EXECUTIVE SUMMARY

This Task 1B Report for the Powder River Basin (PRB) Coal Review describes the existing water resources conditions in the PRB study area. Existing conditions for air quality, social and economic conditions, and other environmental resources are presented in individual baseline (Task 1) reports. The description of current water resources conditions in this report is based on published and unpublished information; information obtained from local, state, and federal agencies and private companies; and a compilation of past and present actions in the Wyoming PRB developed for the Task 2 Report for the PRB Coal Review. The past and present actions summarized in the Task 2 report include surface coal mines (12 active mines and 1 temporarily inactive mine), power plants, railroads, coal technology facilities, major transmission lines, other mines, oil and gas development, major pipelines, reservoirs, and other industrial and non-industrial developments. Descriptions of the past and present activities identified in the Task 2 report were based on the most recent data available at the end of 2003.

For the purpose of this study, the Wyoming PRB study area comprises all of Campbell County, all of Sheridan and Johnson counties less the Bighorn National Forest lands to the west of the PRB, and the northern portion of Converse County. It includes all of the area administered by the Bureau of Land Management (BLM) Buffalo Field Office, a portion of the area administered by the BLM Casper Field Office, and a portion of the Thunder Basin National Grasslands, which is administered by the U.S. Forest Service. State and private lands also are included in the study area. For water resources, the existing conditions are presented for the Powder River Structural Basin (also referred to as the Powder River Physiographic Basin), which includes the Powder/Tongue River Basin and Northeast Wyoming River Basins planning areas. The detailed study area encompassed by the groundwater model domain places emphasis on the overlap between coal mine- and coal bed natural gas (CBNG)-related groundwater drawdown in the eastern PRB. The Task 3B Report for the PRB Coal Review is devoted to potential future impacts to water resources in the area of CBNG development and coal mine expansion in the eastern PRB. It includes a cumulative impact assessment of water quality and channel stability from surface discharge of groundwater from CBNG development.

ES.1 TECHNICAL APPROACH

Existing (2002) regional surface water and groundwater conditions in the Wyoming PRB study area were based on publicly available and accessible data and publications. The two principal studies used included the Powder/Tongue River Basin Study (HKM Engineering et al. 2002a) and the Northeast Wyoming River Basins Study (HKM Engineering et al. 2002b). Data on groundwater levels and groundwater quality primarily were obtained from various water resource and geological publications prepared by the U.S. Geological Survey (USGS). Additional data on groundwater levels came from BLM monitoring well files, the annual reports prepared by the Gillette Area Groundwater Monitoring Organization (GAGMO), the USGS waterdata website, and from the mine permit files of the Wyoming Department of Environmental Quality (WDEQ)/Land Quality Division (LQD). In addition, a numerical groundwater flow model was developed for this study to further analyze existing (2002) groundwater level impacts associated with coal mine dewatering and CBNG development in the eastern portion of the PRB study area.

ES.2 DESCRIPTION OF CURRENT REGIONAL CONDITIONS

Surface and groundwater are utilized extensively throughout the PRB for agricultural water supply, municipal water supply, and both domestic and industrial water supply. Surface water use is limited to major perennial drainages in agricultural areas within the basin found along these drainages. Municipal water supply comes from a combination of surface and groundwater. Domestic and industrial water supply primarily is from groundwater. The Powder/Tongue River Basin receives substantial surface water runoff from the Big Horn Mountains, leading to major agricultural development along drainages in the Tongue River and Powder River basins. Reservoirs are used throughout the basin for agricultural water supply and for municipal water supply in the Powder/Tongue River Basin. The discussion of water use in the Wyoming PRB is divided into the two major water planning areas of the basin, the Powder/Tongue River Basin and the Northeast Wyoming River Basins.

ES.2.1 Water Use

ES.2.1.1 Powder/Tongue River Basin

The main rivers in the Powder/Tongue River Basin are the Tongue River and the Powder River, which derive most of their flow from tributaries with headwaters in the Big Horn Mountains. Water use in the Powder/Tongue River Basin as of 2002 is summarized in **Table ES.2.1-1**.

Table ES.2.1-1
Water Use as of 2002 in the Powder/Tongue River Basin

Water Use	Dry Year		Normal Year		Wet Year	
	(acre-feet per year)					
	Surface Water	Groundwater	Surface Water	Groundwater	Surface Water	Groundwater
Agricultural	178,000	200	184,000	200	194,000	300
Municipal	2,700	500	2,700	500	2,700	500
Domestic	---	4,400	---	4,400	---	4,400
Industrial[1]	---	68,000	---	68,000	---	68,000
Recreation	Non-consumptive					
Environmental	Non-consumptive					
Evaporation	11,300	--	11,300	--	11,300	--
Total	**192,000**	**73,100**	**198,000**	**73,100**	**208,000**	**73,200**

[1]Includes conventional oil and gas production water and CBNG production water.

Source: HKM Engineering et al. 2002a.

As of January 1, 2002, approximately 161,160 acres of land were actively irrigated in the Powder/Tongue River Basin, and the vast majority of these lands were irrigated with surface water. Annual water depletions for surface water as a result of irrigation were approximately 194,000 acre-feet for wet years, 184,000 acre-feet for normal years, and 178,000 acre-feet for dry years (HKM Engineering et al. 2002a). These are estimated depletions and take into account irrigation return flow. The amount of groundwater used for irrigation was approximately

300 acre-feet per year for wet years and 200 acre-feet per year for normal and dry years. Most agricultural wells, especially stock wells, are screened in the Fort Union Formation. Agricultural water use in wet years is often greater than in dry years due to more land being in production.

There are 20 public water supply entities in the Powder/Tongue River Basin consisting of incorporated municipalities, water districts, and privately owned water systems. Two communities obtain water supply from outside the basin. Four of the entities obtain their water supply from surface water and consume approximately 2,700 acre-feet per year (HKM Engineering et al. 2002a). The remaining 16 entities consume approximately 500 acre-feet of groundwater per year. Domestic water use is satisfied by groundwater and totals approximately 2,400 to 4,400 acre-feet per year. Many of the municipal wells and most of the domestic wells are in the Fort Union Formation.

Conventional oil and gas production and CBNG development constitute the principal industrial water use in the Powder/Tongue River Basin. The total estimated groundwater consumption is approximately 68,000 acre-feet per year (HKM Engineering et al. 2002a). Approximately half of this groundwater comes from the Fort Union Formation and is consumed by the CBNG industry.

Recreational water use requires minimum flow releases from reservoirs, minimum water levels in reservoirs, or maintenance of instream flow water rights; however, it is non-consumptive.

Reservoir evaporation is a major source of water loss in the Powder/Tongue River Basin. Evaporation from the 14 key storage reservoirs in the basin totals approximately 11,300 acre-feet per year (HKM Engineering et al. 2002a). This primarily is a loss of surface water and exceeds the surface water and groundwater consumption by municipalities as well as the groundwater consumption by domestic wells. Only agricultural irrigation, conventional oil and gas operations, and CBNG development consume more water.

ES.2.1.2 Northeast Wyoming River Basins

The main rivers in the Northeast Wyoming River Basins are the Belle Fourche in Campbell and Crook counties and the Cheyenne River in Converse, Weston, and Niobrara counties. Water in these rivers and their tributaries comes from groundwater baseflow and from precipitation runoff, especially from heavy storms during the summer months.

Water use in the Northeast Wyoming River Basins as of 2002 is summarized in **Table ES.2.1-2**.

As of 2002, approximately 77,350 acres were irrigated in the Northeast Wyoming River Basins, of which approximately 13,000 acres were irrigated with groundwater. Surface water consumption by irrigation in 2002 totaled 71,000 acre-feet in wet years, 69,000 acre-feet in normal years, and 65,000 acre-feet in dry years (HKM Engineering et al. 2002b). Groundwater consumption for irrigation in 2002 totaled 17,000 acre-feet in wet years and normal years and approximately 11,000 acre-feet in dry years. Most of the groundwater consumption for irrigation was in the Niobrara River drainage, which is not part of the PRB structural basin. Agricultural water use can be higher in wet years than in dry years due to more land being in production.

Table ES.2.1-2
Water Use as of 2002 in the Northeast Wyoming River Basins

Water Use		Dry Year		Normal Year		Wet Year	
		(acre-feet per year)					
		Surface Water	**Groundwater**	**Surface Water**	**Groundwater**	**Surface Water**	**Groundwater**
Agricultural		65,000	11,000	69,000	17,000	71,000	17,000
Municipal		---	9,100	---	9,100	---	9,100
Domestic		---	3,600	---	3,600	---	3,600
Industrial	Oil and Gas[1]	---	46,000	---	46,000	---	46,000
	Other[2]	---	4,700	---	4,700	---	4,700
Recreation		Non-consumptive					
Environmental		Non-consumptive					
Evaporation	Key Reservoirs	14,000	---	14,000	---	14,000	---
	Stock Ponds	6,300	---	6,300	---	6,300	---
Total		**85,300**	**74,400**	**89,300**	**80,400**	**91,300**	**80,400**

[1]Includes conventional oil and gas production water and CBNG production water.
[2]Includes electricity generation, coal mining, and oil refining.

Source: HKM Engineering et al. 2002b.

There are 33 public water supply entities in the Northeast Wyoming River Basins consisting of 9 incorporated municipalities, 19 water districts, and 5 privately owned water systems. Municipal and domestic water use is from groundwater only, and approximately 9,100 acre-feet of groundwater is consumed per year. Domestic groundwater demand is approximately 3,600 acre-feet per year (HKM Engineering et al. 2002b). Domestic water consumption primarily is from the Fort Union Formation. Municipal water consumption is from the Fort Union Formation and aquifers below the Fort Union.

Industrial water use in the Northeast Wyoming River Basins consists of conventional oil and gas production, CBNG development, coal mining, electric power generation, and oil refining. With one exception, groundwater is used exclusively by these industries, and the total use is approximately 50,700 acre-feet per year (HKM Engineering et al. 2002b). The groundwater comes primarily from the Fort Union Formation. Approximately 350 acre-feet per year of treated wastewater from the City of Gillette is used by the Wyodak Power Plant.

Recreational and environmental water uses are non-consumptive. They consist of maintaining minimum water levels in reservoirs and minimum flow releases for instream water rights and aquatic water needs. The largest reservoir in the Northeast Wyoming River Basins is the Keyhole Reservoir, which supports a variety of recreational activities and primarily is used for agricultural irrigation.

Evaporation from the six key storage reservoirs in the Northeast Wyoming River Basins is approximately 14,400 acre-feet of water annually (HKM Engineering et al. 2002b). There are approximately 16,600 stock ponds in the Northeast Wyoming River Basins and these evaporate approximately 6,300 acre-feet of water per year (HKM Engineering et al. 2002b). Thus, total evaporation loss in the Northeast Wyoming River Basins is approximately 20,000 acre-feet per year. Evaporation loss is greater than groundwater consumption by coal mining and greater than groundwater consumption by municipal and domestic water use combined. Only irrigation and CBNG development consume more water.

ES.2.2 Water Availability

ES.2.2.1 Surface Water

ES.2.2.1.1 Powder/Tongue River Basin

The Little Bighorn River, Tongue River, Powder River, Crazy Woman Creek, and Piney Creek carry the largest natural flows in the Powder/Tongue River Basin. Many of the other major drainages are affected by irrigation practices to the extent that their flows are not natural (HKM Engineering et al. 2002a). Water availability in the major subbasins of the Powder/Tongue River Basin is summarized in **Table ES.2.2-1**. This table presents the amount of surface water in acre-feet that is physically available above and beyond allocated surface water in these drainages. As a result of the Yellowstone River Compact, Wyoming must share some of the physically available surface water in the Powder/Tongue River Basin with Montana.

ES.2.2.1.2 Northeast Wyoming River Basins

The Belle Fourche and Cheyenne River basins carry most of the available surface water flow in the Northeast Wyoming River Basins. There are approximately 25 maintained gauging stations in these drainages. Many of these stations measure unnatural flow dominated by irrigation practices. In addition, most surface water flow in the Northeast Wyoming River Basins is intermittent to ephemeral. Total annual available flow for the Northeast Wyoming River Basins is summarized in **Table ES.2.2-2**.

Table ES.2.2-1
Surface Water Availability in the Powder/Tongue River Basin

Subbasin	Surface Water Availability (acre-feet)		
	Wet Years	Normal Years	Dry Years
Little Bighorn River	152,000	113,000	81,000
Tongue River	473,000	326,000	218,000
Clear Creek	213,000	124,000	80,000
Crazy Woman Creek	69,000	32,000	16,000
Powder River	547,000	324,000	16,000
Little Powder River	48,000	12,000	3,000
Total	**1,502,000**	**931,000**	**414,000**

Source: HKM Engineering et al. 2002a.

Table ES.2.2-2
Surface Water Availability in the Northeast Wyoming River Basins

Subbasin	Surface Water Availability (acre-feet)		
	Wet Years	Normal Years	Dry Years
Redwater Creek	34,000	26,000	17,000
Beaver Creek	30,000	20,000	14,000
Cheyenne River	103,000	31,000	5,000
Belle Fourche River	151,000	71,000	13,000
Total	**318,000**	**148,000**	**49,000**

Source: HKM Engineering et al. 2002b.

ES.2.2.2 Groundwater

An estimate of recoverable groundwater in the PRB is provided in **Table ES.2.2-3**.

ES.2.2.2.1 Powder/Tongue River Basin

There are five main aquifers in the Powder/Tongue River Basin that can be used for water supply as described below.

Madison Aquifer System. The Madison Aquifer is the deepest aquifer and lies within the Paleozoic Tensleep Sandstone, Amsden Formation, Madison Limestone, Bighorn Dolomite, and Flathead Sandstone. The Madison Limestone is the thickest unit and is approximately 200 to 1,100 feet thick with a transmissivity ranging from 500 to 90,000 gallons per day per foot (gpd/ft). Well yields from this aquifer have been as high as 4,000 gallons per minute (gpm). Water quality in the Madison Limestone mainly is dominated by calcium-magnesium bicarbonate with locally high concentrations of fluoride and radionuclides. Total dissolved solids (TDS) can range from 600 to 3,000 milligrams per liter (mg/L), with the high TDS water containing sulfates and chlorides. The water is of good quality, and the Madison Limestone is the most important high-yield aquifer in Wyoming for municipal, industrial, and irrigation water supply. Depths to the Madison in the Powder/Tongue River Basin range from approximately 6,000 feet east of Gillette, Wyoming, to as much as 16,000 feet in the southwestern part of the Powder/Tongue River Basin. Recharge to the Madison Limestone is approximately 75,000 acre-feet per year (HKM Engineering et al. 2002a). Other formations within the Madison Aquifer System can yield water; however, the quality of the water is not as good as that found in the Madison Limestone, and well yields are often much lower.

Table ES.2.2-3
Recoverable Groundwater in the PRB

Hydrogeologic Unit	Surface Area (acres)	Average Formation Thickness (feet)	Percentage of Sand/Coal	Average Sand/Coal Thickness (feet)	Specific Yield (percent)	Recoverable Groundwater (acre-feet)
Wasatch-Tongue River Aquifer Sandstones	5,615,609	2,035	50	1,018	13	743,121,790
Wasatch-Tongue River Aquifer Coals	4,988,873	2,035	6	126	0.40	2,516,519
Lebo Confining Layer Sandstones	6,992,929	1,009	33	250	13	227,137,339
Tullock Aquifer Sandstones	7,999,682	1,110	52	430	13	447,246,784

Source: BLM 2003a.

Dakota Aquifer System. The Dakota Aquifer consists of two main formations, the Cloverly Formation and the Newcastle Sandstone, which have a total thickness of approximately 200 feet. Yields from the Dakota Aquifer range from 1 to 40 gpm up to approximately 250 gpm (HKM Engineering et al. 2002a). The transmissivity of the main producing unit, the Cloverly Formation, is in the range of 7 to 230 gpd/ft. Water from the Dakota Aquifer is dominated by sodium bicarbonate with TDS ranging from 300 to 3,000 mg/L. With common well yields in the range of 5 to 20 gpm, the Dakota Aquifer is not a major source of water.

Fox Hills/Lance Aquifer System. The Fox Hills/Lance Aquifer System consists of the Lance Formation and the underlying Fox Hills Sandstone. The Lance Formation ranges from 600 to 3,000 feet in thickness and thickens to the south in the Powder/Tongue River Basin (HKM Engineering et al. 2002a). Well yields from the Lance Formation are approximately 15 gpm or less, and the transmissivity of the Lance Formation is 76 to 2,100 gpd/ft. The water quality in the Lance is dominated by sodium sulfate or calcium sulfate, and the TDS ranges up to 3,000 mg/L. The sodium absorption ratio (SAR) ranges from 1.9 to 39, and the water generally is not suitable for irrigation use, stock use, or domestic use. The Fox Hills Sandstone ranges in thickness up to 700 feet with a transmissivity in the range of 76 to 1,600 gpd/ft. Well yields generally are around 15 gpm but can range up to 50 gpm. The Gillette municipal public water supply has wells in the Fox Hills yielding 85 to 705 gpm (HKM Engineering et al. 2002a). The water quality is similar to that in the Lance Formation. Depths to the formation are on the order of 1,000 feet in most of the Powder/Tongue River Basin. The water quality of the Fox Hills Sandstone limits its usefulness for domestic or stock use. The fluoride content of the water on the east side of the Powder/Tongue River Basin can limit its use for municipal water supply.

Fort Union/Wasatch Aquifer System. Both the Wasatch and the Fort Union formations act as aquifers in the Powder/Tongue River Basin. The Wasatch is more of a local aquifer, while the Fort Union Formation is a regional aquifer. The Wasatch ranges in thickness from 500 to 2,000 feet and is a fine to coarse-grained lenticular sandstone with interbedded shale and coal. The transmissivity ranges from 520 to 2,200 gpd/ft, but well yields generally are less than 15 gpm. The TDS of the water ranges from 141 to 6,620 mg/L (HKM Engineering et al. 2002a), and the sulfate content can range up to 4,000 mg/L, with iron ranging up to 25 mg/L. The Wasatch is a local source of domestic and stock water supply, but it generally is not suitable for irrigation because of the high sodium content. The Fort Union Formation ranges from 1,200 to 3,900 feet in thickness in the Powder/Tongue River Basin and is a fine- to medium-grained siltstone with abundant coal and shale. Well yields from 1 to 60 gpm ranging up to 250 gpm are common, and the transmissivity ranges from 10 to 95 gpd/ft. The TDS content of the water ranges from 484 to 4,630 mg/L with high sulfate (up to 1,870 mg/L) and iron (up to 19 mg/L). The water generally is dominated by sodium bicarbonate and has a high SAR value (up to 32). The Fort Union is a major source of local water supply for domestic and stock water use. Major pumpage in the Fort Union is from CBNG wells, and the average pumping rate per well ranges from approximately 12 to 45 gpm, depending on the depth of the CBNG well.

Quaternary Alluvial Aquifer System. This aquifer system is local in nature and is found in alluvium and terrace deposits near the major drainages of the Powder/Tongue River Basin. The thickness of alluvium ranges up to approximately 100 feet. Well yields of 50 to 300 gpm are possible in local areas, and the transmissivity can range up to 20,300 gpd/ft. TDS for the water can range up to 4,000 mg/L and the chemical nature of the water varies considerably based on location. Water from the Quaternary Alluvial Aquifer has been used for municipal water supply, domestic water supply, and stock use. Quaternary alluvial aquifers that are in hydraulic connection with perennial streams are the main source of water supply in this aquifer system. These shallow alluvial aquifers can be recharged by groundwater flow from the underlying Wasatch Aquifer or from stream infiltration.

ES.2.2.2.2 Northeast Wyoming River Basins

There are six main aquifers underlying the Northeast Wyoming River Basins. One of these, the Arikaree Aquifer, is not within the PRB; the other five are described below.

Madison Aquifer System. The Madison Aquifer along the central and eastern flanks of the PRB consists of four water-bearing formations. From oldest to youngest these are the Whitewood Dolomite, Englewood Limestone, Pahasapa Limestone (equivalent to the Madison Limestone in the northern part of the PRB), and Minnelusa Formation. The Whitewood Dolomite is a massive bedded dolomite 50 to 60 feet thick that contains few wells and has a transmissivity of approximately

6,400 gpd/ft. This unit of the Madison Aquifer System is not used for water supply. The Englewood Limestone is 30 to 60 feet thick, also has very few wells, and is not used for water supply. The principal unit of the Madison Aquifer System that is used for water supply in the eastern PRB is the Pahasapa Limestone. This massive limestone has wells with yields up to 1,000 gpm and a transmissivity that typically ranges from 1,000 to 60,000 gpd/ft but locally can be as high as 300,000 gpd/ft. Water quality at the outcrop of the formation along the eastern flank of the PRB is calcium-magnesium bicarbonate water with a TDS of less than 600 mg/L. The TDS increases basinward to greater than 3,000 mg/L, and the water becomes dominated by sodium sulfate and sodium chloride with increasing concentrations of fluoride and radionuclides. This is the most important high-yield aquifer in Wyoming and is a source of water for municipal water supply as well as industrial, irrigation, and stock water use. The City of Gillette, Wyoming, uses this aquifer for water supply. The overlying Minnelusa Formation also is a major aquifer in the eastern PRB. This unit is 600 to 800 feet thick and consists of sandstone interbedded with limestone, dolomite, and shale. The upper part of the Minnelusa is an aquifer and yields 200 gpm to wells and has a transmissivity up to 900 gpd/ft. Water quality is good near the outcrop of the formation with TDS values below 600 mg/L. Basinward, the TDS increases to around 2,400 mg/L with an average of approximately 773 mg/L. The water quality changes from calcium bicarbonate water to water dominated by calcium sulfate and to sodium chloride waters in the deeper parts of the PRB. Fluoride enrichment and locally high values of radionuclides are a problem for municipal water use. The historical use of water from the Minnelusa has been for public water supply and domestic and stock use.

Dakota Aquifer System. The Dakota Aquifer System in the eastern PRB consists of three water-bearing units. From oldest to youngest, these are the Lakota Formation, Fall River Formation, and Newcastle Sandstone. The Lakota Formation ranges in thickness from 45 to 200 feet and is mainly a sandstone with interbedded conglomerates and shales. The unit generally is not used for water supply and yields 1 to 10 gpm to wells on average with a transmissivity of 220 to 810 gpm/ft. The Fall River Formation also is a sandstone with interbedded shale and siltstone and ranges in thickness from 35 to 150 feet. Well yield and transmissivity are similar to the Lakota Formation, and this unit also is not a source of water supply. The Newcastle Sandstone is the major aquifer of the Dakota Aquifer System in the eastern PRB and ranges in thickness up to 100 feet. As a result of a low transmissivity (up to 140 gpd/ft) and poor water quality within the PRB, this unit is used for water supply only near its exposures along the eastern rim of the PRB. The TDS of water in the basin can range up to 3,200 mg/L with the water dominated by calcium and sodium sulfate. Selenium and radionuclides can be issues of concern in some areas of this aquifer.

Fox Hills/Lance Aquifer System. This aquifer system consists of the Fox Hills Sandstone and the overlying Lance Formation. The Fox Hills Sandstone ranges from 150 to 700 feet in thickness and yields up to 700 gpm to wells. The transmissivity ranges from 70 to 1,600 gpd/ft, and the formation is used for municipal, industrial, domestic, and stock water supply. The water quality is similar to that in the overlying Lance Formation and consists of sodium bicarbonate to sodium sulfate water with a TDS ranging from 600 to 3,000 mg/L and locally high sodium and radionuclide contents. The locally high fluoride content can be a problem for domestic water supply. The Lance Formation ranges in thickness from 500 to 3,000 feet and yields up to 350 gpm to wells. The transmissivity ranges from 170 to 2,100 gpd/ft, and the water quality is similar to the Fox Hills Sandstone. The Lance Formation also is used for municipal, domestic, and stock water supply.

Fort Union/Wasatch Aquifer System. The Fort Union Formation in the eastern PRB ranges in thickness from 1,100 to 2,270 feet and is a coal-bearing sandstone with interbedded siltstone and shale. Flowing wells can have yields of up to 60 gpm from confined units in the Fort Union, and pumped wells produce up to 250 gpm with several hundred feet of drawddown. Transmissivity ranges up to 5,000 gpd/ft. The water quality can be quite variable with TDS ranging up to 8,000 mg/L and the water being dominated by sodium bicarbonate with SAR values ranging from 5.7 to 12.0. The Fort Union is used for municipal, domestic, and stock water supply. Approximately fourteen municipal and public water supply systems in the eastern PRB, including the City of Gillette and adjacent water districts, use the Fort Union for water supply (HKM Engineering et al. 2002b). The overlying Wasatch Formation is mainly sandstone with interbedded shale and coal that ranges up to 1,600 feet in thickness. Well yields are low and generally between 10 to 50 gpm, but can range up to 500 gpm in the southern part of the PRB. The transmissivity ranges up to 4,000 gpd/ft, but averages around 500 gpd/ft. Water quality generally is saline, with TDS values well above 1,000 mg/L and water quality varying from sodium bicarbonate to sodium sulfate. Locally, it is used for domestic and stock water supply and for public water supply for small communities. It is used most commonly for water supply in the southern part of the PRB.

Quaternary Alluvial Aquifer System. Quaternary alluvium can be found along major stream channels in terraces and as alluvial fill in the channels. The thickness ranges up to 100 feet, but is usually less than 50 feet in most areas. Coarse deposits with available water are found along the valleys of the Belle Fourche and Cheyenne rivers and their major tributaries. Well yields up to 1,000 gpm are possible. The transmissivity is highly variable, because of the clay content of the alluvium and can range from 15 to 64,000 gpd/ft. Water quality is highly variable and TDS ranges from approximately 100 to over 4,000 mg/L. The water generally is saline and suitable mostly for stock water and irrigation. The chemical makeup of the water can range from calcium bicarbonate water in areas of limestone bedrock to calcium sulfate water to sodium bicarbonate water in areas where groundwater from the Fort Union Formation discharges into the alluvium. Quaternary alluvial aquifers are often in hydraulic communication with the underlying bedrock (HKM Engineering et al. 2002b), and thus, the water quality can reflect bedrock water quality. Quaternary alluvial aquifers are used for domestic and municipal water supply as well as irrigation and stock water.

ES.2.3 CBNG Water Production and Discharge

In the PRB study area, CBNG development requires depressurization of the Fort Union coal bed aquifers through dewatering. The effect of this development on water resources is described below.

Most of the permitted CBNG wells in the PRB study area are located in the Upper Belle Fourche, Little Powder, and Upper Powder River drainages. Most of the water production by CBNG operations is found in the Upper Belle Fourche, Upper Cheyenne, Little Powder, Upper Tongue River, and Upper and Middle Powder River drainages (BLM 2003a). CBNG water production as of early 2002 was approximately 257 million barrels per year in the Northeast Wyoming River Basins (Upper Belle Fourche and Upper Cheyenne river basins) and approximately 312 million barrels per year in the Powder/Tongue River Basin (Upper and Middle Powder River, Little Powder River, and Upper Tongue River) (Wyoming Oil and Gas Conservation Commission 2005).

Groundwater produced by CBNG wells is often discharged directly to the surface in Wyoming without treatment. In the Powder/Tongue River Basin, this water generally is high in sodium bicarbonate, has TDS values well over 1,000 mg/L, and has a SAR greater than 8, making the water unsuitable for some agricultural uses in Wyoming. The water quality in the coal bed aquifers varies with location and depth in the Wyoming PRB. Groundwater quality in the northwestern part of the PRB is highly variable and generally high in TDS, sodium, calcium, sulfate, and bicarbonate. Groundwater pumped by CBNG wells in the eastern PRB, especially in the Belle Fourche and Cheyenne River basins, is generally low in TDS and low in sodium, allowing for direct discharge to ephemeral drainages (BLM 2003a).

As of early 2002, there were approximately 3,565 permitted CBNG outfalls for water discharge in the PRB. Approximately 43 percent of these outfalls are in the Upper Belle Fourche and Cheyenne River basins, approximately 21 percent are in the Upper Powder River drainage, and approximately 16 percent are in the Little Powder River drainage. This distribution places approximately half of the outfalls in the Powder/Tongue River Basin and approximately half in the Northeast Wyoming River Basins. Discharge at these outfalls ranges from 1 to approximately 25 gpm (BLM 2003a).

In the Belle Fourche and Cheyenne River basins, the discharge of CBNG-produced water directly to ephemeral and intermittent drainages is allowed. This water comes from shallow coal units and generally is low enough in TDS and SAR to be acceptable for direct surface discharge. Studies conducted by the BLM (2003a) have shown that conveyance losses for direct discharge to drainages are approximately 70 to 90 percent, depending on the time of year. Evaporation losses, which are a large component of conveyance losses, can be 80 percent during the summer months in Wyoming. Thus, most CBNG discharge water either infiltrates or evaporates within a few miles of the discharge outfall and generally is not recorded at USGS stream gauging stations. As a result, impacts to surface water flow and quality are limited to within a few miles of the discharge outfall and, as of 2002, have not been recorded by the network of USGS gauging stations.

In the northwestern part of the PRB, especially in the Powder/Tongue River Basin, discharge of CBNG water directly to drainages may not be permitted (BLM 2003a). Indirect discharge of CBNG-produced water involves impoundments similar to stock ponds. These impoundments are unlined and allow the CBNG discharge water to infiltrate into the shallow unsaturated alluvium. Impoundments can have in-channel or off-channel locations and WDEQ regulations differ depending on the location of the impoundment. Impoundments must have monitoring wells to evaluate impacts to alluvial groundwater if the initial groundwater investigation demonstrates that depth to groundwater is less than 150 feet (200 feet if the impoundment is greater than 50 acre-feet in size), and if the groundwater is Class III or better in quality (TDS less than 10,000 mg/L). These requirements apply to both in-channel and off-channel impoundments. Impoundments located within drainages (in-channel impoundments) may have discharge pipes to allow for some water to flow down the drainage in response to storm events. The Wyoming State Engineer's Office regulates the design of in-channel impoundments to ensure water rights are protected. The WDEQ regulates discharges into surface impoundments. Off-channel impoundments must be at least 500 feet from a drainage. The BLM is involved in regulating impoundments as a result of its permitting process for CBNG wells when federal land or federal mineral rights are involved. The WOGCC regulates the construction of impoundments on private and state lands.

Studies of the potential impacts to surface and groundwater quality from infiltration of CBNG water currently are underway by the BLM and private research groups funded by CBNG operators. The results to date are incomplete and very preliminary in nature. In the Bone Pile Creek area of the Upper Belle Fourche drainage, studies by the BLM (2003a) have shown that infiltration of CBNG water does not alter groundwater quality and that infiltration extends downward through the alluvium and into the Upper Wasatch Formation aquifer. At Burger Draw, which is in the Upper Powder River drainage, studies by the BLM (2003a) are ongoing. However, preliminary data suggest mounding of water in the unsaturated alluvium within approximately 15 to 25 feet of the impoundment and reaction between the CBNG water and minerals in the alluvium that increase TDS and other constituents. Infiltration extends to the Upper Wasatch Formation. At Brown Reservoir (Township 44 North, Range 76 West), similar studies found mounding within 15 feet of the impoundment and a water level rise of 10 feet, but no impacts to ephemeral drainages (BLM 2003a).

ES.2.4 Coal Mine Development Effects on Water Resources

Water pumped for dewatering of coal beds by the coal mines of the eastern PRB is: 1) used in the processing of coal; 2) used for dust control or reclamation; or 3) disposed of to ephemeral and intermittent drainages through Wyoming Pollution Discharge Elimination System permits issued by the WDEQ. The exact volume of water used by coal mines each year is not known for each mine, because mines often do not use their entire permitted water consumption volume each year. However, per existing permits in 2002, a total of 7,460 acre-feet of groundwater for consumptive use was allocated to the coal mines of the eastern PRB (Wyoming State Engineer’s Office 2004). Most mines pumped between 300 and 920 acre-feet of groundwater in 2002. Groundwater use by the coal mines may be decreasing from a peak period from 1996 to 1998. This may be due to dewatering of the coal beds by CBNG wells, which increased substantially after 1995.

Water discharged by the coal mines to ephemeral and intermittent drainages is regulated by the WDEQ. Water cannot be discharged to a drainage if it substantially would alter the water quality of the drainage or produce flows that result in erosion to the banks and beds of the streams. Thus, discharge of excess water by the coal mines in accordance with permit criteria should have little or no measurable effect on drainages. Storm water runoff from the coal mines also is regulated and must be diverted to detention ponds to allow for settling of sediment. Storm water that does not infiltrate into the alluvial sands and clays while held in the detention ponds can be allowed to flow into the drainages once most of the sediment has settled.

When coal mines are reclaimed, the overburden is returned to the mined-out portion of the pit as spoils, and the mined area is reclaimed to conditions similar to original conditions for slope and drainage. In the Wyoming PRB, the spoils material gradually resaturates with water as groundwater from the Wasatch Aquifer and the Fort Union coal bed aquifers enters the spoils material. Spoils can take anywhere from 50 to 200 years to resaturate (GAGMO 2001). The water quality in the resaturated spoils usually is high in TDS, sulfate, sodium, and other metals and anions. Monitor wells in spoils from coal mines along the eastern PRB typically have a pH between 6.0 and 7.8, TDS in the range of 1,000 to 4,000 mg/L, bicarbonate values ranging from 500 to 1,300 mg/L, sodium in the range of 200 to 800 mg/L, high sulfate values ranging from 1,000 to 3,500 mg/L, and SAR values in the range of 2.0 to 7.0 (GAGMO 2001). Over time, the spoils are flushed by groundwater flowing through the reclaimed material and downgradient to the northwest in the Wasatch and Fort Union aquifers. Thus, the water quality in the spoils improves over time and becomes similar to that found in these aquifers near the coal mines. The time to flush spoils and improve the water quality varies considerably, based on the permeability of the spoils and groundwater flow rates in the aquifers. Based on an evaluation of coal mines near Gillette, Martin et al. (1988) estimated the time required to flush water from spoils can vary from a few tens to a few hundreds of years.

The coal mines in the study area often mine through ephemeral and intermittent drainages. Drainages as high as third- and fourth-order drainages can be removed by mining. During reclamation, the third-order and higher drainages must be restored. First- and second-order drainages are often not replaced (Martin et al. 1988). Studies summarized by the USGS showed that reclaimed coal mine areas have: 1) a lower infiltration rate for precipitation in the reclaimed areas compared to original natural areas, and 2) sediment loading to drainages during heavy storms that is considerably higher for reclaimed areas compared to the original natural areas. The USGS study found that the percentage of drainages disturbed by coal mining varied from 4 to 26 percent, the increase in runoff for reclaimed areas varied from 0.8 to 7.6 percent, and the increase in sediment erosion averaged approximately 436 percent. The decrease in infiltration rate was approximately 29 percent. The TDS increase in stream waters near reclaimed coal mines ranged from 1 to 7 percent higher than before reclamation (Martin et al. 1988). Thus, the potential impacts of coal mines to surface water features are dependent more on the changes in slope, infiltration capacity, and runoff characteristics of reclaimed areas than on the process of coal mining and disposal of water by coal mines. Over time, reclaimed areas become similar to the original natural areas in terms of soil properties, vegetation, and runoff characteristics; however, this may take a few centuries in the semiarid climate of the PRB.

Groundwater drawdown near the coal mines of the eastern PRB is the result of coal mine dewatering and CBNG depressurization of the coal beds. The drawdown effects for 2002 were modeled for this study as discussed in Section ES.3.

ES.3 GROUNDWATER MODELING

ES.3.1 Groundwater Modeling Protocol and Model Calibration

For purposes of this study, a numerical groundwater flow model was developed for the area of active coal mining in the eastern portion of the PRB study area. The area modeled extended from the coal mines north of Gillette, Wyoming, to the southern extent of coal mining near Wright, Wyoming. The purpose of the Coal Mine Groundwater Model (CMGM) was to provide a tool for estimating the combined impacts on groundwater as a result of coal mining and CBNG development in the eastern portion of the PRB.

As the CMGM is a submodel of the regional PRB model developed for the PRB Oil and Gas Environmental Impact Statement (EIS) (BLM 2003a), modifications to the regional model were required to narrow the focus of the model domain. The regional PRB model was modified in accordance with the CMGM protocol (ENSR and Environmental Solutions, Inc. 2005) which specifies the design and execution parameters. MODFLOW 2000 was chosen as the modeling code, and the modeling platform Groundwater Vistas was chosen for running the model. **Table ES.3.1-1** summarizes the stratigraphy and hydrostratigraphy of the eastern PRB that was used in the CMGM.

Table ES.3.1-1
Regional Model Layers[1]

PRB EIS Regional Model Layer	Geologic Formation	Coal Unit Designation	Geologic Unit	Predominant Lithologies	CMGM HSU
1	Wasatch Formation	--	Upper Wasatch Formation and alluvium	Sandstone, siltstone, claystone	1
2	Wasatch Formation	--	Shallow Wasatch sands	Sandstone, siltstone	1
3	Wasatch Formation	--	Confining unit within Wasatch Formation	Siltstone, claystone	2
4	Wasatch Formation	--	Intermediate Wasatch sands	Sandstone, siltstone	2
5	Wasatch Formation	--	Confining unit within Wasatch Formation	Siltstone, claystone	2
6	Wasatch Formation	--	Deep Wasatch sands	Sandstone, siltstone	3
7	Confining Layer	--	Confining unit at base of Wasatch Formation. Low-permeability clay layer separating Wasatch and Fort Union.	Siltstone, claystone, clay	4
8	Upper Fort Union	Wyodak-Anderson coal as defined by the USGS	Upper Fort Union coal (Unit 1) – Anderson Coal of Goolsby	Coal (minor sandstone, siltstone)	5
9	Upper Fort Union		Confining unit between coal units	Siltstone, claystone	5
10	Upper Fort Union	Wyodak-Anderson coal as defined by the USGS	Upper Fort Union coal (Unit 2) – Canyon Coal of Goolsby	Coal (minor sandstone, siltstone)	5
11	Upper Fort Union		Confining unit between coal units	Siltstone, claystone	5
12	Upper Fort Union	Wyodak-Anderson coal as defined by the USGS	Upper Fort Union coal (Unit 3) – Wall Coal of Goolsby	Coal (minor standstone, siltstone)	5
13	Upper Fort Union		Confining unit between coal units	Siltstone, claystone	5
14	Upper Fort Union	Wyodak-Anderson coal as defined by the USGS	Upper Fort Union coal (Unit 4) – Wyodak Coal of Goolsby	Coal (minor sandstone, siltstone)	5
15	Upper Fort Union	--	Confining unit at base of coal units	Siltstone, claystone	5
16	Lower Fort Union	--	Lebo Shale	Sandstone, siltstone, claystone	6
17	Fort Union Formation	--	Tullock Formation	Sandstone, siltstone	6

[1]PRB Oil and Gas EIS (BLM 2003a) groundwater model stratigraphy compared to CMGM stratigraphy.

The CMGM was first calibrated to steady-state conditions for 1975 and then for transient conditions from 1990 to 2002. The final calibration was to 2002 water level data from approximately 350 coal mine groundwater monitoring wells reported in GAGMO annual reports, from approximately 70 Wasatch Formation monitoring wells available in WDEQ/LQD mine permit files, and both USGS and BLM monitoring wells in the region. The calibration was checked by using the 2002 calibrated model for transient calibration to 2003 water levels in 18 selected well hydrographs for monitoring wells near the coal mines. The 2002 calibration statistics were within the requirements specified in the modeling protocol with the mean, absolute mean, and standard deviation all within 10 percent when these values are divided by the range in water levels for the model in 2002.

ES.3.2 Groundwater Modeling Results

The CMGM results for both the Wasatch and Upper Fort Union formations in the eastern PRB provide information on 1990 and 2002 groundwater elevations, coal mine-related groundwater drawdown for 2002, CBNG-related groundwater drawdown and mounding for 2002, and the combined effects of coal mine dewatering and CBNG development on groundwater levels in 2002. The model results are discussed below.

ES.3.2.1 Wasatch Formation

The Wasatch Formation is not a true aquifer. Groundwater in the Wasatch is found mainly in the thicker permeable sand units and does not form a continuous aquifer, because the sand units themselves are generally discontinuous and often not hydraulically interconnected. However, a groundwater model must treat the Wasatch as a continuous regional aquifer in order to calculate water levels and estimate drawdowns due to groundwater withdrawal. Consequently, a groundwater model of the Wasatch generates water levels and groundwater drawdown contours that are approximate only and not representative of water levels or aquifer behavior in any specific part of the Wasatch. Conversely, the Fort Union Formation is a true regional aquifer. Therefore, comparison of water levels and drawdowns in the Wasatch with those in the Fort Union must be made with caution.

Groundwater levels in the Wasatch Formation for 1990 reflect a period before the beginning of CBNG pumping and a period when the coal mines were beginning to increase dewatering of their mines to facilitate increased coal mining. Modeled groundwater elevations decrease from south to north across the model domain, with groundwater levels in the south near the southern group of coal mines (Subregion 3) around 4,700 to 4,850 feet above mean sea level (amsl) and groundwater elevations near the northern group of coal mines (Subregion 1) at approximately 4,200 to 4,350 feet amsl. The Belle Fourche River and Antelope Creek act as drains and remove water from the Wasatch Formation locally, as is evident in modeled groundwater level depressions near State Route (SR) 59 for the Belle Fourche and west of SR 59 for Antelope Creek. Groundwater drawdown in the Wasatch is evident around the southern group of mines (Subregion 3). There is a suggestion of a slight groundwater mound west of the central group of coal mines (Subregion 2). The northern group of coal mines (Subregion 1) also show a slight depression in groundwater levels within the mine boundaries.

The modeled groundwater levels for 2002 are similar to those for 1990. Groundwater flows from the southern end of the model domain to the northern end of the model domain, with groundwater levels in the south at approximately 4,700 to 4,850 feet amsl and those in the north around 4,200 to 4,350 feet amsl. As in 1990, the Belle Fourche River and Antelope Creek are removing groundwater from the Wasatch Formation. Groundwater drawdown is evident in the southern group of coal mines (Subregion 3), and to some extent in the central group of mines (Subregion 2) and the northern group of mines (Subregion 1). A groundwater mound west of the central group of mines (Subregion 2) is more pronounced, due mainly to CBNG discharge to the Wasatch.

Based on the modeled coal mine-related groundwater drawdown in the Wasatch Formation for 2002, groundwater drawdown in the southern group of mines (Subregion 3) is localized within or very near the coal mine boundaries and is in the range of 10 to 100 feet. For the central group of mines (Subregion 2), drawdown in the Wasatch also is localized near the mines and ranges from 10 to 50 feet. The 10-foot drawdown contour extends a maximum of approximately 3 to 4 miles to the west of the mines. For the northern group of mines (Subregion 1), the drawdown ranges from 10 to 110 feet, and the 10-foot drawdown contour extends west of the coal mines approximately 7 to 8 miles. Groundwater monitoring data in the northern group of mines is limited, and the extent of the 10-foot drawdown contour may be greater than what is actually present in the model results. Modeling suggests that dewatering of the Wasatch in the northern group of mines (Subregion 1) has impacts that extend beyond the mine boundaries; however, in the central and southern mine groups (Subregions 2 and 3, respectively), dewatering impacts to the Wasatch are localized in the vicinity of the mine boundaries.

Modeled groundwater impacts in the Wasatch Formation as a result of CBNG pumping and discharge show groundwater mounding (indicating a rise in groundwater levels since 1990) due to CBNG discharge. The mounding is most evident between Wright and the central group of coal mines (Subregion 2). Mounding is in the range of 10 to 20 feet, with locally high mounding up to 50 feet near the mine boundaries. West of the northern group of mines (Subregion 1), mounding in the Wasatch is in the range of 10 to 50 feet. Mounding in the Wasatch west of the southern group of mines (Subregion 3) is approximately 10 feet.

The modeled sum of groundwater impacts to the Wasatch due to CBNG pumping and discharge and coal mine dewatering shows a drawdown in the range of 10 to 70 feet for the southern group of mines (Subregion 3). For the central group of coal mines (Subregion 2), the total effect resulted in mounding of approximately 20 feet to the west of the coal mines in the CBNG fields and drawdown of 10 to 40 feet within the mine boundaries. For the northern group of mines (Subregion 1), the total effect primarily resulted in drawdown of 10 to 100 feet within or close to the mine boundaries. The Gillette area municipal wells also affect the Wasatch and, per the modeling results, create a drawdown of approximately 10 to 20 feet southeast of Gillette. Thus, for the Wasatch beyond the mine boundaries, the mounding associated with CBNG discharge offsets the drawdown associated with mine dewatering of the Wasatch. Within the mine boundaries, dewatering of the Wasatch by the mines has resulted in drawdown of water levels since 1990.

ES.3.2.2 Upper Fort Union Formation

Based on modeled groundwater elevations in the Upper Fort Union for 1990, groundwater generally flows from south to north across the model domain, with groundwater levels in the south at approximately 4,700 to 4,900 feet amsl and those in the north at approximately 4,100 to 4,250 feet amsl. For the southern group of coal mines (Subregion 3), there is a suggestion of groundwater mounding around and to the west of the mines, with groundwater drawdown within the mine boundaries. The mounding may be an artifact of the drawdown caused by dewatering within the mines. The same pattern, only on a more reduced scale, is found in the central group of mines (Subregion 2). For the northern group of mines (Subregion 1), there is minor groundwater drawdown within the mine boundaries. The drawdown estimates for the northern group of mines is affected by the lack of useable monitoring well data. Many monitoring wells are dry or affected by natural gas, and thus were not used in the modeling. As a result, drawdowns in the Upper Fort

Union for 2002 may be greater than estimated. West of SR 59 near the southern group of mines (Subregion 3), there is a westward bulge in the groundwater contours. This bulge is due to two monitoring wells that have water levels that are not consistent with other monitoring wells in the area. These monitoring wells may be screened differently than other wells, or be affected by a nearby pumping well. Along the southern boundary of the model domain, there is a steep groundwater gradient that is a result of boundary conditions preserved from the original PRB Oil and Gas EIS (BLM 2003) regional groundwater model. This steep groundwater gradient in the Upper Fort Union is an artifact of model design and not a true reflection of groundwater levels. It does not propagate through the model and affect model results.

Based on the modeled groundwater levels in the Upper Fort Union for 2002, there is a complex pattern of drawdown west of the southern group of mines (Subregion 3) that probably is due to the combined effect of coal mine dewatering and CBNG pumping. In the vicinity of the central group of mines (Subregion 2), groundwater drawdown west of the mines due to CBNG pumping is evident. The area near the northern group of mines (Subregion 1) does not show the effect of CBNG pumping in the 2002 groundwater levels. The sharp groundwater gradient in the Upper Fort Union along the southern model boundary is due to retention of model boundary conditions from the original PRB Oil and Gas EIS (BLM 2003) regional groundwater model, and not a reflection of true groundwater levels.

The modeled coal mine-related drawdown in the Upper Fort Union shows that drawdown due to coal mine dewatering primarily is limited to the mine boundaries. In the southern group of mines (Subregion 3), the drawdown ranges from 20 to 180 feet, with the 20-foot drawdown contour extending up to approximately 4 miles west of the mines. For the central and northern groups of mines (Subregions 2 and 1, respectively), drawdown in the Upper Fort Union is limited to the mine boundaries.

Modeled groundwater drawdown in the Upper Fort Union due to CBNG pumping is very pronounced, especially around Wright, Wyoming. For the area west and northwest of the southern group of coal mines (Subregion 3), CBNG-related drawdown is up to 300 feet. Near the central group of coal mines (Subregion 2), CBNG-related drawdown is in the range of 60 to 300 feet and is localized west of the coal mines. Near the northern group of mines (Subregion 1), CBNG-related drawdown is approximately 40 feet and is found in small localized areas to the west of the mines.

Based on the model results, the combined effect of CBNG pumping and coal mine dewatering on the Upper Fort Union is very similar to the effects of CBNG pumping alone, as CBNG pumping greatly dominates that of coal mine dewatering. West of the southern group of mines (Subregion 3), drawdowns of up to 400 feet are observed. Groundwater drawdown within mine boundaries is approximately 20 to 200 feet. For the central group of mines (Subregion 2), groundwater drawdown west of the coal mines is up to 400 feet in areas of CBNG pumping. Within the mine boundaries, groundwater drawdown is approximately 20 to 100 feet. Near the northern group of mines (Subregion 1), the drawdown is approximately 20 to 80 feet. Drawdown in the Upper Fort Union near the Gillette municipal well fields is approximately 20 to 40 feet.