# EVALUATION OF WATER QUALITY CONDITIONS IN COAL MINE BACKFILL IN THE POWDER RIVER BASIN OF WYOMING[1]

Roberta N. Hoy, Kathy Muller Ogle, and Mark Taylor[2]

**Abstract**: In the Powder River Basin of Wyoming, water quality monitoring data were evaluated for a number of wells completed in mine backfill, which have sufficiently recharged for evaluation of mining impacts on water quality. Based on the data reviewed to date, the backfill water quality is usually similar to baseline water quality in the Wyodak-Anderson coal aquifer and Wasatch overburden. However, as the backfill materials recharge, the trends in the concentrations of specific constituents (in particular, total dissolved solids and sulfate) may reflect site-specific conditions, including: proximity to recharge sources (e.g., clinker, unmined coal, and coal fenders between mines); changes in mining activities (e.g., temporary cessation of mining); and local conditions (e.g., leakage from impoundments). In some situations, constituent concentrations increase over time, while in others, constituent concentrations are relatively constant or are decreasing.

## Introduction

The purpose of this paper is to examine water level and water quality data in coal mine backfill aquifers associated with mining of the Wyodak-Anderson coal seam along the eastern edge of the Powder River Basin in Wyoming. Concentrations of total dissolved solids (TDS) and sulfate, along with associated water levels, are examined from backfill aquifers at a northern and a southern group of mines (Figure 1).

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[2]Roberta N. Hoy, Program Principal, Wyoming Department of Environmental Quality/Land Quality Division (WDEQ/LQD), Cheyenne, WY 82009. Kathy Muller Ogle, Program Principal, WDEQ/LQD, Cheyenne, WY. Mark Taylor, Senior Environmental Analyst, WDEQ/LQD, Sheridan, WY 82801.

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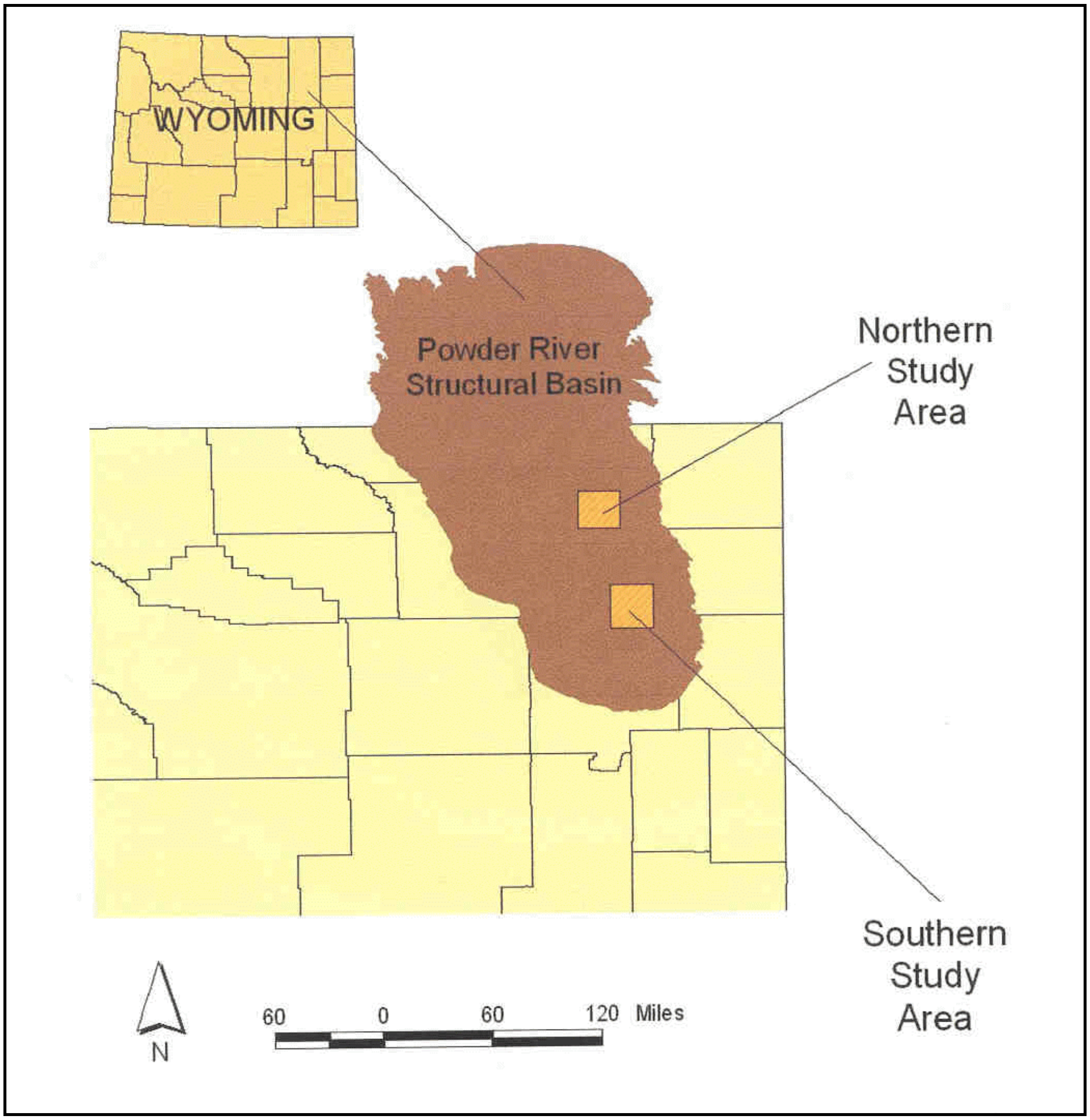


Figure 1. Location of the northern and southern study areas in the Powder River Basin of Wyoming.

The Eastern Edge of The Powder River Basin

The Powder River Basin is a large geologic structural basin located in northeastern Wyoming and southeastern Montana. Structurally, the basin is a north-northwest to south-southeast trending asymmetric syncline. The basin is approximately 250 miles long by 90 miles wide, and contains as much as 23,000 feet of sediment (Denson et al., 1989). The structural fold axis is located along the western part of the basin with the western limb characterized by steeply dipping bedrock and the eastern limb characterized by gently dipping bedrock (Glass et al., 1991).

Discussion in this paper is limited to the formations affected by the coal mining in the eastern Powder River Basin. From oldest to youngest, these formations are: the Paleocene Fort Union Formation; the Eocene Wasatch Formation; and Quaternary clinker. Although alluvial deposits are also affected by mining, the changes to those hydrologic systems are outside the scope of this paper.

Mining started in the eastern Powder River Basin because of shallow depths to thick coal seams along the outcrop of the Fort Union Formation. Most of the commercial coal production is from the Wyodak-Anderson coal seam in the upper Tongue River Member of the Fort Union Formation. Moving west into the basin, the coal is covered with increasing thickness of sediments of the Fort Union Formation and Wasatch Formation. The thickness of the Wyodak-Anderson seam along the eastern edge of the basin is typically between 50 to100 feet, and moving into the basin, the seam begins to split. Interburden in the split varies from 0 to about 10 feet in existing mines. Overburden thicknesses at existing mines range from 0 to over 200 feet. Over geologic time, the coal seam outcrops, including that of the Wyodak-Anderson seam, burned and roasted the overlying rock to form clinker up to 200 feet thick (Coates et al., 1999).

Prior to mining, ground water in the coal seams and the sand lenses and layers in the Fort Union and Wasatch Formations is generally of sufficient quantity and quality for livestock use. Where clinker is laterally continuous and of sufficient thickness, it can contain significant quantities of water meeting livestock (or higher) standards (Heffern and Coates, 1999). In Wyoming, water is classified first by use, and if the water is not in use, then by comparison of ambient water quality data with the water quality standards in Chapter 8 of the Wyoming Department of Environmental Quality (WDEQ), Water Quality Division (WQD) Rules and Regulations. The WQD standards for Livestock Class-of-Use (Class III) for TDS and sulfate are 5,000 and 3,000 milligrams per liter (mg/l), respectively.

In the coal seams and sand lenses and layers, the water quality changes with depth, e.g., moving into the basin from the outcrop along the eastern edge of the basin. In shallower waters, the major ionic composition is variable, but at greater depths, sodium and bicarbonate are the major cation and anion respectively (Lee, 1981; Bartos and Ogle, 2002).

The degree of interconnection between the coal and overburden varies, depending on the amount of shale in the overburden, and is often evident from differing water levels in adjacent coal and overburden wells. Ground water and surface water interaction also varies, depending in part on the amount of shale in the overburden and the location of outcrops. In general, the exchange of ground water and surface water is more significant in the northern and western portions of the basin

Coal Mine Backfill Aquifers

Along the eastern edge of the Powder River Basin, most of the large-scale, commercial coal mining began in the 1970s. Currently, sixteen large strip mines are present along the eastern edge of the Powder River Basin in Wyoming. Each mine consists of one or more open pits, the placement and expansion of which depends on: coal outcrop patterns; erosion of coal along alluvial channels; the presence or absence of clinker; locations of transportation corridors; coal quality; mineral ownership, and similar factors.

Refilling a pit with overburden and interburden materials after the coal is removed results in a reconstructed backfill aquifer. Recharge to the backfill may come from a variety of sources, including: lateral inflow from scoria, alluvium, overburden, and coal (including coal fenders under transportation corridors and between adjacent mines); upward flow from deeper sedimentary deposits; and downward flow from infiltration of precipitation or surface runoff. The water quality of recharging source(s) impacts the water quality of the backfill aquifer in a given pit. In addition, water flowing through the backfill may become more mineralized because of differences in oxidation state and contact with exposed mineral surfaces. The hydrologic characteristics of the backfill aquifers vary depending on the method of backfill placement (e.g., dragline, truck/shovel, or scraper) and the backfill material (e.g, fine or coarse-grained). In some backfill aquifers, flow into and through the aquifer may be relatively rapid; in others, resaturation may proceed very slowly. Martin et al. (1988) predicted that, in general, water in backfill aquifers would meet the Wyoming standard for livestock water quality.

Previous Studies

Studies in the Powder River Basin have indicated that the backfill water quality is similar to pre-mine overburden water quality (Van Voast and Hedges, 1975; Davis et. al., 1978). Van

Voast et al., (1976) found that the first groundwater to enter a backfill aquifer dissolved a high percentage of the available salts; however, subsequent groundwater was less mineralized. This less mineralized water probably resulted from the clay content of the backfill causing reduction and cation exchange as well as the flushing effect of the first groundwater. These researchers concluded that water quality in the backfill aquifers would be degraded until the backfill had been leached by sufficient volumes of water to establish a geochemical equilibrium between the incoming water and the soluble constituents in the backfill. The general geochemical processes are the oxidation of mineral matter and organic matter, reaction of carbon dioxide and water to form carbonic acid, dissolution of calcite and dolomite, precipitation and dissolution of gypsum, cation exchange, and sulfate reduction (Moran, et al., 1978). In the western United States, the primary backfill water quality concern is the elevation of TDS, with sodium, calcium, magnesium and sulfate being the major ionic constituents (Office of Technology Assessment, 1985).

Elevation of TDS and selected major ions in backfill aquifers has been reported at several Montana mines. The TDS concentrations in Montana were found to be about 1.5 times greater than pre-mining concentrations fifteen years after backfill placement (Van Voast et al, 1978). In an update to earlier research at the Colstrip and Decker Mines, Wheaton and Reiten (1996) found that mineralization in the backfill aquifers had increased by 50 to 200 percent, with decreases at some sites which was attributed to flushing of the initial salt load. Sodium, calcium, magnesium and sulfate ions were found to comprise most of the TDS increase at southeastern Montana mines (Reiten and Wheaton, 1993). Clark (1995) identified an increase of about 1,600 mg/l in TDS as water flowed into the backfill aquifer from the coal aquifer and suggested the increase was probably a result of de-dolomitization. The TDS concentrations in two wells at the West Decker Mine ranged from 4,100 to 5,700 mg/l compared to an average concentration of 2,500 mg/l in a larger number of wells. Dissolution of gypsum and carbonate minerals and ion exchange were identified as the most likely processes impacting water quality. Erbes (2000) reported TDS in the backfill aquifer at the Rosebud Mine in Montana to range from 1,200 to 5,500 mg/l after 20 to 25 years of recovery.

## **<u>Analysis</u>**

The analysis concentrated on backfill wells with several years of data and sufficient recovery for meaningful analysis. (Data from wells in reconstructed alluvial channels was not included.) Concentrations of TDS and sulfate were plotted over the period of record. These two water quality parameters were selected for analysis because they have been consistently identified as areas of concern in the literature for backfill water quality and are indicative of conditions affecting other parameters, such as the oxidation state which impacts solubility of metals. (For example, lower sulfate concentrations in backfill wells may be indicative of less oxidized recharge sources with corresponding lower concentrations of metals.)

Northern Mines. Analysis was performed on nine backfill monitor wells in the northern group of six mines (Buckskin, Dry Fork, Eagle Butte, Fort Union, KFx, Rawhide, and Wyodak). These wells have from four to fifteen years of monitoring of backfill water level and water quality reported in the Gillette Area Groundwater Monitoring Organization (GAGMO) 1997 and 2001 reports. For plotting purposes, when a water level was not available for the date of the water quality sample, the water level closest in time to the sampling date was selected. Also plotted is the elevation of the well, screened interval, and land surface, all of which were obtained from mining permits and annual reports on file with the WDEQ/ Land Quality Division.

Southern Mines. Analysis was performed on five backfill wells at a group of three southern mines (Jacobs Ranch, Black Thunder, and North Rochelle) with adjacent boundaries. Three other backfill wells have been installed, but have not yet recovered sufficiently for analysis. The limited recovery in these three wells is apparently due to the continued influence of adjacent mining operations rather than any unanticipated conditions. One of the mines does not yet have any backfill wells, but due to the proximity of this mine to the others, its progression can influence the backfill in the adjacent mines. Baseline water levels and well construction information were reported in mine permits and annual reports. Water level and water quality data collected during recovery, which is from eight to seventeen years, were submitted in annual reports and provided electronically for more convenient analysis.

Water Level Recovery

Once monitor wells are installed in the backfill (usually about two years after backfill placement to allow for settlement), water levels are usually monitored quarterly. Because the backfill aquifer may be in communication with several different layers of material (e.g., overburden, coal, clinker, and alluvium) and may also be recharged by precipitation and surface water runoff, water level recoveries are compared with pre-mine water levels in the coal aquifer for consistency.

<u>Northern Mines</u>. Water levels have recovered from about 36 to 122 percent (Table 1) in the nine backfill aquifer monitor wells in the northern group of mines, although active mining continues in most of the areas. In the fifteen years Well EG16-1R has been monitored, it has recovered to about 122 percent of the estimated baseline water level elevation in the pre-mine coal aquifer (Figure 2). Three other of the nine backfill wells in the northern area have recovered to within 70 to 90 percent of their baseline water levels. Current water levels in four other wells are within 50 to 60 percent of their respective baselines, and one is at about 36 percent. With a few exceptions, the water levels in the wells show a relatively slow, steady increase (Figures 2 through 5).

<u>Southern Mines</u>. Of the five wells analyzed in the southern group of mines, the water level in one (Well JRM11-1R) has recovered to within 90 percent of the baseline water level, which was essentially the same in the coal and overburden (Figure 6). In another (Well JRM15-2R), the water level recovery exceeds the baseline elevation in the coal, but has not recovered to the baseline elevation in the overburden (Figure 7). These two wells show the most recovery in the southern area, even though they recovered at different rates. Well JRM11-1R showed a relatively steady rate of increase of about 2.5 feet per year over almost twenty years of recovery (Figure 6). In contrast, Well JRM15-2R showed a rapid initial increase followed by a much slower rate of increase over a recovery period of about fifteen years (Figure 7).

Of the other three wells analyzed in the southern group of mines, the water level in Well BTB-2 had recovered to within 70 percent of the coal baseline (65 percent of the overburden baseline); however, at that point, the water level began to decline at a steady rate due to additional mining near the well. The water level is now less than 50 percent of the baseline level (Figure 8). In two other wells (Wells BTB-5 and BTB-6), water levels have only recovered to about 20 and 30 percent, respectively; however, they are of interest because of the water quality during early recovery.

Concentrations of Total Dissolved Solids and Sulfate

The response of TDS and sulfate concentrations to factors influencing backfill water quality was evaluated by plotting concentrations versus time. In most instances, water levels and sulfate concentrations in a given well were plotted on the same graph to help evaluate any correlation between recovery rate or magnitude and water quality. TDS concentrations are also plotted on the graphs for the northern wells to evaluate the sulfate contribution to the overall TDS concentration.

Northern Mines. TDS and sulfate concentrations generally track each other, which is probably because in eight of the wells, sulfate is the major anion component of the TDS concentration. Spatially, the TDS concentrations were variable between the nine wells; in the year 2000, the concentrations varied from a low of about 1,272 mg/l to a high of about 8,826 mg/l (Table 1). Seven of the TDS concentrations were in or close to the 4,000 to 6,000 mg/l range. The range in sulfate concentrations is even greater - from 3 mg/l in Well PM-12 to a high of about 4,694 mg/l in Well PM-1 (Table 1). Six wells have sulfate values within the 2,000 to 3,000 mg/l range (Table 1).

Trends in TDS and sulfate concentrations also vary from well to well. Well EG16-1R reflects the classic log-normal pattern of decreasing TDS and sulfate with time that is predicted in the literature. A backfill well installed previously in this area had increasing TDS and sulfate concentrations from 1983 to 1987. The TDS concentrations increased from about 3,400 to 5,000 mg/l, and the sulfate concentrations increased from about 1,750 to 3,200 mg/l (Martin et al., 1988). However, in the last fifteen years of monitoring of Well EG16-1R, the TDS concentrations decreased 59 percent (from about 5,300 to 2,130 mg/l), and the sulfate concentrations decreased 69 percent (from about 3,200 to 973 mg/l) (Figure 2). Similarly, Well EB1603 showed an initial rise and

Table 1. Percent Ground Water Elevation Recovery and Recent Total Dissolved Solids and Sulfate Concentrations in Backfill Monitor Wells in the Northern and Southern Study Areas of the Powder River Basin, Wyoming.

| **Well** | **Years of Monitoring Data Examined** | **Percent Recovery to Baseline Ground Water Elevation in Coal** | **Date of Most Recent Sample Used in Analysis** | **TDS in Most Recent Sample (mg/l)** | **Sulfate in Most Recent Sample (mg/l)** |
|---|---|---|---|---|---|
| Wells in Northern Group of Mines | | | | | |
| EG16-1R | 15 | 122 | 6/1/00 | 2,130 | 973 |
| EB1603 | 14 | 50 | 8/28/00 | 4,382 | 2,227 |
| EB1605 | 13 | 52 | 8/30/00 | 5,892 | 2,996 |
| PM-10 | 4 | 52 | 12/20/00 | 3,996 | 2,363 |
| PM-12 | 4 | 56 | 12/21/00 | 1,272 | 3 |
| PM-1 | 10 | 87 | 12/21/00 | 8,826 | 4,694 |
| LF-4 | 14 | 85 | 6/1/00 | 5,720 | 2,770 |
| LF-5 | 14 | 72 | 6/1/00 | 5,210 | 2,510 |
| LF-6S | 14 | 36 | 6/1/00 | 4,400 | 2,020 |
| Wells in Southern Group of Mines | | | | | |
| JRM11-1R | 17 | 90 | 11/99 | 4,830 | 2,160 |
| JRM15-2R | 15 | >100 | 11/99 | 4,040 | 2,230 |
| BTB-2 | 15 | 70 (before more mining) | 11/17/97 | 2,140 | 857 |
| BTB-5 | 10 | 20 | 5/12/99 | 4,850 | 2,900 |
| BTB-6 | 8 | 50 (before more mining) | 5/12/99 | 1,140 | 75 |

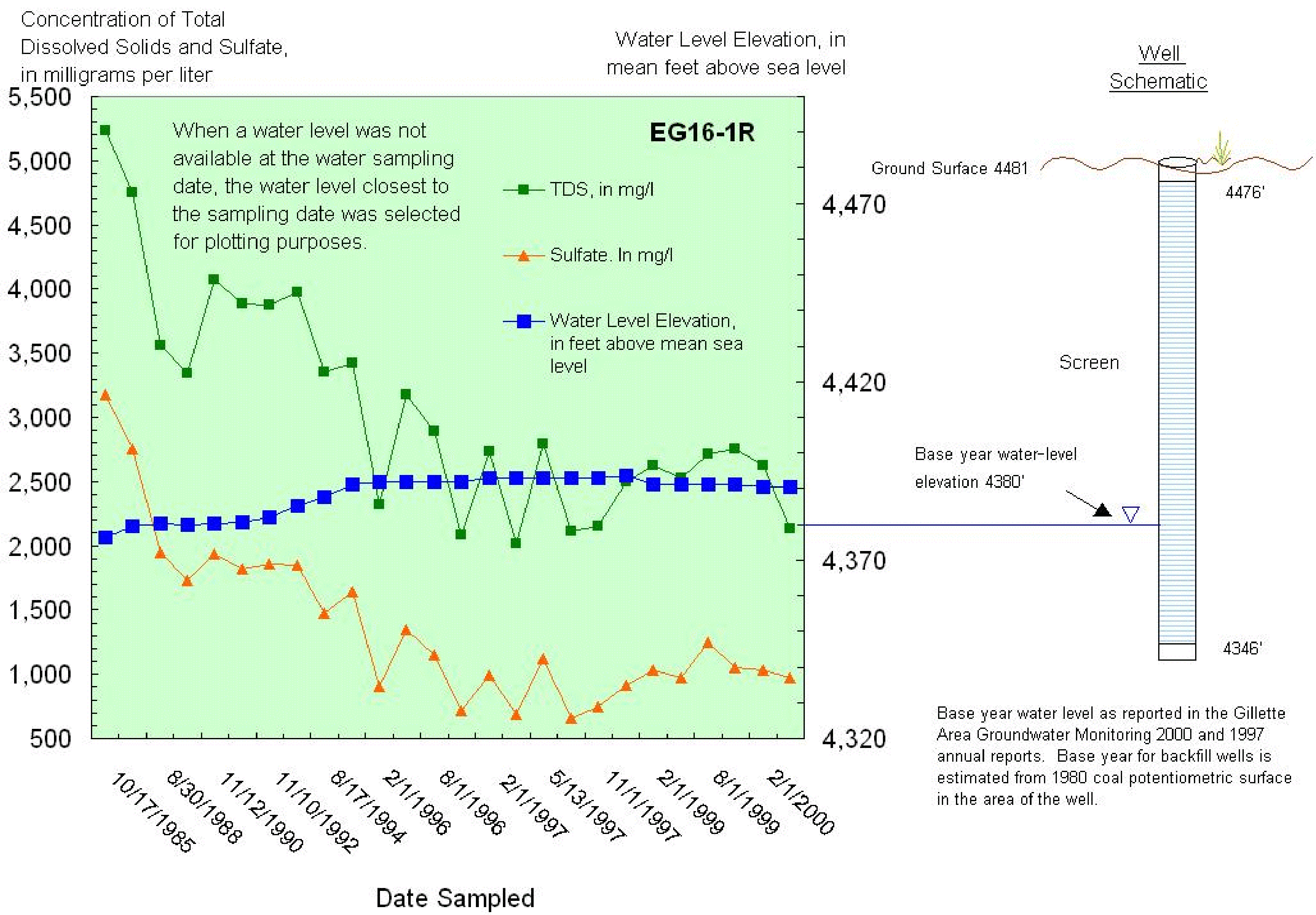


Figure 2. Well schematic and graph of water level elevations and concentrations of total dissolved solids and sulfate in Well EG16-1R.

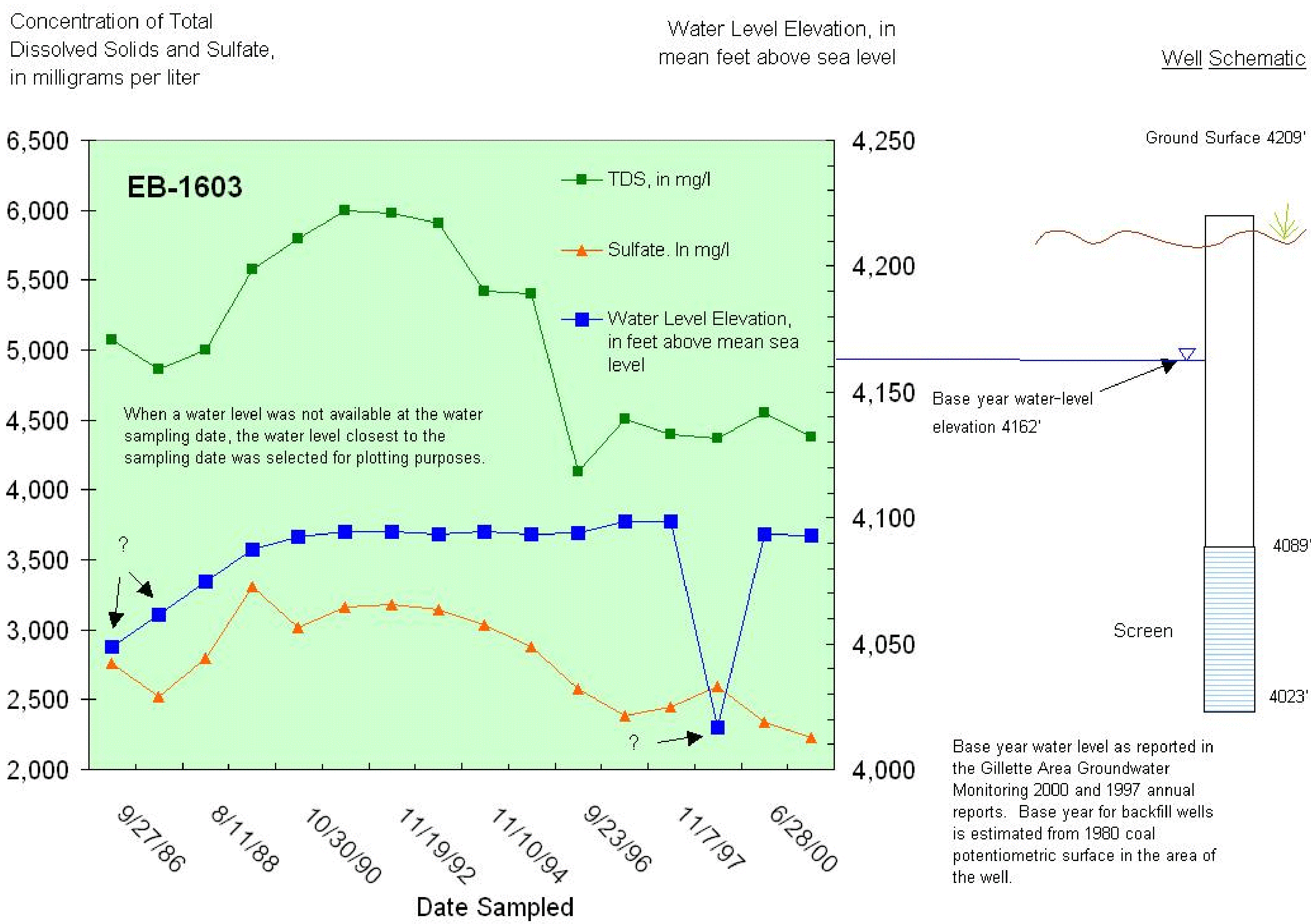


Figure 3. Well schematic and graph of water level elevations and concentrations of total dissolved solids and sulfate in Well 1603.

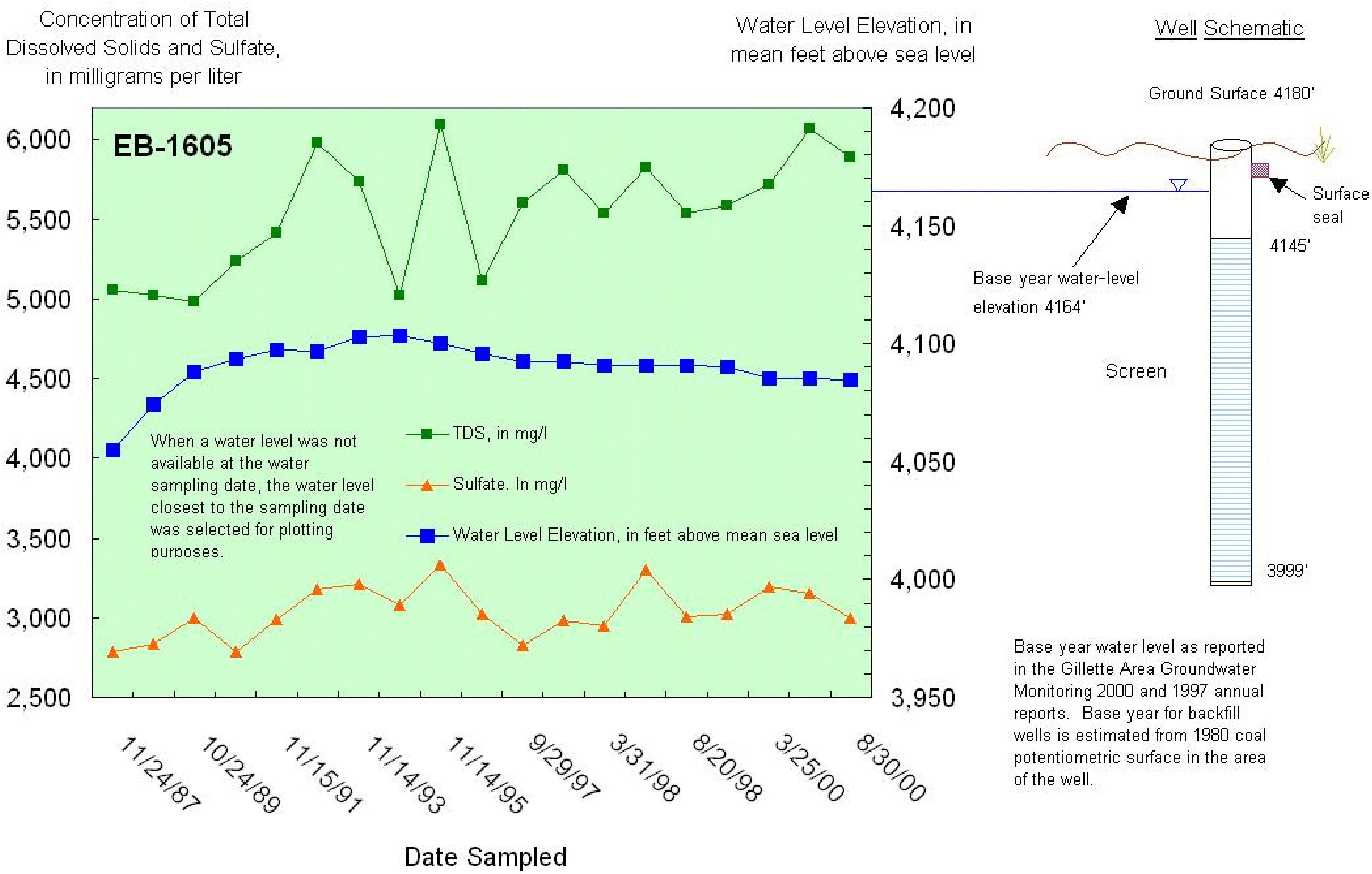


Figure 4. Well schematic and graph of water level elevations and concentrations of total dissolved solids and sulfate in Well 1605.

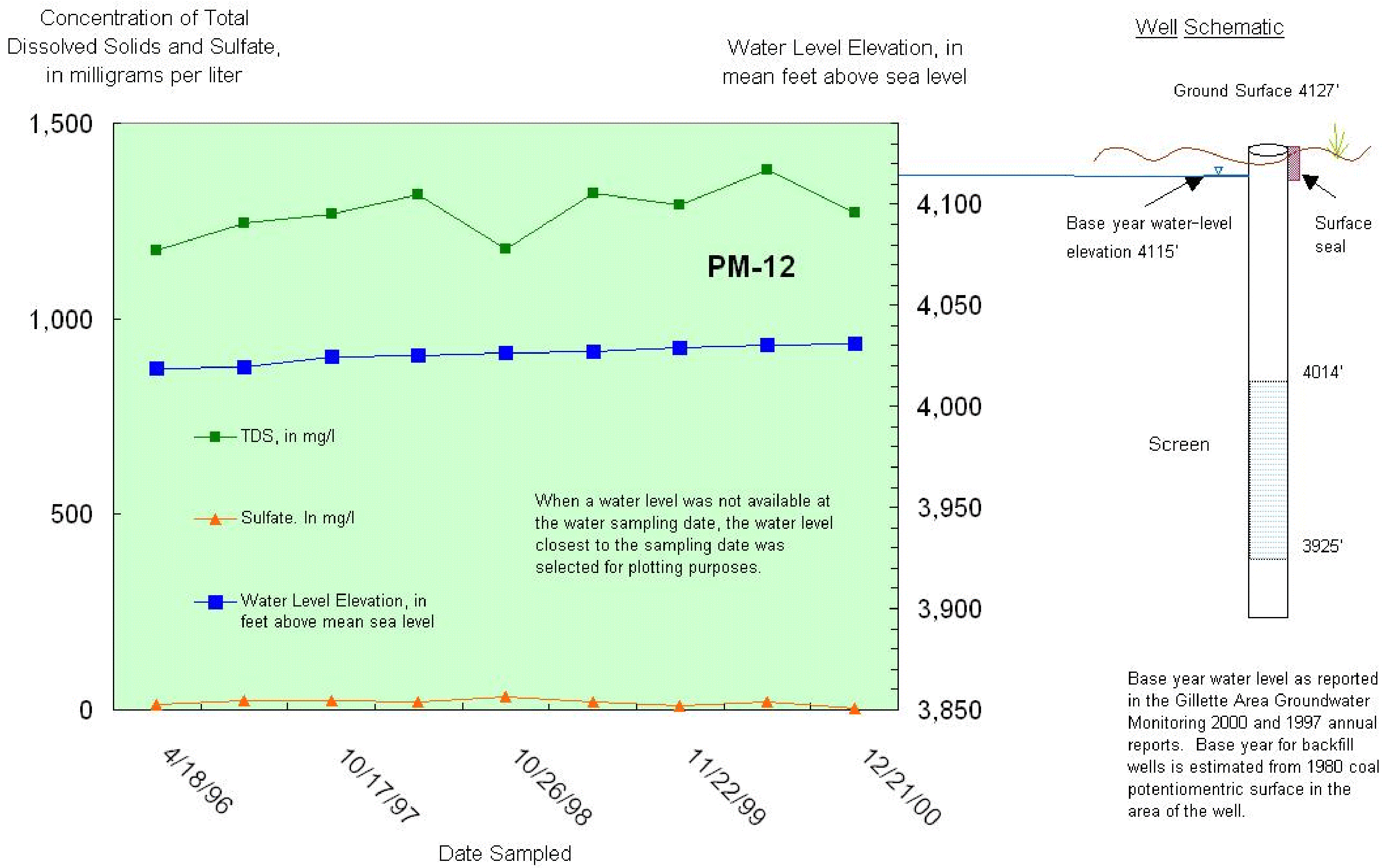


Figure 5. Well schematic and graph of water level elevations and concentrations of total dissolved solids and sulfate in Well PM-12.

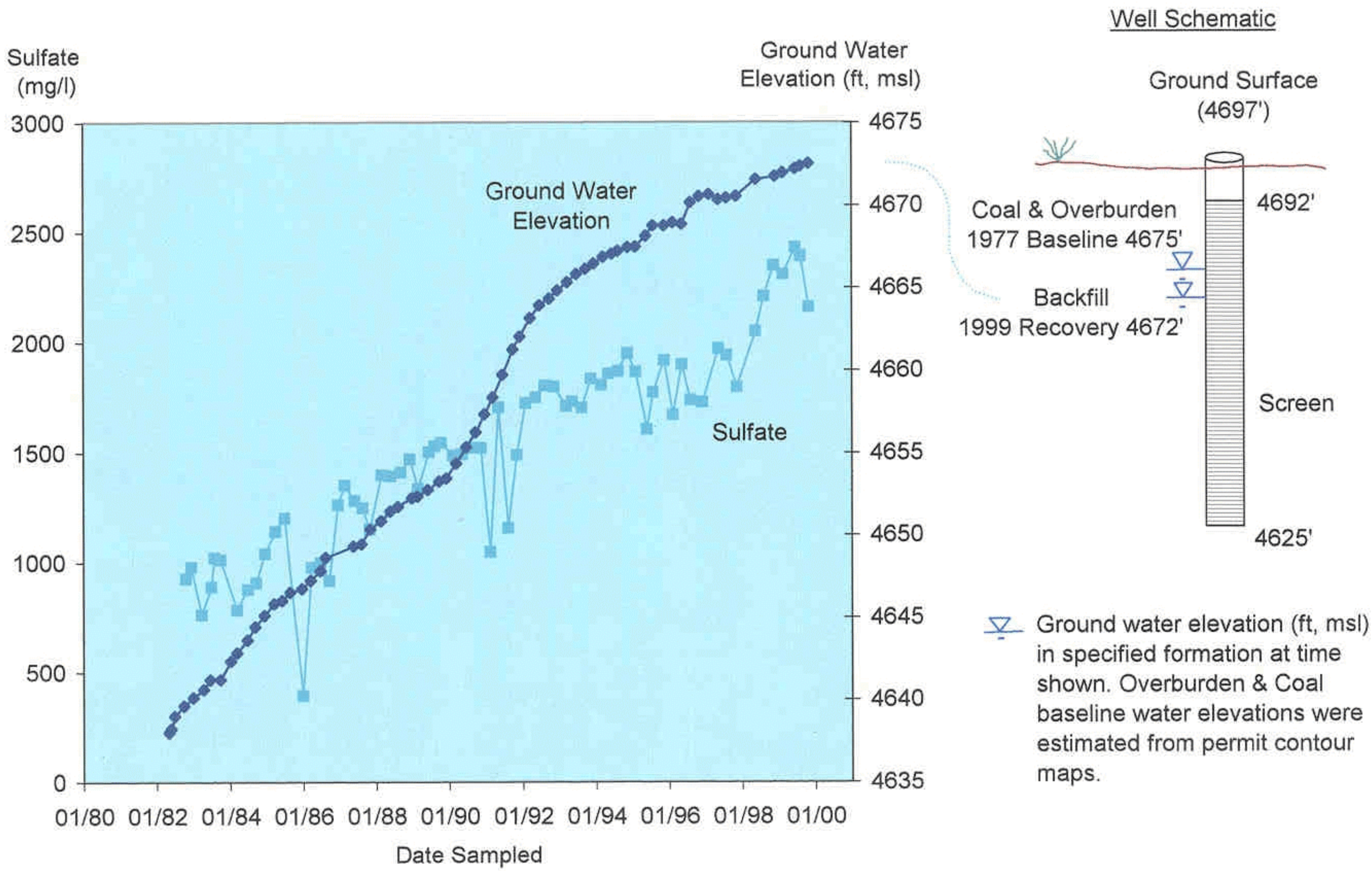


Figure 6. Well schematic and graph of water level elevations and sulfate concentrations in Well JRM11-1R.

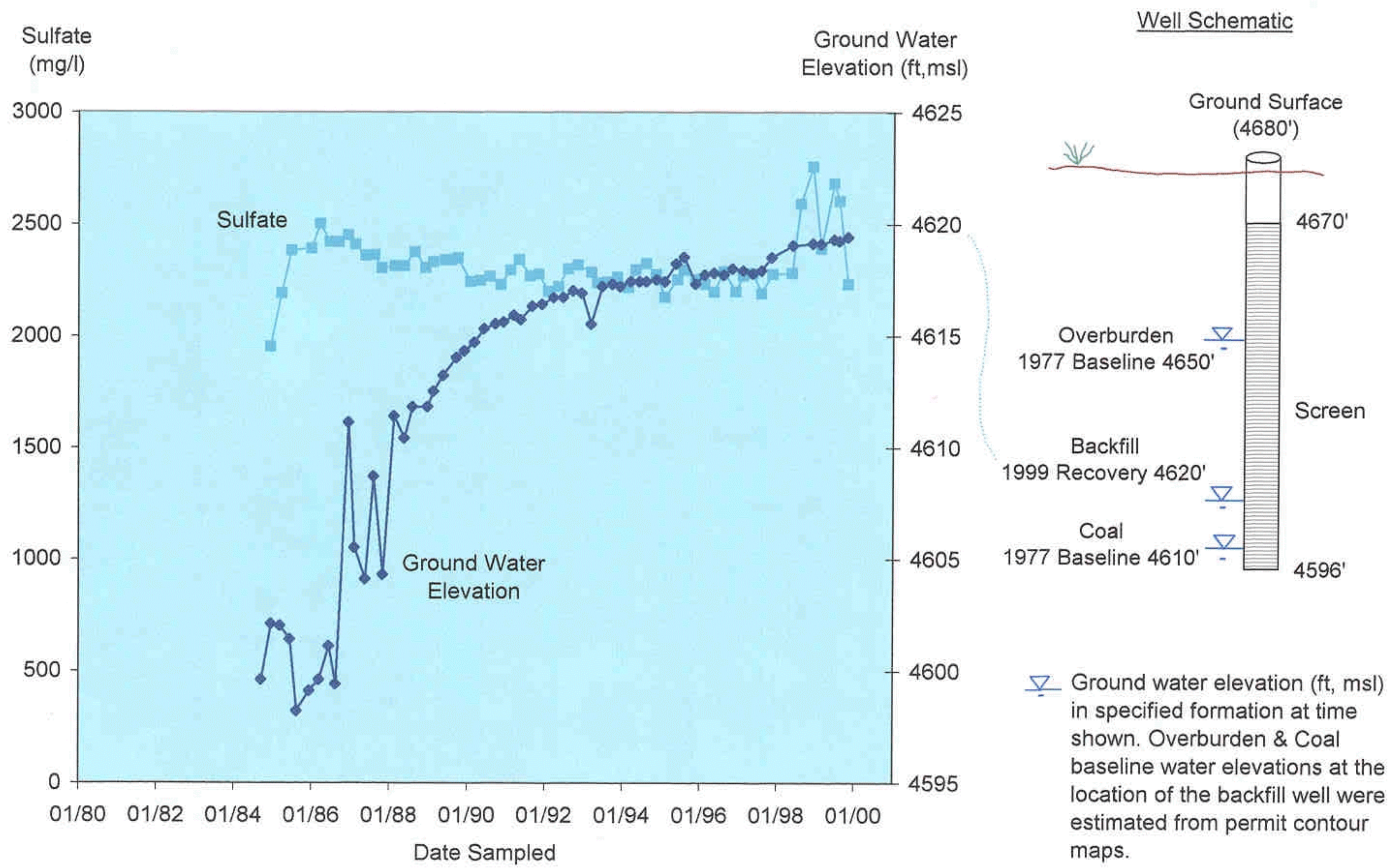


Figure 7. Well schematic and graph of water level elevations and concentrations of sulfate in Well JRM15-2R.

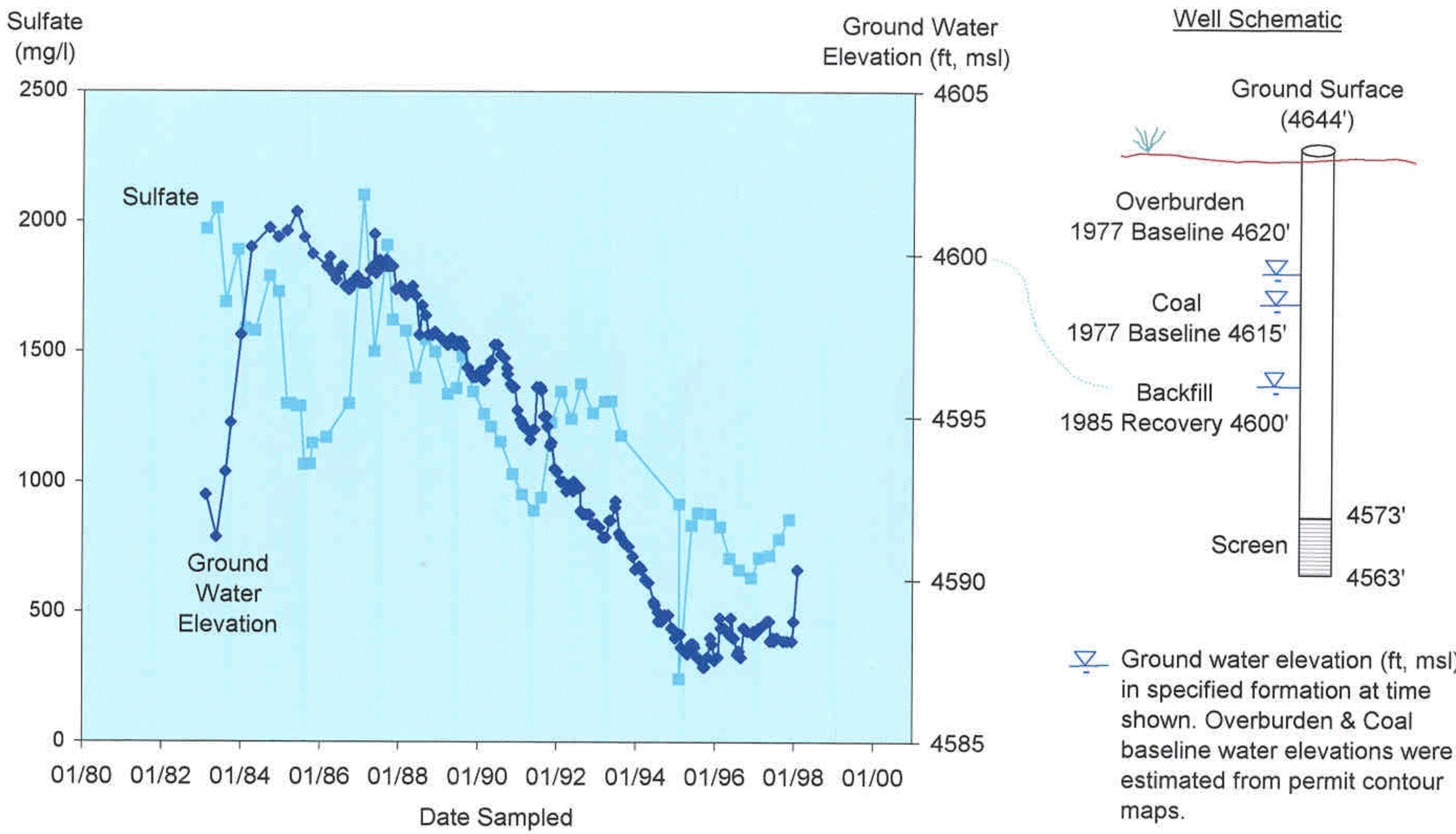


Figure 8. Well schematic and graph of water level elevations and sulfate concentrations in Well BTB-2.

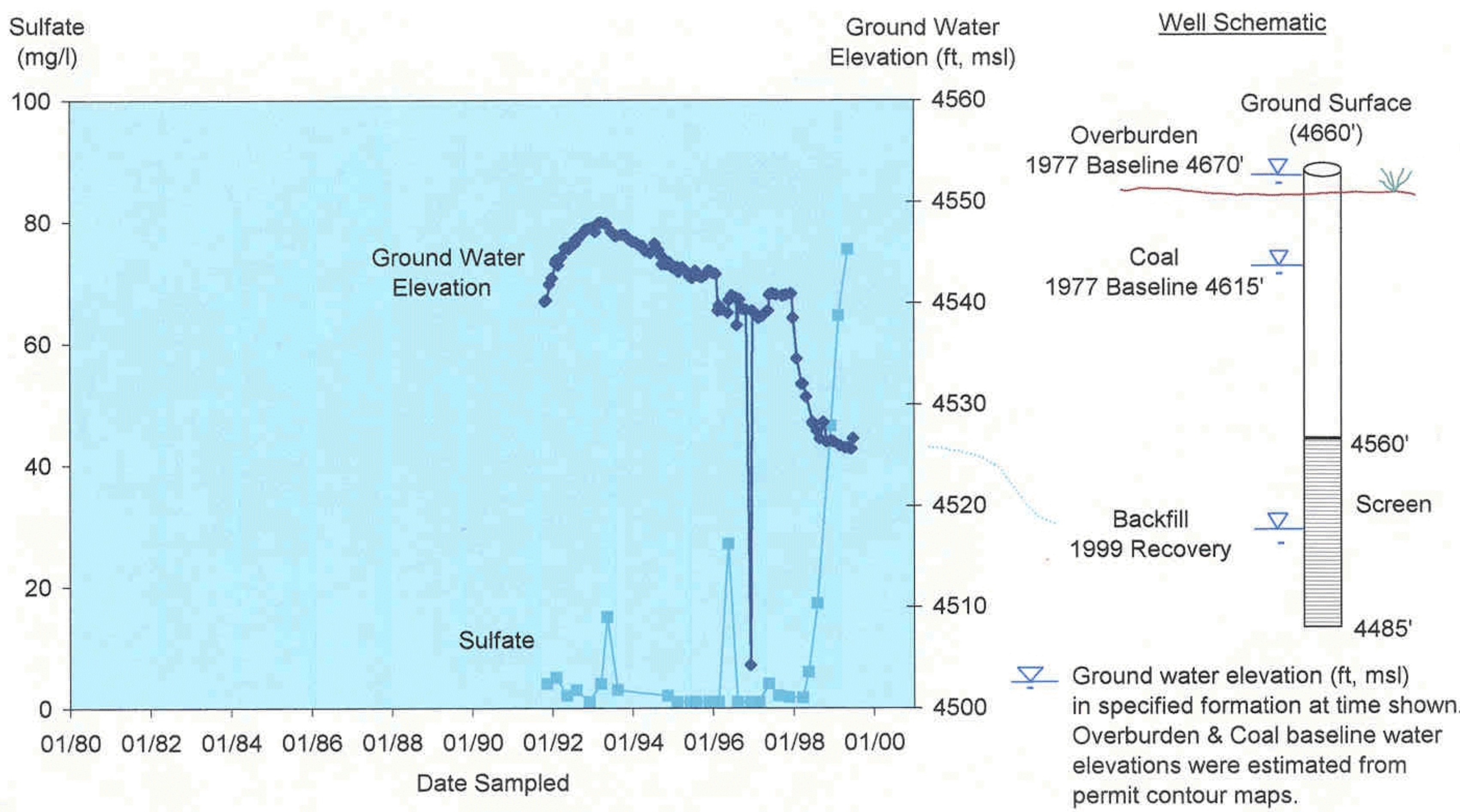


Figure 9. Well schematic and graph of water level elevations and concentrations of sulfate in Well BTB-6.

subsequent decline during fourteen years of monitoring. The highest TDS concentration was about 6,000 mg/l, with the current concentration at 4,382mg/l. The highest sulfate concentration was about 3,300 mg/l, and the current concentration is 2,227 mg/l (Figure 3).

In contrast, in Well EB 1605, there has been a slow upward trend in TDS concentrations with some variability in sulfate concentrations. Concentrations have gone from about 5,000 to 5,892 mg/l (Figure 4). Well PM-12 shows even greater contrast than the other wells. It has low concentrations of TDS and very low sulfate concentrations with little variation over time. The TDS and sulfate concentrations in Well PM-12 are 1,272 and 3 mg/l, respectively (Figure 5).

Southern Mines. The sulfate concentrations in the backfill wells in the southern wells vary considerably over time. In Well JRM11-1R, the sulfate concentration, similar to the water level elevation, has increased steadily over the 17 years of monitoring from initial concentrations of about 1,000 mg/l to about 2,250 mg/l more recently (Figure 6). In contrast, in Well JRM15-2R, the sulfate concentration has remained at about 2,400 mg/l over 15 years of monitoring while the water level increased rapidly initially and then increased gradually (Figure 7).

Of interest also is the water level decline over the last 16 years in Well BTB-2 and the corresponding decrease in sulfate concentration from about 2,000 mg/l to about 750 mg/l (Figure 8). (Note: This well was removed in 1998 due to the recurrence of mining in the area.) Even with this decline, the sulfate concentrations in Well BTB-2 were still significantly higher than those in Well BTB-6, in which the sulfate concentrations were still less than 100 mg/l after 8 years , though rising (Figure 9).

Influences on Water Level Recovery and Water Quality

The variability of the water level and water quality responses in the coal mine backfill wells is considered representative of the varied site-specific factors along the eastern edge of the Powder River Basin. In some instances, identification of the factor(s) that are impacting the backfill conditions is relatively straightforward. For example, the relatively rapid water level recovery in Well JRM11-1R is probably attributable to the presence of scoria aquifers to the east and west of this well. The unexpectedly low sulfate concentrations in Wells PM-12 and BTB-6, in the northern and southern group of mines, respectively, may be attributable to lateral ground water recharge from an area of the coal where sulfate reduction has occurred. For example, water infiltrating backfill from the coal and overburden to the west (from deeper in the basin) would be anticipated to have less sulfate than water infiltrating from the coal and overburden to the north or south.

In other instances, identification of the factor(s) that are impacting the backfill conditions is more complicated, particularly when man-made conditions contribute to the changes. For example, in Well BTB-2, continued mining activities have impacted water level recovery. The recurring activities have apparently also impacted the source(s) of recharge to the well based on the decreasing sulfate concentrations in the well. If recharge had continued from shallower (oxidized) deposits, then the sulfate concentration would have been expected to remain relatively constant. However, the activity that caused the water level declines may have reduced the contribution from shallower deposits, resulting in a corresponding decrease in sulfate concentrations.

Other man-made conditions, such as water withdrawals, well construction, and backfill placement methods, may have varying impacts. For example, increased ground water withdrawals and surface water runoff related to coal bed methane development are expected to have an increasing impact on backfill conditions. In contrast, even though differences in backfill well screen lengths are evident on Figures 2 through 9, the differing responses of similarly constructed wells (e.g., Wells JRM11-1R and JRM15-1R) indicate that well construction may not have a dominant impact on backfill sampling results. Though not analyzed for this paper, the differences in the hydraulic conductivity of each backfill aquifers due to differences in local overburden materials and backfill placement methods, may also impact backfill conditions.

## **Summary**

Because mining is currently active along the eastern edge of the Powder River Basin in Wyoming, there are significant local changes in the groundwater flow patterns due to the opening of pits, pit advancement, and reclamation activities. These constant and interactive disturbances make it difficult to identify specific causes and effects on backfill recharge and water quality. However, several differing responses are evident in plots of water level recovery and TDS and sulfate concentrations to date. Some of the backfill wells have not fully saturated so continued changes are anticipated in response to both natural and man-made factors as the backfill fully resaturates and water begins to move through the reconstructed hydrologic system.

Backfill recovery was an area of active research until the mid-1980's but has received less attention since then due to funding decreases. Backfill wells will continue to be monitored, and water level, water quality, and hydraulic conductivity data evaluated. As saturation increases in existing wells, data from more existing wells is analyzed, and new wells are installed, specific factors contributing to backfill recovery should become more readily identifiable. Based on the information available to date, the broad conclusion of Martin et al. (1988), that backfill aquifers will meet the WQD livestock water quality standards, remains viable. However, the site-specific conditions contribute to the variety of water level and water quality responses during resaturation of the backfill.

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