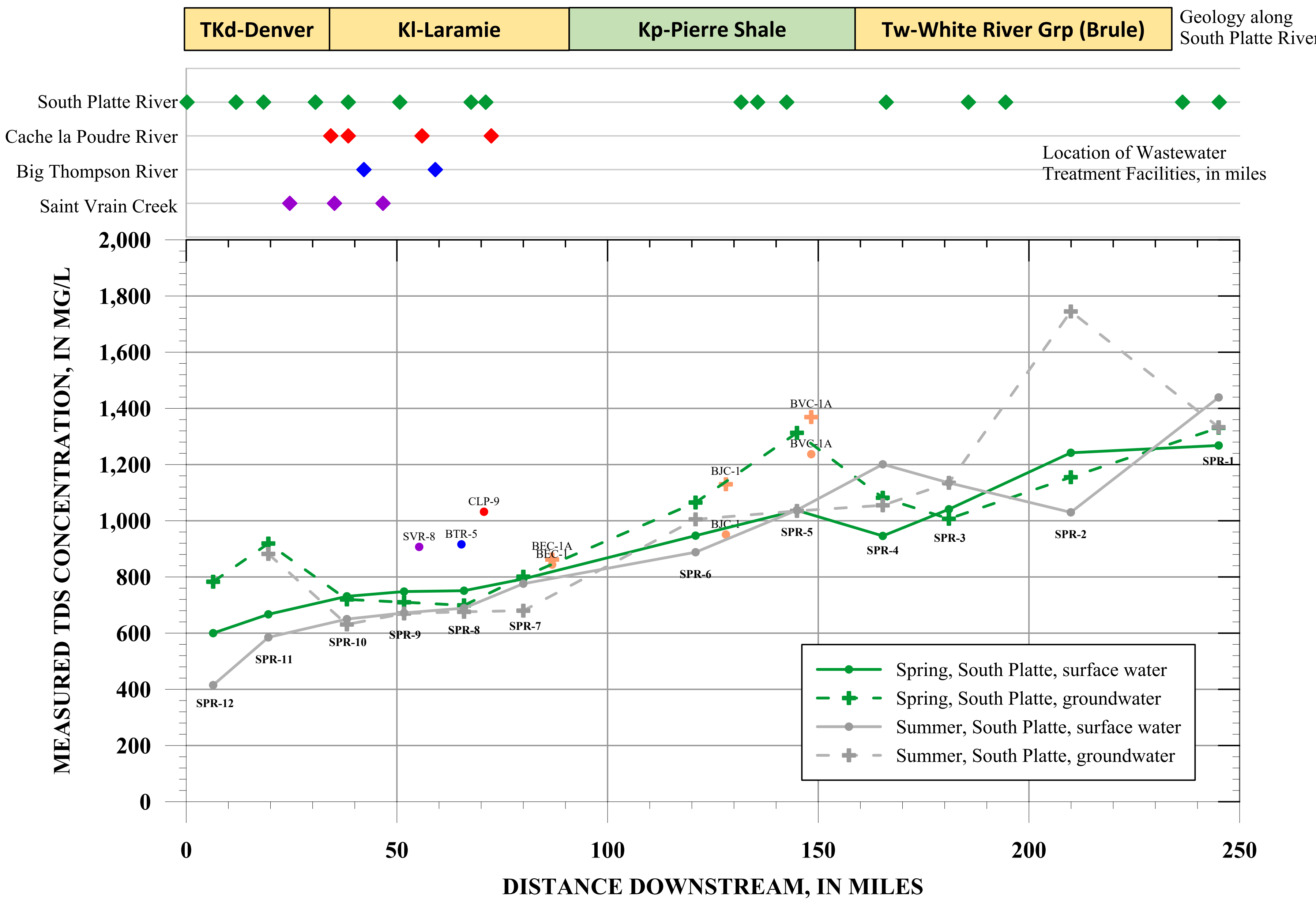


Figure 6-1. Total dissolved solids concentrations along the South Platte River

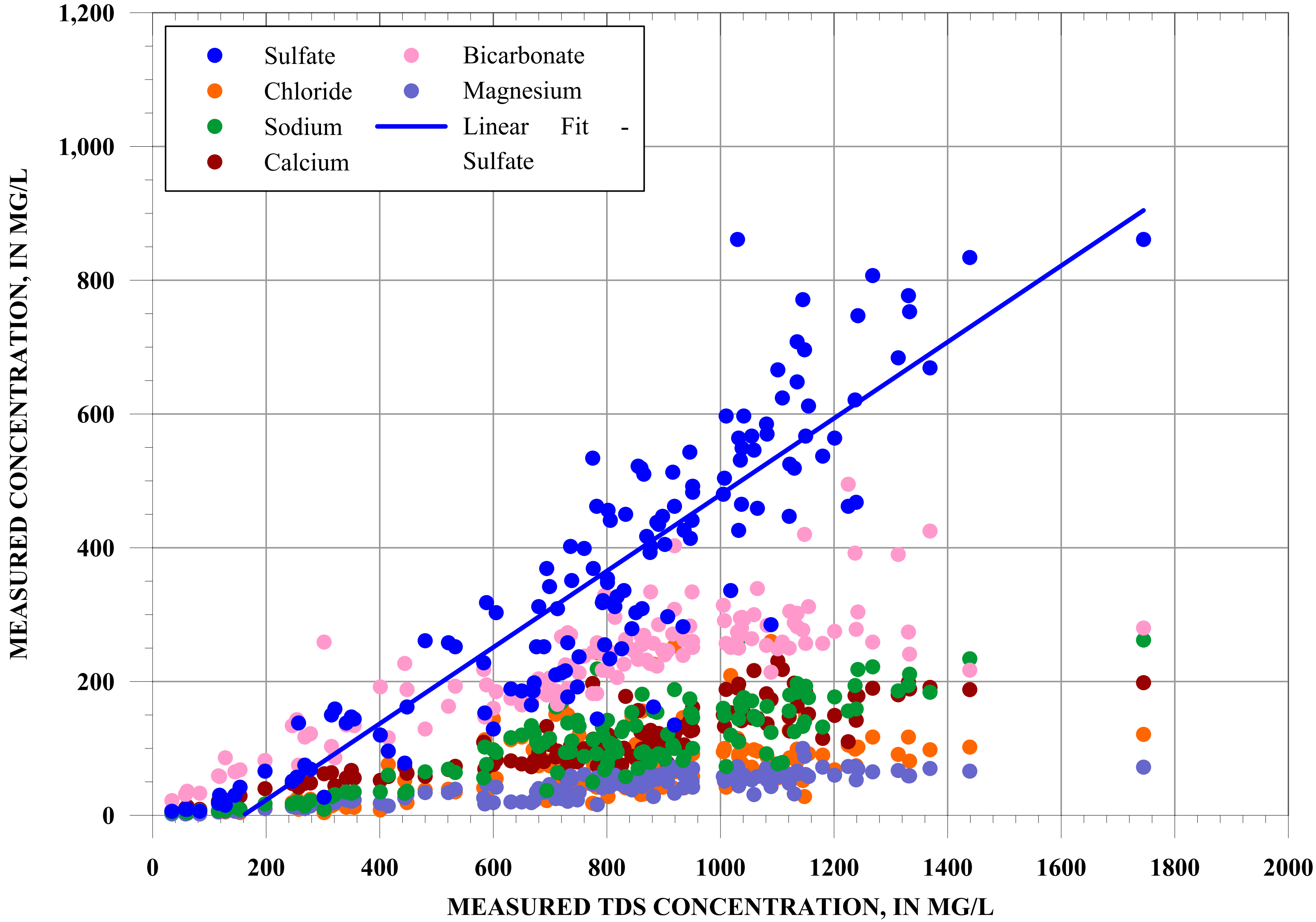


Figure 6-2. Increasing Total Dissolved Solids and major ion concentrations

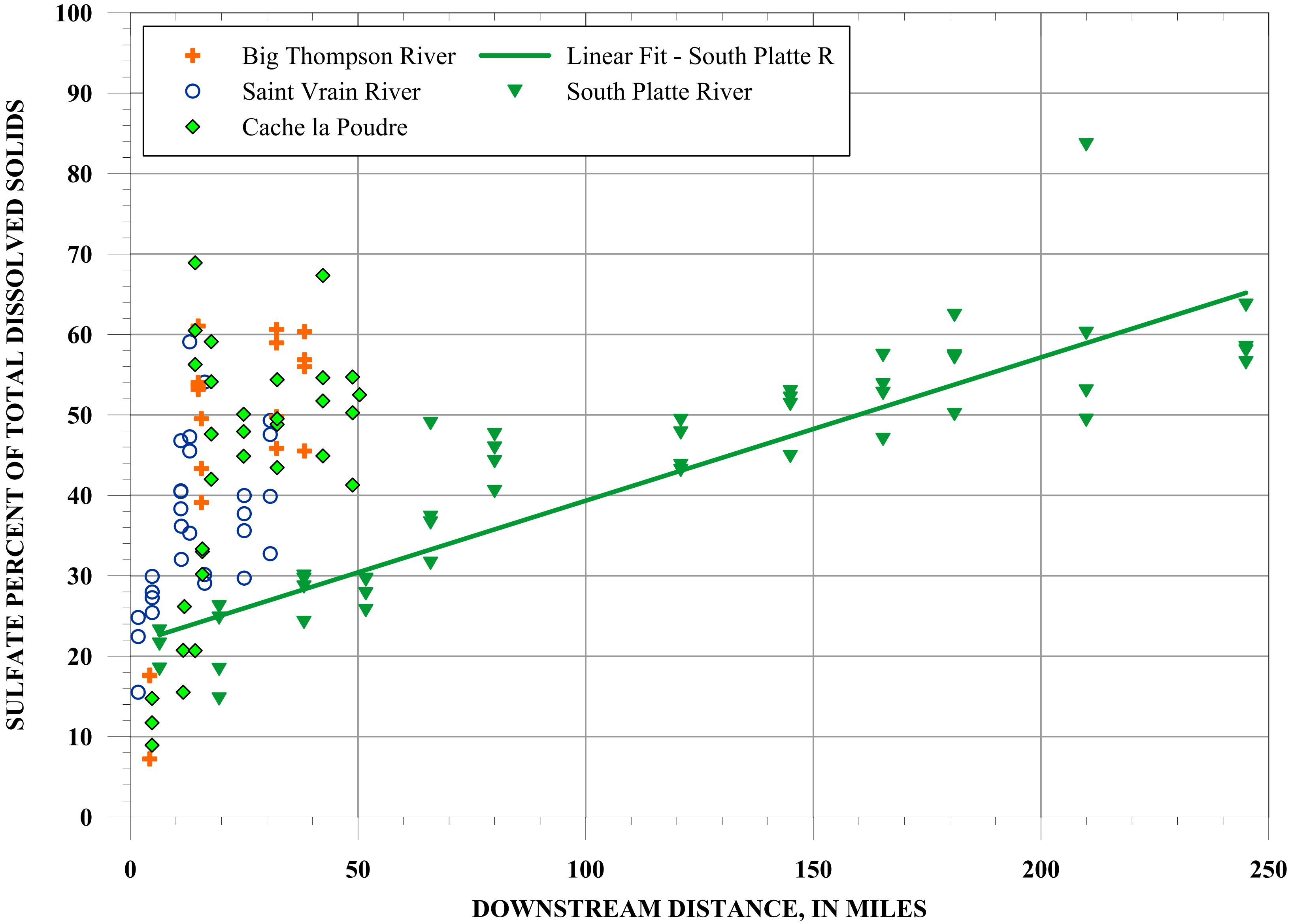


Figure 6-3. Sulfate percentage of Total Dissolved Solids with downstream distance

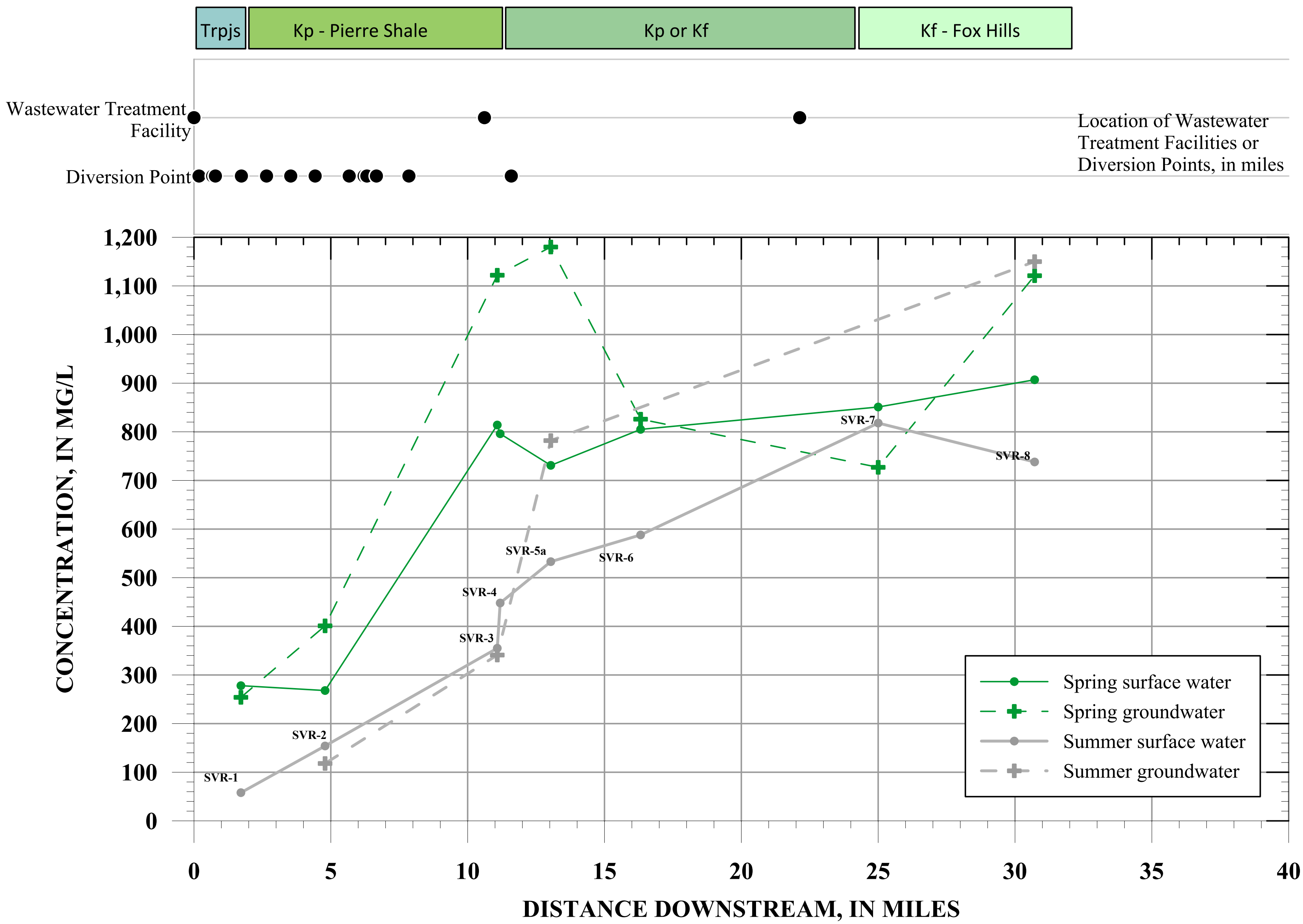


Figure 6-4. Total Dissolved Solids concentrations along the Saint Vrain River

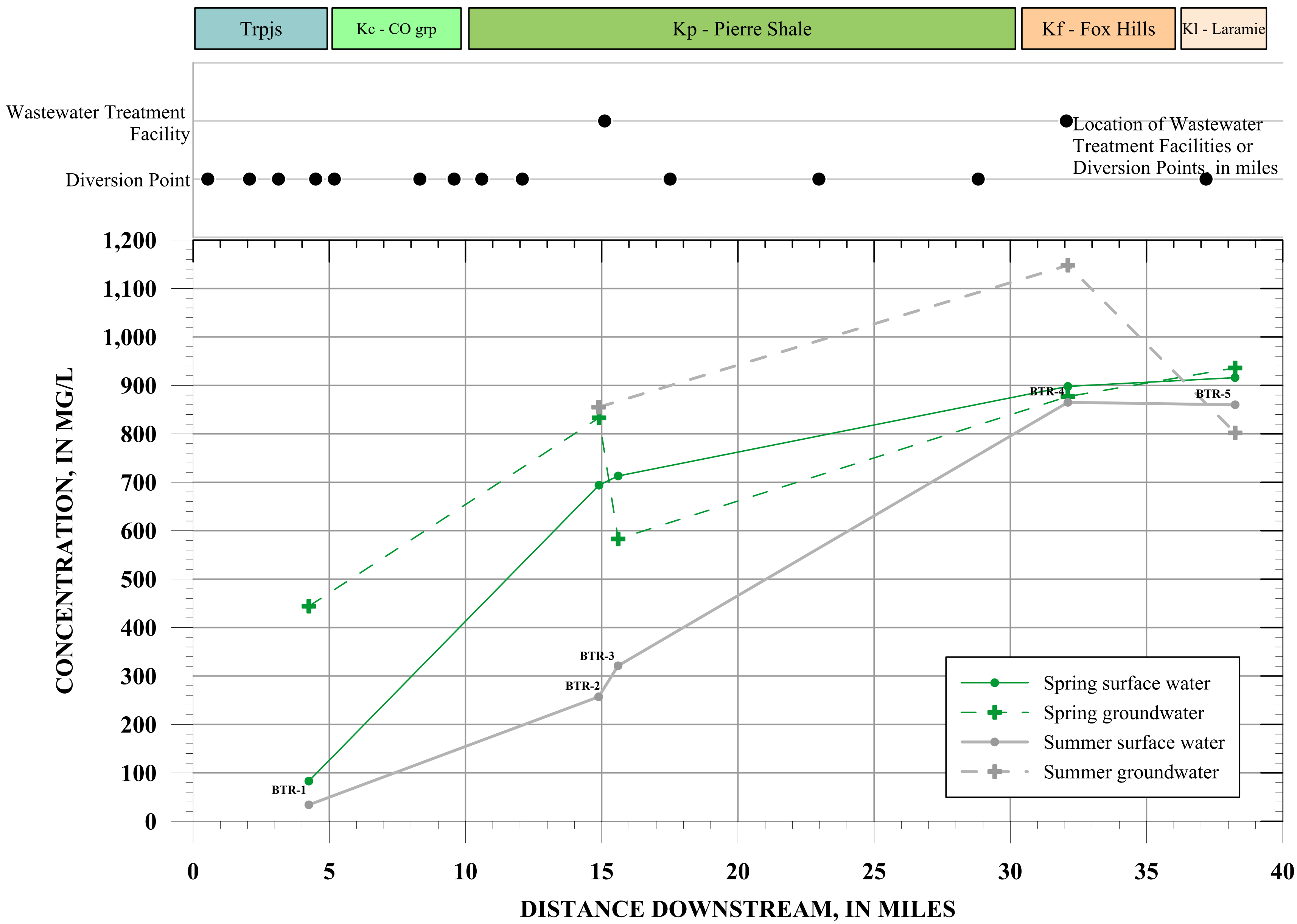


Figure 6-5. Total Dissolved Solids concentrations along the Big Thompson River

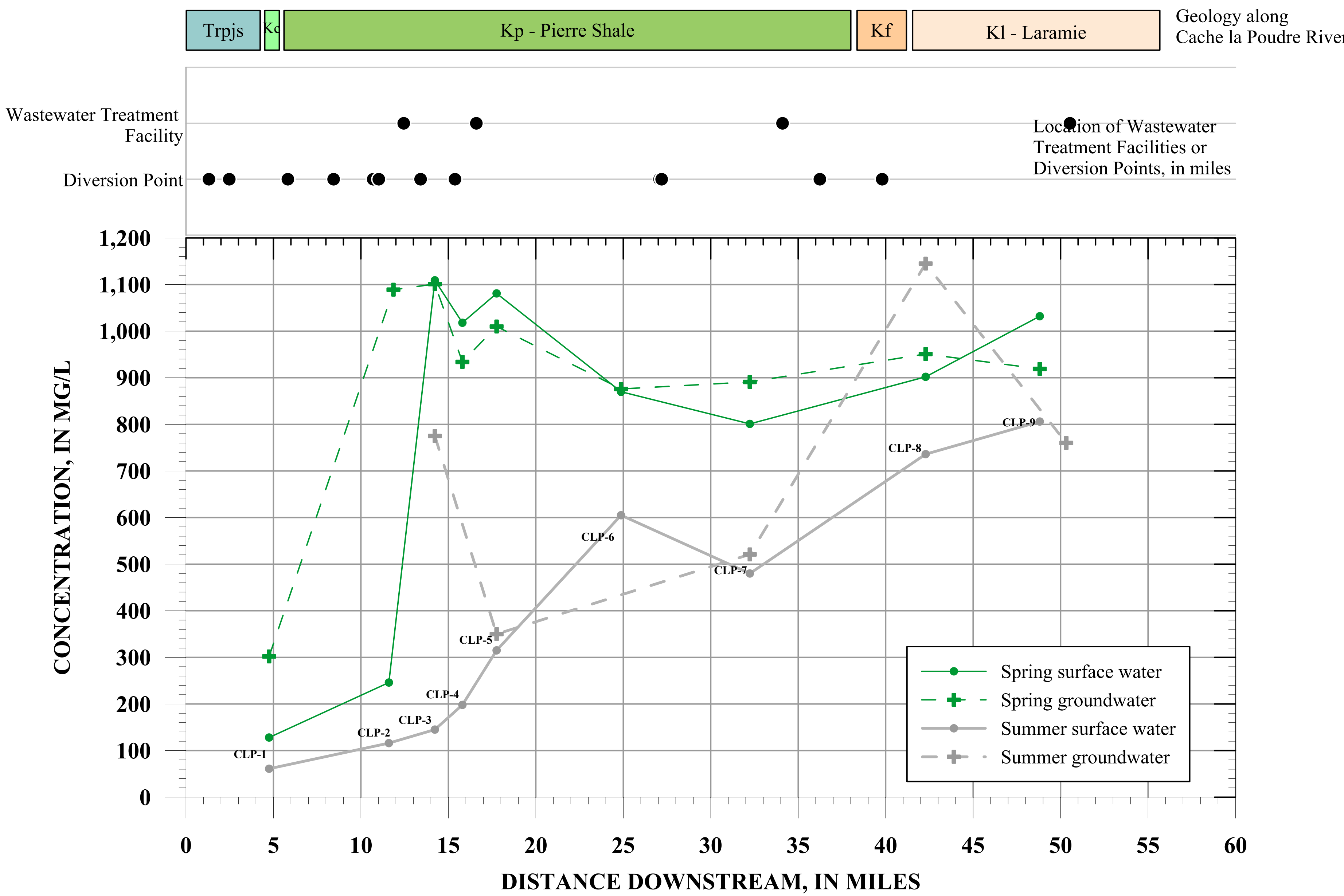


Figure 6-6. Total Dissolved Solids concentrations along the Cache la Poudre River

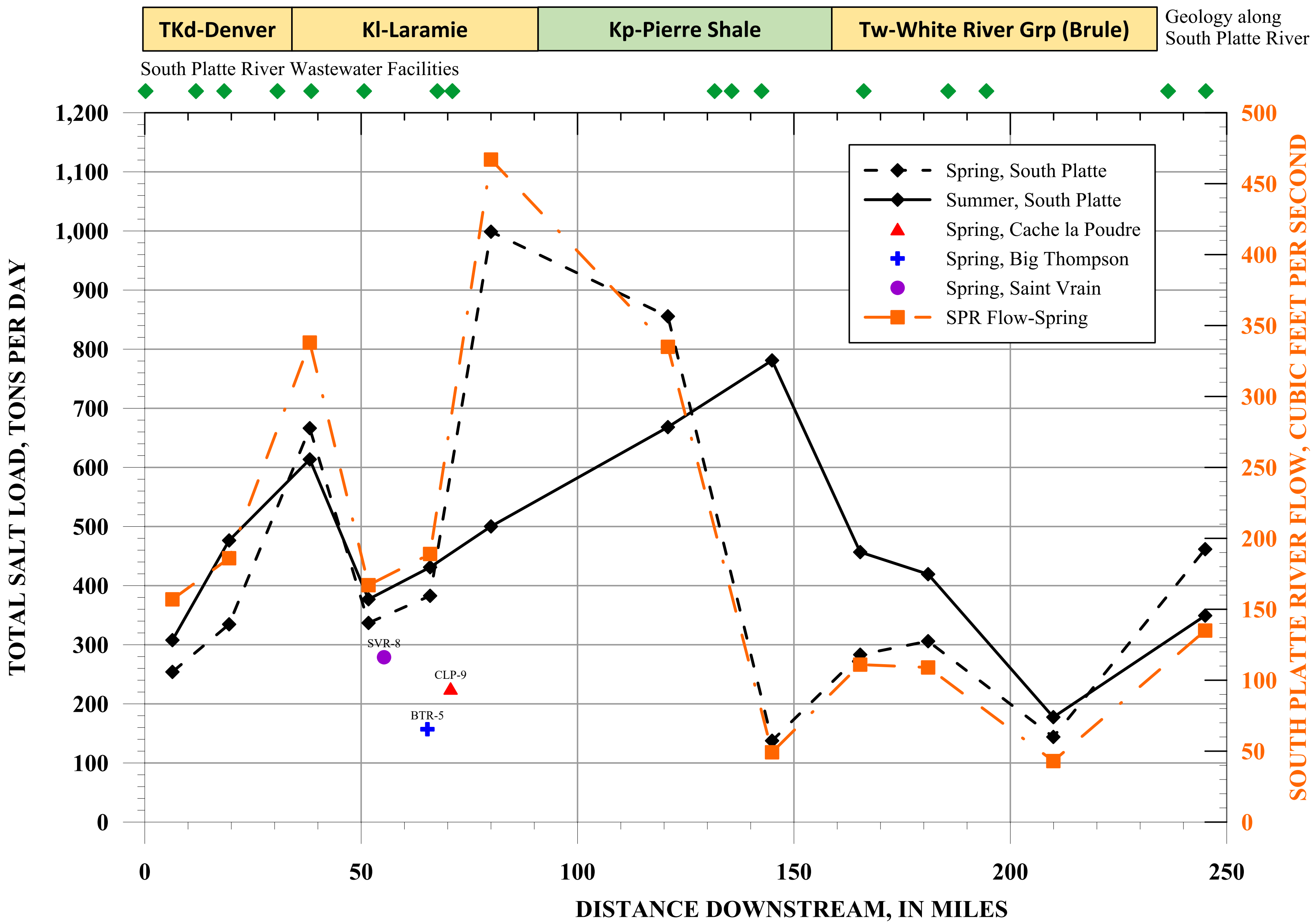


Figure 6-7. Total salt load at sampling locations along South Platte River and at tributary confluences

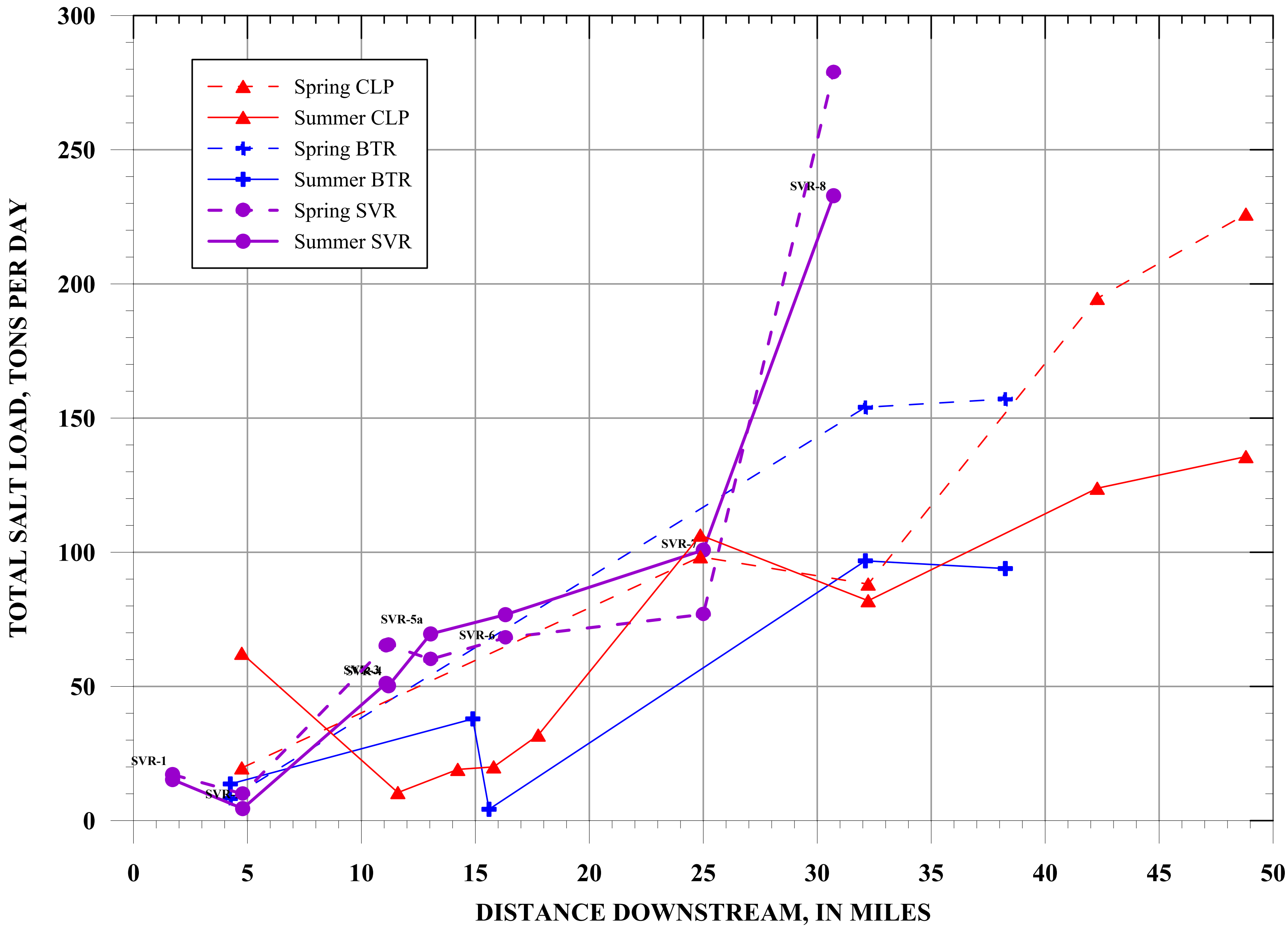


Figure 6-8. Total salt load at sampling locations along the major tributaries

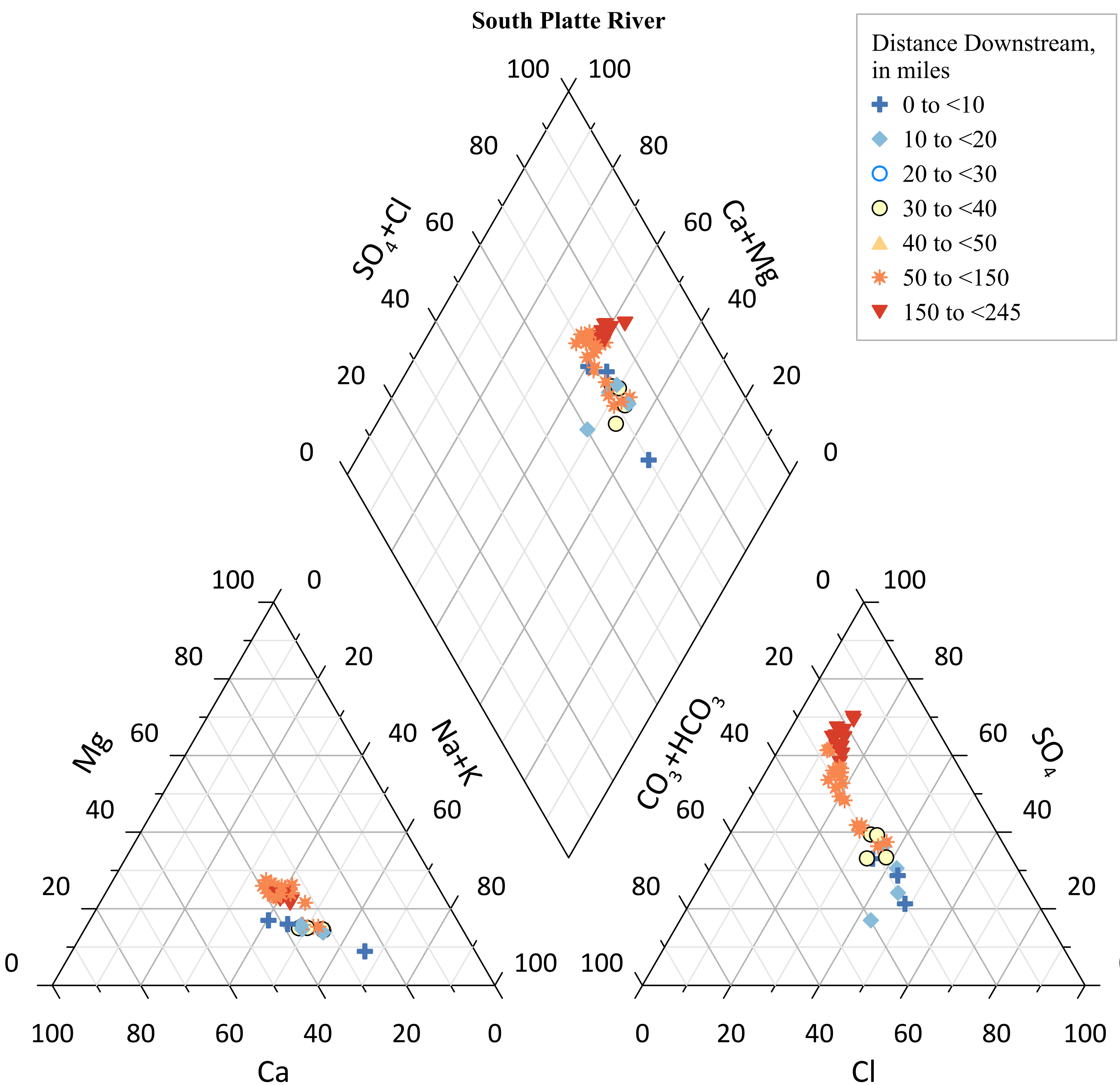


Figure 6-9. Piper diagram illustrating major ion evolution with downstream distance in the South Platte River

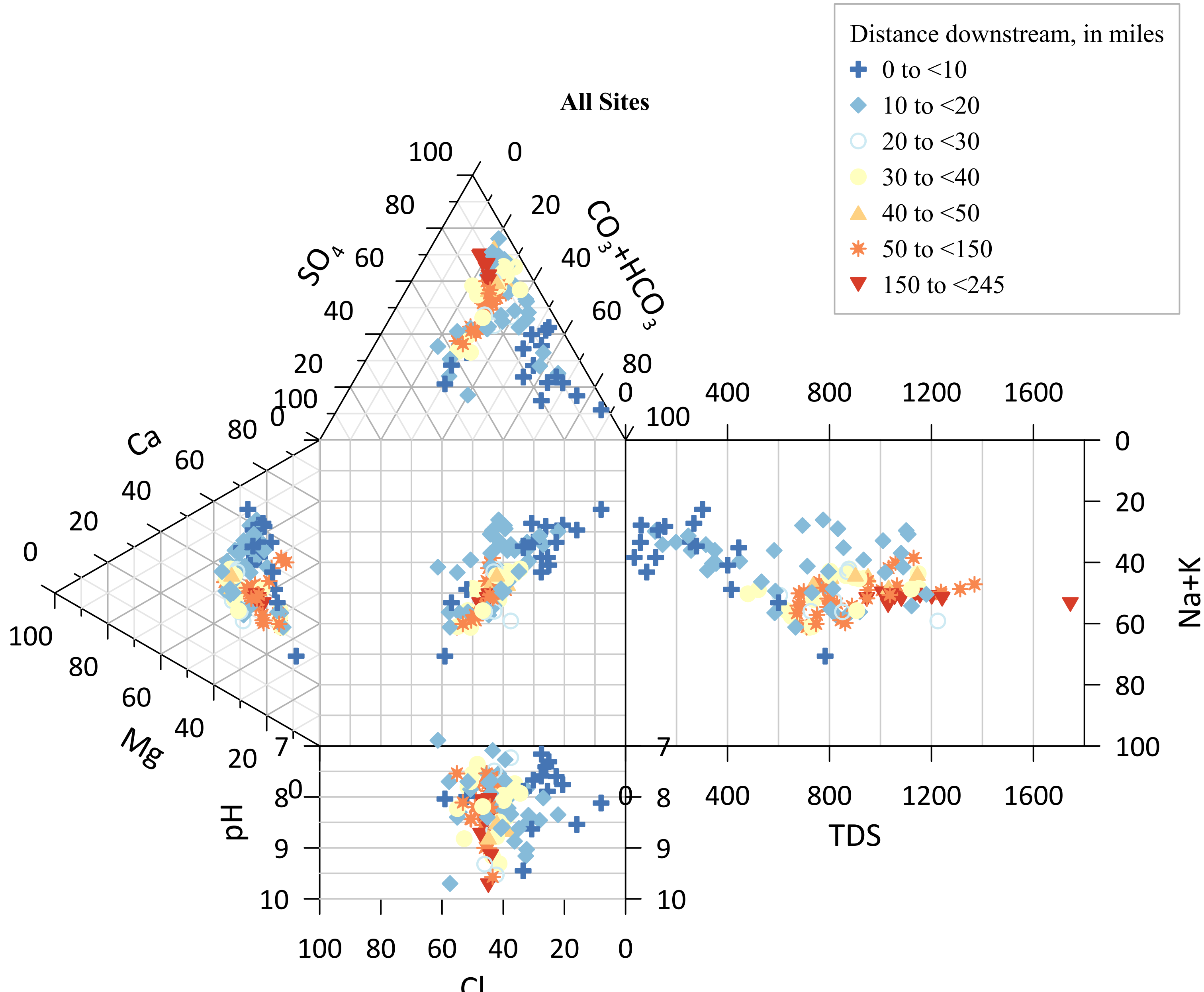


Figure 6-10. Durov diagram illustrating water-quality evolution with downstream distance in the South Platte River and its major tributaries

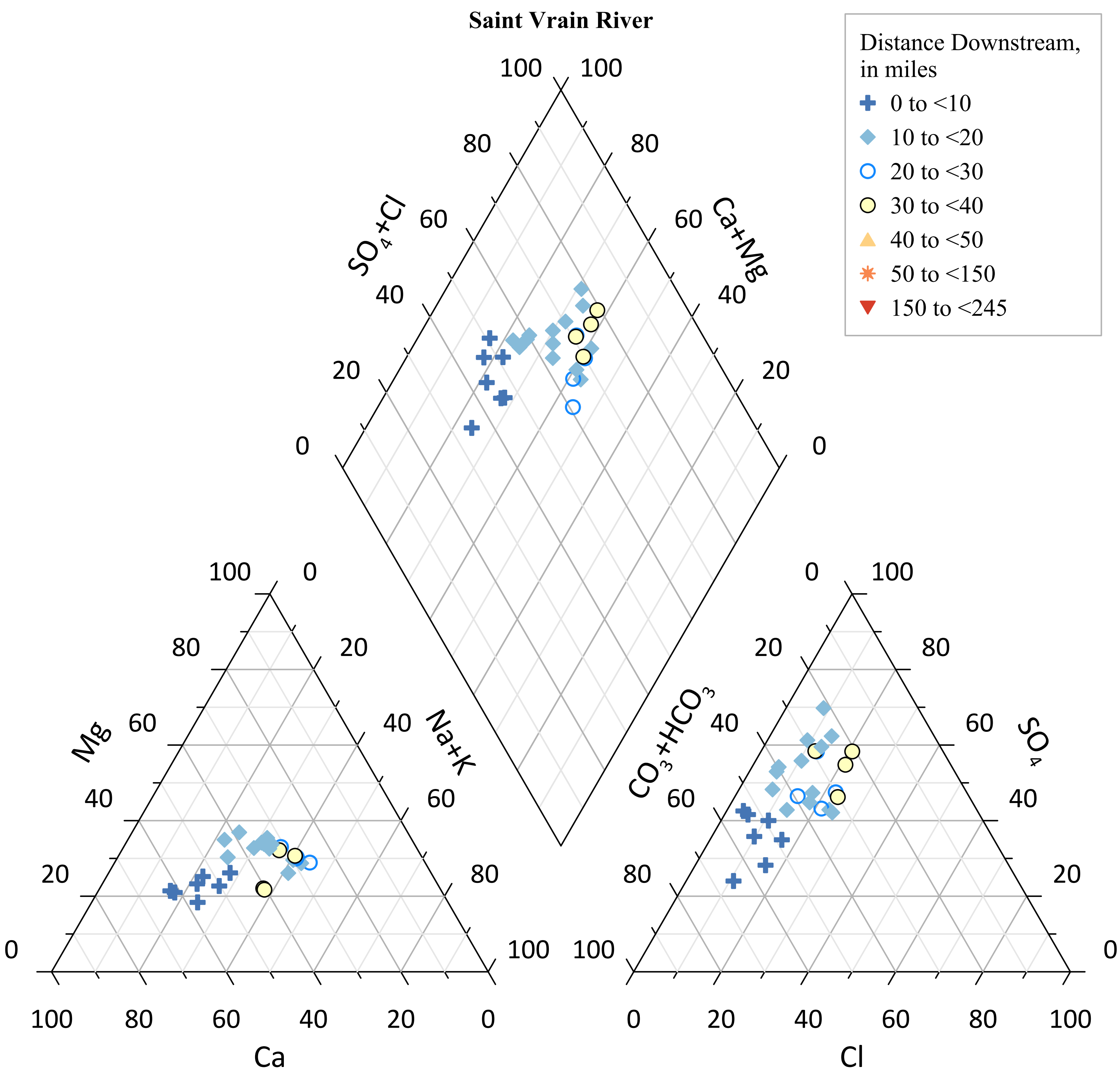


Figure 6 11. Piper diagram illustrating major ion evolution with downstream distance in the Saint Vrain River

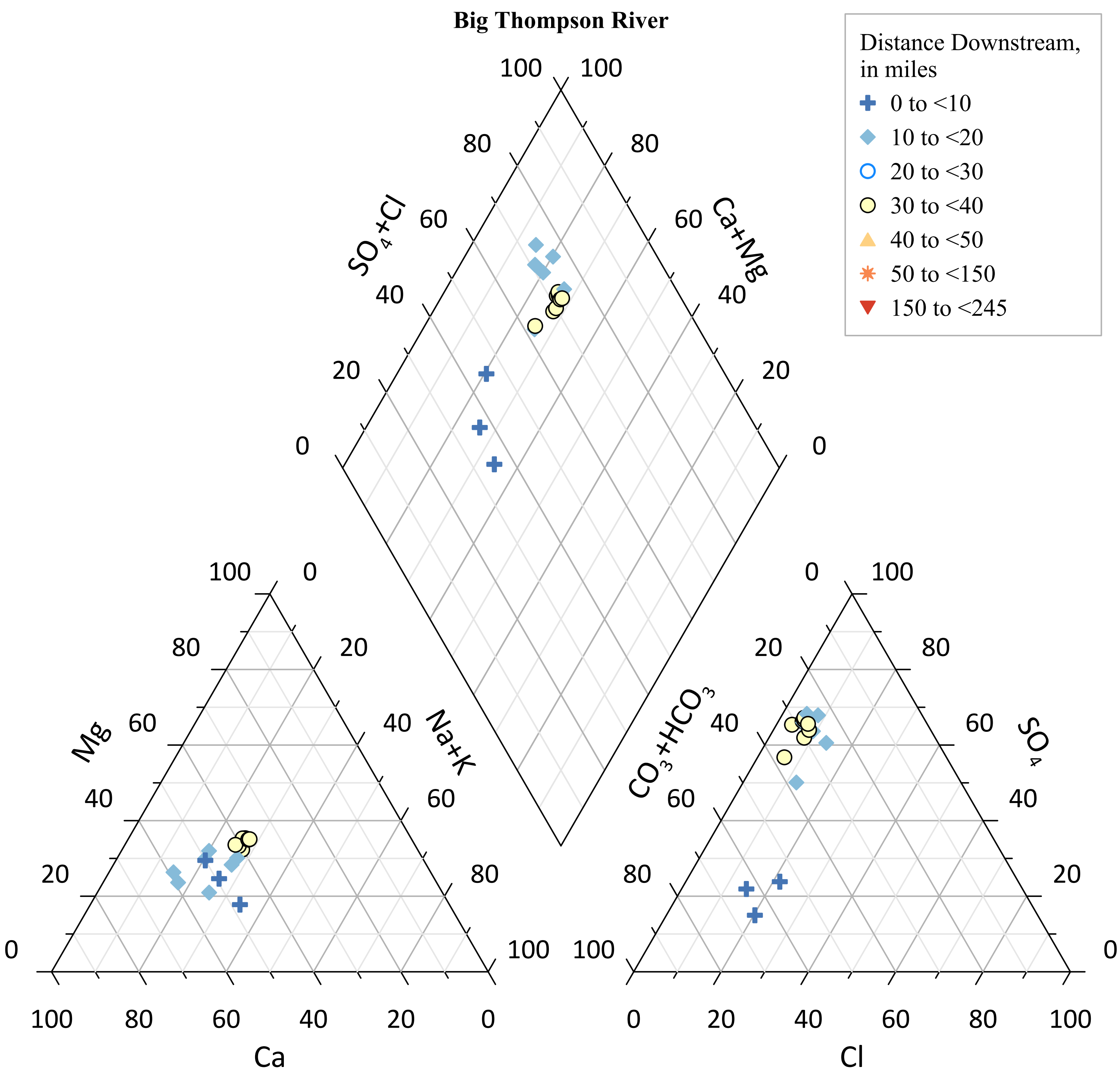


Figure 6 12. Piper diagram illustrating major ion evolution with downstream distance in the Big Thompson River

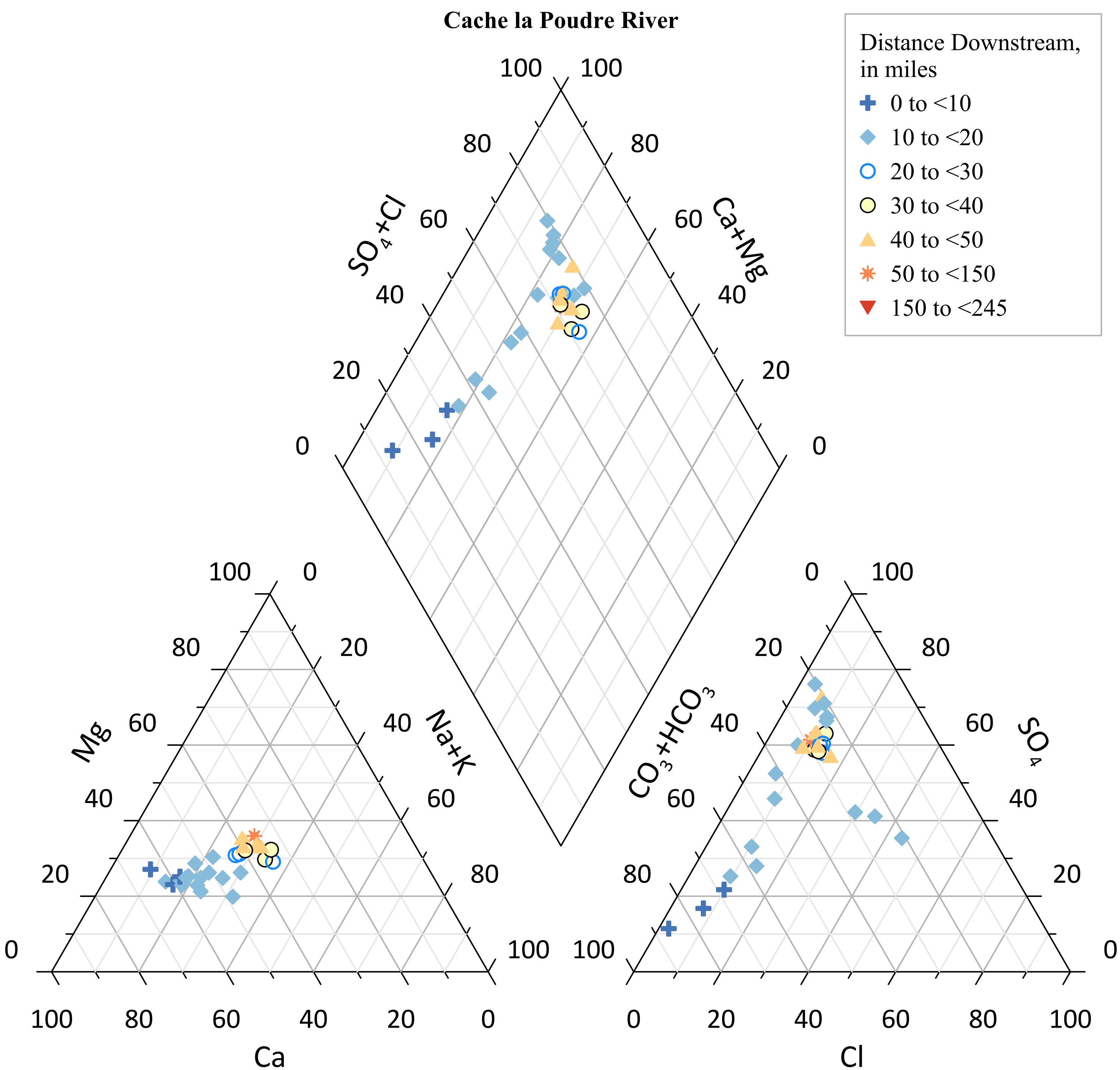


Figure 6 13. Piper diagram illustrating major ion evolution with downstream distance in the Cache la Poudre River

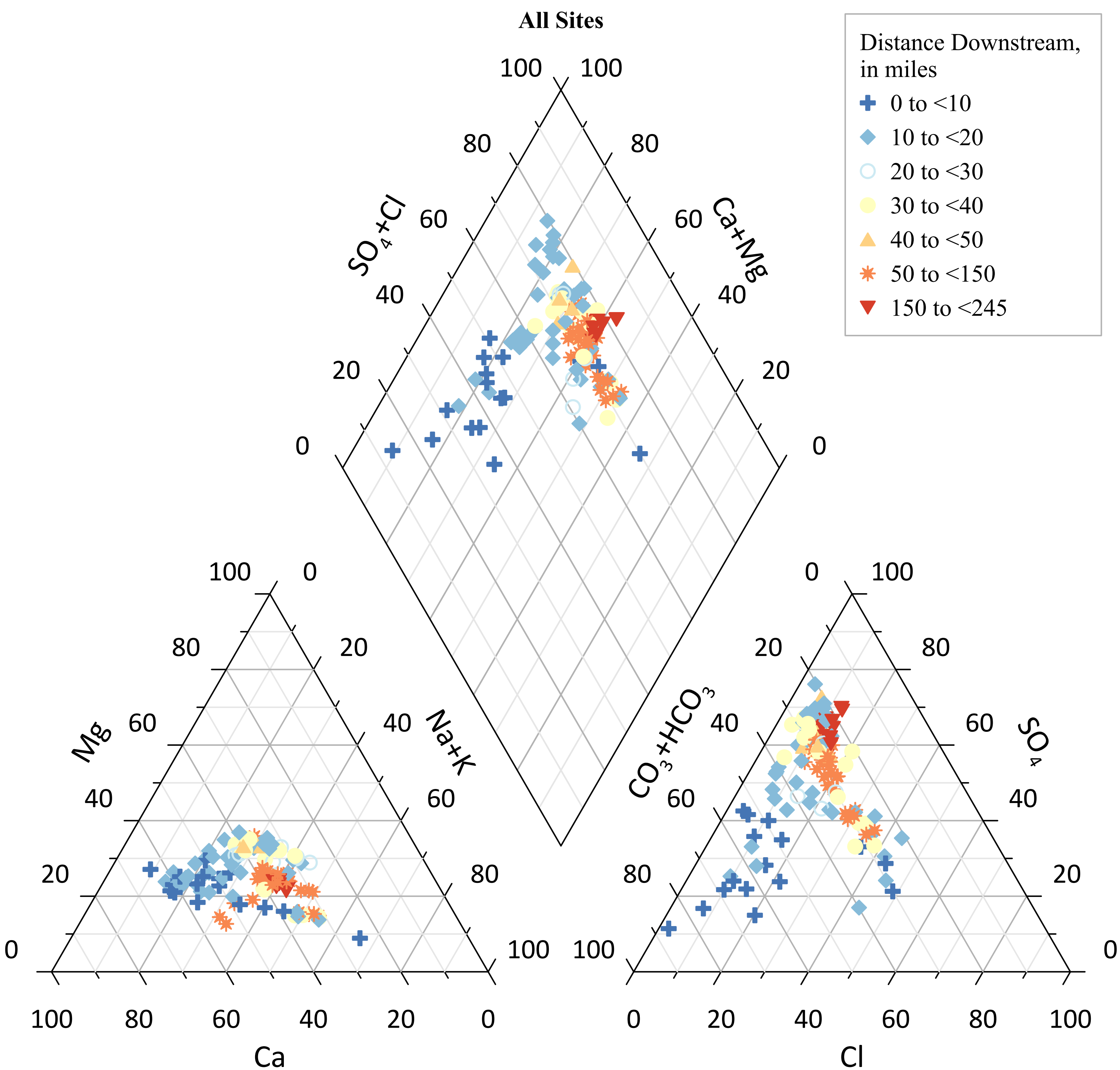


Figure 6 14. Piper diagram illustrating major ion evolution in the South Platte River and its major tributaries

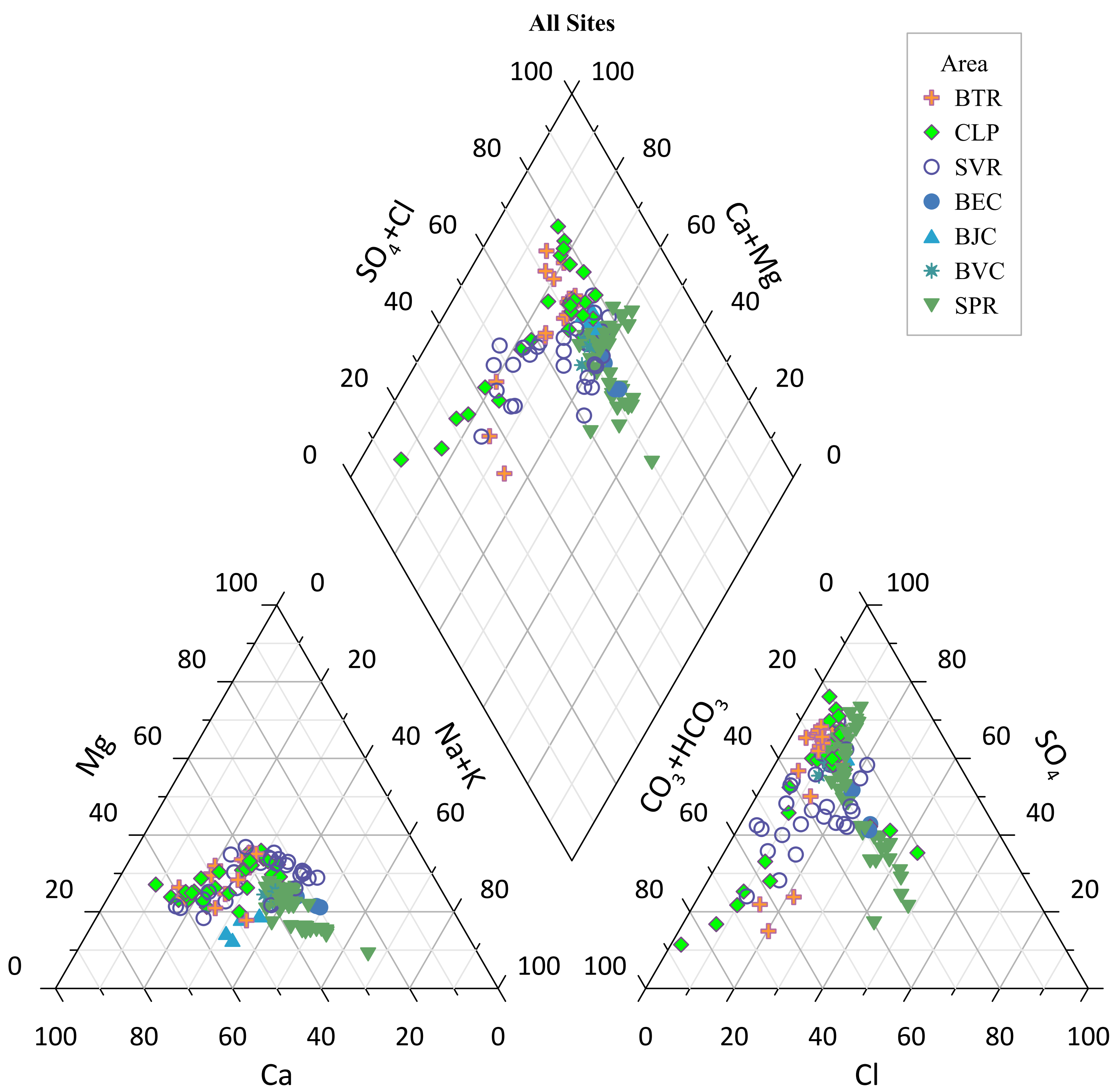


Figure 6 15. Piper diagram illustrating major ion evolution with downstream distance in the South Platte River and its major tributaries

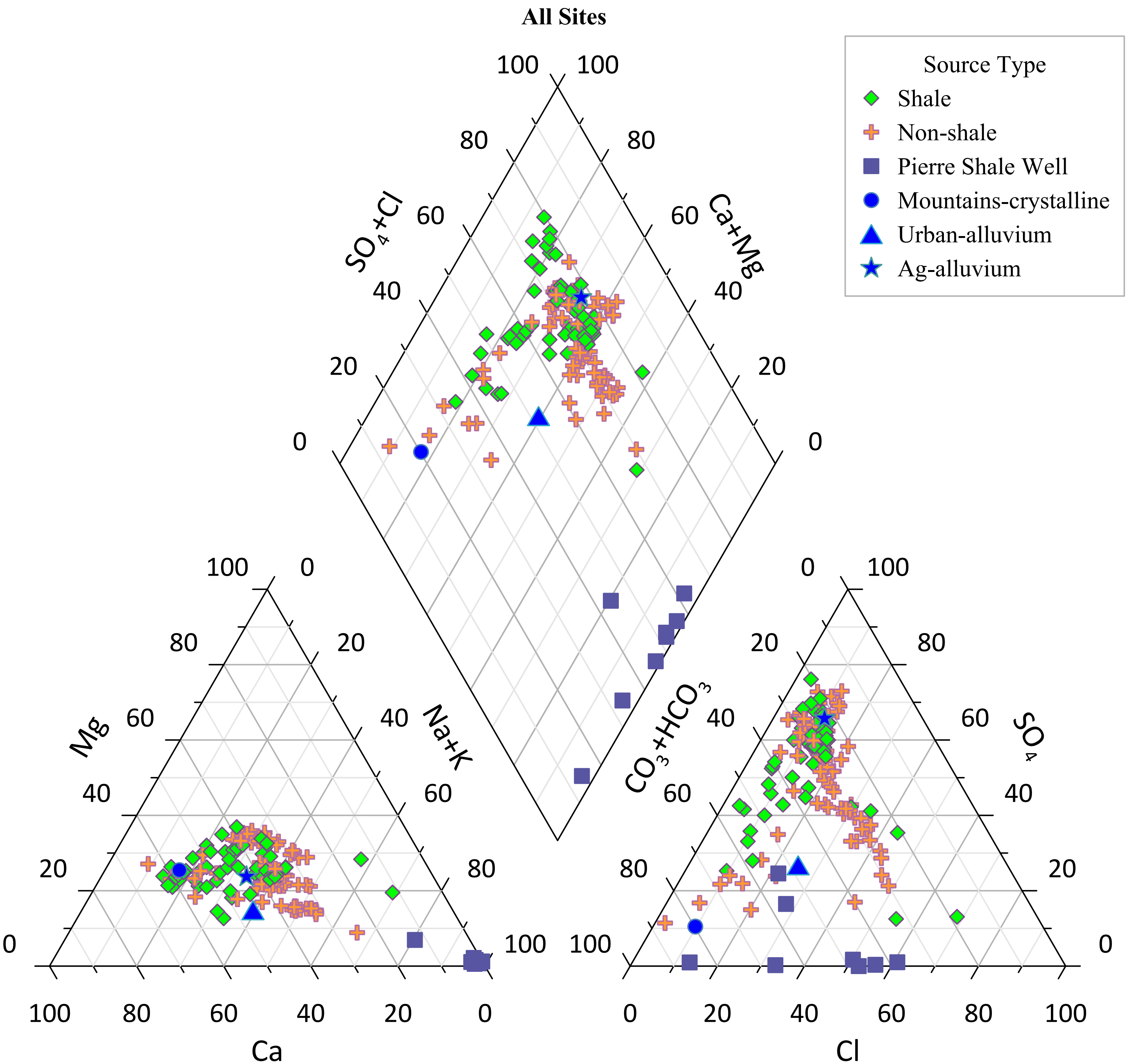


Figure 6 16. **Piper diagram comparing geology, land use, and historical Pierre shale groundwater water types**

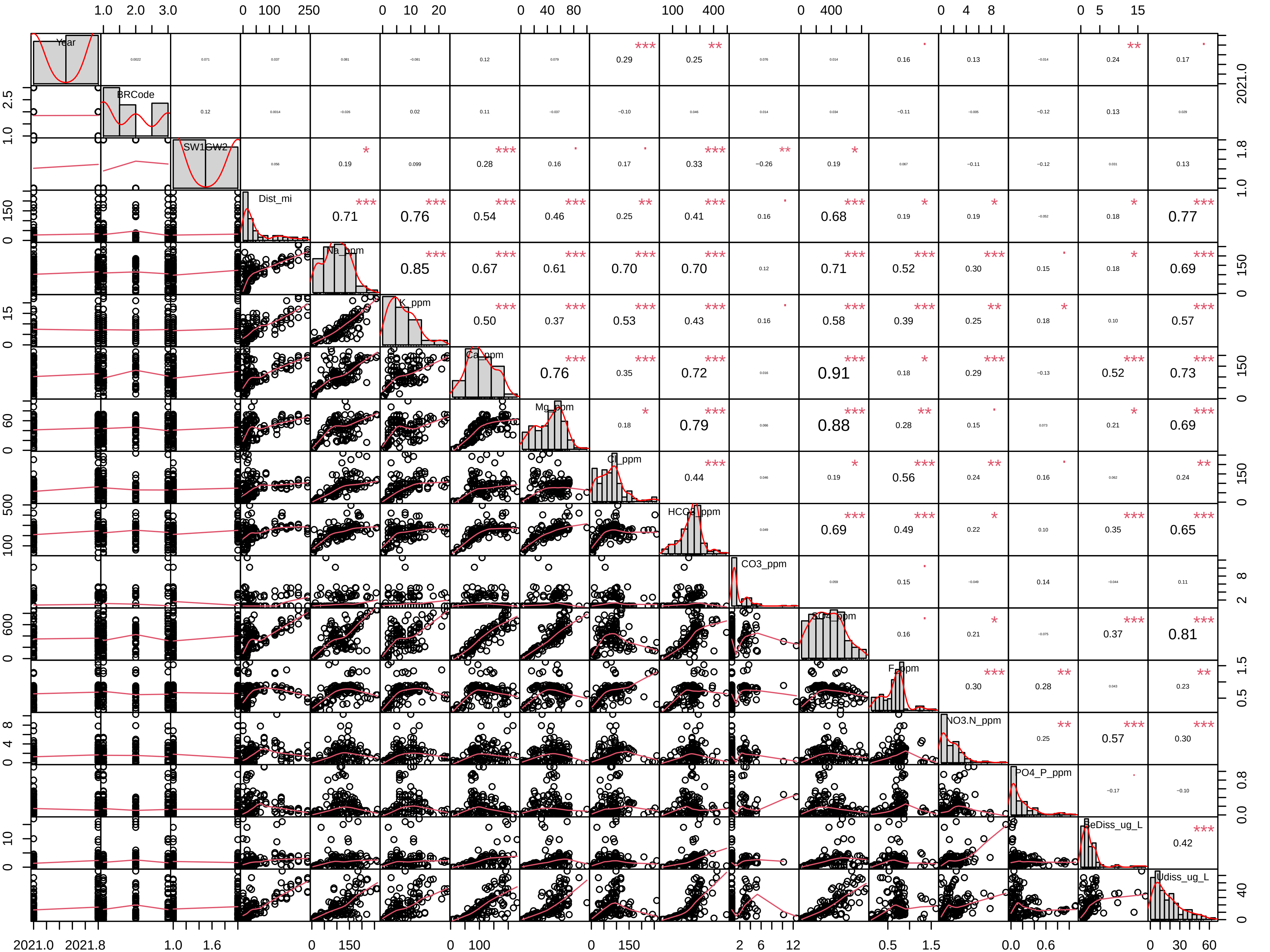


Figure 6 17. Water-quality correlation matrix

Figure 6-17. Water-quality correlation matrix showing the dependence between all variables.

- The distribution of each variable is shown diagonally.
- On the bottom of the diagonal: the bivariate scatter plots with a fitted line displayed.
- On the top of the diagonal: the value of the correlation plus the significance level as stars
- Each significance level is associated with the * symbol:
    - p-values(0, 0.001, 0.01, 0.05, 0.1, 1) <=> symbols(“***”, “**”, “*”, “.”, " “)

Source: http://www.sthda.com/english/wiki/correlation-matrix-a-quick-start-guide-to-analyze-format-and-visualize-a-correlation-matrix-using-r-software

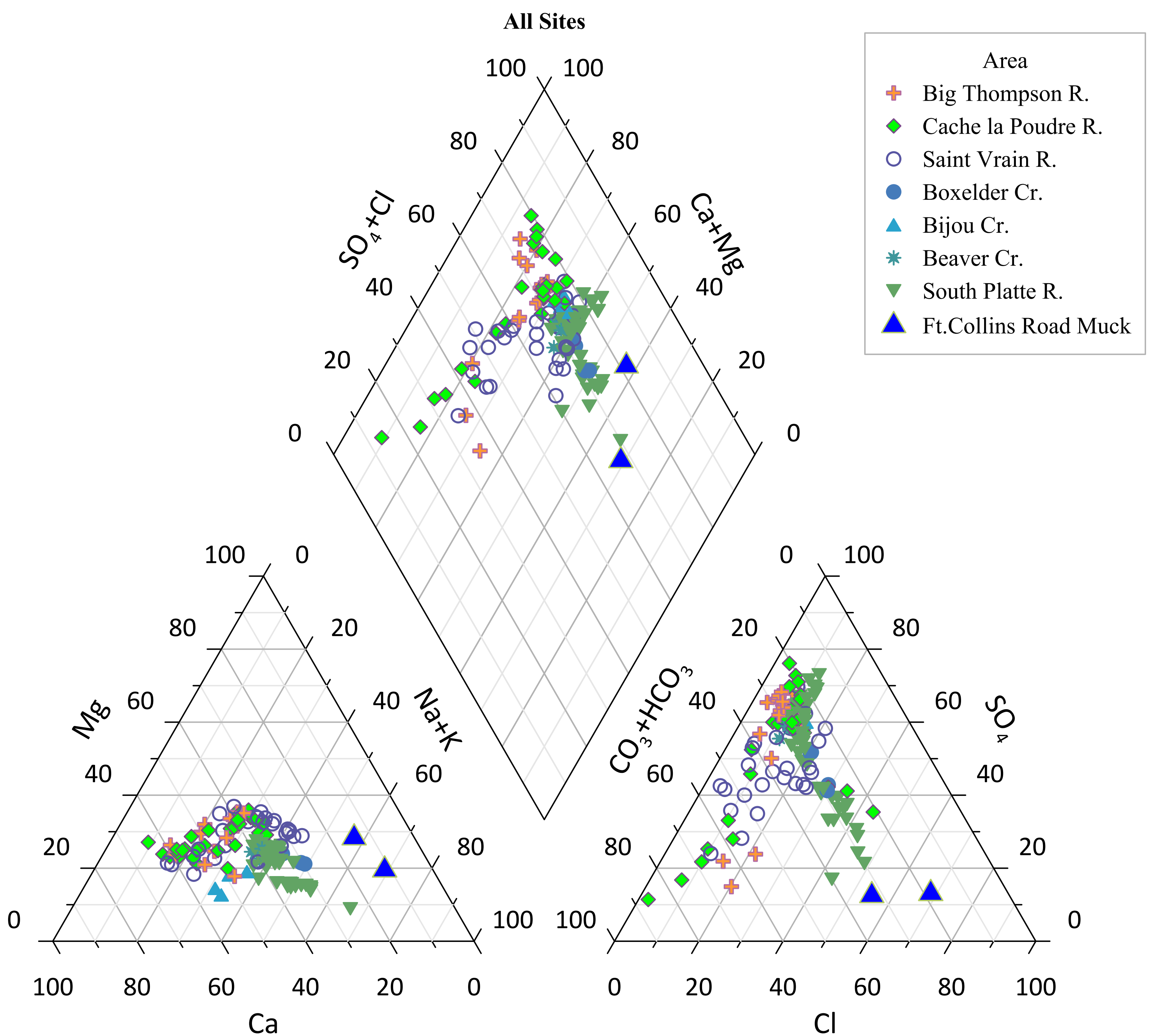


Figure 6-18. Road de-icing runoff ions compared to groundwater and surface water samples

APPENDIX A
TABULAR WATER-QUALITY DATA

Table A-1. Sampling locations, dates, and downstream distances

Loc-ation	Type	Sample ID	Latitude	Longitude	Distance Down-stream (miles)	Distance Along SPR (miles)	Sample Date	Sample Time	Mini-piezo Head inches	Inferred Bedrock Formation	Bedrock Type
BTR-1	SW	BTR-1-SW	40.415010	-105.195578	4.25		8/17/2021	15:10		Trpjs or PPif	Terrestrial
BTR-2	SW	BTR-2-SW	40.382712	-105.054917	14.89		8/18/2021	9:15		Kp-Pierre shale	Marine
BTR-3	SW	BTR-3-SW	40.386662	-105.044158	15.60		8/18/2021	10:50		Kp-Pierre shale	Marine
BTR-4	SW	BTR-4-SW	40.338867	-104.853492	32.11		8/18/2021	12:25		Kf-Fox Hills	Marine
BTR-5	SW	BTR-5-SW	40.351362	-104.775049	38.25		8/18/2021	14:25		Kl-Laramie	Coastal
BTR-2	GW	BTR-2-GW	40.382712	-105.054917	14.89		8/18/2021	9:35	0.13	Kp-Pierre shale	Marine
BTR-4	GW	BTR-4-GW	40.338867	-104.853492	32.11		8/18/2021	12:50	0.88	Kf-Fox Hills	Marine
BTR-5	GW	BTR-5-GW	40.351362	-104.775049	38.25	39.20	8/18/2021	15:00	0.38	Kl-Laramie	Coastal
CLP-1	SW	CLP-1-SW	40.629787	-105.168657	4.75		8/11/2021	16:20		Trpjs or PPif	Terrestrial
CLP-2	SW	CLP-2-SW	40.588526	-105.069555	11.60		8/11/2021	17:15		Kp-Pierre shale	Marine
CLP-3	SW	CLP-3-SW	40.577958	-105.034923	14.23		8/12/2021	9:25		Kp-Pierre shale	Marine
CLP-4	SW	CLP-4-SW	40.559744	-105.021264	15.80		8/12/2021	10:35		Kp-Pierre shale	Marine
CLP-5	SW	CLP-5-SW	40.546790	-105.000712	17.76		8/12/2021	12:25		Kp-Pierre shale	Marine
CLP-6	SW	CLP-6-SW	40.485670	-104.958685	24.87		8/12/2021	15:05		Kp-Pierre shale	Marine
CLP-7	SW	CLP-7-SW	40.447692	-104.889319	32.23		8/16/2021	9:40		Kp-Pierre shale	Marine
CLP-8	SW	CLP-8-SW	40.445871	-104.773256	42.29		8/16/2021	13:30		Kf-Fox Hills	Marine
CLP-9	SW	CLP-9-SW	40.424429	-104.680398	48.81		8/17/2021	10:00		Kl-Laramie	Coastal
CLP-3	GW	CLP-3-GW	40.577958	-105.034923	14.23		8/12/2021	9:45	2	Kp-Pierre shale	Marine
CLP-5	GW	CLP-5-GW	40.546790	-105.000712	17.76		8/12/2021	13:40	0.13	Kp-Pierre shale	Marine
CLP-7	GW	CLP-7-GW	40.447692	-104.889319	32.23		8/12/2021	17:00	0.75	Kp-Pierre shale	Marine
CLP-8	GW	CLP-8-GW	40.445871	-104.773256	42.29		8/16/2021	14:15	-0.1	Kf-Fox Hills	Marine
CLP-9	GW	CLP-9-GW	40.440509	-104.691772	50.32	55.82	8/17/2021	13:45	-1.5	Kl-Laramie	Coastal
SVR-1	SW	SVR-1-SW	40.210131	-105.235024	1.71		8/9/2021	8:55		Kc-CO Grp	Marine
SVR-2	SW	SVR-2-SW	40.186789	-105.191300	4.79		8/9/2021	11:30		Kp-Pierre shale	Marine

Loc-ation	Type	Sample ID	Latitude	Longitude	Distance Down-stream (miles)	Distance Along SPR (miles)	Sample Date	Sample Time	Mini-piezo Head inches	Inferred Bedrock Formation	Bedrock Type
SVR-3	SW	SVR-3-SW	40.155026	-105.090650	11.08		8/9/2021	16:30		Kp-Pierre shale	Marine
SVR-4	SW	SVR-4-SW	40.154113	-105.088545	11.19		8/10/2021	9:10		Kp-Pierre shale	Marine
SVR-5a	SW	SVR-5-SW	40.152125	-105.055196	13.04		8/10/2021	11:05		Kp or Kf	Marine
SVR-6	SW	SVR-6-SW	40.160375	-105.008080	16.32		8/10/2021	12:45		Kp or Kf	Marine
SVR-7	SW	SVR-7-SW	40.204069	-104.906932	25.00		8/10/2021	14:40		Kf-Fox Hills	Marine
SVR-8	SW	SVR-8-SW	40.257844	-104.880591	30.72		8/11/2021	13:15		Kf-Fox Hills	Marine
SVR-2	GW	SVR-2-GW	40.186789	-105.191300	4.79		8/9/2021	11:55	0	Kp-Pierre shale	Marine
SVR-3	GW	SVR-3-GW	40.155026	-105.090650	11.08		8/9/2021	16:45	1	Kp-Pierre shale	Marine
SVR-5a	GW	SVR-5-GW	40.152125	-105.055196	13.04		8/10/2021	11:30	0.5	Kp or Kf	Marine
SVR-7	GW	SVR-7-GW	40.204069	-104.906932	25.00		8/10/2021	15:05	0.25	Kf-Fox Hills	Marine
SVR-8	GW	SVR-8-GW	40.257844	-104.880591	30.72	31.82	8/11/2021	13:55		Kf-Fox Hills	Marine
BEC-1	SW	BEC-1-SW	40.371140	-104.469107			8/23/2021	14:15		Kl-Laramie	Coastal
BEC-1	GW	BEC-1-GW	40.371140	-104.469107			8/23/2021	15:00	-0.375	Kl-Laramie	Coastal
BJC-1	SW	BJC-1-SW	40.280245	-103.877141			8/25/2021	12:25		Kp-Pierre shale	Marine
BJC-1	GW	BJC-1-GW	40.280245	-103.877141			8/25/2021	12:40	1.375	Kp-Pierre shale	Marine
BVC-1	SW	BVC-1-SW	40.320673	-103.545908			8/25/2021	8:20		Kp-Pierre shale	Marine
BVC-1	GW	BVC-1-GW	40.320673	-103.545908			8/25/2021	8:45	0	Kp-Pierre shale	Marine
SPR-12	SW	SPR-12-SW	39.746348	-105.015844	6.39		8/19/2021	9:05		Tkd-Denver	Terrestrial
SPR-11	SW	SPR-11-SW	39.885423	-104.902112	19.49		8/19/2021	11:30		Tkd-Denver	Terrestrial
SPR-10	SW	SPR-10-SW	40.081391	-104.821549	38.13		8/19/2021	13:45		TKda or Tkd	Terrestrial
SPR-9	SW	SPR-9-SW	40.224721	-104.849895	51.70		8/23/2021	9:05		Kl-Laramie	Terr-Coastal
SPR-8	SW	SPR-8-SW	40.349793	-104.762969	65.93		8/23/2021	11:35		Kl-Laramie	Terr-Coastal
SPR-7	SW	SPR-7-SW	40.412446	-104.563890	80.00		8/25/2021	15:50		Kl-Laramie	Terr-Coastal
SPR-6	SW	SPR-6-SW	40.336456	-103.969967	120.88		8/25/2021	14:00		Kp-Pierre shale	Marine

Loc-ation	Type	Sample ID	Latitude	Longitude	Distance Down-stream (miles)	Distance Along SPR (miles)	Sample Date	Sample Time	Mini-piezo Head inches	Inferred Bedrock Formation	Bedrock Type
SPR-5	SW	SPR-5-SW	40.321593	-103.595145	144.94		8/25/2021	10:10		Kp-Pierre shale	Marine
SPR-4	SW	SPR-4-SW	40.473847	-103.345846	165.31		8/24/2021	10:30		Kp-Pierre shale	Marine
SPR-3	SW	SPR-3-SW	40.627556	-103.181302	181.00		8/24/2021	8:20		Kp-Pierre shale	Marine
SPR-2	SW	SPR-2-SW	40.841632	-102.805165	209.94		8/24/2021	13:00		Tw-White River	Terrestrial
SPR-1	SW	SPR-1-SW	40.972918	-102.251291	245.02		8/24/2021	14:35		Tw-White River	Terrestrial
SPR-11	GW	SPR-11-GW	39.885423	-104.902112	19.49		8/19/2021	13:00	0.0625	Tkd-Denver	Terrestrial
SPR-10	GW	SPR-10-GW	40.081391	-104.821549	38.13		8/19/2021	14:10	0	TKda or Tkd	Terrestrial
SPR-9	GW	SPR-9-GW	40.224721	-104.849895	51.70		8/23/2021	9:35	-0.063	Kl-Laramie	Terr-Coastal
SPR-8	GW	SPR-8-GW	40.349793	-104.762969	65.93		8/23/2021	11:55	0	Kl-Laramie	Terr-Coastal
SPR-7	GW	SPR-7-GW	40.412446	-104.563890	80.00		8/25/2021	16:00	0.5	Kl-Laramie	Terr-Coastal
SPR-6	GW	SPR-6-GW	40.336456	-103.969967	120.88		8/25/2021	14:15	0.25	Kp-Pierre shale	Marine
SPR-5	GW	SPR-5-GW	40.321593	-103.595145	144.94		8/25/2021	10:30	0.375	Kp-Pierre shale	Marine
SPR-4	GW	SPR-4-GW	40.473847	-103.345846	165.31		8/24/2021	10:50	0.5	Kp-Pierre shale	Marine
SPR-3	GW	SPR-3-GW	40.627556	-103.181302	181.00		8/24/2021	8:58	0.5	Kp-Pierre shale	Marine
SPR-2	GW	SPR-2-GW	40.841632	-102.805165	209.94		8/24/2021	13:20	0.25	Tw-White River	Terrestrial
SPR-1	GW	SPR-1-GW	40.972918	-102.251291	245.02		8/24/2021	14:59	0.375	Tw-White River	Terrestrial
BTR-1	SW	BTR-1-SW	40.415099	-105.195254	4.2		3/23/2022	9:30	--	Trpjs or PPif	Terrestrial
BTR-2A	SW	BTR-2A-SW	40.395933	-105.097954	14.9		3/23/2022	12:15	--	Kp-Pierre shale	Marine
BTR-3	SW	BTR-3-SW	40.386612	-105.044084	15.6		3/23/2022	14:15	--	Kp-Pierre shale	Marine
BTR-4	SW	BTR-4-SW	40.338867	-104.853492	32.1		3/24/2022	8:15	--	Kf-Fox Hills	Marine
BTR-5	SW	BTR-5-SW	40.351403	-104.775055	38.2		3/24/2022	9:10	--	Kl-Laramie	Terrestrial
BTR-1	GW	BTR-1-GW	40.415099	-105.195254	4.2		3/23/2022	10:05	0.0625	Trpjs or PPif	Terrestrial
BTR-2A	GW	BTR-2A-GW	40.395933	-105.097954	14.9		3/23/2022	12:40	0.125	Kp-Pierre shale	Marine
BTR-3	GW	BTR-3-GW	40.386612	-105.044084	15.6		3/23/2022	15:00	0.5	Kp-Pierre shale	Marine

Loc-ation	Type	Sample ID	Latitude	Longitude	Distance Down-stream (miles)	Distance Along SPR (miles)	Sample Date	Sample Time	Mini-piezo Head inches	Inferred Bedrock Formation	Bedrock Type
BTR-4	GW	BTR-4-GW	40.338867	-104.853492	32.1		3/28/2022	9:00	0.75	Kf-Fox Hills	Marine
BTR-5	GW	BTR-5-GW	40.351403	-104.775055	38.2	39.20	3/28/2022	9:55	0.25	Kl-Laramie	Terrestrial
CLP-1	SW	CLP-1-SW	40.629787	-105.168657	4.8		3/14/2022	11:59	--	Trpjs or PPif	Terrestrial
CLP-2	SW	CLP-2-SW	40.588526	-105.069555	11.6		3/14/2022	13:03	--	Kp-Pierre shale	Marine
CLP-3	SW	CLP-3-SW	40.577958	-105.034923	14.2		3/14/2022	14:20	--	Kp-Pierre shale	Marine
CLP-4	SW	CLP-4-SW	40.558763	-105.019170	15.8		3/14/2022	15:50	--	Kp-Pierre shale	Marine
CLP-5	SW	CLP-5-SW	40.546734	-105.000800	17.8		3/15/2022	9:10	--	Kp-Pierre shale	Marine
CLP-6	SW	CLP-6-SW	40.485626	-104.958554	24.9		3/14/2022	17:30	--	Kp-Pierre shale	Marine
CLP-7	SW	CLP-7-SW	40.447725	-104.889148	32.2		3/15/2022	14:25	--	Kp-Pierre shale	Marine
CLP-8	SW	CLP-8-SW	40.445871	-104.773256	42.3		3/15/2022	11:10	--	Kf-Fox Hills	Marine
CLP-9	SW	CLP-9-SW	40.440445	-104.692211	48.8	55.82	3/15/2022	17:20	--	Kl-Laramie	Terrestrial
CLP-1	GW	CLP-1-GW	40.629781	-105.168761	4.8		3/21/2022	12:40	1.375	Trpjs or PPif	Terrestrial
CLP-Insitu	GW	Insitu-Mid	40.587644	-105.065714	11.9		3/21/2022	16:30	--	Kp-Pierre shale	Marine
CLP-3	GW	CLP-3-GW	40.577958	-105.034923	14.2		3/16/2022	16:25	3.75	Kp-Pierre shale	Marine
CLP-4	GW	CLP-4-GW	40.558763	-105.019170	15.8		3/16/2022	13:30	0.25	Kp-Pierre shale	Marine
CLP-5	GW	CLP-5-GW	40.546734	-105.000800	17.8		3/16/2022	11:45	0.25	Kp-Pierre shale	Marine
CLP-6	GW	CLP-6-GW	40.485626	-104.958554	24.9		3/16/2022	9:35	0.25	Kp-Pierre shale	Marine
CLP-7	GW	CLP-7-GW	40.447725	-104.889148	32.2		3/15/2022	15:15	0.125	Kp-Pierre shale	Marine
CLP-7	GW	CLP-7-GW	40.447692	-104.889319	32.2		3/20/2022	17:25	0.188	Kp-Pierre shale	Marine
CLP-8	GW	CLP-8-GW	40.445871	-104.773256	42.3		3/15/2022	15:50	0.25	Kf-Fox Hills	Marine
CLP-9	GW	CLP-9-GW	40.440509	-104.691772	48.8	55.82	3/15/2022	17:45	0.25	Kl-Laramie	Terrestrial
CLP-9	GW	CLP-9-GW	40.440415	-104.691827	48.8	55.82	3/20/2022	13:40	0.125	Kl-Laramie	Terrestrial
SVR-1	SW	SVR-1-SW	40.210131	-105.235024	1.7		3/24/2022	15:15	--	Kc-CO Grp	Marine
SVR-2	SW	SVR-2-SW	40.186811	-105.191273	4.8		3/24/2022	14:40	--	Kp-Pierre shale	Marine
SVR-3	SW	SVR-3-SW	40.155026	-105.090650	11.1		3/24/2022	13:50	--	Kp-Pierre shale	Marine

Loc-ation	Type	Sample ID	Latitude	Longitude	Distance Down-stream (miles)	Distance Along SPR (miles)	Sample Date	Sample Time	Mini-piezo Head inches	Inferred Bedrock Formation	Bedrock Type
SVR-4	SW	SVR-4-SW	40.154113	-105.088567	11.2		3/24/2022	13:20	--	Kp-Pierre shale	Marine
SVR-5A	SW	SVR-5A-SW	40.152034	-105.055160	13.0		3/24/2022	12:45	--	Kp-Pierre shale	Marine
SVR-6	SW	SVR-6-SW	40.160375	-105.008080	16.3		3/24/2022	11:55	--	Kp or Kf	Marine
SVR-7	SW	SVR-7-SW	40.204069	-104.906660	25.0		3/24/2022	10:59	--	Kf-Fox Hills	Marine
SVR-8	SW	SVR-8-SW	40.257844	-104.880591	30.7	31.82	3/24/2022	10:25	--	Kf-Fox Hills	Marine
SVR-1	GW	SVR-1-GW	40.210131	-105.235024	1.7		3/31/2022	10:55	0.125	Kc-CO Grp	Marine
SVR-2	GW	SVR-2-GW	40.186811	-105.191273	4.8		3/29/2022	13:45	0.375	Kp-Pierre shale	Marine
SVR-3	GW	SVR-3-GW	40.155026	-105.090650	11.1		3/29/2022	11:15	0.875	Kp-Pierre shale	Marine
SVR-5A	GW	SVR-5A-GW	40.152034	-105.055160	13.0		3/28/2022	15:10	0.25	Kp or Kf	Marine
SVR-6	GW	SVR-6-GW	40.160391	-105.007986	16.3		3/28/2022	14:10	0.125	Kp or Kf	Marine
SVR-7	GW	SVR-7-GW	40.204069	-104.906660	25.0		3/28/2022	13:00	0.3125	Kf-Fox Hills	Marine
SVR-8	GW	SVR-8-GW	40.257844	-104.880591	30.7	31.82	3/28/2022	11:20	0.0625	Kf-Fox Hills	Marine
SPR-12	SW	SPR-12-SW	39.746285	-105.015849	6.4	6.39	4/7/2022	15:00	--	Tkd-Denver	Terrestrial
SPR-11	SW	SPR-11-SW	39.885423	-104.902112	19.5	19.49	4/7/2022	12:55	--	Tkd-Denver	Terrestrial
SPR-10	SW	SPR-10-SW	40.081265	-104.821538	38.1	38.13	4/7/2022	10:50	--	TKda or Tkd	Terrestrial
SPR-09	SW	SPR-9-SW	40.224670	-104.849884	51.7	51.70	4/7/2022	8:25	--	Kl-Laramie	Terr-Coastal
SPR-08	SW	SPR-8-SW	40.349651	-104.762621	65.9	65.93	4/6/2022	16:40	--	Kl-Laramie	Terr-Coastal
SPR-07	SW	SPR-7-SW	40.412545	-104.563876	80.0	80.00	4/6/2022	14:35	--	Kl-Laramie	Terr-Coastal
SPR-06	SW	SPR-6-SW	40.336456	-103.969967	120.9	120.88	4/5/2022	15:30	--	Kp-Pierre shale	Marine
SPR-05	SW	SPR-5-SW	40.321593	-103.595145	144.9	144.94	4/5/2022	11:30	--	Kp-Pierre shale	Marine
SPR-04	SW	SPR-4-SW	40.473838	-103.345782	165.3	165.31	4/4/2022	16:10	--	Kp-Pierre shale	Marine
SPR-03	SW	SPR-3-SW	40.626173	-103.180306	181.0	181.00	4/4/2022	14:45	--	Kp-Pierre shale	Marine
SPR-02	SW	SPR-2-SW	40.841732	-102.804850	209.9	209.94	4/4/2022	12:25	--	Tw-White River	Terrestrial
SPR-01	SW	SPR-1-SW	40.973649	-102.250534	245.0	245.02	4/4/2022	9:45	--	Tw-White River	Terrestrial

Loc-ation	Type	Sample ID	Latitude	Longitude	Distance Down-stream (miles)	Distance Along SPR (miles)	Sample Date	Sample Time	Mini-piezo Head inches	Inferred Bedrock Formation	Bedrock Type
SPR-12	GW	SPR-12-GW	39.746285	-105.015849	6.4	6.39	4/7/2022	15:30	0.375	Tkd-Denver	Terrestrial
SPR-11	GW	SPR-11-GW	39.885423	-104.902112	19.5	19.49	4/7/2022	13:25	0.25	Tkd-Denver	Terrestrial
SPR-10	GW	SPR-10-GW	40.081265	-104.821538	38.1	38.13	4/7/2022	10:30	0.375	TKda or Tkd	Terrestrial
SPR-09	GW	SPR-9-GW	40.224670	-104.849884	51.7	51.70	4/7/2022	8:50	0.375	Kl-Laramie	Terr-Coastal
SPR-08	GW	SPR-8-GW	40.349651	-104.762621	65.9	65.93	4/6/2022	16:55	0.4375	Kl-Laramie	Terr-Coastal
SPR-07	GW	SPR-7-GW	40.412545	-104.563876	80.0	80.00	4/6/2022	15:10	0.25	Kl-Laramie	Terr-Coastal
SPR-06	GW	SPR-6-GW	40.336456	-103.969967	120.9	120.88	4/5/2022	15:50	0.75	Kp-Pierre shale	Marine
SPR-05	GW	SPR-5-GW	40.321593	-103.595145	144.9	144.94	4/5/2022	12:00	0.5	Kp-Pierre shale	Marine
SPR-04	GW	SPR-4-GW	40.473838	-103.345782	165.3	165.31	4/4/2022	16:35	0.5	Kp-Pierre shale	Marine
SPR-03	GW	SPR-3-GW	40.626173	-103.180306	181.0	181.00	4/4/2022	15:05	0.25	Kp-Pierre shale	Marine
SPR-02	GW	SPR-2-GW	40.841732	-102.804850	209.9	209.94	4/4/2022	12:40	0.5	Tw-White River	Terrestrial
SPR-01	GW	SPR-1-GW	40.973649	-102.250534	245.0	245.02	4/4/2022	10:10	0.75	Tw-White River	Terrestrial
BEC-1	SW	BEC-1-SW	40.371140	-104.469107	86.85	86.85	4/6/2022	8:30	--	Kl-Laramie	Terr-Coastal
BJC-1	SW	BJC-1-SW	40.280245	-103.877141	128.08	128.08	4/5/2022	13:55	--	Kp-Pierre shale	Marine
BVC-1A	SW	BVC-1A-SW	40.334254	-103.546660	148.33	148.33	4/5/2022	9:55	--	Kp-Pierre shale	Marine
BEC-1A	GW	BEC-1A-GW	40.363296	-104.481434	86.85	86.85	4/6/2022	13:00	1.5	Kl-Laramie	Terr-Coastal
BJC-1	GW	BJC-1-GW	40.280245	-103.877141	128.08	128.08	4/5/2022	14:15	6.625	Kp-Pierre shale	Marine
BVC-1A	GW	BVC-1A-GW	40.334254	-103.546660	148.33	148.33	4/5/2022	10:25	2.125	Kp-Pierre shale	Marine

Location	Type	Sample ID	Latitude	Longitude	Distance Down-stream (miles)	Distance Along SPR (miles)	Sample Date
BTR-1	SW	BTR-1-SW	40.415099	-105.195254	4.2	31.31	3/23/2022
BTR-2A	SW	BTR-2A-SW	40.395933	-105.097954	14.9	41.96	3/23/2022
BTR-3	SW	BTR-3-SW	40.386612	-105.044084	15.6	42.66	3/23/2022
BTR-4	SW	BTR-4-SW	40.338867	-104.853492	32.1	59.17	3/24/2022
BTR-5	SW	BTR-5-SW	40.351403	-104.775055	38.2	65.31	3/24/2022
BTR-1	GW	BTR-1-GW	40.415099	-105.195254	4.2	31.31	3/23/2022
BTR-2A	GW	BTR-2A-GW	40.395933	-105.097954	14.9	41.96	3/23/2022
BTR-3	GW	BTR-3-GW	40.386612	-105.044084	15.6	42.66	3/23/2022
BTR-4	GW	BTR-4-GW	40.338867	-104.853492	32.1	59.17	3/28/2022
BTR-5	GW	BTR-5-GW	40.351403	-104.775055	38.2	65.31	3/28/2022
CLP-1	SW	CLP-1-SW	40.629787	-105.168657	4.8	26.61	3/14/2022
CLP-2	SW	CLP-2-SW	40.588526	-105.069555	11.6	33.46	3/14/2022
CLP-3	SW	CLP-3-SW	40.577958	-105.034923	14.2	36.09	3/14/2022
CLP-4	SW	CLP-4-SW	40.558763	-105.019170	15.8	37.66	3/14/2022
CLP-5	SW	CLP-5-SW	40.546734	-105.000800	17.8	39.62	3/15/2022
CLP-6	SW	CLP-6-SW	40.485626	-104.958554	24.9	46.73	3/14/2022
CLP-7	SW	CLP-7-SW	40.447725	-104.889148	32.2	54.09	3/15/2022
CLP-8	SW	CLP-8-SW	40.445871	-104.773256	42.3	64.15	3/15/2022
CLP-9	SW	CLP-9-SW	40.440445	-104.692211	48.8	70.67	3/15/2022
CLP-1	GW	CLP-1-GW	40.629781	-105.168761	4.8	26.61	3/21/2022
CLP-Insitu	GW	Insitu-MW-Mid	40.587644	-105.065714	11.9	33.72	3/21/2022
CLP-3	GW	CLP-3-GW	40.577958	-105.034923	14.2	36.09	3/16/2022
CLP-4	GW	CLP-4-GW	40.558763	-105.019170	15.8	37.66	3/16/2022
CLP-5	GW	CLP-5-GW	40.546734	-105.000800	17.8	39.62	3/16/2022
CLP-6	GW	CLP-6-GW	40.485626	-104.958554	24.9	46.73	3/16/2022
CLP-7	GW	CLP-7-GW	40.447725	-104.889148	32.2	54.09	3/15/2022
CLP-7	GW	CLP-7-GW	40.447692	-104.889319	32.2	54.09	3/20/2022
CLP-8	GW	CLP-8-GW	40.445871	-104.773256	42.3	64.15	3/15/2022
CLP-9	GW	CLP-9-GW	40.440509	-104.691772	48.8	70.67	3/15/2022
CLP-9	GW	CLP-9-GW	40.440415	-104.691827	48.8	70.67	3/20/2022
SVR-1	SW	SVR-1-SW	40.210131	-105.235024	1.7	26.28	3/24/2022
SVR-2	SW	SVR-2-SW	40.186811	-105.191273	4.8	29.36	3/24/2022
SVR-3	SW	SVR-3-SW	40.155026	-105.090650	11.1	35.65	3/24/2022
SVR-4	SW	SVR-4-SW	40.154113	-105.088567	11.2	35.76	3/24/2022
SVR-5A	SW	SVR-5A-SW	40.152034	-105.055160	13.0	37.61	3/24/2022
SVR-6	SW	SVR-6-SW	40.160375	-105.008080	16.3	40.89	3/24/2022
SVR-7	SW	SVR-7-SW	40.204069	-104.906660	25.0	49.57	3/24/2022
SVR-8	SW	SVR-8-SW	40.257844	-104.880591	30.7	55.29	3/24/2022
SVR-1	GW	SVR-1-GW	40.210131	-105.235024	1.7	26.28	3/31/2022
SVR-2	GW	SVR-2-GW	40.186811	-105.191273	4.8	29.36	3/29/2022
SVR-3	GW	SVR-3-GW	40.155026	-105.090650	11.1	35.65	3/29/2022
SVR-5A	GW	SVR-5A-GW	40.152034	-105.055160	13.0	37.61	3/28/2022

Location	Type	Sample ID	Latitude	Longitude	Distance Down-stream (miles)	Distance Along SPR (miles)	Sample Date
SVR-6	GW	SVR-6-GW	40.160391	-105.007986	16.3	40.89	3/28/2022
SVR-7	GW	SVR-7-GW	40.204069	-104.906660	25.0	49.57	3/28/2022
SVR-8	GW	SVR-8-GW	40.257844	-104.880591	30.7	55.29	3/28/2022
SPR-12	SW	SPR-12-SW	39.746285	-105.015849	6.4	6.39	4/7/2022
SPR-11	SW	SPR-11-SW	39.885423	-104.902112	19.5	19.49	4/7/2022
SPR-10	SW	SPR-10-SW	40.081265	-104.821538	38.1	38.13	4/7/2022
SPR-09	SW	SPR-9-SW	40.224670	-104.849884	51.7	51.70	4/7/2022
SPR-08	SW	SPR-8-SW	40.349651	-104.762621	65.9	65.93	4/6/2022
SPR-07	SW	SPR-7-SW	40.412545	-104.563876	80.0	80.00	4/6/2022
SPR-06	SW	SPR-6-SW	40.336456	-103.969967	120.9	120.88	4/5/2022
SPR-05	SW	SPR-5-SW	40.321593	-103.595145	144.9	144.94	4/5/2022
SPR-04	SW	SPR-4-SW	40.473838	-103.345782	165.3	165.31	4/4/2022
SPR-03	SW	SPR-3-SW	40.626173	-103.180306	181.0	181.00	4/4/2022
SPR-02	SW	SPR-2-SW	40.841732	-102.804850	209.9	209.94	4/4/2022
SPR-01	SW	SPR-1-SW	40.973649	-102.250534	245.0	245.02	4/4/2022
SPR-12	GW	SPR-12-GW	39.746285	-105.015849	6.4	6.39	4/7/2022
SPR-11	GW	SPR-11-GW	39.885423	-104.902112	19.5	19.49	4/7/2022
SPR-10	GW	SPR-10-GW	40.081265	-104.821538	38.1	38.13	4/7/2022
SPR-09	GW	SPR-9-GW	40.224670	-104.849884	51.7	51.70	4/7/2022
SPR-08	GW	SPR-8-GW	40.349651	-104.762621	65.9	65.93	4/6/2022
SPR-07	GW	SPR-7-GW	40.412545	-104.563876	80.0	80.00	4/6/2022
SPR-06	GW	SPR-6-GW	40.336456	-103.969967	120.9	120.88	4/5/2022
SPR-05	GW	SPR-5-GW	40.321593	-103.595145	144.9	144.94	4/5/2022
SPR-04	GW	SPR-4-GW	40.473838	-103.345782	165.3	165.31	4/4/2022
SPR-03	GW	SPR-3-GW	40.626173	-103.180306	181.0	181.00	4/4/2022
SPR-02	GW	SPR-2-GW	40.841732	-102.804850	209.9	209.94	4/4/2022
SPR-01	GW	SPR-1-GW	40.973649	-102.250534	245.0	245.02	4/4/2022
BEC-1	SW	BEC-1-SW	40.371140	-104.469107	86.85	86.85	4/6/2022
BJC-1	SW	BJC-1-SW	40.280245	-103.877141	128.08	128.08	4/5/2022
BVC-1A	SW	BVC-1A-SW	40.334254	-103.546660	148.33	148.33	4/5/2022
BEC-1A	GW	BEC-1A-GW	40.363296	-104.481434	86.85	86.85	4/6/2022
BJC-1	GW	BJC-1-GW	40.280245	-103.877141	128.08	128.08	4/5/2022
BVC-1A	GW	BVC-1A-GW	40.334254	-103.546660	148.33	148.33	4/5/2022

Location	Type	Sample Time	Mini-piezo Head inches	Inferred Bedrock Formation	Bedrock Type	Nearest River Guage
BTR-1	SW	9:30	--	Trpjs or PPif	Terrestrial	DWR Guage BTABCMCO
BTR-2A	SW	12:15	--	Kp-Pierre Shale	Marine	USGS Guage 06741510
BTR-3	SW	14:15	--	Kp-Pierre Shale	Marine	USGS Guage 06741510
BTR-4	SW	8:15	--	Kf-Fox Hills	Marine	DWR Guage BIGLASCO
BTR-5	SW	9:10	--	Kl-Laramie	Terrestrial	DWR Guage BIGLASCO
BTR-1	GW	10:05	0.0625	Trpjs or PPif	Terrestrial	DWR Guage BTABCMCO
BTR-2A	GW	12:40	0.125	Kp-Pierre Shale	Marine	USGS Guage 06741510
BTR-3	GW	15:00	0.5	Kp-Pierre Shale	Marine	USGS Guage 06741510
BTR-4	GW	9:00	0.75	Kf-Fox Hills	Marine	DWR Guage BIGLASCO
BTR-5	GW	9:55	0.25	Kl-Laramie	Terrestrial	DWR Guage BIGLASCO
CLP-1	SW	11:59	--	Trpjs or PPif	Terrestrial	DWR Guage CLAFTCCO
CLP-2	SW	13:03	--	Kp-Pierre Shale	Marine	USGS Guage 06752260
CLP-3	SW	14:20	--	Kp-Pierre Shale	Marine	USGS Guage 06752260
CLP-4	SW	15:50	--	Kp-Pierre Shale	Marine	USGS Guage 06752280
CLP-5	SW	9:10	--	Kp-Pierre Shale	Marine	USGS Guage 06752280
CLP-6	SW	17:30	--	Kp-Pierre Shale	Marine	DWR Guage CLARIVCO
CLP-7	SW	14:25	--	Kp-Pierre Shale	Marine	DWR Guage CLARIVCO
CLP-8	SW	11:10	--	Kf-Fox Hills	Marine	DWR Guage CLAWASCO
CLP-9	SW	17:20	--	Kl-Laramie	Terrestrial	DWR Guage CLAWASCO
CLP-1	GW	12:40	1.375	Trpjs or PPif	Terrestrial	DWR Guage CLAFTCCO
CLP-Insitu	GW	16:30	--	Kp-Pierre Shale	Marine	--
CLP-3	GW	16:25	3.75	Kp-Pierre Shale	Marine	USGS Guage 06752260
CLP-4	GW	13:30	0.25	Kp-Pierre Shale	Marine	USGS Guage 06752280
CLP-5	GW	11:45	0.25	Kp-Pierre Shale	Marine	USGS Guage 06752280
CLP-6	GW	9:35	0.25	Kp-Pierre Shale	Marine	DWR Guage CLARIVCO
CLP-7	GW	15:15	0.125	Kp-Pierre Shale	Marine	DWR Guage CLARIVCO
CLP-7	GW	17:25	0.188	Kp-Pierre Shale	Marine	DWR Guage CLARIVCO
CLP-8	GW	15:50	0.25	Kf-Fox Hills	Marine	DWR Guage CLAWASCO
CLP-9	GW	17:45	0.25	Kl-Laramie	Terrestrial	DWR Guage CLAWASCO
CLP-9	GW	13:40	0.125	Kl-Laramie	Terrestrial	DWR Guage CLAWASCO
SVR-1	SW	15:15	--	Kc-CO Grp	Marine	DWR Guage SVCLYOCO
SVR-2	SW	14:40	--	Kp-Pierre Shale	Marine	DWR Guage SVCHGICO
SVR-3	SW	13:50	--	Kp-Pierre Shale	Marine	DWR Guage SVCLOPCO
SVR-4	SW	13:20	--	Kp-Pierre Shale	Marine	DWR Guage SVCLOPCO
SVR-5A	SW	12:45	--	Kp-Pierre Shale	Marine	DWR Guage SVCLOPCO
SVR-6	SW	11:55	--	Kp or Kf	Marine	DWR Guage SVCLOPCO
SVR-7	SW	10:59	--	Kf-Fox Hills	Marine	DWR Guage SVCLOPCO
SVR-8	SW	10:25	--	Kf-Fox Hills	Marine	DWR Guage SVCPLACO
SVR-1	GW	10:55	0.125	Kc-CO Grp	Marine	DWR Guage SVCLYOCO
SVR-2	GW	13:45	0.375	Kp-Pierre Shale	Marine	DWR Guage SVCHGICO
SVR-3	GW	11:15	0.875	Kp-Pierre Shale	Marine	DWR Guage SVCLOPCO
SVR-5A	GW	15:10	0.25	Kp or Kf	Marine	DWR Guage SVCLOPCO

Location	Type	Sample Time	Mini-piezo Head inches	Inferred Bedrock Formation	Bedrock Type	Nearest River Guage
SVR-6	GW	14:10	0.125	Kp or Kf	Marine	DWR Guage SVCLOPCO
SVR-7	GW	13:00	0.3125	Kf-Fox Hills	Marine	DWR Guage SVCLOPCO
SVR-8	GW	11:20	0.0625	Kf-Fox Hills	Marine	DWR Guage SVCPLACO
SPR-12	SW	15:00	--	Tkd-Denver	Terrestrial	DWR Guage PLADENCO
SPR-11	SW	12:55	--	Tkd-Denver	Terrestrial	DWR guage PLAHENCO
SPR-10	SW	10:50	--	TKda or Tkd	Terrestrial	USGS Guage 06721000
SPR-09	SW	8:25	--	Kl-Laramie	Terr-Coastal	DWR Guage PLAPLACO
SPR-08	SW	16:40	--	Kl-Laramie	Terr-Coastal	DWR Guage PLAPLACO
SPR-07	SW	14:35	--	Kl-Laramie	Terr-Coastal	DWR Guage PLAKERCO
SPR-06	SW	15:30	--	Kp-Pierre Shale	Marine	DWR Guage PLAWELCO
SPR-05	SW	11:30	--	Kp-Pierre Shale	Marine	DWR Guage PLABALCO
SPR-04	SW	16:10	--	Kp-Pierre Shale	Marine	DWR Guage PLAATWCO
SPR-03	SW	14:45	--	Kp-Pierre Shale	Marine	DWR Guage PLAATWCO
SPR-02	SW	12:25	--	Tw-White River	Terrestrial	DWR Guage PLACROCO
SPR-01	SW	9:45	--	Tw-White River	Terrestrial	DWR Guage ONEJURCO
SPR-12	GW	15:30	0.375	Tkd-Denver	Terrestrial	DWR Guage PLADENCO
SPR-11	GW	13:25	0.25	Tkd-Denver	Terrestrial	DWR guage PLAHENCO
SPR-10	GW	10:30	0.375	TKda or Tkd	Terrestrial	USGS Guage 06721000
SPR-09	GW	8:50	0.375	Kl-Laramie	Terr-Coastal	DWR Guage PLAPLACO
SPR-08	GW	16:55	0.4375	Kl-Laramie	Terr-Coastal	DWR Guage PLAPLACO
SPR-07	GW	15:10	0.25	Kl-Laramie	Terr-Coastal	DWR Guage PLAKERCO
SPR-06	GW	15:50	0.75	Kp-Pierre Shale	Marine	DWR Guage PLAWELCO
SPR-05	GW	12:00	0.5	Kp-Pierre Shale	Marine	DWR Guage PLABALCO
SPR-04	GW	16:35	0.5	Kp-Pierre Shale	Marine	DWR Guage PLAATWCO
SPR-03	GW	15:05	0.25	Kp-Pierre Shale	Marine	DWR Guage PLAATWCO
SPR-02	GW	12:40	0.5	Tw-White River	Terrestrial	DWR Guage PLACROCO
SPR-01	GW	10:10	0.75	Tw-White River	Terrestrial	DWR Guage ONEJURCO
BEC-1	SW	8:30	--	Kl-Laramie	Terr-Coastal	none on creek
BJC-1	SW	13:55	--	Kp-Pierre Shale	Marine	none on creek
BVC-1A	SW	9:55	--	Kp-Pierre Shale	Marine	none on creek
BEC-1A	GW	13:00	1.5	Kl-Laramie	Terr-Coastal	none on creek
BJC-1	GW	14:15	6.625	Kp-Pierre Shale	Marine	none on creek
BVC-1A	GW	10:25	2.125	Kp-Pierre Shale	Marine	none on creek

Ppif=Penn-Perm Ingleside & Fountain Fms, combined

Location	Type	Stream flow (ft3/s)	Field Temp C	Field pH	Field SPC uS_cm	Field DO mg_L	Field ORP eH	Field Turbidity NTU	Field TDS (mg/L)	Salinity (PSU)
BTR-1	SW	36.8	2.24	7.59	110.2	12.58	334.3	1.88	71.3	0.05
BTR-2A	SW	no data	6.35	7.68	1137	10.2	251.1	25.6	739	0.56
BTR-3	SW	no data	11.95	7.68	1211	11.77	180	0.44	787.5	0.6
BTR-4	SW	63.6	5.37	7.97	1521	9.47	223.4	12	987.5	0.75
BTR-5	SW	63.6	5.19	8.07	1554	10.59	219.7	3.64	1010.5	0.77
BTR-1	GW	35	6.17	7.89	719.4	9.12	270.3	603	467.3	0.35
BTR-2A	GW	no data	9.12	7.27	1416	6.67	-52.1	0	920	0.71
BTR-3	GW	no data	16.1	8.87	966.5	7.87	-107.6	70	628.3	0.48
BTR-4	GW	67.1	8.3	7.93	1514	9.23	182.2	972.3	14.71	0.75
BTR-5	GW	67.1	9.07	7.94	1559	8.96	153.2	30.1	1010	0.78
CLP-1	SW	56.9	5.31	8.54	214.9	12.95	219.2	0.37	139.8	0.1
CLP-2	SW	no data	7.54	8.46	422.9	12.7	241.5	0	275.3	0.2
CLP-3	SW	no data	11.2	8.16	1966	11.55	248.3	0	1277	1
CLP-4	SW	no data	11.23	8.4	1784	12.21	278.2	1.0259	1158.1	0.9
CLP-5	SW	no data	5.76	7.93	1948	9.1	311.6	0.558446	1266.1	0.98
CLP-6	SW	41.9	10.11	8.65	1486	13.2	220.6	17.6038	969.35	0.75
CLP-7	SW	40.8	8.22	8.78	1356	14.86	148.2	n/m	892.36	1.61
CLP-8	SW	80	7.45	8.49	1551	11.33	269.5	n/m	1007	0.77
CLP-9	SW	81.2	10.27	8.79	1631	14.68	256.2	n/m	1058.9	0.82
CLP-1	GW	70.3	7.78	8.12	509.7	9.47	243.6	249	330.2	0.24
CLP-Insitu	GW	--	11:02	21:21	2:24	6:43	16:48	0:00	0:00	22:19
CLP-3	GW	no data	8.85	8.22	1867	9.7	230.2	n/m	1214.4	0.94
CLP-4	GW	no data	8.07	7.85	1603	7.32	115.1	2.7	1041.8	0.8
CLP-5	GW	no data	9.18	7.78	1728	9.3	-85	n/m	1123.1	0.87
CLP-6	GW	39.8	6	7.74	1479	6.87	-32.1	1.1	954.5	0.73
CLP-7	GW	40.3	--	--	--	--	--	--	--	--
CLP-7	GW	40.3	16.65*	8.13	1975	8.31	235.8	114.2	1286.4	1.02
CLP-8	GW	80	12.08	7.87	1565	6.56	197.47	n/m	1014.3	0.79
CLP-9	GW	81.2	--	--	--	--	--	--	--	--
CLP-9	GW	67.4	12.9	8.32	1601	8.62	178	37	1040.2	0.81
SVR-1	SW	22.9	14.65	9.45	419.3	13.16	128	0	271.3	0.2
SVR-2	SW	13.8	11.95	8.63	448.7	11.44	174.3	0	291.93	0.22
SVR-3	SW	29.7	10.75	8.62	1407	12.54	178.4	4.96	914.74	0.71
SVR-4	SW	30.5	7.9	8.62	1320	10.93	191.1	0	857.64	0.65
SVR-5A	SW	30.5	10.89	8.59	1218	13.83	188.8	3.91	792.1	0.61
SVR-6	SW	31.4	7.62	8.4	1368	10.38	216.7	6.38	889.24	0.68
SVR-7	SW	33.5	7.37	9.32	1457	10.28	222.8	10.59	946.84	0.72
SVR-8	SW	114	6.36	8.19	1527	10.55	219.9	9.51	993.08	0.76
SVR-1	GW	32.8	10.2	7.67	434	6.73	126.2	n/a	281	0.21
SVR-2	GW	5.04	9.8	7.31	643.8	7.99	212.8	46	418.16	0.31
SVR-3	GW	31.3	11.1	8.09	1916	8.71	-69	232	1244.4	0.97
SVR-5A	GW	28.1	16.8	7.54	1959	7.31	64.3	160	1273.1	1.01

Location	Type	Stream flow (ft3/s)	Field Temp C	Field pH	Field SPC uS_cm	Field DO mg_L	Field ORP eH	Field Turbidity NTU	Field TDS (mg/L)	Salinity (PSU)
SVR-6	GW	28.4	13.06	7.72	1353	4.17	253.4	23.44	880.14	0.68
SVR-7	GW	29.2	13.33	7.49	1135	7.22	189.3	0.96	737.4	0.57
SVR-8	GW	99.1	11.02	7.36	1875	7.01	202	0	1217.4	0.95
SPR-12	SW	157	12.7	n/a*	1040	11.98	68.1	n/a	676	0.52
SPR-11	SW	186	13.8	9.7	1196	9.76	116.6	n/a	779	0.6
SPR-10	SW	338	9.4	8.23	1257	9.82	140.5	n/a	810	0.63
SPR-09	SW	167	4.9	8.11	1279	9.13	153.9	n/a	831	0.64
SPR-08	SW	189	8.7	8.2	1267	8.88	142	n/a	818	0.63
SPR-07	SW	467	10	9.57	1364	9.11	116.8	n/a	27	0.42
SPR-06	SW	335	10.6	8.22	1434	8.25	159.1	n/a	932	0.72
SPR-05	SW	49.2	10.2	8.19	1547	8.54	93.6	n/a	1006	0.78
SPR-04	SW	111	17.9	9.74	1668	9.14	113.9	n/a	1085	0.85
SPR-03	SW	109	15.2	8.07	1790	8.89	147	n/a	1164	0.91
SPR-02	SW	43	11.9	8.45	2062	9.51	133.1	n/a	1341	1.06
SPR-01	SW	135	6.2	8.25	2110	9.95	138.4	n/a	1321	1.08
SPR-12	GW	157	13.2	8.04	1368	7.42	83.5	n/a	888	0.68
SPR-11	GW	186	14.5	7.7	1540	6.94	-114.5	n/a	1003	0.78
SPR-10	GW	338	10.8	7.7	1280	7.43	150.9	n/a	831	0.64
SPR-09	GW	167	7.6	7.54	1231	5.17	151	n/a	800	0.62
SPR-08	GW	189	8.9	7.67	1210	8.2	146.1	n/a	786	0.61
SPR-07	GW	441	7.7	7.74	1392	8	139.5	n/a	905	0.7
SPR-06	GW	321	12.6	7.66	1684	7.45	163.9	n/a	1095	0.86
SPR-05	GW	50.2	10.6	7.73	2040	7.88	125.7	n/a	1328	1.05
SPR-04	GW	114	18.3	9.17	1868	6.89	110.1	n/a	1214	0.95
SPR-03	GW	109	18.3	7.83	1776	6.79	138.9	n/a	1152	0.9
SPR-02	GW	46.3	12.6	8.02	1986	5.07	153.2	n/a	1290	1.02
SPR-01	GW	135	11.4	7.96	2202	8.01	184.4	n/a	1435	1.14
BEC-1	SW	--	0:00	10:33	0:00	18:57	7:12	n/a	0:00	17:16
BJC-1	SW	--	21:36	12:57	0:00	19:12	4:48	n/a	0:00	18:28
BVC-1A	SW	--	21:36	16:33	0:00	7:26	#######	n/a	0:00	23:31
BEC-1A	GW	--	21:36	10:19	0:00	8:24	0:00	n/a	0:00	8:24
BJC-1	GW	--	19:12	14:38	0:00	11:45	9:36	n/a	0:00	20:38
BVC-1A	GW	--	0:00	17:31	0:00	3:50	16:48	n/a	0:00	1:55

Location	Type	Lab pH	SAR	Adjusted SAR	EC (mmho/cm)	TDS-gravimetric (ppm)	Cations (me/L)	Anions (me/L)	Total Alkalinity (CaCO3) (ppm)
BTR-1	SW	7.7	0.5	0.3	0.12	83	0.9	0.9	27
BTR-2A	SW	7.8	0.7	0.9	1.12	*694*	11.3	11.3	148
BTR-3	SW	8.1	1.4	1.7	1.15	*713*	10.8	11	138
BTR-4	SW	8.1	1.7	2.0	1.46	*898*	14.7	14.8	205
BTR-5	SW	8.1	1.8	2.2	1.47	*916*	17	16.5	224
BTR-1	GW	8.2	0.8	1	0.7	444	7.3	6.9	189
BTR-2A	GW	7.9	1	1.4	1.34	*833*	15	14.8	217
BTR-3	GW	*9.0*	1.2	1.6	0.93	*583*	10.2	9.9	196
BTR-4	GW	8.0	1.6	2	1.41	*877*	15.5	14.9	276
BTR-5	GW	8.1	1.7	2	1.5	*936*	14.1	14.4	217
CLP-1	SW	8.1	0.3	0.3	0.22	128	2	1.9	71
CLP-2	SW	8.2	0.5	0.6	0.41	246	4.2	3.8	111
CLP-3	SW	8.1	1.2	1.6	1.8	*1109*	19.2	19.5	215
CLP-4	SW	8.3	2.1	2.7	1.64	*1018*	17.7	17.2	209
CLP-5	SW	8	1.5	1.8	1.75	*1081*	19.0	18.5	210
CLP-6	SW	8.4	1.7	2	1.41	*870*	14.6	14.6	194
CLP-7	SW	*8.3*	1.6	1.8	1.3	*801*	12.4	12.6	181
CLP-8	SW	8.2	1.6	1.9	1.45	*902*	13.9	14.2	199
CLP-9	SW	8.4	2.1	2.4	1.65	*1032*	15.7	15.9	210
CLP-1	GW	8.0	0.3	0.3	0.49	302	4.9	5	214
CLP-Insitu	GW	7.2	2.2	2.8	1.76	*1089*	17.9	17	176
CLP-3	GW	8	1.2	1.6	1.77	*1101*	19.8	19.7	206
CLP-4	GW	7.9	1.6	2.1	1.51	*934*	13.7	14	198
CLP-5	GW	7.7	1.2	1.5	1.62	*1010*	17.9	17.9	211
CLP-6	GW	7.8	1.6	1.9	1.41	*876*	13.4	13.6	187
CLP-7	GW	7.7	1.7	2.1	1.43	*891*	15.3	15.6	235
CLP-7	GW	--	--	--	--	--	--	--	--
CLP-8	GW	7.8	1.8	2.1	1.53	*951*	16.7	16.2	215
CLP-9	GW	8.4	1.8	2.2	1.49	*919*	16.1	16.8	259
CLP-9	GW	--	--	--	--	--	--	--	--
SVR-1	SW	*8.7*	0.7	0.8	0.45	278	4.5	4.2	105
SVR-2	SW	8.3	0.5	0.5	0.44	268	3.9	3.9	98
SVR-3	SW	8.4	2	2.4	1.3	*814*	14.7	13.9	248
SVR-4	SW	8.3	1.4	1.6	1.27	*796*	12.3	12.6	275
SVR-5A	SW	8.2	2	2.4	1.17	*731*	12.7	12.2	227
SVR-6	SW	8.3	2.5	2.8	1.3	*805*	12	11.9	197
SVR-7	SW	8.3	2.8	3.2	1.4	*851*	14.8	13.6	202
SVR-8	SW	8.1	2.6	3	1.45	*907*	13.5	13.6	204
SVR-1	GW	8.2	0.7	0.7	0.41	254	4.2	4.2	119
SVR-2	GW	7.4	1	1.2	0.64	401	5.7	5.9	158
SVR-3	GW	8.1	3.3	4.1	1.82	*1122*	19.3	18.4	253
SVR-5A	GW	7.8	2.4	2.7	1.91	*1180*	17.6	18	212

Location	Type	Lab pH	SAR	Adjusted SAR	EC (mmho/cm)	TDS-gravimetric (ppm)	Cations (me/L)	Anions (me/L)	Total Alkalinity (CaCO3) (ppm)
SVR-6	GW	7.9	2.8	3.2	1.32	*826*	13.3	12.1	206
SVR-7	GW	7.7	2.3	2.7	1.18	*727*	10.2	10.5	186
SVR-8	GW	7.6	2.9	3.7	1.8	*1121*	18.2	17.3	205
SPR-12	SW	*8.8*	2.6	3	0.97	*600*	9.8	9.8	139
SPR-11	SW	8.2	3.6	4.3	1.12	*667*	11.4	11.4	156
SPR-10	SW	8.2	3.6	4.3	1.15	*731*	11.8	11.2	158
SPR-09	SW	8.2	3.6	4.3	1.18	*748*	12.3	11.2	160
SPR-08	SW	8.4	3.1	3.6	1.21	*751*	13	12.2	178
SPR-07	SW	8.3	2.5	3	1.28	*793*	14.1	13.4	201
SPR-06	SW	8.3	2.9	3.6	1.51	*947*	17.4	15.9	215
SPR-05	SW	8.3	2.9	3.7	1.63	*1037*	18.7	17.4	234
SPR-04	SW	8.5	3.1	3.9	1.6	*946*	19.8	19.1	239
SPR-03	SW	8.5	3	3.9	1.68	*1041*	20.6	20.4	247
SPR-02	SW	8.5	3.5	4.6	1.95	*1242*	24.5	23.8	257
SPR-01	SW	8.3	3.5	4.4	2.02	*1268*	25.1	24.6	216
SPR-12	GW	8.3	6	7.6	1.28	*783*	14.8	14.2	215
SPR-11	GW	8.2	3.9	5.4	1.42	*919*	17.4	16.6	335
SPR-10	GW	8.2	4	5	1.17	*720*	14.3	13.6	222
SPR-09	GW	8.2	3.9	4.6	1.14	*710*	13.9	11.9	155
SPR-08	GW	8.2	2.3	2.8	1.13	*699*	14.2	13.2	170
SPR-07	GW	8.2	2.8	3.3	1.29	*801*	16.2	14.4	201
SPR-06	GW	8.0	2.5	3.3	1.75	*1065*	18.5	18.2	281
SPR-05	GW	8.1	3	3.9	2.15	*1313*	23	23.3	323
SPR-04	GW	8.3	3	3.8	1.77	*1082*	18.9	19.3	238
SPR-03	GW	8.4	2.8	3.5	1.66	*1007*	17.6	18.4	243
SPR-02	GW	8.3	3.1	4	1.86	*1155*	20.4	20.7	260
SPR-01	GW	8.2	3.1	4.1	2.12	*1331*	23.6	24.3	228
BEC-1	SW	*8.2*	3.4	4.1	1.36	*844*	14.6	14.3	206
BJC-1	SW	7.9	2.6	3.6	1.59	*951*	18.2	17.1	207
BVC-1A	SW	7.7	3.1	4	1.99	*1237*	23.8	22.3	323
BEC-1A	GW	8.2	3.8	4.7	1.39	*862*	16.7	15.3	212
BJC-1	GW	7.9	2.2	3.1	1.8	*1130*	18.2	18.7	238
BVC-1A	GW	8.0	2.9	3.8	2.22	*1369*	23.6	23.9	352

Location	Type	Total Hardness (CaCO3) (ppm)	Sodium (ppm)	Potassium (ppm)	Calcium (ppm)	Magnesium (ppm)	Chloride (ppm)	Bicarb (HCO3) (ppm)
BTR-1	SW	31	7	< 1	8.9	2	6	33
BTR-2A	SW	483	37	2	132.8	36	22	180
BTR-3	SW	394	64	5	96.1	37	52	166
BTR-4	SW	533	90	4	109.5	62	42	247
BTR-5	SW	615	105	5	125.5	72	41	271
BTR-1	GW	291	33	2	72.8	26	52	227
BTR-2A	GW	624	58	2	177.8	43	41	263
BTR-3	GW	381	56	7	109.3	26	41	218
BTR-4	GW	580	88	3	127	63	32	334
BTR-5	GW	513	87	5	105.3	60	41	262
CLP-1	SW	83	7	1	22.8	6	5	86
CLP-2	SW	174	17	2	47.5	13	19	134
CLP-3	SW	787	79	3	218	58	72	259
CLP-4	SW	616	120	3	153.3	56	209	251
CLP-5	SW	747	92	5	181.7	70	71	254
CLP-6	SW	529	88	6	120.3	55	67	232
CLP-7	SW	445	77	5	97.6	48	58	216
CLP-8	SW	508	84	5	109.7	56	61	240
CLP-9	SW	540	110	5	110.9	63	91	250
CLP-1	GW	222	9	2	62.1	16	4	259
CLP-Insitu	GW	612	124	9	173.1	43	260	214
CLP-3	GW	819	77	4	230.7	58	56	249
CLP-4	GW	501	82	3	131.9	41	146	239
CLP-5	GW	728	73	5	188.2	62	42	257
CLP-6	GW	491	79	5	113.4	50	61	227
CLP-7	GW	551	92	9	122.4	59	65	285
CLP-7	GW	--	--	--	--	--	--	--
CLP-8	GW	609	100	4	127.3	70	58	260
CLP-9	GW	582	100	6	121	67	65	308
CLP-9	GW	--	--	--	--	--	--	--
SVR-1	SW	178	22	2	48.3	14	24	122
SVR-2	SW	162	14	1	47.8	10	15	117
SVR-3	SW	503	104	4	100.7	60	84	296
SVR-4	SW	467	68	2	94.8	55	60	329
SVR-5A	SW	423	94	6	85.6	50	76	273
SVR-6	SW	359	108	6	71.6	43	100	236
SVR-7	SW	435	134	7	84.2	54	106	243
SVR-8	SW	403	121	6	77.6	50	112	246
SVR-1	GW	168	20	2	46.8	12	24	143
SVR-2	GW	205	35	2	52.2	18	8	192
SVR-3	GW	569	180	3	126	61	86	305
SVR-5A	GW	588	132	6	115	72	90	257

Location	Type	Total Hardness (CaCO3) (ppm)	Sodium (ppm)	Potassium (ppm)	Calcium (ppm)	Magnesium (ppm)	Chloride (ppm)	Bicarb (HCO3) (ppm)
SVR-6	GW	379	125	8	75.1	46	100	249
SVR-7	GW	302	94	3	59.1	37	79	225
SVR-8	GW	568	156	4	147.1	48	127	250
SPR-12	SW	269	98	6	76	19	144	160
SPR-11	SW	262	134	13	72.6	19	168	187
SPR-10	SW	275	138	13	74.8	21	150	190
SPR-09	SW	296	142	12	79.9	23	137	192
SPR-08	SW	352	133	9	83.5	34	120	213
SPR-07	SW	431	119	11	99.1	44	82	241
SPR-06	SW	523	153	10	126.2	50	94	258
SPR-05	SW	572	161	11	141.5	52	96	280
SPR-04	SW	594	174	12	141.1	58	100	283
SPR-03	SW	633	176	13	153	60	99	293
SPR-02	SW	733	218	17	178.5	69	102	304
SPR-01	SW	746	222	18	190	65	117	259
SPR-12	GW	252	219	11	74	16	243	258
SPR-11	GW	450	188	8	125	33	253	403
SPR-10	GW	332	169	15	90.5	25	162	267
SPR-09	GW	322	162	15	87	25	151	186
SPR-08	GW	457	115	5	105.7	46	74	205
SPR-07	GW	488	142	10	112.2	50	93	242
SPR-06	GW	604	143	5	145	58	96	339
SPR-05	GW	729	186	12	180.2	67	91	390
SPR-04	GW	563	163	21	136.7	53	88	284
SPR-03	GW	545	149	10	133.1	51	100	291
SPR-02	GW	619	176	13	151.2	58	92	312
SPR-01	GW	743	194	14	198.9	59	117	274
BEC-1	SW	378	154	12	88.3	38	149	248
BJC-1	SW	578	146	11	161.4	42	92	251
BVC-1A	SW	752	194	13	178.9	73	99	392
BEC-1A	GW	427	181	14	99.2	43	156	255
BJC-1	GW	628	125	10	197.6	32	85	288
BVC-1A	GW	769	184	8	191.2	70	98	425

Location	Type	Carb (CO3) (ppm)	Sulfate as S (SO4-S) (ppm)	Sulfate (SO4) (ppm)	Fluoride (ppm)	NO3-N (ppm)	Ortho Phosphorus (P) (ppm)	Boron (ppm)	Total Fe (ppm)
BTR-1	SW	< 1.0	2	6	0.16	0.5	0.03	0.01	0.08
BTR-2A	SW	< 1.0	123	*369*	0.27	0.5	0.02	0.05	0.19
BTR-3	SW	< 1.0	103	*309*	0.52	5	0.04	0.17	0.08
BTR-4	SW	< 1.0	*149*	*447*	0.61	3.3	0.2	0.23	0.04
BTR-5	SW	< 1.0	*171*	*513*	0.61	3.4	0.19	0.24	0.05
BTR-1	GW	< 1.0	26	78	0.25	1	0.02	0.03	0.24
BTR-2A	GW	< 1.0	*150*	*450*	0.35	0.1	0.04	0.1	*2.4*
BTR-3	GW	12.6	76	228	0.39	0.5	0.42	0.07	*1.61*
BTR-4	GW	< 1.0	134	*402*	0.66	1.2	0.03	0.19	< 0.01
BTR-5	GW	< 1.0	142	*426*	0.65	0.6	0.19	0.25	0.19
CLP-1	SW	< 1.0	5	15	0.3	0.4	< 0.01	0.02	0.07
CLP-2	SW	< 1.0	17	51	0.35	0.3	0.02	0.04	0.13
CLP-3	SW	< 1.0	208	*624*	0.66	1.6	0.01	0.22	0.10
CLP-4	SW	2.5	112	*336*	0.54	0.8	0.01	0.21	0.12
CLP-5	SW	< 1.0	195	*585*	0.64	1.5	0.02	0.23	0.07
CLP-6	SW	3.2	139	*417*	0.88	1.3	0.16	0.21	0.18
CLP-7	SW	2.5	*116*	*348*	0.82	1	0.07	0.19	0.05
CLP-8	SW	< 1.0	*135*	*405*	0.85	1.7	0.05	0.22	0.1
CLP-9	SW	3.5	*142*	*426*	0.84	2.2	0.03	0.21	0.08
CLP-1	GW	< 1.0	9	27	0.44	0.5	0.01	0.03	*0.37*
CLP-Insitu	GW	< 1.0	95	*285*	0.31	1.5	< 0.01	0.17	0.24
CLP-3	GW	< 1.0	222	*666*	0.58	1.3	0.02	0.2	0.26
CLP-4	GW	< 1.0	94	*282*	0.42	0.9	0.03	0.15	0.04
CLP-5	GW	< 1.0	199	*597*	0.32	0.1	0.15	0.15	*1.82*
CLP-6	GW	< 1.0	*131*	*393*	0.79	0.2	0.06	0.2	*0.86*
CLP-7	GW	< 1.0	145	*435*	0.5	0.5	0.02	0.21	*1.17*
CLP-7	GW	--	--	--	--	--	--	--	--
CLP-8	GW	< 1.0	*164*	*492*	0.69	0.2	0.08	0.21	*0.78*
CLP-9	GW	4.6	*154*	*462*	0.58	2.1	0.07	0.23	*0.54*
CLP-9	GW	--	--	--	--	--	--	--	--
SVR-1	SW	3.2	23	69	0.37	0.2	0.03	0.04	0.13
SVR-2	SW	1.3	25	75	0.34	0.1	< 0.01	0.02	0.15
SVR-3	SW	3.8	104	*312*	0.73	0.6	< 0.01	0.19	0.07
SVR-4	SW	3.7	85	*255*	1.53	0.7	0.01	0.17	0.06
SVR-5A	SW	< 1.0	86	*258*	0.82	2.2	0.86	0.2	0.09
SVR-6	SW	2.8	78	234	0.85	2.9	0.91	0.2	0.12
SVR-7	SW	2.4	101	*303*	0.85	3	0.9	0.22	0.1
SVR-8	SW	< 1.0	99	*297*	0.84	3.7	0.95	0.23	0.09
SVR-1	GW	< 1.0	19	57	0.39	0.3	0.02	0.03	0.29
SVR-2	GW	< 1.0	40	120	0.13	0.1	0.01	0.05	*1.38*
SVR-3	GW	< 1.0	175	*525*	0.28	0.1	0.03	0.22	*0.89*
SVR-5A	GW	< 1.0	179	*537*	0.67	0.9	0.42	0.31	0.12

Location	Type	Carb (CO3) (ppm)	Sulfate as S (SO4-S) (ppm)	Sulfate (SO4) (ppm)	Fluoride (ppm)	NO3-N (ppm)	Ortho Phosphorus (P) (ppm)	Boron (ppm)	Total Fe (ppm)
SVR-6	GW	< 1.0	83	249	0.89	0.4	0.93	0.2	*0.45*
SVR-7	GW	< 1.0	72	216	1.61	0.4	0.04	0.19	0.11
SVR-8	GW	< 1.0	149	*447*	0.8	3.9	0.08	0.27	< 0.01
SPR-12	SW	5.3	43	129	0.79	2.3	0.35	0.13	0.1
SPR-11	SW	< 1.0	55	165	0.83	2.3	0.27	0.24	0.14
SPR-10	SW	< 1.0	59	177	0.85	1.9	0.26	0.25	0.09
SPR-09	SW	< 1.0	64	192	0.89	2.7	0.21	0.24	0.08
SPR-08	SW	2.8	*79*	237	0.89	3.2	0.44	0.23	0.04
SPR-07	SW	2.8	107	*321*	0.81	5.2	1.11	0.24	0.04
SPR-06	SW	2.8	138	*414*	0.88	3.2	0.29	0.24	0.06
SPR-05	SW	3.1	155	*465*	0.82	3.8	0.41	0.24	0.07
SPR-04	SW	5.1	181	*543*	0.82	1.6	0.1	0.24	0.03
SPR-03	SW	5	199	*597*	0.77	1.8	0.09	0.25	0.02
SPR-02	SW	5.2	249	*747*	0.7	2.3	0.1	0.29	0.03
SPR-01	SW	3	269	*807*	0.51	2.2	< 0.01	0.27	0.1
SPR-12	GW	2.7	48	144	1.34	0.2	0.09	0.25	0.27
SPR-11	GW	< 1.0	45	135	1.31	0.2	0.16	0.19	*1.06*
SPR-10	GW	< 1.0	71	213	0.85	2.6	0.26	0.24	0.04
SPR-09	GW	< 1.0	70	210	0.89	1.9	0.29	0.22	< 0.01
SPR-08	GW	< 1.0	*114*	*342*	0.78	7.8	0.06	0.19	0.01
SPR-07	GW	< 1.0	118	*354*	0.71	5.4	0.47	0.22	0.03
SPR-06	GW	< 1.0	153	*459*	1.26	4.2	0.07	0.25	0.02
SPR-05	GW	< 1.0	228	*684*	0.81	0.4	0.22	0.32	0.07
SPR-04	GW	3.4	190	*570*	1.37	1	0.1	0.26	0.01
SPR-03	GW	3.7	168	*504*	0.76	1.7	0.14	0.24	< 0.01
SPR-02	GW	3.2	204	*612*	0.7	2	0.15	0.28	< 0.01
SPR-01	GW	< 1.0	259	*777*	0.38	3.7	0.07	0.24	0.01
BEC-1	SW	< 1.0	*93*	*279*	0.91	3.1	0.25	0.25	*0.55*
BJC-1	SW	< 1.0	161	*483*	0.77	4.3	0.02	0.19	0.02
BVC-1A	SW	< 1.0	207	*621*	0.88	1.4	0.13	0.3	0.17
BEC-1A	GW	< 1.0	*103*	*309*	0.9	2.8	0.29	0.23	*0.92*
BJC-1	GW	< 1.0	173	*519*	0.75	**10.3**	0.03	0.18	0.09
BVC-1A	GW	< 1.0	223	*669*	0.53	2.4	0.05	0.35	0.11

Location	Type	Manganese (ppm)	Barium, Dissolved (ug/L)	Lab Qualifier	Selenium, Dissolved (ug/L)	Lab Qualifier	Uranium, Dissolved (ug/L)	Lab Qualifier
BTR-1	SW	< 0.01	13		ND	U	0.43	J
BTR-2A	SW	*0.06*	85		14		10	
BTR-3	SW	0.02	47		6		8.9	
BTR-4	SW	0.03	50		3.8	J	22	
BTR-5	SW	0.02	50		3.7	J	21	
BTR-1	GW	0.02	67		0.6	J	3	
BTR-2A	GW	*0.56*	64		ND	U	7.3	
BTR-3	GW	*0.33*	76		ND	U	2	
BTR-4	GW	*0.14*	31	^+	2.4	J	**41**	
BTR-5	GW	0.03	59	^+	2.9	J	21	
CLP-1	SW	0.02	33		ND	U	2.1	
CLP-2	SW	*0.07*	61		ND	U	3.4	
CLP-3	SW	*0.12*	56		4.5	J	16	
CLP-4	SW	*0.08*	100		3.6	J	11	
CLP-5	SW	*0.08*	48		3.8	J	19	
CLP-6	SW	*0.13*	110		0.46	J	**43**	
CLP-7	SW	*0.06*	51		1.9	J	12	
CLP-8	SW	*0.14*	52		2.9	J	17	
CLP-9	SW	0.1	55		3	J	22	
CLP-1	GW	*0.06*	36		ND	U	2.3	
CLP-Insitu	GW	*0.21*	150		2.3	J	26	
CLP-3	GW	0.04	77		9.7		23	
CLP-4	GW	0.02	120		3.7	J	12	
CLP-5	GW	*2.23*	150		ND	U	2.9	
CLP-6	GW	*0.12*	49		2.5	J	13	
CLP-7	GW	*0.15*	--	--	--	--	--	--
CLP-7	GW	--	84		1.9	J	20	
CLP-8	GW	*0.88*	110		0.37	J	27	
CLP-9	GW	0.01	--	--	--	--	--	--
CLP-9	GW	--	120		1.6	J	14	
SVR-1	SW	0.01	45		ND	U	3.8	
SVR-2	SW	0.01	51		0.43	J	4.9	
SVR-3	SW	0.04	77		2.6	J	16	
SVR-4	SW	0.02	69		1.7	J	24	
SVR-5A	SW	0.02	55		1.4	J	13	
SVR-6	SW	0.03	52		2.3	J	11	
SVR-7	SW	0.02	51		1.7	J	13	
SVR-8	SW	0.03	51		1.9	J	14	
SVR-1	GW	0.05	34		ND	U	4.3	
SVR-2	GW	*0.52*	100		ND	U	5.6	
SVR-3	GW	*0.57*	59		ND	U	7.2	
SVR-5A	GW	0.04	47		2	J	25	

Location	Type	Manganese (ppm)	Barium, Dissolved (ug/L)	Lab Qualifier	Selenium, Dissolved (ug/L)	Lab Qualifier	Uranium, Dissolved (ug/L)	Lab Qualifier
SVR-6	GW	0.04	72		1.1	J	13	
SVR-7	GW	0.02	51		0.71	J	15	
SVR-8	GW	*0.43*	32		1.6	J	22	
SPR-12	SW	*0.09*	56		1.5	J	12	
SPR-11	SW	*0.06*	43		1.2	J	6.8	
SPR-10	SW	0.05	60		1	J	7.6	
SPR-09	SW	0.03	52		1.1	J	9.1	
SPR-08	SW	0.01	53		1.5	J	12	
SPR-07	SW	< 0.01	49		1.9	J	19	
SPR-06	SW	0.04	49		3	J	25	
SPR-05	SW	0.03	42		4	J	30	
SPR-04	SW	0.05	38		3.2	J	**44**	
SPR-03	SW	< 0.01	42		3.4	J	**48**	
SPR-02	SW	0.01	41		3.9	J	**54**	
SPR-01	SW	< 0.01	46		3.1	J	**55**	
SPR-12	GW	0.1	18		0.76	J	7.2	
SPR-11	GW	*2.79*	150		ND	U	2	
SPR-10	GW	< 0.01	53		1.1	J	9.6	
SPR-09	GW	*0.22*	69		1.4	J	8.7	
SPR-08	GW	*1.26*	51		3.4	J	15	
SPR-07	GW	*0.12*	55		2.9	J	24	
SPR-06	GW	0.01	38		5.1		**32**	
SPR-05	GW	*0.08*	68		0.93	J	**50**	
SPR-04	GW	0.3	55		2	J	28	
SPR-03	GW	0.01	38		3.8	J	**45**	
SPR-02	GW	< 0.01	41		4	J	**52**	
SPR-01	GW	0.04	63		4	J	**57**	
BEC-1	SW	< 0.01	50		1.6	J	17	
BJC-1	SW	*0.22*	29		8.9		**35**	
BVC-1A	SW	*0.19*	23		4.8	J	**36**	
BEC-1A	GW	0.01	56		1.3	J	24	
BJC-1	GW	*0.96*	27		15		**37**	
BVC-1A	GW	*0.19*	28		16		**66**	

Location	Type	Chloride (mg/l)	Lab Qualifier	Bromide (mg/l)	Lab Qualifier	Cl/Br Ratio	Na/Br Ratio	TDS Est (ppm)	lbs-Acre9in-Na
BTR-1	SW	8		ND	U	n/a	n/a	70	14
BTR-2A	SW	30		ND	U	n/a	n/a	*672*	74
BTR-3	SW	60		ND	U	n/a	n/a	*690*	128
BTR-4	SW	48		ND	U	n/a	n/a	*876*	180
BTR-5	SW	49		ND	U	n/a	n/a	*882*	210
BTR-1	GW	58		ND	U	n/a	n/a	419	66
BTR-2A	GW	45		ND	U	n/a	n/a	*804*	116
BTR-3	GW	42		ND	U	n/a	n/a	*557*	112
BTR-4	GW	43		0.25	J	172	352	*846*	176
BTR-5	GW	51		ND	U	n/a	n/a	*900*	174
CLP-1	SW	6.6		ND	U	n/a	n/a	132	14
CLP-2	SW	22		ND	U	n/a	n/a	244	34
CLP-3	SW	80		0.28	J	286	282	*1080*	158
CLP-4	SW	230		0.49	J	469	245	*984*	240
CLP-5	SW	91		0.3	J	303	307	*1050*	184
CLP-6	SW	68		0.28	J	243	314	*846*	176
CLP-7	SW	63		0.24	J	263	321	*780*	154
CLP-8	SW	68		0.62		110	135	*870*	168
CLP-9	SW	110		0.48	J	229	229	*990*	220
CLP-1	GW	3.9		ND	U	n/a	n/a	292	18
CLP-Insitu	GW	300		0.84		357	148	*1056*	248
CLP-3	GW	61		0.24	J	254	321	*1062*	154
CLP-4	GW	170		0.4	J	425	205	*906*	164
CLP-5	GW	47		0.23	J	204	317	*972*	146
CLP-6	GW	70		0.24	J	292	329	*846*	158
CLP-7	GW	--		--	--	--	--	*858*	184
CLP-7	GW	110		0.37	J	297	249	--	--
CLP-8	GW	67		0.88		76	114	*918*	200
CLP-9	GW	--		--	--	--	--	*894*	200
CLP-9	GW	81		0.5		162	200	--	--
SVR-1	SW	30		ND	U	n/a	n/a	272	44
SVR-2	SW	20		ND	U	n/a	n/a	266	28
SVR-3	SW	100		0.27	J	370	385	*780*	208
SVR-4	SW	70		ND	U	n/a	n/a	*762*	136
SVR-5A	SW	87		ND	U	n/a	n/a	*702*	188
SVR-6	SW	130		0.39	J	333	277	*780*	216
SVR-7	SW	130		0.32	J	406	419	*840*	268
SVR-8	SW	140		0.49	J	286	247	*870*	242
SVR-1	GW	29		ND	U	n/a	n/a	246	40
SVR-2	GW	20		ND	U	n/a	n/a	382	70
SVR-3	GW	120		0.41	J	293	439	*1092*	360
SVR-5A	GW	110		0.26	J	423	508	*1146*	264

Location	Type	Chloride (mg/l)	Lab Qualifier	Bromide (mg/l)	Lab Qualifier	Cl/Br Ratio	Na/Br Ratio	TDS Est (ppm)	lbs-Acre9in-Na
SVR-6	GW	140		0.28	J	500	446	*792*	250
SVR-7	GW	97		0.48	J	202	196	*708*	188
SVR-8	GW	150		0.43	J	349	363	*1080*	312
SPR-12	SW	170		0.27	J	630	363	*583*	196
SPR-11	SW	190		0.33	J	576	406	*672*	268
SPR-10	SW	190		0.36	J	528	383	*690*	276
SPR-09	SW	190		0.37	J	514	384	*708*	284
SPR-08	SW	160		0.36	J	444	369	*726*	266
SPR-07	SW	130		0.42	J	310	283	*768*	238
SPR-06	SW	130		0.44	J	295	348	*904*	306
SPR-05	SW	130		0.56		232	288	*977*	322
SPR-04	SW	120		0.6		200	290	*960*	348
SPR-03	SW	120		0.61		197	289	*1008*	352
SPR-02	SW	140		0.7		200	311	*1170*	436
SPR-01	SW	140		0.73		192	304	*1212*	444
SPR-12	GW	280		0.27	J	1037	811	*768*	438
SPR-11	GW	280		0.5		560	376	*852*	376
SPR-10	GW	200		0.37	J	541	457	*702*	338
SPR-09	GW	180		0.36	J	500	450	*684*	324
SPR-08	GW	88		0.28	J	314	411	*678*	230
SPR-07	GW	140		0.38	J	368	374	*774*	284
SPR-06	GW	130		0.63		206	227	*1053*	286
SPR-05	GW	120		0.67		179	278	*1288*	372
SPR-04	GW	130		0.77		169	212	*1062*	326
SPR-03	GW	120	F1	0.58	F2 F1	207	257	*996*	298
SPR-02	GW	130		0.66		197	267	*1116*	352
SPR-01	GW	140		0.74		189	262	*1272*	388
BEC-1	SW	200		0.66		303	233	*816*	308
BJC-1	SW	120		0.47	J	255	311	*953*	292
BVC-1A	SW	130		0.63		206	308	*1194*	388
BEC-1A	GW	190		0.65		292	278	*834*	362
BJC-1	GW	110		0.63		175	198	*1079*	250
BVC-1A	GW	130		0.83		157	222	*1330*	368

Location	Type	lbs-Acre9in-Ca	lbs-Acre9in-Mg	lbs-Acre9in-K	lbs-Acre9in-Total Hardness	lbs-Acre9in-NO3	lbs-Acre9in-S	lbs-Acre9in-HCO3
BTR-1	SW	18	4	< 2	62	1	4	66
BTR-2A	SW	266	72	4	966	1	246	360
BTR-3	SW	192	74	10	788	10	206	332
BTR-4	SW	220	124	8	1066	6.6	298	494
BTR-5	SW	252	144	10	1230	6.8	342	542
BTR-1	GW	146	52	4	582	2	52	454
BTR-2A	GW	356	86	4	1248	< 0.2	300	526
BTR-3	GW	218	52	14	762	1	152	436
BTR-4	GW	254	126	6	1160	2.4	268	668
BTR-5	GW	210	120	10	1026	1.2	284	524
CLP-1	SW	46	12	1	166	0.8	10	172
CLP-2	SW	96	26	2	348	0.6	34	268
CLP-3	SW	436	116	3	1574	3.2	416	518
CLP-4	SW	306	112	3	1232	1.6	224	502
CLP-5	SW	364	140	10	1494	3	390	508
CLP-6	SW	240	110	6	1058	2.6	278	464
CLP-7	SW	196	96	10	890	2	232	432
CLP-8	SW	220	112	10	1016	3.4	270	480
CLP-9	SW	222	126	10	1080	4.4	284	500
CLP-1	GW	124	32	4	444	1	18	518
CLP-Insitu	GW	346	86	18	1224	3	190	428
CLP-3	GW	462	116	8	1638	2.6	444	498
CLP-4	GW	264	82	6	1002	1.8	188	478
CLP-5	GW	376	124	10	1456	0.2	398	514
CLP-6	GW	226	100	10	982	0.4	262	454
CLP-7	GW	244	118	18	1102	1	290	570
CLP-7	GW	--	--	--	--	--	--	--
CLP-8	GW	254	140	8	1218	0.4	328	520
CLP-9	GW	242	134	12	1164	4.2	308	616
CLP-9	GW	--	--	--	--	--	--	--
SVR-1	SW	96	28	4	356	0.4	46	244
SVR-2	SW	96	20	2	324	0.2	50	234
SVR-3	SW	202	120	8	1006	1.2	208	592
SVR-4	SW	190	110	4	934	1.4	170	658
SVR-5A	SW	172	100	12	846	4.4	172	546
SVR-6	SW	144	86	12	718	5.8	156	472
SVR-7	SW	168	108	14	870	6	202	486
SVR-8	SW	156	100	12	806	7.4	198	492
SVR-1	GW	94	24	4	336	0.6	38	286
SVR-2	GW	104	36	4	410	0.2	80	384
SVR-3	GW	252	122	6	1138	0.2	350	610
SVR-5A	GW	230	144	12	1176	1.8	358	514

Location	Type	lbs-Acre9in-Ca	lbs-Acre9in-Mg	lbs-Acre9in-K	lbs-Acre9in-Total Hardness	lbs-Acre9in-NO3	lbs-Acre9in-S	lbs-Acre9in-HCO3
SVR-6	GW	150	92	16	758	0.8	166	498
SVR-7	GW	118	74	6	604	0.8	144	450
SVR-8	GW	294	96	8	1136	7.8	298	500
SPR-12	SW	152	38	12	538	4.6	86	320
SPR-11	SW	146	38	26	524	4.6	110	374
SPR-10	SW	150	42	26	550	3.8	118	380
SPR-09	SW	160	46	24	592	5.4	128	384
SPR-08	SW	168	68	18	704	6.4	158	426
SPR-07	SW	198	88	22	862	10.4	214	482
SPR-06	SW	252	100	20	1046	6.4	276	516
SPR-05	SW	284	104	22	1144	7.6	310	560
SPR-04	SW	282	116	24	1188	3.2	362	566
SPR-03	SW	306	120	26	1266	3.6	398	586
SPR-02	SW	356	138	34	1466	4.6	498	608
SPR-01	SW	380	130	36	1492	4.4	538	518
SPR-12	GW	148	32	22	504	0.4	96	516
SPR-11	GW	250	66	16	900	0.4	90	806
SPR-10	GW	182	50	30	664	5.2	142	534
SPR-09	GW	174	50	30	644	3.8	140	372
SPR-08	GW	212	92	10	914	15.6	228	410
SPR-07	GW	224	100	20	976	10.8	236	484
SPR-06	GW	290	116	10	1208	8.4	306	678
SPR-05	GW	360	134	24	1458	0.8	456	780
SPR-04	GW	274	106	42	1126	2	380	568
SPR-03	GW	266	102	20	1090	3.4	336	582
SPR-02	GW	302	116	26	1238	4	408	624
SPR-01	GW	398	118	28	1486	7.4	518	548
BEC-1	SW	176	76	24	756	6.2	186	496
BJC-1	SW	322	84	22	1156	8.6	322	502
BVC-1A	SW	358	146	26	1504	2.8	414	784
BEC-1A	GW	198	86	28	854	5.6	206	510
BJC-1	GW	396	64	20	1256	20.6	346	576
BVC-1A	GW	382	140	16	1538	4.8	446	850

Location	Type	lbs-Acre9in-CO3	lbs-Acre9in-Cl	lbs-Acre9in-Total Alkalinity	lbs-Acre9in-B	lbs-Acre9in-Fl	lbs-Acre9in-Ortho P	lbs-Acre9in-Total Fe	lbs-Acre9in-Mn
BTR-1	SW	< 2	12	54	0.02	0.4	0.06	0.16	< 0.02
BTR-2A	SW	< 2	44	294	0.1	0.6	0.04	0.38	0.12
BTR-3	SW	< 2	104	272	0.34	1	0.08	0.16	0.04
BTR-4	SW	< 2	84	406	0.46	1.2	0.4	0.08	0.06
BTR-5	SW	< 2	82	444	0.48	1.2	0.38	0.1	0.04
BTR-1	GW	< 2	104	372	0.06	0.4	0.04	0.48	0.04
BTR-2A	GW	< 2	82	430	0.2	0.6	0.08	4.8	1.12
BTR-3	GW	26	82	398	0.14	0.8	0.84	3.22	0.66
BTR-4	GW	< 2	64	548	0.38	1.4	0.06	< 0.02	0.28
BTR-5	GW	< 2	82	430	0.5	1.4	0.38	0.38	0.06
CLP-1	SW	< 2	10	142	0.04	0.6	< 0.02	0.14	0.04
CLP-2	SW	< 2	38	220	0.08	0.8	0.04	0.26	0.14
CLP-3	SW	< 2	144	426	0.44	1.4	0.02	0.2	0.24
CLP-4	SW	6	418	420	0.42	1	0.02	0.24	0.16
CLP-5	SW	< 2	142	416	0.46	1.2	0.04	0.14	0.16
CLP-6	SW	6	134	390	0.42	1.8	0.32	0.36	0.26
CLP-7	SW	6	116	364	0.38	1.6	0.14	0.1	0.12
CLP-8	SW	< 2	122	392	0.44	1.6	0.1	0.2	0.28
CLP-9	SW	8	182	422	0.42	1.6	0.06	0.16	0.2
CLP-1	GW	< 2	8	424	0.06	0.8	0.02	0.74	0.12
CLP-Insitu	GW	< 2	520	350	0.34	0.6	< 0.02	0.48	0.42
CLP-3	GW	< 2	112	408	0.4	1.2	0.04	0.52	0.08
CLP-4	GW	< 2	292	392	0.3	0.8	0.06	0.08	0.04
CLP-5	GW	< 2	84	420	0.3	0.6	0.3	3.64	4.46
CLP-6	GW	< 2	122	372	0.4	1.6	0.12	1.72	0.24
CLP-7	GW	< 2	130	468	0.42	1	0.04	2.34	0.3
CLP-7	GW	--	--	--	--	--	--	--	--
CLP-8	GW	< 2	116	426	0.42	1.4	0.16	1.56	1.76
CLP-9	GW	10	130	520	0.46	1.2	0.14	1.08	0.02
CLP-9	GW	--	--	--	--	--	--	--	--
SVR-1	SW	6	48	210	0.08	0.8	0.06	0.26	0.02
SVR-2	SW	2	30	196	0.04	0.6	< 0.02	0.3	0.02
SVR-3	SW	8	168	498	0.38	1.4	< 0.02	0.14	0.08
SVR-4	SW	8	120	552	0.34	3	0.02	0.12	0.04
SVR-5A	SW	< 2	152	448	0.4	1.6	1.72	0.18	0.04
SVR-6	SW	6	200	396	0.4	1.6	1.82	0.24	0.06
SVR-7	SW	4	212	406	0.44	1.8	1.8	0.2	0.04
SVR-8	SW	< 2	224	402	0.46	1.6	1.9	0.18	0.06
SVR-1	GW	< 2	48	234	0.06	0.8	0.04	0.58	0.1
SVR-2	GW	< 2	16	316	0.1	0.2	0.02	2.76	1.04
SVR-3	GW	< 2	172	500	0.44	0.6	0.06	1.78	1.14
SVR-5A	GW	< 2	180	420	0.62	1.4	0.84	0.24	0.08

Location	Type	lbs-Acre9in-CO3	lbs-Acre9in-Cl	lbs-Acre9in-Total Alkalinity	lbs-Acre9in-B	lbs-Acre9in-Fl	lbs-Acre9in-Ortho P	lbs-Acre9in-Total Fe	lbs-Acre9in-Mn
SVR-6	GW	< 2	200	408	0.4	1.8	1.86	0.9	0.08
SVR-7	GW	< 2	158	370	0.38	3.2	0.08	0.22	0.04
SVR-8	GW	< 2	254	410	0.54	1.6	0.16	< 0.02	0.86
SPR-12	SW	10	288	280	0.26	1.6	0.7	0.2	0.18
SPR-11	SW	< 2	336	306	0.48	1.6	0.54	0.28	0.12
SPR-10	SW	< 2	300	310	0.5	1.6	0.52	0.18	0.1
SPR-09	SW	< 2	274	314	0.48	1.8	0.42	0.16	0.06
SPR-08	SW	6	240	358	0.46	1.8	0.88	0.08	0.02
SPR-07	SW	6	164	404	0.48	1.6	2.22	0.08	< 0.02
SPR-06	SW	6	188	432	0.48	1.8	0.58	0.12	0.08
SPR-05	SW	6	192	470	0.48	1.6	0.82	0.14	0.06
SPR-04	SW	10	200	482	0.48	1.6	0.2	0.06	0.1
SPR-03	SW	10	198	498	0.5	1.6	0.18	0.04	< 0.02
SPR-02	SW	10	204	516	0.58	1.4	0.2	0.06	0.02
SPR-01	SW	6	234	434	0.54	1	< 0.02	0.2	< 0.02
SPR-12	GW	6	486	432	0.5	2.6	0.18	0.54	0.2
SPR-11	GW	< 2	506	660	0.38	2.6	0.32	2.12	5.58
SPR-10	GW	< 2	324	436	0.48	1.6	0.52	0.08	< 0.02
SPR-09	GW	< 2	302	306	0.44	1.8	0.58	< 0.02	0.44
SPR-08	GW	< 2	148	336	0.38	1.6	0.12	0.02	2.52
SPR-07	GW	< 2	186	396	0.44	1.4	0.94	0.06	0.24
SPR-06	GW	< 2	192	556	0.5	2.6	0.14	0.04	0.02
SPR-05	GW	< 2	182	640	0.64	1.6	0.44	0.14	0.16
SPR-04	GW	6	176	478	0.52	2.8	0.2	0.02	0.6
SPR-03	GW	8	200	488	0.48	1.6	0.28	< 0.02	0.02
SPR-02	GW	6	184	522	0.56	1.4	0.3	< 0.02	< 0.02
SPR-01	GW	< 2	234	450	0.48	0.8	0.14	0.02	0.08
BEC-1	SW	< 2	298	406	0.5	1.8	0.5	1.1	< 0.02
BJC-1	SW	< 2	184	412	0.38	1.6	0.04	0.04	0.44
BVC-1A	SW	< 2	198	642	0.6	1.8	0.26	0.34	0.38
BEC-1A	GW	< 2	312	418	0.46	1.8	0.58	1.84	0.02
BJC-1	GW	< 2	170	472	0.36	1.6	0.06	0.18	1.92
BVC-1A	GW	< 2	196	696	0.7	1	0.1	0.22	0.38

Location	Type	lbs-Acre9in-TDS	Molar Ratio-Ca:SO4	Molar Ratio-Na:Cl
BTR-1	SW	166	3.56	1.80
BTR-2A	SW	1388	0.86	2.59
BTR-3	SW	1426	0.75	1.90
BTR-4	SW	1796	0.59	3.30
BTR-5	SW	1832	0.59	3.95
BTR-1	GW	888	2.24	0.98
BTR-2A	GW	1666	0.95	2.18
BTR-3	GW	1166	1.15	2.11
BTR-4	GW	1754	0.76	4.24
BTR-5	GW	1872	0.59	3.27
CLP-1	SW	256	3.64	2.16
CLP-2	SW	492	2.23	1.38
CLP-3	SW	2218	0.84	1.69
CLP-4	SW	2036	1.09	0.89
CLP-5	SW	2162	0.74	2.00
CLP-6	SW	1740	0.69	2.03
CLP-7	SW	1602	0.67	2.05
CLP-8	SW	1804	0.65	2.12
CLP-9	SW	2064	0.62	1.86
CLP-1	GW	604	5.51	3.47
CLP-Insitu	GW	2178	1.46	0.74
CLP-3	GW	2202	0.83	2.12
CLP-4	GW	1868	1.12	0.87
CLP-5	GW	2020	0.76	2.68
CLP-6	GW	1752	0.69	2.00
CLP-7	GW	1782	0.67	2.18
CLP-7	GW	--		
CLP-8	GW	1902	0.62	2.66
CLP-9	GW	1838	0.63	2.37
CLP-9	GW	--		
SVR-1	SW	556	1.68	1.41
SVR-2	SW	536	1.53	1.44
SVR-3	SW	1628	0.77	1.91
SVR-4	SW	1592	0.89	1.75
SVR-5A	SW	1462	0.80	1.91
SVR-6	SW	1610	0.73	1.67
SVR-7	SW	1702	0.67	1.95
SVR-8	SW	1814	0.63	1.67
SVR-1	GW	508	1.97	1.28
SVR-2	GW	802	1.04	6.75
SVR-3	GW	2244	0.58	3.23
SVR-5A	GW	2360	0.51	2.26

Location	Type	lbs-Acre9in-TDS	Molar Ratio-Ca:SO4	Molar Ratio-Na:Cl
SVR-6	GW	1652	0.72	1.93
SVR-7	GW	1454	0.66	1.83
SVR-8	GW	2242	0.79	1.89
SPR-12	SW	1200	1.41	1.05
SPR-11	SW	1334	1.05	1.23
SPR-10	SW	1462	1.01	1.42
SPR-09	SW	1496	1.00	1.60
SPR-08	SW	1502	0.84	1.71
SPR-07	SW	1586	0.74	2.24
SPR-06	SW	1894	0.73	2.51
SPR-05	SW	2074	0.73	2.59
SPR-04	SW	1892	0.62	2.68
SPR-03	SW	2082	0.61	2.74
SPR-02	SW	2484	0.57	3.30
SPR-01	SW	2536	0.56	2.93
SPR-12	GW	1566	1.23	1.39
SPR-11	GW	1838	2.22	1.15
SPR-10	GW	1440	1.02	1.61
SPR-09	GW	1420	0.99	1.65
SPR-08	GW	1398	0.74	2.40
SPR-07	GW	1602	0.76	2.35
SPR-06	GW	2130	0.76	2.30
SPR-05	GW	2626	0.63	3.15
SPR-04	GW	2164	0.57	2.86
SPR-03	GW	2014	0.63	2.30
SPR-02	GW	2310	0.59	2.95
SPR-01	GW	2662	0.61	2.56
BEC-1	SW	1688	0.76	1.59
BJC-1	SW	1902	0.80	2.45
BVC-1A	SW	2474	0.69	3.02
BEC-1A	GW	1724	0.77	1.79
BJC-1	GW	2260	0.91	2.27
BVC-1A	GW	2738	0.69	2.90

Location	Type
BTR-1	SW
BTR-2A	SW
BTR-3	SW
BTR-4	SW
BTR-5	SW
BTR-1	GW
BTR-2A	GW
BTR-3	GW
BTR-4	GW
BTR-5	GW
CLP-1	SW
CLP-2	SW
CLP-3	SW
CLP-4	SW
CLP-5	SW
CLP-6	SW
CLP-7	SW
CLP-8	SW
CLP-9	SW
CLP-1	GW
CLP-Insitu	GW
CLP-3	GW
CLP-4	GW
CLP-5	GW
CLP-6	GW
CLP-7	GW
CLP-7	GW
CLP-8	GW
CLP-9	GW
CLP-9	GW
SVR-1	SW
SVR-2	SW
SVR-3	SW
SVR-4	SW
SVR-5A	SW
SVR-6	SW
SVR-7	SW
SVR-8	SW
SVR-1	GW
SVR-2	GW
SVR-3	GW
SVR-5A	GW

Location	Type
SVR-6	GW
SVR-7	GW
SVR-8	GW
SPR-12	SW
SPR-11	SW
SPR-10	SW
SPR-09	SW
SPR-08	SW
SPR-07	SW
SPR-06	SW
SPR-05	SW
SPR-04	SW
SPR-03	SW
SPR-02	SW
SPR-01	SW
SPR-12	GW
SPR-11	GW
SPR-10	GW
SPR-09	GW
SPR-08	GW
SPR-07	GW
SPR-06	GW
SPR-05	GW
SPR-04	GW
SPR-03	GW
SPR-02	GW
SPR-01	GW
BEC-1	SW
BJC-1	SW
BVC-1A	SW
BEC-1A	GW
BJC-1	GW
BVC-1A	GW

Location	Type	Sample ID	Latitude	Longitude	Distance Downstream (miles)	Sample Date	Sample Time	Mini-piezo Head inches
BTR-1	SW	BTR-1-SW	40.415010	-105.195578	4.25	8/17/2021	15:10	
BTR-2	SW	BTR-2-SW	40.382712	-105.054917	14.89	8/18/2021	9:15	
BTR-3	SW	BTR-3-SW	40.386662	-105.044158	15.60	8/18/2021	10:50	
BTR-4	SW	BTR-4-SW	40.338867	-104.853492	32.11	8/18/2021	12:25	
BTR-5	SW	BTR-5-SW	40.351362	-104.775049	38.25	8/18/2021	14:25	
BTR-2	GW	BTR-2-GW	40.382712	-105.054917	14.89	8/18/2021	9:35	0.13
BTR-4	GW	BTR-4-GW	40.338867	-104.853492	32.11	8/18/2021	12:50	0.88
BTR-5	GW	BTR-5-GW	40.351362	-104.775049	38.25	8/18/2021	15:00	0.38
CLP-1	SW	CLP-1-SW	40.629787	-105.168657	4.75	8/11/2021	16:20	
CLP-2	SW	CLP-2-SW	40.588526	-105.069555	11.60	8/11/2021	17:15	
CLP-3	SW	CLP-3-SW	40.577958	-105.034923	14.23	8/12/2021	9:25	
CLP-4	SW	CLP-4-SW	40.559744	-105.021264	15.80	8/12/2021	10:35	
CLP-5	SW	CLP-5-SW	40.546790	-105.000712	17.76	8/12/2021	12:25	
CLP-6	SW	CLP-6-SW	40.485670	-104.958685	24.87	8/12/2021	15:05	
CLP-7	SW	CLP-7-SW	40.447692	-104.889319	32.23	8/16/2021	9:40	
CLP-8	SW	CLP-8-SW	40.445871	-104.773256	42.29	8/16/2021	13:30	
CLP-9	SW	CLP-9-SW	40.424429	-104.680398	48.81	8/17/2021	10:00	
CLP-3	GW	CLP-3-GW	40.577958	-105.034923	14.23	8/12/2021	9:45	2
CLP-5	GW	CLP-5-GW	40.546790	-105.000712	17.76	8/12/2021	13:40	0.13
CLP-7	GW	CLP-7-GW	40.447692	-104.889319	32.23	8/12/2021	17:00	0.75
CLP-8	GW	CLP-8-GW	40.445871	-104.773256	42.29	8/16/2021	14:15	-0.1
CLP-9	GW	CLP-9-GW	40.440509	-104.691772	50.32	8/17/2021	13:45	-1.5
SVR-1	SW	SVR-1-SW	40.210131	-105.235024	1.71	8/9/2021	8:55	
SVR-2	SW	SVR-2-SW	40.186789	-105.191300	4.79	8/9/2021	11:30	
SVR-3	SW	SVR-3-SW	40.155026	-105.090650	11.08	8/9/2021	16:30	
SVR-4	SW	SVR-4-SW	40.154113	-105.088545	11.19	8/10/2021	9:10	
SVR-5a	SW	SVR-5-SW	40.152125	-105.055196	13.04	8/10/2021	11:05	
SVR-6	SW	SVR-6-SW	40.160375	-105.008080	16.32	8/10/2021	12:45	
SVR-7	SW	SVR-7-SW	40.204069	-104.906932	25.00	8/10/2021	14:40	
SVR-8	SW	SVR-8-SW	40.257844	-104.880591	30.72	8/11/2021	13:15	
SVR-2	GW	SVR-2-GW	40.186789	-105.191300	4.79	8/9/2021	11:55	0
SVR-3	GW	SVR-3-GW	40.155026	-105.090650	11.08	8/9/2021	16:45	1
SVR-5a	GW	SVR-5-GW	40.152125	-105.055196	13.04	8/10/2021	11:30	0.5
SVR-7	GW	SVR-7-GW	40.204069	-104.906932	25.00	8/10/2021	15:05	0.25
SVR-8	GW	SVR-8-GW	40.257844	-104.880591	30.72	8/11/2021	13:55	
BEC-1	SW	BEC-1-SW	40.371140	-104.469107		8/23/2021	14:15	
BEC-1	GW	BEC-1-GW	40.371140	-104.469107		8/23/2021	15:00	-0.375
BJC-1	SW	BJC-1-SW	40.280245	-103.877141		8/25/2021	12:25	
BJC-1	GW	BJC-1-GW	40.280245	-103.877141		8/25/2021	12:40	1.375
BVC-1	SW	BVC-1-SW	40.320673	-103.545908		8/25/2021	8:20	
BVC-1	GW	BVC-1-GW	40.320673	-103.545908		8/25/2021	8:45	0
SPR-12	SW	SPR-12-SW	39.746348	-105.015844	6.39	8/19/2021	9:05	
SPR-11	SW	SPR-11-SW	39.885423	-104.902112	19.49	8/19/2021	11:30	
SPR-10	SW	SPR-10-SW	40.081391	-104.821549	38.13	8/19/2021	13:45	

Location	Type	Sample ID	Latitude	Longitude	Distance Downstream (miles)	Sample Date	Sample Time	Mini-piezo Head inches
SPR-9	SW	SPR-9-SW	40.224721	-104.849895	51.70	8/23/2021	9:05	
SPR-8	SW	SPR-8-SW	40.349793	-104.762969	65.93	8/23/2021	11:35	
SPR-7	SW	SPR-7-SW	40.412446	-104.563890	80.00	8/25/2021	15:50	
SPR-6	SW	SPR-6-SW	40.336456	-103.969967	120.88	8/25/2021	14:00	
SPR-5	SW	SPR-5-SW	40.321593	-103.595145	144.94	8/25/2021	10:10	
SPR-4	SW	SPR-4-SW	40.473847	-103.345846	165.31	8/24/2021	10:30	
SPR-3	SW	SPR-3-SW	40.627556	-103.181302	181.00	8/24/2021	8:20	
SPR-2	SW	SPR-2-SW	40.841632	-102.805165	209.94	8/24/2021	13:00	
SPR-1	SW	SPR-1-SW	40.972918	-102.251291	245.02	8/24/2021	14:35	
SPR-11	GW	SPR-11-GW	39.885423	-104.902112	19.49	8/19/2021	13:00	0.0625
SPR-10	GW	SPR-10-GW	40.081391	-104.821549	38.13	8/19/2021	14:10	0
SPR-9	GW	SPR-9-GW	40.224721	-104.849895	51.70	8/23/2021	9:35	-0.0625
SPR-8	GW	SPR-8-GW	40.349793	-104.762969	65.93	8/23/2021	11:55	0
SPR-7	GW	SPR-7-GW	40.412446	-104.563890	80.00	8/25/2021	16:00	0.5
SPR-6	GW	SPR-6-GW	40.336456	-103.969967	120.88	8/25/2021	14:15	0.25
SPR-5	GW	SPR-5-GW	40.321593	-103.595145	144.94	8/25/2021	10:30	0.375
SPR-4	GW	SPR-4-GW	40.473847	-103.345846	165.31	8/24/2021	10:50	0.5
SPR-3	GW	SPR-3-GW	40.627556	-103.181302	181.00	8/24/2021	8:58	0.5
SPR-2	GW	SPR-2-GW	40.841632	-102.805165	209.94	8/24/2021	13:20	0.25
SPR-1	GW	SPR-1-GW	40.972918	-102.251291	245.02	8/24/2021	14:59	0.375

Location	Type	Inferred Bedrock Formation	Bedrock Type	Nearest River Guage	Stream flow (ft3/s)	Field Temp C	Field pH
BTR-1	SW	Trpjs or PPif	Terrestrial	DWR Guage BTABCMCO	149	19.6	7.89
BTR-2	SW	Kp-Pierre Shale	Marine	USGS Guage 06741510	54.7	18.6	8.04
BTR-3	SW	Kp-Pierre Shale	Marine	USGS Guage 06741510	4.89	20.1	8.14
BTR-4	SW	Kf-Fox Hills	Marine	DWR Guage BIGLASCO	41.5	19.9	8.23
BTR-5	SW	Kl-Laramie	Terr-Coastal	DWR Guage BIGLASCO	40.5	23	8.4
BTR-2	GW	Kp-Pierre Shale	Marine	USGS Guage 06741510	54.7	20.6	7.71
BTR-4	GW	Kf-Fox Hills	Marine	DWR Guage BIGLASCO	41.5	18.5	7.74
BTR-5	GW	Kl-Laramie	Terr-Coastal	DWR Guage BIGLASCO	40.5	24.7	7.88
CLP-1	SW	Trpjs or PPif	Terrestrial	DWR Guage CLAFTCCO	379	17.9	7.76
CLP-2	SW	Kp-Pierre Shale	Marine	USGS Guage 06752260	33.4	21.6	8.35
CLP-3	SW	Kp-Pierre Shale	Marine	USGS Guage 06752260	48.8	16.4	8.02
CLP-4	SW	Kp-Pierre Shale	Marine	USGS Guage 06752280	37.5	17.8	8.51
CLP-5	SW	Kp-Pierre Shale	Marine	USGS Guage 06752280	37.5	19.7	8.34
CLP-6	SW	Kp-Pierre Shale	Marine	DWR Guage CLARIVCO	65.2	25.3	9.53
CLP-7	SW	Kp-Pierre Shale	Marine	DWR Guage CLARIVCO	63.3	20.8	9.16
CLP-8	SW	Kf-Fox Hills	Marine	DWR Guage CLAWASCO	62.4	24	8.64
CLP-9	SW	Kl-Laramie	Terr-Coastal	DWR Guage CLAWASCO	62.4	20.4	8.46
CLP-3	GW	Kp-Pierre Shale	Marine	USGS Guage 06752260	48.8	18	7.54
CLP-5	GW	Kp-Pierre Shale	Marine	USGS Guage 06752280	37.5	21.3	7.85
CLP-7	GW	Kp-Pierre Shale	Marine	DWR Guage CLARIVCO	65.2	28.3	9.31
CLP-8	GW	Kf-Fox Hills	Marine	DWR Guage CLAWASCO	62.4	25.4	8.08
CLP-9	GW	Kl-Laramie	Terr-Coastal	DWR Guage CLAWASCO	62.4	25.3	8.29
SVR-1	SW	Kc-CO Grp	Marine	DWR Guage SVCLYOCO	97.8	13.2	7.6
SVR-2	SW	Kp-Pierre Shale	Marine	DWR Guage SVCHGICO	10.8	20	7.41
SVR-3	SW	Kp-Pierre Shale	Marine	DWR Guage SVCLOPCO	53.4	24.9	9.16
SVR-4	SW	Kp-Pierre Shale	Marine	DWR Guage SVCLOPCO	41.6	17.3	8.36
SVR-5a	SW	Kp or Kf	Marine	DWR Guage SVCLOPCO	48.4	20.3	8.22
SVR-6	SW	Kp or Kf	Marine	DWR Guage SVCLOPCO	48.4	21.7	8.25
SVR-7	SW	Kf-Fox Hills	Marine	DWR Guage SVCLOPCO	45.7	24.4	8.56
SVR-8	SW	Kf-Fox Hills	Marine	DWR Guage SVCPLACO	117	23.6	8.49
SVR-2	GW	Kp-Pierre Shale	Marine	DWR Guage SVCHGICO	10.8	26.8	7.16
SVR-3	GW	Kp-Pierre Shale	Marine	DWR Guage SVCLOPCO	53.4	25.8	9.03
SVR-5a	GW	Kp or Kf	Marine	DWR Guage SVCLOPCO	48.4	21.3	7.09
SVR-7	GW	Kf-Fox Hills	Marine	DWR Guage SVCLOPCO	45.7	23	7.23
SVR-8	GW	Kf-Fox Hills	Marine	DWR Guage SVCPLACO	117	17.3	7.55
BEC-1	SW	Kl-Laramie	Terr-Coastal	none on creek		23.4	9
BEC-1	GW	Kl-Laramie	Terr-Coastal	none on creek		31	8.55
BJC-1	SW	Kp-Pierre Shale	Marine	none on creek		15.9	7.88
BJC-1	GW	Kp-Pierre Shale	Marine	none on creek		17.2	7.65
BVC-1	SW	Kp-Pierre Shale	Marine	none on creek		20	8.56
BVC-1	GW	Kp-Pierre Shale	Marine	none on creek		21	8
SPR-12	SW	Tkd-Denver	Terrestrial	DWR Guage PLADENCO	275	20.6	7.99
SPR-11	SW	Tkd-Denver	Terrestrial	DWR guage PLAHENCO	302	22.4	8.3
SPR-10	SW	TKda or Tkd	Terrestrial	USGS Guage 06721000	350	23.9	8.82

Location	Type	Inferred Bedrock Formation	Bedrock Type	Nearest River Guage	Stream flow (ft3/s)	Field Temp C	Field pH
SPR-9	SW	Kl-Laramie	Terr-Coastal	DWR Guage PLAPLACO	208	19.5	8.28
SPR-8	SW	Kl-Laramie	Terr-Coastal	DWR Guage PLAPLACO	232	21.5	8.37
SPR-7	SW	Kl-Laramie	Terr-Coastal	DWR Guage PLAKERCO	239	25.1	8.64
SPR-6	SW	Kp-Pierre Shale	Marine	DWR Guage PLAWELCO	279	25	9.01
SPR-5	SW	Kp-Pierre Shale	Marine	DWR Guage PLABALCO	279	19.4	8.55
SPR-4	SW	Kp-Pierre Shale	Marine	DWR Guage PLAATWCO	141	20.7	8.64
SPR-3	SW	Kp-Pierre Shale	Marine	DWR Guage PLAATWCO	137	18.9	8.53
SPR-2	SW	Tw-White River	Terrestrial	DWR Guage PLACROCO	63.9	27.7	8.75
SPR-1	SW	Tw-White River	Terrestrial	DWR Guage ONEJURCO	90	29.9	8.79
SPR-11	GW	Tkd-Denver	Terrestrial	DWR guage PLAHENCO	302	21.7	7.7
SPR-10	GW	TKda or Tkd	Terrestrial	USGS Guage 06721000	350	23.5	7.81
SPR-9	GW	Kl-Laramie	Terr-Coastal	DWR Guage PLAPLACO	208	20.4	7.78
SPR-8	GW	Kl-Laramie	Terr-Coastal	DWR Guage PLAPLACO	232	23.8	8.12
SPR-7	GW	Kl-Laramie	Terr-Coastal	DWR Guage PLAKERCO	239	23.8	8.24
SPR-6	GW	Kp-Pierre Shale	Marine	DWR Guage PLAWELCO	279	25.2	8.09
SPR-5	GW	Kp-Pierre Shale	Marine	DWR Guage PLABALCO	279	20.9	8.28
SPR-4	GW	Kp-Pierre Shale	Marine	DWR Guage PLAATWCO	141	24.7	8.19
SPR-3	GW	Kp-Pierre Shale	Marine	DWR Guage PLAATWCO	137	19	8.08
SPR-2	GW	Tw-White River	Terrestrial	DWR Guage PLACROCO	63.9	24.7	8.09
SPR-1	GW	Tw-White River	Terrestrial	DWR Guage ONEJURCO	90	28.1	8.07

Location	Type	Field SPC uS_cm	Field DO mg_L	Field ORP eH	Field Turbidity NTU	Lab pH	SAR	Adjusted SAR	EC mmho_cm	TDS Gravimetric ppm	Cations me_L
BTR-1	SW	60.6	7.65	128.6	7.21	7.6	0.3	0.2	0.08	34	0.6
BTR-2	SW	409.1	7.65	115.1	12.9	7.9	0.6	0.6	0.43	257	4.4
BTR-3	SW	502	8.04	121.3	11.24	7.8	1	1.0	0.52	321	5.3
BTR-4	SW	1336	7.04	143.6	71.4	8	1.7	2.0	1.38	*865*	16.1
BTR-5	SW	1359	8.17	116.5	23.2	8.2	1.6	2.0	1.39	*860*	16.2
BTR-2	GW	1329	6.27	32.9	23	7.6	1.2	1.5	1.37	*855*	15.8
BTR-4	GW	1783	5.85	140.8	2.9	7.8	2.1	2.8	1.84	*1148*	22.5
BTR-5	GW	1269	5.26	65	5	7.8	1.6	1.9	1.28	*802*	15.0
CLP-1	SW	89.5	7.9	103.3	9.47	7.7	0.3	0.2	0.11	61	1.1
CLP-2	SW	161	7.46	87.3	6.01	7.8	0.3	0.3	0.17	116	1.8
CLP-3	SW	205.1	8.3	133.8	6.8	7.9	0.5	0.5	0.22	145	2.4
CLP-4	SW	310	8.28	134.9	10.31	8	0.6	0.6	0.33	198	3.6
CLP-5	SW	496.5	7.89	109.3	12.1	8	0.8	0.9	0.52	315	6.0
CLP-6	SW	973	7.6	105.7	24.41	*9*	2.1	2.4	1.00	*605*	12.0
CLP-7	SW	921	7.18	138.5	15.3	*8.6*	1.7	1.7	0.77	480	8.7
CLP-8	SW	1184	10.14	152.6	16.6	8.3	1.8	2.2	1.20	*736*	14.4
CLP-9	SW	1255	7.14	129.9	22.4	8.2	1.7	2.0	1.29	*806*	14.8
CLP-3	GW	1216	1.2	127.5	8.4	7.7	0.8	1.1	1.26	775	15.9
CLP-5	GW	553	2.37	-111.3	3.4	8.1	0.9	1.0	0.57	350	6.6
CLP-7	GW	817	7.2	129.7	16.8	8.1	1.7	1.9	0.83	*521*	9.5
CLP-8	GW	1897	5.88	-78.1	13.1	8	2	2.5	1.85	*1145*	23.4
CLP-9	GW	1208	5.2	116.2	3.85	8.2	1.7	2.0	1.23	*760*	14.0
SVR-1	SW	88.7	8.78	-45	1.75	7.6	0.3	0.2	0.1	58	0.9
SVR-2	SW	227.7	8.07		29.6	7.6	0.4	0.4	0.23	154	2.4
SVR-3	SW	556	9.77		10.08	*8.8*	1	1.1	0.56	355	6.3
SVR-4	SW	652	7.6	27.6	10.7	8.1	0.9	1.0	0.65	448	7.3
SVR-5a	SW	835	8.7		6.05	8.1	1.5	1.7	0.86	*533*	9.8
SVR-6	SW	971	6.73	15.3	29.33	8.1	1.7	1.9	0.98	*588*	11.0
SVR-7	SW	1010	8.6		19.7	8.3	2.1	2.3	1.03	*818*	12.0
SVR-8	SW	1151	7.98	216.3	21	8.3	2.3	2.6	1.20	*738*	13.8
SVR-2	GW	186.9	7.2		376	7.3	0.5	0.4	0.2	118	2.2
SVR-3	GW	568	6.6		23	*8.6*	1	1.1	0.55	341	6.2
SVR-5a	GW	1150	2.34		42.3	7.4	1.8	2.1	1.16	*782*	13.5
SVR-7	GW	1891	1.95		7.82	7.5	2.8	3.4	1.87	*1225*	20.9
SVR-8	GW	1796	0.71	167.1	4.7	7.7	3.1	4.0	1.87	*1150*	22.8
BEC-1	SW	1261	9.74	117.4	18.5	*8.6*	2.8	3.3	1.28	*792*	14.1
BEC-1	GW	1351	6.07	90	109	8.2	2.7	3.2	1.33	*830*	14.7
BJC-1	SW	1496	5.5	156.8	0.9	7.8	2.4	3.2	1.65	*1032*	20
BJC-1	GW	1656	5.57	155.4	28	7.7	2.5	3.7	1.72	*1059*	20.2
BVC-1	SW	1447	4.84	126.6	4.3	8.3	2.9	3.7	1.57	*1239*	18.8
BVC-1	GW	1507	7.03	5.8	7	7.8	2.7	3.7	1.54	*950*	18.2
SPR-12	SW	653	6.75	136.6	20.5	8	1.8	1.9	0.66	415	6.8
SPR-11	SW	895	8.19	127.2	4.3	8	2.9	3.2	0.93	*585*	9.6
SPR-10	SW	1033	9.38	100.6	8.2	8.4	3.1	3.6	1.05	*650*	11.0

Location	Type	Field SPC uS_cm	Field DO mg_L	Field ORP eH	Field Turbidity NTU	Lab pH	SAR	Adjusted SAR	EC mmho_cm	TDS Gravimetric ppm	Cations me_L
SPR-9	SW	1084	7.32	140.7	16.1	8.1	3.1	3.6	1.09	*672*	11.5
SPR-8	SW	1076	7.51	102.6	18	8.2	2.5	3.0	1.11	*689*	11.8
SPR-7	SW	1229	9.38	128.8	10	8.4	2.2	2.7	1.26	*776*	15.0
SPR-6	SW	1403	10.49	155.3	8.2	8.5	3	3.5	1.44	*888*	16.9
SPR-5	SW	1609	7.94	135.1	12	8.3	3	3.8	1.67	*1038*	20.2
SPR-4	SW	1546	8.79	138.2	8.7	8.3	3.1	3.9	1.7	*1201*	20.5
SPR-3	SW	1772	7.97	135.8	6.5	8.2	3.1	4.0	1.83	*1135*	21.8
SPR-2	SW	2256	9.64	129	11.7	8.4	4	5.0	2.28	*1030*	27.4
SPR-1	SW	2116	8.83	123.3	6.7	8.3	3.7	4.6	2.15	*1439*	25.7
SPR-11	GW	1398	4.71	-128.5	4.8	7.8	3.5	4.5	1.41	*882*	14.5
SPR-10	GW	1015	3.75	65.7	6.5	7.8	3	3.4	1.03	*631*	11.1
SPR-9	GW	1080	5.51	63.9	4.1	7.7	3.3	3.9	1.09	*670*	11.3
SPR-8	GW	1076	4.64	112.9	19.3	8	2.6	3.0	1.10	*676*	11.9
SPR-7	GW	1077	6.21	132.4	20	8.1	2.2	2.6	1.11	*680*	12.7
SPR-6	GW	1599	6.57	142.1	3.2	7.9	2.8	3.6	1.62	*1005*	19.5
SPR-5	GW	1625	4.83	112	3.7	8.1	3	3.8	1.68	*1035*	20.1
SPR-4	GW	1650	6.28	127.5	3.2	8	3.1	3.9	1.68	*1055*	19.5
SPR-3	GW	1889	5.95	132.5	3.4	7.9	3.2	4.2	1.93	*1135*	23.3
SPR-2	GW	2288	3.36	125.1	3.5	7.9	4	5.2	2.32	*1745*	27.9
SPR-1	GW	1963	5.27	127.4	2.8	7.9	3.4	4.3	2.00	*1333*	24.1

Location	Type	Anions me_L	Total Alkalinity as CaCO3 ppm	Total Hardness as CaCO3 ppm	Sodium ppm	Potassium ppm	Calcium ppm	Magnesium ppm	Chloride ppm
BTR-1	SW	0.6	18	26	4	0	7	2	3
BTR-2	SW	4.4	62	176	19	2	42	17	9
BTR-3	SW	5.3	71	189	31	3	44	19	17
BTR-4	SW	16.2	223	593	95	6	122	69	32
BTR-5	SW	16.4	223	598	93	6	124	69	31
BTR-2	GW	16.1	192	630	70	5	157	57	47
BTR-4	GW	22.2	346	817	140	3	181	88	28
BTR-5	GW	14.5	203	550	86	6	120	60	28
CLP-1	SW	0.9	30	45	4	0	13	3	3
CLP-2	SW	1.5	49	73	7	1	21	5	5
CLP-3	SW	1.9	54	90	12	1	26	6	7
CLP-4	SW	3.0	68	142	17	2	40	10	10
CLP-5	SW	5.2	85	235	28	3	64	18	14
CLP-6	SW	11.2	166	383	94	8	83	42	55
CLP-7	SW	8.7	110	287	65	5	58	34	38
CLP-8	SW	14.3	226	506	95	7	104	59	45
CLP-9	SW	14.8	199	533	90	6	113	60	51
CLP-3	GW	14.6	150	684	50	3	197	46	18
CLP-5	GW	5.9	122	255	33	3	67	21	13
CLP-7	GW	9.2	136	312	69	8	68	34	39
CLP-8	GW	22.1	230	867	133	9	180	100	52
CLP-9	GW	13.6	198	504	88	6	100	61	47
SVR-1	SW	0.8	25	33	5	0	10	2	3
SVR-2	SW	2.1	56	98	9	1	29	6	4
SVR-3	SW	5.7	117	236	35	2	56	23	12
SVR-4	SW	7.0	156	287	36	2	63	31	19
SVR-5a	SW	9.6	160	345	64	6	73	39	35
SVR-6	SW	11.0	162	376	76	6	72	47	35
SVR-7	SW	11.9	172	385	95	7	74	48	53
SVR-8	SW	12.8	186	445	111	6	88	54	55
SVR-2	GW	1.8	48	80	10	6	22	6	6
SVR-3	GW	5.6	116	236	35	2	56	23	12
SVR-5a	GW	13.8	149	468	92	7	94	56	42
SVR-7	GW	20.8	407	579	156	98	110	73	105
SVR-8	GW	20.5	211	717	193	5	185	61	150
BEC-1	SW	13.2	184	408	132	10	95	41	94
BEC-1	GW	13.8	189	438	132	11	100	45	100
BJC-1	SW	19.2	221	673	144	11	196	44	88
BJC-1	GW	19.7	247	669	148	13	216	31	98
BVC-1	SW	16.7	232	576	159	13	142	53	74
BVC-1	GW	16.6	276	568	151	10	144	50	67
SPR-12	SW	6.2	96	203	60	5	58	14	76
SPR-11	SW	9	122	243	102	10	69	17	113
SPR-10	SW	10.2	138	276	120	11	77	20	117

Location	Type	Anions me_L	Total Alkalinity as CaCO3 ppm	Total Hardness as CaCO3 ppm	Sodium ppm	Potassium ppm	Calcium ppm	Magnesium ppm	Chloride ppm
SPR-9	SW	10.0	153	297	122	11	82	22	96
SPR-8	SW	11.1	166	342	108	8	80	34	83
SPR-7	SW	14.3	205	493	113	10	114	50	77
SPR-6	SW	15.2	189	503	154	10	111	54	76
SPR-5	SW	18.8	247	625	170	13	155	57	77
SPR-4	SW	18.4	230	623	177	13	149	60	68
SPR-3	SW	21.0	235	666	184	17	163	62	99
SPR-2	SW	25.9	230	779	257	22	190	73	115
SPR-1	SW	24.0	182	745	234	23	188	66	102
SPR-11	GW	14	212	377	156	9	104	28	*226*
SPR-10	GW	10.0	144	286	116	11	81	20	113
SPR-9	GW	9.7	148	278	126	13	76	21	98
SPR-8	GW	10.8	166	348	110	9	81	35	75
SPR-7	GW	12.1	169	399	103	8	93	40	74
SPR-6	GW	18.2	259	617	160	7	150	58	95
SPR-5	GW	18.0	245	623	169	13	154	57	73
SPR-4	GW	18.2	219	586	171	16	146	53	72
SPR-3	GW	22.0	250	718	197	16	177	66	81
SPR-2	GW	26.1	231	795	262	23	198	72	121
SPR-1	GW	22.0	199	718	211	22	189	59	81

Location	Type	Bicarbonate HCO3 ppm	Carbonate CO3 ppm	Sulfate as S SO4_S ppm	Sulfate SO4 ppm	Fluoride ppm	NO3-N ppm	Ortho Phosphorus as P ppm	Boron ppm
BTR-1	SW	22	0	2	6	0.14	0.1	0.02	0
BTR-2	SW	75	0	46	138	0.2	0.1	0.02	0.03
BTR-3	SW	86	0	53	159	0.29	1.6	0.03	0.07
BTR-4	SW	269	0	*170*	510	0.63	4	0.21	0.23
BTR-5	SW	268	0	*173*	519	0.62	3.4	0.21	0.21
BTR-2	GW	233	0	*174*	522	0.13	0	0.01	0.08
BTR-4	GW	420	0	*232*	696	0.33	0	0.03	0.21
BTR-5	GW	246	0	*152*	456	0.44	2.6	0.22	0.19
CLP-1	SW	36	0	3	9	0.15	0	0.01	0
CLP-2	SW	59	0	6	18	0.2	0.1	0.02	0
CLP-3	SW	65	0	10	30	0.19	0.2	0.09	0.01
CLP-4	SW	82	0	22	66	0.22	0.3	0.08	0.02
CLP-5	SW	103	0	50	150	0.27	0.4	0.12	0.05
CLP-6	SW	185	10.2	*101*	303	0.89	0.3	0.47	0.16
CLP-7	SW	129	3.2	*87*	261	0.64	0	0.05	0.14
CLP-8	SW	270	3.3	*134*	402	0.81	0.8	0.16	0.21
CLP-9	SW	239	0	*147*	441	0.7	3.6	0.09	0.2
CLP-3	GW	182	0	*178*	534	0.39	0.1	0.03	0.15
CLP-5	GW	147	0	49	147	0.54	0	0.11	0.1
CLP-7	GW	163	0	*86*	258	0.68	0.1	0.04	0.16
CLP-8	GW	277	0	*257*	771	0.63	0	0.13	0.22
CLP-9	GW	238	0	*133*	399	0.72	1.3	0.15	0.19
SVR-1	SW	31	0	3	9	0.12	0	0	0.01
SVR-2	SW	68	0	14	42	0.23	0	0.01	0.01
SVR-3	SW	134	5.1	48	144	0.45	0.1	0.01	0.08
SVR-4	SW	188	0	54	162	0.81	0.2	0.01	0.07
SVR-5a	SW	193	0	*84*	252	0.7	2.6	0.8	0.15
SVR-6	SW	195	0	*106*	318	0.7	2.5	0.54	0.17
SVR-7	SW	206	2.2	*109*	327	0.7	2.1	0.41	0.18
SVR-8	SW	223	2.5	*117*	351	0.76	2.4	0.47	0.19
SVR-2	GW	58	0	10	30	0.29	0	0.02	0.23
SVR-3	GW	135	3.4	46	138	0.44	0.1	0.01	0.08
SVR-5a	GW	182	0	*154*	462	0.71	0	0.29	0.2
SVR-7	GW	495	0	*154*	462	0.66	0	0.22	0.25
SVR-8	GW	257	0	*189*	567	0.74	3	0.12	0.25
BEC-1	SW	217	4.9	*106*	318	0.81	3.1	0.24	0.19
BEC-1	GW	226	0	*112*	336	0.82	2.8	0.18	0.19
BJC-1	SW	268	0	188	564	0.72	6.8	0.03	0.16
BJC-1	GW	300	0	182	546	0.87	7.9	0.02	0.19
BVC-1	SW	278	2.9	156	468	0.77	2.7	0.35	0.21
BVC-1	GW	334	0	147	441	0.67	0.1	0.65	0.18
SPR-12	SW	116	0	32	96	0.76	2.3	0.24	0.08
SPR-11	SW	147	0	51	153	0.81	2.7	0.34	0.16
SPR-10	SW	165	2.1	62	186	0.84	2.9	0.26	0.18

Location	Type	Bicarbonate HCO3 ppm	Carbonate CO3 ppm	Sulfate as S SO4_S ppm	Sulfate SO4 ppm	Fluoride ppm	NO3-N ppm	Ortho Phosphorus as P ppm	Boron ppm
SPR-9	SW	184	0	66	198	0.84	2.5	0.26	0.17
SPR-8	SW	200	0	*84*	252	0.78	2.7	0.29	0.17
SPR-7	SW	244	3.2	123	369	0.74	4.3	1.1	0.18
SPR-6	SW	223	4.3	146	438	0.83	1.7	0.14	0.22
SPR-5	SW	296	3.1	183	549	0.75	2.6	0.38	0.22
SPR-4	SW	275	3.2	*188*	564	0.76	1.4	0.13	0.23
SPR-3	SW	282	0	*216*	648	0.71	0.9	0.07	0.24
SPR-2	SW	274	3.8	*287*	861	0.6	1	0.03	0.3
SPR-1	SW	217	2.6	*278*	834	0.48	1	0.01	0.27
SPR-11	GW	257	0	54	162	1.26	0	0.07	0.17
SPR-10	GW	175	0	63	189	0.74	0.3	0.55	0.17
SPR-9	GW	180	0	62	186	0.85	1.4	0.5	0.17
SPR-8	GW	200	0	*84*	252	0.75	2	0.34	0.17
SPR-7	GW	204	0	104	312	0.73	2.4	0.44	0.16
SPR-6	GW	314	0	160	480	1.29	4.7	0.07	0.22
SPR-5	GW	295	0	177	531	0.72	0.8	0.31	0.22
SPR-4	GW	264	0	*189*	567	0.76	0	0.14	0.22
SPR-3	GW	302	0	*236*	708	0.75	0	0.1	0.25
SPR-2	GW	280	0	*287*	861	0.6	1.3	0.13	0.3
SPR-1	GW	241	0	*251*	753	0.5	1.4	0.1	0.25

Location	Type	Total Fe ppm	Manganese ppm	Barium Dissolved ug_L	Lab Qualifier	Selenium Dissolved ug_L	Lab Qualifier	Uranium Dissolved ug_L	Lab Qualifier
BTR-1	SW	0.14	0.01	8.1		0	ND	0.39	J
BTR-2	SW	0.24	0.04	34		0.86	J	2.5	
BTR-3	SW	0.26	0.04	35		1.1	J	2.5	
BTR-4	SW	0.5	*0.07*	72		4.4	J	21	
BTR-5	SW	0.28	*0.09*	73		3.7	J	20	
BTR-2	GW	0.29	*0.53*	120		0.37	J	7.3	
BTR-4	GW	0.25	*0.47*	35		0.73	J	57	
BTR-5	GW	0.17	*0.32*	78		3.9	J	22	
CLP-1	SW	0.17	0.03	19		0	ND	0.49	J
CLP-2	SW	0.18	0.03	28		0	ND	1.1	
CLP-3	SW	0.14	0.02	30		0	ND	1.1	
CLP-4	SW	0.18	0.03	35		0.62	J	1.8	
CLP-5	SW	0.16	0.04	39		0.67	J	3.4	
CLP-6	SW	0.12	0.02	59		1.8	J	6.8	
CLP-7	SW	0.02	0	43		1.0	J	5.5	
CLP-8	SW	*0.33*	*0.1*	73		2.2	J	14	
CLP-9	SW	0.19	0.03	69		2.4	J	19	
CLP-3	GW	0.08	0.01	50		0	ND	8.2	
CLP-5	GW	*0.52*	*0.09*	36		0	ND	1.4	
CLP-7	GW	0.43	0.01	n/a		n/a		n/a	
CLP-8	GW	*0.62*	*0.82*	110		0.37	J	23	
CLP-9	GW	0.02	0	70		2.2	J	16	
SVR-1	SW	0.19	0.02	14		0	ND	0.36	J
SVR-2	SW	*0.47*	*0.09*	41		0.56	J	1.2	
SVR-3	SW	0.26	0.02	36		1.6	J	4.8	
SVR-4	SW	0.24	0.04	58		0.75	J	8.3	
SVR-5a	SW	0.16	0.03	44		2.2	J	8.7	
SVR-6	SW	0.45	*0.06*	48		1.8	J	8.6	
SVR-7	SW	0.24	*0.06*	48		1.6	J	8.5	
SVR-8	SW	0.06	0.02	61		1.6	J	11	
SVR-2	GW	*7.2*	*0.17*	100		0	ND	0.32	J
SVR-3	GW	0.34	*0.06*	41		1.6	J	5.8	
SVR-5a	GW	0.12	*0.09*	32		0	ND	6.1	
SVR-7	GW	*3.39*	*1.87*	310		0.45	J	6.8	
SVR-8	GW	0.08	*0.46*	110		0.8	J	21	
BEC-1	SW	*0.62*	0.02	68	^+	1.6	J	15	
BEC-1	GW	*1.33*	*0.44*	66	^+	1.8	J	19	
BJC-1	SW	0	*0.19*	31	B	10		**36**	
BJC-1	GW	*0.76*	*0.84*	39	B	17		**32**	
BVC-1	SW	0.1	0	79	B	3.7	J	27	
BVC-1	GW	0.23	*1.18*	73	B	0.52	J	11	
SPR-12	SW	0.07	0	51		1	J	5	
SPR-11	SW	0.09	0.02	43		1.1	J	5.7	
SPR-10	SW	0.06	0.04	48		1.1	J	6.5	

Location	Type	Total Fe ppm	Manganese ppm	Barium Dissolved ug_L	Lab Qualifier	Selenium Dissolved ug_L	Lab Qualifier	Uranium Dissolved ug_L	Lab Qualifier
SPR-9	SW	0.13	0.03	58		1.1	J	7.7	
SPR-8	SW	0.15	*0.06*	59		1.6	J	9.4	
SPR-7	SW	0.12	0.03	57	B	1.9	J	18	
SPR-6	SW	0.09	0.03	52	B	2	J	21	
SPR-5	SW	0.12	0.04	50	B	3.7	J	29	
SPR-4	SW	0.06	0.03	42	^+	2.7	J	30	
SPR-3	SW	0.03	0.03	45	^+	3.1	J	**36**	
SPR-2	SW	0.11	0.04	47	^+	2.4	J	**42**	
SPR-1	SW	0.05	0.02	48	B	2.1	J	**38**	
SPR-11	GW	*0.58*	*2.73*	170		0	ND	0.74	J
SPR-10	GW	0.06	*0.56*	61		0.67	J	8	
SPR-9	GW	0.03	*1.53*	66		1.5	J	7.5	
SPR-8	GW	0.04	0.02	41	^+	1.4	J	9.5	
SPR-7	GW	0.11	*0.17*	43	B	1.9	J	9.4	
SPR-6	GW	0.04	*0.15*	46	B	4.6	J	29	
SPR-5	GW	0.01	0.02	42	B	3.3	J	29	
SPR-4	GW	0	*2.06*	36	^+	0	ND	30	
SPR-3	GW	0	0	56	^+	0.56	J	**48**	
SPR-2	GW	0	0.01	53	^+	2	J	**42**	
SPR-1	GW	0.01	0	50	B	1.7	J	**37**	

Location	Type	Chloride (mg/l)	Lab Qualifier	Bromide (mg/l)	Lab Qualifier	Cl/Br Ratio	Na/Br Ratio	TDS Est ppm	lbs-Acre9in-Na
BTR-1	SW							45	8
BTR-2	SW							257	38
BTR-3	SW							315	62
BTR-4	SW							828	190
BTR-5	SW							836	186
BTR-2	GW							820	140
BTR-4	GW							1104	280
BTR-5	GW							770	172
CLP-1	SW							64	8
CLP-2	SW							103	14
CLP-3	SW							130	24
CLP-4	SW							196	34
CLP-5	SW							312	56
CLP-6	SW							597	188
CLP-7	SW							462	130
CLP-8	SW							722	190
CLP-9	SW							773	180
CLP-3	GW							755	100
CLP-5	GW							340	66
CLP-7	GW							497	138
CLP-8	GW							1112	266
CLP-9	GW							738	176
SVR-1	SW							58	10
SVR-2	SW							141	18
SVR-3	SW							335	70
SVR-4	SW							388	72
SVR-5a	SW							513	128
SVR-6	SW							587	152
SVR-7	SW							616	190
SVR-8	SW							718	222
SVR-2	GW							118	20
SVR-3	GW							332	70
SVR-5a	GW							697	184
SVR-7	GW							1123	312
SVR-8	GW							1121	386
BEC-1	SW							769	264
BEC-1	GW							800	264
BJC-1	SW							991	288
BJC-1	GW							1031	296
BVC-1	SW							943	318
BVC-1	GW							924	302
SPR-12	SW							397	120
SPR-11	SW							555	204
SPR-10	SW							630	240

Location	Type	Chloride (mg/l)	Lab Qualifier	Bromide (mg/l)	Lab Qualifier	Cl/Br Ratio	Na/Br Ratio	TDS Est ppm	lbs-Acre9in-Na
SPR-9	SW							654	244
SPR-8	SW							665	216
SPR-7	SW							756	226
SPR-6	SW							862	308
SPR-5	SW							1004	340
SPR-4	SW							1021	354
SPR-3	SW							1098	368
SPR-2	SW							1369	514
SPR-1	SW							1288	468
SPR-11	GW							848	312
SPR-10	GW							619	232
SPR-9	GW							651	252
SPR-8	GW							657	220
SPR-7	GW							664	206
SPR-6	GW							972	320
SPR-5	GW							1010	338
SPR-4	GW							1008	342
SPR-3	GW							1161	394
SPR-2	GW							1394	524
SPR-1	GW							1201	422

Location	Type	lbs-Acre9in-Ca	lbs-Acre9in-Mg	lbs-Acre9in-K	lbs-Acre9in-Total Hardness	lbs-Acre9in-NO3	lbs-Acre9in-S	lbs-Acre9in-HCO3	lbs-Acre9in-CO3
BTR-1	SW	14	4	0	52	0.2	4	44	0
BTR-2	SW	84	34	4	352	0.2	92	150	0
BTR-3	SW	88	38	6	378	3.2	106	172	0
BTR-4	SW	244	138	12	1186	8	340	538	0
BTR-5	SW	248	138	12	1196	6.8	346	536	0
BTR-2	GW	314	114	10	1260	0	348	466	0
BTR-4	GW	360	176	6	1634	0	464	840	0
BTR-5	GW	240	120	12	1100	5.2	304	492	0
CLP-1	SW	26	6	0	90	0	6	72	0
CLP-2	SW	42	10	2	146	0.2	12	118	0
CLP-3	SW	52	12	2	180	0.4	20	130	0
CLP-4	SW	80	20	4	284	0.6	44	164	0
CLP-5	SW	128	36	6	470	0.8	100	206	0
CLP-6	SW	166	84	16	766	0.6	202	370	20
CLP-7	SW	116	68	10	574	0	174	258	6
CLP-8	SW	208	118	14	1012	1.6	268	540	6
CLP-9	SW	226	120	12	1066	7.2	294	478	0
CLP-3	GW	394	92	6	1368	0	356	364	0
CLP-5	GW	134	42	6	510	0	98	294	0
CLP-7	GW	136	68	16	624	0.2	172	326	0
CLP-8	GW	360	200	18	1734	0	514	554	0
CLP-9	GW	200	122	12	1008	2.6	266	476	0
SVR-1	SW	20	4	0	66	0	6	62	0
SVR-2	SW	58	12	2	196	0	28	136	0
SVR-3	SW	112	46	4	472	0.2	96	268	10
SVR-4	SW	126	62	4	574	0.4	108	376	0
SVR-5a	SW	146	78	12	690	5.2	168	386	0
SVR-6	SW	144	94	12	752	5	212	390	0
SVR-7	SW	148	96	14	770	4.2	218	412	4
SVR-8	SW	176	108	12	890	4.8	234	446	6
SVR-2	GW	44	12	12	160	0	20	116	0
SVR-3	GW	112	46	4	472	0.2	92	270	6
SVR-5a	GW	188	112	14	936	0	308	364	0
SVR-7	GW	220	146	196	1158	0	308	990	0
SVR-8	GW	370	122	10	1434	6	378	514	0
BEC-1	SW	190	82	20	816	6.2	212	434	10
BEC-1	GW	200	90	22	876	5.6	224	452	0
BJC-1	SW	392	88	22	1346	13.6	376	536	0
BJC-1	GW	432	62	26	1338	15.8	364	600	0
BVC-1	SW	284	106	26	1152	5.4	312	556	6
BVC-1	GW	288	100	20	1136	0.2	294	668	0
SPR-12	SW	116	28	10	406	4.6	64	232	0
SPR-11	SW	138	34	20	486	5.4	102	294	0
SPR-10	SW	154	40	22	552	5.8	124	330	4

Location	Type	lbs-Acre9in-Ca	lbs-Acre9in-Mg	lbs-Acre9in-K	lbs-Acre9in-Total Hardness	lbs-Acre9in-NO3	lbs-Acre9in-S	lbs-Acre9in-HCO3	lbs-Acre9in-CO3
SPR-9	SW	164	44	22	594	5	132	368	0
SPR-8	SW	160	68	16	684	5.4	168	400	0
SPR-7	SW	228	100	20	986	8.6	246	488	6
SPR-6	SW	222	108	20	1006	3.4	292	446	8
SPR-5	SW	310	114	26	1250	5.2	366	592	6
SPR-4	SW	298	120	26	1246	2.8	376	550	6
SPR-3	SW	326	124	34	1332	1.8	432	564	0
SPR-2	SW	380	146	44	1558	2	574	548	8
SPR-1	SW	376	132	46	1490	2	556	434	6
SPR-11	GW	208	56	18	754	0	108	514	0
SPR-10	GW	162	40	22	572	0.6	126	350	0
SPR-9	GW	152	42	26	556	2.8	124	360	0
SPR-8	GW	162	70	18	696	4	168	400	0
SPR-7	GW	186	80	16	798	4.8	208	408	0
SPR-6	GW	300	116	14	1234	9.4	320	628	0
SPR-5	GW	308	114	26	1246	1.6	354	590	0
SPR-4	GW	292	106	32	1172	0	378	528	0
SPR-3	GW	354	132	32	1436	0	472	604	0
SPR-2	GW	396	144	46	1590	2.6	574	560	0
SPR-1	GW	378	118	44	1436	2.8	502	482	0

Location	Type	lbs-Acre9in-Cl	lbs-Acre9in-Total Alkalinity	lbs-Acre9in-B	lbs-Acre9in-Fl	lbs-Acre9in-Ortho P	lbs-Acre9in-Total Fe	lbs-Acre9in-Mn	lbs-Acre9in-TDS
BTR-1	SW	6	36	0	0.2	0.04	0.28	0.02	68
BTR-2	SW	18	122	0.06	0.4	0.04	0.48	0.08	514
BTR-3	SW	34	140	0.14	0.6	0.06	0.52	0.08	642
BTR-4	SW	64	440	0.46	1.2	0.42	1	0.14	1730
BTR-5	SW	62	438	0.42	1.2	0.42	0.56	0.18	1720
BTR-2	GW	94	382	0.16	0.2	0.02	0.58	1.06	1710
BTR-4	GW	56	688	0.42	0.6	0.06	0.5	0.94	2296
BTR-5	GW	56	404	0.38	0.8	0.44	0.34	0.64	1604
CLP-1	SW	6	60	0	0.4	0.02	0.34	0.06	122
CLP-2	SW	10	96	0	0.4	0.04	0.36	0.06	232
CLP-3	SW	14	106	0.02	0.4	0.18	0.28	0.04	290
CLP-4	SW	20	134	0.04	0.4	0.16	0.36	0.06	396
CLP-5	SW	28	168	0.1	0.6	0.24	0.32	0.08	630
CLP-6	SW	110	338	0.32	1.8	0.94	0.24	0.04	1210
CLP-7	SW	76	222	0.28	1.2	0.1	0.04	0	960
CLP-8	SW	90	454	0.42	1.6	0.32	0.66	0.2	1472
CLP-9	SW	102	392	0.4	1.4	0.18	0.38	0.06	1612
CLP-3	GW	36	298	0.3	0.8	0.06	0.16	0.02	1550
CLP-5	GW	26	242	0.2	1	0.22	1.04	0.18	700
CLP-7	GW	78	268	0.32	1.4	0.08	0.86	0.02	1042
CLP-8	GW	104	454	0.44	1.2	0.26	1.24	1.64	2290
CLP-9	GW	94	390	0.38	1.4	0.3	0.04	0	1520
SVR-1	SW	6	50	0.02	0.2	0	0.38	0.04	116
SVR-2	SW	8	112	0.02	0.4	0.02	0.94	0.18	308
SVR-3	SW	24	236	0.16	0.8	0.02	0.52	0.04	710
SVR-4	SW	38	308	0.14	1.6	0.02	0.48	0.08	896
SVR-5a	SW	70	316	0.3	1.4	1.6	0.32	0.06	1066
SVR-6	SW	70	320	0.34	1.4	1.08	0.9	0.12	1176
SVR-7	SW	106	344	0.36	1.4	0.82	0.48	0.12	1636
SVR-8	SW	110	374	0.38	1.6	0.94	0.12	0.04	1476
SVR-2	GW	12	94	0.46	0.6	0.04	14.4	0.34	236
SVR-3	GW	24	234	0.16	0.8	0.02	0.68	0.12	682
SVR-5a	GW	84	298	0.4	1.4	0.58	0.24	0.18	1564
SVR-7	GW	210	812	0.5	1.4	0.44	6.78	3.74	2450
SVR-8	GW	300	420	0.5	1.4	0.24	0.16	0.92	2300
BEC-1	SW	188	372	0.38	1.6	0.48	1.24	0.04	1584
BEC-1	GW	200	372	0.38	1.6	0.36	2.66	0.88	1660
BJC-1	SW	176	440	0.32	1.4	0.06	0	0.38	2064
BJC-1	GW	196	492	0.38	1.8	0.04	1.52	1.68	2118
BVC-1	SW	148	466	0.42	1.6	0.7	0.2	0	2478
BVC-1	GW	134	548	0.36	1.4	1.3	0.46	2.36	1900
SPR-12	SW	152	190	0.16	1.6	0.48	0.14	0	830
SPR-11	SW	226	240	0.32	1.6	0.68	0.18	0.04	1170
SPR-10	SW	234	278	0.36	1.6	0.52	0.12	0.08	1300

Location	Type	lbs-Acre9in-Cl	lbs-Acre9in-Total Alkalinity	lbs-Acre9in-B	lbs-Acre9in-Fl	lbs-Acre9in-Ortho P	lbs-Acre9in-Total Fe	lbs-Acre9in-Mn	lbs-Acre9in-TDS
SPR-9	SW	192	302	0.34	1.6	0.52	0.26	0.06	1344
SPR-8	SW	166	328	0.34	1.6	0.58	0.3	0.12	1378
SPR-7	SW	154	412	0.36	1.4	2.2	0.24	0.06	1552
SPR-6	SW	152	380	0.44	1.6	0.28	0.18	0.06	1776
SPR-5	SW	154	496	0.44	1.4	0.76	0.24	0.08	2076
SPR-4	SW	136	460	0.46	1.6	0.26	0.12	0.06	2402
SPR-3	SW	198	462	0.48	1.4	0.14	0.06	0.06	2270
SPR-2	SW	230	462	0.6	1.2	0.06	0.22	0.08	2060
SPR-1	SW	204	364	0.54	1	0.02	0.1	0.04	2878
SPR-11	GW	452	422	0.34	2.6	0.14	1.16	5.46	1764
SPR-10	GW	226	288	0.34	1.4	1.1	0.12	1.12	1262
SPR-9	GW	196	294	0.34	1.6	1	0.06	3.06	1340
SPR-8	GW	150	328	0.34	1.6	0.68	0.08	0.04	1352
SPR-7	GW	148	336	0.32	1.4	0.88	0.22	0.34	1360
SPR-6	GW	190	514	0.44	2.6	0.14	0.08	0.3	2010
SPR-5	GW	146	484	0.44	1.4	0.62	0.02	0.04	2070
SPR-4	GW	144	434	0.44	1.6	0.28	0	4.12	2110
SPR-3	GW	162	494	0.5	1.6	0.2	0	0	2270
SPR-2	GW	242	458	0.6	1.2	0.26	0	0.02	3490
SPR-1	GW	162	394	0.5	1	0.2	0.02	0	2666

Location	Type	Molar Ratio- Ca:SO4	Molar Ratio- Na:Cl
BTR-1	SW	2.64	2.06
BTR-2	SW	0.73	3.26
BTR-3	SW	0.66	2.81
BTR-4	SW	0.57	4.58
BTR-5	SW	0.57	4.63
BTR-2	GW	0.72	2.30
BTR-4	GW	0.62	7.71
BTR-5	GW	0.63	4.74
CLP-1	SW	3.46	2.06
CLP-2	SW	2.81	2.16
CLP-3	SW	2.05	2.64
CLP-4	SW	1.45	2.62
CLP-5	SW	1.02	3.08
CLP-6	SW	0.65	2.64
CLP-7	SW	0.54	2.64
CLP-8	SW	0.62	3.26
CLP-9	SW	0.62	2.72
CLP-3	GW	0.89	4.28
CLP-5	GW	1.09	3.91
CLP-7	GW	0.64	2.73
CLP-8	GW	0.56	3.94
CLP-9	GW	0.60	2.89
SVR-1	SW	2.74	2.57
SVR-2	SW	1.65	3.47
SVR-3	SW	0.93	4.50
SVR-4	SW	0.93	2.92
SVR-5a	SW	0.70	2.82
SVR-6	SW	0.54	3.35
SVR-7	SW	0.54	2.76
SVR-8	SW	0.60	3.11
SVR-2	GW	1.75	2.57
SVR-3	GW	0.97	4.50
SVR-5a	GW	0.49	3.38
SVR-7	GW	0.57	2.29
SVR-8	GW	0.78	1.98
BEC-1	SW	0.71	2.17
BEC-1	GW	0.72	2.04
BJC-1	SW	0.83	2.52
BJC-1	GW	0.95	2.33
BVC-1	SW	0.73	3.31
BVC-1	GW	0.78	3.48
SPR-12	SW	1.45	1.22
SPR-11	SW	1.08	1.39
SPR-10	SW	0.99	1.58

Location	Type	Molar Ratio- Ca:SO4	Molar Ratio- Na:Cl
SPR-9	SW	0.99	1.96
SPR-8	SW	0.76	2.01
SPR-7	SW	0.74	2.26
SPR-6	SW	0.61	3.12
SPR-5	SW	0.68	3.40
SPR-4	SW	0.63	4.01
SPR-3	SW	0.60	2.87
SPR-2	SW	0.53	3.45
SPR-1	SW	0.54	3.54
SPR-11	GW	1.54	1.06
SPR-10	GW	1.03	1.58
SPR-9	GW	0.98	1.98
SPR-8	GW	0.77	2.26
SPR-7	GW	0.72	2.15
SPR-6	GW	0.75	2.60
SPR-5	GW	0.69	3.57
SPR-4	GW	0.62	3.66
SPR-3	GW	0.60	3.75
SPR-2	GW	0.55	3.34
SPR-1	GW	0.60	4.02

Location	Type
BTR-1	SW
BTR-2	SW
BTR-3	SW
BTR-4	SW
BTR-5	SW
BTR-2	GW
BTR-4	GW
BTR-5	GW
CLP-1	SW
CLP-2	SW
CLP-3	SW
CLP-4	SW
CLP-5	SW
CLP-6	SW
CLP-7	SW
CLP-8	SW
CLP-9	SW
CLP-3	GW
CLP-5	GW
CLP-7	GW
CLP-8	GW
CLP-9	GW
SVR-1	SW
SVR-2	SW
SVR-3	SW
SVR-4	SW
SVR-5a	SW
SVR-6	SW
SVR-7	SW
SVR-8	SW
SVR-2	GW
SVR-3	GW
SVR-5a	GW
SVR-7	GW
SVR-8	GW
BEC-1	SW
BEC-1	GW
BJC-1	SW
BJC-1	GW
BVC-1	SW
BVC-1	GW
SPR-12	SW
SPR-11	SW
SPR-10	SW

Location	Type
SPR-9	SW
SPR-8	SW
SPR-7	SW
SPR-6	SW
SPR-5	SW
SPR-4	SW
SPR-3	SW
SPR-2	SW
SPR-1	SW
SPR-11	GW
SPR-10	GW
SPR-9	GW
SPR-8	GW
SPR-7	GW
SPR-6	GW
SPR-5	GW
SPR-4	GW
SPR-3	GW
SPR-2	GW
SPR-1	GW

Location	Type	Inferred Bedrock Formation	Stream flow (ft3/s)	Total Salt Load (tons/day)	Load-Sodium (tons/day)	Load-Potassium (tons/day)	Load-Calcium (tons/day)
BTR-1	SW	Trpjs or PPif	36.8	8.2	0.7		0.9
BTR-2A	SW	Kp-Pierre Shale	no data				
BTR-3	SW	Kp-Pierre Shale	no data				
BTR-4	SW	Kf-Fox Hills	63.6	154.0	15.4	0.7	18.8
BTR-5	SW	Kl-Laramie	63.6	157.1	18.0	0.9	21.5
CLP-1	SW	Trpjs or PPif	56.9	19.6	1.1	0.2	3.5
CLP-2	SW	Kp-Pierre Shale	no data				
CLP-3	SW	Kp-Pierre Shale	no data				
CLP-4	SW	Kp-Pierre Shale	no data				
CLP-5	SW	Kp-Pierre Shale	no data				
CLP-6	SW	Kp-Pierre Shale	41.9	98.3	9.9	0.7	13.6
CLP-7	SW	Kp-Pierre Shale	40.8	88.1	8.5	0.6	10.7
CLP-8	SW	Kf-Fox Hills	80	194.6	18.1	1.1	23.7
CLP-9	SW	Kl-Laramie	81.2	226.0	24.1	1.1	24.3
SVR-1	SW	Kc-CO Grp	22.9	17.2	1.4	0.1	3.0
SVR-2	SW	Kp-Pierre Shale	13.8	10.0	0.5	0.0	1.8
SVR-3	SW	Kp-Pierre Shale	29.7	65.2	8.3	0.3	8.1
SVR-4	SW	Kp-Pierre Shale	30.5	65.5	5.6	0.2	7.8
SVR-5A	SW	Kp-Pierre Shale	30.5	60.1	7.7	0.5	7.0
SVR-6	SW	Kp or Kf	31.4	68.2	9.1	0.5	6.1
SVR-7	SW	Kf-Fox Hills	33.5	76.9	12.1	0.6	7.6
SVR-8	SW	Kf-Fox Hills	114	278.9	37.2	1.8	23.9
SPR-12	SW	Tkd-Denver	157	254.0	41.5	2.5	32.2
SPR-11	SW	Tkd-Denver	186	334.6	67.2	6.5	36.4
SPR-10	SW	TKda or Tkd	338	666.3	125.8	11.9	68.2
SPR-09	SW	Kl-Laramie	167	336.9	64.0	5.4	36.0
SPR-08	SW	Kl-Laramie	189	382.8	67.8	4.6	42.6
SPR-07	SW	Kl-Laramie	467	998.7	149.9	13.9	124.8
SPR-06	SW	Kp-Pierre Shale	335	855.6	138.2	9.0	114.0
SPR-05	SW	Kp-Pierre Shale	49.2	137.6	21.4	1.5	18.8
SPR-04	SW	Kp-Pierre Shale	111	283.2	52.1	3.6	42.2
SPR-03	SW	Kp-Pierre Shale	109	306.0	51.7	3.8	45.0
SPR-02	SW	Tw-White River	43	144.0	25.3	2.0	20.7
SPR-01	SW	Tw-White River	135	461.7	80.8	6.6	69.2
BEC-1	SW	Kl-Laramie	--				
BJC-1	SW	Kp-Pierre Shale	--				
BVC-1A	SW	Kp-Pierre Shale	--				

Location	Type	Inferred Bedrock Formation	Stream flow (ft3/s)	Load-Magnesium (tons/day)	Load-Chloride (tons/day)	Load-Bicarb (HCO3) (tons/day)
BTR-1	SW	Trpjs or PPif	36.8	0.2	0.6	3.3
BTR-2A	SW	Kp-Pierre Shale	no data			
BTR-3	SW	Kp-Pierre Shale	no data			
BTR-4	SW	Kf-Fox Hills	63.6	10.6	7.2	42.4
BTR-5	SW	Kl-Laramie	63.6	12.3	7.0	46.5
CLP-1	SW	Trpjs or PPif	56.9	0.9	0.8	13.2
CLP-2	SW	Kp-Pierre Shale	no data			
CLP-3	SW	Kp-Pierre Shale	no data			
CLP-4	SW	Kp-Pierre Shale	no data			
CLP-5	SW	Kp-Pierre Shale	no data			
CLP-6	SW	Kp-Pierre Shale	41.9	6.2	7.6	26.2
CLP-7	SW	Kp-Pierre Shale	40.8	5.3	6.4	23.8
CLP-8	SW	Kf-Fox Hills	80	12.1	13.2	51.8
CLP-9	SW	Kl-Laramie	81.2	13.8	19.9	54.7
SVR-1	SW	Kc-CO Grp	22.9	0.9	1.5	7.5
SVR-2	SW	Kp-Pierre Shale	13.8	0.4	0.6	4.4
SVR-3	SW	Kp-Pierre Shale	29.7	4.8	6.7	23.7
SVR-4	SW	Kp-Pierre Shale	30.5	4.5	4.9	27.1
SVR-5A	SW	Kp-Pierre Shale	30.5	4.1	6.3	22.5
SVR-6	SW	Kp or Kf	31.4	3.6	8.5	20.0
SVR-7	SW	Kf-Fox Hills	33.5	4.9	9.6	22.0
SVR-8	SW	Kf-Fox Hills	114	15.4	34.4	75.6
SPR-12	SW	Tkd-Denver	157	8.0	61.0	67.7
SPR-11	SW	Tkd-Denver	186	9.5	84.3	93.8
SPR-10	SW	TKda or Tkd	338	19.1	136.7	173.2
SPR-09	SW	Kl-Laramie	167	10.4	61.7	86.5
SPR-08	SW	Kl-Laramie	189	17.3	61.2	108.6
SPR-07	SW	Kl-Laramie	467	55.4	103.3	303.5
SPR-06	SW	Kp-Pierre Shale	335	45.2	84.9	233.1
SPR-05	SW	Kp-Pierre Shale	49.2	6.9	12.7	37.2
SPR-04	SW	Kp-Pierre Shale	111	17.4	29.9	84.7
SPR-03	SW	Kp-Pierre Shale	109	17.6	29.1	86.1
SPR-02	SW	Tw-White River	43	8.0	11.8	35.3
SPR-01	SW	Tw-White River	135	23.7	42.6	94.3
BEC-1	SW	Kl-Laramie	--			
BJC-1	SW	Kp-Pierre Shale	--			
BVC-1A	SW	Kp-Pierre Shale	--			

Location	Type	Inferred Bedrock Formation	Stream flow (ft3/s)	Load-Carb (CO3) (tons/day)	Load-Sulfate (SO4) (tons/day)	Load-Uranium (lbs/day)
BTR-1	SW	Trpjs or PPif	36.8		0.6	0.1
BTR-2A	SW	Kp-Pierre Shale	no data			
BTR-3	SW	Kp-Pierre Shale	no data			
BTR-4	SW	Kf-Fox Hills	63.6		76.7	7.5
BTR-5	SW	Kl-Laramie	63.6		88.0	7.2
CLP-1	SW	Trpjs or PPif	56.9		2.3	0.6
CLP-2	SW	Kp-Pierre Shale	no data			
CLP-3	SW	Kp-Pierre Shale	no data			
CLP-4	SW	Kp-Pierre Shale	no data			
CLP-5	SW	Kp-Pierre Shale	no data			
CLP-6	SW	Kp-Pierre Shale	41.9	0.4	47.1	9.7
CLP-7	SW	Kp-Pierre Shale	40.8	0.3	38.3	2.6
CLP-8	SW	Kf-Fox Hills	80		87.4	7.3
CLP-9	SW	Kl-Laramie	81.2	0.8	93.3	9.6
SVR-1	SW	Kc-CO Grp	22.9	0.2	4.3	0.5
SVR-2	SW	Kp-Pierre Shale	13.8	0.0	2.8	0.4
SVR-3	SW	Kp-Pierre Shale	29.7	0.3	25.0	2.6
SVR-4	SW	Kp-Pierre Shale	30.5	0.3	21.0	3.9
SVR-5A	SW	Kp-Pierre Shale	30.5		21.2	2.1
SVR-6	SW	Kp or Kf	31.4	0.2	19.8	1.9
SVR-7	SW	Kf-Fox Hills	33.5	0.2	27.4	2.3
SVR-8	SW	Kf-Fox Hills	114		91.3	8.6
SPR-12	SW	Tkd-Denver	157	2.2	54.6	10.2
SPR-11	SW	Tkd-Denver	186		82.8	6.8
SPR-10	SW	TKda or Tkd	338		161.3	13.9
SPR-09	SW	Kl-Laramie	167		86.5	8.2
SPR-08	SW	Kl-Laramie	189	1.4	120.8	12.2
SPR-07	SW	Kl-Laramie	467	3.5	404.3	47.9
SPR-06	SW	Kp-Pierre Shale	335	2.5	374.0	45.2
SPR-05	SW	Kp-Pierre Shale	49.2	0.4	61.7	8.0
SPR-04	SW	Kp-Pierre Shale	111	1.5	162.6	26.3
SPR-03	SW	Kp-Pierre Shale	109	1.5	175.5	28.2
SPR-02	SW	Tw-White River	43	0.6	86.6	12.5
SPR-01	SW	Tw-White River	135	1.1	293.8	40.1
BEC-1	SW	Kl-Laramie	--			
BJC-1	SW	Kp-Pierre Shale	--			
BVC-1A	SW	Kp-Pierre Shale	--			

Location	Type	Inferred Bedrock Formation	Stream flow (ft3/s)	Total Salt Load (tons/day)	Load-Sodium (tons/day)	Load-Potassium (tons/day)	Load-Calcium (tons/day)
BTR-1	SW	Trpjs or PPif	149	13.7	1.6	0.0	2.7
BTR-2	SW	Kp-Pierre Shale	54.7	37.9	2.8	0.3	6.2
BTR-3	SW	Kp-Pierre Shale	4.89	4.2	0.4	0.0	0.6
BTR-4	SW	Kf-Fox Hills	41.5	96.8	10.6	0.7	13.7
BTR-5	SW	Kl-Laramie	40.5	93.9	10.2	0.7	13.6
CLP-1	SW	Trpjs or PPif	379	62.3	4.1	0.0	13.3
CLP-2	SW	Kp-Pierre Shale	33.4	10.4	0.6	0.1	1.9
CLP-3	SW	Kp-Pierre Shale	48.8	19.1	1.6	0.1	3.4
CLP-4	SW	Kp-Pierre Shale	37.5	20.0	1.7	0.2	4.0
CLP-5	SW	Kp-Pierre Shale	37.5	31.9	2.8	0.3	6.4
CLP-6	SW	Kp-Pierre Shale	65.2	106.4	16.5	1.4	14.5
CLP-7	SW	Kp-Pierre Shale	63.3	81.9	11.1	0.9	10.0
CLP-8	SW	Kf-Fox Hills	62.4	123.9	16.0	1.2	17.5
CLP-9	SW	Kl-Laramie	62.4	135.6	15.1	1.0	19.1
SVR-1	SW	Kc-CO Grp	97.8	15.3	1.3	0.0	2.7
SVR-2	SW	Kp-Pierre Shale	10.8	4.5	0.3	0.0	0.8
SVR-3	SW	Kp-Pierre Shale	53.4	51.1	5.0	0.3	8.0
SVR-4	SW	Kp-Pierre Shale	41.6	50.3	4.0	0.2	7.0
SVR-5a	SW	Kp or Kf	48.4	69.6	8.4	0.8	9.6
SVR-6	SW	Kp or Kf	48.4	76.8	9.9	0.8	9.4
SVR-7	SW	Kf-Fox Hills	45.7	100.8	11.7	0.9	9.1
SVR-8	SW	Kf-Fox Hills	117	232.9	35.0	1.9	27.8
BEC-1	SW	Kl-Laramie					
BJC-1	SW	Kp-Pierre Shale					
BVC-1	SW	Kp-Pierre Shale					
SPR-12	SW	Tkd-Denver	275	307.8	44.5	3.7	43.0
SPR-11	SW	Tkd-Denver	302	476.5	83.1	8.1	56.4
SPR-10	SW	TKda or Tkd	350	613.5	113.3	10.4	72.5
SPR-9	SW	Kl-Laramie	208	377.0	68.4	6.2	45.7
SPR-8	SW	Kl-Laramie	232	431.1	67.6	5.0	50.2
SPR-7	SW	Kl-Laramie	239	500.2	72.8	6.4	73.4
SPR-6	SW	Kp-Pierre Shale	279	668.2	115.9	7.5	83.3
SPR-5	SW	Kp-Pierre Shale	279	781.0	127.9	9.8	116.8
SPR-4	SW	Kp-Pierre Shale	141	456.7	67.3	4.9	56.8
SPR-3	SW	Kp-Pierre Shale	137	419.4	68.0	6.3	60.4
SPR-2	SW	Tw-White River	63.9	177.5	44.3	3.8	32.8
SPR-1	SW	Tw-White River	90	349.3	56.8	5.6	45.6

Location	Type	Inferred Bedrock Formation	Stream flow (ft3/s)	Load-Magnesium (tons/day)	Load-Chloride (tons/day)	Load-Bicarb (HCO3) (tons/day)
BTR-1	SW	Trpjs or PPif	149	0.8	1.2	8.8
BTR-2	SW	Kp-Pierre Shale	54.7	2.5	1.3	11.1
BTR-3	SW	Kp-Pierre Shale	4.89	0.3	0.2	1.1
BTR-4	SW	Kf-Fox Hills	41.5	7.7	3.6	30.1
BTR-5	SW	Kl-Laramie	40.5	7.5	3.4	29.3
CLP-1	SW	Trpjs or PPif	379	3.1	3.1	36.8
CLP-2	SW	Kp-Pierre Shale	33.4	0.5	0.5	5.3
CLP-3	SW	Kp-Pierre Shale	48.8	0.8	0.9	8.6
CLP-4	SW	Kp-Pierre Shale	37.5	1.0	1.0	8.3
CLP-5	SW	Kp-Pierre Shale	37.5	1.8	1.4	10.4
CLP-6	SW	Kp-Pierre Shale	65.2	7.4	9.7	32.5
CLP-7	SW	Kp-Pierre Shale	63.3	5.8	6.5	22.0
CLP-8	SW	Kf-Fox Hills	62.4	9.9	7.6	45.4
CLP-9	SW	Kl-Laramie	62.4	10.1	8.6	40.2
SVR-1	SW	Kc-CO Grp	97.8	0.5	0.8	8.2
SVR-2	SW	Kp-Pierre Shale	10.8	0.2	0.1	2.0
SVR-3	SW	Kp-Pierre Shale	53.4	3.3	1.7	19.3
SVR-4	SW	Kp-Pierre Shale	41.6	3.5	2.1	21.1
SVR-5a	SW	Kp or Kf	48.4	5.1	4.6	25.2
SVR-6	SW	Kp or Kf	48.4	6.1	4.6	25.5
SVR-7	SW	Kf-Fox Hills	45.7	5.9	6.5	25.4
SVR-8	SW	Kf-Fox Hills	117	17.0	17.4	70.4
BEC-1	SW	Kl-Laramie				
BJC-1	SW	Kp-Pierre Shale				
BVC-1	SW	Kp-Pierre Shale				
SPR-12	SW	Tkd-Denver	275	10.4	56.4	86.0
SPR-11	SW	Tkd-Denver	302	13.8	92.0	119.7
SPR-10	SW	TKda or Tkd	350	18.9	110.4	155.7
SPR-9	SW	Kl-Laramie	208	12.3	53.9	103.2
SPR-8	SW	Kl-Laramie	232	21.3	51.9	125.1
SPR-7	SW	Kl-Laramie	239	32.2	49.6	157.3
SPR-6	SW	Kp-Pierre Shale	279	40.6	57.2	167.8
SPR-5	SW	Kp-Pierre Shale	279	42.9	57.9	222.7
SPR-4	SW	Kp-Pierre Shale	141	22.8	25.9	104.6
SPR-3	SW	Kp-Pierre Shale	137	22.9	36.6	104.2
SPR-2	SW	Tw-White River	63.9	12.6	19.8	47.2
SPR-1	SW	Tw-White River	90	16.0	24.8	52.7

Location	Type	Inferred Bedrock Formation	Stream flow (ft3/s)	Load-Carb (CO3) (tons/day)	Load-Sulfate (SO4) (tons/day)	Load-Uranium (lbs/day)
BTR-1	SW	Trpjs or PPif	149	0.0	2.4	0.2
BTR-2	SW	Kp-Pierre Shale	54.7	0.0	20.4	0.4
BTR-3	SW	Kp-Pierre Shale	4.89	0.0	2.1	0.0
BTR-4	SW	Kf-Fox Hills	41.5	0.0	57.1	2.4
BTR-5	SW	Kl-Laramie	40.5	0.0	56.7	2.2
CLP-1	SW	Trpjs or PPif	379	0.0	9.2	0.5
CLP-2	SW	Kp-Pierre Shale	33.4	0.0	1.6	0.1
CLP-3	SW	Kp-Pierre Shale	48.8	0.0	3.9	0.1
CLP-4	SW	Kp-Pierre Shale	37.5	0.0	6.7	0.2
CLP-5	SW	Kp-Pierre Shale	37.5	0.0	15.2	0.3
CLP-6	SW	Kp-Pierre Shale	65.2	1.8	53.3	1.2
CLP-7	SW	Kp-Pierre Shale	63.3	0.5	44.6	0.9
CLP-8	SW	Kf-Fox Hills	62.4	0.6	67.7	2.4
CLP-9	SW	Kl-Laramie	62.4	0.0	74.2	3.2
SVR-1	SW	Kc-CO Grp	97.8	0.0	2.4	0.1
SVR-2	SW	Kp-Pierre Shale	10.8	0.0	1.2	0.0
SVR-3	SW	Kp-Pierre Shale	53.4	0.7	20.7	0.7
SVR-4	SW	Kp-Pierre Shale	41.6	0.0	18.2	0.9
SVR-5a	SW	Kp or Kf	48.4	0.0	32.9	1.1
SVR-6	SW	Kp or Kf	48.4	0.0	41.5	1.1
SVR-7	SW	Kf-Fox Hills	45.7	0.3	40.3	1.0
SVR-8	SW	Kf-Fox Hills	117	0.8	110.8	3.5
BEC-1	SW	Kl-Laramie				
BJC-1	SW	Kp-Pierre Shale				
BVC-1	SW	Kp-Pierre Shale				
SPR-12	SW	Tkd-Denver	275	0.0	71.2	3.7
SPR-11	SW	Tkd-Denver	302	0.0	124.6	4.6
SPR-10	SW	TKda or Tkd	350	2.0	175.6	6.1
SPR-9	SW	Kl-Laramie	208	0.0	111.1	4.3
SPR-8	SW	Kl-Laramie	232	0.0	157.7	5.9
SPR-7	SW	Kl-Laramie	239	2.1	237.8	11.6
SPR-6	SW	Kp-Pierre Shale	279	3.2	329.6	15.8
SPR-5	SW	Kp-Pierre Shale	279	2.3	413.1	21.8
SPR-4	SW	Kp-Pierre Shale	141	1.2	214.5	11.4
SPR-3	SW	Kp-Pierre Shale	137	0.0	239.4	13.3
SPR-2	SW	Tw-White River	63.9	0.7	148.4	7.2
SPR-1	SW	Tw-White River	90	0.6	202.4	9.2

APPENDIX B
GRAPHICAL WATER-QUALITY DATA

Table B-1. Reference location distances along the South Platte River

Location	Distance along South Platte River (miles)
Littleton	0
Thornton	17
Brighton	30
Fort Lupton	40
Platteville	50
Saint Vrain River confluence	56.4
Big Thompson River confluence	66.3
Cache la Poudre River confluence	77.7
Kersey	87
Box Elder Creek confluence	87
Weldona	121
Bijou Creek confluence	128
Fort Morgan	130
Brush	142
Synder	145
Beaver Creek confluence	148
Sterling	180
Crook	210
Julesburg	245

Saint Vrain River length to confluence	31.82
Big Thompson River length to confluence	39.2
Cache la Poudre River length to confluence	55.82

APPENDIX B-1
SOUTH PLATTE RIVER GRAPHS

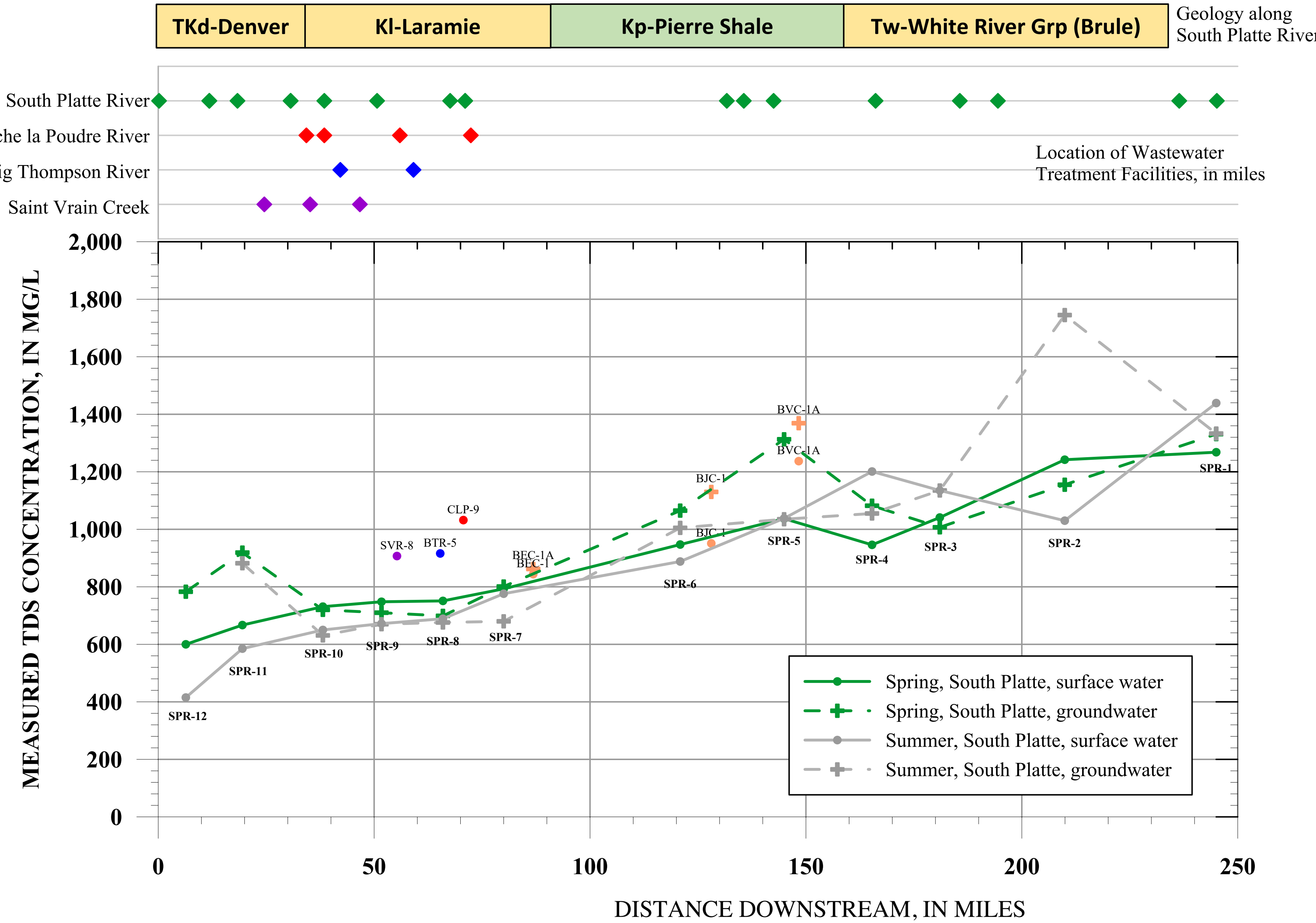


Figure B-1-1. Total Dissolved Solids concentrations along the South Platte River

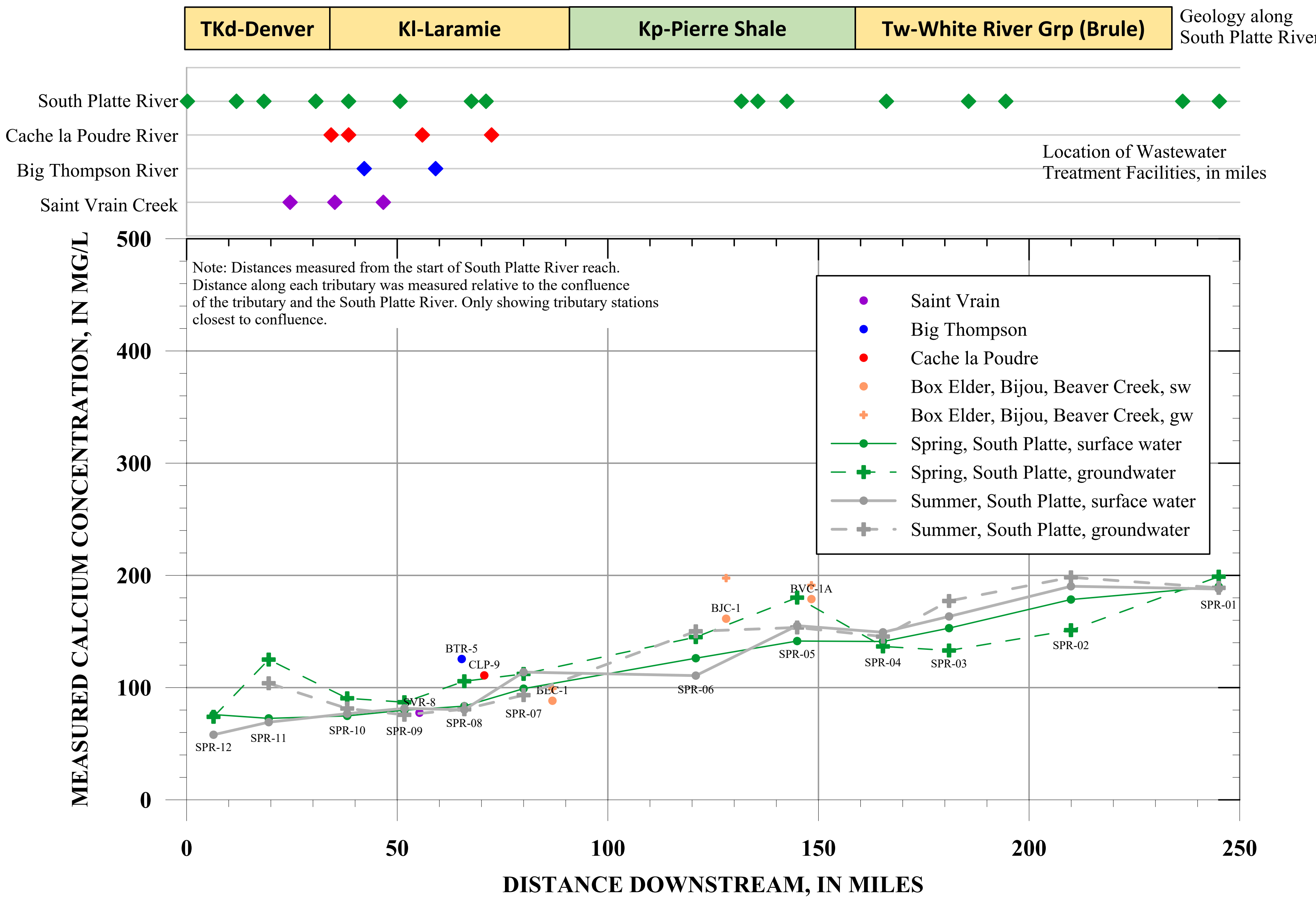


Figure B-1-2. Calcium concentrations along the South Platte River

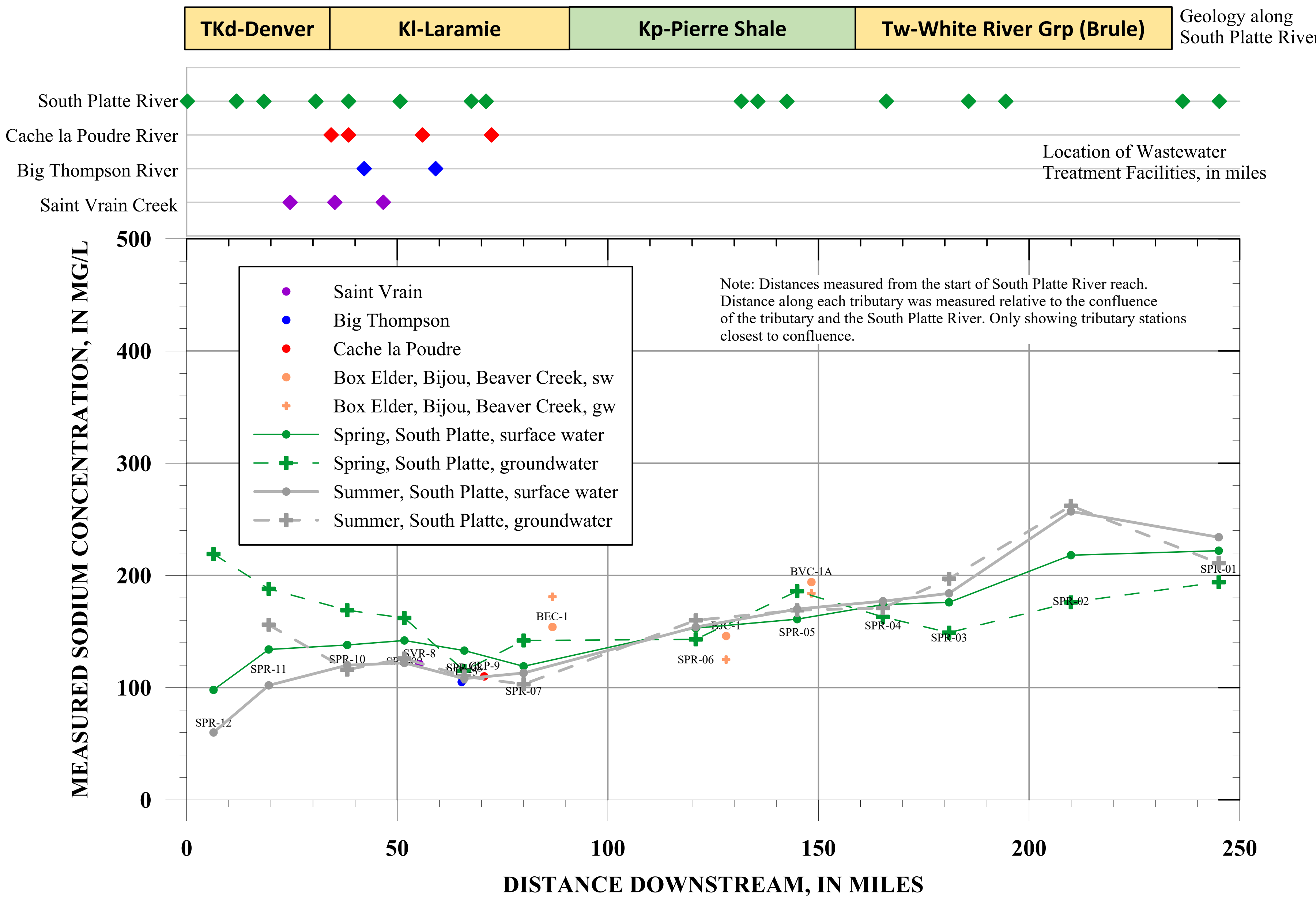


Figure B-1-3. Sodium concentrations along the South Platte River

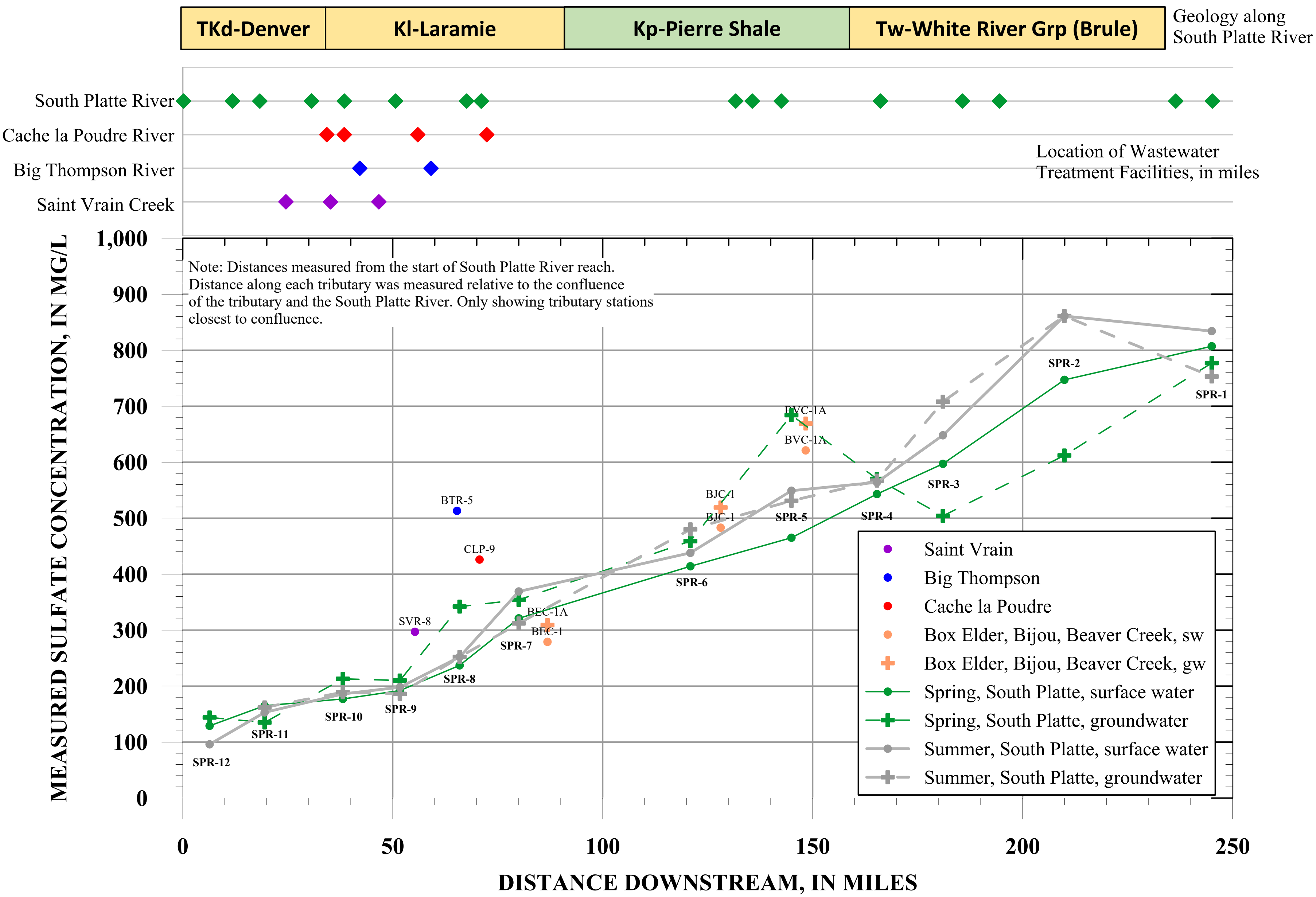


Figure B-1-4. Sulfate concentrations along the South Platte River

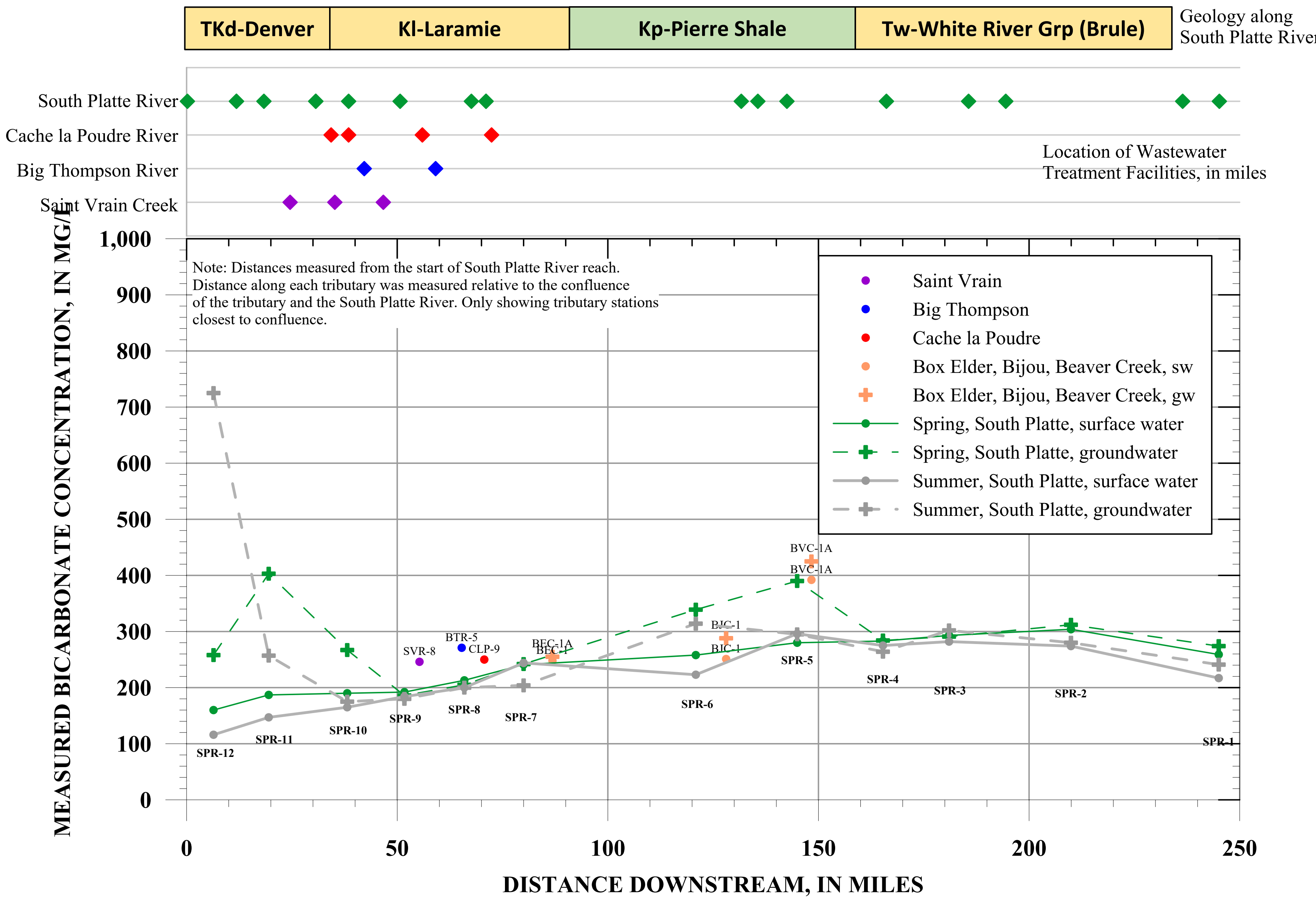


Figure B-1-5. Bicarbonate concentrations along the South Platte River

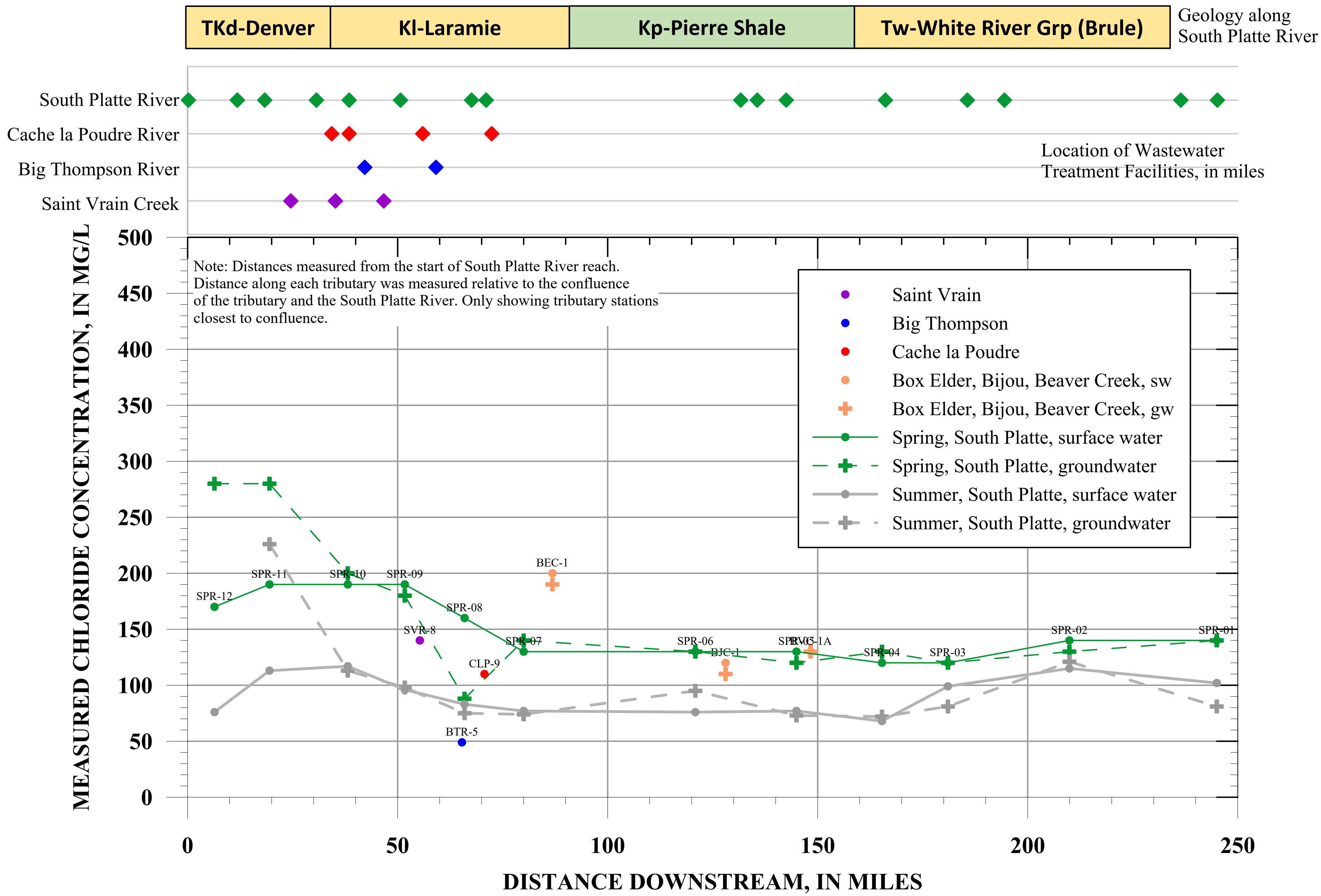


Figure B-1-6. Chloride concentrations along the South Platte River

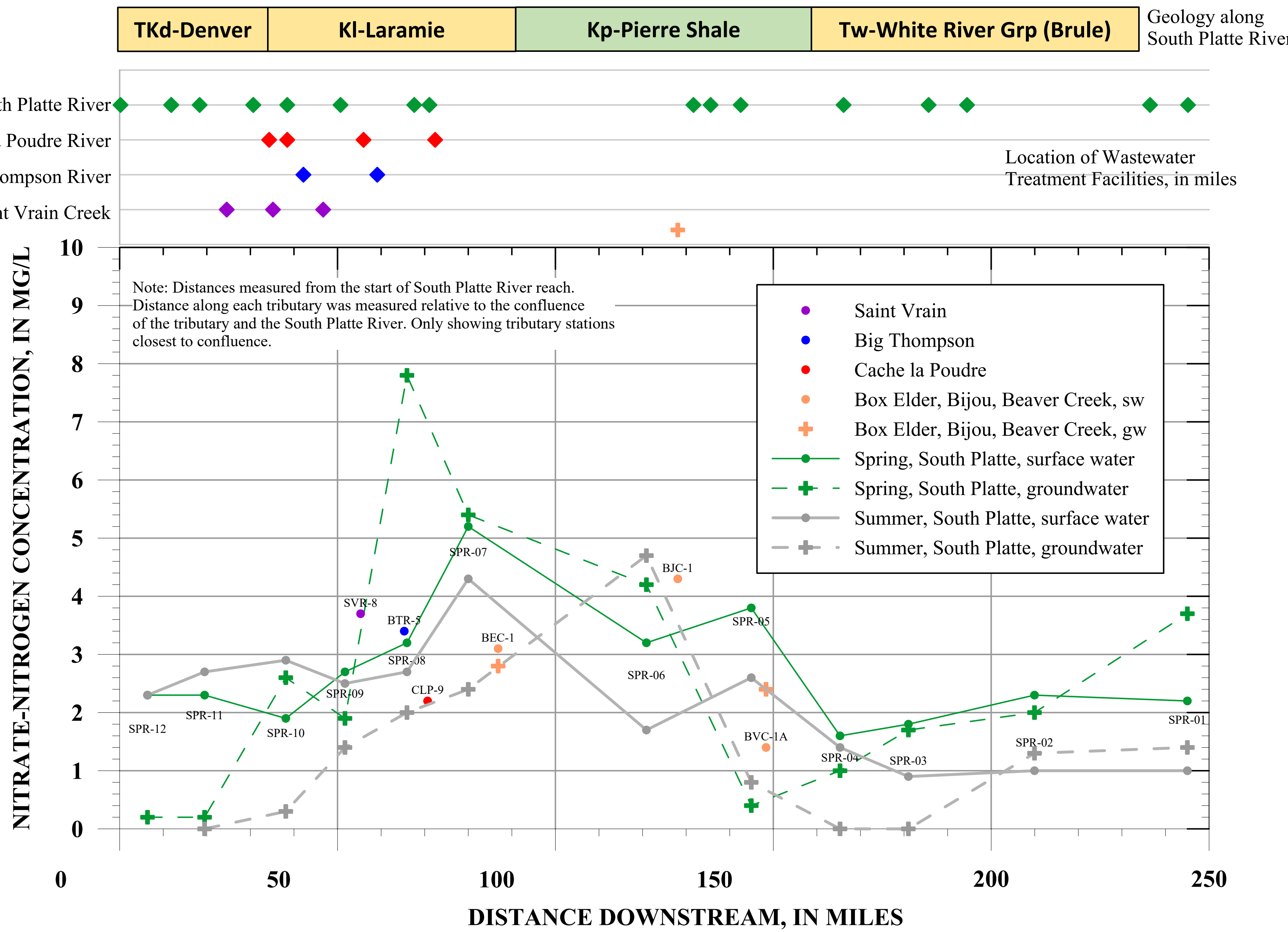


Figure B-1-7. Nitrate as nitrogen concentrations along the South Platte River

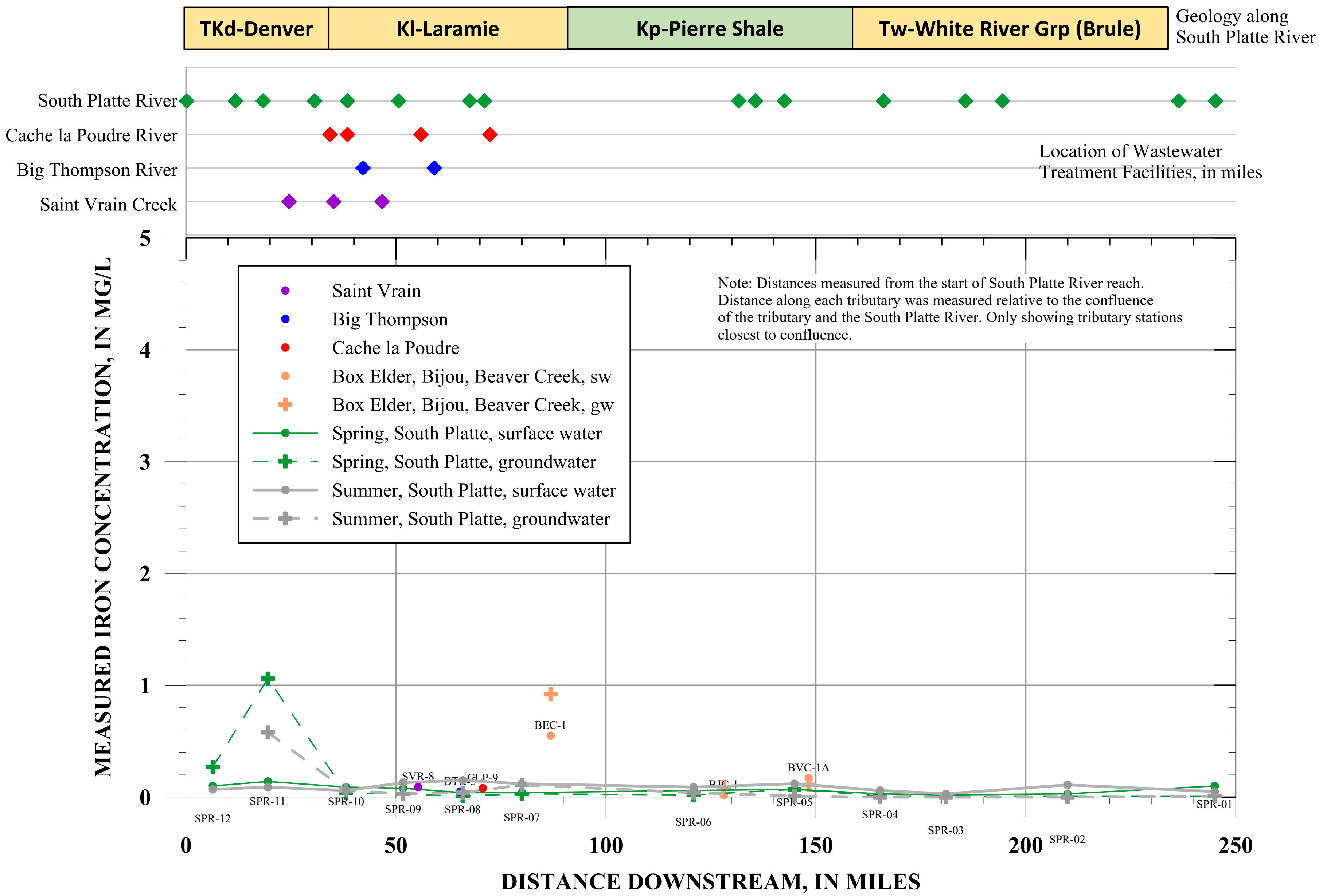


Figure B-1-8. Iron concentrations along the South Platte River

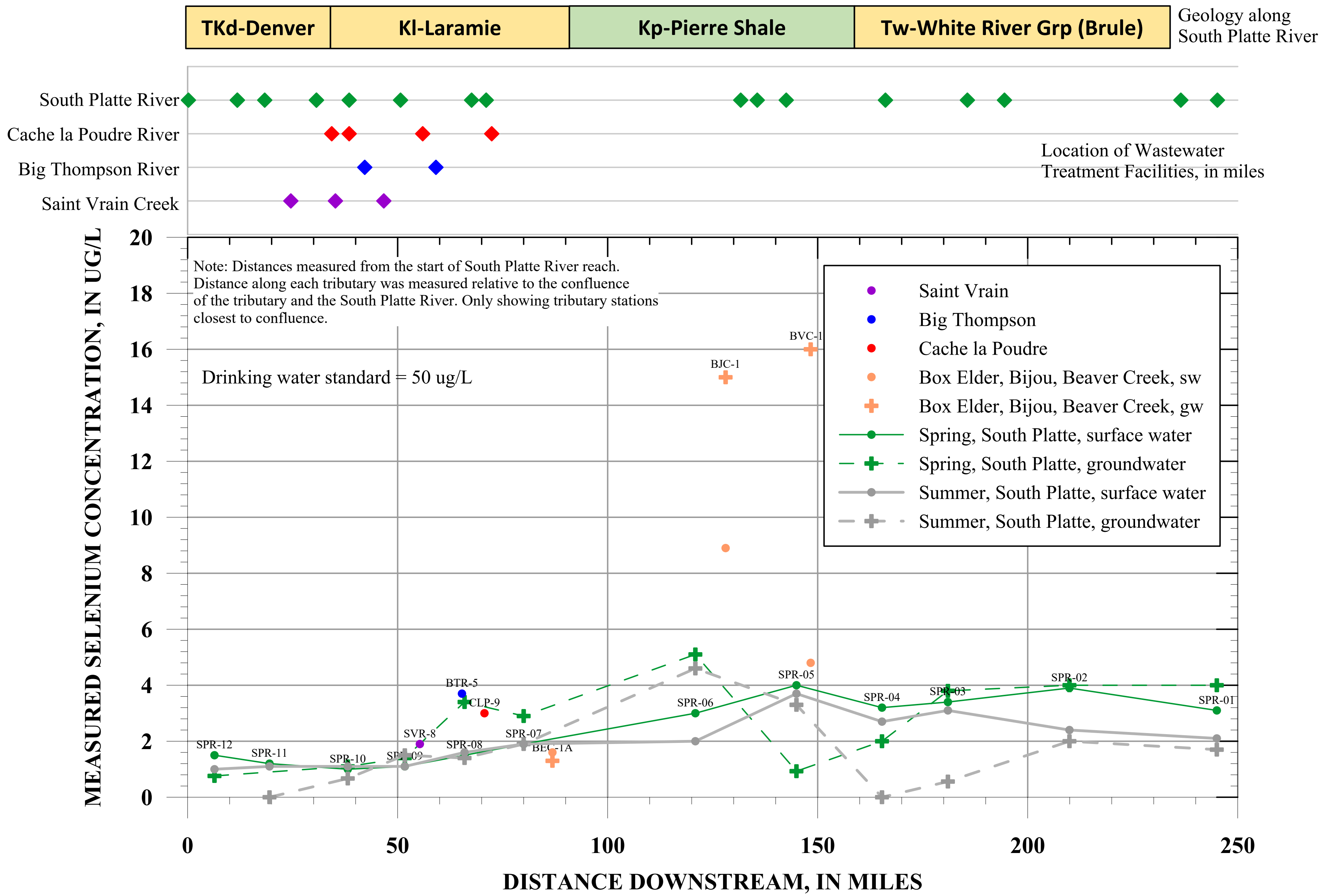


Figure B-1-9. Selenium concentrations along the South Platte River

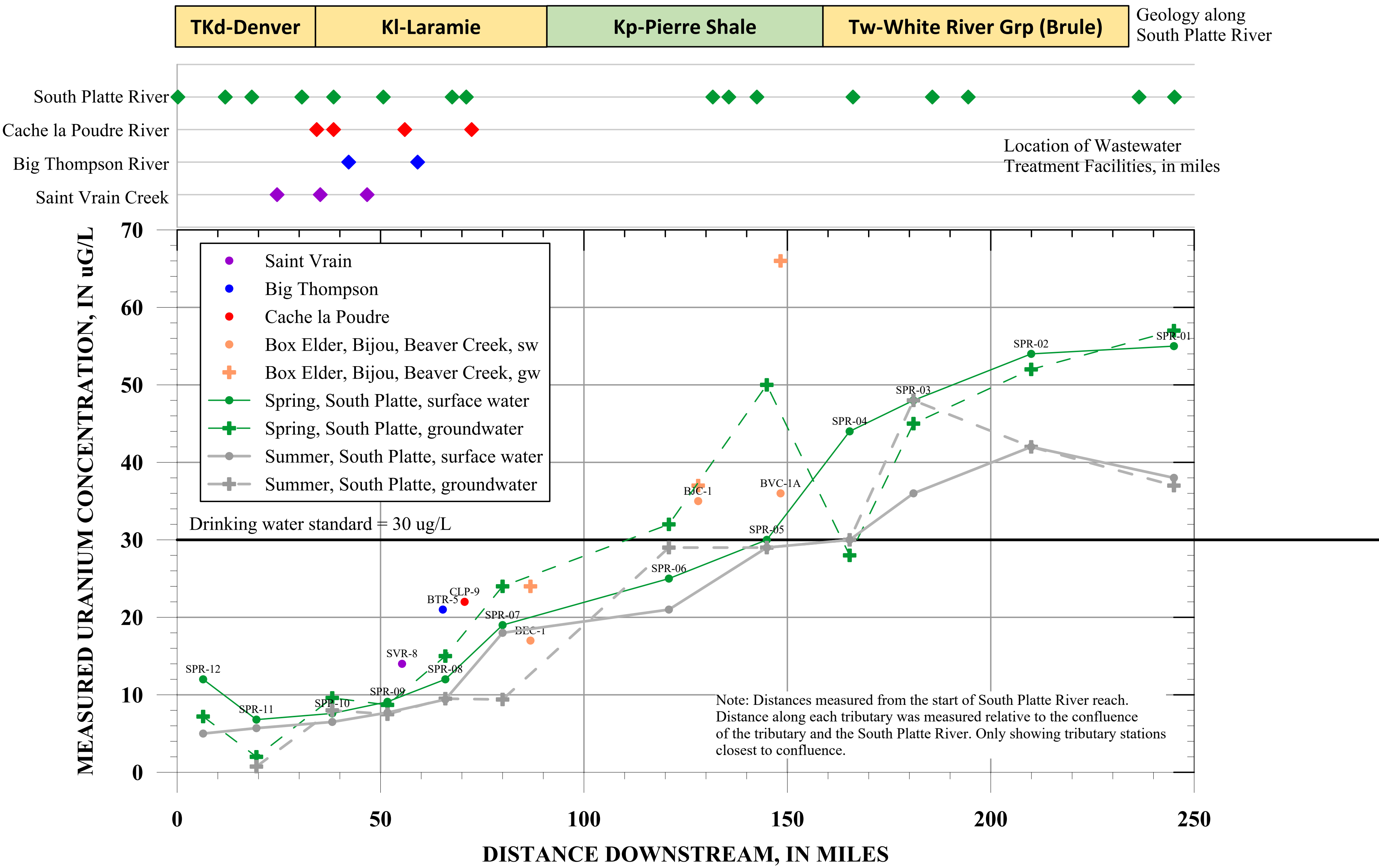


Figure B-1-10. Uranium concentrations along the South Platte River

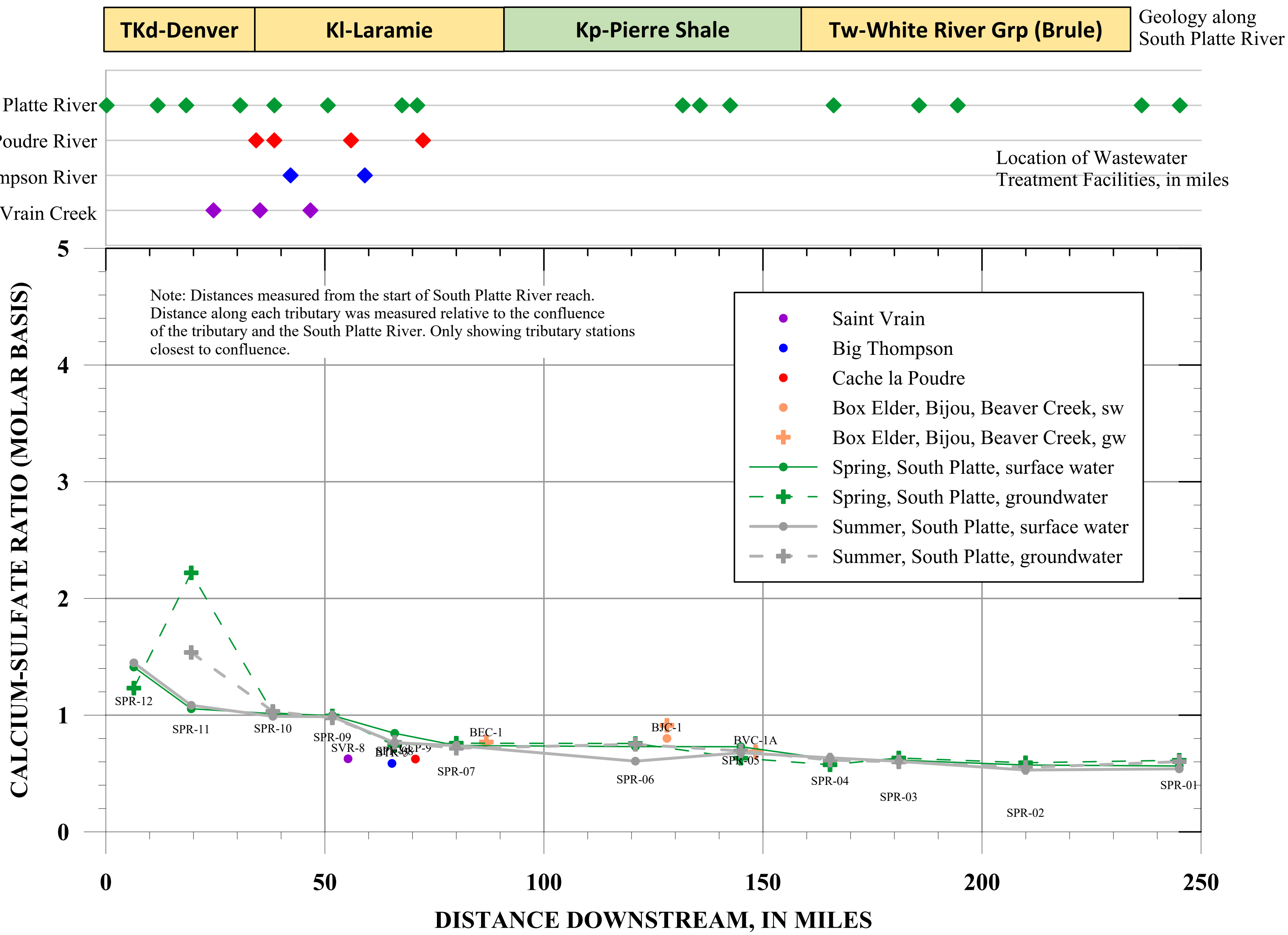


Figure B-1-11. Calcium-Sulfate ratio ($Ca:SO_4$) in South Platte River

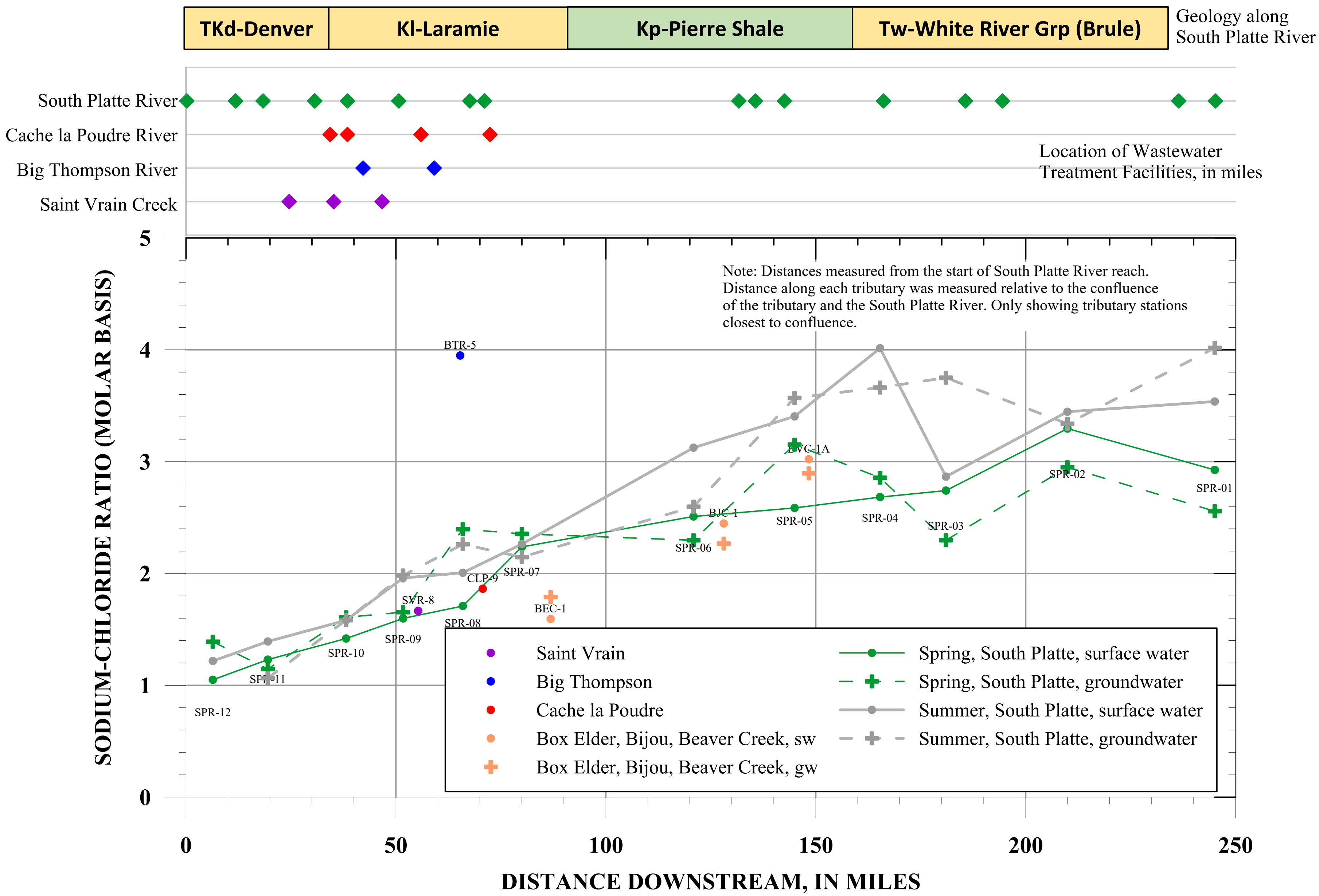


Figure B-1-12. Sodium-Chloride ratio (Na:Cl) in South Platte River and tributaries

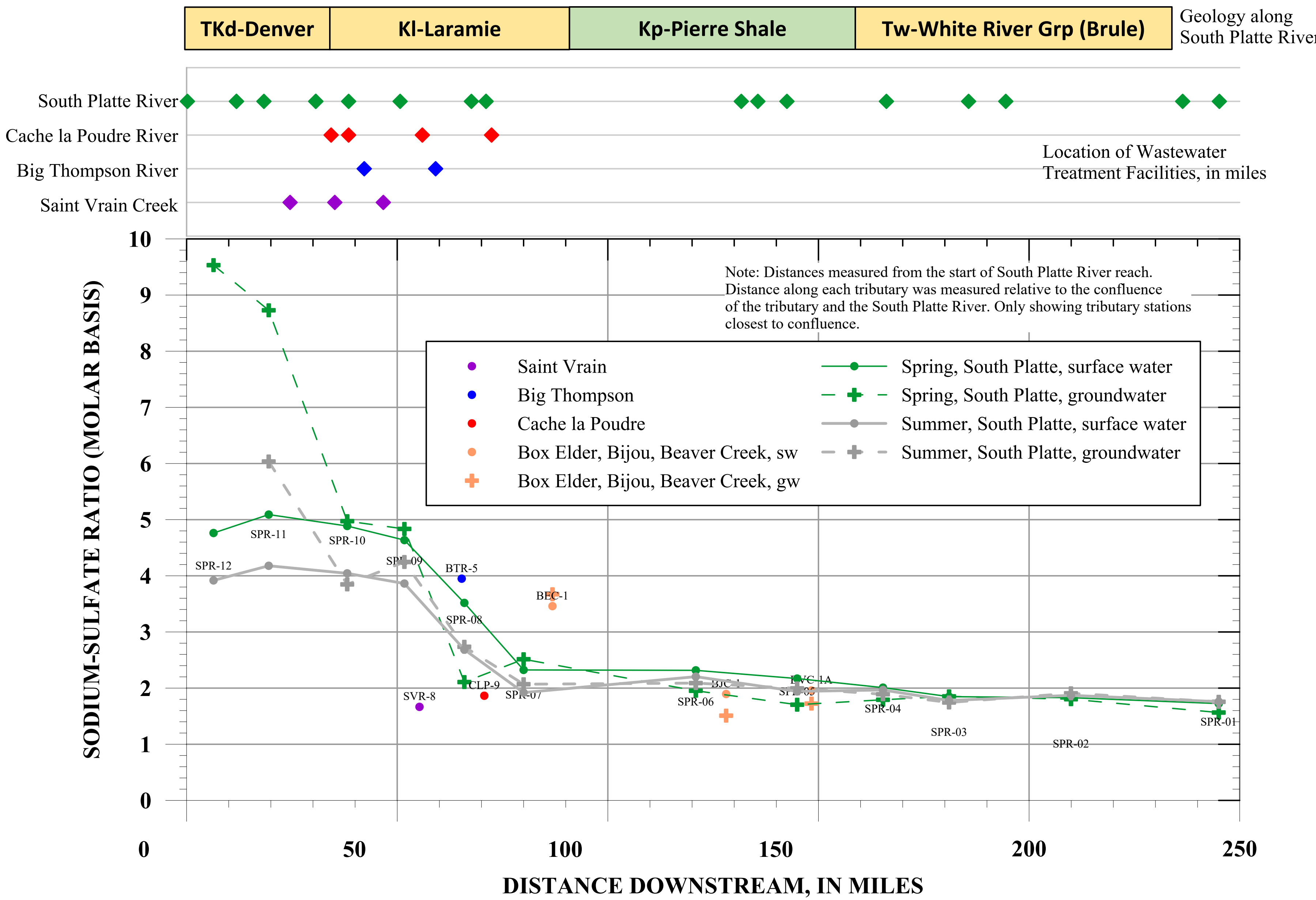


Figure B-1-13. Sodium-Sulfate ratio (Na_2:SO_4) along the South Platte River

APPENDIX B-2
SAINT VRAIN RIVER GRAPHS

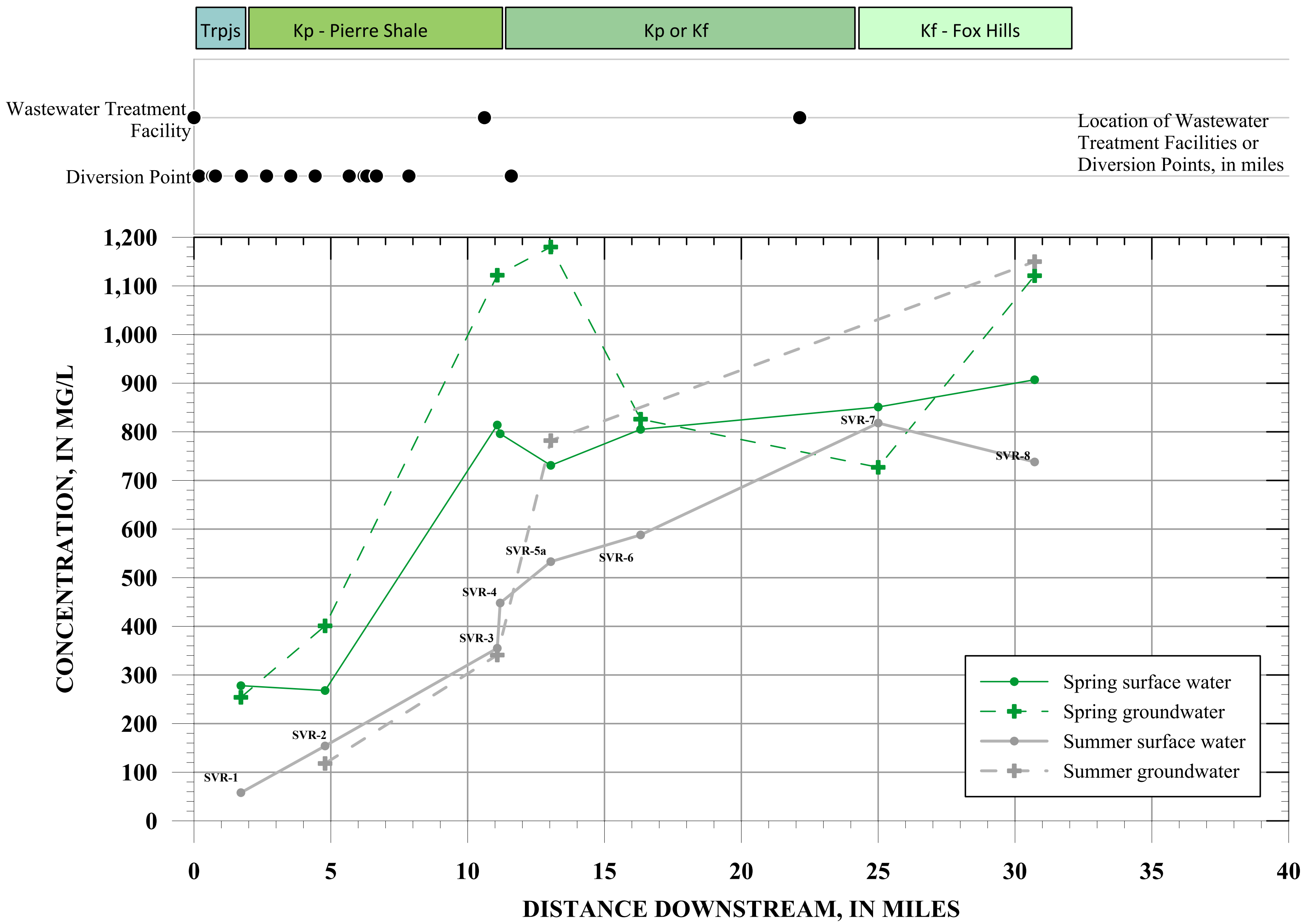


Figure B-2-1. Total Dissolved Solids concentrations along the Saint Vrain River

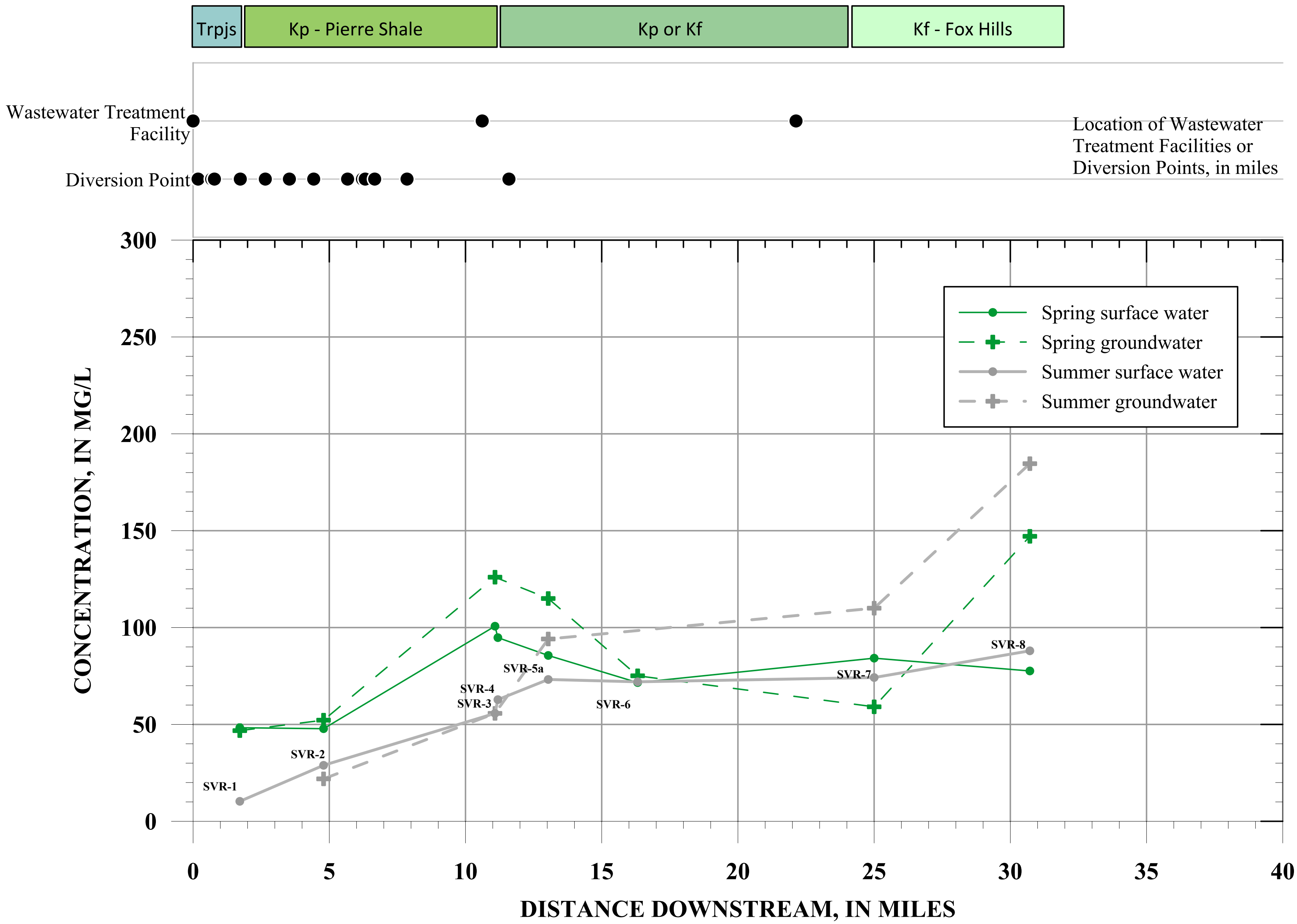


Figure B-2-2. Calcium concentration along the Saint Vrain River

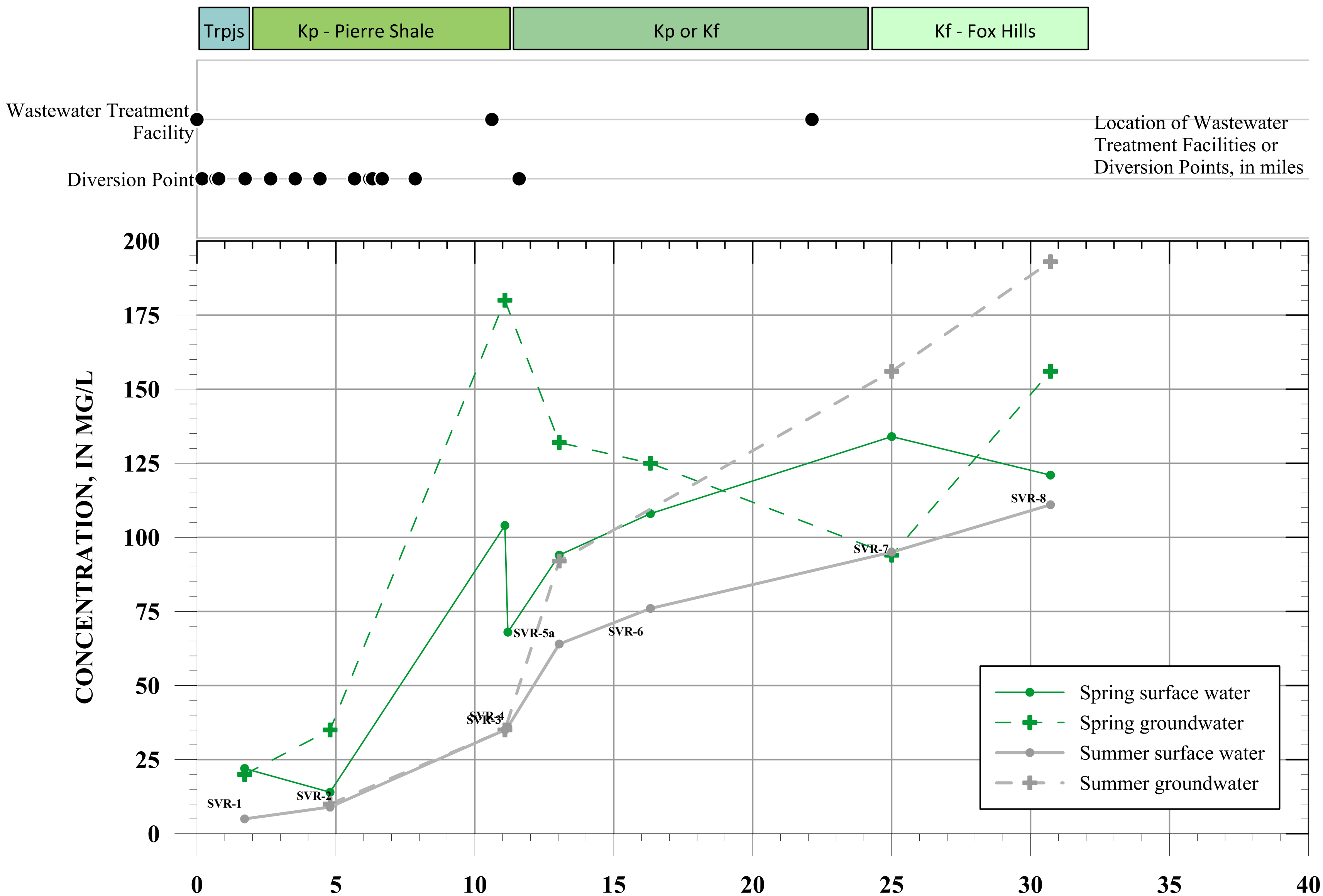


Figure B-2-3. Sodium concentrations along the Saint Vrain River

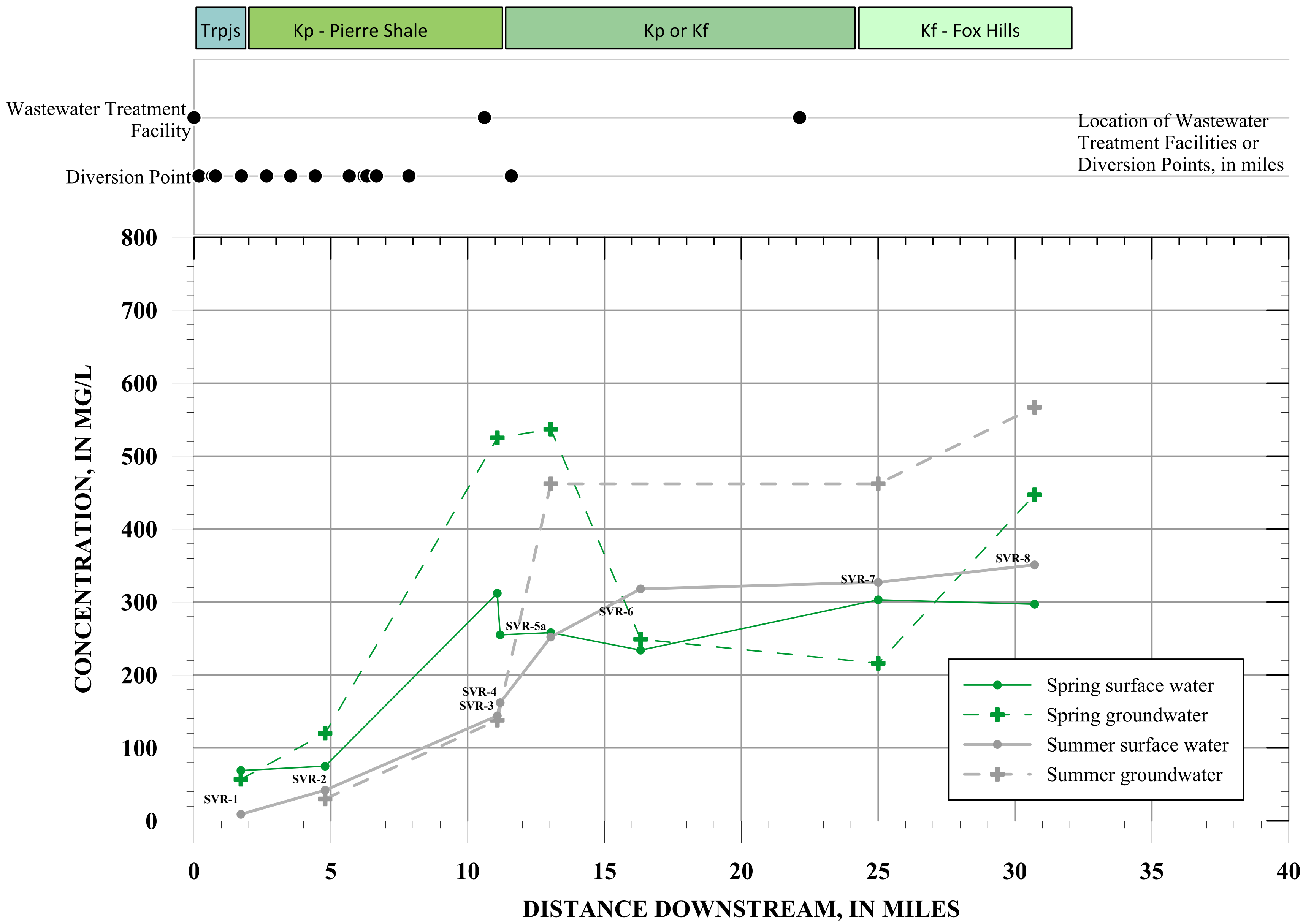


Figure B-2-4. Sulfate concentrations along the Saint Vrain River

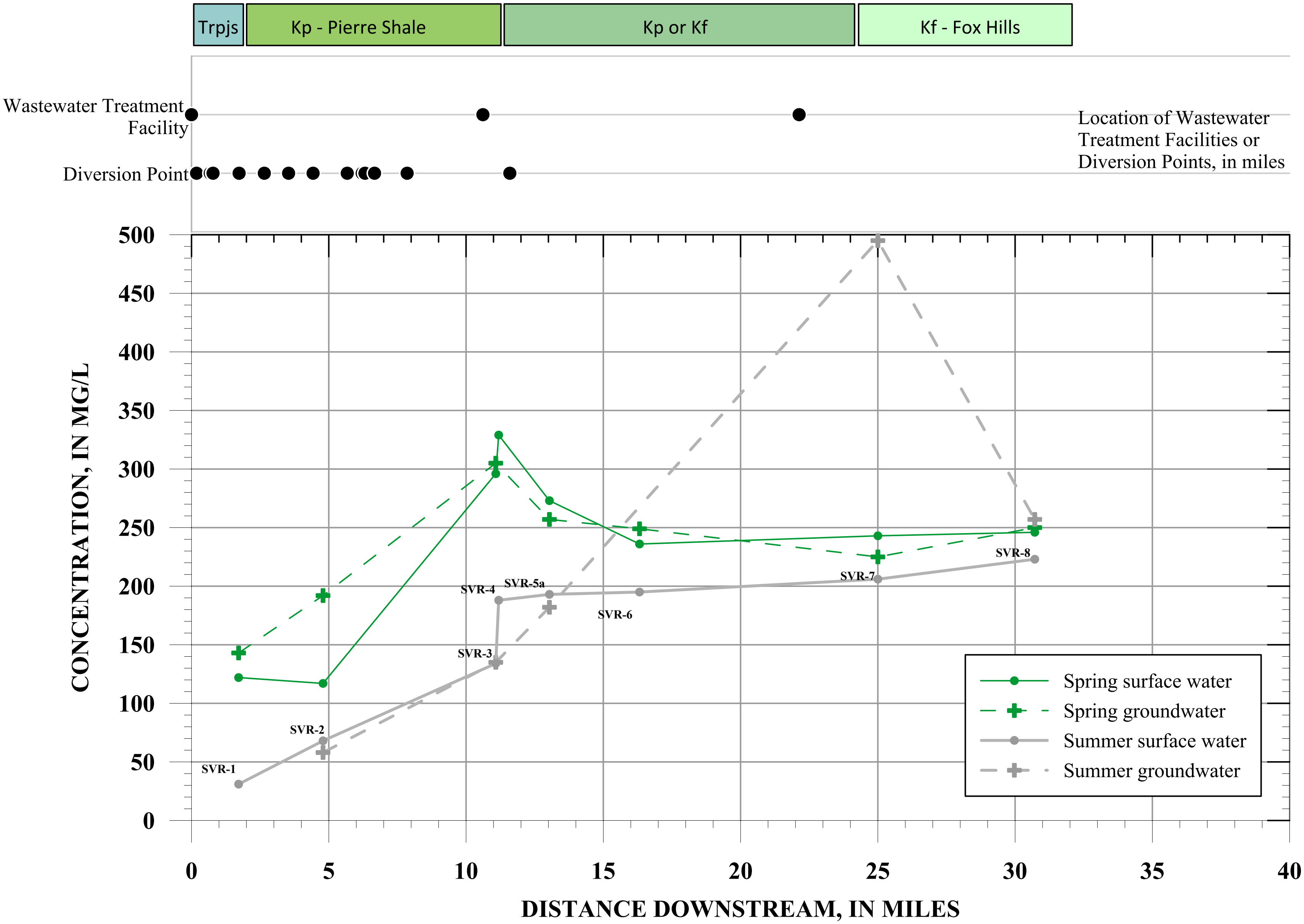


Figure B-2-5. Bicarbonate concentrations along the Saint Vrain River

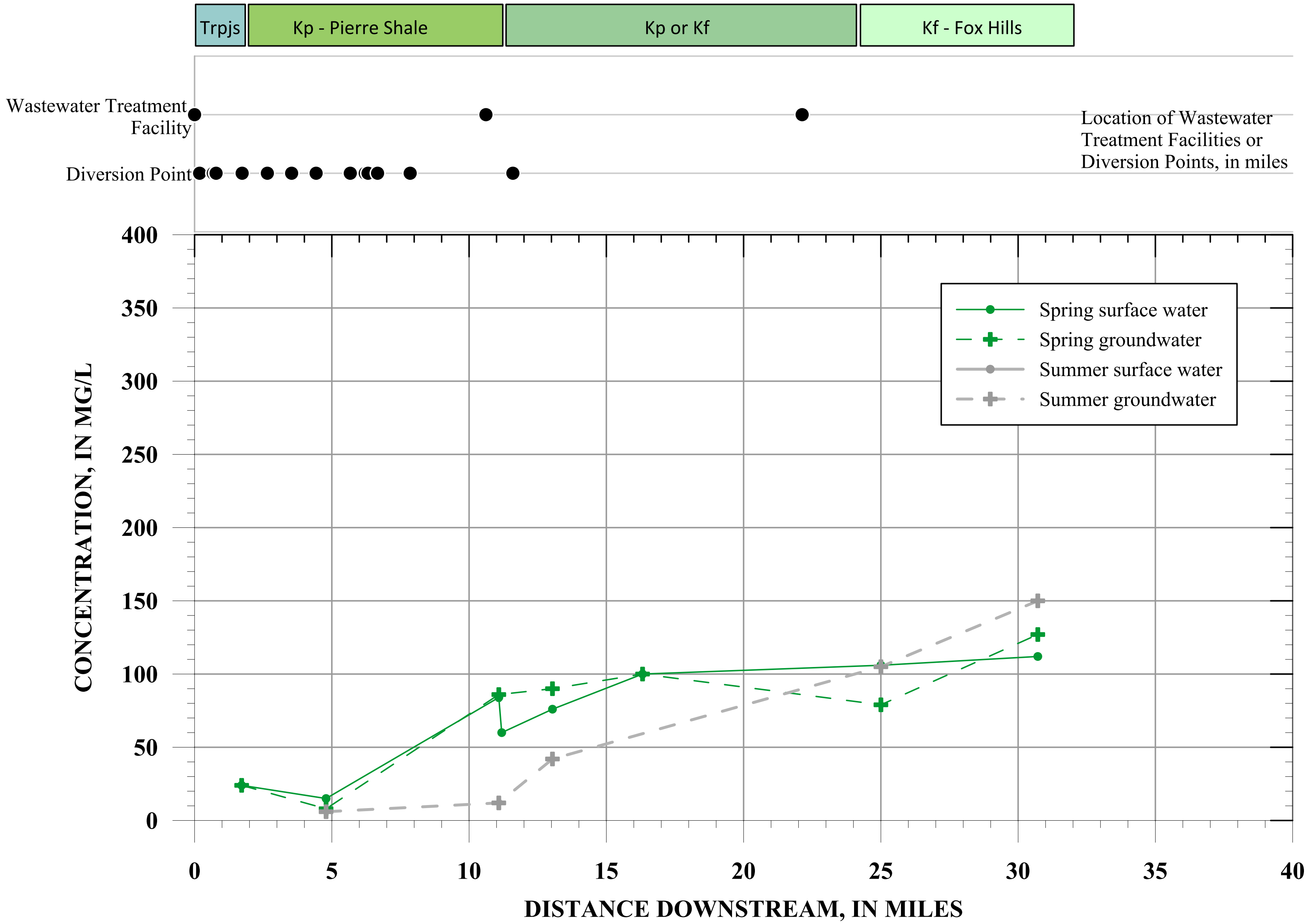


Figure B-2-6. Chloride concentrations along the Saint Vrain River

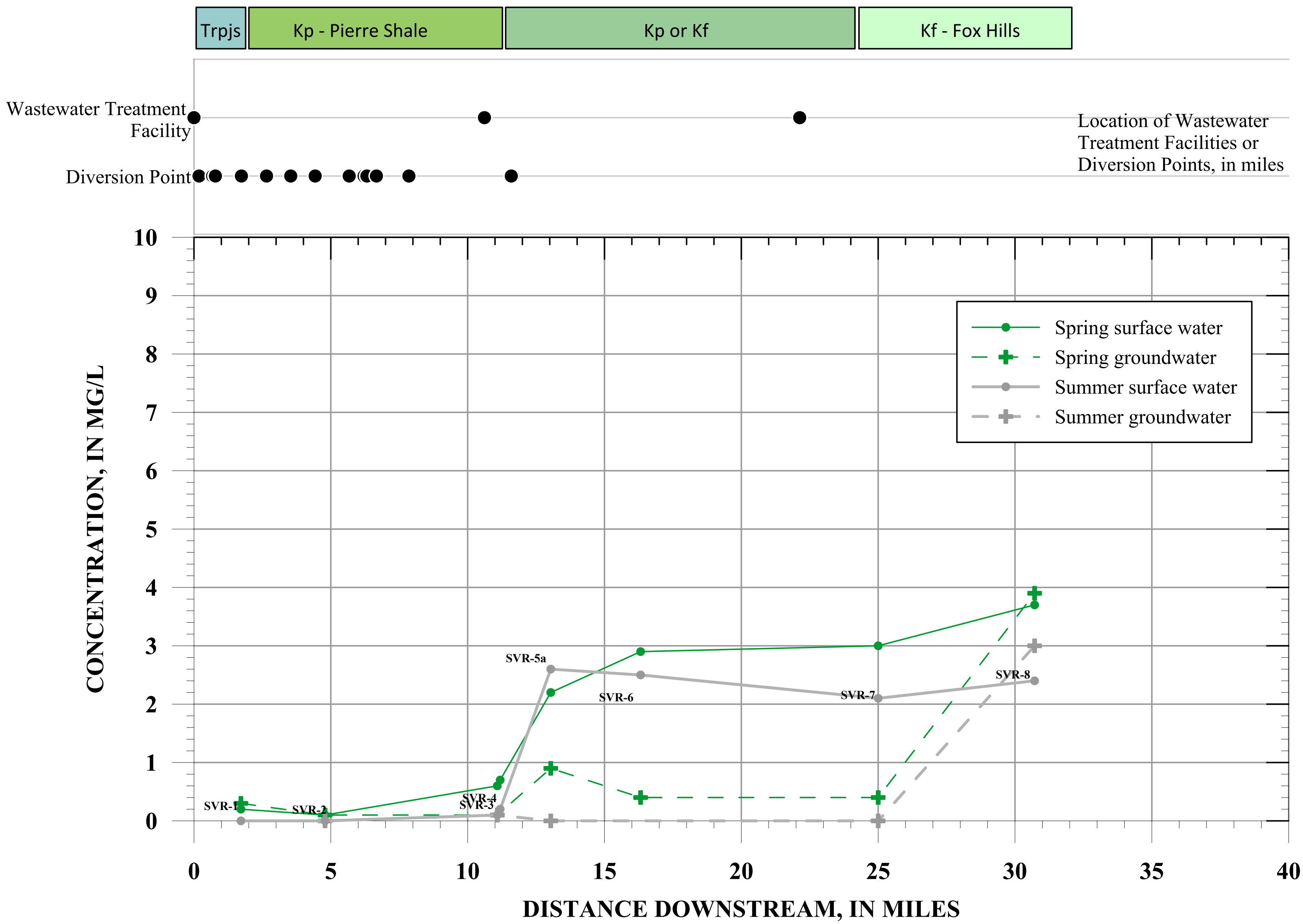


Figure B-2-7. Nitrate as nitrogen concentrations along the Saint Vrain River

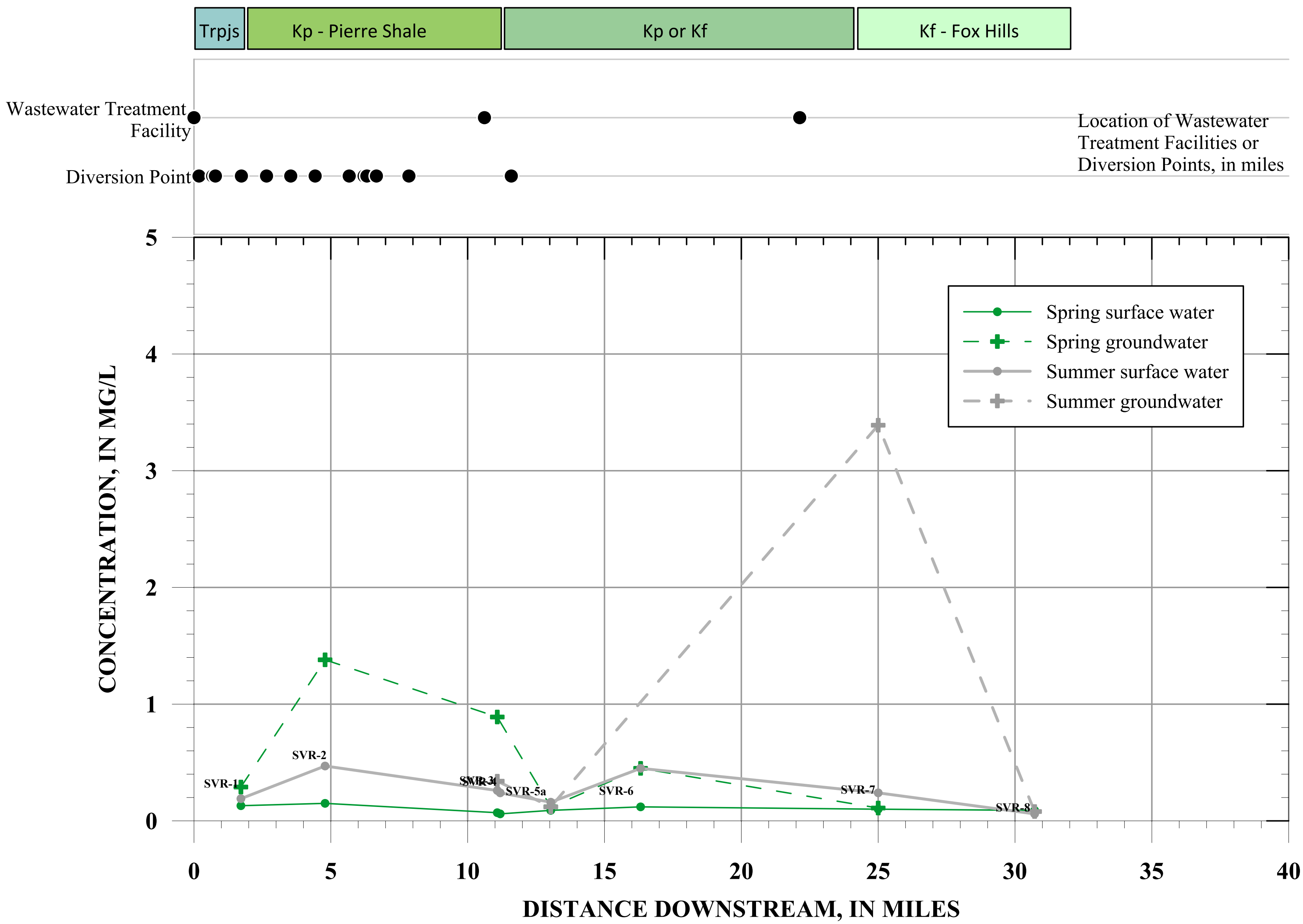


Figure B-2-8. Total iron concentrations along the Saint Vrain River

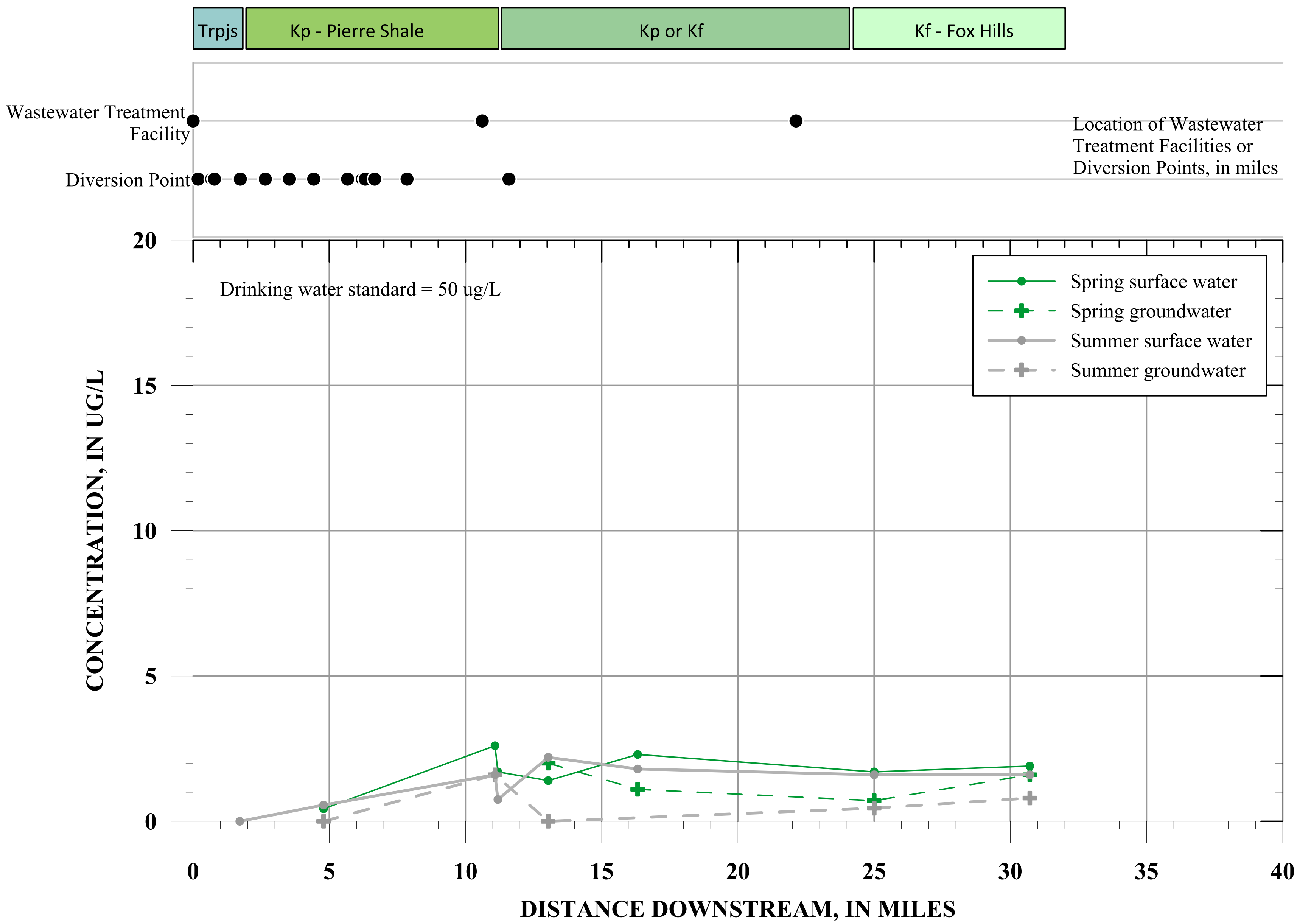


Figure B-2-9. Selenium concentrations along the Saint Vrain River

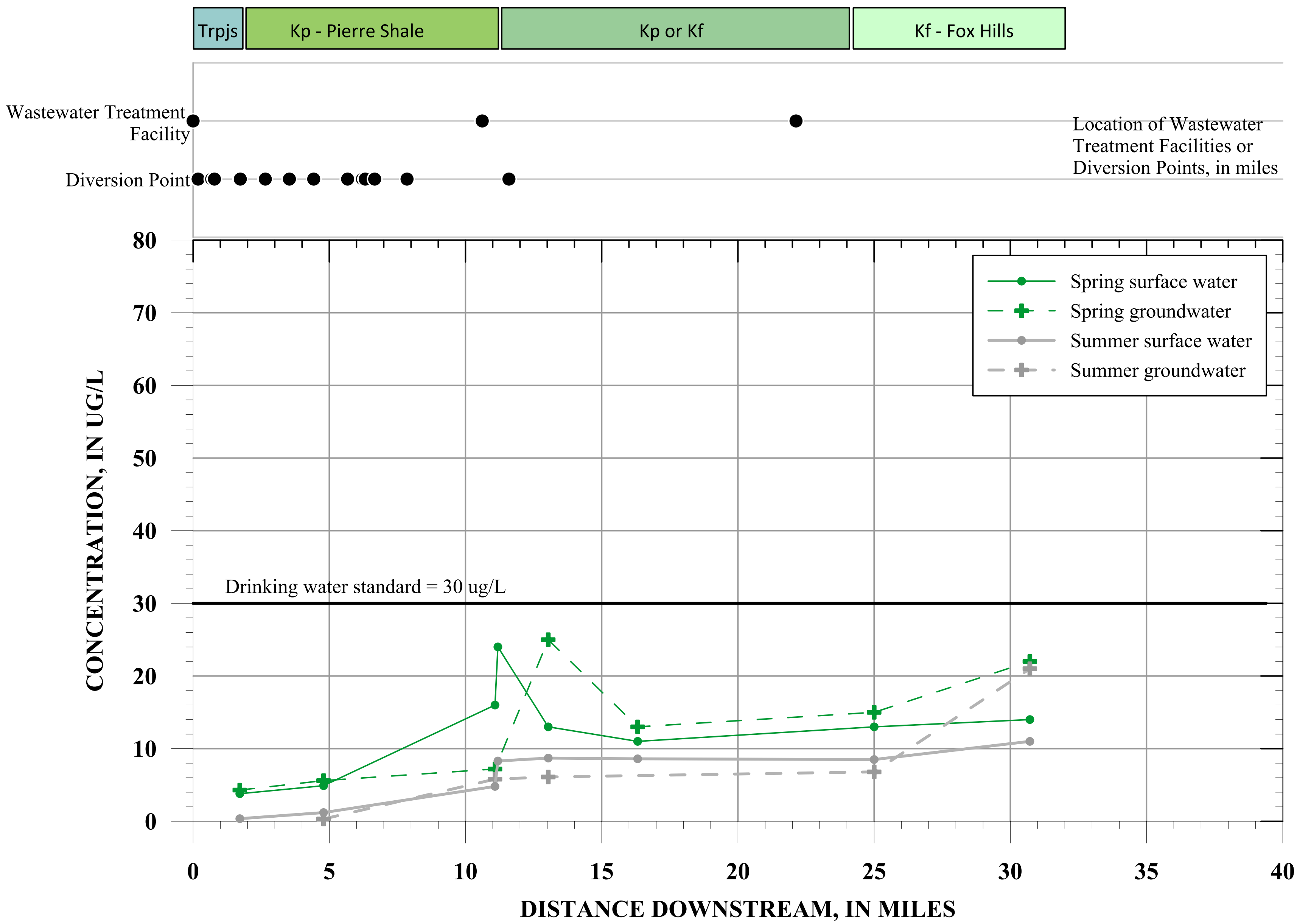


Figure B-2-10. Uranium concentrations along the Saint Vrain River

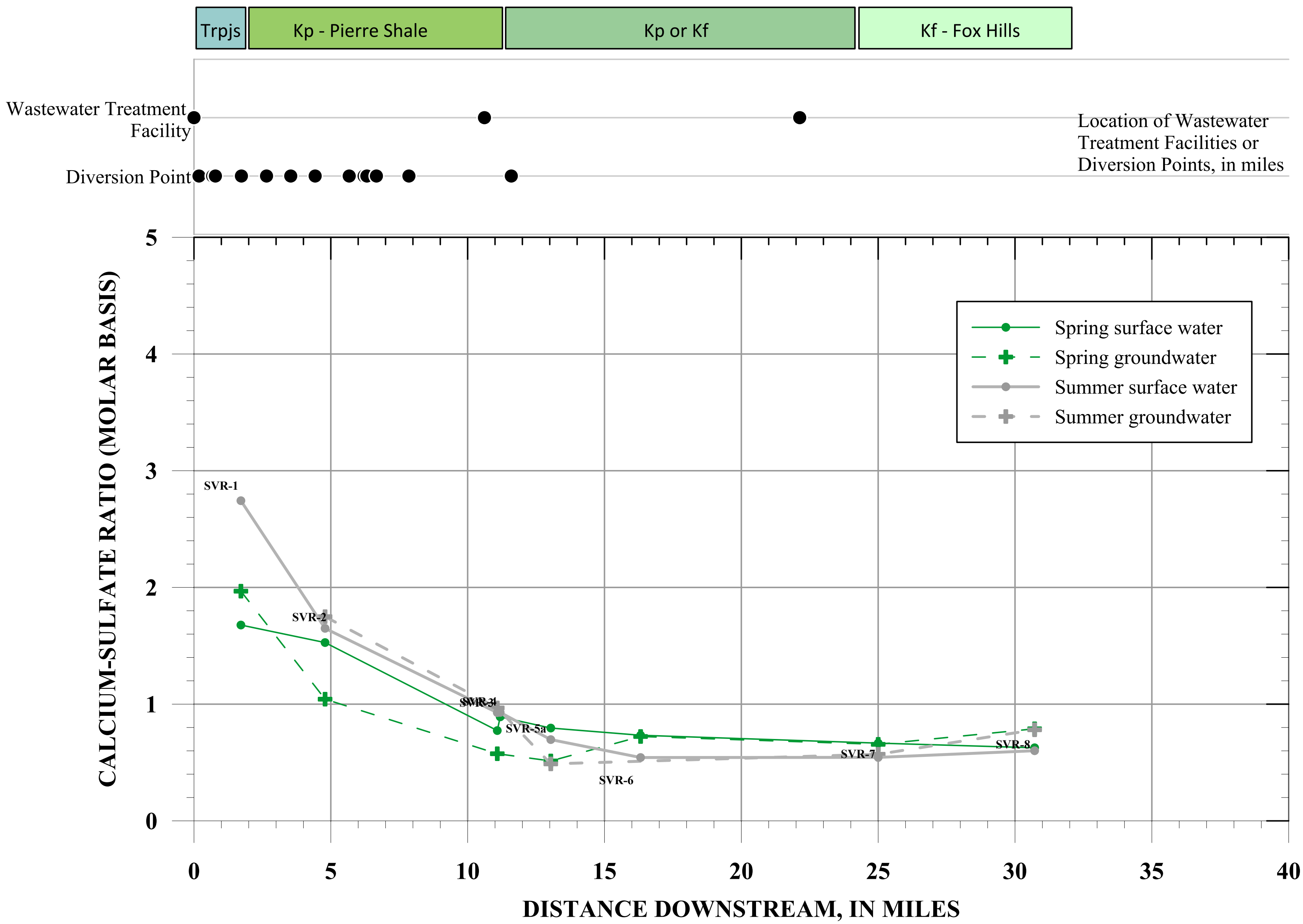


Figure B-2-11. Calcium-Sulfate Ratio ($Ca:SO_4$) along the Saint Vrain River

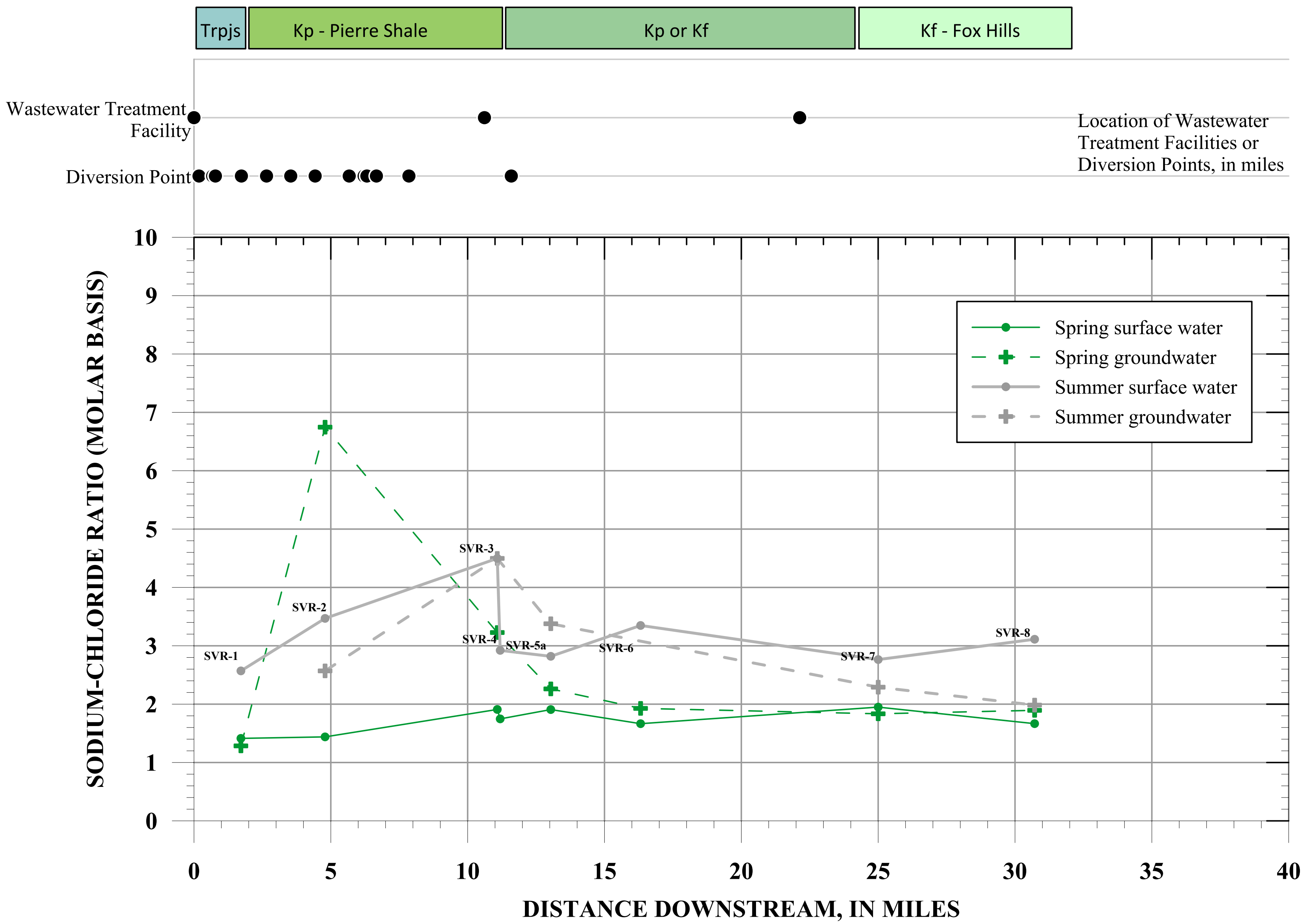


Figure B-2-12 Sodium-Chloride (Na:Cl) ratio along the Saint Vrain River

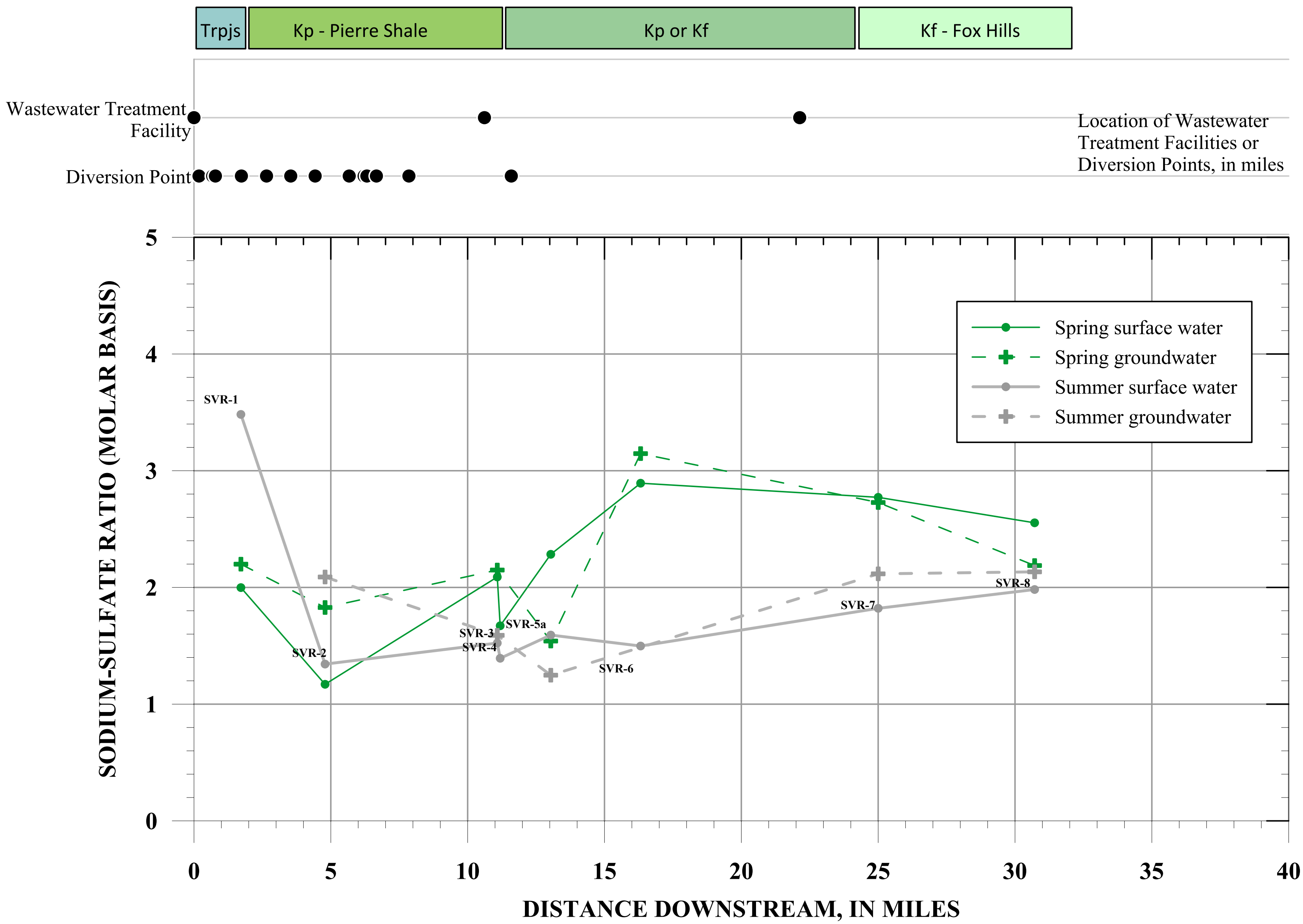


Figure B-2-13. Sodium-Sulfate Ratio (Na_2:SO_4) along the Saint Vrain River

APPENDIX B-3
BIG THOMPSON RIVER GRAPHS

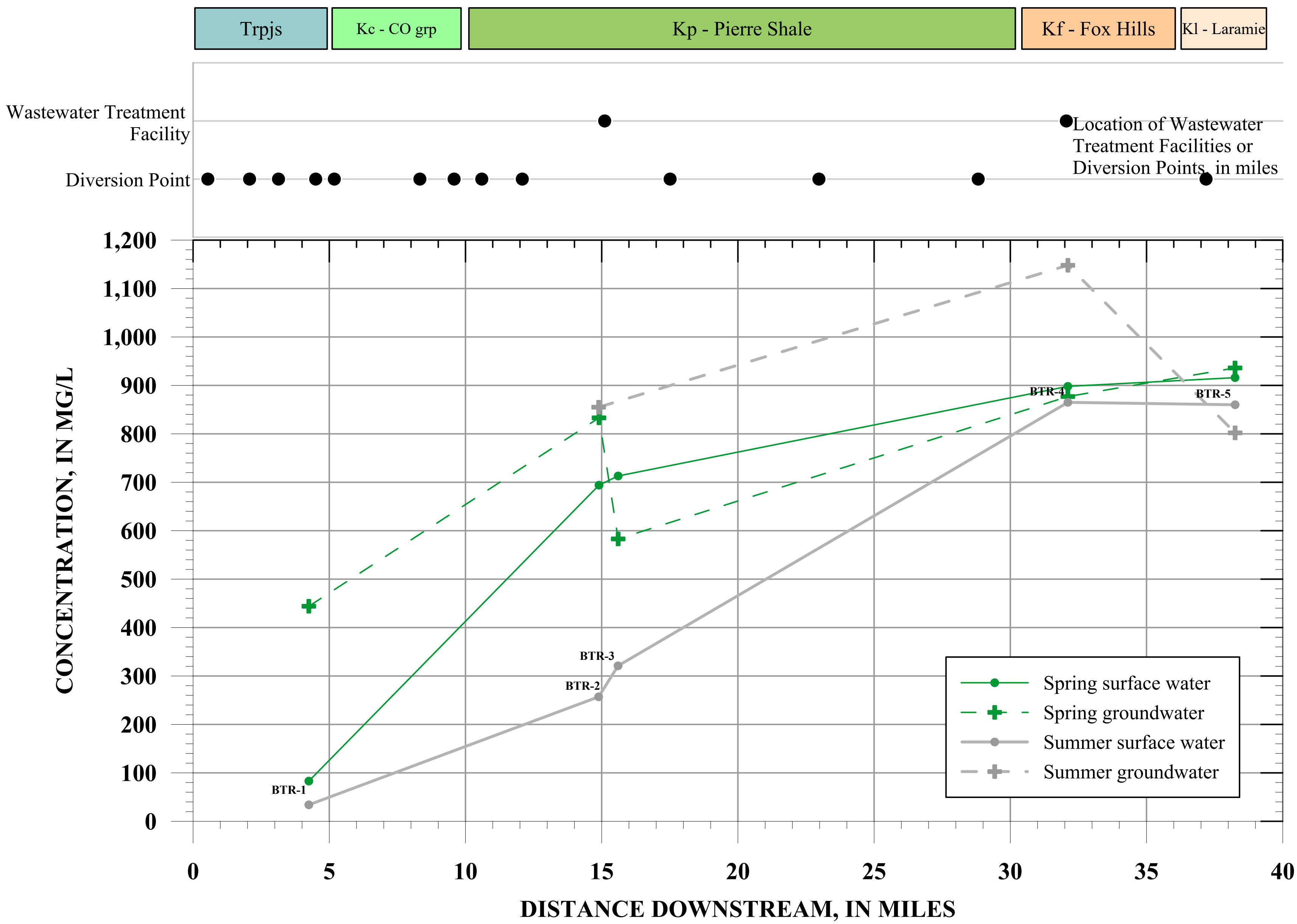


Figure B-3-1. Total Dissolved Solids concentrations along the Big Thompson River

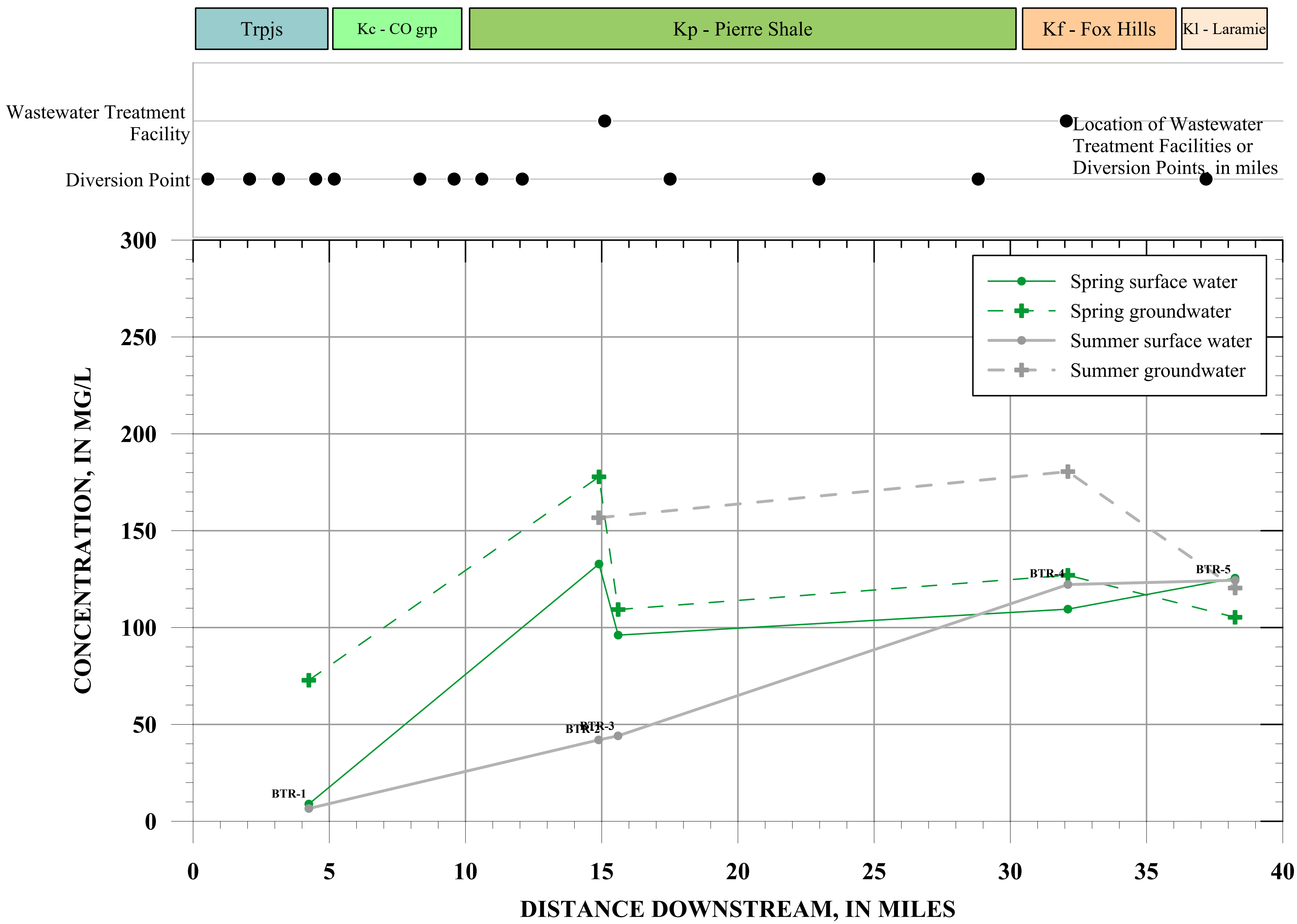


Figure B-3-2. Calcium concentration in Big Thompson River

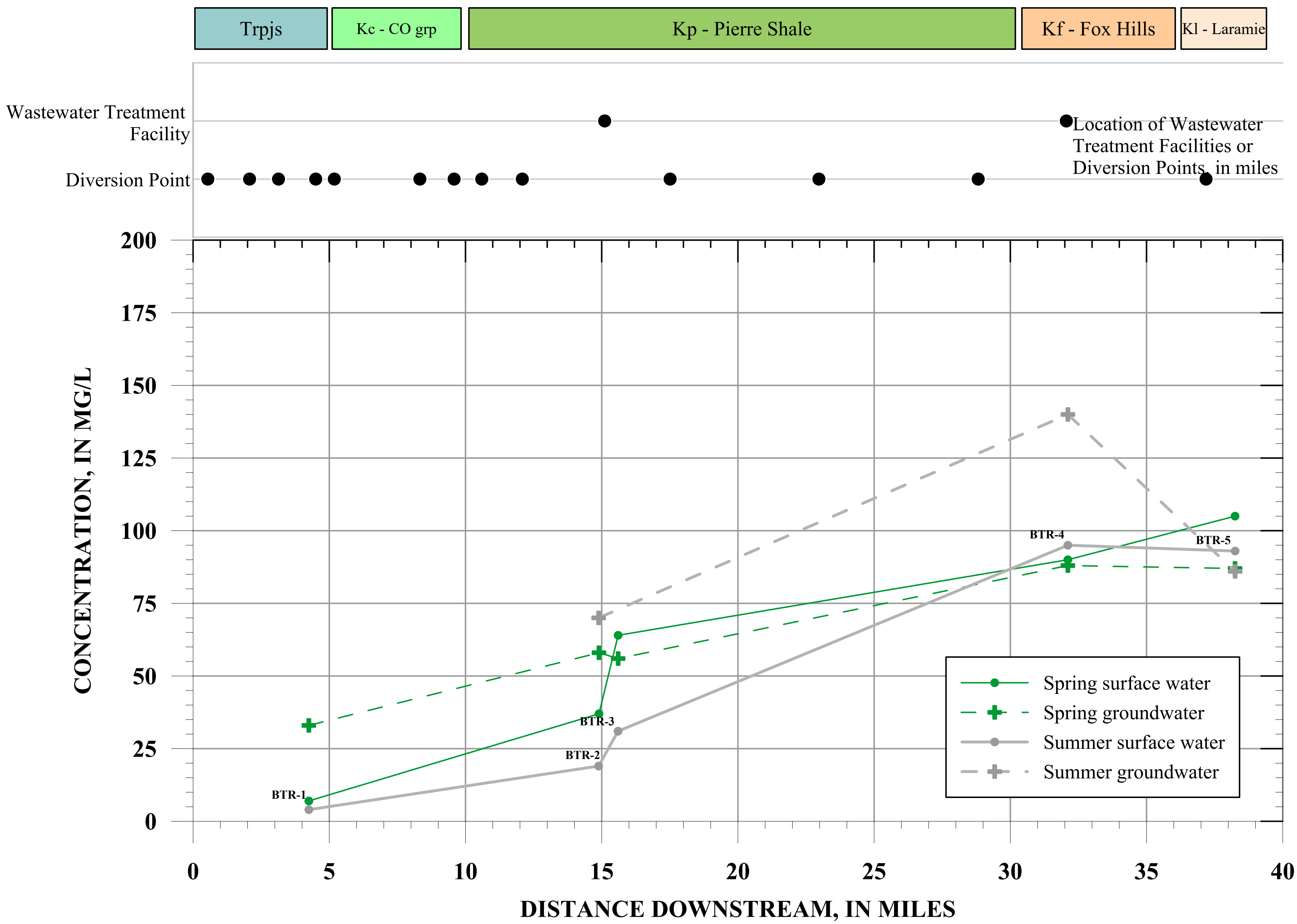


Figure B-3-3. Sodium concentrations along the Big Thompson River

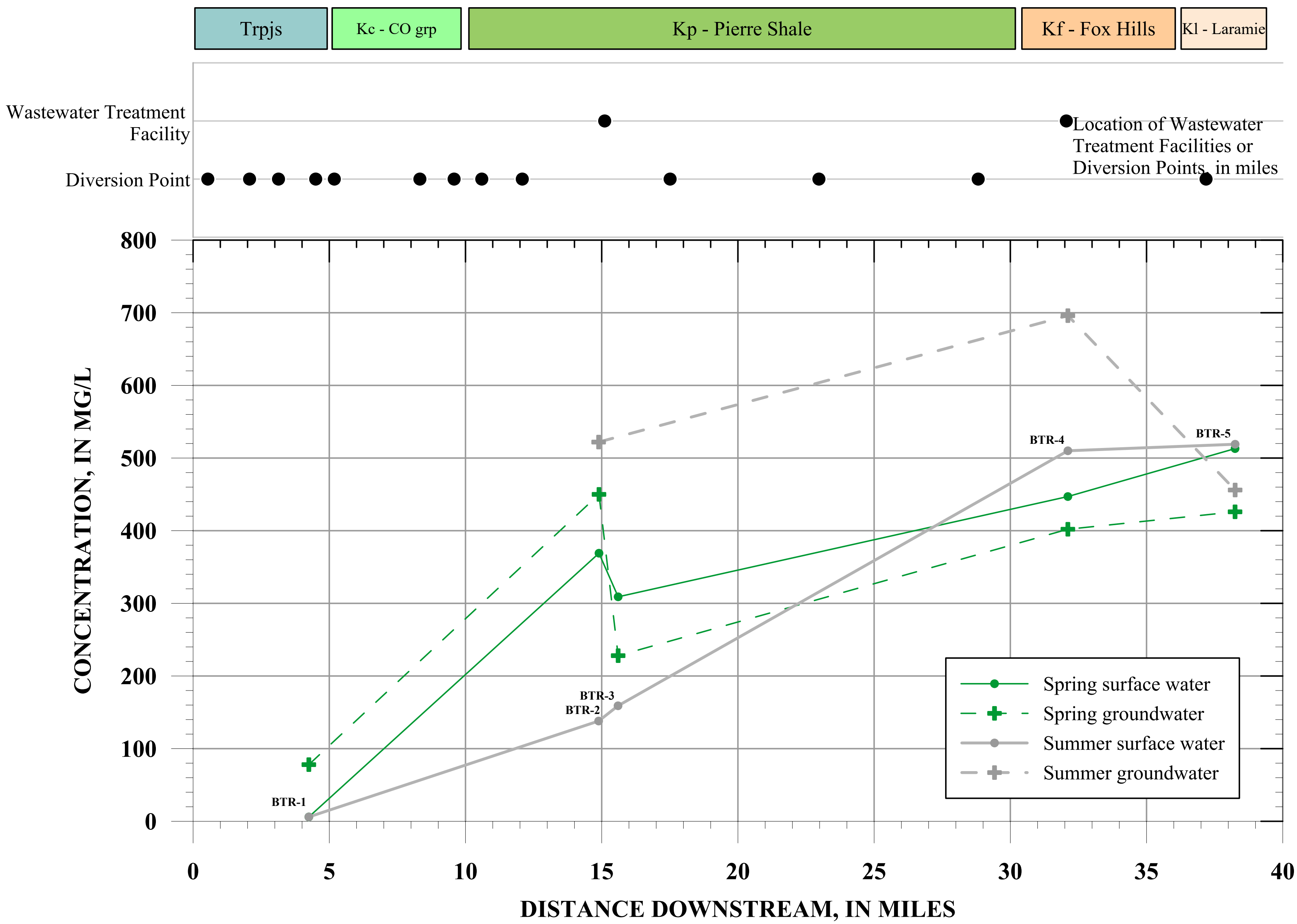


Figure B-3-4. Sulfate concentrations along the Big Thompson River

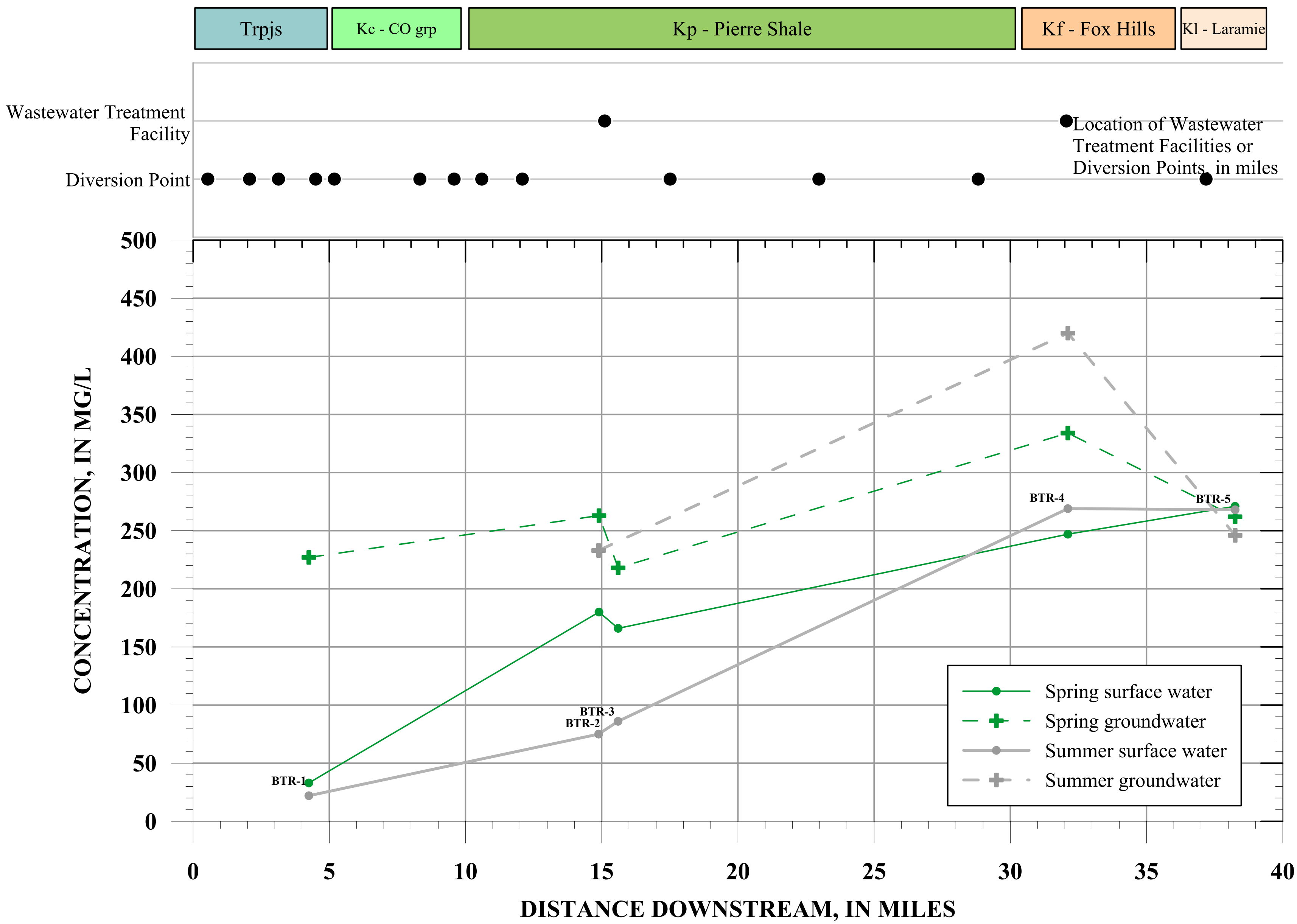


Figure B-3-5. Bicarbonate concentrations along the Big Thompson River

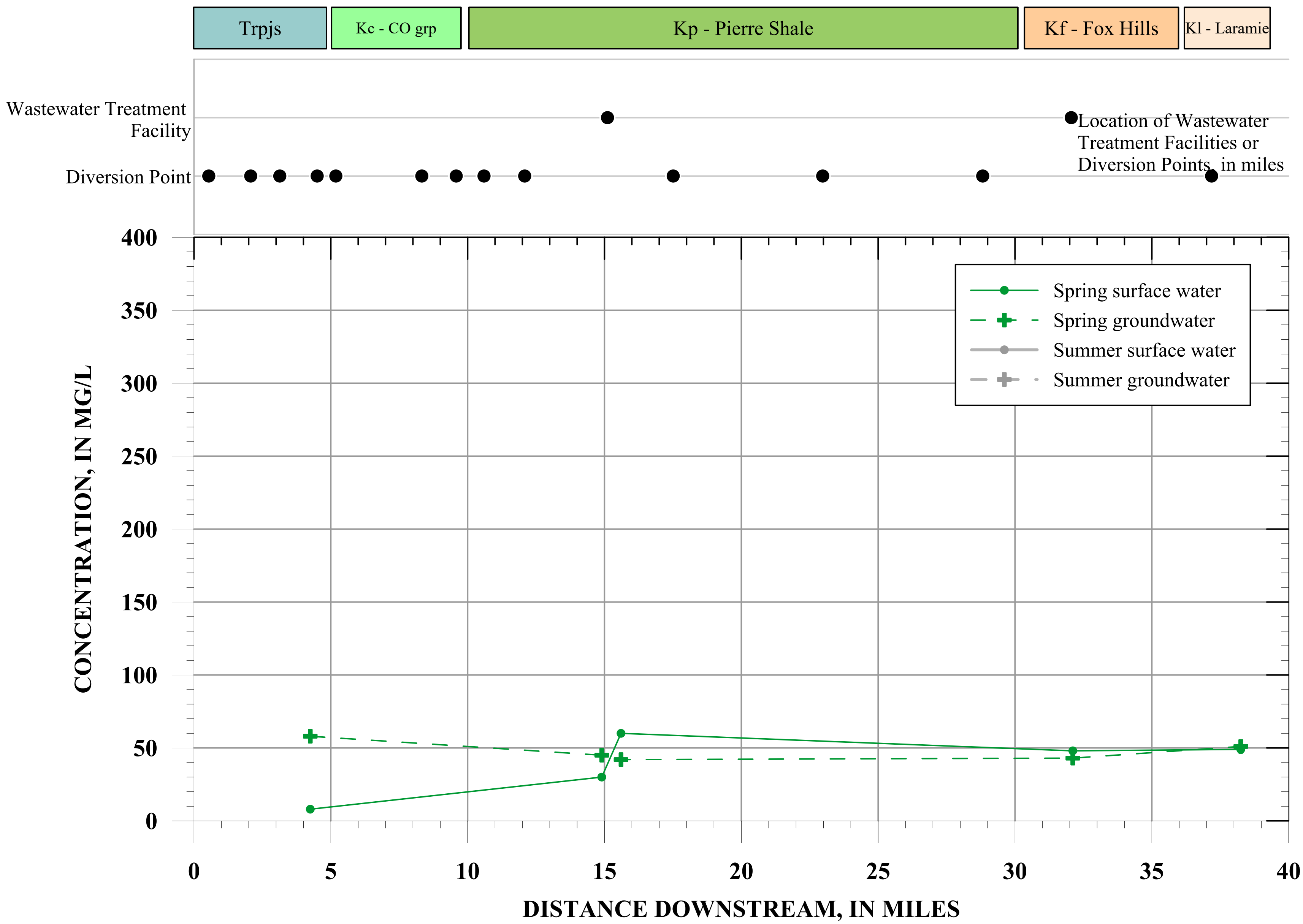


Figure B-3-6. Chloride concentrations along the Big Thompson River

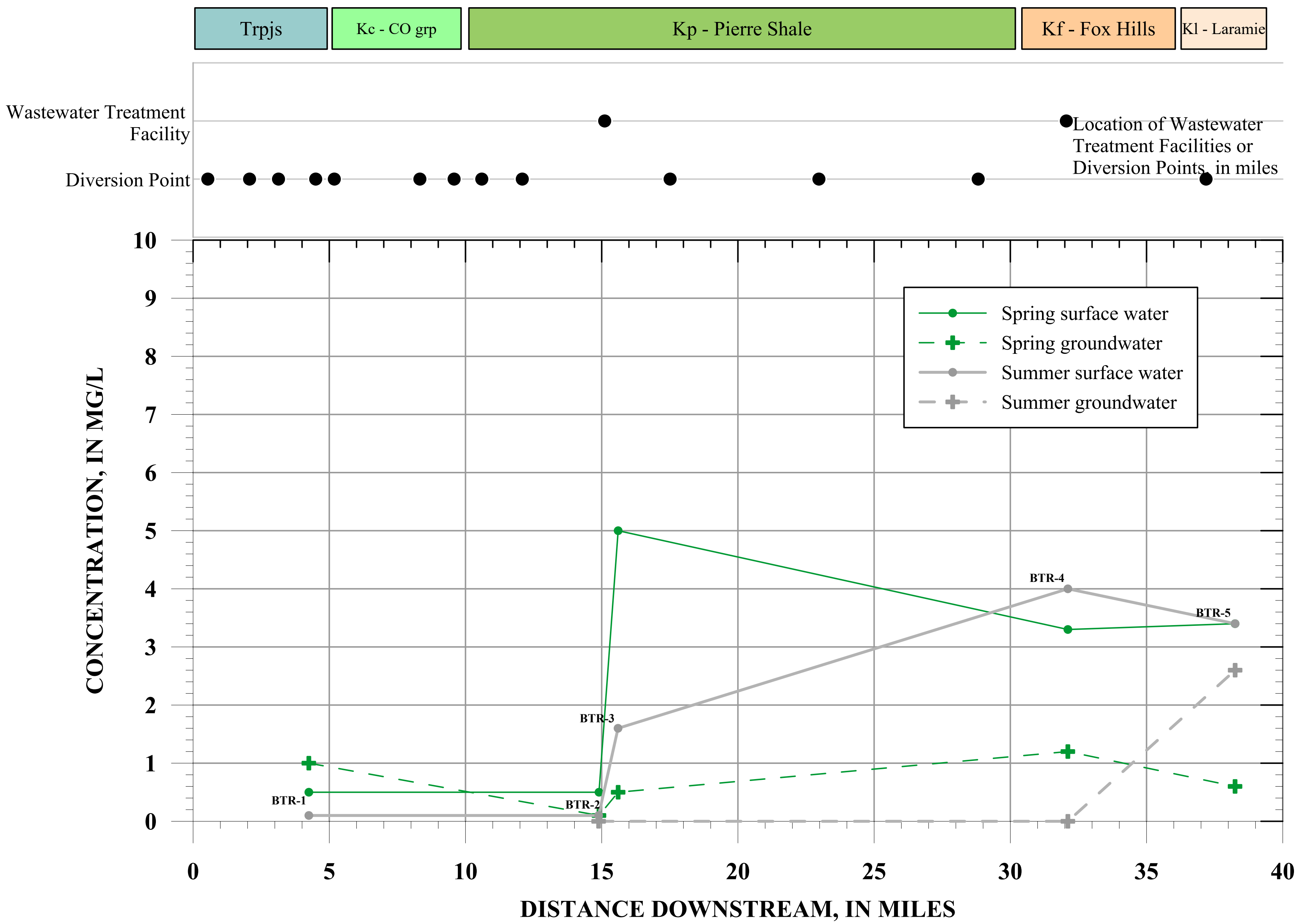


Figure B-3-7. Nitrate as nitrogen concentrations along the Big Thompson River

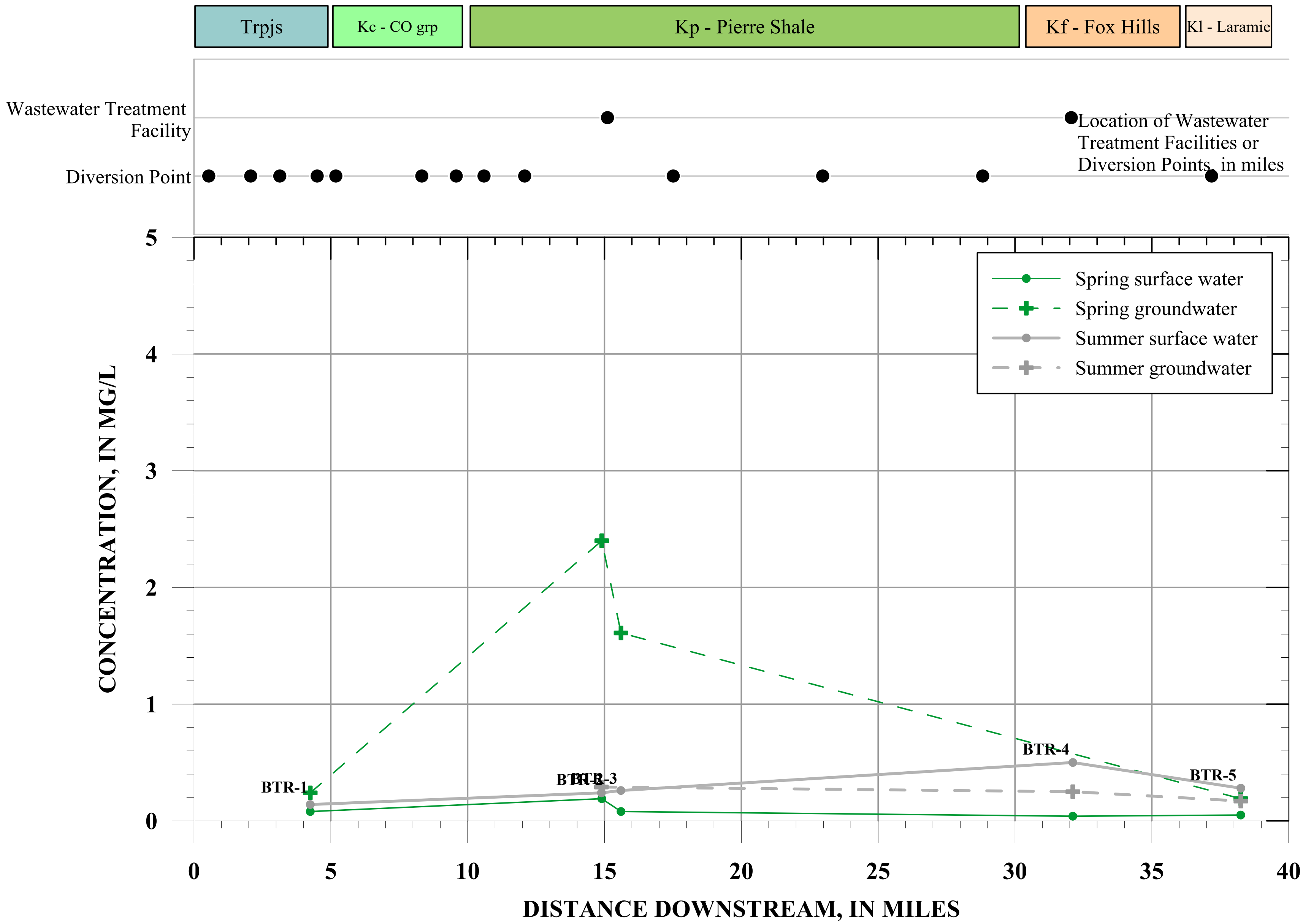


Figure B-3-8. %otal iron concentrations along the Big Thompson River

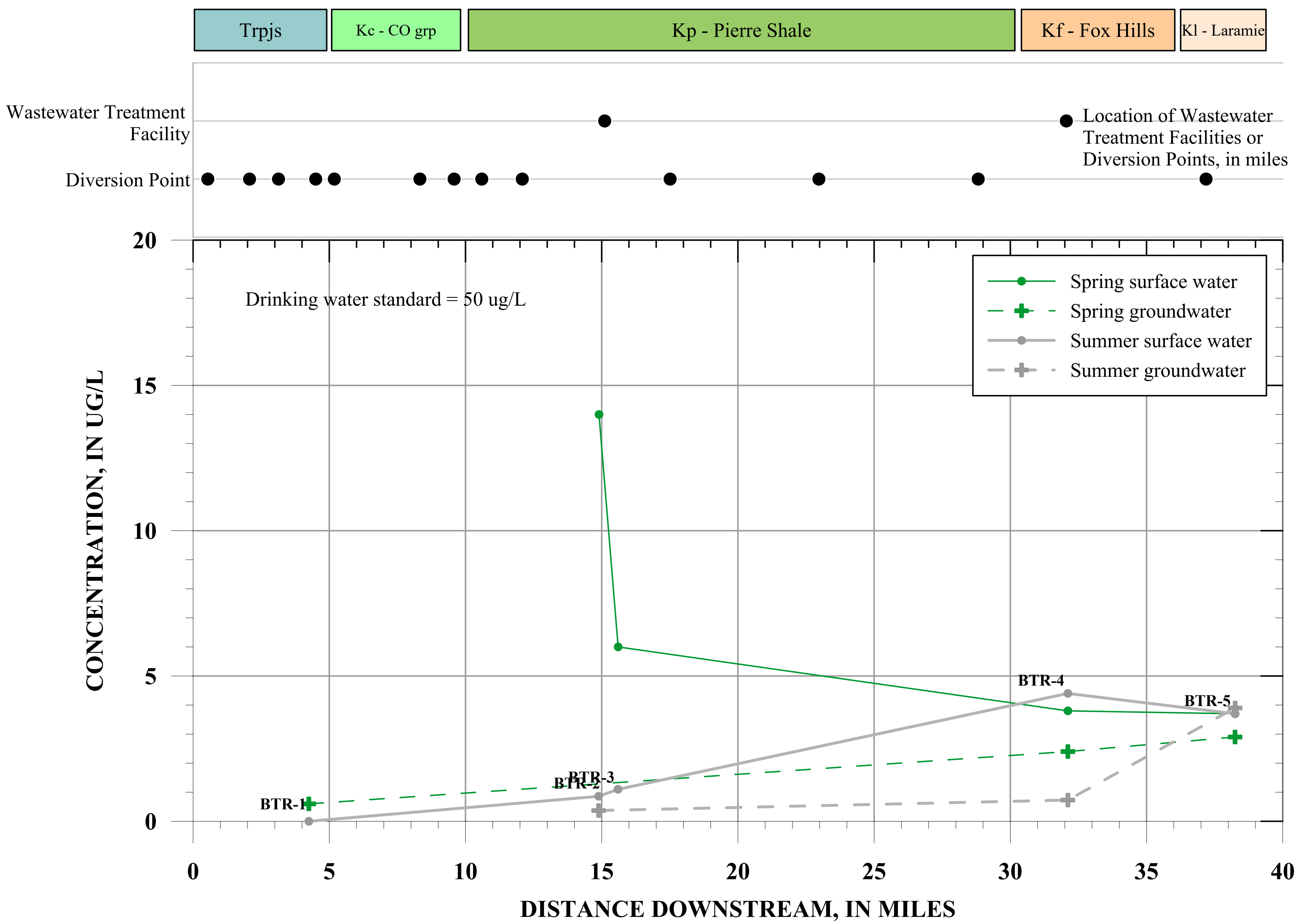


Figure B-3-9. Selenium concentrations along the Big Thompson River

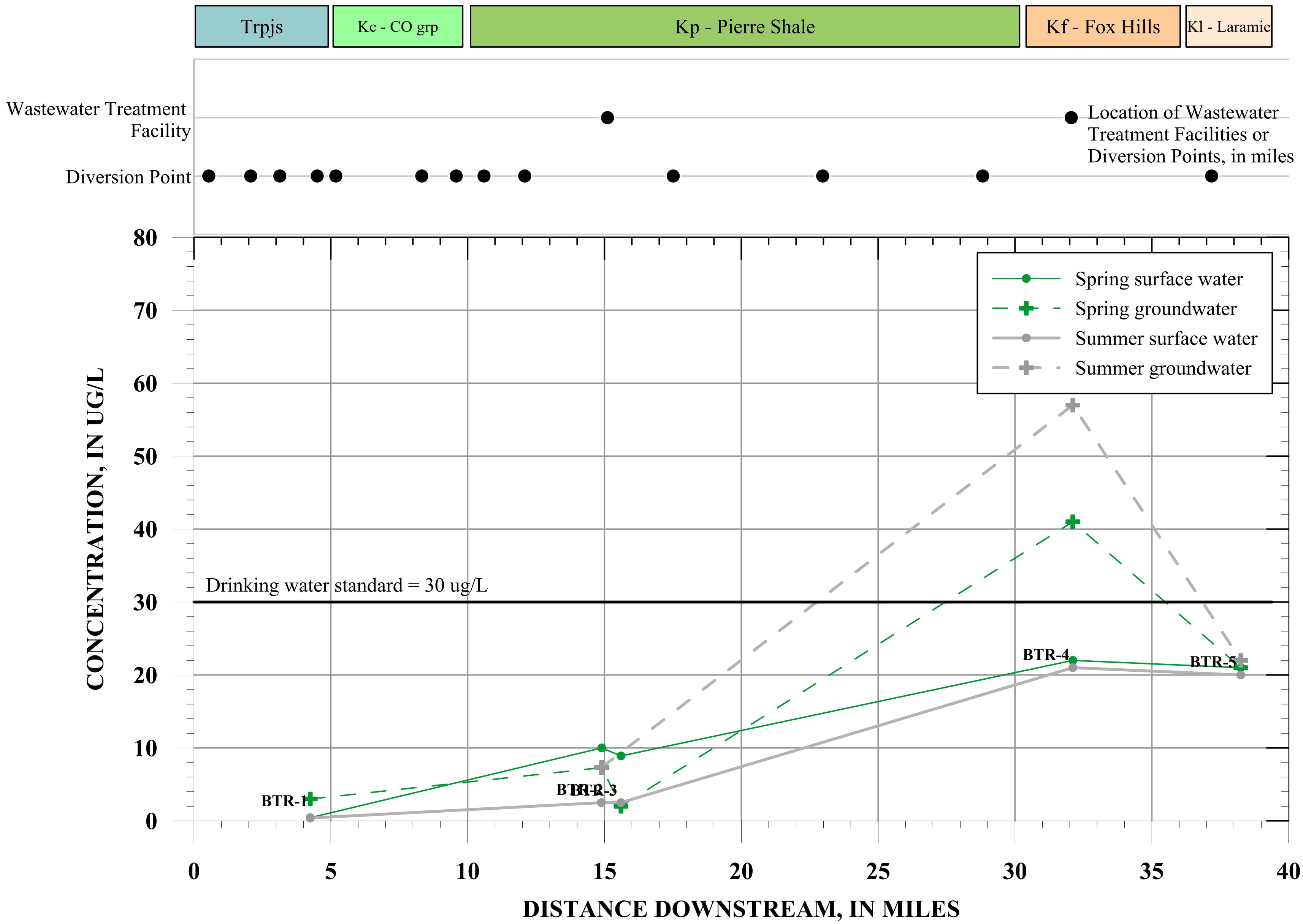


Figure B-3-10. Uranium concentrations along the Big Thompson River

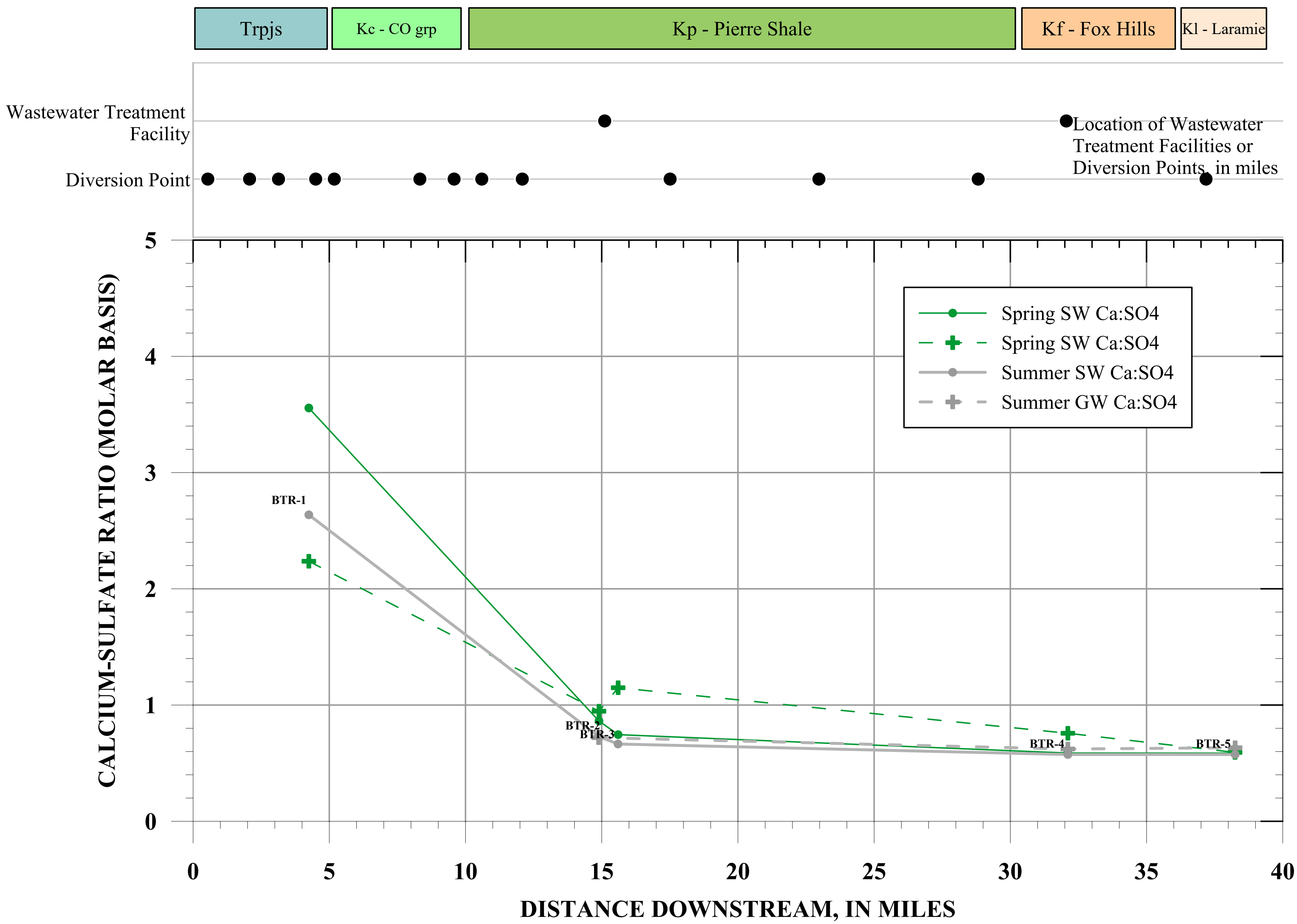


Figure B-3-11. Calcium-Sulfate ratio ($Ca:SO_4$) in Big Thompson River

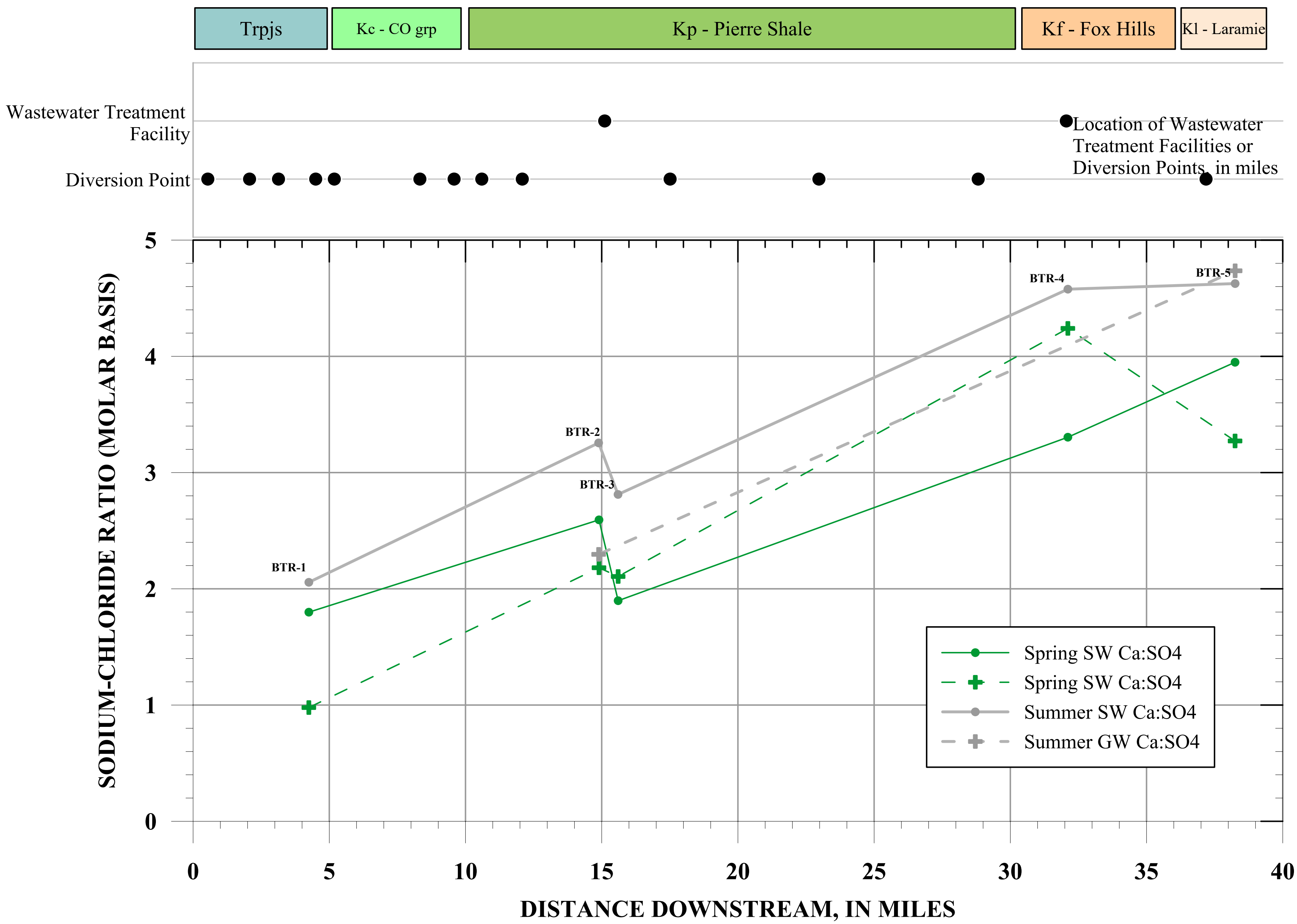


Figure B-3-12. Sodium-Chloride (Na:Cl) ratio in Big Thompson River

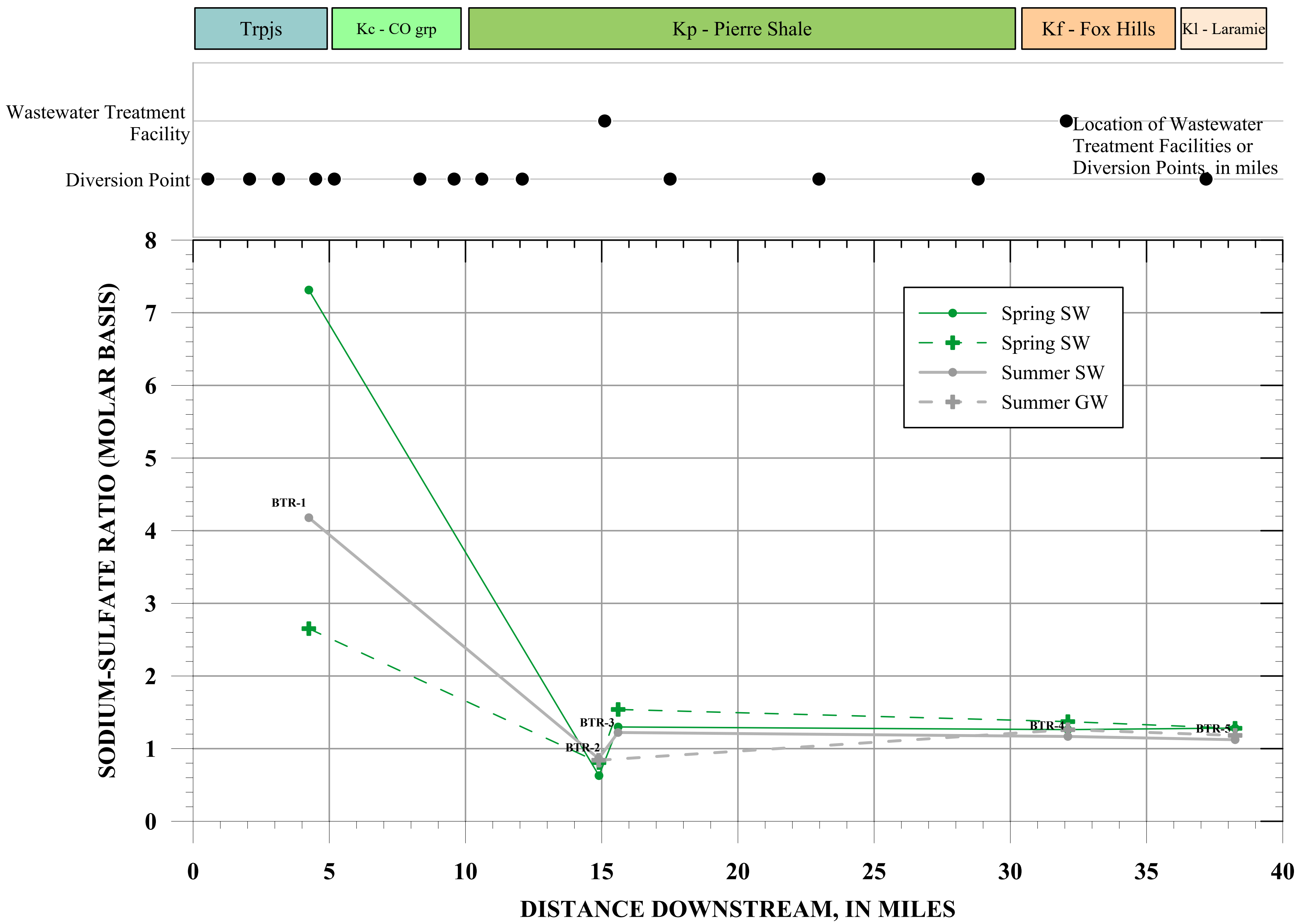


Figure B-3-13. Sodium-Sulfate ratio (Na_2:SO_4) in Big Thompson River

APPENDIX B-4
CACHE LA POUDRE RIVER GRAPHS

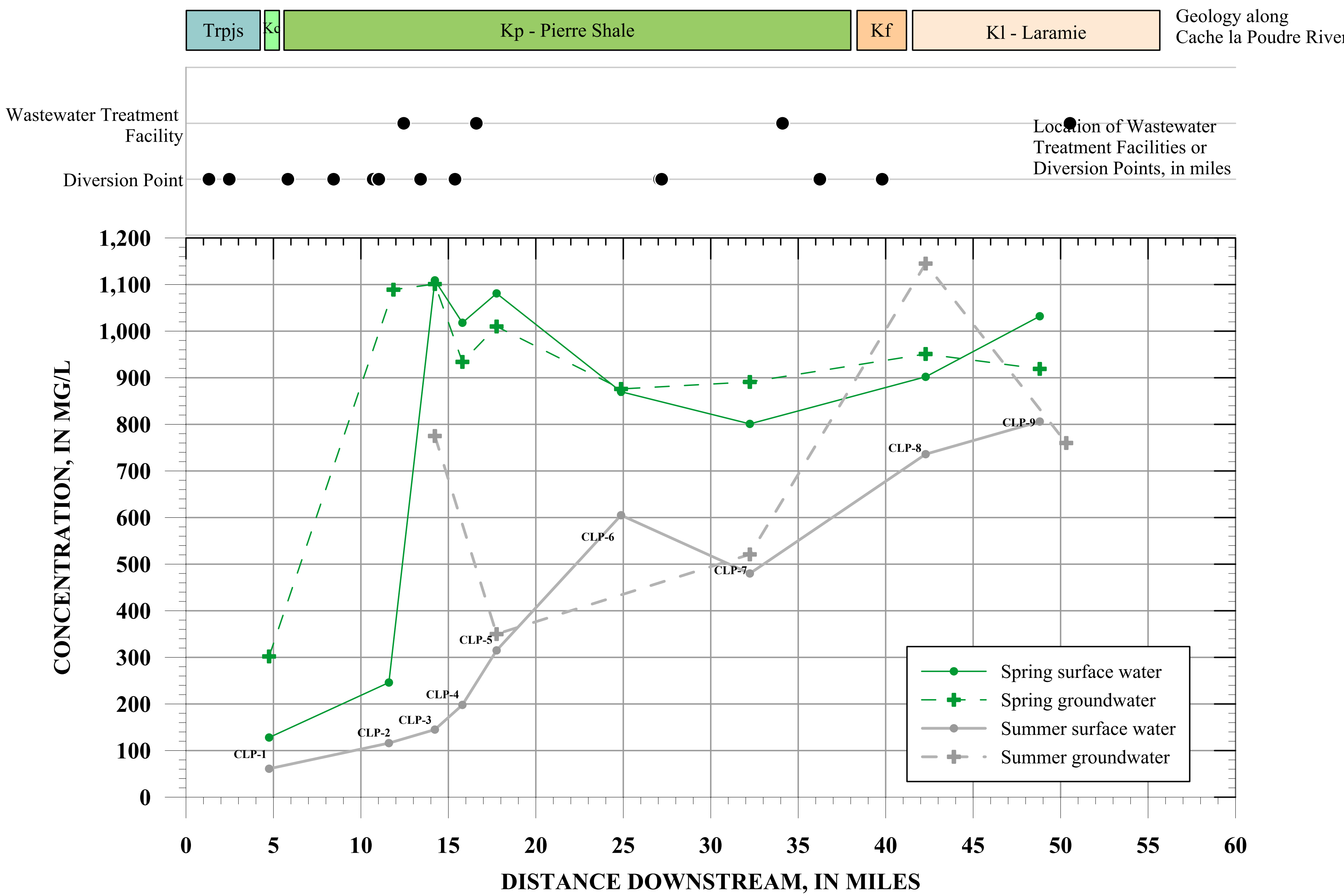


Figure B-4-1. Total Dissolved Solids concentrations along the Cache la Poudre River

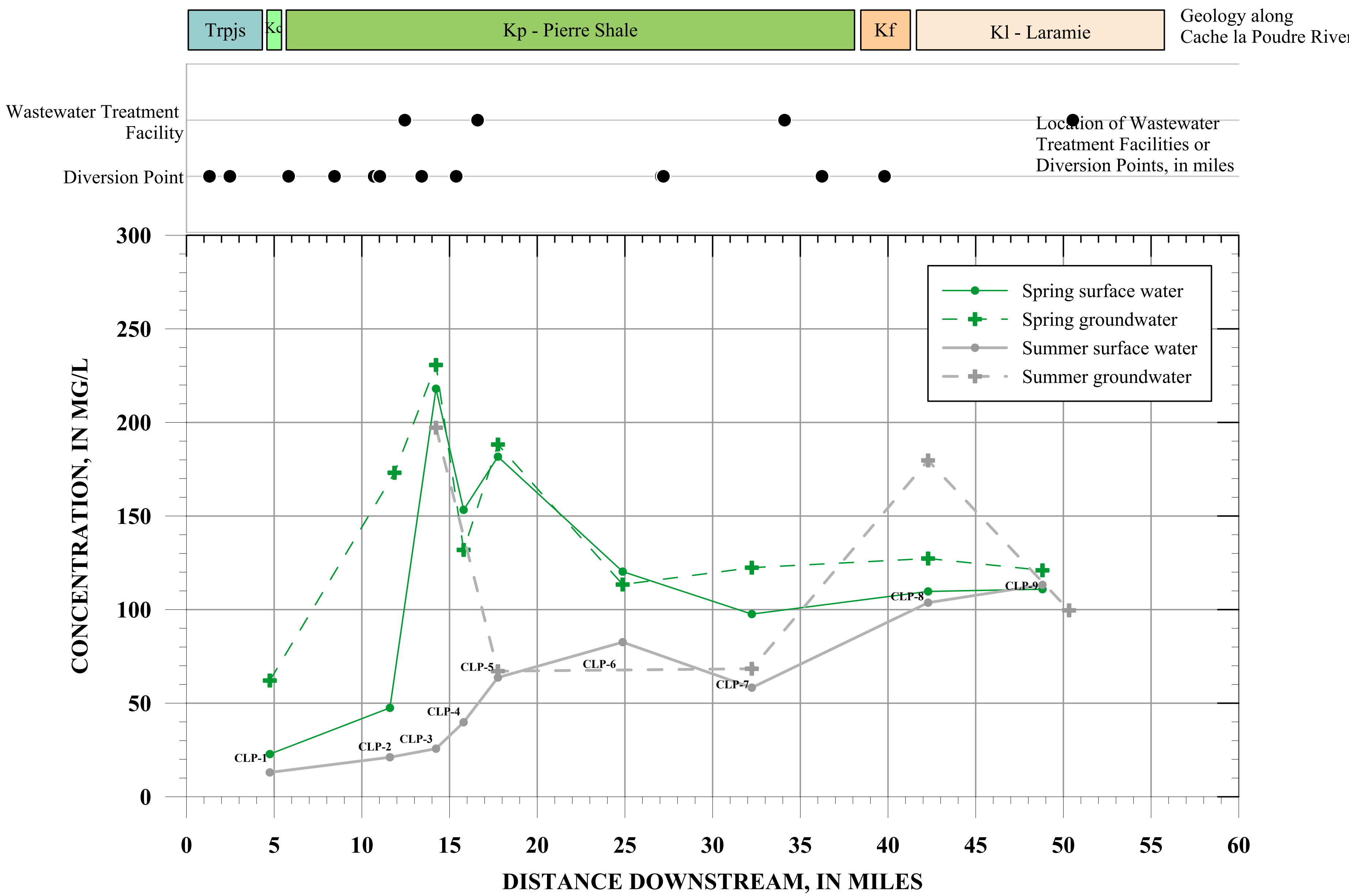


Figure B-4-2. Calcium concentrations along the Cache la Poudre River

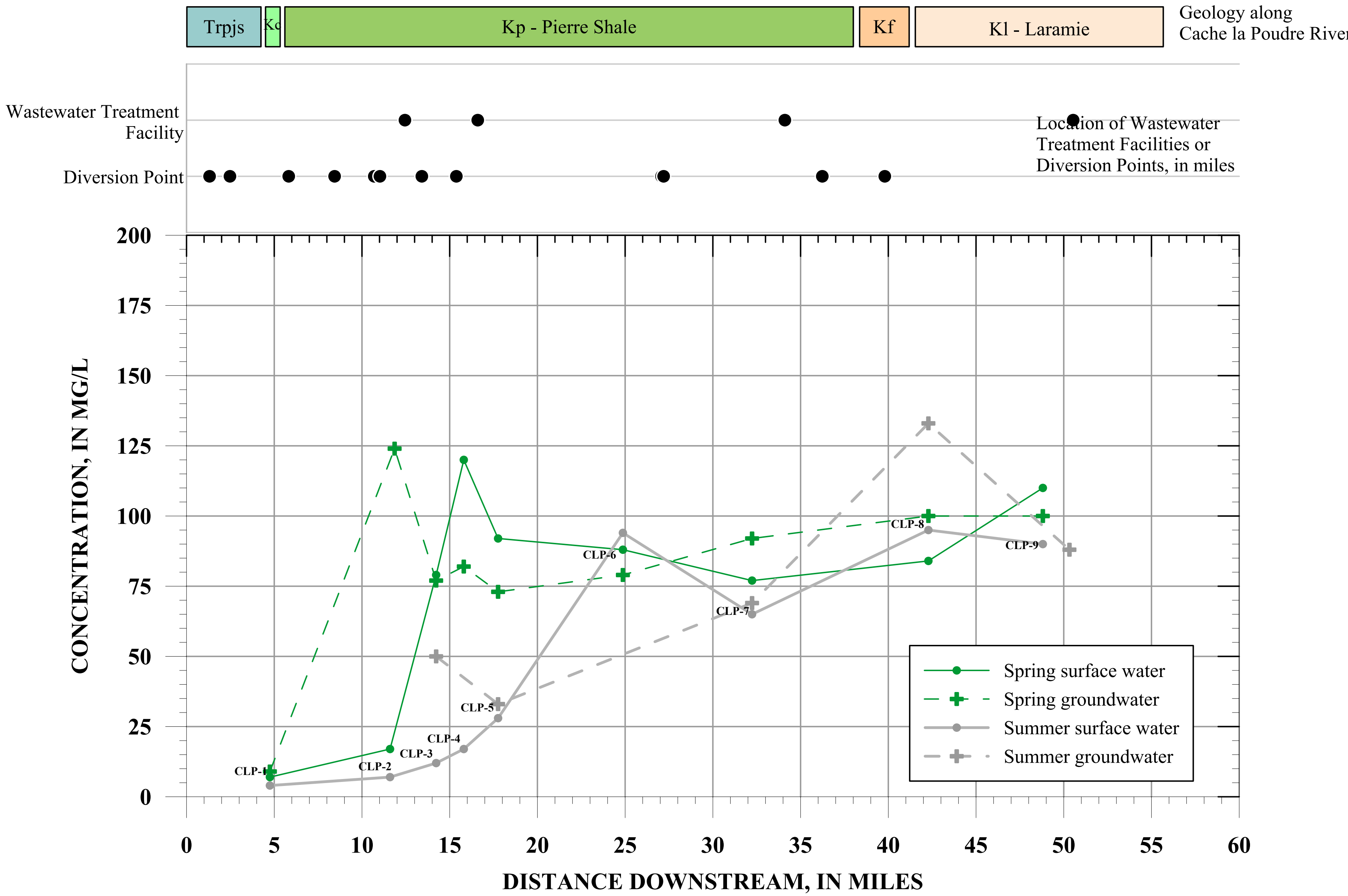


Figure B-4-3. Sodium concentrations along the Cache la Poudre River

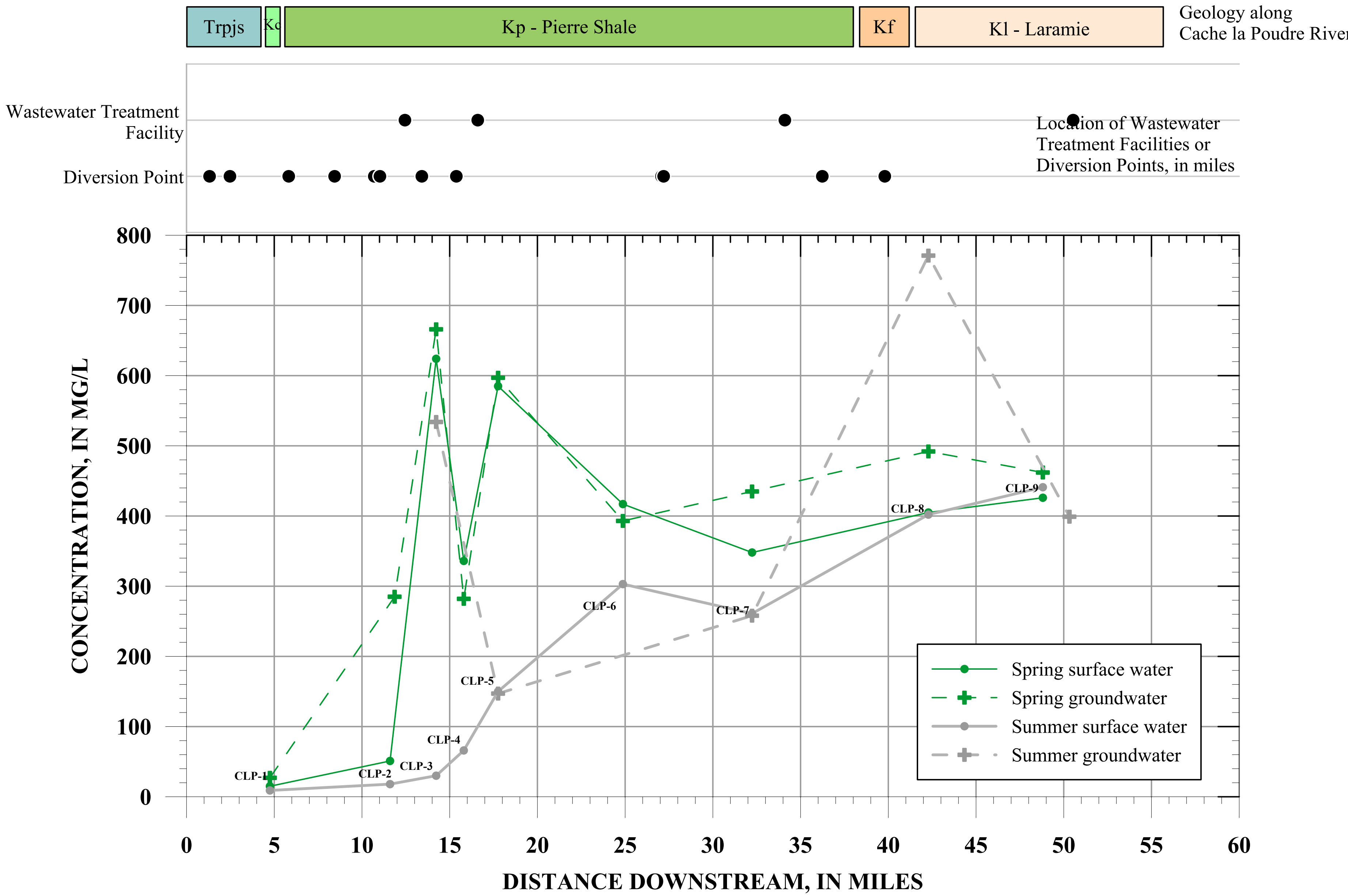


Figure B-4-4. Sulfate concentrations along the Cache la Poudre River

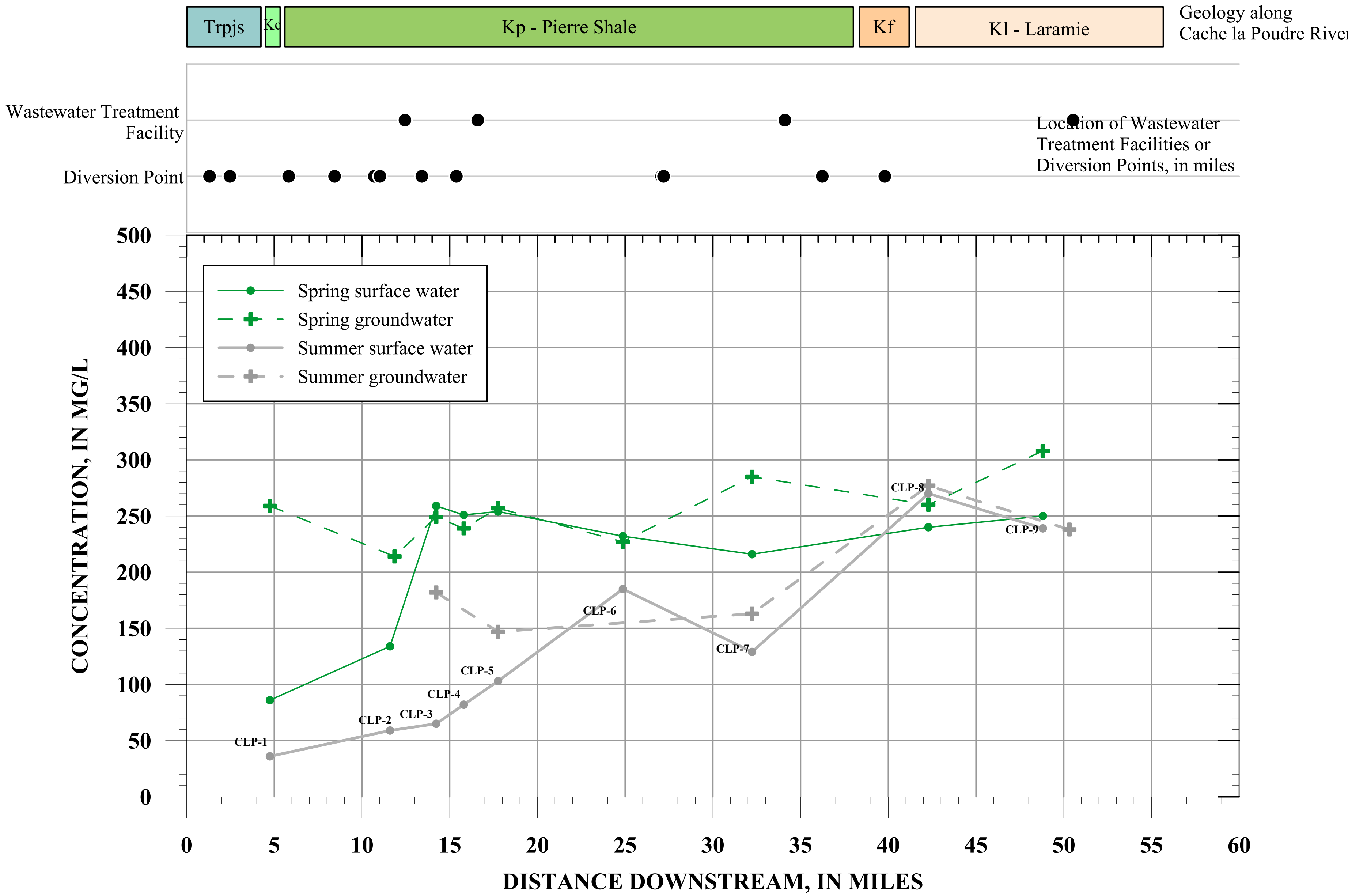


Figure B-4-5. Bicarbonate concentrations along the Cache la Poudre River

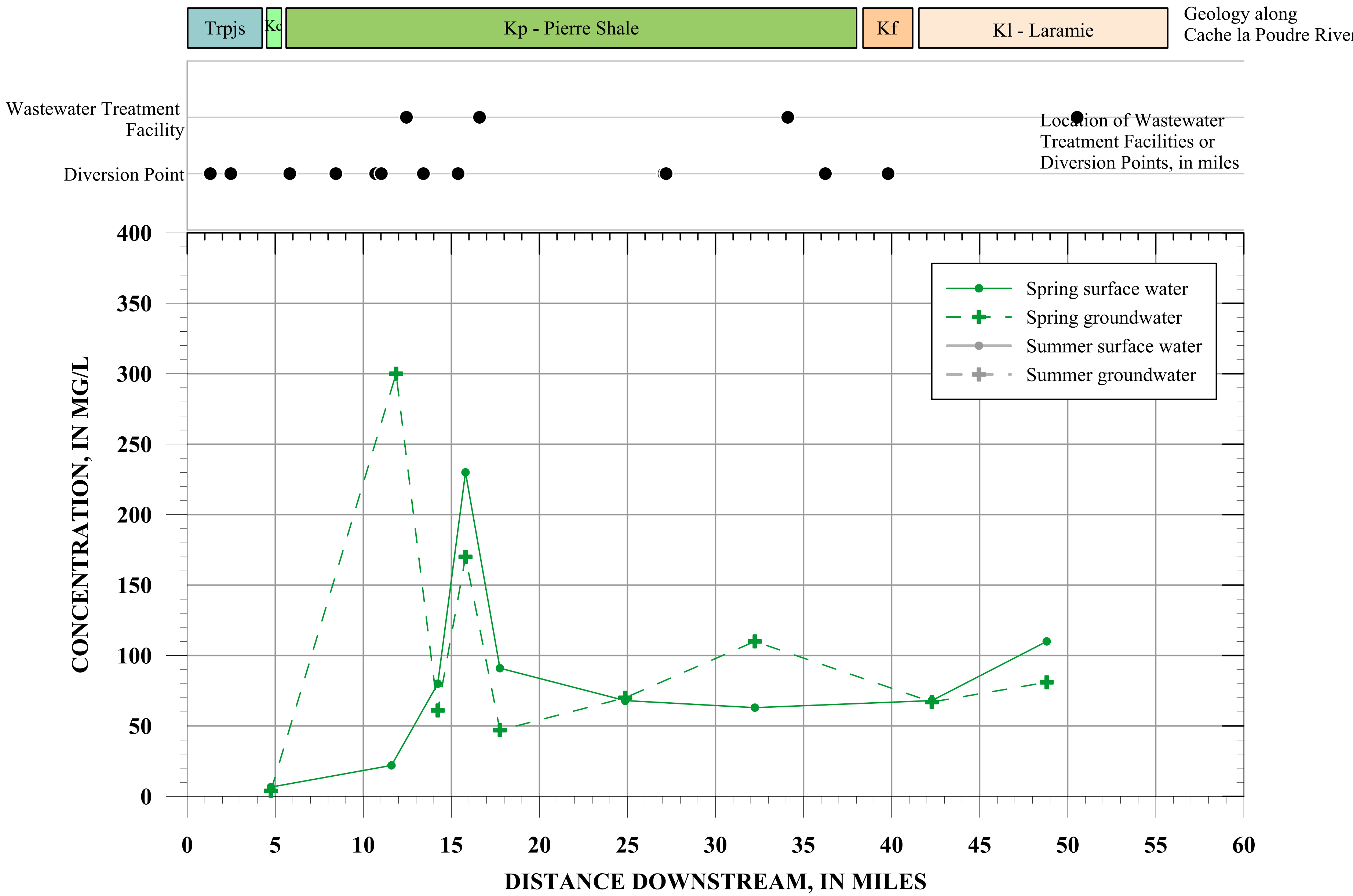


Figure B-4-6. Chloride concentrations along the Cache la Poudre River

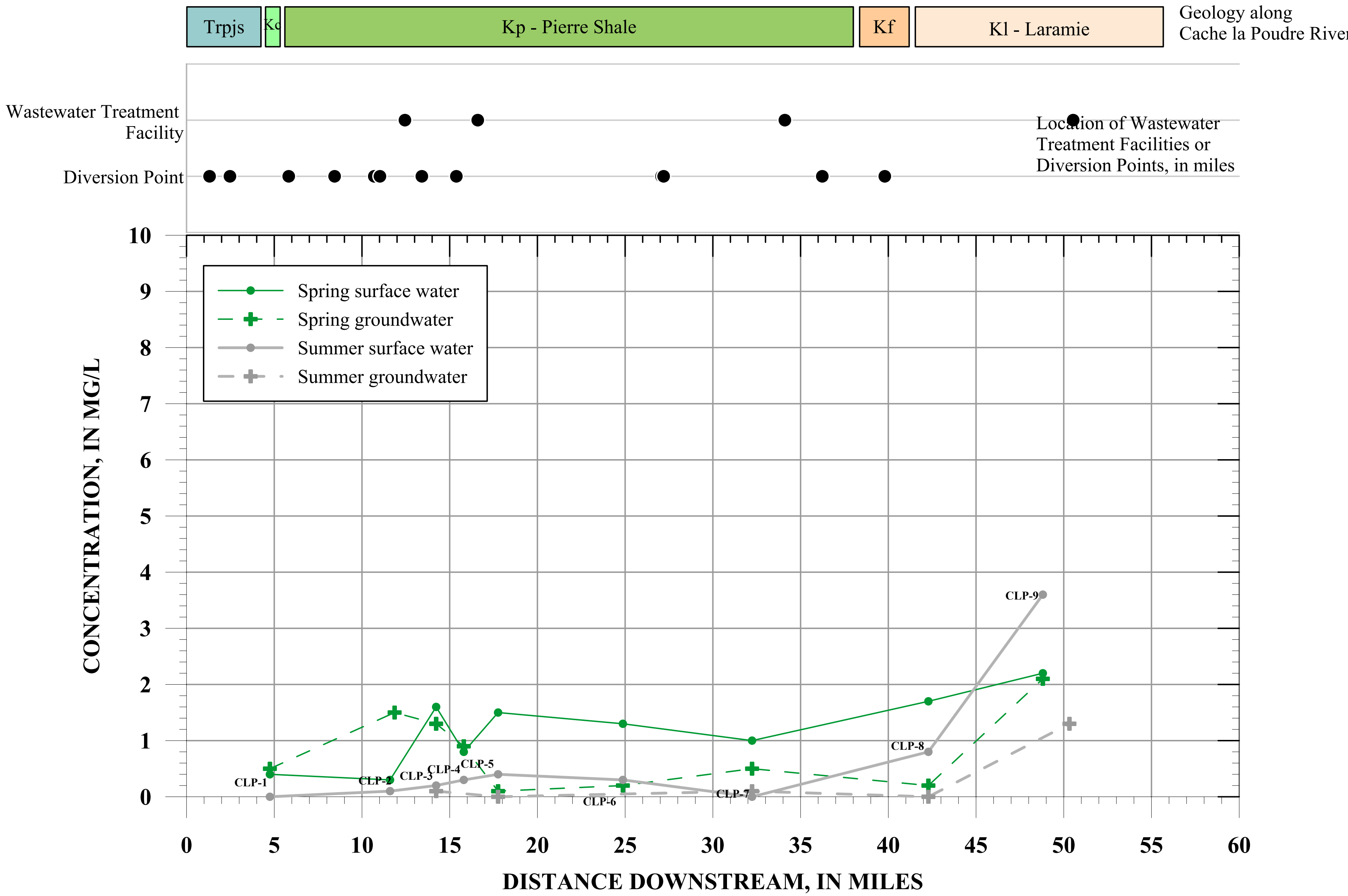


Figure B-4-7. Nitrate as nitrogen concentrations along the Cache la Poudre River

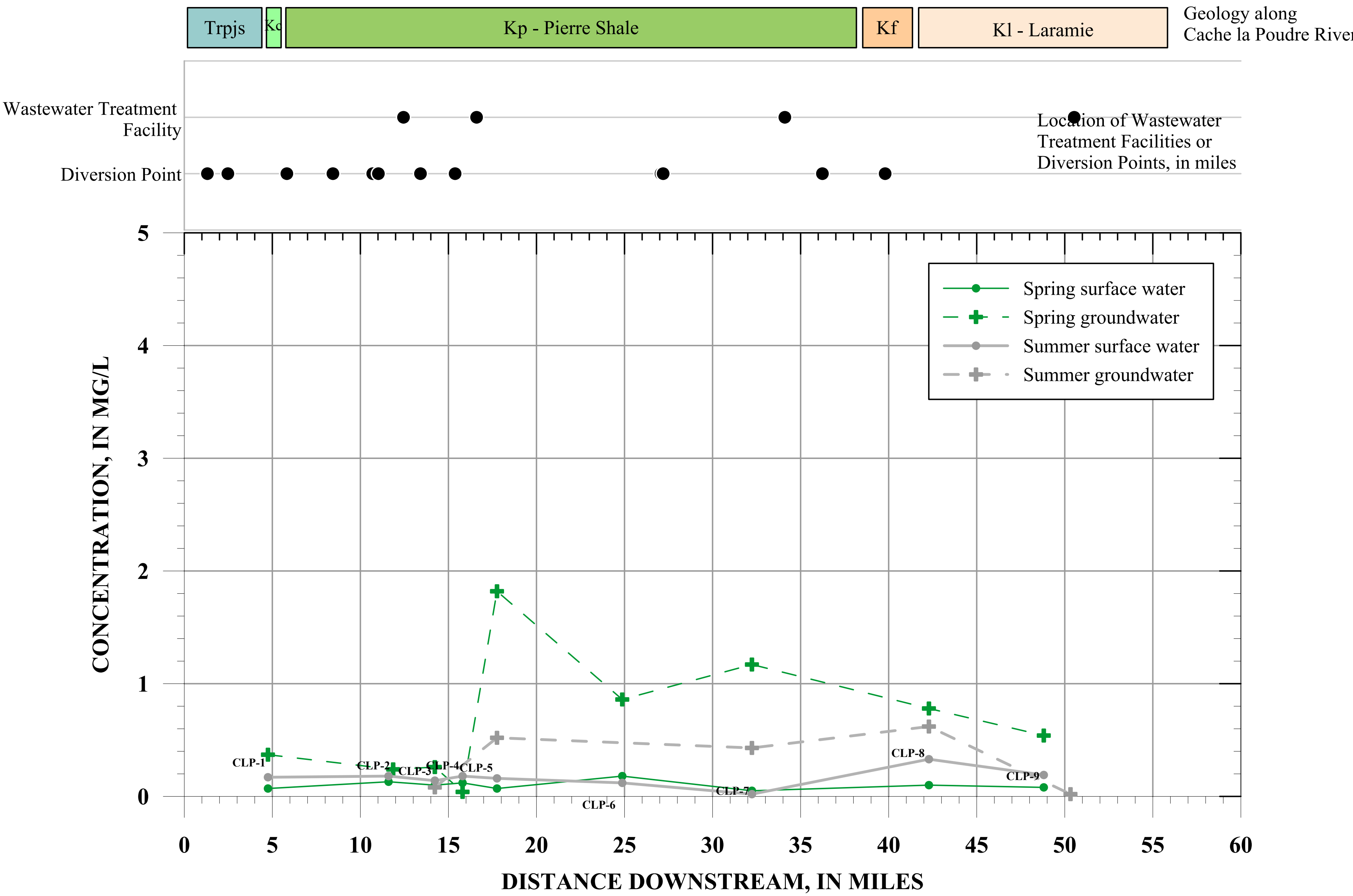


Figure B-4-8. Total iron concentrations along the Cache la Poudre River

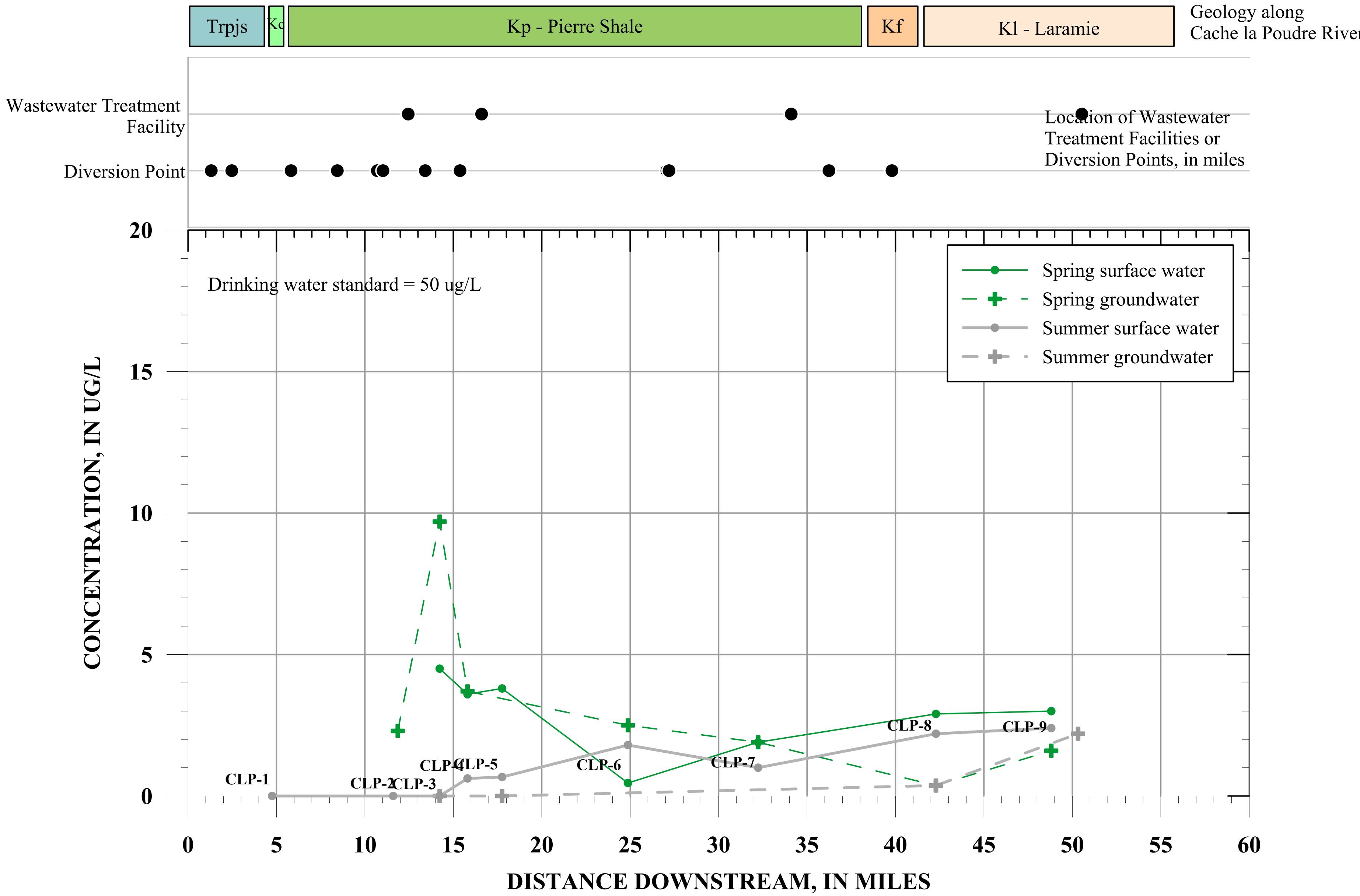


Figure B-4-9. Selenium concentrations along the Cache la Poudre River

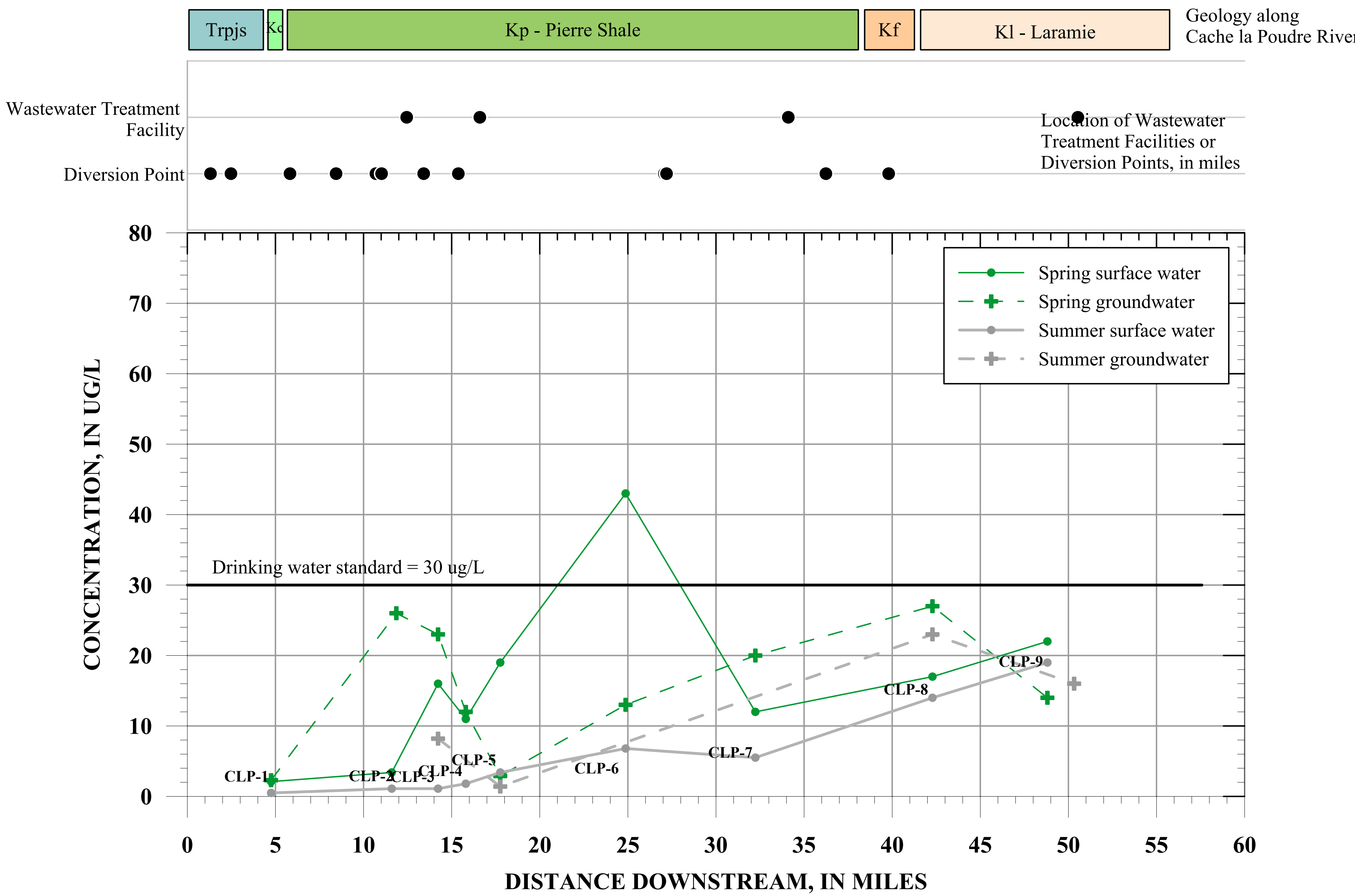


Figure B-4-10. Uranium concentrations along the Cache la Poudre River

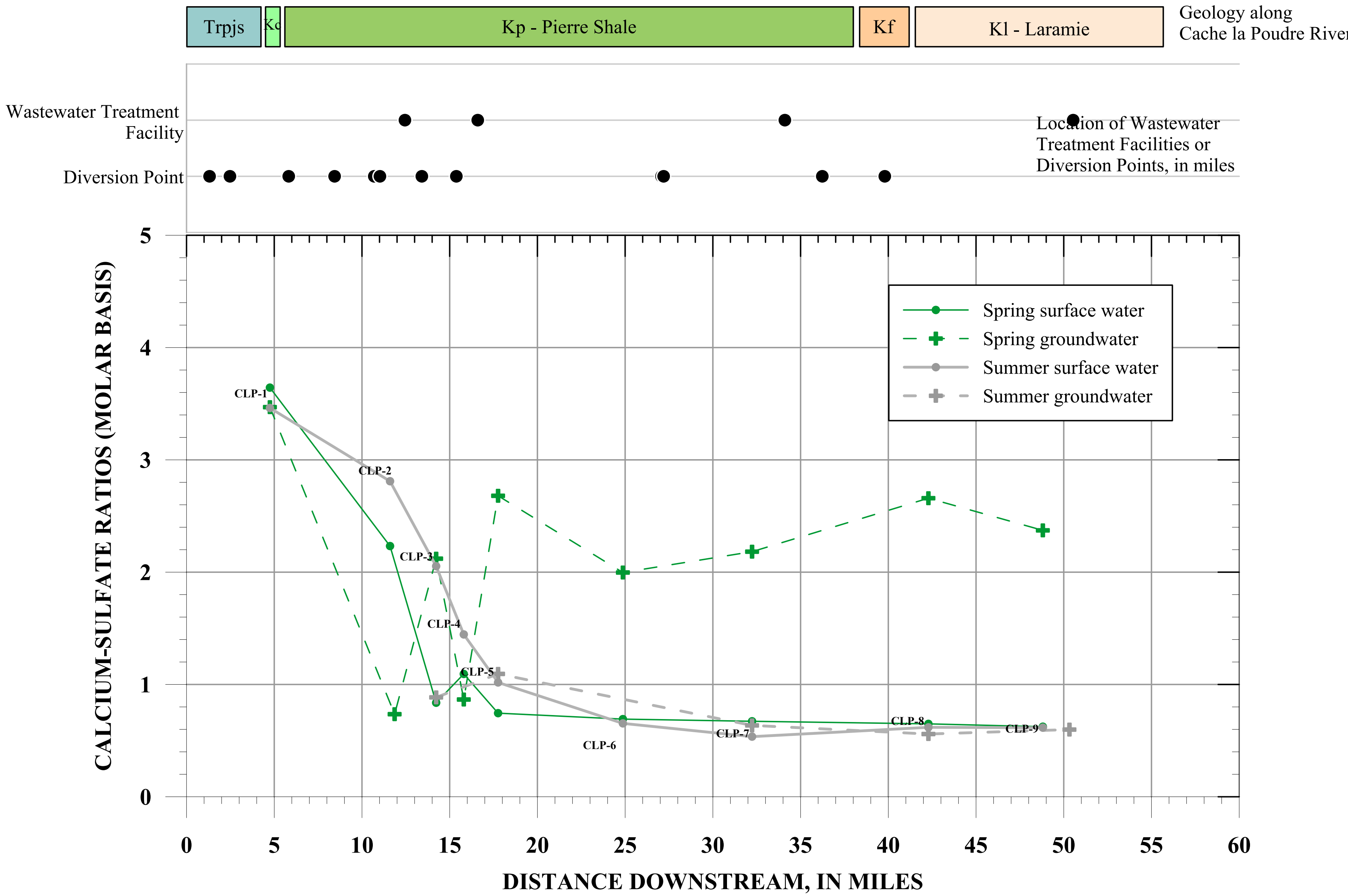


Figure B-4-11. Calcium-Sulfate ratio ($Ca:SO_4$) along the Cache la Poudre River

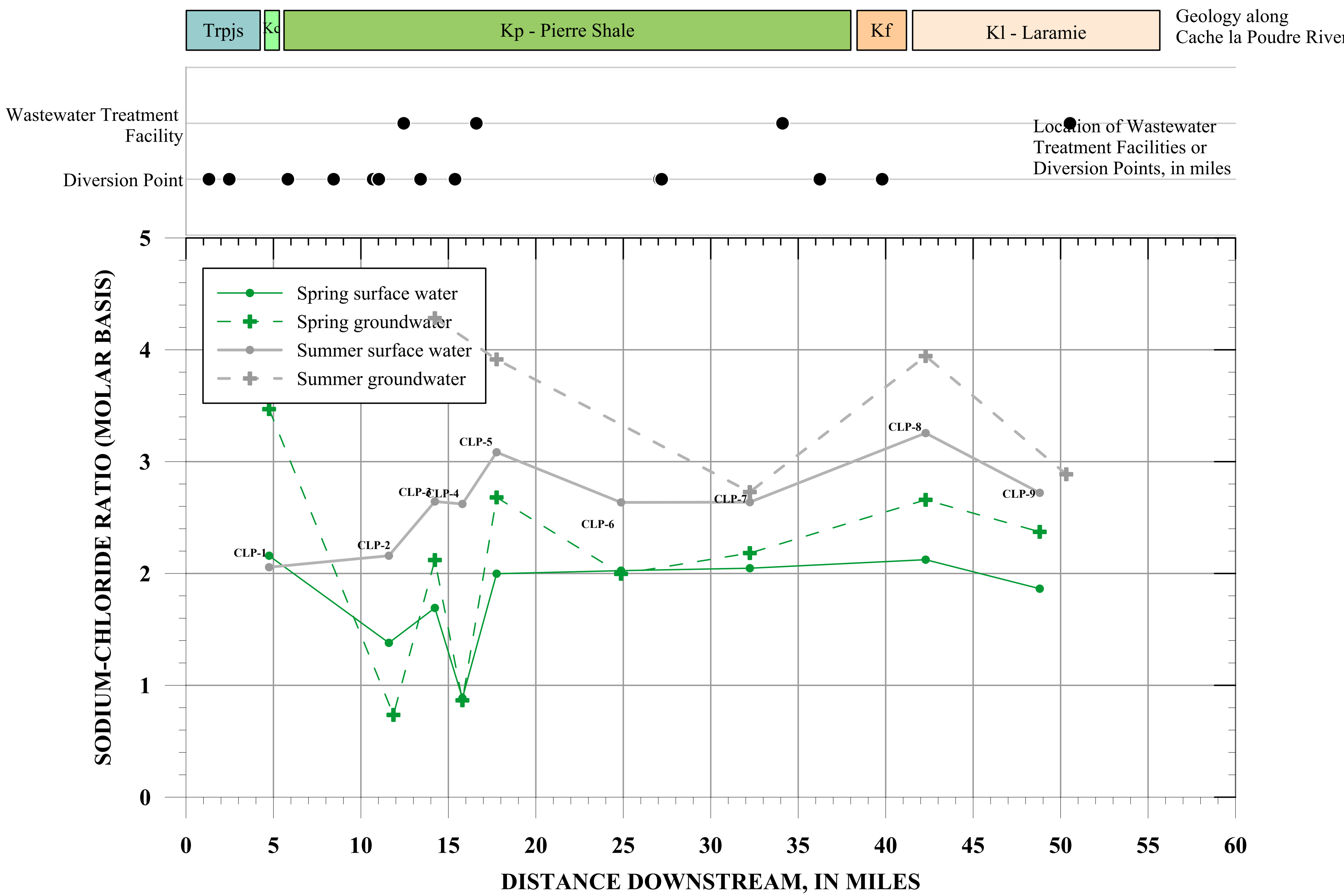


Figure B-4-12. Sodium-Chloride (Na:Cl) ratio along the Cache la Poudre River

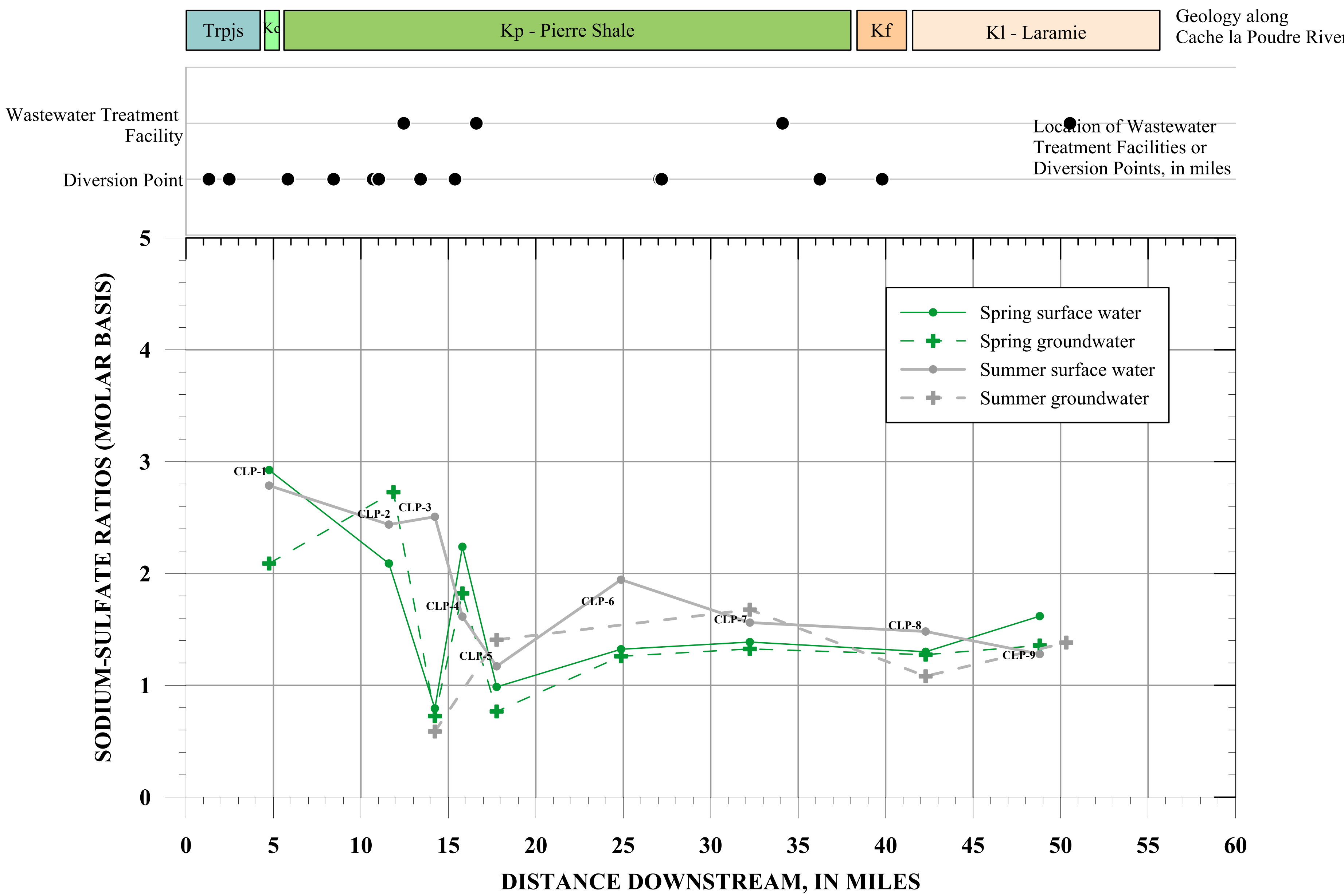


Figure B-4-13. Sodium-Sulfate ratio (Na_2:SO_4) along the Cache la Poudre River