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

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

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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.](image)

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 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 7.](image)

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

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

Water Quality

During mine backfilling, the overburden
stratigraphic column as placed in the mine pit is
approximately inverted from its original orientation.

Figure 12. A nearly complete picture of drawdown and recovery near a small
col 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.

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 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 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
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.

**References**


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