AN EVALUATION OF GROUND WATER CONDITIONS IN THE COLSTRIP COAL DEPOSIT, MONTANA[1]

Kirk Waren and Angela McDannel[2]

Abstract. An evaluation of groundwater conditions in the vicinity of coal mines near Colstrip, Montana was conducted in 2001 as part of a cumulative hydrologic impact analysis. This analysis was required due to permitting activities associated with an expansion of the Rosebud Mine.

Active coal mining operations at the Rosebud mine have expanded outward as low-cover coal is sought. Much of the remaining, unmined coal nearest to Colstrip and the adjacent coal-fired power plant is relatively high-cover coal, so mining has slowed in the interior area of the coal deposit in favor of lower-cost mining at the edges. Because the interior, high cover coal will eventually be mined according to mine plans, presently inactive pits remain open for future use. As the mine expands, additional information gained through hydrologic monitoring contributes to and increases the understanding of the groundwater system and how it is affected by mining.

Overall, groundwater flow directions are similar to pre-mine conditions. Where coal has been mined out, mine pit backfilled spoil maintains the groundwater flow formerly occurring in the coal seam. However, groundwater head distribution has changed significantly in some areas, and some of these head differences may be retained in the post mining groundwater environment. As mining operations have expanded, data suggests recharge to the principle coal seams may be more localized than was previously thought, and groundwater recharge from the Little Wolf Mountains southwest and upgradient of the coal deposit is limited. Drawdown of groundwater levels in the McKay coal seam, which lies beneath the mined Rosebud coal exceeds that observed in the Rosebud coal at many sites. While this phenomenon has previously been attributed to the presence of inadequately plugged coal exploration boreholes, data suggests this explanation is less likely near recent mining activities.

Additional Key Words: aquifer, confined, drawdown, spoil

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Introduction

The Colstrip coal deposit is located in the semi-arid northern Great Plains in southeastern Montana near the town of Colstrip. Colstrip is surrounded on three sides by areas permitted for mining. These areas are parts of two active surface mines, the Rosebud Mine operated by Western Energy Company, and the Big Sky Mine, operated by Big Sky Coal Company. Within the areas being mined, and adjacent to the town of Colstrip, is the Colstrip coal-fired electic power generation complex. A portion of the coal currently mined at Rosebud Mine fuels the neighboring power generation complex. Coal is also exported from the two mines via rail to various destinations.

The Colstrip coalfield is part of the Fort Union coal region and is situated in the northwest part of the Powder River Basin, a structural basin centered in northeastern Wyoming (Figure 1). Roberts et al. (1999) provide a concise overview of the geology and coal resources of the Colstrip coalfield. In their work, Roberts et al. (1999) describe the Colstrip coalfield as defined by the extent of the principal mineable coal seams, the Rosebud, McKay, and Robinson coal seams and bounded to the south by the Crow and Northern Cheyenne Indian Reservation boundaries. In contrast, this paper focuses on the eastern part of the Colstrip coalfield, that area defined as the Colstrip coal deposit by Matson and Blumer (1973), and particularly that portion of the coal deposit where hydrogeologic data is available largely as a result of the Colstrip area mining operations. The western part of the Colstrip coal field includes another mine, the Absaloka mine, not discussed in this report.

Geologic and Topographic Setting

In the vicinity of Colstrip, the Fort Union formation is characterized by nearly flat-lying sedimentary rocks, including claystones, siltstones and fine-grained sandstones interbedded with multiple coal seams of considerable lateral extent. The rock formations generally dip gently, less than a few degrees, to the south-southeast. The topographic setting is an erosional landscape that slopes generally north-northeast toward the Yellowstone River. Consequently, erosion has brought the coal seams close to the surface along irregular lines, similar to a topographic contour in rugged country (Figure 2).

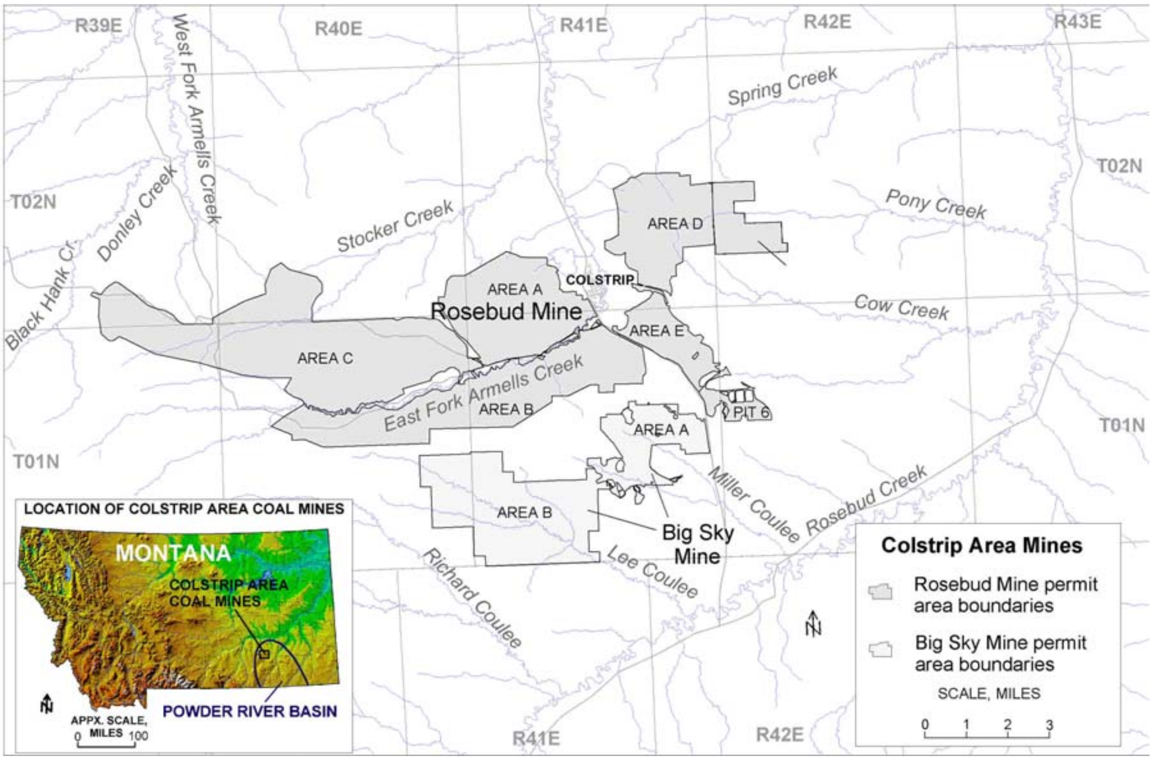

Figure 1. Location Map.

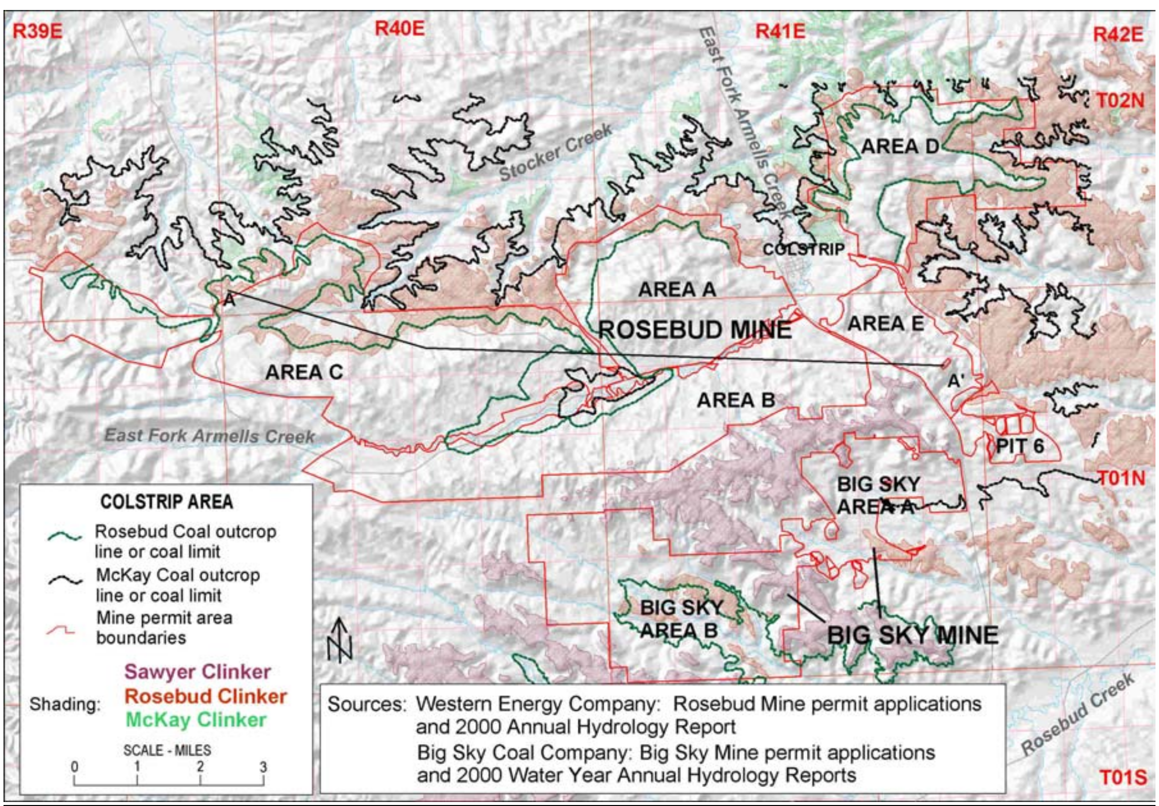

Figure 2. Coal outcrop or limit, and mapped scoria deposits in the Colstrip area.

Mineable coal occurs in areas of relatively low cover. Throughout the region, prehistoric coal fires have removed portions of coal seams, leaving behind clinker, or scoria, rocks baked by the burning coal. The clinker, though highly fractured, forms a hard, erosion-resistant rock, commonly forming ridges. In many places, the edges of the coal seams have burned, and coal is found only at depth some distance away from where it originally cropped out. Figure 2 shows mapped scoria deposits from three coal seams in the Colstrip area. The Sawyer clinker is stratigraphically higher than the Rosebud coal.

The Rosebud seam is the current source of coal mined in the Colstrip area. The deeper and thinner McKay coal seam was mined at Big Sky Mine Area A, but in other areas it has not been mined. The Rosebud seam averages 23 feet thick and the McKay averages 9 feet thick. Figure 3 is a cross section view of a portion of the Rosebud Mine. This cross section is vertically exaggerated. Note that high areas are typically capped by sandstone. The cross section is about eleven miles across (about 58,000 feet), but the total vertical relief of the structure of the continuous McKay coal is only about 250 feet.

The principal streams draining the Colstrip coal deposit in the vicinity of mining are Rosebud Creek and East Fork Armell's Creek. Rosebud Creek is a perennial stream. East Fork Armell's Creek is largely intermittent, with some perennial reaches. Both streams receive contributions from coal seams and other water bearing units incised by the tributary system, as well as seasonal surface flow.

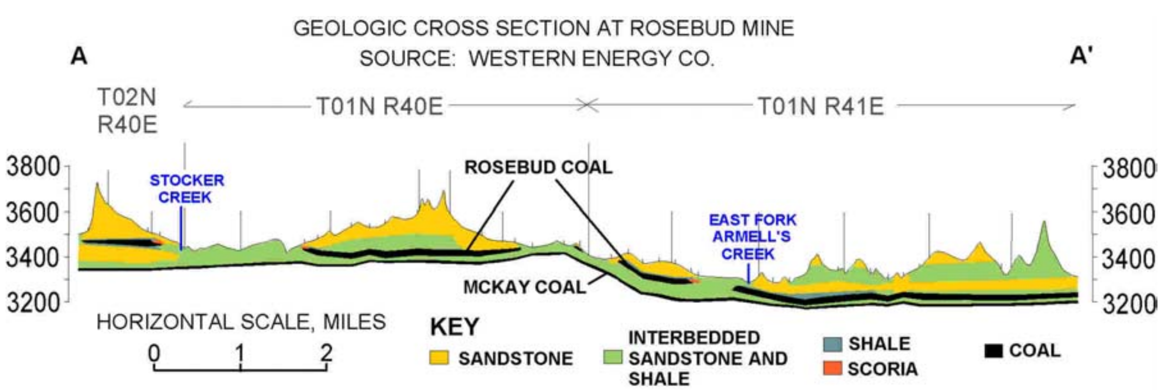

Figure 3. Cross sectional view of a portion of the Rosebud Mine (cross section location is shown in Figure 2.

Recent Mining Activities

Active operations at the Rosebud mine have expanded outward as low-cover coal is sought. Much of the remaining, unmined coal nearest to Colstrip and the adjacent coal-fired power plant is relatively high-cover coal, so mining has slowed in the interior area of the coal deposit in favor of lower-cost mining at the edges. Because the interior, high cover coal will eventually be mined according to mine plans, presently inactive pits remain open for future use. Figure 4 shows areas of recent mining activity. Note that most recent mining occurs at the distal edges of the mine.

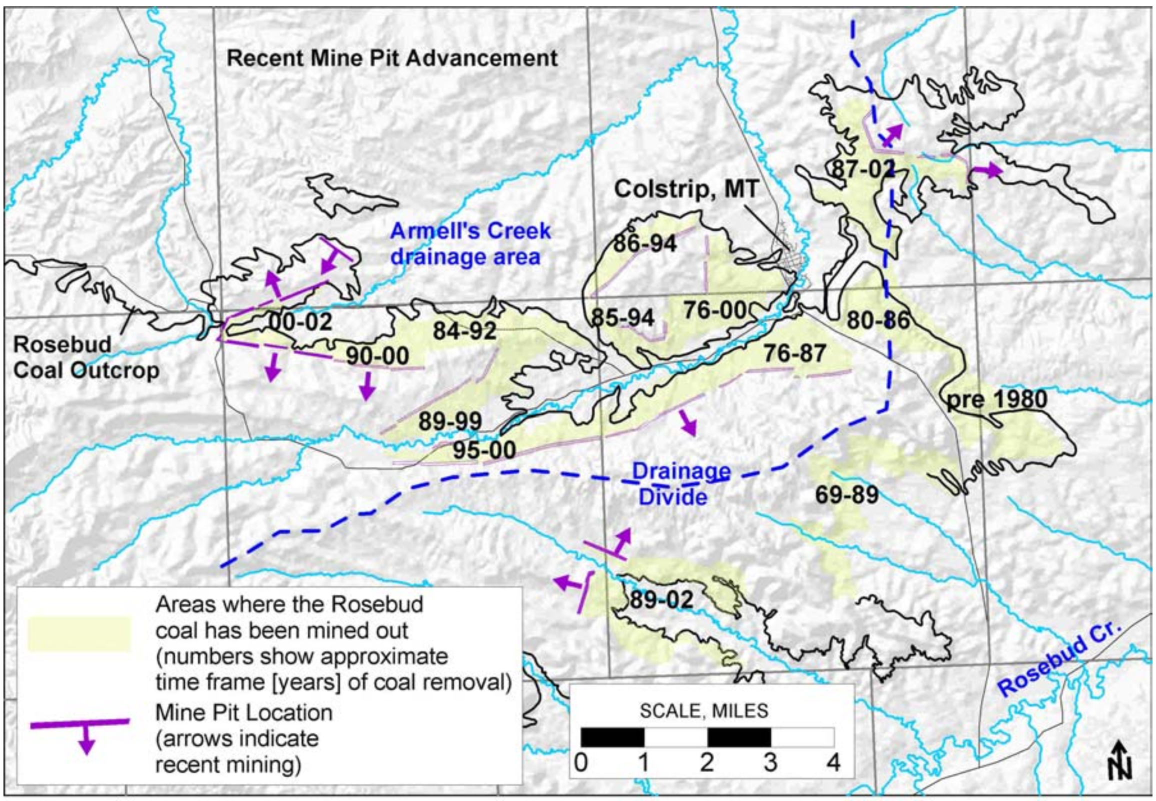

Figure 4. Recent mining activity (shown by arrows) at the Colstrip area mines.

Hydrogeologic Conditions

In the vicinity of the Colstrip mines, coal seams typically contain water, and are commonly saturated in interior areas, away from outcrops. Coal seams generally have modest transmissivity values and well yields. However, because they are laterally extensive and typically provide adequate amounts and quality of water for stock and domestic uses, coal seams are important aquifers in the region. Sandstones in this area are typically discontinuous, and therefore can prove to be difficult targets for water wells. Alluvial aquifers are also good water sources, but obviously occur in limited localities.

The Rosebud and McKay coal seams contain groundwater, and hundreds of groundwater monitoring wells are used to monitor conditions in these aquifers in the vicinity of the mines. Most of the monitoring is done by the coal mines and power generation complex, and some is done by the Montana Bureau of Mines and Geology. The potentiometric surfaces of the coal aquifers has been monitored, mapped, and analyzed many times during the history of mining. Van Voast and Reiten (1988) summarized the impacts of coal mining on groundwater conditions at the Colstrip area mines. Their findings showed that as coal is removed and voids filled with disturbed overburden backfill, or spoils, the coal aquifers are replaced by spoils aquifers. They also found that the bulk of groundwater enters the spoils laterally from surrounding, undisturbed aquifers, as opposed to recharge from precipitation.

Figure 5 is a map showing the groundwater surface in the Rosebud coal as mapped from monitoring well data within and around the Colstrip area mines. The green contours show the potentiometric surface in December 1976 as mapped by Van Voast et al. (1977). Blue contours show the potentiometric surface as of Fall, 2000, based on data from Western Energy Co., Big Sky Coal Company, Montana Bureau of Mines and Geology, and Pacific Power and Light. Monitoring well locations for the Fall, 2000 contours are shown as blue dots.

Overall, groundwater gradients as mapped in 2000 are similar to those mapped in 1976. In the vicinity of Rosebud Mine Area E and Pit 6 (Figure 5, location [a]), coal mining was completed in 1986 and the surface has been reclaimed. Increasing groundwater levels are observed in many of the spoils monitoring wells in this part of the mine. Location [b] in Figure 5 is an area near a divide that mining has approached from both the Rosebud Mine to the north and Big Sky Mine to the southeast. Groundwater levels in coal aquifers in this area have declined some 40 feet since the mid-1980's. Note the substantial shift in the position of the 1976 and 2000 3300 ft. groundwater elevation contours near location [b]. Mining has been completed at Big Sky Mine Area A, southeast of location [b], and that area has been reclaimed. A long series of pits remain open at Rosebud Mine to the north. In this area, it is uncertain whether groundwater levels will return to their original, pre-mine levels. Nevertheless, both coal seams are expected to remain saturated and the groundwater system will still function much as it did before mining.

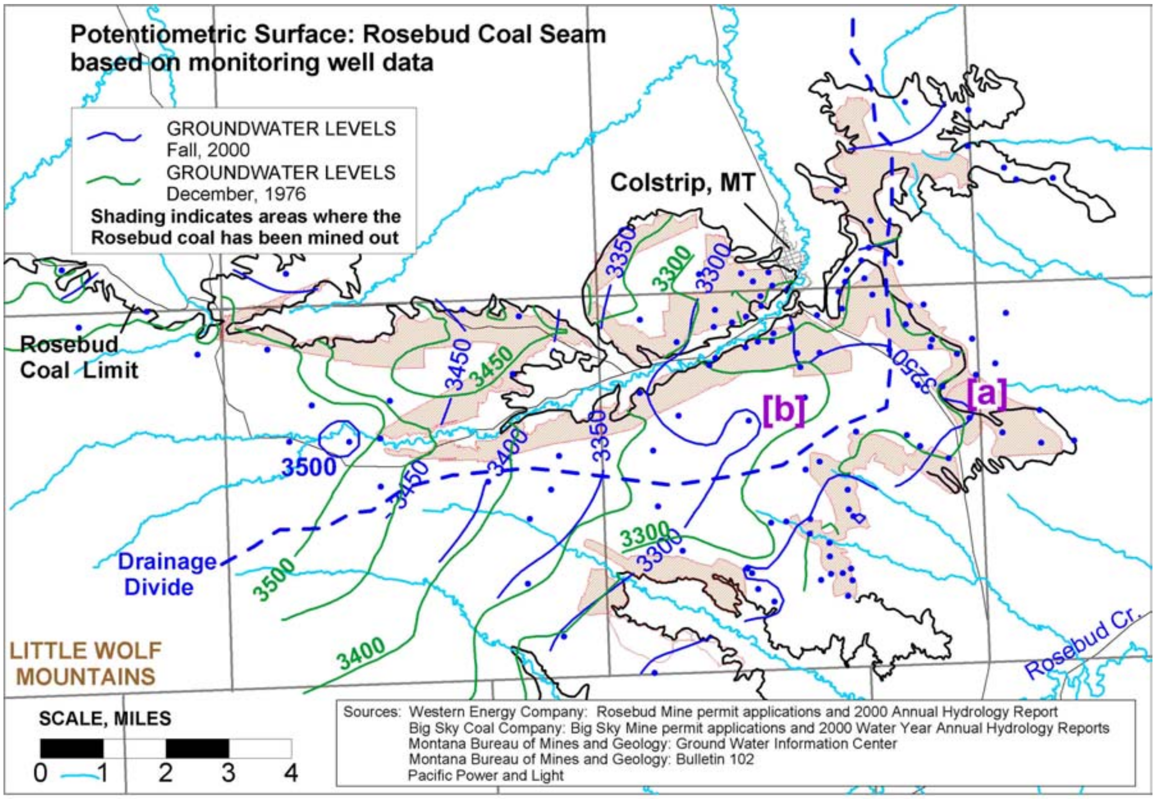

Figure 5. Comparison of 1976 and 2000 groundwater potentiometric surfaces for the Rosebud coal seam. See text for explanation of locations designated [a] and [b]. Contour interval 50 feet.

Because the groundwater gradient is generally from west to east in the mine areas west of Colstrip, the principal recharge area for the coal aquifers has long been considered the uplands west of the mines. However, as mining and groundwater data collection expands, accumulating data pose some interesting findings regarding the recharge and discharge zones for the coal aquifers.

Figure 6 is a map depicting both Rosebud and McKay potentiometric surfaces for year 2000, based on data from monitoring wells. Notice in the western part of the mapped groundwater gradient, west of the annotated monitoring well sites, that the Rosebud coal groundwater gradient is considerably flatter than it is to the east in the central part of the map. The gradient in this area seems to indicate a groundwater reecharge area is associated with the segment of Rosebud Creek upstream and upgradient of the mine. Groundwater contours for the deeper McKay coal seem to follow suit. It may be that the coal seams are so deeply buried under the highlands to the south-

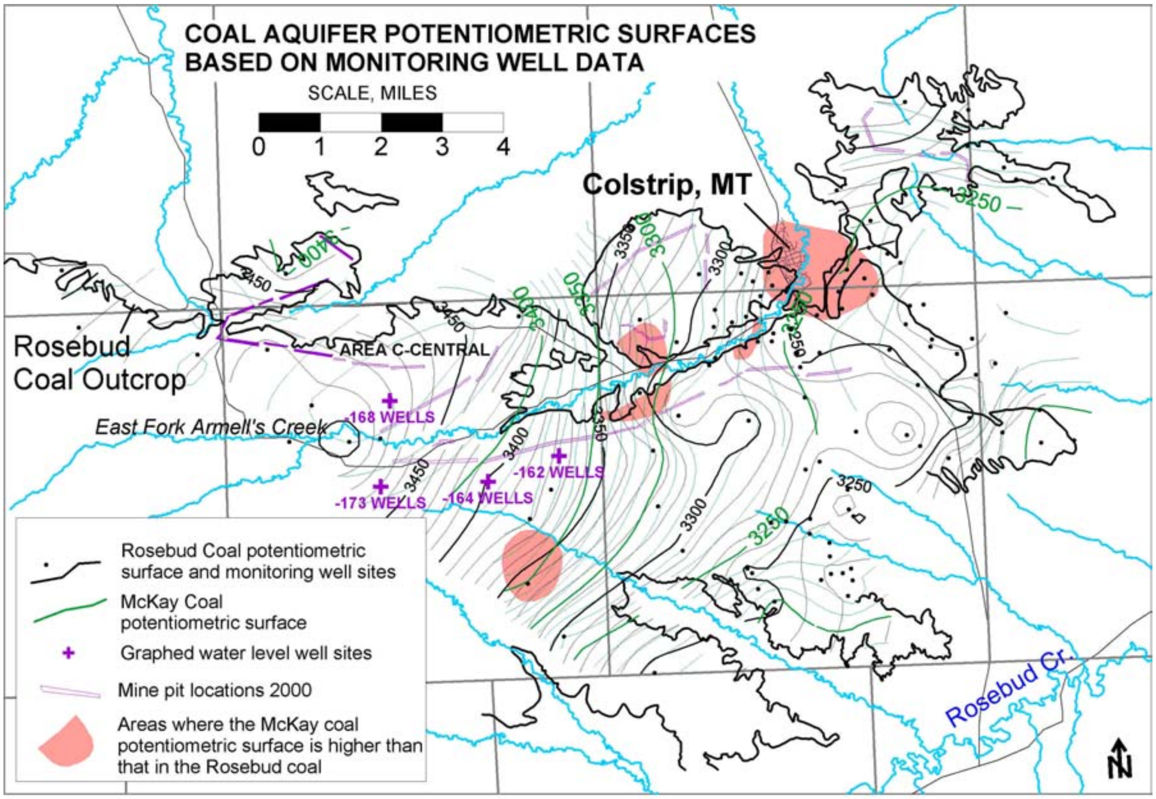

Figure 6. Coal aquifer potentiometric surfaces based on monitoring well data.

west that recharge is not so much concentrated at the core of the highlands, but perhaps occurs more at the edges of the highlands where the coal is at shallower depth.

Also shown on Figure 6 are areas where the potentiometric surface of the McKay coal exceeds that of the Rosebud coal, based on monitoring well data. As a rule of thumb, the vertical groundwater gradient is generally downward in interior areas away from coal limits or outcrops. Hence, the water level found in the Rosebud coal is typically at a higher elevation than the water level in the underlying McKay coal. Consequently, the McKay coal potentially receives recharge from the overlying Rosebud coal in most areas where the two coal seams are present. Discharge areas for both coals include springs at outcrops and subcrops, and this water feeds springs occurring in various drainages and also discharges to the alluvium of East Fork Armell's Creek. Figure 7 shows groundwater levels at selected well sets located in the vicinity of more recent mining. The nomenclature for wells is as follows: The letter W indicates wells from

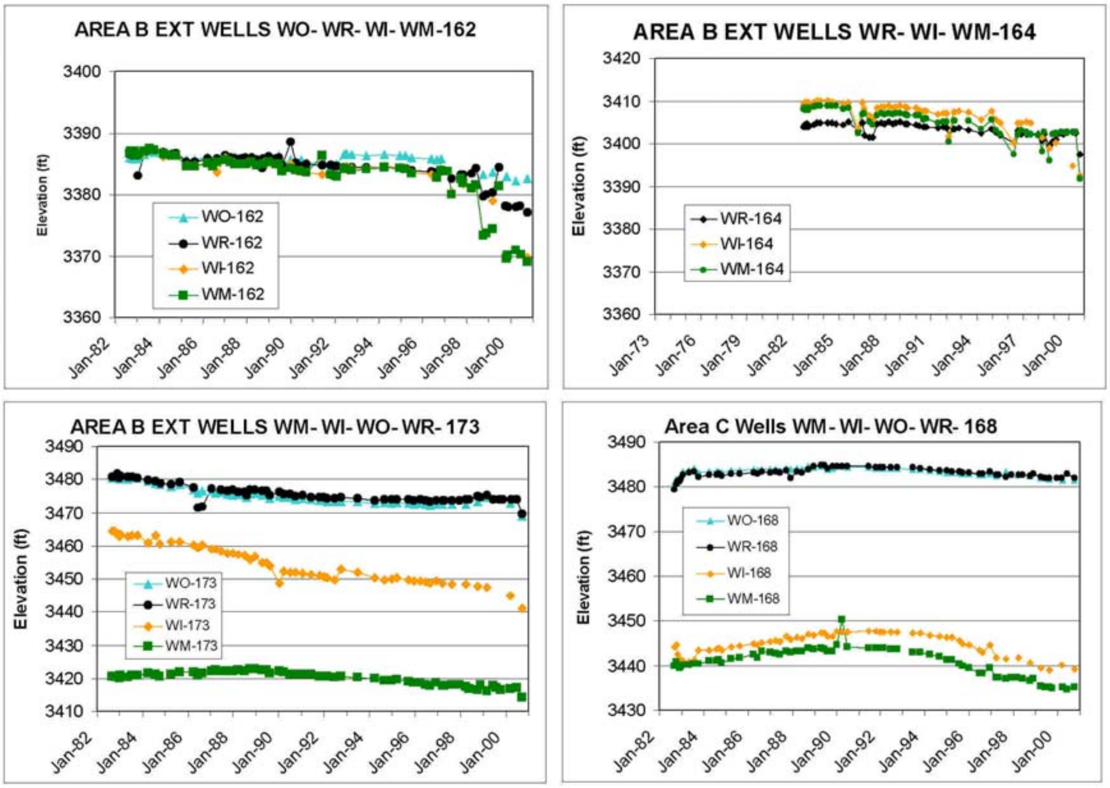

Figure 7. Graphs of water levels in selected well sets (locations shown in Figure 6). See text for explanation.

Western Enery Co.'s database. The second letter indicates the strata that the wells are completed in: O = overburden above the Rosebud coal seam, R = Rosebud coal seam, I = interburden between the Rosebud and McKay coal seams, M = McKay coal seam. Mining in Area B-West, south of East Fork Armell's Creek, and just north of the –173, -164, and –162 well sets as shown in Figure 6 was initiated in the mid 1990's. Notice that groundwater levels in the –164 and –162 well sets were historically at similar elevations in the two coal seams at these monitoring well sites. As mining progressed south toward the wells groundwater levels declined in both coal seams. At both well sets, drawdown observed in the deeper McKay coal exceeds that observed in the Rosebud coal. Area C-Central of Rosebud mine is located north of the –168 wells, as shown in Figure 6. Mining in Area C-Central was initiated in the mid-1980's. These well sets are located at sites where the potentiometric surface in the Rosebud coal is 40 to 60 feet higher than that in the underlying McKay coal. At these wells, drawdown also appears to be occurring in both coal seams.

Van Voast and Reiten (1988) noted that groundwater levels declined not only in the Rosebud coal, but also in the underlying McKay coal. Drawdown observed in the McKay coal sometimes exceeded that observed in the Rosebud. This was attributed to the confined condition of the McKay coal and differences in aquifer characteristics between the Rosebud coal and the McKay coal. Declines in the McKay coal were not predicted to occur as a result of mining, because it was thought that the clay beds in interburden between the coal seams would preclude significant hydrologic changes in the McKay coal. Van Voast and Reiten (1988) suggested poorly plugged coal exploration boreholes and fracturing of interburden during blasting as likely causes for the unanticipated vertical hydraulic connection between aquifers. Wheaton and Reiten (1996) conducted investigations of this phenomenon in the vicinity of Big Sky Mine Area B. They concluded that several factors may have contributed to greater drawdown observed in the unmined McKay coal seam relative to that in the Rosebud. These factors were differences in aquifer properties, mining-induced interception of recharge from shallower aquifers, and loss of groundwater through exploration boreholes.

Figure 8 is another map depicting both Rosebud and McKay potentiometric surfaces. In this map approximate water level elevations in pits and pit bottom elevations from a detailed year 2000 map of the mine (Western Energy Co., 2001) have been added and used in groundwater contour placement to reflect groundwater conditions more accurately. Pit bottom elevations were used in areas where the pits are dry and the Rosebud Coal is mined out. The relation between groundwater levels in the Rosebud coal and the underlying McKay coal depicted in this map is quite different than that shown in Figure 6. In this map, it is clear that the presence of open pits may greatly increase the area of lower groundwater head in the Rosebud relative to head in the McKay. Such reversal of vertical groundwater gradient would disrupt the natural groundwater recharge and discharge relationship between the strata. However, the shaded area is based on McKay coal data from wells. There is a paucity of data concerning McKay coal water levels at pit locations. Therefore, it is presently uncertain how much the McKay coal potentiometric surface may be influenced at and near pit locations. Perhaps the McKay coal potentiometric map resembles the revised Rosebud map (shown in Figure 8) that includes pit water level data.

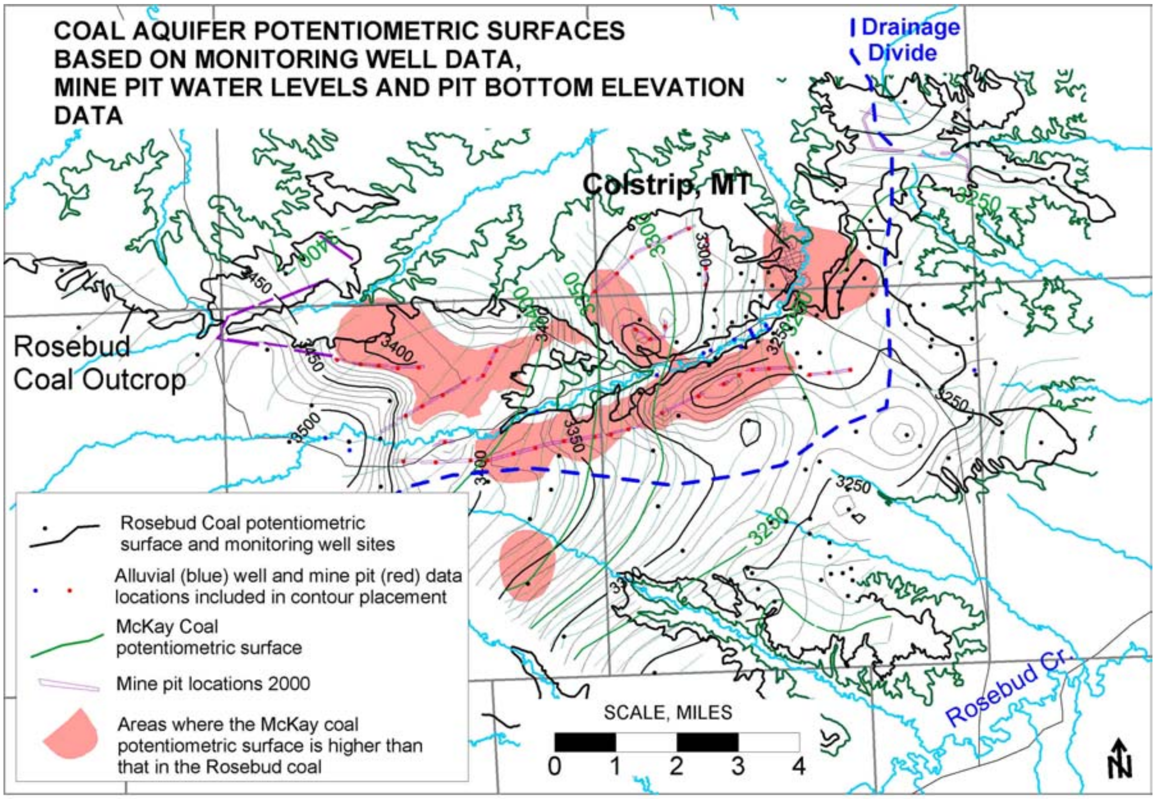

Figure 8. Coal aquifer potentiometric surfaces based on monitoring well data combined with mine pit water levels, pit bottom elevation data, and including alluvial well data from East Fork Armell's Creek alluvium.

As mining has expanded westward in the 1990's, the phenomenon of groundwater level declines in the deeper, unmined McKay coal exceeding those observed in the Rosebud coal continues to be observed in monitoring wells located at various distances from mining. The practice of drilling dense patterns of coal exploration wells through the Rosebud coal and into the McKay coal was not prevalent in areas mined in the 1990's, and borehole plugging methods should have improved. It appears that groundwater level declines in the deeper McKay coal are related to pit dewatering activities that affect the potentiometric surface of the Rosebud coal, and that this can occur even without the presence of densely spaced or poorly plugged exploration boreholes. As alluded to in earlier work (Wheaton and Reiten, 1996), the groundwater level declines in the McKay coal may result in part from changes in recharge/discharge relationships between strata. As shown in Figure 8, the shaded areas indicating higher head in the McKay coal than in the overlying Rosebud coal may now be potential groundwater discharge areas for the McKay coal, whereas before mining large portions of these areas were potential recharge areas.

Sets of water level change maps were constructed for the Rosebud and Mckay coal seams. Each map compares water level changes observed in wells over a four-year period to the locations of mining activities during the same period. Five sets cover the 20-year interval from 1980 to 2000. These maps are shown in Figures 9, 10 and 11. The patterns of declines and rises of water levels in are similar in the Rosebud and Mckay coal seams. Water level declines occur near mining, and then recovery occurs in both spoil aquifers and the McKay coal in areas where mining has been completed.

The declining groundwater levels in the deeper, unmined coal seam are somewhat mysterious. Because available information suggests the McKay coal is highly confined conditions, groundwater level impacts to overlying aquifers would not be expected in the McKay coal. This same type of unexpected hydraulic connection between shallow and deep aquifers was observed in a study conducted by the Montana Department of Natural Resources and Conservation in the late 1990's (Voeller and Waren, 1997). This work focused on irrigation return flow in the Flint Creek basin of western Montana. It was found that groundwater levels in deep, confined shale aquifers reacted in the same manner and magnitude as groundwater levels in overlying shallow sand and gravel aquifers affected by irrigation water infiltration. The confining layer was a soft clay that yielded virtually no water. In one shallow and deep well set, aquifer tests demonstrated no detectible hydraulic communication between shallow and deep wells, yet groundwater level monitoring showed that the shallow and deep aquifer potentiometric level responses to irrigation activities were nearly identical, varying on the order of 20 feet over the seasons. Subsequent groundwater modeling efforts by Kauffman (1999) for this study area revealed that the reaction of groundwater level changes in the deep shale aquifer could not be reproduced in a groundwater flow model without assigning some substantial hydraulic connection through the clay. While this assumed hydraulic connection was justified by the possibility that clay layers were not continuous, this could not be verified.

The similarity of the Flint Creek findings and the observations of groundwater level fluctuations in the McKay coal is that groundwater level changes seem to occur in certain confined aquifers as a result of large changes in groundwater levels in shallower aquifers, even

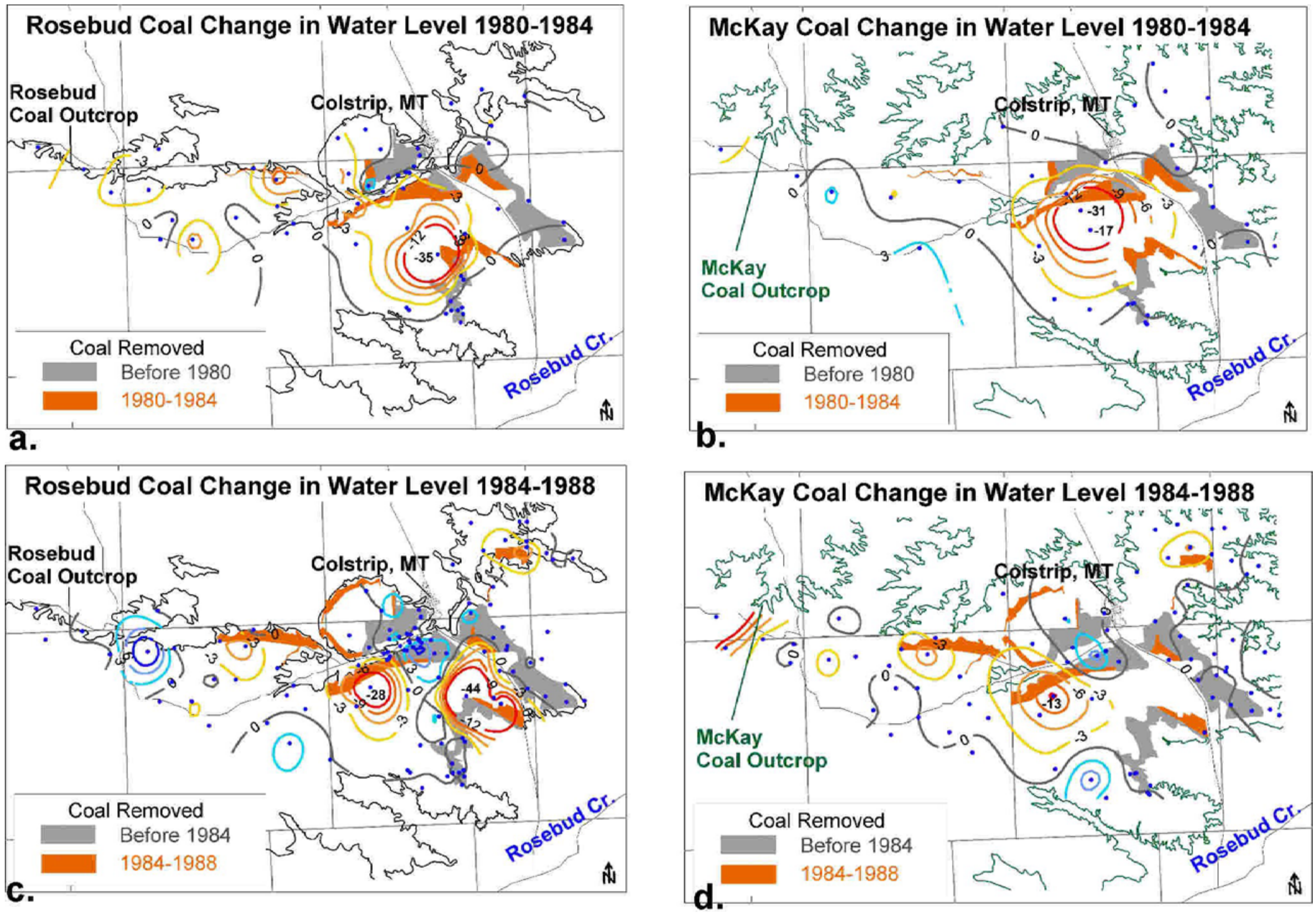

Figure 9. Contour maps of water level changes (in feet) observed in wells completed in the Rosebud coal (including spoils and selected alluvial wells) and Mckay coal aquifers, 1980 to 1984 (a and b), and 1984 to 1988 (c and d). Mining activity for each period is shown by shading. Contour interval = 3 feet.

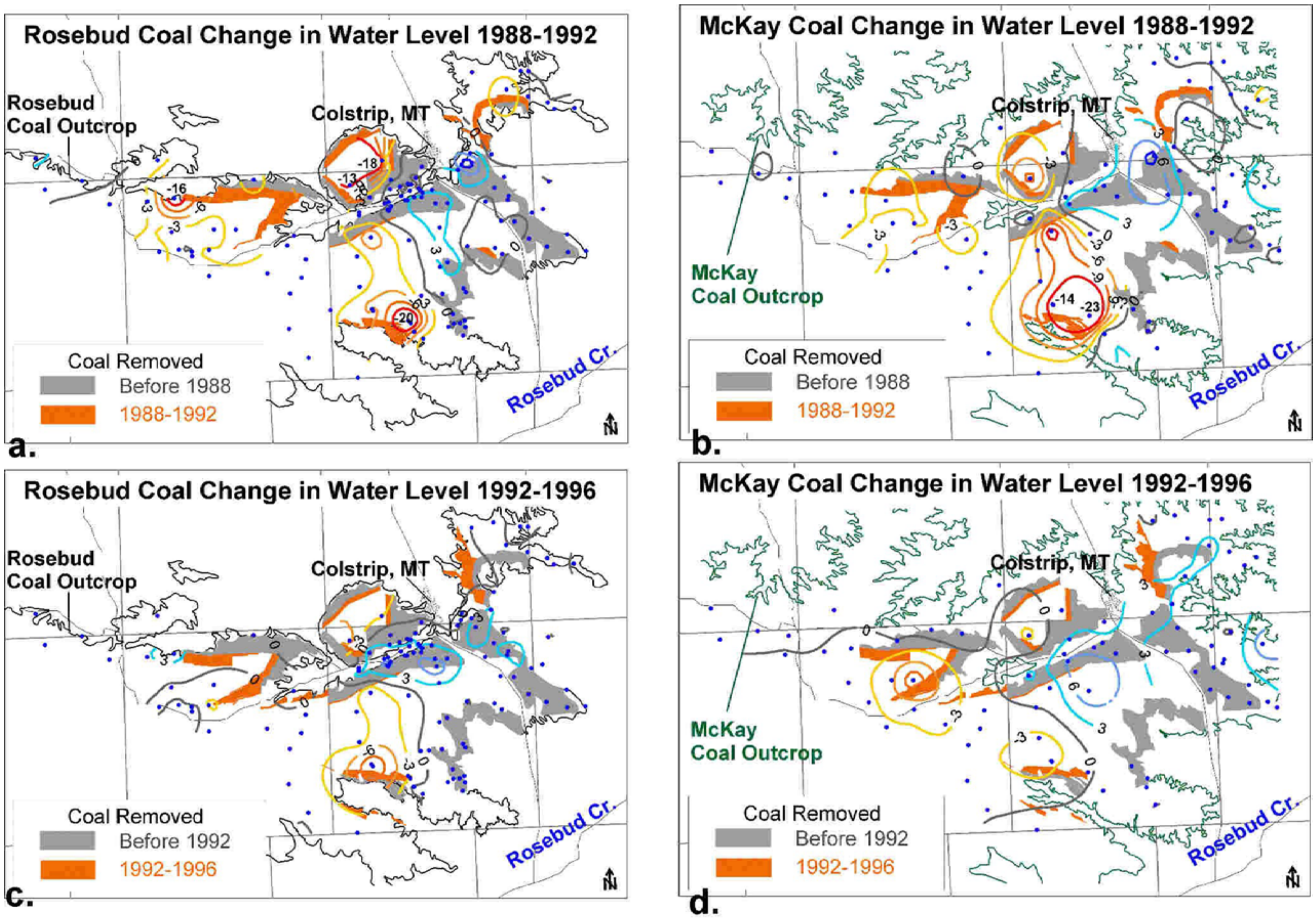

Figure 10. Contour maps of water level changes (in feet) observed in wells completed in the Rosebud coal (including spoils and selected alluvial wells) and Mckay coal aquifers, 1988 to 1992 (a and b), and 1992 to 1996 (c and d). Mining activity for each period is shown by shading. Contour interval = 3 feet.

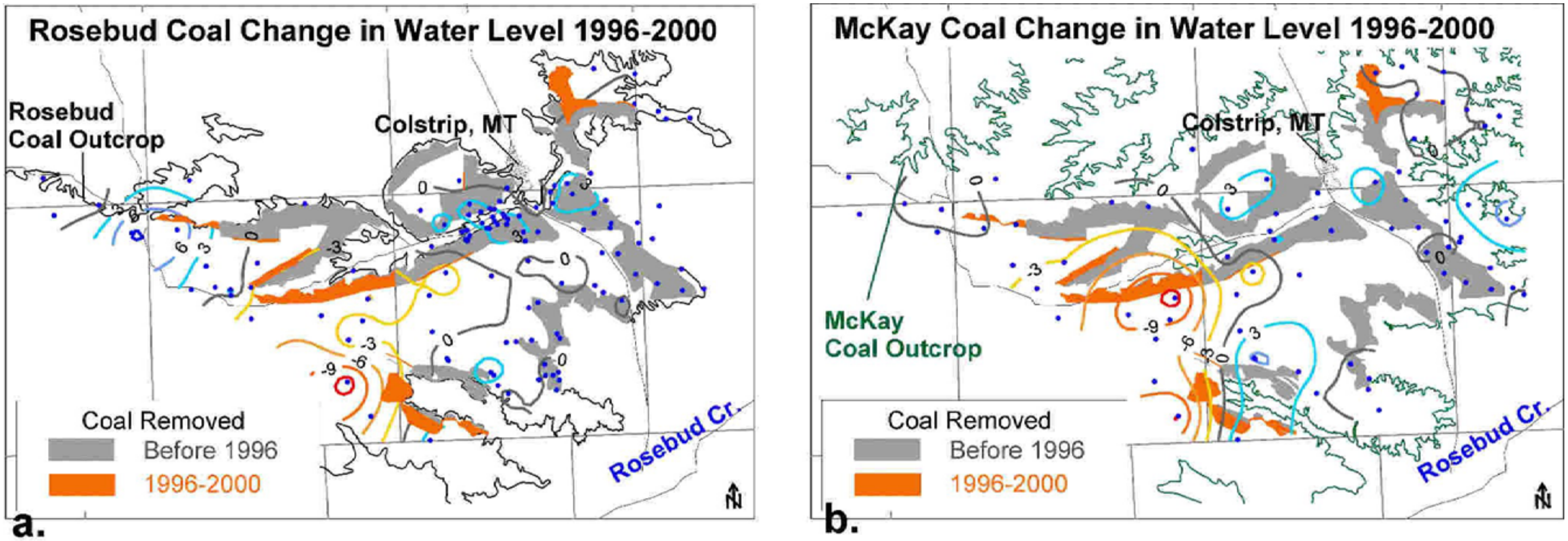

Figure 11. Contour maps of water level changes (in feet) observed in wells completed in the Rosebud coal (including spoils and selected alluvial wells) and Mckay coal aquifers, 1996 to 2000 (a and b). Mining activity for each period is shown by shading. Contour interval = 3 feet.

though available data suggests a poor hydraulic connection. In both cases, the confining materials are poorly consolidated Tertiary age sediments. Perhaps the hydraulic characteristics of the confining strata cannot be fully evaluated by point data such as provided by aquifer tests or well logs. On a large scale, discontinuities in clay layers or fractures may short-circuit the confining layer. Poorly plugged exploration boreholes and fracturing of interburden caused by blasting certainly could contribute to a hydraulic connection through the interburden. However, it is not yet possible to eliminate the possibility that groundwater levels in the McKay coal or other deeper aquifers may decline as a result of dewatering activities associated with mining regardless of such induced connectivity.

Conclusions

As mining operations have expanded, coal aquifer potentiometric maps suggest that recharge to the principal coal seams may be more localized than was previously thought, and that groundwater recharge from the Little Wolf Mountains southwest and upgradient of the coal deposit is limited. Drawdown of groundwater levels in the McKay coal seam, which lies beneath the mined Rosebud coal, exceeds that observed in the Rosebud coal at many sites. Inadequately plugged boreholes and fractures in interburden caused by blasting likely contribute to the hydraulic connection between the mined and unmined coal seams in places, but these explanations may not apply to all areas, particularly areas most recently mined. Eventually, perhaps further research and analyses will be able to definitively show exactly why drawdown occurs in a deeper, confined coal aquifer at the Colstrip area mines, even though available information suggests it should be hydraulically separated from overlying coal. Until such time, we can only note that such impacts do tend to occur and utilize this observation in assessing the impacts of future mining on deeper aquifers.

Acknowledgements

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