OVERVIEW OF COAL-BED METHANE DEVELOPMENT AND A DISCUSSION OF MONTANA IMPACTS[1]

by

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Abstract. Natural gas (methane) production from coal beds is a new and important industry in Wyoming and Montana. Methane forms by biogenic and thermogenic alteration of the coal. Coal-bed methane (CBM) is held in the coal seam by adsorption to the coal combined with hydrostatic pressure of water in the coal cleats. Production is accomplished by reducing the water pressure, allowing methane to be released from the cleat faces and micro-pores in the coal. Water pressure in the coal aquifer is reduced across large areas by pumping water from well fields.

Although coal-bed methane represents a clean, economical energy source, the extraction of large volumes of water over a large portion of the Powder River Basin raises significant concerns. Coal beds are important aquifers in the southeastern Montana coal region. With development of methane from the coal, the potential exists for reducing water availability over much of the region. More than 10 feet of drawdown have occurred within a 1- to 2-mile radius around development near Decker, Montana, during the first year of production. As additional wells come on line and with continued pumping the area of influence will expand. The quality of water discharged from the wells is dominated by sodium and bicarbonate ions, with SAR values frequently greater than 40. Disposal options being considered for this water include land application, direct discharge to drainages or rivers, storage in impoundments, or re-injection. To date, direct discharge to the Tongue River has been the default alternative in Montana. Impacts to channel stability and downstream irrigators seem likely. Initial methane development is occurring within the area of hydrologic influence of active coal mines. The cumulative effect of these activities and the interception of mine-spoils recharge by coal-bed methane wells have raised questions about restoration of the hydrologic balance during mine reclamation.

Additional Key Words: Hydrogeologic impacts; SAR; Tongue River

Introduction

Natural gas (methane) production from coal-beds is a new and potentially important industry in Wyoming and Montana. Coal-bed methane forms by microbial activity during coalification and early burial of organic rich sediments and by thermal generation at higher temperatures with increasing depth of burial. Much of the methane generated during burial is lost to the atmosphere (Law and Rice, 1993). Some researchers have suggested that modern bacteria continue to generate methane in shallow coal beds. The realization that CBM represented a new energy resource for the nation occurred during mine safety work in Alabama (Pashin and Hinkle, 1997).

Based on data published by the Potential Gas Committee (Schwochow, 1999) coal bed methane (CBM) may represent about 15 percent of total natural gas reserves in the United States. CBM production is well established in New Mexico, Colorado, Alabama, and Wyoming, and is rapidly being explored and developed in the Powder River Basin area of Montana.

Although economic benefits to the region from CBM gas production appear promising, residents of the Tongue River watershed are concerned over potential impacts to surface-water and ground-water resources. To assess impacts in the Powder River Basin, the Bureau of Land Management (BLM) has completed the

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WYODAK Environmental Impact Statement (BLM, 1999) and is working on other Environmental Impact Statement and Environmental Analysis documents to assess impacts in Montana.

The Tongue River contains relatively high-quality water that presently supports irrigation, livestock, important fisheries, and riparian ecosystems. Mean annual discharge for the Tongue River at the Montana-Wyoming state line is 463 cubic feet per second (cfs) and at its confluence with the Yellowstone River 423 cfs, based on USGS streamflow records. Sodium adsorption ratios (SAR) typically range from less than 1 at the state line to more than 2 at Miles City. Specific conductance (SC) values are normally below 500 umhos/cm at the state line and less than 1,000 umhos/cm at Miles City (USGS monitoring data).

Coal seams are important aquifers for local stock and domestic uses in southeastern Montana. These aquifers are important targets for water-well drilling in the area because they are the most laterally continuous lithologic units capable of transmitting usable quantities of water and provide water of the best quality. The coal beds sustain springs and provide ground-water baseflow to streams. Water sources are frequently considered the limiting factor for economic growth in the region. Land owners, mineral estate holders and government agencies are faced with the task of deciding on the location, timing and extent of coal-bed methane development that will occur in Montana in the near future.

To provide a source of information on CBM activities and natural resource publications, the Montana Bureau of Mines and Geology (MBMG) and the Bureau of Land Management have jointly created a searchable, annotated bibliography on a web page. Readers interested in finding additional information on any subject relating to the Powder River Basin or coal-bed methane are encouraged to visit this site at: http:\\mbmgcoal\msubillings\edu. MBMG is also nearing completion of several GIS maps to show CBM development and hydrologic resources. The first of these shows major coal crops in southeastern Montana (Van Voast, 2001).

Regional Setting

CBM development in Montana is currently concentrated in the Decker area (Figure 1). This area is sparsely populated, semi-arid grassland with rolling to ruggedly dissected topography. Most of the land is utilized for cattle ranching, dryland farming, or coal mining with flood-irrigated farmlands along stream valley floors.

Paleocene-age sandstone, shale and subbituminous coal beds of the Tongue River Member of the Fort Union Formation underlie the region. Coal seams of the Tongue River Member split and converge due to the depositional setting (Flores and Bader, 1999). The result is a complex stratigraphic package of interbedded aquifers and aquitards.

Coal resources in the Powder River Basin are estimated at 1.3 trillion tons (Rightmire, and others, 1984). Of the numerous coal beds in the Powder River Basin, the primary targets for CBM development are the Anderson, Dietz and Canyon (WYODAK in Wyoming) and the Knobloch (Table 1).

Recharge to the ground-water systems occurs along clinker-capped ridges, at areas of outcrops of sandstone and coal, and where streams cross these outcrops. Ground-water flows through sandstone and coal aquifers from topographically high recharge areas to low areas along major stream and river valleys. In the Decker area of Montana, ground-water flow is eastward from the Wolf Mountains toward the Tongue River and northward toward the Yellowstone River. The major components of a ground-water flow system are shown in Figure 2.

Ground-water flow in coal seams is primarily along cleat faces. In the Decker area the direction of maximum hydraulic conductivity is most likely northwest-southeast with secondary hydraulic conductivity oriented northeast-southwest. The ratio of anisotropy is estimated to be about 1:0.6 (Davis, 1984). Many of the faults in the region have been shown to be ground-water flow barriers (Van Voast and Reiten, 1988).

Ground-water quality near recharge areas is dominated by sulfide oxidation and typically reflects high concentrations of sulfate and total dissolved solids (TDS). Cation exchange with sodic shales increases the proportion of sodium relative to calcium and magnesium. Consequently the water has sodium adsorption ratio (SAR) values that frequently exceed 40 and in some wells exceed 50 (Van Voast and Hedges, 1975). The high values of TDS and SAR render the water unsuitable for irrigation. Deeper anaerobic conditions in the coal promote sulfate reduction, resulting in sodium bicarbonate dominated water.

CBM Production

CBM is held on cleat surfaces and in micro-pores in coal (Law and Rice,1993; Rightmire, Eddy and Kirr, 1984). The gas is held in place by attractive forces

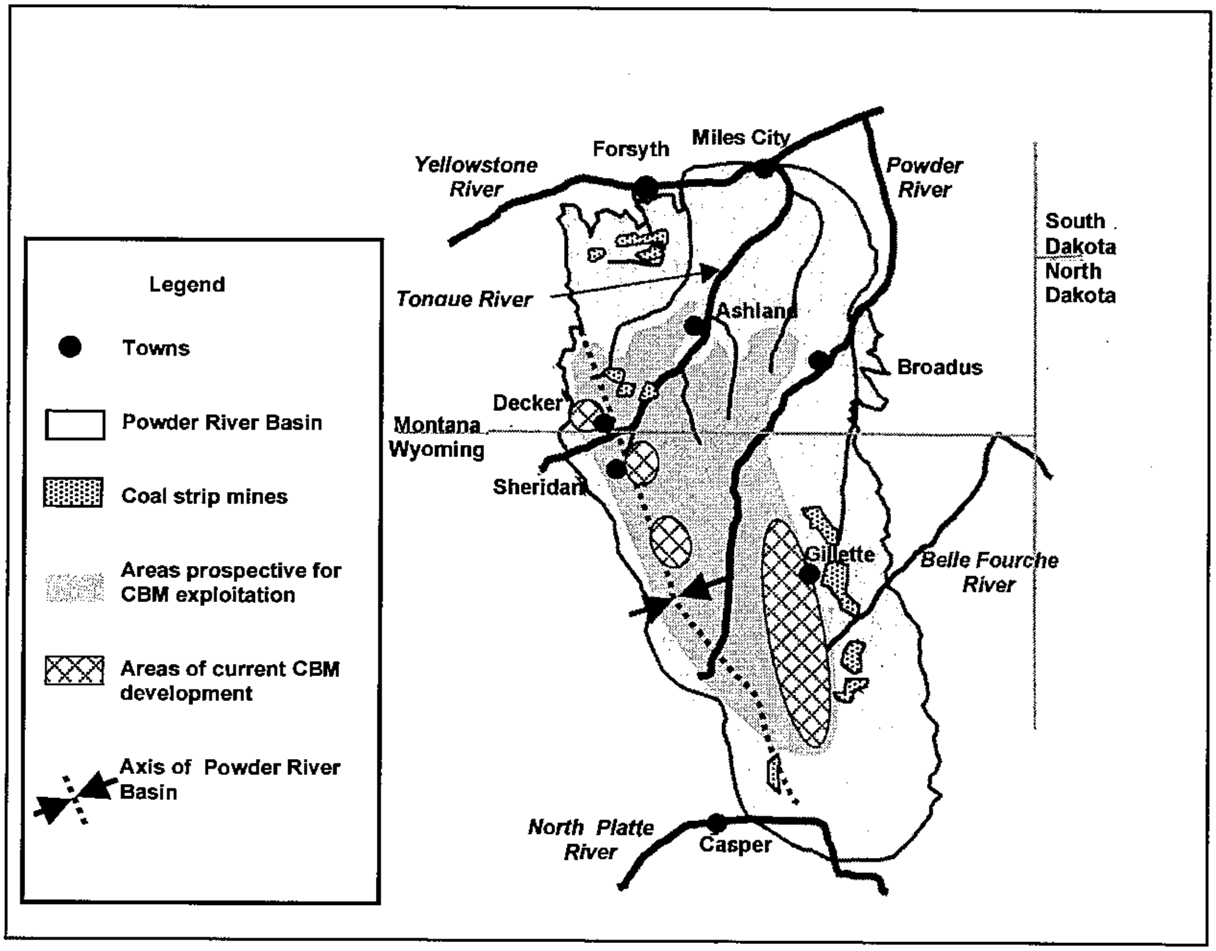

Figure 1. The Powder River Basin in Montana and Wyoming is a major coal-producing region. Thick beds of sub-bituminous coal also hold commercial quantities of methane.

Table 1. Correlation of names used by companies and agencies for coal beds in the Decker, Montana area.

MBMG Matson and Blumer, 1973	USGS McLellan, and others, 1990	DECKER MINE	SPRING CK MINE	CONSOL COAL Van Voast, 1998	REDSTONE GAS PARTNERS
ROLAND	ROLAND		ROLAND	A	ROLAND
SMITH	SMITH		SMITH	C - D	SMITH
ANDERSON	ANDERSON, D1	D1 UPPER		G	D1
DIETZ 1	D2 UPPER	D1 LOWER	ANDERSON - DIETZ	M	D2
DIETZ 2	D2 LOWER / D3	D2		M	D3
CANYON	CANYON	CANYON / D3	CANYON	O	MONARCH
COOK/CARNEY	COOK/CARNEY	D4	D4		CARNEY
WALL	WALL		D6	R	WALL

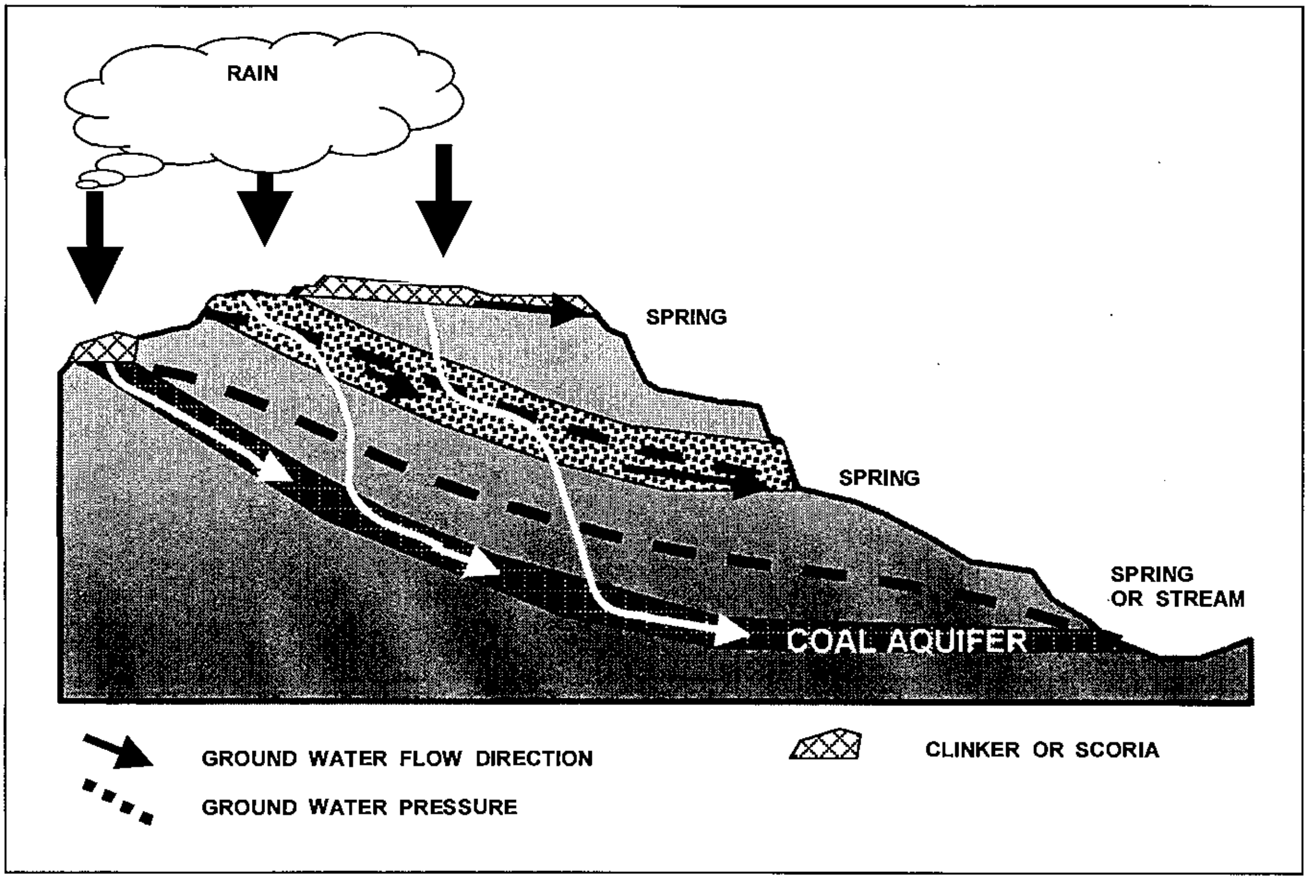

Figure 2. Simplified diagram of a typical local ground-water flow system in southeastern Montana. The main areas of recharge are areas of clinker where rain and snow can easily percolate into the subsurface.

between the coal and the gas and by hydrostatic pressure from ground water in the coal. The gas is released if the hydrostatic pressure is reduced. Wells, drilled and completed in the coal, are fitted with water pumps. Pumping water from the coal reduces the hydrostatic pressure allowing the gas to desorb. The gas and water move to the well as a two-phase fluid. The water enters the pump and is discharged through the water line. The gas flows up the well casing and is removed through gas lines to a low-pressure compressor.

Greater efficiency in reducing water pressure in the coal beds is achieved by completing wells in grid patterns called pods. Pods in Montana typically cover an area of about 800 acres and consist of 10 to 15 wells completed in each coal seam. In some areas, up to 4 coal seams are targeted, and pods may consist of as many as 40 or 50 wells. A central, low pressure compressor receives gas produced from the wells and advances the gas to a high pressure compressor station that receives gas from several pods, moving the gas into pipelines for delivery to market

As of August, 2000 there were 2,131 producing wells registered in Wyoming, with an additional 1,207 wells that were drilled but not yet on line.

The first CBM development in Montana and Wyoming has occurred adjacent to coal mines, where the hydrostatic pressure in the aquifers has already been partially reduced by mine dewatering. CBM wells are being installed west of coal mines near Decker, Montana where the Anderson-Dietz coals are being mined. These plus the deeper Canyon, Cook and Wall coals are prospective for CBM. Nomenclature for the coal seams in the Decker area varies somewhat between companies and agencies (Table 1). In Montana, 158 wells were producing of 172 drilled. As of June, 2000 (the last report available from the Montana Board of Oil and Gas Conservation at the time of this writing) about 800 gallons per minute (gpm) of water was being discharged from 57 producing wells in Montana.

CBM reserve estimates are based on gas content per ton of coal. Lower rank coals, such as the sub-bituminous coals in the Powder River Basin contain much lower quantities of gas than higher rank coals such as those in the San Juan Basin. However, due to the vast reserves of coal in the Powder River Basin, the reserves of gas are large, estimated at 9 trillion cubic feet (Schwochow, 1999). Likewise, production from individual wells in the Powder River Basin is lower than other areas, typically peaking at about 200,000 cubic feet per day, and expected to decrease over the following 15 years.

Impacts

Most concerns over CBM production stem from the need to withdraw large volumes of ground water in order to decrease coal seam hydrostatic pressure, allowing release of methane gas. The ground water is then discharged as a waste product to nearby drainages. Compared to the receiving streams, the discharge water typically contains much higher concentrations of sodium and may also carry elevated concentrations of other constituents, including iron, boron and ammonia. The Tongue River can carry only limited amounts of this water before irrigation uses are impacted. Production from individual CBM wells is expected to last for up to 15 years, and total field production will last much longer. Water levels in aquifers may require decades to recover. During periods of production and recovery, water available at springs and wells will be reduced. During recovery, stream flows may decline to less than present levels due to the loss of ground-water base flow.

Ground-water levels have been measured at wells in and adjacent to coal-strip mines near Decker, Montana for more than 25-years by Montana Bureau of Mines and Geology and mining companies. Coal-bed methane development has begun in Montana in an area where some of these monitoring wells are located (Figure 3). Monitoring in the Decker vicinity has documented a slow decline in ground-water levels in the coal seams within about 15 miles of coal mines where the effects of two mines converge (Van Voast and Reiten, 1988). Hydrographs of this effect are shown in figures 4 and 5. Coal mine related drawdown near the West Decker Mine is shown on Figure 6. CBM influences have been marked by a rapid water level drop in comparison to the mine-induced drawdown (Figure 5). In the first year of production over 10-feet of drawdown has occurred within a 1- to 2-mile radius around CBM development near Decker, Montana (Figure 6). As additional wells come on line and with continued pumping, the area of influence will expand.

Ground-water-level monitoring near CBM production is complicated by violent degassing and foaming that can occur in monitoring wells. Consequently, once degassing has started in a monitor well, true water levels are difficult to evaluate. Several coal-mine monitoring wells have been abandoned due to degassing problems.

The chemistry of water discharged from the CBM wells is dominated by sodium and bicarbonate ions, with SAR values frequently greater than 40. Disposal options being considered for this water include land application, direct discharge to drainages or rivers, storage in impoundments, or re-injection. To date, direct discharge to rivers has been the default alternative in Montana.

A simple mixing model was used to estimate changes in SAR and specific conductance (SC) due to future CBM development in the Tongue River watershed. The USGS monitored streamflow and collected water-quality samples at a site downstream of the town of Ashland, Montana, near the Brandenburg Bridge, from 1974 through 1981. Most of the potential CBM development areas are upstream from this site. Therefore, the mixing model was run based on data from the Brandenburg Bridge site.

Average annual streamflow at this location was 492 cfs. SC values ranged from 350 to 1300 umhos/cm, averaging 810 for the measurements made. SAR ranged from 0.6 to 2.2 and averaged 1.2 at this site during the reported period. Average monthly values are shown on Figure 7.

Several assumptions are necessary to perform a simple mixing model analysis. First, 3,000 CBM wells were assumed to be discharging 15 gpm each directly to the Tongue River. Industry estimates that 10,000 CBM wells may be installed and put on line during the next 10 years, and for the sake of this analysis it was estimated that about 30% of those would discharge directly to the Tongue River. This number of wells represents an increase in annual average flow of 100 cfs.

Based on past water-quality data from coal wells in the CBM producing area of Montana, discharge water is expected to be dominated by ions of sodium and bicarbonate, with very little calcium and magnesium. Based on work by Van Voast and Hedges (1975), an average SAR value of 50 and SC of 2,000 was chosen for this model. Using a mass balance

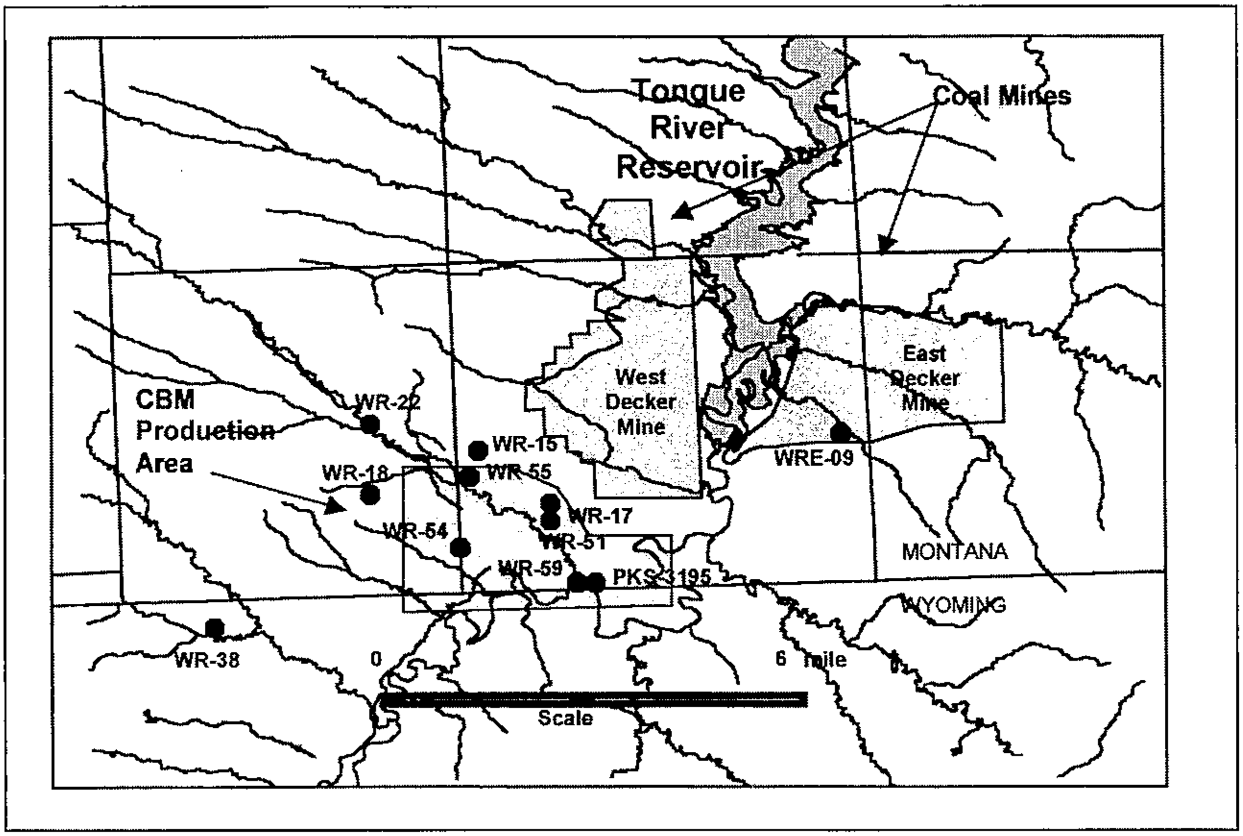

Figure 3. Map showing locations of selected monitoring wells near areas of coal mine and coal-bed methane development.

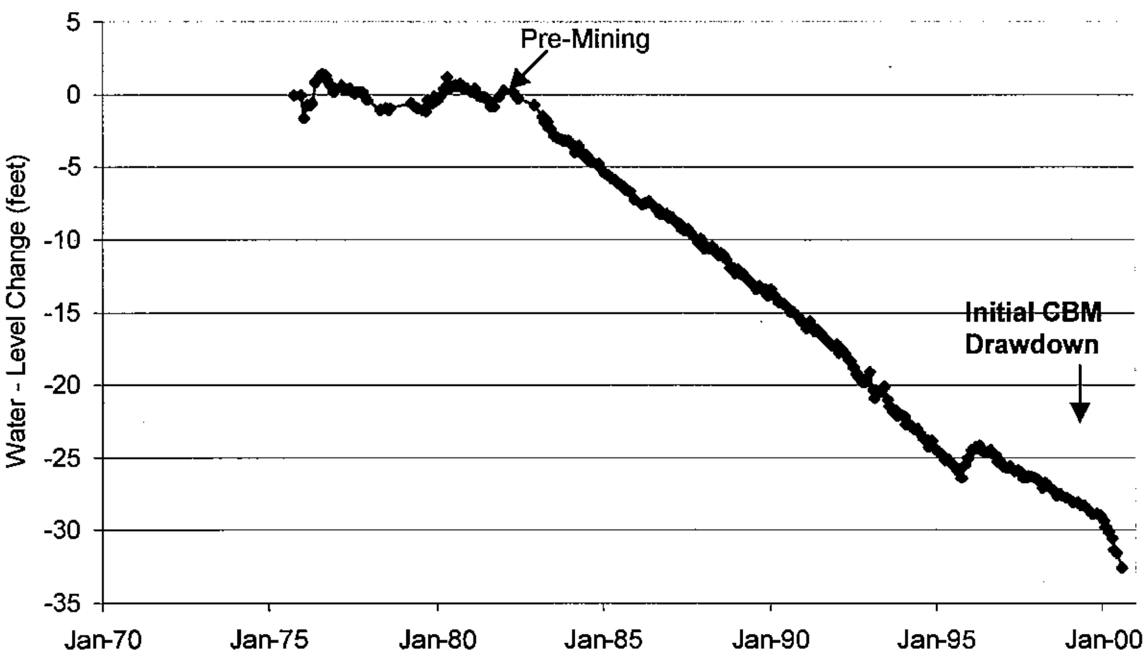

Figure 4. Hydrograph for well WR-22 showing baseline water levels in the combined Anderson, Dietz coal seam, and drawdown related to coal mining and the beginning of CBM drawdown

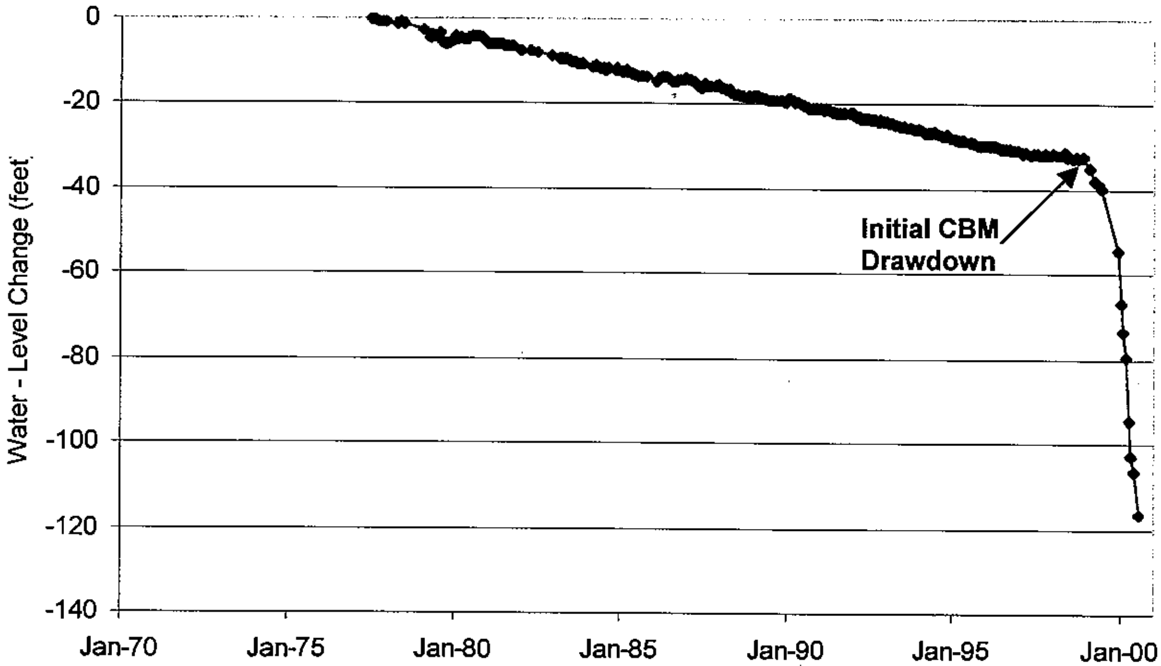

Figure 5. Hydrograph for well WR-51 showing slower water-level drawdown related to coal mining in the combined Anderson, Dietz coal seam, and the onset of rapid drawdown associated with coal-bed methane development.

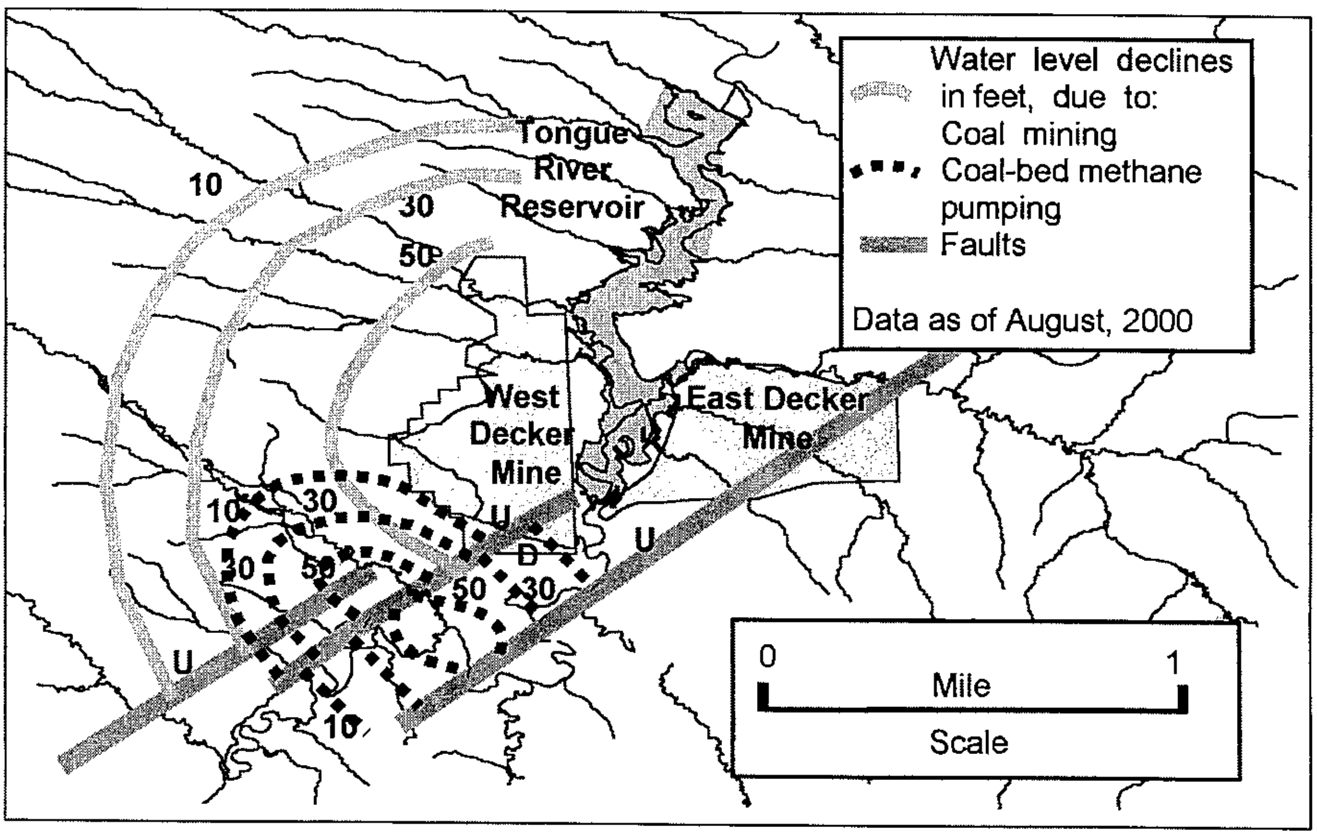

Figure 6. An area of potentiometric decline has formed around the Decker coal mines during 30 years of mining. Superimposed on that drawdown is an area of additional depressurization due to coal-bed methane development.

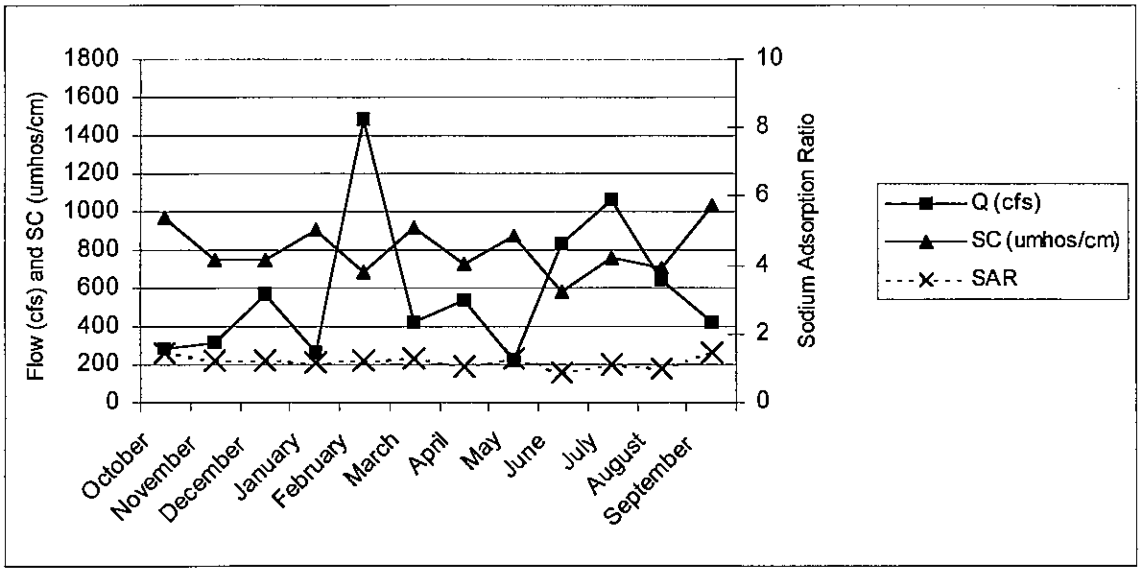

Figure 7. Comparison of measured flow, specific conductance and sodium adsorption ratio for the Tongue River at Brandenburg Bridge with no CBM impacts. Average of Monthly Data from U.S. Geological Survey monitoring programs, 1974-1981.

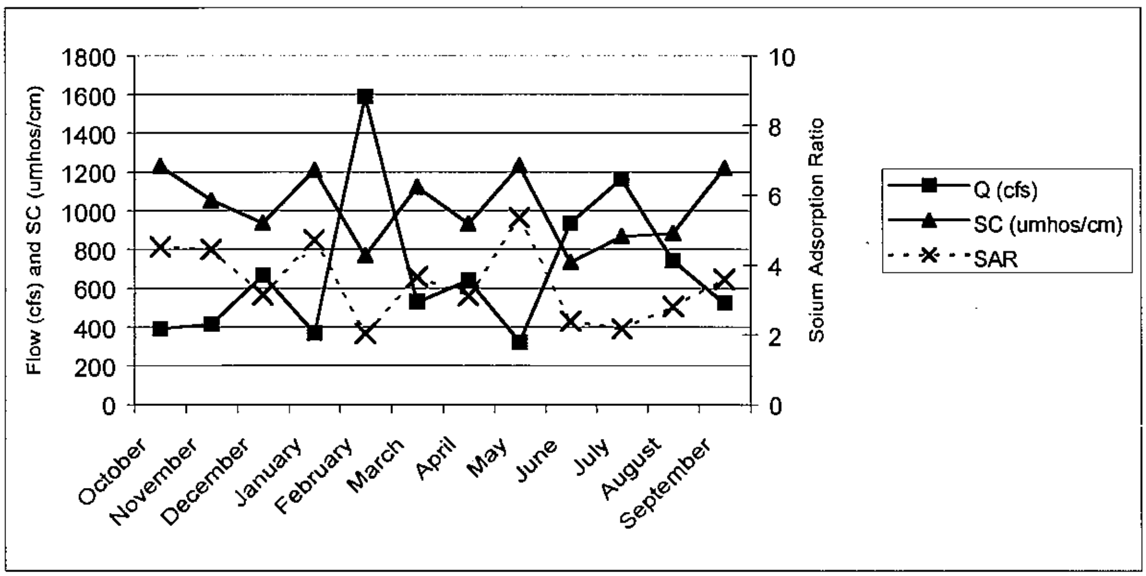

Figure 8. Comparison of calculated flow, specific conductance and sodium adsorption ratio for the Tongue River at Brandenburg Bridge receiving discharge from 3,000 CBM wells. Estimated by mixing anticipated CBM loads with the data presented in Figure 7

approach, these concentrations were mixed with monthly average values from USGS data. Average monthly values calculated from the mixing model are shown in Figure 8.

A comparison of figures 7 and 8 shows that during the normal irrigation period (June through August) the SAR values in the river increase from a baseline of around 1, to between 2 and 3. SC during this time of the year increases from between 600 and 800 umhos/cm to between 700 and 900 umhos/cm. Flow increases 100 cfs. The significance of these impacts depends on the use of the water (Hason, Gratten and Fulton, 1999). For watering livestock this is insignificant. For irrigation uses, a two-fold increase in SAR may be significant over long-periods of use, depending of the soil and irrigation practices.

Conclusions

Coal-bed methane represents a new and economical source of energy. A broadly diversified energy base is important to a nation with an economic system based on inexpensive energy.

Hydrostatic pressure in aquifers is being reduced for several miles outside CBM production areas. Reduced water availability at wells and springs is expected. Monitoring wells, some with several decades of measurements, are impacted by degassing.

Impacts to channel stability and downstream irrigators seem likely. Early methane development is occurring within the area of hydrologic influence of active coal mines. The cumulative effect of these activities and the interception of mine-spoils recharge by coal-bed methane wells have raised questions about restoration of the hydrologic balance during mine reclamation.

Due to the stratigraphically complex nature of the Tongue River Member and the current uncertainties regarding development levels, hydrogeologic models will not accurately predict drawdown and recovery related to CBM production. Likewise, water quality models may only be useful for providing conceptual descriptions of changes to the Tongue River. Only through long-term active monitoring programs will impacts be determined and analyses developed that can be transferred to future development sites.

The contrast between a valuable energy source for the nation and impacts from development of that energy source that will be borne by local landowners creates a difficult situation for regulators.

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