A Quarter Century of Coal Mining and Hydrogeologic Research in Southeastern Montana [1]

by

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Abstract. Two valuable natural resources coexist in eastern Montana -- coal and ground water. Water related issues are the major concerns during coal mine permit decisions. Due to the concerns about mining related impacts, ground water in the vicinity of coal mines has been continuously monitored since 1970. The continuity and duration of the Montana Bureau of Mines and Geology monitoring program under a variety of geologic, mining, and post-mining conditions have provided a fundamental knowledge on impacts to water levels and water quality. Coal beds are among the most dependable and utilized aquifers in eastern Montana, due to their lateral continuity and fracture-related transmissivity. In response to coal strip mining, water levels in coal-bed aquifers have dropped at distances as far as 2 miles away from mines near Colstrip, and as far as 15 miles from mines near Decker. Water levels typically return to pre-mining levels within several years after pits are backfilled. Mining-induced drawdown in stratigraphically deeper aquifers exceed those in mined aquifers in some areas, and relate to inadequately plugged boreholes from older exploration drilling programs. Dissolved-solids concentrations of water in the spoils aquifers have increased by 50 to 200 percent due to the dissolution of newly available salts of calcium, magnesium, sodium and sulfate. However, in some sites freshening of the water appears to be occurring as initial salt loads are flushed through the systems. Water-quality impacts are expected in off-site and deeper aquifers due to normal ground-water flow, and in deeper aquifers due to poorly plugged exploration drill holes. However, downgradient impacts to water quality are rarely observed. Future ground-water monitoring should document stable water levels and improving water quality as spoils aquifers reach equilibrium with local undisturbed hydrologic systems.

Additional Key Words: hydrogeologic impacts, spoil aquifers, aquifer recovery

Introduction

Ground water and coal are both very important natural resources in eastern Montana. Coal beds are the most widely used and dependable aquifers in the Fort Union coal region due to their lateral continuity and fractured nature. About 120 billion tons of coal reserves exist in eastern Montana, representing nearly one-third of the nations total coal base (Figure 1). Ground-water monitoring is a major step in developing predictive tools that will be used in future mine impact assessments. The Montana Bureau of Mines and Geology (MBMG) has been collecting hydrogeologic data in coal mine areas since 1970. Interpretations of this long-term database have provided numerous insights into coal mining impacts to, and in some cases recovery of, hydrogeologic systems.

Twenty five-years of observations in a network that now includes over 200 wells have produced an accurate picture of the hydrogeologic impacts near surface coal mines in Montana. The wells were carefully located to give information of pre-mining, mining, and post-mining conditions. In general, the observations follow the predictions developed in the 1970's by state regulators, mine company hydrologists, the MBMG and the U. S. Geological Survey (USGS) and are contained in numerous publications including (USGS, 1974; Van Voast and Hedges, 1975; Van Voast and others, 1977; USGS, 1979; Dollhopf and others, 1981; Davis, 1984; Van Voast and Reiten, 1988). Generally, post-mining ground-water levels appear to be approaching pre-mining levels. Recovery to pre-mine water quality is less evident.

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Long-term observations provide background data for new mine areas, and are part of the basis for impact assessment for mine permit decisions. Research programs have successfully crossed company boundaries and allowed the recognition of more and broader trends. The data and research results have proven essential for responsible coal development and for ground-water protection. Over the long duration of this work, many State and federal agencies and several mining companies have generously provided funding or other assistance. Of particular note is the U.S. Bureau of Land Management who have assisted the program almost from its inception in 1973. Their need and interest for comprehensive results has also been highly gratifying.

Regional Setting

Southeastern Montana is semi-arid; most areas receive less than 15 inches of precipitation per year. The Paleocene Fort Union Formation, composed of shales, sandstones and coal seams, is exposed at ground surface over most of the coal mining region of Montana. The remainder of the surficial geologic units are alluvium and clinker. Clinker is overburden sandstone and shale that has been baked and broken as a result of the burning of underlying coal seams. Coal seams mined in Montana are subbituminous and are in the Tongue River Member of the Fort Union Formation.

Generalized thickness patterns and stratigraphic relationships are presented in Figure 2 for selected coal mine areas in southeastern Montana. Mines in the Colstrip area target the Rosebud coal, near the bottom of the Tongue River Member. The Rosebud coal seam averages about 25 feet thick (Matson and Blumer, 1973). The stratigraphically lower McKay seam, typically 8 to 10 feet thick, had been mined near Colstrip but due to poor coal quality mining was discontinued. Mines near Decker target a system of diverging and converging seams making up the D-1 (upper and lower) and the D-2, which are in the upper portion of the Tongue River Member (Matson and Blumer, 1973). At the Ash Creek mine, the D-1 upper coal was mined, and interburden down to near the top of the combined D-1 lower and D-2 was removed. At the west Decker mine, the D-1 (upper and lower units combined) has a thickness of approximately 50 feet and is currently being mined. At east Decker, the D-I upper, lower and D-2 have thicknesses of about 25 feet, 15 feet and 15 feet respectively and are all penetrated by mining.

Ground-water recharge occurs along topographically high ridges where clinker is exposed. Ground water flows from topographically higher areas to lower areas, providing base flow for local springs and regional streams and rivers, and infiltrates downward to recharge stratigraphically deeper aquifers. Near recharge areas, oxidizing conditions generate large amounts of salts that are readily available for dissolution by percolating ground water. Where products of sulfide weathering (sulfates) are present, large concentrations of total dissolved solids (TDS) occur, predominantly consisting of calcium, magnesium and sulfate ions. Along the flow path, calcium and magnesium exchange for sodium in sodic shales, increasing the proportion of sodium. In the deepest portions of the flow paths, under anaerobic conditions, sulfate is reduced and water quality is dominated by sodium and bicarbonate ions.

Two distinct ground-water settings are monitored as part of the MBMG coal-hydrogeology program. Near the mines at Colstrip, ground water is dominated by ions of magnesium, calcium and sulfate, representing local recharge. Near Decker, ground water is dominated by sodium and bicarbonate ions, indicating a position farther along the flow path.

Mining Impacts

Water Levels

Surface mines typically open at the coal croplines, with long pits following the topographic contours. Mine pits, oriented perpendicular to flow directions, intercept ground water and induce flow from storage along the pit walls, which are sometimes several miles long. New mine pits are opened and previous ones backfilled in a leap-frog fashion that progresses into new coal to be mined. In Montana mines thus far, the progressions have all been upgradient into areas of increasing hydrostatic pressure. As overburden material and coal are removed during the mining process, water flows into the mine pit from the exposed face of the aquifers. Water is collected in sumps, and pumped from the mine pits to maintain dry working areas. Much of the pit water is used for mine-related purposes such as dust suppression. Excess water is discharged to otherwise ephemeral stream channels. Water flowing into the pits, and its subsequent removal causes drawdown to occur in adjacent aquifers.

Also, it has been recognized recently that older exploration drilling programs have provided avenues for inter-aquifer mixing of ground water. Leakage through inadequately plugged boreholes near active surface mines is allowing drawdown to occur in deeper aquifers that are

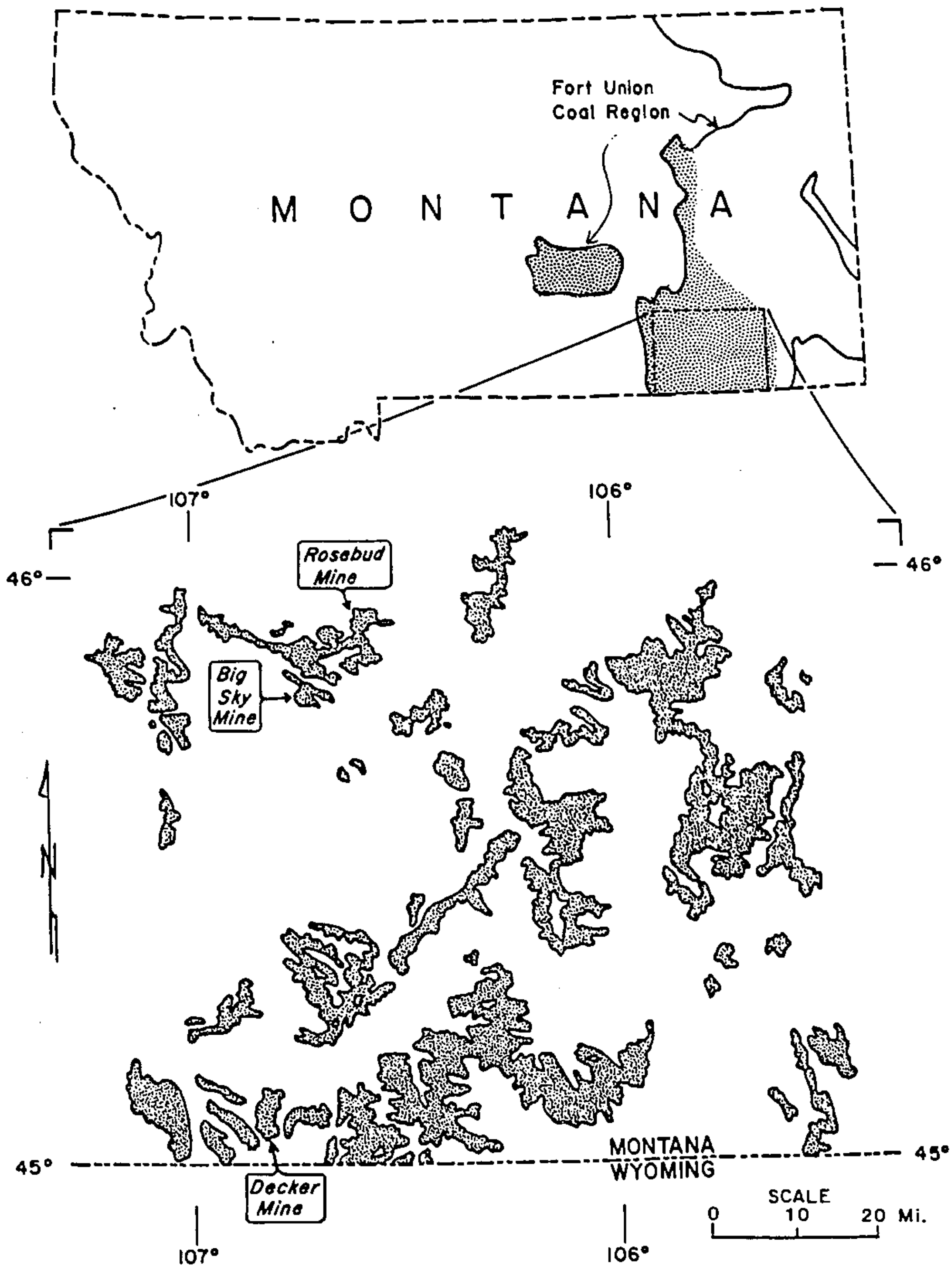

Figure 1. The Rosebud, Big Sky, and Decker mine areas are in the subbituminous portion (stippled pattern) of the Fort Union coal region.

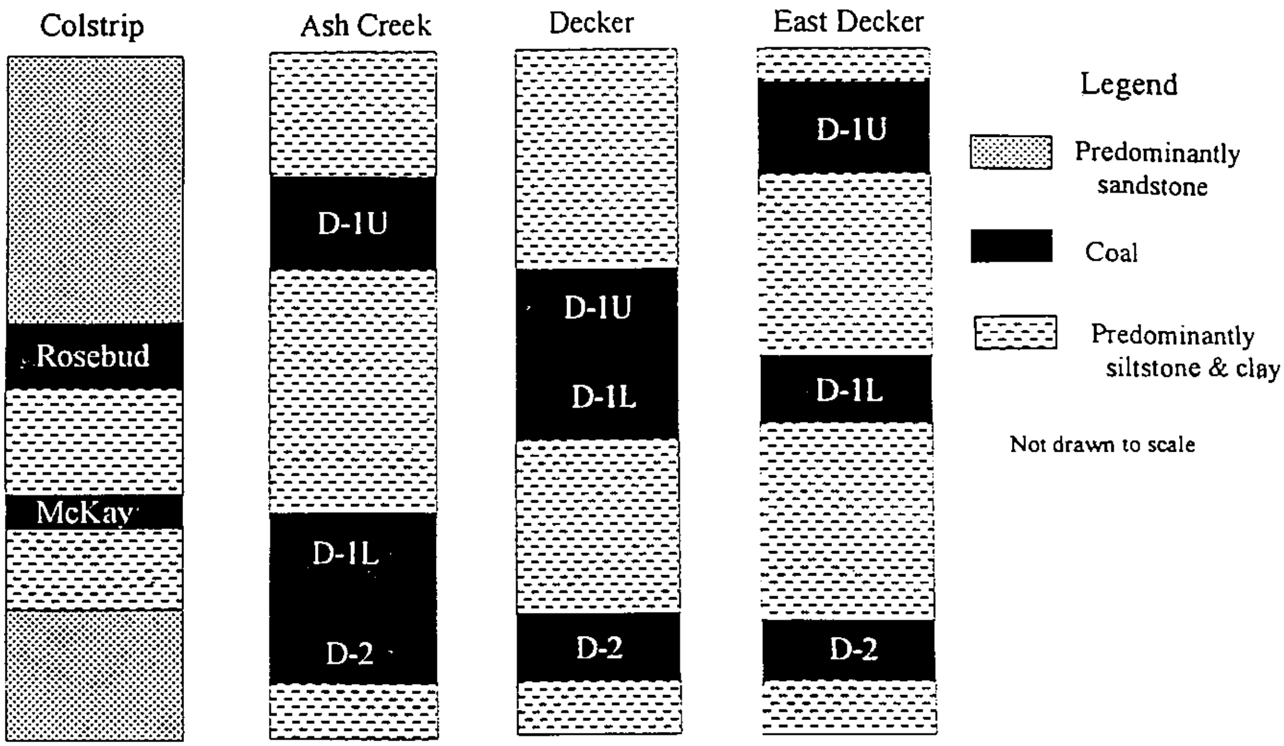

Figure 2. Near Colstrip the Rosebud seam is mined. The D-1 upper and the interburden were removed at Ash Creek; the D-1 and D-2 seams are mined at the Decker mine. Associated with the Fort Union Formation coals are interfingered clay, siltstone and sandstone. Sediments are more fine grained near Decker than near Colstrip.

otherwise not disturbed by mining (Van Voast and Reiten, 1988) (Wheaton and Reiten, 1996). In the past, exploration boreholes were plugged with bentonite slurries containing around 5-percent solids by volume, or in some cases with drill cuttings. Current practices utilize either high solids bentonite slurries or bentonite chips. The use of drill cuttings to seal boreholes has been discontinued.

Blasted and broken overburden backfilled in the pits replaces the original coal and sandstone aquifers. When the last pit in a mine sequence is backfilled, ground-water flow from adjacent bedrock aquifers (unmined coal and overburden) begins to saturate the spoils material; in Montana very little recharge occurs by infiltration of precipitation through the spoils. Mean hydraulic conductivity of the spoils material has been found to be similar to that of the pre-mine coal aquifers, averaging about 1 foot per day (Van Voast and Reiten, 1988). Because of the similarity in flow characteristics, water levels in spoils are returning to approximate pre-mine levels as the spoils are saturated and approach hydrostatic equilibrium.

Monitoring wells installed in and adjacent to mine areas are used to document water-level drawdowns related to pit inflow and inter-aquifer leakage during mining, and post-mining recovery of water levels during resaturation as the ground-water systems recover. In the Colstrip area, wells have been in place and monitored since 1974 (Figure 3). The primary aquifers are the Rosebud and McKay coal seams, both of which have been targets of mining. Currently only the upper seam, the Rosebud, is being mined. Pit inflows from the Rosebud coal and overburden sandstones and borehole leakage are causing water-level declines that typically begin when the mine pits are about two miles from the monitoring wells. As the pits progressively advance toward the wells, drawdown increases, eventually creating cones of depression tens of feet below pre-mining levels. Though the McKay coal is not being mined and is separated beneath the Rosebud seam by 30 or more feet of poorly permeable silty clay, drawdown is occurring (Figure 4), and at a greater rate than in the Rosebud seam because of leakage between coal seams and deeper aquifers through inadequately plugged exploration boreholes (Wheaton and Reiten, 1996).

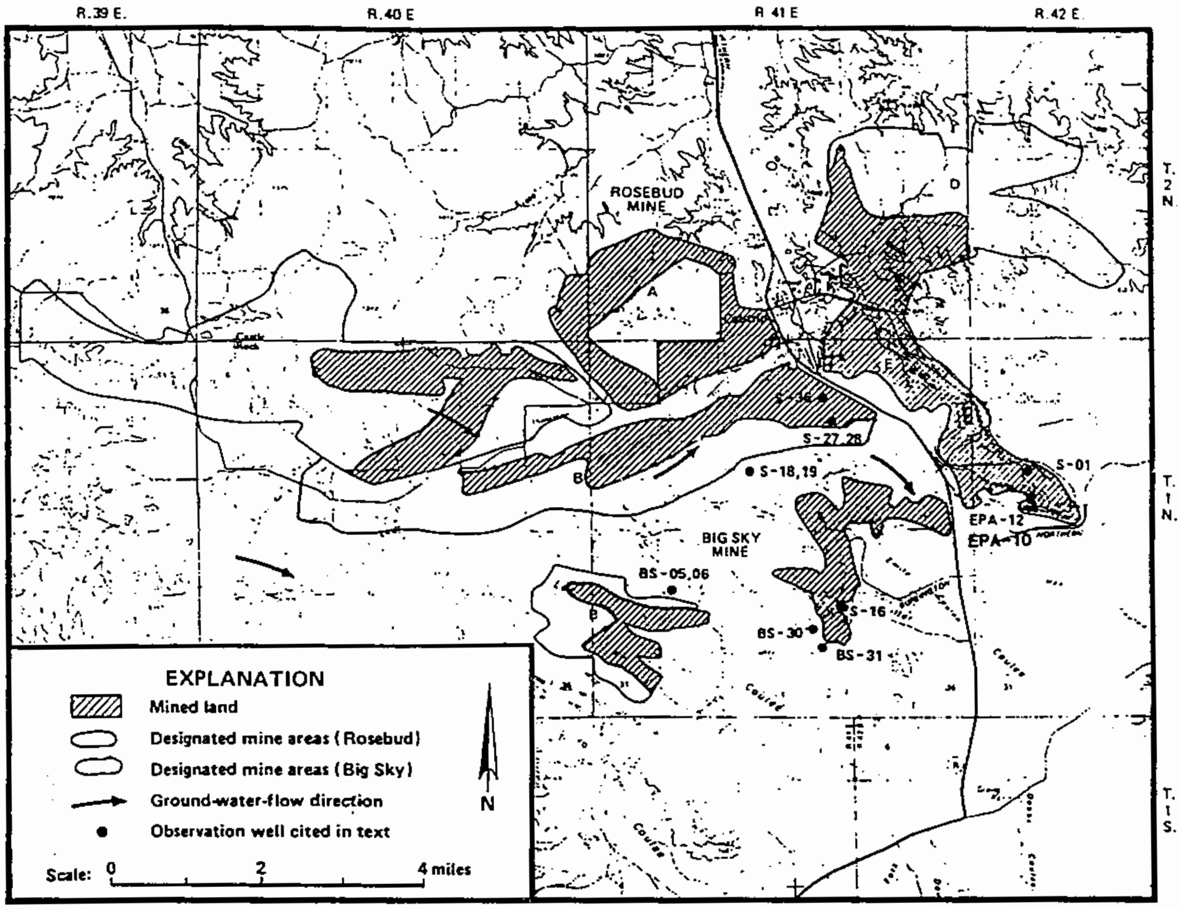

Figure 3. Many wells are monitored in and near the Rosebud and Big Sky mines. Those mentioned are shown here.

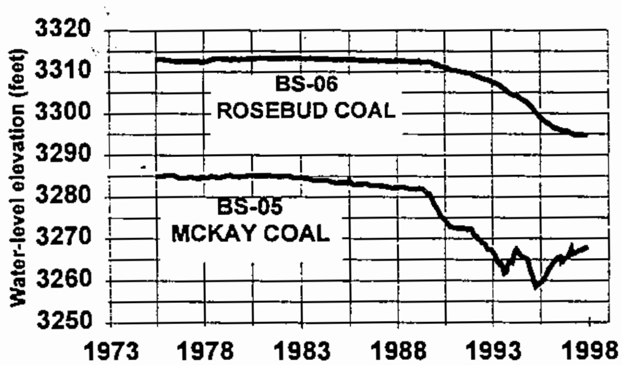

Figure 4. Water levels adjacent to coal-strip mines respond to pit inflow and dewatering. At this location the unmined McKay coal shows a greater response than the mined Rosebud coal due to poorly plugged bore holes.

Company data indicate recharge occurring in a stratigraphically deeper sandstone.

After the coal is removed and the mine pits are backfilled the spoils materials resaturates and adjacent bedrock aquifer water levels recover. The rate at which water levels recover varies between sites, but normally requires more than 20 years.

Numerous spoils monitoring wells have been installed. Spoils well S-36 was installed near the location where the Rosebud and McKay coal water levels were monitored in wells S-28 and S-27 respectively, until mining removed these coal wells. Figure 5 shows the

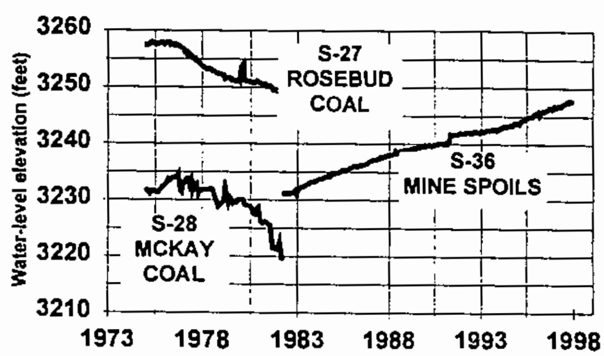

Figure 5. Well S-36 was drilled to replace mined out bedrock wells S-27 and S-28. Monitoring data from spoils well S-36 indicates water levels will likely recover to approach pre-mining levels

water level responses in the coal aquifers as mining approached and removed the site. Water-levels in the spoils aquifer at this location has risen slowly but steadily, having recovered about 15 feet toward the pre-mining level of the Rosebud coal (Figure 5). Full recovery has not yet occurred because the mine pit in this area is still open and intercepting part of the recharge to the spoils.

Fairly rapid recovery of adjacent coal aquifers impacted by mining is demonstrated by the water-level responses at Rosebud coal monitoring well BS-30 (Figure 6). Water levels in this well recovered during about 2 years, and have remained steady with seasonal fluctuations since.

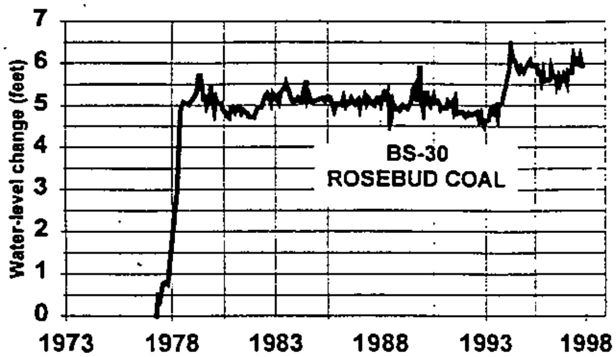

Figure 6. On the upgradient edge of the mine pit, water levels in the Rosebud coal seam recovered rapidly after mine reclamation.

Long-term water-level data show generally varying rates of recovery in the spoils such as at sites EPA-12 (Figure 7) and S-01 (Figure 8). Long-term data provide documentation of events that would be missed or improperly interpreted with shorter term databases. As

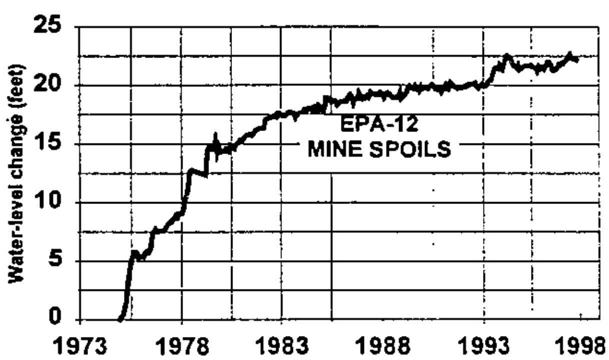

Figure 7. Water levels near spoils well EPA-12 have been recovering over a period of several decades.

an example, major recharge events roughly a decade apart are shown on Figure 8 and to a lesser degree on Figure 7. Those on Figure 8 clearly demonstrate the sporadic occurrences of ground-water recharge during years of unusually high precipitation in a semiarid climate, in contrast to the annual periodicity common in more humid conditions.

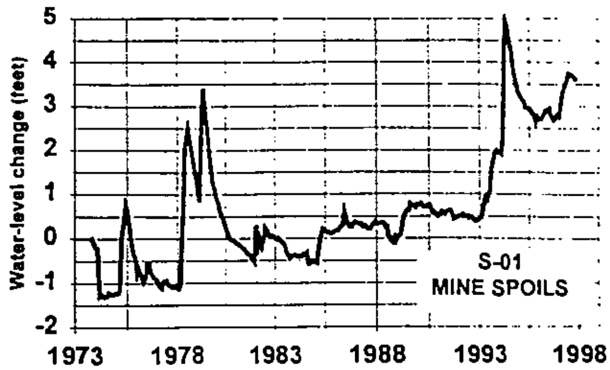

Figure 8. Recharge events that are decades apart are recorded in monitor data at spoils well S-01.

A geographic array of drawdown and recovery has been recorded in coal-bed aquifers associated with the West Decker Mine in Montana and the much smaller Ash Creek Mine in Wyoming (Figure 9). Well WR-22 (Figure 10) shows concurrent drawdowns from both mines and also shows a recovery as the smaller mine was backfilled and abandoned in 1996. Drawdowns at neither mine affected the water table in an alluvial aquifer between the two pits (Figure 11). Close to the Ash Creek Mine the full drawdown (Figure 12) probably exceeded 60 feet; at West Decker, total drawdown is about 100 feet. As pits of the West Decker Mine are progressively backfilled, a spoils aquifer is progressively being established and saturated by lateral inflow from an adjacent coal aquifer (Figure 13). At spoils well DS-03 for example, water levels and fluctuations are controlled by conditions in nearby alluvium along the Tongue River Reservoir, closely east of the mine. In 1997 the reservoir water level was lowered to an all time low to allow spillway reconstruction. This low surface-water level is reflected in the latest records for the adjacent spoils aquifer (Figure 13).

Water-level reactions to mining and reclamation in the various geologic units and mine settings at the Colstrip and Decker areas are substantially different. They result from differences in clay type and content, different positions in regional and local flow systems, variability of vertical and lateral recharge, and different aquifer storativities and transmissivities as discussed by Van Voast and Reiten (1988). In all cases, however, the impacts to stratigraphically deeper aquifers, not disturbed

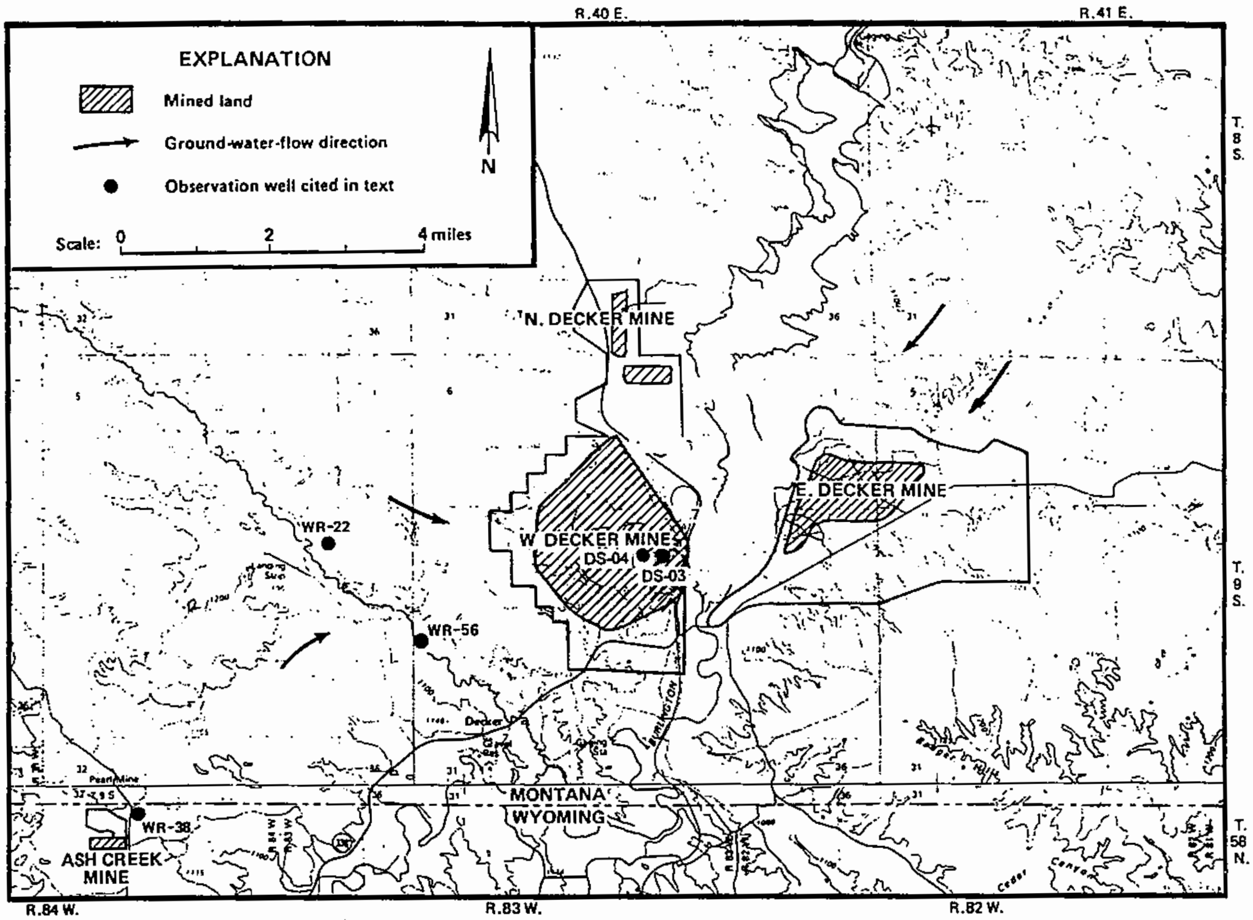

Figure 9. Ground water is monitored near several mines in the Decker area. Observation wells shown here are those mentioned in this report.

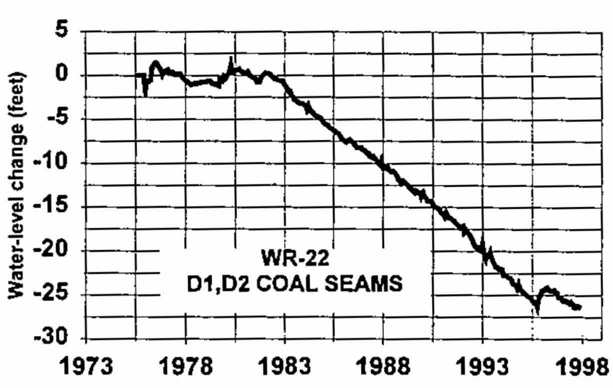

Figure 10. Water-level drawdown in response to mining in the Decker area has been very dramatic.

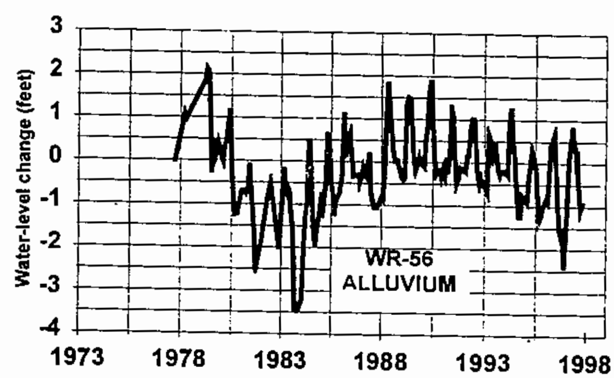

Figure 11. Water-level drawdown affecting underlying bedrock aquifers (Figure 10) has not been reflected in the overlying alluvium.

by mining, are being observed and attributed to poorly plugged coal-exploration boreholes (Wheaton and Reiten, 1996). The resulting hydrologic continuity created between aquifers, although mostly innocuous during active mining operations, will probably have far greater post-mining significance because of impacts to ground-water quality.

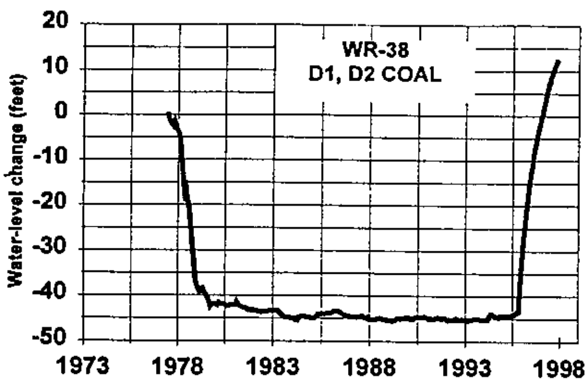

Figure 12. A nearly complete picture of draw down and recovery near a small coal mine is apparent in long-term monitoring data.

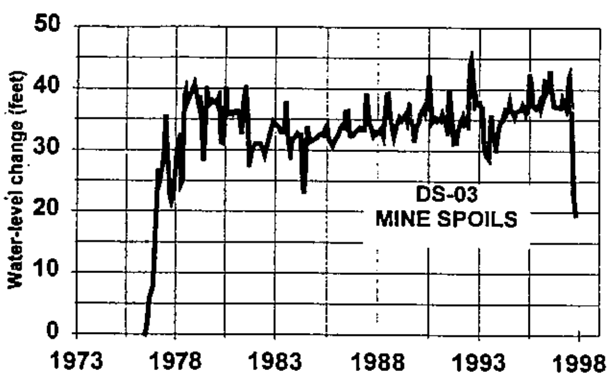

Figure 13. Recovery of water levels frequently occurs within about 2 years of mine reclamation. Seasonal fluctuations near well DS-03 reflect stage at the nearby Tongue River Reservoir.

Water Quality

During mine backfilling, the overburden stratigraphic column as placed in the mine pit is approximately inverted from its original orientation. Near-surface unsaturated and weathered rock layers become the skeletal material for the spoils aquifer. This process, when combined with blasting and fracturing during material handling, presents an abundance of available soluble salts. Dissolution of these salts causes increases in total dissolved solids (TDS) concentrations in the spoils aquifers that are 50 percent to 200 percent greater than the adjacent bedrock aquifers. Also, ion exchange reactions in the spoils may increase the ratio of sodium to calcium and magnesium concentrations as the surface area of shale that is exposed to ground-water flow is increased by mining. Mining breaks the shale layers into small chunks and pieces which, as part of the backfill process, are dropped into the pit to become part of the aquifer skeletal material.

Near Colstrip, TDS concentrations in undisturbed aquifers are typically around 1,500 to 2,000 mg/L, dominated by magnesium, calcium and sulfate ions. Particularly good quality water is apparent in Rosebud Coal monitoring well S-19 (Figure 14). As flow from the undisturbed aquifers discharges to the

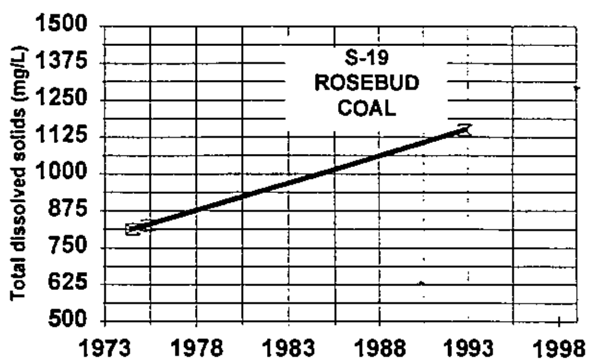

Figure 14. Undisturbed bedrock water quality is reflected in monitoring data for the Rosebud coal.

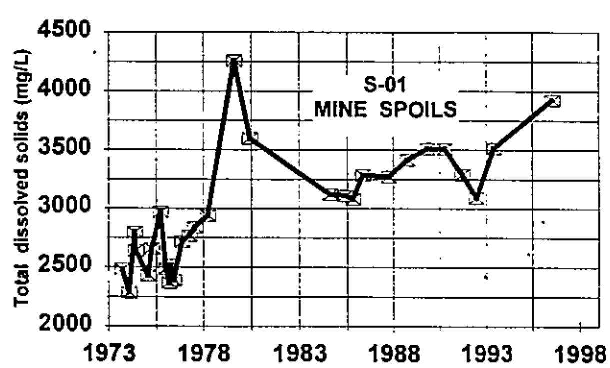

Figure 15. Water quality in the spoils is variable. TDS concentration at well S-01 continues a slow increase even after more than 20 years.

mine spoils, TDS concentrations increase as the soluble salts are mobilized. Much as in the undisturbed aquifers, water in the spoils aquifers near Colstrip is generally dominated by magnesium, calcium and sulfate, although the concentrations in the spoils water is far more variable than in undisturbed aquifers. The TDS load in the spoils near S-01 has continued to increase since the 1970's (Figure 15). The peak in TDS in 1979 clearly corresponds to the recharge event that same year (Figure 8), and represents an influx of recharge-mobilized weathering products (sulfate salts) to the aquifer. A peak may have also occurred in 1994, but was not documented by sampling. Where new salts are made available by weathering and oxidation, and are periodically dissolved

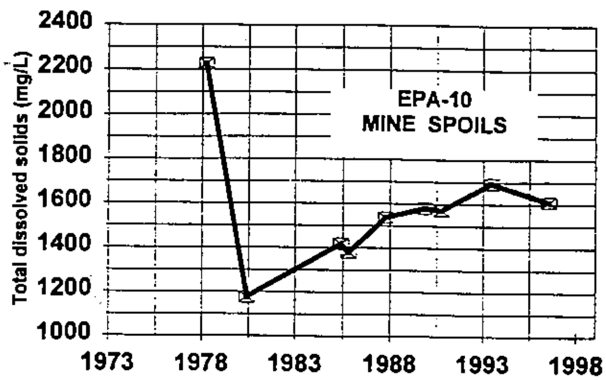

Figure 16. Water quality that compares favorably to pre-mining conditions (Figure 14) is due to the salts in the spoils material having largely been flushed by recharge.

and leached to the saturated zone, the dissolved solids concentrations remain elevated. In other places, available salts are being removed from the system by dissolution and flushing, and are not being replaced. There are a few examples where this may be happening, such as near EPA-10, where the TDS concentration is now very near that of bedrock aquifers at about 1,600 mg/L (Figure 16). As the dissolved solids laden spoils water moves downgradient, it is expected to impact adjacent off-site and also stratigraphically deeper aquifers. This has occurred in only a few known locations such as the underburden sandstone aquifer near S-16 (Figure 17) where the off-site TDS load increased markedly through the 1980's. Depending on periodic replenishing of weathering and oxidation products, the spoils aquifer may freshen due to natural flushing and impacts to receiving aquifers may decrease. The amount of sulfides available for oxidation and the rate of

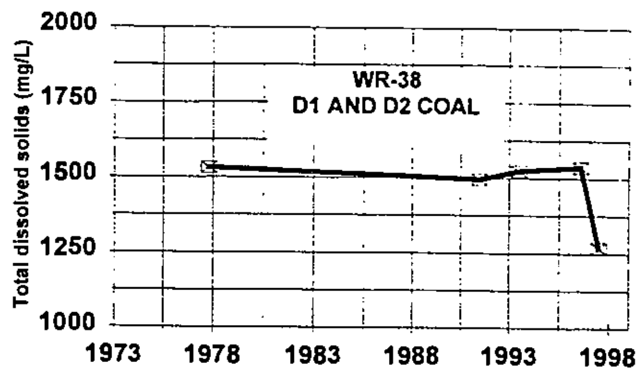

Figure 18. Water-quality trends in undisturbed coal aquifers near Decker show generally low and stable TDS concentrations.

recharge will determine future water quality in the mine spoils.

Similar responses to mining are occurring near Decker, where undisturbed water quality is dominated by sodium and bicarbonate ions. Background water quality in the combined D-1 lower and D-2 coal seam shows a TDS concentration of about 1,500 mg/L at well WR-38 through the year 1995 (Figure 18). Whether the sudden

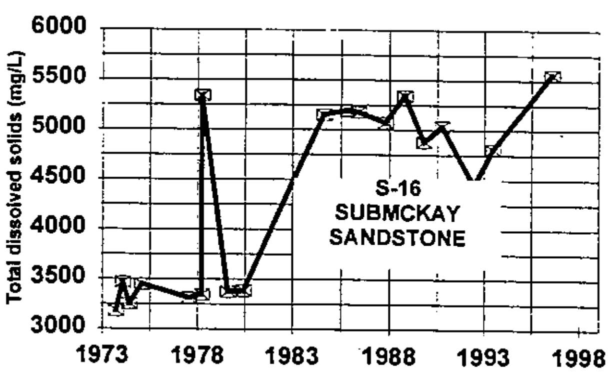

Figure 17. As the salt laden spoils water moves off-site, downgradient impacts are expected. Documented in only a few wells, downgradient impacts are apparent in tha underburden at S-16.

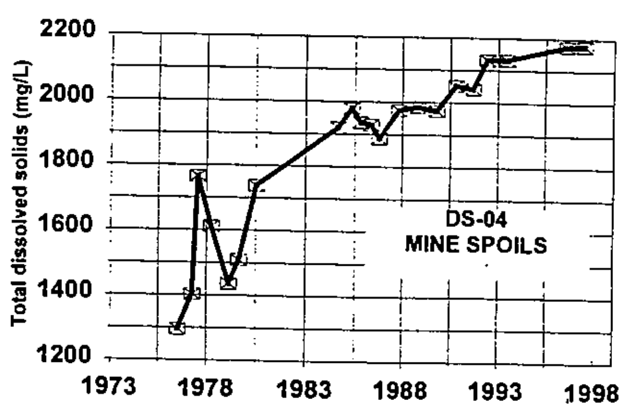

Figure 19. Water-quality data from DS-04 indicate fairly low, but continuously rising TDS concentrations.

decrease in 1996 is related to closure of the Ash Creek Mine will be determined with future monitoring. Water quality in the West Decker spoils near well DS-04 is dominated by sodium and bicarbonate ions, with a low but increasing TDS concentration (Figure 19). Nearby, at well DS-03, TDS concentrations peaked at about 7,500 mg/L during the late 1970's and now are near 2,500 mg/L (Figure 20). Ground-water quality at DS-03 is dominated by sodium and bicarbonate ions, but has a higher percent sulfate concentration than does DS-04. Generally at both DS-03 and DS-04 the sulfate concentration as an increasing percentage of total anions directly reflects changes in TDS concentration. As TDS concentrations increase, the ratio of sulfate to bicarbonate increases.

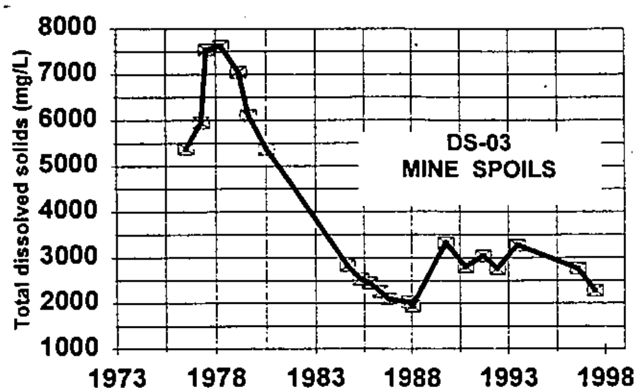

Figure 20. Water-quality data from DS-03 indicate the available salts have for the most part been flushed from that region of the spoils, possibly accelerated by strong fluctuations in water levels (Figure 13).

Conclusions

Surface coal mining does cause significant impacts to water levels and flow in local hydrogeological systems; however, these systems will eventually recover to near pre-mining conditions. Water levels are lowered for several miles around mines, with less impact occurring at greater distances. Post-mining recovery of water levels is sometimes accomplished within a few years, depending on availability of recharge from adjacent aquifers. The mean hydraulic conductivity value in spoils aquifers approaches that of undisturbed bedrock aquifers (Van Voast and Reiten, 1988). Thus, the quantity of water resources available after mining is very similar to the pre-mining conditions.

Ground water is of poor quality for many years after mining is completed. Sufficient time has not passed for complete recovery of any existing mine area. Certainly at some sites, return to pre-mining quality will eventually occur; at other sites where soluble salts are continuously generated by weathering and oxidation, the impacts to water quality may be permanent. Documentation of water-quality recovery in a mined area will be necessary to provide the data needed to allow accurate predictions of the duration of water-quality impacts. In order for the water quality to approach pre-mining conditions the salts must be dissolved and flushed from the saturated spoils and reclamation plans must allow for the through-flow of ground water. The ultimate fate of the flushed salts is not yet clear, because downgradient off-site TDS increases are not as high as expected.

Drawdowns in unmined, stratigraphically lower coal aquifers have been documented and are attributed to old, poorly plugged exploration boreholes. Because heads in the mined aquifers and spoils aquifers are higher than in underlying aquifers, there is a potential for poor quality spoils water to migrate to deeper aquifers through the boreholes. Current borehole plugging procedures are greatly improved over past practices (Wheaton and others, 1994), and should reduce or eliminate the vertical leakage in future mining areas.

The hydrologic monitoring at Montana surface coal mines has produced special information on mining impacts. The interpretation of hydrologic information has greatly improved our understanding of ground-water systems in mined areas. The types, severities, and durations of impacts are being scrutinized; the most important information yet to develop is a stronger knowledge and predictability of impacts and durations. Continuing the twenty-five-year history of this work, in cooperation with the U.S. Bureau of Land Management and other agencies, will refine and extend the understanding necessary for responsible coal development in the region.

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