3.0 WATER RESOURCES OF THE WYOMING POWDER RIVER BASIN

3.1 Introduction

The Powder River structural basin of Wyoming, often referred to as the PRB, encompasses five major drainages. The drainages in the northern part of the basin include the Powder River, Tongue River, and Little Powder River. In the central and southern parts of the basin, the major drainages are the Belle Fourche and Cheyenne rivers. Surface water flows to the north into Montana in the northern part of the basin and to the east-northeast into South Dakota in the southern and central parts of the basin. Regional groundwater flow in Tertiary-age formations of the basin generally is to the north and into Montana. Thus, water in the Wyoming PRB, especially surface water, is shared to some degree with bordering states. Existing Wyoming water law and water compacts with adjacent states reflect this need to share surface water resources.

Water is one of the critical resources of the PRB. Agriculture in the basin depends primarily on surface water resources and to a lesser degree on groundwater resources for irrigation. The stock industry in the basin depends on shallow groundwater wells in Tertiary formations and overlying alluvial formations for water. Municipal water is obtained from both surface water reservoirs and groundwater. Domestic water supply mainly comes from shallow groundwater found in Tertiary formations and to a lesser degree from overlying alluvial formations found along major rivers. Industrial use of water mainly is from groundwater. The coal industry of the eastern PRB must dewater the Tertiary coal units prior to removal of the coal. Surface strip mining of coal also requires the removal or realignment of drainages. The recently developed CBNG industry also must dewater Tertiary coal-bearing units in order to free the methane gas from the coal. Industrial use of groundwater in the basin thus competes with municipal, domestic, and to some degree with agricultural use of water resources. This competing demand for water in the basin has become a political issue for Wyoming over the past 10 years.

The discussion of water resources in the PRB focuses on two main issues: 1) current water use in the basin and 2) industrial use of water resources by the coal mine and CBNG industries. The discussion of water resources also serves to update the water resources section of the Coal Development Status Check (BLM 1996) by comparing current (year 2002) water use by the coal mine and CBNG industries to what was predicted in past BLM EAs and EISs and by the USGS cumulative assessment (Martin et al. 1988). The discussion of current water use was based on two recently completed state water plans: 1) the Powder/Tongue River Basin Plan (HKM Engineering et al. 2002a) and 2) the Northeast Wyoming River Basins Plan (HKM Engineering et al. 2002b). Water demand and impacts to water resources by the coal mine industry were based on annual hydrologic reports and Cumulative Hydrologic Impact Assessments (CHIAs) available from WDEQ/LQD and on the annual reports of the GAGMO. Current (2002) water consumption by the CBNG industry was based on production data supplied to the Wyoming Oil and Gas Conservation Commission (WOGCC) and on water quality data available in scientific reports by Wyoming state agencies and the USGS.

3.2 Basin Description

The PRB in Wyoming is a synclinal structural basin bounded on the west by the Big Horn Mountains, on the south by the Laramie Range and the Casper Arch, and on the east by uplifted and tilted beds of Tertiary stratigraphic units and the Black Hills. The basin is open on the north and continues into Montana. The basin is encompassed by two major river basin planning areas in northeastern Wyoming, the Powder/Tongue River Basin and the Northeast Wyoming River Basins. The water resources of the Wyoming PRB are discussed with reference to these two major river basin planning areas in order to be consistent with hydrologic studies and reports prepared by the State of Wyoming.

3.2.1 Powder/Tongue River Basin

The Powder/Tongue River Basin (**Figure 1-3**) covers the northern and northwestern portions of the PRB and includes the drainages of the Little Bighorn, Tongue, Powder, and Little Powder rivers. The Little Bighorn River is not part of the Powder River structural basin. This river basin encompasses all or part of Sheridan, Johnson, Campbell, Natrona, and Converse counties in north-central Wyoming. All of the rivers in the Powder/Tongue River Basin flow north into Montana and eventually into the Yellowstone River. The climate in this part of the basin is semi-arid, with average annual precipitation in the range of 13 to 15 inches. The topography is typical of the high plains with hilly to rugged uplands, wide valleys, and badlands. The Big Horn Mountains rise to approximately 13,000 feet above mean sea level (amsl) on the western side of the basin, and snowmelt in these mountains provides most of the surface water flow for the major drainages.

Significant water features in the Tongue River Basin include the Tongue River, Goose Creek, Big Goose Creek, Little Goose Creek, and Prairie Dog Creek (HKM Engineering et al. 2002a). Storage reservoirs in the Tongue River Basin include Twin Lakes, Big Goose Creek Reservoir, Bighorn Reservoir, and Dome Lake.

Significant streams in the PRB include the Powder River, Little Powder River, Clear Creek, and Crazy Woman Creek. Significant storage facilities include Lake DeSmet, Kearney Lake, Willow Park Reservoir, Cloud Peak Reservoir, and Tie Hack Reservoir in the Clear Creek watershed; Wallows Creek in the drainage of Crazy Woman Creek; Dull Knife Reservoir on the North Fork of the Powder River; and Lower Salt Reservoir on Salt Creek (HKM Engineering et al. 2002a).

Water development and use on the Tongue, Powder, and Little Powder rivers are governed by the Yellowstone River Compact of 1950 (HKM Engineering et al. 2002a). This compact divides the water of the tributaries of the Yellowstone River between Montana and Wyoming. Unappropriated or unused total divertible flow in these three tributaries of the Yellowstone River is allocated to Wyoming and Montana as follows:

- Tongue River: 40 percent to Wyoming, 60 percent to Montana
- Powder River and Little Powder River: 42 percent to Wyoming, 58 percent to Montana

In Wyoming, the state constitution establishes water in the state to be the property of the state. Consequently, all development and management of water resources in Wyoming is governed by the state, and water use is administered by the State Engineer and the State Board of Control,

which consists of the State Engineer and the Superintendent of each of the four water divisions of the state (HKM Engineering et al. 2002a).

3.2.2 Northeast Wyoming River Basins

The Northeast Wyoming River Basins (**Figure 1-3**) encompass the drainages of the central and southern part of the PRB that are found in the main coal-producing area of the eastern PRB from Gillette, Wyoming, south to the area around Wright, Wyoming. Drainages included in the Northeast Wyoming River Basins are the Little Missouri River, Belle Fourche River, Cheyenne River, and Upper Niobrara River. The Little Missouri and the Upper Niobrara are mostly outside of the Powder River structural basin and do not drain areas of active coal mining. The rivers of the Northeast Wyoming River Basins drain into South Dakota and Nebraska (Upper Niobrara).

The topography is much like that of the Powder/Tongue River Basin, except that the Big Horn Mountains are not present. The Laramie Range bounds the basin on the south, and precipitation typically ranges from 13 to 15 inches per year. The lack of a major mountain range like the Big Horn Mountains means that surface water flow is dependent on precipitation within the basin (HKM Engineering et al. 2002b). Topographic elevations range from 3,500 to 6,000 feet amsl in the plains and from 4,500 feet to 6,000 feet amsl in the Black Hills, which border the basin on the east.

The major drainages that are within the PRB are the Belle Fourche and Cheyenne rivers. Significant tributaries of these two rivers are listed below (HKM Engineering et al. 2002b):

- Belle Fourche River Tributaries: Redwater Creek, Beaver Creek, Caballo Creek, Blacktail Creek, Lytle Creek, Miller Creek, Inyan Kara Creek, Donkey Creek, and Arch Creek

- Cheyenne River Tributaries: Dry Fork Cheyenne River, Antelope Creek, Lightning Creek, Lance Creek, and Beaver Creek

The largest storage facility is the Keyhole Reservoir on the Belle Fourche River northeast of Moorcroft. Other reservoirs include the Gillette Reservoir on Donkey Creek, Stone #2 Reservoir on Bonepile Creek, Betty Reservoir on the South Fork of the Cheyenne River, Spencer Reservoir and M.W. Reservoir on Stockade Beaver Creek, Robbers Roost Reservoir on Robbers Roost Creek, Clark and Metzger Reservoir on Alum Creek, Klodt Reservoir on Mush Creek, and Tract 37 Reservoir on the North Fork of the Little Missouri River (HKM Engineering et al. 2002b). These reservoirs initially were built to support the stock industry that began after 1875 in Wyoming. Additional reservoirs were built for irrigation water supply, and in 1952 the U.S. Bureau of Reclamation constructed the Keyhole Reservoir to provide irrigation water for Wyoming and South Dakota (HKM Engineering et al. 2002b). Irrigation water supply is the main use of these reservoirs today.

Water development is regulated by the same laws and state agencies that regulate water use in the Powder/Tongue River Basin. Water compacts that govern surface water use in the Northeast Wyoming River Basins are the Belle Fourche River Compact of 1943 and the Upper Niobrara River Compact of 1962. The Belle Fourche River Compact recognizes all Wyoming rights existing at the time of the compact and permits Wyoming unlimited use of surface water for stock reservoirs not exceeding 20 acre-feet of capacity. In addition, Wyoming is allowed to use 10 percent of the

available flow in the Belle Fourche River in excess of that needed to supply water rights existing at the time of the compact. However, no reservoir in Wyoming constructed after the compact can exceed 1,000 acre-feet of capacity. Reservoirs used for CBNG discharge water are excepted from this rule.

The Upper Niobrara River Compact between Wyoming and Nebraska restricts stock reservoirs to a maximum of 20 acre-feet of capacity. Diversion of surface water in the Upper Niobrara River is regulated. Groundwater development also is regulated by the compact. Compacts for the Cheyenne River and the Little Missouri River have not yet been ratified (HKM Engineering et al. 2002b).

The Belle Fourche River and the Cheyenne River are the major drainages of the eastern PRB coal area. Tributaries to these rivers are the drainages most affected by surface coal mining. North of Gillette, a few of the northern-most coal mines fall within the Little Powder River drainage. CBNG development south of Gillette falls within the Belle Fourche and Cheyenne river drainages. North of Gillette, CBNG development is within the Powder/Tongue River Basin.

3.3 Basin Water Use Profile

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 and agricultural areas within the basin found mainly 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 PRB is divided into the two major water planning areas of the basin, the Powder/Tongue River Basin and the Northeast Wyoming River Basins. Much of the information that follows was taken from two water plans prepared for the Wyoming Water Development Commission (HKM Engineering et al. 2002a,b).

3.3.1 Powder/Tongue River Basin

The Powder/Tongue River Basin has ample surface water supply as a result of snowmelt and runoff from the Big Horn Mountains. Both the Tongue River and the Powder River derive most of their flow from tributaries that head in the Big Horns. Agricultural development in this area is dependent on surface water flow for irrigation water. Municipal water supply is derived from reservoirs near the Big Horns that trap surface runoff, and from groundwater. Domestic water supply is mainly from groundwater. The summary that follows was taken from a more detailed water plan developed by HKM Engineering et al. (2002a) for the Wyoming Water Development Commission. **Table 3.3-1** summarizes water use in the Powder/Tongue River Basin as of 2002.

3.3.1.1 Agricultural Water Use

Irrigated agricultural lands in the Powder/Tongue River Basin primarily are associated with forage production for the livestock industry. Primary crops are alfalfa, grass hay, and pasture grass. Lesser amounts of small grains and corn also are produced (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. Water depletions for surface water were approximately 194,000 acre-feet for wet years, 184,000 acre-feet for normal years, and 178,000 acre-feet for dry years (see **Table 3.3-2**) (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 279 acre-feet for wet years and 194 acre-feet for normal and dry years (see **Table 3.3-3**). Agricultural water use in wet years can be higher than in dry years due to more land being in production. The location of agricultural wells is shown in **Figure 3.3-1**. Most agricultural wells, especially stock wells, are screened in the Fort Union Formation.

Table 3.3-1
Water Use as of 2002 in the Powder/Tongue River Basin

	Dry Year		Normal Year		Wet Year	
	(approximate acre-feet per year)					
Water Use	**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.

3.3.1.2 Municipal and Domestic Water Use

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 4,400 acre-feet per year. **Table 3.3-4** summarizes municipal water use in the Powder/Tongue River Basin. **Figure 3.3-2** shows the location of municipal wells, and **Figure 3.3-3** shows the location of domestic wells. Many of the municipal wells and most of the domestic wells are in the Fort Union Formation.

3.3.1.3 Industrial Water Use

Conventional oil and gas production and CBNG development constitute the industrial water use in the Powder/Tongue River Basin. Both of these industries consume groundwater. The 2002 total estimated groundwater consumption is approximately 68,000 acre-feet per year (see **Table 3.3-1**) (HKM Engineering et al. 2002a). Approximately half of this groundwater comes from the Fort Union Formation and is consumed by the CBNG industry. Conventional oil and gas wells consume

Table 3.3-2
Agricultural Surface Water Depletions in the Powder/Tongue River Basin

Source of Water Supply	Climate Stations[1]	Active Irrigation (acres)	Hydrologic Condition	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
				(acre-feet)												
Little Bighorn Basin	Sheridan	1,781	Wet	0	0	0	0	56	370	731	618	206	0	0	0	1,981
			Normal	0	0	0	6	126	421	654	640	216	0	0	0	2,063
			Dry	0	0	0	29	342	402	539	369	162	0	0	0	1,843
Tongue River Basin	Sheridan	62,760	Wet	0	0	0	27	1,994	12,268	24,914	20,365	9,461	2	0	0	69,031
			Normal	0	0	0	189	4,614	15,398	22,463	21,741	6,960	3	0	0	71,368
			Dry	0	0	0	1,049	11,422	14,764	21,219	14,108	5,458	8	0	0	68,028
Upper Clear Creek	Buffalo	39,176	Wet	0	0	0	18	1,606	8,482	15,170	13,276	6,295	4	0	0	44,851
			Normal	0	0	0	148	4,023	11,228	13,811	13,489	5,201	5	0	0	47,905
			Dry	0	0	0	825	6,202	11,096	13,418	9,207	3,755	8	0	0	44,511
Lower Clear Creek	Buffalo and Weston	7,174	Wet	0	0	0	27	329	1,491	2,915	2,443	1,202	3	0	0	8,410
			Normal	0	0	0	56	735	2,065	2,528	2,431	991	4	0	0	8,810
			Dry	0	0	0	203	1,325	1,924	2,488	1,656	713	6	0	0	8,315
Upper Crazy Woman Creek	Buffalo	12,324	Wet	0	0	0	6	506	2,678	4,774	4,160	1,975	1	0	0	14,100
			Normal	0	0	0	47	1,265	3,541	4,346	4,228	1,631	2	0	0	15,060
			Dry	0	0	0	259	1,949	3,498	4,222	2,885	1,178	3	0	0	13,994
Lower Crazy Woman Creek	Buffalo and Weston	1,418	Wet	0	0	0	54	130	278	498	447	213	5	0	0	1,625
			Normal	0	0	0	66	173	326	423	394	173	6	0	0	1,561
			Dry	0	0	0	96	184	302	403	305	138	9	0	0	1,437
Upper Powder River	Kaycee	18,107	Wet	0	0	0	210	2,288	5,307	9,336	8,568	4,331	20	0	0	30,060
			Normal	0	0	0	207	1,085	3,879	5,715	5,910	1,827	27	0	0	18,650
			Dry	0	0	0	551	1,214	4,558	8,036	5,462	2,393	38	0	0	22,252
South Fork Powder River	Kaycee and Midwest	2,103	Wet	0	0	0	5	304	725	1,157	1,028	548	1	0	0	3,768
			Normal	0	0	0	4	25	251	425	567	64	1	0	0	1,337
			Dry	0	0	0	6	7	218	684	457	176	1	0	0	1,549
Lower Powder River	Buffalo and Weston	6,440	Wet	0	0	0	322	779	1,324	2,253	2,045	947	32	0	0	7,702
			Normal	0	0	0	378	747	1,222	1,653	1,527	626	36	0	0	6,189
			Dry	0	0	0	494	548	1,115	1,662	1,298	588	55	0	0	5,760
Little Powder River Basin	Weston	9,873	Wet	0	0	0	655	939	2,339	3,435	3,183	1,611	24	0	0	12,186
			Normal	0	0	0	591	1,119	2,142	3,039	2,763	1,325	21	0	0	11,000
			Dry	0	0	0	580	1,678	1,982	2,814	2,048	825	17	0	0	9,944
Total		**161,156**	**Wet**	**0**	**0**	**0**	**1,324**	**8,930**	**35,261**	**65,181**	**56,131**	**26,790**	**91**	**0**	**0**	**193,708**
			Normal	**0**	**0**	**0**	**1,691**	**13,914**	**40,475**	**55,057**	**53,690**	**18,915**	**105**	**0**	**0**	**183,847**
			Dry	**0**	**0**	**0**	**4,091**	**24,870**	**39,862**	**55,485**	**37,795**	**15,386**	**145**	**0**	**0**	**177,634**

[1]Where more than one climate station is listed, the stations were weighted 50-50.

Source: HKM Engineering et al. 2002a.

Table 3.3-3
Agricultural Groundwater Depletions in the Powder/Tongue River Basin

Source of Water Supply	Climate Stations[1]	Active Irrigation (acres)	Hydrologic Condition	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
				(acre-feet)												
Upper Clear Creek	Buffalo	20	Wet	0	0	0	0	1	4	8	7	3	0	0	0	23
			Normal	0	0	0	0	2	6	7	7	3	0	0	0	25
			Dry	0	0	0	0	3	6	7	5	2	0	0	0	23
Upper Crazy Woman Creek	Buffalo	97	Wet	0	0	0	0	4	20	37	34	16	0	0	0	112
			Normal	0	0	0	0	10	27	34	35	13	0	0	0	119
			Dry	0	0	0	2	15	27	33	24	10	0	0	0	110
Upper Powder River	Kaycee	58	Wet	0	0	0	0	8	17	31	28	14	0	0	0	98
			Normal	0	0	0	0	0	6	11	15	1	0	0	0	34
			Dry	0	0	0	0	0	6	19	12	4	0	0	0	41
Lower Powder River	Buffalo and Weston	28	Wet	0	0	0	0	4	8	15	14	6	0	0	0	46
			Normal	0	0	0	0	0	3	5	7	1	0	0	0	16
			Dry	0	0	0	0	0	2	9	6	2	0	0	0	19
Total		**203**	**Wet**	**0**	**0**	**0**	**0**	**17**	**49**	**91**	**83**	**39**	**0**	**0**	**0**	**279**
			Normal	**0**	**0**	**0**	**0**	**13**	**42**	**58**	**64**	**18**	**0**	**0**	**0**	**194**
			Dry	**0**	**0**	**0**	**3**	**18**	**40**	**68**	**47**	**18**	**0**	**0**	**0**	**194**

[1]Where more than one climate station is listed, the stations were weighted 50-50.

Source: HKM Engineering et al. 2002a.

groundwater to stimulate production. For the year 2000, approximately 2,343 wells produced approximately 44,000 acre-feet of water, and 1,593 injection wells consumed approximately 38,000 acre-feet of water (HKM Engineering et al. 2002a). Most of the water produced by oil and gas wells was reused for injection and came from units below the Fort Union Formation. As of January 1, 2002, there were approximately 9,390 CBNG wells of record in the Powder/Tongue River Basin. Most of these wells were in the Powder River, Little Powder River, and Tongue River drainages. Approximately 36,900 acre-feet of groundwater per year from the Fort Union Formation (HKM Engineering et al. 2002a) was consumed from these wells in the production of CBNG. This amounts to approximately 3.9 acre-feet per well per year. As of 2002, a total of 50,500 acre-feet of groundwater had been pumped by CBNG wells since the 1990s in the Powder/Tongue River Basin (HKM Engineering et al. 2002a). The location of industrial wells is shown in **Figure 3.3-4**, and the location of CBNG wells is shown in **Figure 3.3-5**. No water currently is being used for the electric power industry, although Lake DeSmet has been developed as a surface water reservoir for future electric power generation (HKM Engineering et al. 2002a).

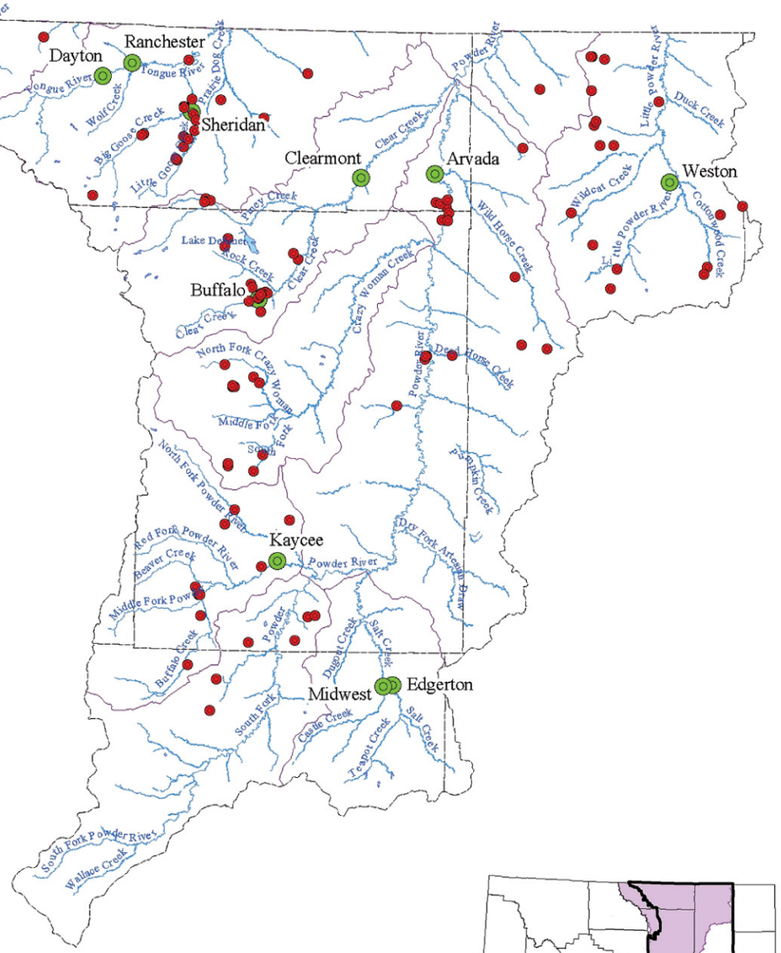
Table 3.3-4
Municipal Water Use in the Powder/Tongue River Basin

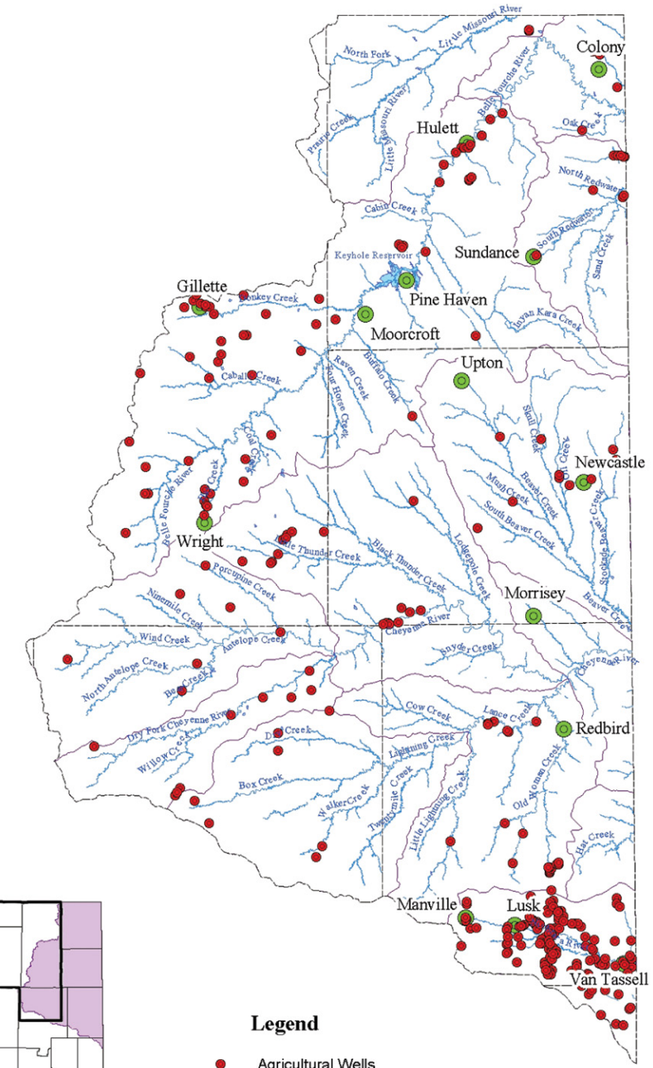
Municipality	Population[1]	Gpcpd[2]	Annual Use (million gallons)
Anderson I&SD	Supplied by City of Gillette		
Arvada WD	Individual wells, no central system		
Town of Clearmont	125	220	10.0
Cook Road WD	225	N/A	--
Countryside WUA	250	N/A	--
Eight-mile Subdivision	90	140	4.6
Green Valley Estates I&SD	72	N/A	--
Heritage Village W&SD	700	81	20.7
Town of Kaycee	300	210	23.0
Linch Utility	20	N/A	--
Means W&SD	300	600	65.7
Pine Butte I&DS	100	N/A	--
Prairie View/Champion I&SD	Individual wells, no central system		

[1]Based on the 2000 census.
[2]Gallons per capita per day.
Source: HKM Engineering et al. 2002a.

3.3.1.4 Recreational and Environmental Water Use

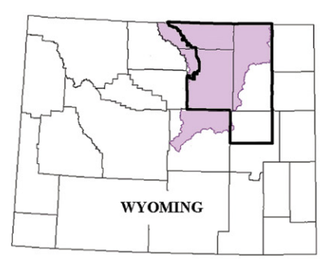
Lake DeSmet is the largest body of recreational water in the Powder/Tongue River basin. Recreational and environmental water use requires minimum flow releases from reservoirs, minimum water levels in reservoirs, or maintenance of instream flow water rights. However, recreational water use is non-consumptive.

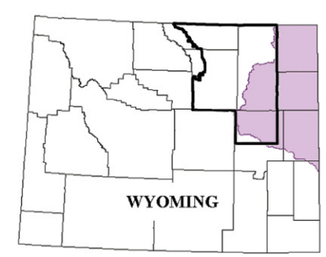




Legend

- Agricultural Wells
- Communities





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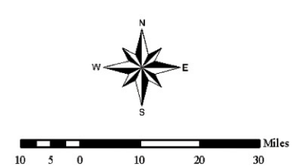
- Agricultural Wells
- Communities



Powder/Tongue River Basin Planning Area

Northeast Wyoming River Basins Planning Area

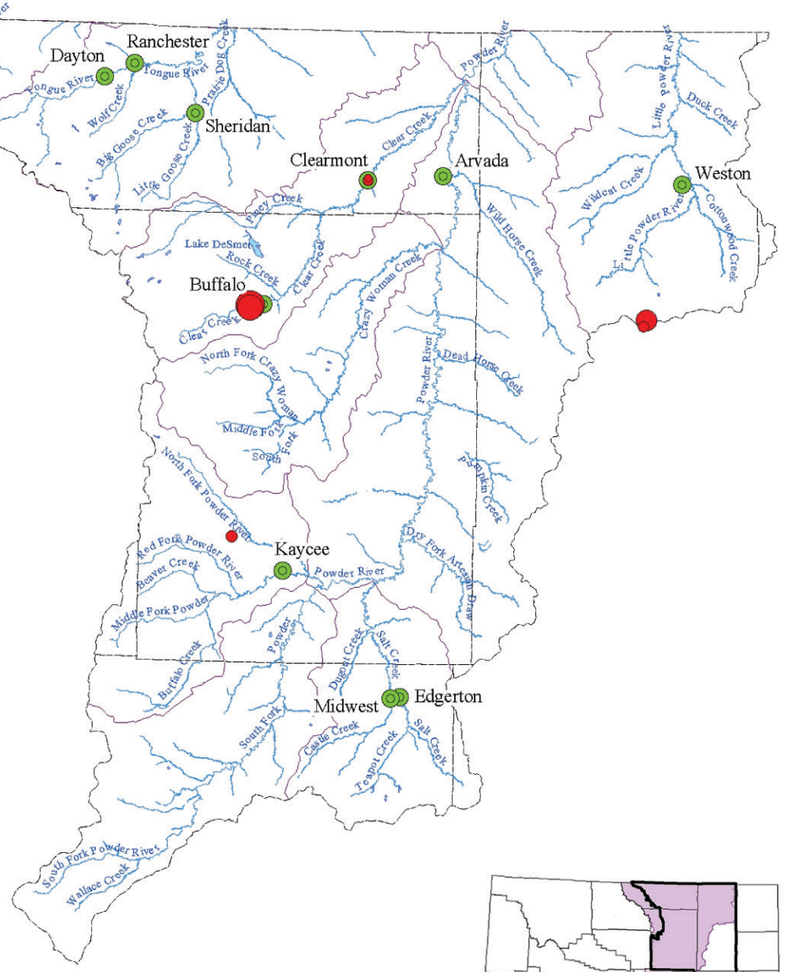
Source: HKM Engineering et al. 2002a,b.

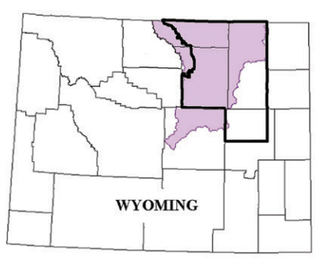
Powder River Basin Coal Review

Figure 3.3-1

Agricultural Wells

11/22/09





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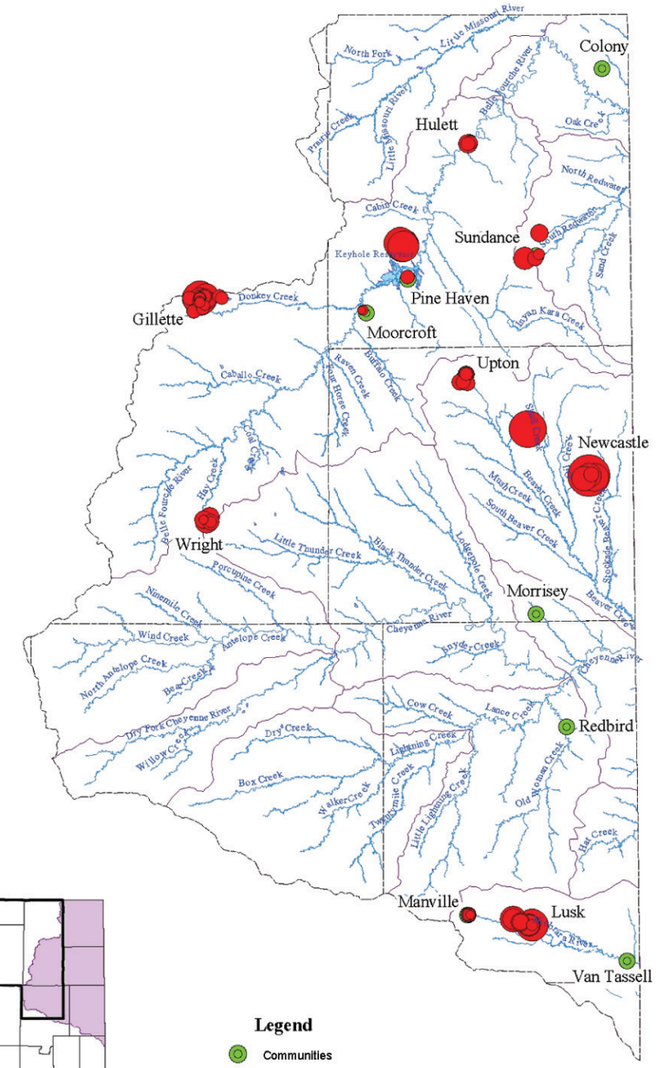
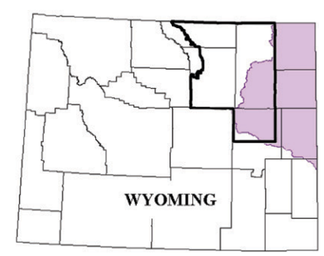
Communities

Municipal Well Yield (GPM)

- 100
- 250
- 500
- 750
- 1,000

Powder/Tongue River Basin Planning Area





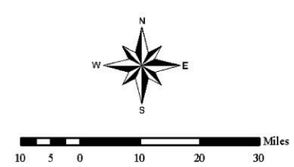
Legend

Communities

Municipal Well Yield (GPM)

- 100
- 250
- 500
- 750
- 1,000

Northeast Wyoming River Basins Planning Area



Powder River Basin Coal Review

Figure 3.3-2

Municipal Wells

Source: HKM Engineering et al. 2002a,b.

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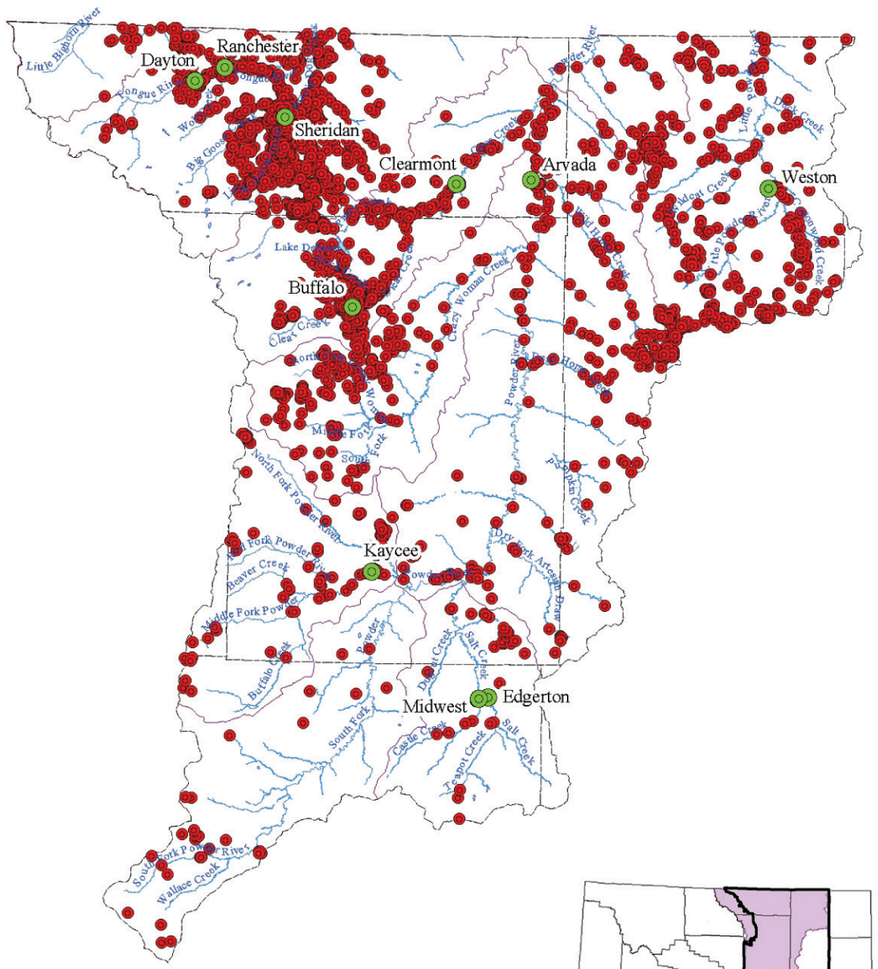
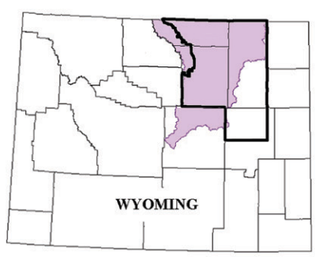
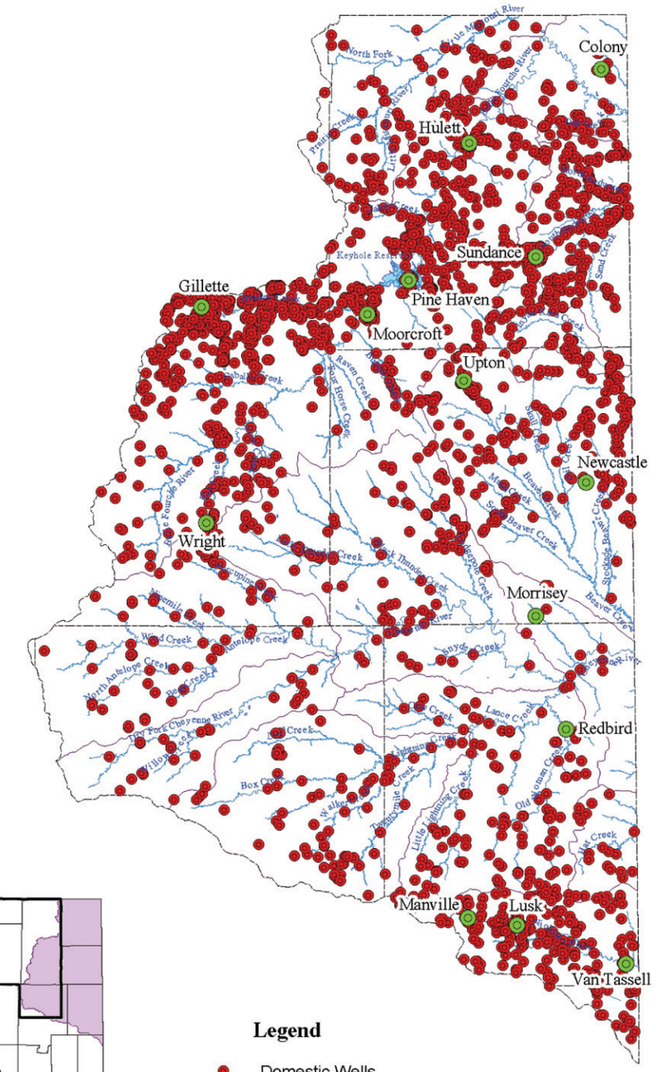


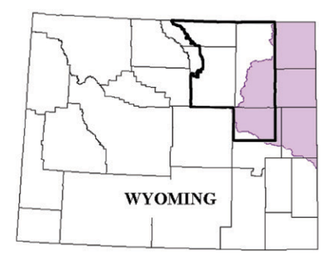


Legend

- Domestic Wells
- Communities

Powder/Tongue River Basin Planning Area

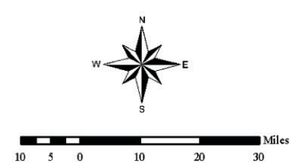




Legend

- Domestic Wells
- Communities

Northeast Wyoming River Basins Planning Area



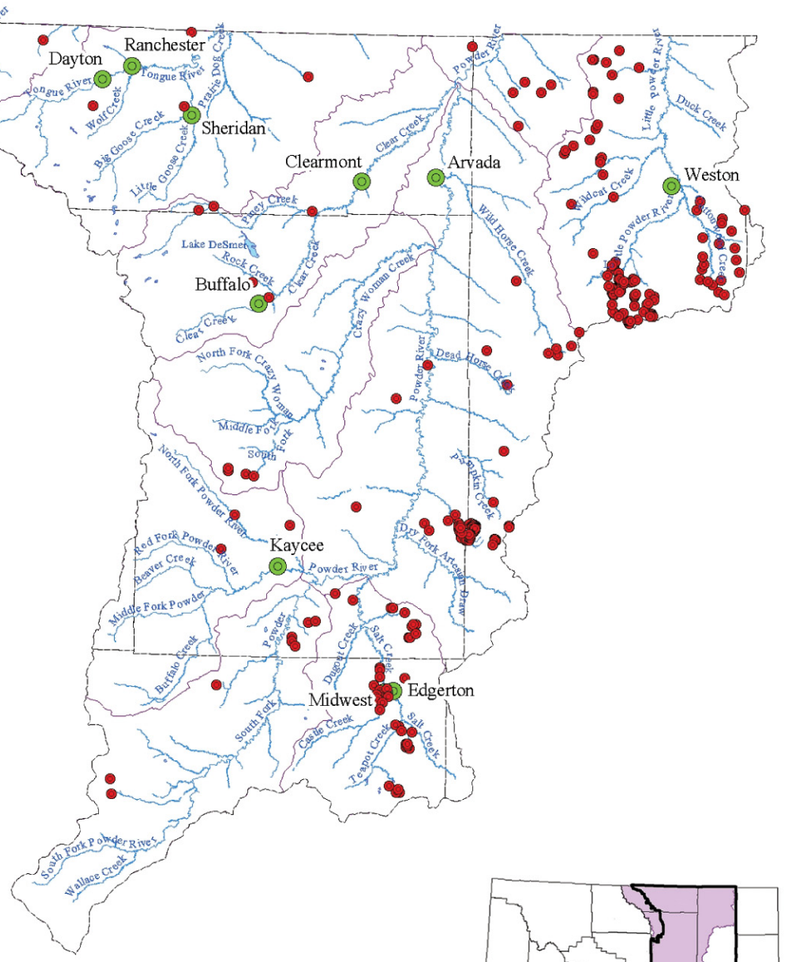
Powder River Basin Coal Review

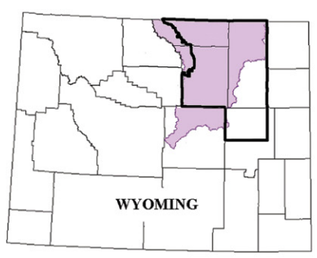
Figure 3.3-3

Domestic Wells

Source: HKM Engineering et al. 2002a,b.

07/27/06

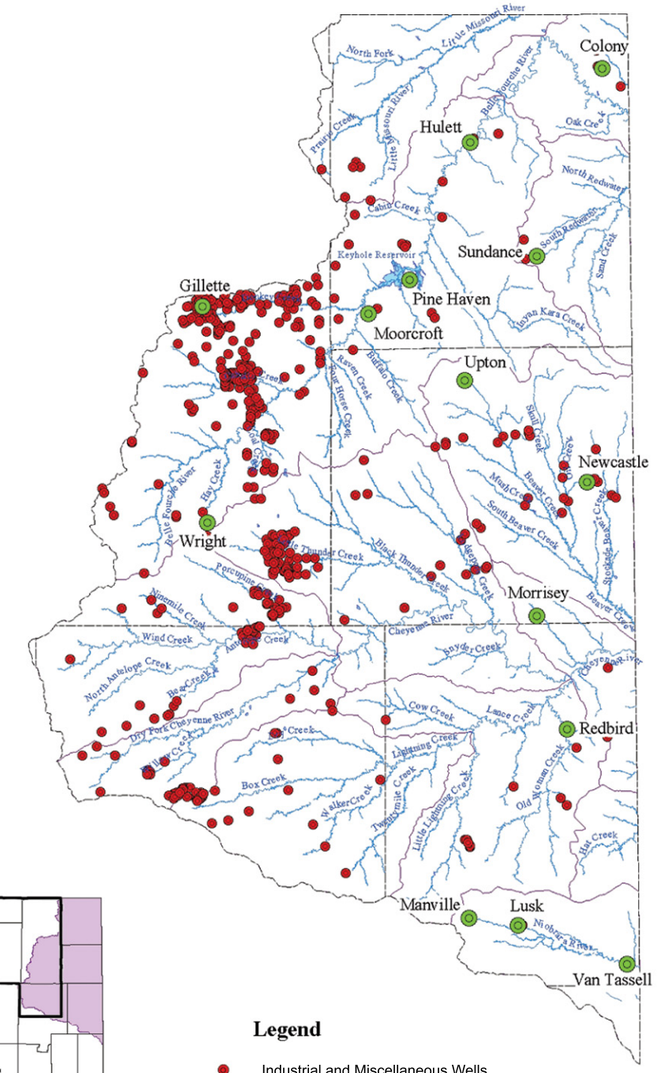


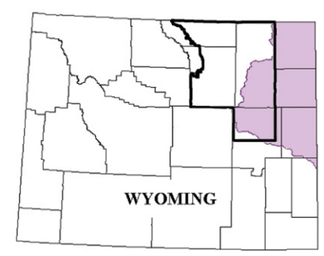


Legend

- Industrial and Miscellaneous Wells
- Communities

Powder/Tongue River Basin Planning Area

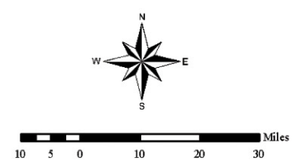




Legend

- Industrial and Miscellaneous Wells
- Communities

Northeast Wyoming River Basins Planning Area



Powder River Basin Coal Review

Figure 3.3-4

Industrial and Miscellaneous Wells

Source: HKM Engineering et al. 2002a,b.

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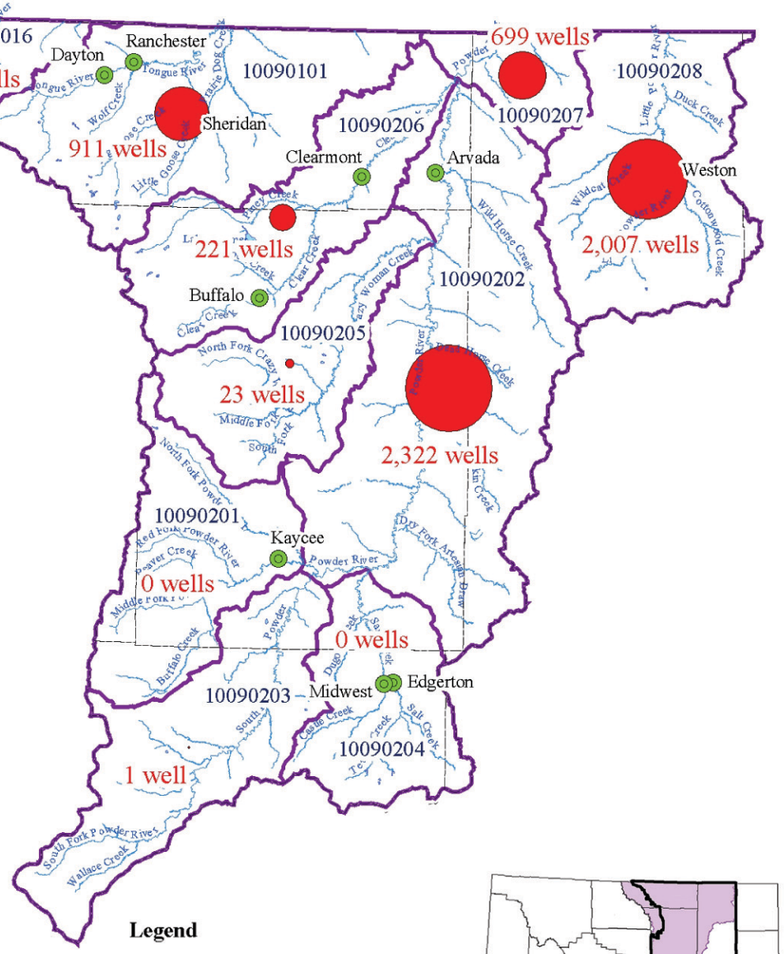
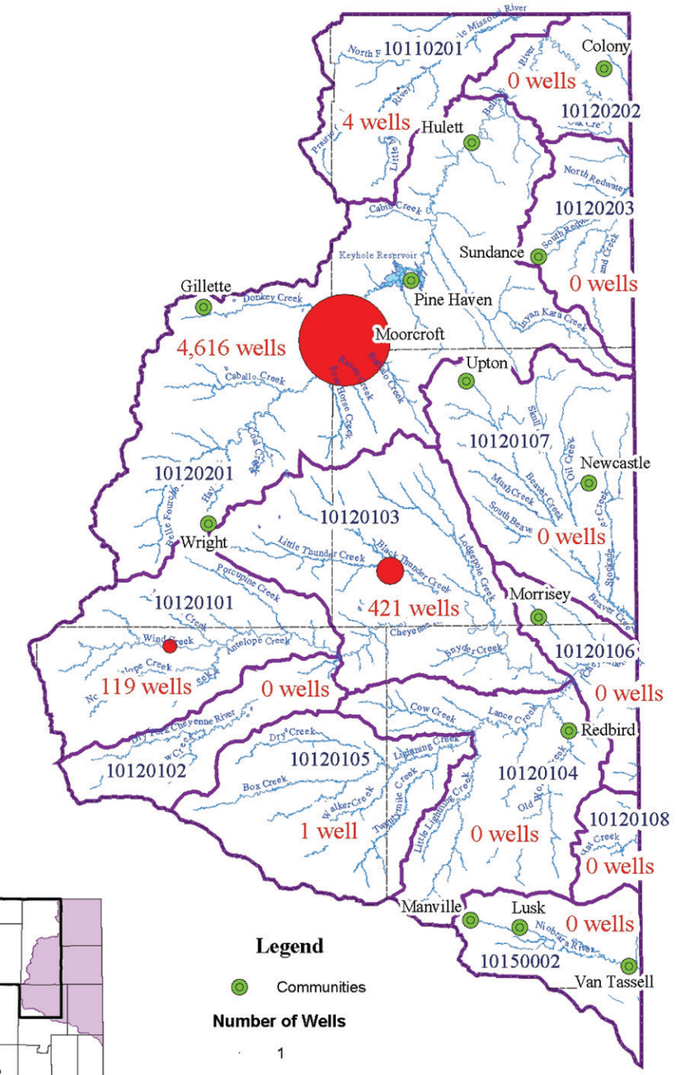
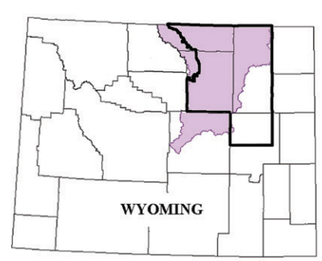
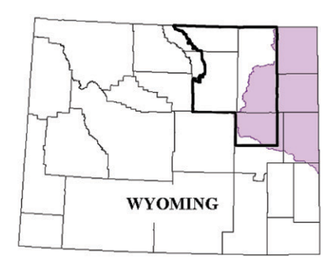








Legend

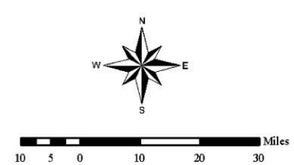
- Communities

Number of Wells

- 1
- 10
- 50
- 100
- 1,000

Powder/Tongue River Basin Planning Area

Northeast Wyoming River Basins Planning Area



Powder River Basin Coal Review

Figure 3.3-5

CBNG Wells

Source: HKM Engineering et al. 2002a,b.

07/27/06

3.3.1.5 Reservoir Evaporation

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 (see **Figure 3.3-6** and **Table 3.3-1**) (HKM Engineering et al. 2002a). This is primarily 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. **Table 3.3-5** summarizes reservoir evaporation from key storage reservoirs.

Table 3.3-5
Reservoir Evaporation in the Powder/Tongue River Basin

Key Storage Reservoirs	Active Capacity (acre-feet)	Dam Height (feet)	Surface Area (acres)	Annual Net Evaporation Loss (acre-feet)
Big Goose Park	10,362	85	318	557
Big Horn	4,624	45	179	296
Cross Creek	798	30	51	278
Cloud Peak	3,570	36	174	85
Dome Lake No. 1	1,506	30	96	8,372
Dull Knife	4,345	80	130	170
Healy	5,140	50	246	205
Kearney Lake	6,324	67	193	556
Lake Desmet	111,827	80	2,653	291
Muddy Guard No. 2	1,934	57	48	113
Sawmill	1,275	38	75	136
Tie Hack	2,435	110	63	148
Twin Lakes	1,317	54	52	112
Willow Park	4,457	56	213	N/A

Source: HKM Engineering et al. 2002a.

3.3.2 Northeast Wyoming River Basins

The Northeast Wyoming River Basins are those that lie to the northeast, east, and southeast of Gillette, Wyoming, in Crook, southeastern Campbell, Weston, northern Converse, and northern Niobrara counties. The main rivers are the Belle Fourche in Campbell and Crook counties and the Cheyenne River in Converse, Weston, and Niobrara counties. The Little Missouri River lies in northern Crook County and is not part of the Powder River structural basin; however, it does border the coal mines north of Gillette, Wyoming. The Niobrara River is not part of the Powder River structural basin and is not near the coal mines of the eastern PRB. Important tributaries to the Belle Fourche River that are near coal mines are Caballo Creek and Hay Creek; important tributaries to the Cheyenne River that are near coal mines are North Antelope Creek, Porcupine Creek, Little Thunder Creek, Black Thunder Creek, and Willow Creek. Except for the Niobrara River, the Northeast Wyoming River Basins drain into South Dakota. Water in the rivers comes from groundwater baseflow and from precipitation, especially from heavy storms during the summer months. Over the past 10 years, discharge of groundwater from CBNG wells has contributed locally to flow in these drainages. The topography is typical of the High Plains – rolling topography with

elevated tablelands and numerous incised drainages. There are no large mountains in the Northeast Wyoming River Basins.

3.3.2.1 Agricultural Water Use

Irrigated agricultural lands in the Northeast Wyoming River Basins are associated with forage production for the livestock industry. Crops are mainly alfalfa, grass hay, and pasture grass. Approximately 77,350 acres are irrigated in the Northeast Wyoming River Basins, with approximately 13,000 of these acres being irrigated by 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 (see **Table 3.3-6**) (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. Water use in wet years can exceed that in dry years due to more land being in production. Agricultural irrigation wells are shown in **Figure 3.3-1**. As shown in **Table 3.3-7**, most of the groundwater consumption for irrigation was in the Niobrara River drainage. **Tables 3.3-8** and **3.3-9** show the relative surface and groundwater depletion, respectively, in the Northeast Wyoming River Basins.

Table 3.3-6
Water Use as of 2002 in the Northeast Wyoming River Basins

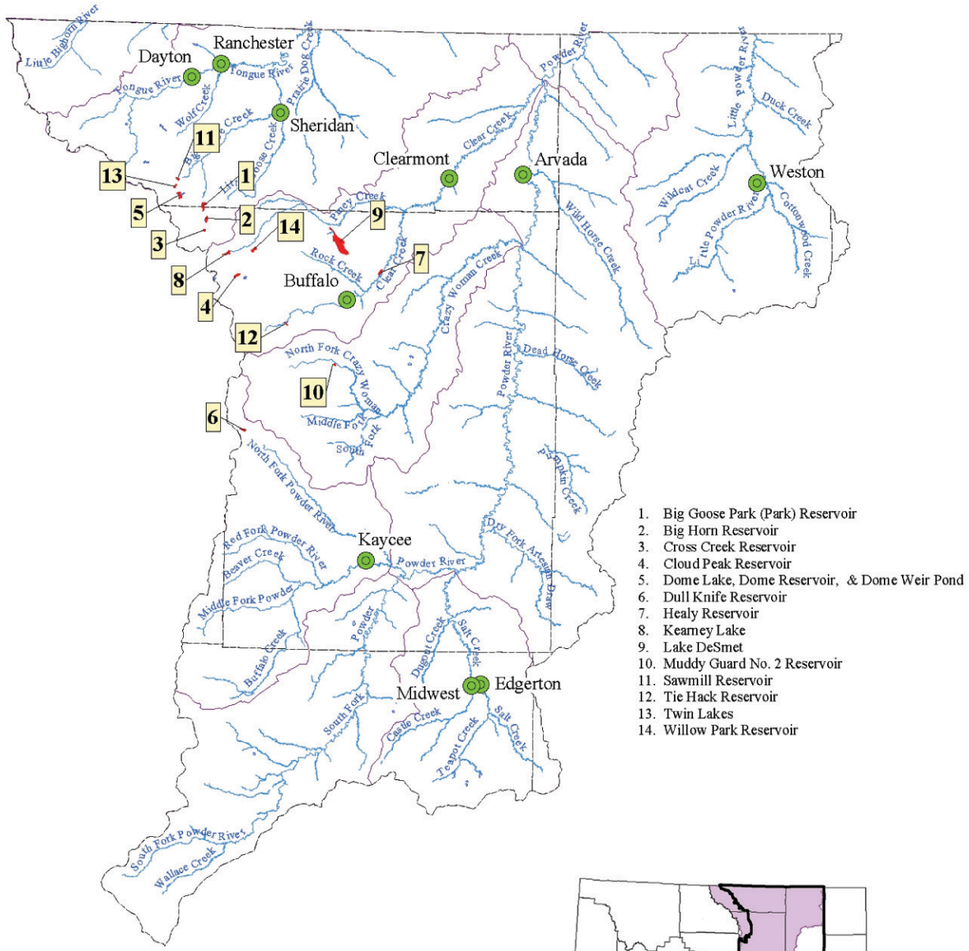
Water Use		Dry Year		Normal Year		Wet Year	
		(approximate acre-feet per year)					
		Surface Water	Groundwater	Surface Water	Groundwater	Surface Water	Groundwater
Agricultural		65,000	11,000	69,000	17,000	71,000	17,000
Municipal		---	9,100	---	9,100	---	9,100
Domestic		---	3,600	---	3,600	---	3,600
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.

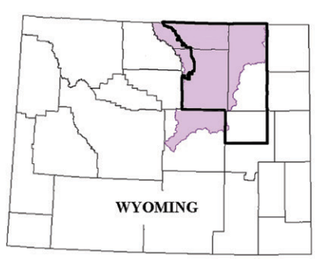
Source: HKM Engineering et al. 2002b.

3.3.2.2 Municipal and Domestic Water Use

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 (**Table 3.3-10**). Municipal 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 (see **Table 3.3-6**) (HKM Engineering et al. 2002b). **Figure 3.3-2** shows the location of municipal wells, and **Figure 3.3-3** shows the location of domestic wells. Domestic water consumption is mainly from the Fort Union Formation. Municipal water consumption is from the Fort Union Formation and aquifers below the Fort Union.



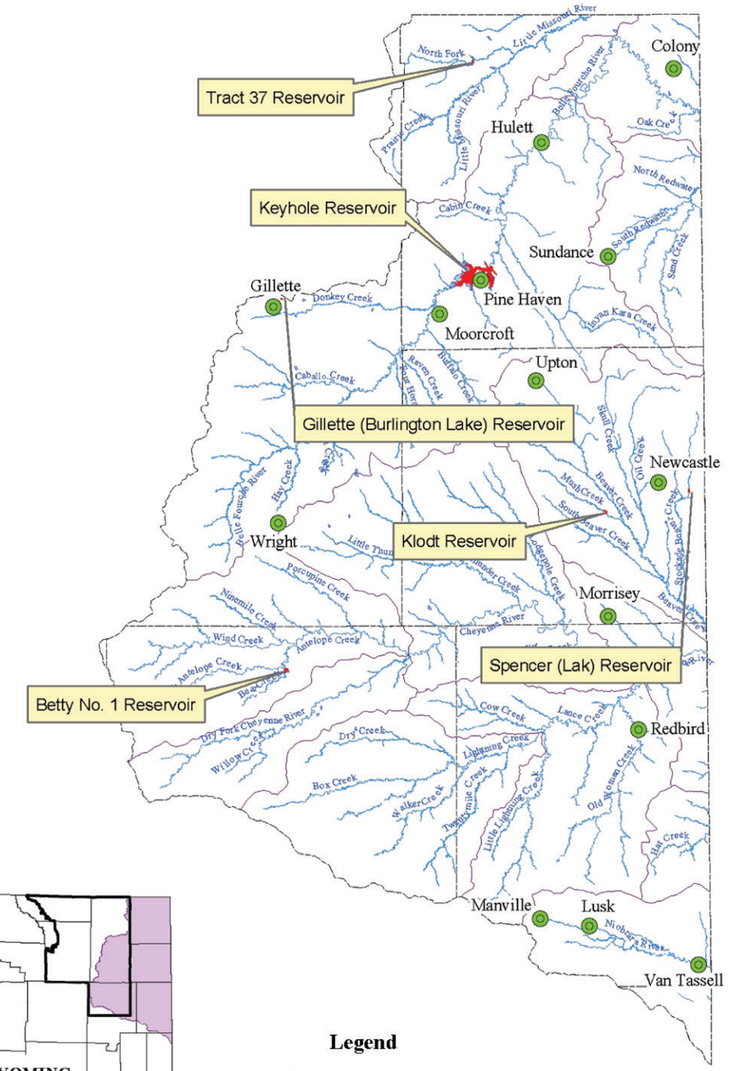
1. Big Goose Park (Park) Reservoir
2. Big Horn Reservoir
3. Cross Creek Reservoir
4. Cloud Peak Reservoir
5. Dome Lake, Dome Reservoir, & Dome Weir Pond
6. Dull Knife Reservoir
7. Healy Reservoir
8. Kearney Lake
9. Lake DeSmet
10. Muddy Guard No. 2 Reservoir
11. Sawmill Reservoir
12. Tie Hack Reservoir
13. Twin Lakes
14. Willow Park Reservoir

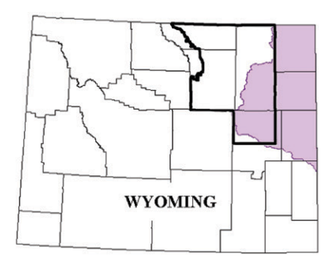


Legend

- Communities
- Major Reservoirs

Powder/Tongue River Basin Planning Area





Legend

- Communities
- Major Reservoirs

Northeast Wyoming River Basins Planning Area

N
W E
S

Miles
10 5 0 10 20 30

Powder River Basin Coal Review

Figure 3.3-6

Reservoirs

07/27/06

Source: HKM Engineering et al. 2002a,b.

Table 3.3-7
Irrigated Lands in the Northeast Wyoming River Basins by Source of Water

Subbasin Name	Hydrologic Unit Code	Primary Source of Agricultural Water Supply (acre-feet)		
		Groundwater	Surface Water	Total
Upper Little Missouri	10110201	0	10,140	10,140
Upper Belle Fourche	10120201	930	13,138	14,068
Lower Belle Fourche	10120202	186	5,714	5,900
Redwater Creek	10120203	164	2,213	2,377
Upper Cheyenne	10120103	127	7,145	7,272
Antelope Creek	10120101	0	1,250	1,250
Beaver Creek	10120107	273	11,276	11,549
Hat Creek	10120108	0	1,941	1,941
Lance Creek	10120104	667	7,395	8,062
Lightning Creek	10120105	469	2,385	2,854
Dry Fork Cheyenne	10120102	32	1,436	1,468
Angostura Reservoir	10120106	0	4,204	4,204
Niobrara Headwaters	10150002	14,950	847	15,797
Total		**17,798**	**69,084**	**86,882**

Source: HKM Engineering et al. 2002b.

3.3.2.3 Industrial Water Use

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. Groundwater is used exclusively by these industries, and the total use is approximately 50,700 acre-feet per year (see **Table 3.3-6**) (HKM Engineering et al. 2002b). The groundwater comes mainly from the Fort Union Formation. **Figure 3.3-4** shows the location of industrial wells other than CBNG wells. Electric power generation comes from two power plants, the Wyodak Power Plant and the Osage Power Plant. The Wyodak Power Plant is near Gillette and consumes approximately 700 acre-feet of water per year. Half of this water comes from treated wastewater from the City of Gillette. The Osage Power Plant uses 870 acre-feet of groundwater per year. Coal mine water use is based on data from five mines, which use a combined total of 2,700 acre-feet of groundwater per year (HKM Engineering et al. 2002b). Permitted coal mine water use for 2002 totaled approximately 7,500 acre-feet for all operating coal mines in the eastern PRB of Wyoming (Wyoming State Engineer's Office [WSEO] 2004). CBNG wells in the Northeast Wyoming River Basins totaled approximately 5,161 wells by the end of 2001; the wells consumed approximately 35,600 acre-feet of water per year. A total of 99,700 acre-feet of groundwater has been pumped and discharged by CBNG wells since the 1990s (HKM Engineering et al. 2002b). Most of the CBNG

Table 3.3-8
Agricultural Surface Water Depletions in the Northeast Wyoming River Basins

Source of Water Supply	Climate Stations[1]	Active Irrigation (acres)	Hydrologic Condition	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
				(acre-feet)												
Little Missouri River	Colony, Weston	9,799	Wet	0	0	0	614	1,047	1,828	3,427	3,082	1,577	72	0	0	11,648
			Normal	0	0	0	532	1,138	2,000	2,912	2,514	1,276	83	0	0	10,455
			Dry	0	0	0	775	1,451	1,813	2,640	2,005	972	103	0	0	9,759
Upper Belle Fourche River	Gillette	3,312	Wet	0	0	0	57	281	698	1,229	1,118	529	4	0	0	3,915
			Normal	0	0	0	79	344	671	1,003	942	416	10	0	0	3,465
			Dry	0	0	0	173	413	683	898	669	309	8	0	0	3,152
Middle Belle Fourche River	Moorcroft	9,011	Wet	0	0	0	103	562	1,573	2,990	2,942	1,546	17	0	0	9,734
			Normal	0	0	0	109	745	1,941	2,620	2,708	1,264	19	0	0	9,406
			Dry	0	0	0	216	1,382	1,908	2,290	1,961	858	16	0	0	8,630
Lower Belle Fourche River	Colony	5,584	Wet	0	0	0	99	348	997	2,261	1,867	1,065	23	0	0	6,661
			Normal	0	0	0	100	530	1,325	2,001	1,787	886	29	0	0	6,656
			Dry	0	0	0	206	1,309	1,241	1,789	1,226	567	37	0	0	6,374
Redwater Creek	Sundance	2,213	Wet	0	0	0	6	84	342	776	608	298	0	0	0	2,115
			Normal	0	0	0	12	138	481	756	696	267	1	0	0	2,350
			Dry	0	0	0	21	303	394	627	400	190	1	0	0	1,937
Upper Beaver Creek	Upton	669	Wet	0	0	0	2	38	147	256	203	144	1	0	0	791
			Normal	0	0	0	3	47	147	199	212	124	1	0	0	733
			Dry	0	0	0	9	142	137	202	128	80	1	0	0	698
Middle Beaver Creek	Newcastle, Upton	6,000	Wet	0	0	0	12	331	1,439	2,360	1,714	1,327	5	0	0	7,188
			Normal	0	0	0	27	435	1,475	1,914	1,930	1,155	3	0	0	6,938
			Dry	0	0	0	92	1,292	1,337	1,894	1,156	723	3	0	0	6,496
Lower Beaver Creek	Morrisey, Newcastle	3,561	Wet	0	0	0	54	201	682	1,005	768	558	22	0	0	3,291
			Normal	0	0	0	59	244	828	1,065	1,114	636	22	0	0	3,969
			Dry	0	0	0	79	604	713	875	574	378	20	0	0	3,242
Northern Tributaries to Cheyenne River	Morrisey	7,958	Wet	0	0	0	209	362	1,685	2,025	2,105	886	228	0	0	7,501
			Normal	0	0	0	196	747	1,474	1,762	1,900	923	112	0	0	7,113
			Dry	0	0	0	322	1,296	1,848	1,845	1,178	938	148	0	0	7,577
Southern Tributaries to Cheyenne River	Redbird	12,736	Wet	0	0	0	323	1,151	3,086	4,186	4,096	2,065	11	0	0	14,919
			Normal	0	0	0	612	1,287	3,282	4,093	3,669	2,040	5	0	0	14,988
			Dry	0	0	0	730	2,633	3,464	3,721	2,589	1,195	39	0	0	14,371
Lower Cheyenne River	Morrisey, Redbird	2,602	Wet	0	0	0	58	109	556	680	697	295	63	0	0	2,458
			Normal	0	0	0	55	238	502	594	644	308	31	0	0	2,372
			Dry	0	0	0	95	453	630	625	391	307	41	0	0	2,542
Niobrara River	Lusk	847	Wet	0	0	0	1	67	250	303	323	113	0	0	0	1,057
			Normal	0	0	0	7	73	255	259	262	151	0	0	0	1,007
			Dry	0	0	0	20	40	144	222	160	58	1	0	0	646
Total		**64,292**	**Wet**	**0**	**0**	**0**	**1,539**	**4,582**	**13,282**	**21,499**	**19,524**	**10,405**	**446**	**0**	**0**	**71,277**
			Normal	**0**	**0**	**0**	**1,790**	**5,965**	**14,381**	**19,177**	**18,377**	**9,446**	**315**	**0**	**0**	**69,451**
			Dry	**0**	**0**	**0**	**2,738**	**11,318**	**14,313**	**17,627**	**12,436**	**6,574**	**417**	**0**	**0**	**65,424**

[1]Where more than one climate station is listed, the stations were weighted equally.

Source: HKM Engineering et al. 2002b.

Table 3.3-9
Agricultural Groundwater Depletions in the Northeast Wyoming River Basins

Source of Water Supply	Climate Stations[1]	Active Irrigation (acres)	Hydrologic Condition	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
				(acre-feet)												
Little Missouri River	Colony, Weston	0	Wet	0	0	0	0	0	0	0	0	0	0	0	0	0
			Normal	0	0	0	0	0	0	0	0	0	0	0	0	0
			Dry	0	0	0	0	0	0	0	0	0	0	0	0	0
Upper Belle Fourche River	Gillette	352	Wet	0	0	0	0	0	25	146	177	89	0	0	0	437
			Normal	0	0	0	0	0	32	121	171	72	0	0	0	396
			Dry	0	0	0	0	0	37	112	108	49	0	0	0	306
Middle Belle Fourche River	Moorcroft	112	Wet	0	0	0	0	0	5	38	51	28	0	0	0	123
			Normal	0	0	0	0	0	10	33	50	23	0	0	0	117
			Dry	0	0	0	0	2	11	30	34	15	0	0	0	91
Lower Belle Fourche River	Colony	186	Wet	0	0	0	0	5	28	81	75	44	0	0	0	233
			Normal	0	0	0	0	12	40	72	76	37	0	0	0	237
			Dry	0	0	0	3	37	38	66	49	22	0	0	0	215
Redwater Creek	Sundance	163	Wet	0	0	0	0	0	3	53	63	40	0	0	0	159
			Normal	0	0	0	0	0	11	49	66	33	0	0	0	159
			Dry	0	0	0	0	0	10	42	45	24	0	0	0	120
Upper Beaver Creek	Upton	0	Wet	0	0	0	0	0	0	0	0	0	0	0	0	0
			Normal	0	0	0	0	0	0	0	0	0	0	0	0	0
			Dry	0	0	0	0	0	0	0	0	0	0	0	0	0
Middle Beaver Creek	Newcastle, Upton	143	Wet	0	0	0	0	0	14	54	58	43	0	0	0	168
			Normal	0	0	0	0	0	14	44	64	37	0	0	0	159
			Dry	0	0	0	0	1	13	43	39	24	0	0	0	120
Lower Beaver Creek	Morrisey, Newcastel	0	Wet	0	0	0	0	0	0	0	0	0	0	0	0	0
			Normal	0	0	0	0	0	0	0	0	0	0	0	0	0
			Dry	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern Tributaries to Cheyenne River	Morrisey	127	Wet	0	0	0	0	0	12	33	46	20	0	0	0	112
			Normal	0	0	0	0	1	11	29	44	21	0	0	0	105
			Dry	0	0	0	0	1	16	31	27	20	0	0	0	95
Southern Tributaries to Cheyenne River	Redbird	387	Wet	0	0	0	0	11	72	146	161	84	0	0	0	474
			Normal	0	0	0	1	21	93	145	161	83	0	0	0	505
			Dry	0	0	0	6	69	102	135	102	46	0	0	0	461
Lower Cheyenne River	Morrisey, Redbird	0	Wet	0	0	0	0	0	0	0	0	0	0	0	0	0
			Normal	0	0	0	0	0	0	0	0	0	0	0	0	0
			Dry	0	0	0	0	0	0	0	0	0	0	0	0	0
Niobrara River	Lusk	11,566	Wet	0	0	0	1	387	3,397	4,528	5,105	1,797	0	0	0	15,515
			Normal	0	0	0	29	948	3,650	3,880	4,271	2,407	1	0	0	15,185
			Dry	0	0	0	207	615	2,064	3,351	2,527	898	1	0	0	9,663
Total		**13,036**	**Wet**	**0**	**0**	**0**	**1**	**704**	**3,557**	**5,078**	**5,736**	**2,145**	**0**	**0**	**0**	**17,222**
			Normal	**0**	**0**	**0**	**31**	**982**	**3,861**	**4,373**	**4,903**	**2,713**	**1**	**0**	**0**	**16,864**
			Dry	**0**	**0**	**0**	**216**	**726**	**2,292**	**3,809**	**2,930**	**1,098**	**1**	**0**	**0**	**11,072**

[1]Where more than one climate station is listed, the stations were weighted equally.

Source: HKM Engineering et al. 2002b.

Table 3.3-10
Municipal Water Use in the Northeast Wyoming River Basins

Municipality	Population[1]	Gpcpd	Annual Use (million gallons)
American Road W&SD	210	104	8.0
Antelope Valley	800	N/A	N/A
Cambria I&SD	110	140	5.6
Cedar Hills	250	40	3.7
Central Campbell Co. I&SD	1,500	60	32.9
Collins Heights I&SD	250	N/A	N/A
Crestview WD	490	150	26.8
Force Road JPB	250	360	32.9
Fox Park I&SD	843	N/A	N/A
Freedom Hills Subdivision	400	N/A	N/A
City of Gillette	22,000	200	1,606.0
Town of Hulett	450	100	16.4
Lance Creek W&SD	40	525	250
Lost Springs	N/A	N/A	N/A
City of Lusk	1,600	160	93.4
Town of Manville	100	700	25.6
Town of Moorcroft	770	130	36.5
City of Newcastle	3,300	225	271.0
Newton Industrial Park I&SD	25	160	1.5
Osage WD	216	230	18.1
Peoples I&SD	80	N/A	N/A
Town of Pine Haven	222	220	17.8
Salt Creek WD	500	150	27.4
Southfork Estates I&SD	115	80	3.4
Sunburst W&SD	Water supplied by City of Gillette		
City of Sundance	1,250	150	68.4
Town of Upton	950	225	78.0
Van Tassell	N/A	N/A	N/A
Vista West I&SD	250	100	9.1
Wessex I&SD	21	150	1.1
West End WD	300	50	5.5
Westridge WUA	260	240	22.8
Wright W&SD	1,500	219	119.9

[1]2000 Census.

Source: HKM Engineering et al. 2002b.

activity has been in the Belle Fourche drainage (**Figure 3.3-5**). Conventional oil and gas wells totaled approximately 2,878 wells by the end of 2001; they produced approximately 10,200 acre-feet of water. An estimated 1,127 injection wells consumed approximately 10,400 acre-feet of water (HKM Engineering et al. 2002b). **Figure 3.3-5** shows the general locations of CBNG wells as of January 1, 2002.

3.3.2.4 Recreational and Environmental Water Use

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 (**Figure 3.3-6**), which supports a variety of recreational activities and primarily is used for agricultural irrigation.

3.3.2.5 Reservoir Evaporation

There are six key storage reservoirs in the Northeast Wyoming River Basins (see **Figure 3.3-6**). Evaporation from these six reservoirs is approximately 14,400 acre-feet of water annually (see **Table 3.3-11**) (HKM Engineering et al. 2002b). The largest of the reservoirs is the Keyhole Reservoir with an active capacity of approximately 186,000 acre-feet (HKM Engineering et al. 2002b). This reservoir is near Moorcroft and Pine Haven on the Belle Fourche River drainage. 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 20,700 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.

Table 3.3-11
Reservoir Evaporation in the Northeast Wyoming River Basins

Key Storage Reservoirs	Active Capacity (acre-feet)	Dam Height (feet)	Surface Area (acres)	Annual Net Evaporation Loss (acre-feet)
Betty No. 1	1,345	32	171	355
Gillette	2,080	10	145	N/A
Keyhole	185,800	115	13,686	12,915
Klodt	980	26	124	317
Spencer	2,162	45	126	224
Tract 37	2,454	31	302	560

Source: HKM Engineering et al. 2002b.

3.4 Basin Water Availability

Water availability in the PRB is an issue of concern, especially for the future. Industrial use of groundwater by the CBNG industry and the increasing demands on surface water for irrigation and general water supply are presenting potential problems for long-term use of water in the basin. This section summarizes data on surface and groundwater availability. Impacts to groundwater resources associated with the coal mining industry and CBNG development are discussed in later sections. Most of the data on surface and groundwater availability presented in this section come from the Powder/Tongue River Basin Water Plan (HKM Engineering et al. 2002a) and the Northeast

Wyoming River Basins Water Plan (HKM Engineering et al. 2002b) prepared for the Wyoming Water Development Commission.

3.4.1 Surface Water Availability

Surface water availability primarily is a function of precipitation runoff, with some groundwater baseflow additions during the summer and fall months. Surface water availability is defined as the water physically available above and beyond surface water resources already allocated for use (HKM Engineering et al. 2002a). Stream flow at gauging stations and estimates of stream flow for ungauged drainages are a measure of surface water flow. Surface water availability is that flow minus allocated water currently in use. The Powder/Tongue River Basin Water Plan (HKM Engineering et al. 2002a) and the Northeast Wyoming River Basins Water Plan (HKM Engineering et al. 2002b) both describe how surface water flows were determined and how surface water availability was calculated. This section summarizes the pertinent results from these two water plans.

3.4.1.1 Powder/Tongue River Basin

There are approximately 114 stream gauging stations in the Powder/Tongue River Basin. Most of these are maintained by the USGS or WSEO. Flow at these gauging stations has to take into account surface water diversions, irrigation return flow, and storage in reservoirs before the “natural flow” can be estimated. Some gauges measure mostly “unnatural flow” in that they measure surface water flow dictated mainly by irrigation practices. For ungauged drainages, flow can be estimated in Wyoming using the regression equations developed by the USGS and summarized by Miller (2003). The results of these calculations are presented in the Powder/Tongue River Basin Water Plan (HKM Engineering et al. 2002a).

Table 3.4-1 shows that rivers such as the Little Bighorn River, Tongue River, Powder River, Crazy Woman Creek, and Piney Creek carry the largest natural flows. Many of the other major drainages in the Powder/Tongue River Basin are affected by irrigation practices to the extent that their flows are not natural (HKM Engineering et al. 2002a). **Table 3.4-2** presents the estimates for ungauged natural flows. Water availability in the major subbasins of the Powder/Tongue River Basin is summarized in **Table 3.4-3**. 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 (see Section 3.2.1, Powder/Tongue River Basin). During normal years, for example, there remains about 931,000 acre-feet of surface water available for additional allocation in Wyoming in the Powder/Tongue River Basin. Appendix A presents a summary of surface water quality data from selected USGS gauging stations in the Powder/Tongue River Basin. **Table 3.4-4** summarizes electrical conductivity (EC) and sodium adsorption ratio (SAR) values for key rivers in the PRB. EC is a measure of total salinity, while SAR can be used to determine the potential use of the water for agriculture. SAR values greater than 8 are unsuitable for some agricultural uses.

Table 3.4-1
Summary of Normal Year Stream Flows (1970 to 1999) at Natural Flow Stations in the Powder/Tongue River Basin

Basin	Station Number	Station Name	Average Stream Flow for 1970-1999 (acre-feet)												
			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Little Bighorn	06288600	Little Bighorn River below Dayton Gulch near Burgess Junction, Wyoming	422	303	267	237	196	220	361	3,862	6,199	1,629	778	463	14,937
	06288700	Dry Fork Little Bighorn River below Lick Creek near Burgess Junction, Wyoming	1,854	1,591	1,477	1,379	1,227	1,329	1,722	6,442	9,677	4,367	2,630	2,024	35,720
	06288960	Little Bighorn River near Parkman, Wyoming	4,002	3,337	3,079	2,837	2,458	2,766	3,732	17,480	27,873	10,893	6,005	4,414	88,877
	06288975	Elkhorn Creek above Fuller Ranch Ditch near Parkman, Wyoming	116	101	92	86	75	88	139	470	602	186	136	123	2,213
	06288990	West Fork Little Bighorn River near Parkman, Wyoming	932	790	731	671	589	675	901	3,871	5,812	2,315	1,355	1,037	19,677
	06289000	Little Bighorn River at State Line near Wyola, Montana	5,412	4,543	4,226	3,927	3,465	3,879	5,112	21,438	33,132	13,750	7,872	5,948	112,704
	06289100	Red Canyon Creek near Parkman, Wyoming	35	31	25	27	23	42	214	545	241	64	31	27	1,304
	06289800	East Pass Creek near Parkman, Wyoming	474	391	365	339	303	331	552	1,928	2,318	1,057	644	510	9,211
	06291200	Lodge Grass Creek at state line near Wyola, Montana	466	351	310	282	238	273	581	3,838	5,310	1,658	784	529	14,620
Tongue	06297000	South Fork Tongue River near Dayton, Wyoming	1,462	1,069	976	816	655	749	1,756	14,632	20,914	5,932	2,554	1,700	53,216
	06297480	Tongue River at Tongue Canyon Campground near Dayton, Wyoming	5,140	3,987	3,650	3,349	2,827	3,124	5,922	31,052	40,989	14,721	7,889	5,768	128,419
	06298000	Tongue River near Dayton, Wyoming	5,232	4,031	3,687	3,369	2,853	3,163	6,003	31,944	41,798	15,382	8,019	5,825	131,306
	06298480	Little Tongue River at Steamboat Point near Dayton, Wyoming	137	96	85	74	59	71	239	2,024	2,889	689	280	176	6,819
	06298490	Little Tongue River above South Fork Little Tongue River near Dayton, Wyoming	102	70	60	52	40	47	133	1,615	2,453	532	202	121	5,427
	06298500	Little Tongue River near Dayton, Wyoming	228	162	140	127	111	124	392	3,153	4,156	1,074	427	278	10,372
	06299480	Wolf Creek below Alden Creek near Wolf, Wyoming	481	347	306	269	221	261	757	5,691	8,097	2,060	859	561	19,909
	06299490	Wolf Creek above Red Canyon Creek near Wolf, Wyoming	537	404	362	330	272	308	753	5,442	7,717	2,019	857	564	19,565
	06299500	Wolf Creek at Wolf, Wyoming	543	405	355	321	281	301	827	5,443	7,591	2,118	934	627	19,746
	06300500	East Fork Big Goose Creek near Big Horn, Wyoming	434	279	208	210	153	169	516	4,890	10,683	3,453	1,208	777	22,980
	06301480	Coney Creek above Twin Lakes	31	19	13	10	7	9	46	1,069	1,782	423	84	55	3,548

Table 3.4-1 (Continued)

Basin	Station Number	Station Name	Average Stream Flow for 1970-1999 (acre-feet)												
			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
		near Big Horn, Wyoming													
Powder	06309200	Middle Fork Powder River near Barnum, Wyoming	458	392	362	328	296	434	2,192	9,883	4,450	1,052	528	430	20,805
	06309260	Buffalo Creek above North Fork Buffalo Creek near Arminto, Wyoming	31	26	23	20	18	29	229	1,337	562	91	37	28	2,429
	06309270	North Fork Buffalo Creek near Arminto, Wyoming	87	74	68	61	55	81	383	1,674	775	195	102	83	3,639
	06309280	Buffalo Creek below North Fork Buffalo Creek near Arminto, Wyoming	0	0	0	0	0	0	51	1,904	700	41	3	1	2,700
	06309450	Beaver Creek below Bayer Creek near Barnum, Wyoming	183	160	144	127	117	163	545	1,824	1,026	395	238	186	5,106
	06309460	Beaver Creek above White Panther Ditch near Barnum, Wyoming	603	555	539	513	479	566	1,040	2,191	1,524	876	673	595	10,154
	06311000	North Fork Powder River near Hazelton, Wyoming	305	230	190	148	127	143	546	3,946	3,634	1,076	481	347	11,173
	06313950	North Fork Crazy Woman Creek below Pole Creek near Buffalo, Wyoming	670	487	403	316	261	305	1,062	5,365	5,452	1,909	946	698	17,873
	06314000	North Fork Crazy Woman Creek near Buffalo, Wyoming	681	494	412	327	273	313	1,079	5,238	5,249	1,878	934	700	17,577
	06314500	North Fork Crazy Woman Creek below Spring Draw near Buffalo, Wyoming	581	430	358	268	229	273	1,081	7,809	7,212	2,176	946	671	22,032
	06315480	Poison Creek below Tetley Spring near Mayoworth, Wyoming	224	179	155	129	114	128	321	1,133	1,112	490	290	233	4,508
	06315490	Poison Creek near Mayoworth, Wyoming	256	207	181	153	134	152	362	1,195	1,174	541	331	268	4,954
	06315500	Middle Fork Crazy Woman Creek near Greub, Wyoming	728	568	492	398	350	426	1,222	5,982	5,545	2,015	1,045	796	19,565
	06317300	Sourdough Creek near Buffalo, Wyoming	73	56	47	36	30	33	96	822	847	265	115	84	2,504
	06317340	Little Sourdough Creek near Buffalo, Wyoming	34	20	7	3	2	5	188	201	133	35	16	25	668
	06319470	South Rock Creek at forest boundary near Buffalo, Wyoming	461	353	296	234	199	220	818	5,550	5,256	1,631	730	520	16,268
	06319480	South Rock Creek above Red Canyon near Buffalo, Wyoming	439	336	278	216	186	208	790	5,473	5,219	1,595	706	502	15,949
	06321500	North Piney Creek near Story, Wyoming	829	650	535	441	374	472	1,688	10,668	9,908	2,619	1,137	897	30,217

Source: HKM Engineering et al. 2002a.

Table 3.4-2
Summary of Estimated Stream Flows at Ungauged Natural Flow Nodes in the Powder/Tongue River Basin

Basin	Station Name	Estimated Average Stream Flow for 1970-1999 (acre-feet)												
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Tongue	Rapid Creek just below Little Rapid Creek in Section 32, T55N, R85W	98	73	65	58	49	54	156	1,050	1,453	407	169	110	3,742
	Beaver Creek at bottom of Section 26, T55N, R85W	27	20	18	16	14	15	43	290	402	113	47	30	1,034
	Soldier Creek at right edge of Section 28, T56N, R85W	60	44	39	35	30	33	95	640	886	248	103	67	2,281
	Prairie Dog Creek just above Dutch Creek in Section 34, T57N, R83W	487	1,314	3,453	2,229	3,493	2,296	1,963	1,560	1,253	886	725	673	20,332[1]
Powder	Red Fork Powder River just below North & South Forks Red Fork Powder River in Section 29, T44N, R84W	2,706	2,511	2,415	2,290	2,104	2,477	4,405	9,771	7,396	4,024	3,071	2,695	45,866
	Kelly Creek at top of Section 21, T49N, R82W	73	55	45	36	30	35	132	629	646	228	106	75	2,092
	Little North Fork Crazy Woman Creek just below Grossett Canyon in Section 14, T49N, R83W	166	125	103	82	69	80	299	1,425	1,463	516	240	170	4,737
	Muddy Creek at diversion near East Side of Section 35, T49N, R83W	153	115	94	75	63	73	275	1,309	1,344	474	220	156	4,351
	Billy Creek at diversion to O'Malley Draw in Section 13, T48N, R83W	96	79	69	59	52	59	151	481	477	212	125	98	1,957
	Little Piney Creek just below Bear Gulch in Section 28, T53N, R83W	324	421	625	676	1,295	1,250	811	544	470	309	338	273	7,336[1]
	North & South Forks Shell Creek (combined), at confluence of Little North Fork Shell Creek and North Fork Shell Creek in Section 11, and confluence of unnamed tributary & South Fork Shell Creek in Section 14; all in T52N, R83W	56	42	35	28	23	27	114	701	745	219	90	62	2,141
	Johnson Creek at top of Section 22, T51N, R83W	53	41	33	27	22	26	109	672	714	210	86	59	2,052
	French Creek at Penrose Ditch diversion in Section 27, T51N, R83W	128	98	80	64	53	62	262	1,614	1,715	504	207	142	4,928

[1] The monthly and annual flows for Prairie Dog Creek and Little Piney Creek are the average of the dry, normal, and wet year monthly and annual flows.

Source: HKM Engineering et al. 2002a.

Table 3.4-3
Surface Water Availability in the Powder/Tongue River Basin

Subbasin	Surface Water Availability (acre-feet per year)		
	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.

3.4.1.2 Northeast Wyoming River Basins

Stream flow in the major drainages of the Northeast Wyoming River Basins is much less than in the Powder/Tongue River Basin due to the absence of a major mountain range to provide snowmelt runoff. Surface water availability in the Northeast Wyoming River Basins is presented in detail in the Northeast Wyoming River Basins Water Plan (HKM Engineering et al. 2002b), and pertinent data are summarized in this section.

A summary of average monthly and annual flows at gauging stations is presented in **Table 3.4-5**. There are approximately 25 maintained gauging stations in the Cheyenne and Belle Fourche drainages. Many of these stations measure unnatural flow dominated by irrigation practices. As most surface water flow in the Northeast Wyoming River Basins is intermittent to ephemeral, there are many ungauged drainages. Thus, surface water flow estimates and ultimately surface water availability in the Northeast Wyoming River Basins is based on estimates from regression equations developed by the USGS (Miller 2003). **Table 3.4-6** summarizes estimates of flow in ungauged ephemeral and intermittent drainages. Total annual available flow for the Northeast Wyoming River Basins is summarized in **Table 3.4-7**. The Belle Fourche and Cheyenne river basins carry most of the available surface water flow in the Northeast Wyoming River Basins. Appendix A contains surface water quality data for selected drainages in the Northeast Wyoming River Basins; **Table 3.4-4** presents EC and SAR values for drainages in the PRB.

3.4.2 Groundwater Availability

Groundwater availability is determined more by interference caused by groundwater drawdown on permitted municipal and domestic water users than on the amount of available water. Because many stratigraphic formations contain a considerable supply of water in storage relative to probable demands for water, groundwater supply is an issue of aquifer drawdown and aquifer water quality and impacts to water supply wells from continued drawdown in an aquifer. An estimate of recoverable groundwater in the PRB is provided in **Table 3.4-8**. This section summarizes the major water supply aquifers of the PRB and their hydraulic characteristics that ultimately determine drawdown from wells.

Table 3.4-4
Stream Electrical Conductivity and Sodium Absorption Ratio Values for the PRB

Subwatershed	Drainage Area (square mile)	Station Location	Station ID #	EC (µS/cm)[1]			SAR			Water Quality Period of Record
				7Q10[2]	Low Monthly Flow	Maximum Monthly Flow	7Q10	Low Monthly Flow	Maximum Monthly Flow	
Upper Tongue River	1,477	Tongue River at state line near Decker, Montana	06306300	1,179	731	318	1.29	0.86	0.36	1981-2001
Upper Powder River	6,050	Powder River at Arvada, Wyoming	06317000	NA	3,400	1,797	NA	7.83	4.76	1981-2001
Salt Creek	769	Salt Creek near Sussex, Wyoming	06313400	6,741	5,668	5,204	25.1	23.6	18.9	1981-2001
Crazy Woman Creek	945	Crazy Woman Creek at Upper Station near Arvada, Wyoming	06316400	NA	1,937	1,066	NA	2.26	1.29	1972-1990; 2001
Clear Creek	1,110	Clear Creek near Arvada, Wyoming	06324000	3,879	1,276	883	3.96	1.46	1.07	1987-1989; 2001
Middle Powder River	8,088	Powder River at Moorhead, Montana	06324500	4,400	2,154	1,421	6.15	4.62	3.92	1930-1972; 1975-2001
Little Powder River	1,235	Little Powder River above Dry Creek near Weston, Wyoming	06324970	NA	3,300	1,785	NA	6.94	4.44	1981-2001
Antelope Creek	959	Antelope Creek near Teckla, Wyoming	06364700	NA	2,354	1,800	NA	2.6	2.82	1978-1981; 2001
Upper Cheyenne River	5,270	Cheyenne River near Riverview, Wyoming	06386500	NA	4,127	2,271	NA	8.66	5.63	1969-1970 1975-1980
Upper Belle Fourche River	1,690	Belle Fourche River below Moorcroft, Wyoming	06426500	NA	2,755	1,532	NA	6.77	3.81	1981-1993; 2000-2001

[1] µS/cm = micoSiemens per centimeter

[2] 7Q10 = The average low flow for 7 consecutive days that occurs once every 10 years or has a 10 percent chance of occurrence in any given year.

Source: BLM 2003a.

Table 3.4-5
Summary of Stream Flows at Gauging Stations in the Northeast Wyoming River Basins

Basin	Station Number	Station Name	Natural Flow	Average Stream Flow for 1970-1999 (acre-feet)												
				Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Cheyenne	06364700	Antelope Creek near Teckla, Wyoming	No	97	64	18	22	159	545	291	1,520	1,005	361	148	93	4,323
	06365300	Dry Fork Cheyenne River near Bill, Wyoming	No	3	6	5	3	17	44	20	194	37	30	8	1	366
	06365900	Cheyenne River near Dull Center, Wyoming	No	176	101	26	36	407	798	633	3,475	2,247	854	425	66	9,244
	06375600	Little Thunder Creek near Hampshire, Wyoming	No	3	4	5	5	48	86	11	824	131	135	100	2	1,354
	06376300	Black Thunder Creek near Hampshire, Wyoming	No	307	16	0	51	272	846	308	1,788	671	549	405	498	5,710
	06378300	Lodgepole Creek near Hampshire, Wyoming	No	1	2	1	1	2	45	33	223	91	32	34	1	464
	06386000	Lance Creek near Riverview, Wyoming	No	133	111	83	333	870	1,205	902	5,594	2,717	2,993	2,078	694	17,713
	06386500	Cheyenne River near Spencer, Wyoming	No	275	233	71	1,023	1,487	866	2,040	20,050	9,286	2,103	535	3,453	41,423
	06392900[1]	Beaver Creek at Mallo Camp near Four Corners, Wyoming	Yes	112	102	100	97	98	127	138	136	144	131	120	112	1,415
	06392950[1]	Stockade Beaver Creek near Newcastle, Wyoming	No	786	763	785	769	721	877	785	654	675	699	730	751	8,996
	06394000[1]	Beaver Creek near Newcastle, Wyoming	No	876	804	796	881	2,381	5,716	2,353	3,250	2,339	1,106	797	497	21,796
	06395000	Cheyenne River at Edgemont, South Dakota	No	1,910	1,416	684	800	3,106	8,847	4,275	14,156	10,524	4,720	3,269	1,700	55,407

Table 3.4-5 (Continued)

Basin	Station Number	Station Name	Natural Flow	Average Stream Flow for 1970-1999 (acre-feet)												
				Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Belle Fourche	06425720	Belle Fourche River below Rattlesnake Creek near Piney, Wyoming	No	6	6	12	24	79	212	66	685	236	101	149	20	1,596
	06425780	Belle Fourche River above Dry Creek near Piney, Wyoming	No	21	6	14	45	190	611	131	1,097	282	239	179	70	2,887
	06425900	Caballo Creek at Mouth near Piney, Wyoming	No	13	10	1	10	27	221	30	788	76	99	45	18	1,339
	06425950	Raven Creek near Moorcroft, Wyoming	No	6	0	0	2	54	169	3	78	2	7	13	0	333
	06426400	Donkey Creek near Moorcroft, Wyoming	No	34	18	33	20	37	1,707	145	2,309	104	17	5	4	4,434
	06426500	Belle Fourche River below Moorcroft, Wyoming	No	682	203	149	420	1,761	4,664	2,268	5,169	2,134	997	515	281	19,243
	USBR Gage	Belle Fourche River - total Keyhole Reservoir Discharge	No	114	320	0	1	0	881	784	2,149	2,402	4,821	4,526	761	16,759
	06427500	Belle Fourche River below Keyhole Reservoir	No	257	260	103	104	96	1,015	760	2,194	2,362	4,833	4,600	833	17,417
	06428200	Belle Fourche River near Alva, Wyoming	No	1,826	1,648	1,063	1,375	2,419	7,705	7,511	10,171	7,526	4,925	4,981	1,998	53,148
	06428500	Belle Fourche River at Wyoming - South Dakota State Line	No	2,307	2,082	1,272	1,741	3,233	10,987	10,552	15,575	12,134	6,507	5,402	2,336	74,127
	06429905	Sand Creek near Ranch A near Beulah, Wyoming	Yes	1,312	1,307	1,285	1,237	1,092	1,231	1,288	1,881	1,776	1,499	1,480	1,334	16,722
	06430500	Redwater Creek at Wyoming-South Dakota State Line	No	2,108	2,077	2,043	2,006	1,928	2,240	2,367	3,697	3,135	2,190	2,245	2,119	28,155
Niobrara	06454000[2]	Niobrara River at Wyoming-Nebraska State Line	No	150	151	159	179	207	316	297	249	208	143	151	118	2,328

[1]Study Period: 1975-1982, 1992-1997.
[2]Study Period: 1970-1994.

Source: HKM Engineering et al. 2002b.

Table 3.4-6
Summary of Estimated Stream Flow at Ungauged Flow Nodes in the Northeast Wyoming River Basins

Basin	Station Name/Location	Estimated Average Stream Flow for 1970-1999 (acre-feet)												
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Cheyenne	Willow Creek at mouth in Section 28, T38N, R72W	9	0	0	3	76	238	4	109	3	10	18	0	470
	Woody Creek at mouth in Section 5, T39N, R69W	1	0	0	0	10	31	0	14	0	1	2	0	59
	Lake Creek at mouth in Section 30, T40N, R68W	3	0	0	1	23	72	1	33	1	3	5	0	142
	Sheep Creek at mouth in Section 7, T40N, R67W	1	0	0	0	7	23	0	11	0	1	2	0	45
	Wagonhound Creek at mouth in Section 31, T41N, R67W	2	0	0	1	15	48	1	22	1	2	4	0	96
	Snyder Creek at mouth in Section 23, T40N, R64W	8	0	0	3	71	223	3	103	3	10	17	0	441
	Boggy Creek at mouth in Section 32, T40N, R63W	2	0	0	1	20	61	1	28	1	3	5	0	122
	Sevenmile Creek at mouth in Section 34, T40N, R63W	1	0	0	0	10	30	0	14	0	1	2	0	58
	Mule Creek at mouth in Section 6, T39N, R61W	4	0	0	1	31	96	1	44	1	4	7	0	189
	Robbers' Roost Creek at mouth in Section 23, T40N, R61W	5	0	0	2	43	136	2	63	2	6	10	0	269
	Beaver Creek just below Mush Creek in Section 32, T44N, R62W	33	0	0	10	292	1,187	15	546	16	51	77	0	2,227
	Oil Creek at mouth in Section 26, T43N, R62W	346	0	0	61	3,958	6,405	377	2,930	87	275	2,425	0	16,864
	Blacktail Creek at mouth in Section 2, T41N, R61W	200	195	193	186	163	188	191	293	262	240	215	198	2,524
	Dry Beaver Creek just above Beaver Creek in Section 4, T47N, R60W	107	99	97	92	95	111	133	136	141	130	118	107	1,366
Belle Fourche	Dry Creek at mouth in Section 29, T47N, R70W	2	0	0	1	14	43	1	20	1	2	3	0	87
	Yellow Hammer Creek at mouth in Section 10, T47N, R70W	1	0	0	0	5	16	0	7	0	1	1	0	31
	Whitetail Creek at mouth in Section 32, T48N, R69W	1	0	0	0	8	24	0	11	0	1	2	0	47
	Four Horse Creek at mouth in Section 11, T48N, R69W	8	0	0	3	73	228	4	105	3	10	17	0	451
	Timber Creek at mouth in Section 2, T48N, R69W	2	0	0	1	19	60	1	27	1	3	5	0	119
	Buffalo Creek at mouth in Section 14, T49N, R68W	11	0	0	3	93	290	4	133	4	12	22	0	572
	Donkey Creek just upstream of gauge in Section 30, T50N, R68W	0	0	0	413	1,135	3,278	1,555	4,005	946	0	0	0	11,332
	Trail Creek at mouth in Section 24, T50N, R68W	1	0	0	0	10	32	0	15	0	1	2	0	61
	Dry Creek at mouth in Section 24, T50N, R68W	2	0	0	1	14	45	1	21	1	2	3	0	90
	Robinson Creek at mouth in Section 18, T50N, R67W	1	0	0	0	4	14	0	6	0	1	1	0	27
	Duck Creek at mouth in Section 8, T50N, R67W	5	0	0	4	59	115	4	53	2	5	24	0	271
	Miller Creek at mouth in Section 9, T50N, R67W	58	0	0	41	672	1,314	44	604	18	57	271	0	3,079
	Smoke Creek at mouth in Section 9, T50N, R67W	1	0	0	1	17	34	1	16	0	1	7	0	78
	Berger Creek at mouth in Section 12, T50N, R67W	2	0	0	2	28	56	2	26	1	2	11	0	130

Table 3.4-6 (Continued)

Basin	Station Name/Location	Estimated Average Stream Flow for 1970-1999 (acre-feet)												
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Belle Fourche (cont.)	Lone Tree Creek at mouth in Section 26, T51N, R67W	5	0	0	4	62	121	4	55	2	5	25	0	283
	Wind Creek at mouth in Section 13, T50N, R67W	133	0	0	93	1,539	3,008	101	1,382	41	129	620	0	7,046
	Deer Creek at mouth in Section 23, T51N, R67W	28	0	0	20	325	635	21	292	9	27	131	0	1,488
	Eggie Creek at mouth in Section 21, T51N, R66W	4	0	0	3	45	88	3	40	1	4	18	0	206
	Mule Creek at mouth in Section 15, T50N, R66W	17	0	0	12	197	385	13	177	5	17	79	0	902
	Cottonwood Creek at mouth in Section 35, T51N, R66W	5	0	0	3	52	102	3	47	1	4	21	0	238
	Arch Creek at mouth in Section 11, T51N, R66W	7	0	0	2	62	195	3	90	3	8	15	0	385
	Inyan Kara Creek at mouth in Section 25, T52N, R66W	1,154	1,142	1,122	1,083	1,028	1,311	1,128	1,750	1,553	1,319	1,310	1,165	15,065
	Cabin Creek at mouth in Section 14, T52N, R66W	5	0	0	2	47	148	2	68	2	6	11	0	291
	Miller Creek at mouth in Section 12, T52N, R66W	5	0	0	1	39	122	2	56	2	5	9	0	241
	Lytle Creek at mouth in Section 8, T53N, R65W	3	0	0	1	27	84	1	39	1	4	6	0	166
	Whitetail Creek at mouth in Section 14, T54N, R65W	83	82	81	78	69	77	81	118	112	94	93	84	1,052
	Blacktail Creek at mouth in Section 12, T54N, R65W	210	209	205	198	175	197	206	301	284	240	237	213	2,675
	Beaver Creek at mouth in Section 1, T55N, R64W	459	457	449	433	382	431	451	658	621	524	518	467	5,850
	East Creek at mouth in Section 32, T55N, R63W	48	48	47	45	40	45	47	68	65	55	54	49	611
	Arnold Creek at mouth in Section 28, T55N, R63W	22	22	22	21	18	21	22	32	30	25	25	23	283
	Horse Creek at mouth in Section 19, T56N, R61W	76	75	74	71	63	71	74	108	102	86	85	77	962
	Pine Creek at mouth in Section 33, T56N, R61W	172	171	168	162	143	161	169	247	233	197	194	175	2,192
	Kilpatrick Creek at mouth in Section 3, T55N, R61W	69	69	68	65	58	65	68	99	94	79	78	70	882
	Kruger Creek at mouth in Section 11, T55N, R61W	34	34	33	32	28	32	33	48	46	39	38	34	431
	Oak Creek at mouth in Section 20, T55N, R60W	216	215	211	203	179	202	212	309	292	247	243	219	2,748
	South Redwater Creek just above Sand Creek in Section 31, T53N, R60W	565	563	553	533	470	530	555	810	765	646	637	575	7,202
	Redwater Creek just above South Redwater Creek in Section 31, T53N, R60W	287	286	281	271	239	269	282	411	388	328	324	292	3,658

Note: Monthly and annual flows are averaged from the wet, dry, and normal estimated flows.

Source: HKM Engineering et al. 2002b.

Table 3.4-7
Surface Water Availability in the Northeast Wyoming River Basins

Subbasin	Surface Water Availability (acre-feet per year)		
	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.

Table 3.4-8
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	6.2	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.

3.4.2.1 Powder/Tongue River Basin

There are five main aquifers in the Powder/Tongue River Basin that can be used for water supply. These aquifers are listed below in order from oldest to youngest. **Table 3.4-9** summarizes the hydrologic properties of the major aquifers.

- Madison Aquifer System
- Dakota Aquifer System
- Fox Hills/Lance Aquifer System
- Fort Union/Wasatch Aquifer System
- Quaternary Alluvial Aquifer System

Table 3.4-9
Summary of Groundwater Availability/Development Potential of Major Aquifer Systems, Powder/Tongue River Basin Plan Area

Major Aquifer System	Geologic Unit	Thickness (feet)	Lithologic Character	Hydrological Character[1,2,3]	General Water Quality[3]	Availability/Development Potential[3,4]	Remarks[3]
Quaternary Alluvial Aquifer System	Alluvium and Terrace Deposits	0 to 100+	Silt, sand, and gravel; unconsolidated and interbedded; present along most streams.	Yield of 50 to 300 gpm may be possible, often through induced recharge. Terraces topographically high and often drained. Specific capacity 0.3 to 7 gpm/ft; permeability 380 and 1,100 gpd/ft^2; and transmissivity 9,700 and 20,300 gpd/ft from two tests in Sheridan County (Lowry and Cummings 1966). Coarser deposits have better aquifer properties.	TDS content generally ranges from about 100 to >4,000 mg/L. Chemical characteristics of water differ geographically. Chemical type and mineralization of the water can be expected to vary depending on underlying rock types and the nature and degree of interconnection with surface water. Alluvial deposits in the western part of the planning area generally contain water of better quality than alluvial deposits in the eastern part. Suitability for municipal/public, domestic, irrigation, and stock use is variable and dependent on location and above factors.	Historical source for municipal/public, domestic, and stock use. Production has ranged up to 250 gpm with induced infiltration of surface water. Groundwater development potential generally better in coarse-grained deposits and poorer in fine-grained materials. Moderate to high yields might be possible to optimally located and properly designed wells if induced infiltration from surface water can be tolerated in the upper reaches of the Powder River and Piney, Clear, and Crazy Woman creeks. Moderate supplies may be able to be developed in thicker deposits of coarse material in the alluvuim of Prairie Dog Creek as well as the alluvium of the Tongue River and Dutch Creek (Lowry and Cummings 1966; Whitcomb et al. 1966).	Quaternary alluvial aquifers generally in hydraulic connection with all bedrock aquifers in outcrop areas and also with surface waters. Alluvial aquifers in larger valleys provide hydraulic interconnection between otherwise hydraulically isolated bedrock aquifers (Whitcomb 1965). Alluvial aquifers also serve as interchange point and storage for groundwater in the hydrologic cycle (Davis and Rechard 1977; Davis 1976); induced recharge from surface waters is probable in areas of extensive development.
Fort Union/Wasatch Aquifer System	Wasatch Formation	500 to 2,000±	Fine- to coarse-grained lenticular sandstones interbedded with shale and coal. Yields water from lenticular sandstone and to a lesser extent from jointed coal and clinker beds (Hodson, Pearl, and Druse 1977). Divided into two conglomeratic members (Kingsbury and Moncrief members) near the Bighorn Mountains (Lowry and Cummings 1966).	Yields generally <15 gpm. Specific capacity of Wasatch wells and those completed in the coarse-grained facies of the Wasatch Formation in Sheridan County averaged 0.33 and 1.0 gpm/ft, respectivley; permeability 6.5 gpd/ft^2 (one test - coal, Sheridan County); transmissivity 520 gpd/ft (one test - coal, Sheridan County); and 2,200 gpd/ft (one test - sandstone, Sheridan County) (Lowry and Cummings 1966).	TDS content of waters is variable and ranges from 141 to 6,620 mg/L (Larson 1984). Sulfate and iron content range from 0.6 to 4,080 mg/L and 0 to 25 mg/L, respectively, and water varies from soft to very hard. Dominant cations generally are sodium, calcium and magnesium, sodium and calcium, or sodium and magnesium. (Lowry and Cummings 1966; Whitcomb et al. 1966).	Important local source for domestic and stock water supply. Yields from fine-grained facies generally small, barely adequate for stock and domestic use. and generally can be expected to be <15 gpm. Wells completed in the Kingsbury Conglomerate and Moncrief Members may have potential for higher production. Water quality generally suitable for domestic supplies although undesireable constituents may make other water sources more attractive, if available. Water quality suitability for stock ranges from poor to good. Generally unsuitable for irrigation due to high salinity and sodium content.	Kingsbury Conglomerate and Moncrief Members located at the base of the mountains in Sheridan County.

Table 3.4-9 (Continued)

Major Aquifer System	Geologic Unit	Thickness (feet)	Lithologic Character	Hydrological Character[1,2,3]	General Water Quality[3]	Availability/Development Potential[3,4]	Remarks[3]
Fort Union/Wasatch Aquifer System (continued)	Fort Union Formation	1,200 to 3,900	Sandstone, fine- to medium-grained, lenticular, interbedded with siltstone, coal, and shale. "Clinker" associated with coal outcrops.	Flowing yields of 1 to 60 gpm reported where confined. Pumped yields up to 250 gpm with several hundred feet of drawdown (eastern Campbell County, east of planning area). Specific capacity for 85 wells in Sheridan County averaged 0.42 gpm/ft; permeability 2.5 and 7.9 gpd/ft^2, transmissivity 10 and 95 gpd/ft, and storage coefficient 9.0 X 10^{-5} and 3.5 X 10^{-4} for tests performed on two wells in Sheridan County (Lowry and Cummings 1966). Coal and clinker generally better aquifer properties than sandstones. Locally, clinker transmissivity up to 3,000,000 gpd/ft; anisotropy and leaky confining layers are common.	TDS content of waters is variable and ranges from 484 to 4,630 mg/L (Larson 1984). Sulfate and iron content range from 0.3 to 1,870 mg/L and 0.06 to 19 mg/L, respectively. Water varies from soft to very hard and is generally a sodium bicarbonate type (Lowry and Cummings 1966; Whitcomb et al. 1966). Water co-produced with CBNG is predominantly sodium bicarbonate type with TDS content and SAR (15 samples) of 540 to 2,010 mg/L (mean of 1,309 mg/L) and 7.7 to 32 (mean of 19.82), respectively, in planning area (Rice et al. 2000). BLM Wyodak EIS assumed average TDS concentration of 764 mg/L (BLM 1999a,b).	Important, extensively used, relatively shallow (<1,000 feet in depth) local source for domestic and stock supply. Low yields, generally less than 25 gpm, can be expected. Four of the 12 municipal/public supply wells in service for the City of Gillette (east of planning area) as of 1994 had been tested at pumping rates ranging from 50 to 130 gpm (Wester-Wetstein and Associates, Inc. 1994).	Total of 6,820 CBNG wells permitted with WSEO in planning area as of 12/31/00. Maximum, minimum, and mean depths and range of actual yields listed on permits were 92 to 4,100 (mean 637) feet below ground surface and 1 to 60 (mean 49) gpm, respectively. Range of depths to main water bearing zone listed on WSEO permits were 58 to 3,816 (mean 580) feet below ground surface. BLM Exxon Pistol Point EA assumed average water production for each CBNG well to average between 30 and 45 gpm (BLM 1992). BLM Lower Prairie Dog Creek EA assumed average water production for each CBNG well to be 15 gpm (BLM 1999). BLM Wyodak EIS assumed average expected water production to be 12 gpm over the estimated 12-year life of each CBNG well (BLM 1999a,b). BLM Wyodak Drainage EA assumed average water production for each CBNG well to be 11.1 gpm (BLM 2000).
Fox Hills/Lance Aquifer System	Lance Formation	600 to 1,900 (north) 1,950 to 3,000 (south)	Sandstone, fine- to medium-grained, lenticular, interbedded with sandy siltstone, claystone, and shale.	Generally yields less than 15 gpm with specific capacities 0.03 to 0.16 gpm/ft in planning area. Limited development due to uneconomical drilling depths. In eastern area of Powder River structural basin, yields up to 350 gpm but with large drawdowns and long well completion intervals; permeability 34 gpd/ft^2; transmissivity 76 to 2,100 gpd/ft for wells also completed in Fox Hills Sandstone.	TDS content in waters generally range from <500 to 3,060 mg/L. Composition variable, mainly sodium sulfate or calcium sulfate. Variable iron (0 to 6.03 mg/L) and sulfate (<100 to 1,780 mg/L) content, SAR 1.9 to 39. Generally undesireable for domestic water source due to possible high iron, manganese, and sulfate content. Generally fair to poor for stock use. Unsuitable for irrigation due to high salinity and/or high SAR.	Historical source for domestic and stock supply. Generally yields less than 15 gpm in planning area. Development limited due to uneconomical drilling depths. Water quality generally suitable for domestic supplies although undesireable constituents may make other water sources more attractive, if available. Water quality suitability for stock ranges from poor to good. Generally unsuitable for irrigation due to high salinity and/or sodium content.	--
	Fox Hills Sandstone	0 to 700	Sandstone, fine- to medium-grained, interbedded with shale and siltstone.	Generally yields less than 15 gpm with specific capacities 0.03 to 0.37 gpm/ft in planning area. Transmissivity 76 to 1,600 gpd/ft for wells also completed in Lance Formation. Limited development due to uneconomical drilling depths.	Similar to Lance Formation. Water suitable for domestic use, usually present only near outcrop. Water suitable for stock use generally found at depths of up to 1,000 feet, away from outcrop. The quality of water may be unsatisfactory for domestic and stock use where the the aquifer is deeper than 1,000 feet (Crist and Lowry 1972).	Historical source for municipal/public, domestic, and stock supply. Generally yields less than 15 gpm in planning area. No more than 50 gpm can be expected from wells completed in the planning area (Natrona County). Well for Town of Edgerton produced 25 gpm with a specific capacity of 0.037 gpm/ft (Crist and Lowry 1972). Development limited due to uneconomical drilling depths. Tested yields of Gillette municipal/public supply wells (east of planning area) have ranged from 85 to 705 gpm (Wester-Wetstein and Associates, Inc. 1994).	High fluoride content may be of concern in eastern part of planning area. Has been used as municipal/public water supply source for Town of Edgerton. Has been used for oil well water flooding operations in eastern Powder River structural basin.

Table 3.4-9 (Continued)

Major Aquifer System	Geologic Unit	Thickness (feet)	Lithologic Character	Hydrological Character[1,2,3]	General Water Quality[3]	Availability/Development Potential[3,4]	Remarks[3]
Dakota Aquifer System	Muddy Sandstone (New Castle Sandstone)	0 to 40±	Light gray, fine-grained, lenticular sandstone and siltstone often termed a member of Thermopolis Shale.	Minor unit of Dakota Aquifer System. Oil field data (Powder River structural basin): porosity 5 to 20 percent; permeability <7 gpd/ft^2; and transmissivity <150 gpd/ft.	No data in planning area.	No data in planning area. Groundwater possibilities in planning area generally not known. Probably capable of yielding small quantities of no more than 10 gpm water to wells. Deep drilling depths probably would preclude consideration other than at outcrops. Dakota Aquifer System historical source for domestic and stock use in eastern Powder River structural basin.	--
	Cloverly Formation	140 to 150	Interbedded dark shale and brown siltstone with 15 to 45 feet of basal, fine- to coarse-grained, well sorted sandstone.	Flowing yields of 1 to 40 gpm, up to 250 gpm reported for pumped wells (south of planning area); specific capacity 0.12 to 0.2 gpm/ft. Oil field data: porosity 15 to 18 percent, permeability 0.4 to 4 gpd/ft^2; and transmissivity 7 to 230 gpd/ft.	Water from Cloverly and Morrison formations in Natrona County predominantly sodium bicarbonate type. Other types include calcium bicarbonate, calcium sulfate, sodium sulfate, and calcium sulfate. TDS content ranges between 300 and 3,000 mg/L.	Generally deeply buried in planning area except at outcrops. Yields small supplies to springs at outcrops. Well yields of 5 to 20 gpm may be expected. Yields of greater than 100 gpm may be possible from complete section of rocks.	--
Madison Aquifer System	Tensleep Sandstone	50 to 250 (Northwestern Basin) <500 (Southwestern Basin)	Fine- to medium-grained, massive, crossbedded sandstone with occasional thin dolomite beds.	Unit of Madison Aquifer System. Flowing yields up to 400 gpm; specific capacity 1 gpm/ft. Oil field data: porosity 0 to 24 percent; permeability 0 to 21 gpd/ft^2; and transmissivity 0 to 1,900 gpd/ft.	Water type is variable (magnesium carbonate, calcium magnesium sulfate, sodium sulfate, calcium sodium sulfate, calcium sulfate), and concentration of TDS varies directly to distance from the outcrop and generally ranges from <300 to 3,240 mg/L. Generally very hard but suitable for domestic, stock, and irrigation use at or near outcrop (Crist and Lowry 1972; Whitcomb et al. 1966). TDS content 204 to 2,930 mg/L in six samples in Natrona County (Larson 1984).	Sandstone generally well cemented, but primary permeability is sufficient at most locations to permit yields of 50 gpm to wells. There is potential for higher yields where secondary permeability is high. Yield of 600 gpm reported for an irrigation well at the foot of the Bighorn Mountains in Johnson County. Development may be limited economically due to deep drilling depths in Johnson County in outcrop area or in narrow belt generally less than about 1 mile paralleling the east margin of the outcrop (Whitcomb et al. 1966; Crist and Lowry 1972).	--

Table 3.4-9 (Continued)

Major Aquifer System	Geologic Unit	Thickness (feet)	Lithologic Character	Hydrological Character[1,2,3]	General Water Quality[3]	Availability/Development Potential[3,4]	Remarks[3]
Madison Aquifer System (continued)	Amsden Formation	150 to 300 (Northwestern Basin) 0 to 200 (Southwestern Basin)	Red and purple shale with some sandstone, cherty dolomite, and limestone.	Aquitard unless fractured.	--	Generally deeply buried in planning area except at outcrops. Groundwater possibility generally not known.	--
	Madison Limestone	1,100± (Northwestern Basin) 200 to 400 (Southwestern Basin)	Limestone, dolomitic limestone, and dolomite; sandy at base.	Principal unit of Madison Aquifer System. Flowing yields over 4,000 gpm but highly variable, specific capacity <1 to 50 but is flow-dependent, transmissivity 500 to 90,000 gpd/ft or higher and highly variable.	Waters at outcrop: TDS <600mg/L, predominantly calcium and magnesium bicarbonate type water. TDS increases basinward to >3,000 mg/L, sodium sufate chloride predominating. Fluoride enrichment characteristic of Madison System waters throughout the Powder River structural basin. Concentrations of radionuclides could be of concern in some areas.	Probably most important high yield aquifer in Wyoming. Historical source for municipal/public water supply, industrial, irrigation, and stock use in Powder River structural basin. Several fish hatcheries use Pahasapa/Madison aquifer as water source in northeastern part of Powder River structural basin. Yields variable geographically and dependent on secondary permeability. Drilling depths may inhibit development.	Total estimated recharge to the Madison Limestone in the Powder River structural basin in 1973 was approximately 75,000 acre-feet/year (WSEO 1976).
	Bighorn Dolomite	400 to 500 (Northwestern Basin) absent (Southwestern Basin)	Massive dolomite, becoming thinly-bedded at top and sandy at base.	Generally deeply buried except in outcrop areas. Groundwater possibilities generally not known.	--	Groundwater possibilities generally not known. Probably would yield water to wells depending on secondary permeability.	--
	Flathead Sandstone	345± (Northwestern Basin) 90 (Southwestern Basin)	Tan to reddish sandstone, locally conglomeratic, interbedded with green shale and siltstone.	Minor unit of Madison Aquifer System. Not exploited due to deep burial; however, a few wells yield water near outcrops.	--	Groundwater possibilities generally not known. Probably would yield water to wells depending on secondary permeability. Generally deeply buried except in outcrop areas. Yields small quantities of water to springs from sandstone and conglomerate in the Bighorn Mountains (McCullough 1966; Crist and Lowry 1972).	--

[1] Reported yields may reflect development needs rather than aquifer capability; higher yields can sometimes be expected, with corresponding drawdown increases. Reported water well transmissivities or permeabilities may be for wells completed in two aquifers or screened in only part of a single aquifer. Reported ranges include varying amounts of data (Feathers et al. 1981).
[2] Oil field (and USGS test) data are variously derived resulting in internal inconsistencies in this compilation. Permeabilities are measured on cores or derived from other data, and transmissivities are from drill stem tests or calculated from permeability. Test data are usually for limited horizons of high anticipated yields and, therefore, are not representative of the formation as a whole (Feathers et al. 1981).
[3] gpm = gallons per minute.
gpm/ft = gallons per minute per foot.
gpd/ft = gallons per day per foot.
gpd/ft^2 = gallons per day per cubic foot.
TDS = total dissolved solids.
mg/L = milligrams per liter.
[4] Actual development potential would require site-specific office and field investigations to define aquifer capability and constraints unique to each project and site.

Taken from: Feathers, Libra, Stephenson, and Eisen 1981, *Occurrence and Characteristics of Groundwater in the Powder River Basin, Wyoming*

Source: HKM Engineering et al. 2002a.

Madison Aquifer System: The Paleozoic Madison Aquifer system is the deepest aquifer system analyzed and comprises the 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 primarily is dominated by calcium-magnesium carbonate with locally high concentrations of fluoride and radionuclides. TDS can range from 600 to 3,000 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). The 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.

The Dakota Aquifer System: The Dakota Aquifer System 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 are on the order of 15 gpm or less, and the transmissivity of the Lance Formation is 76 to 2,100 gpd/ft. The water quality in the Lance Formation is dominated by sodium sulfate or calcium sulfate, and TDS ranges up to 3,000 mg/L. 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; however, they 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; however, 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 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; however, 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.

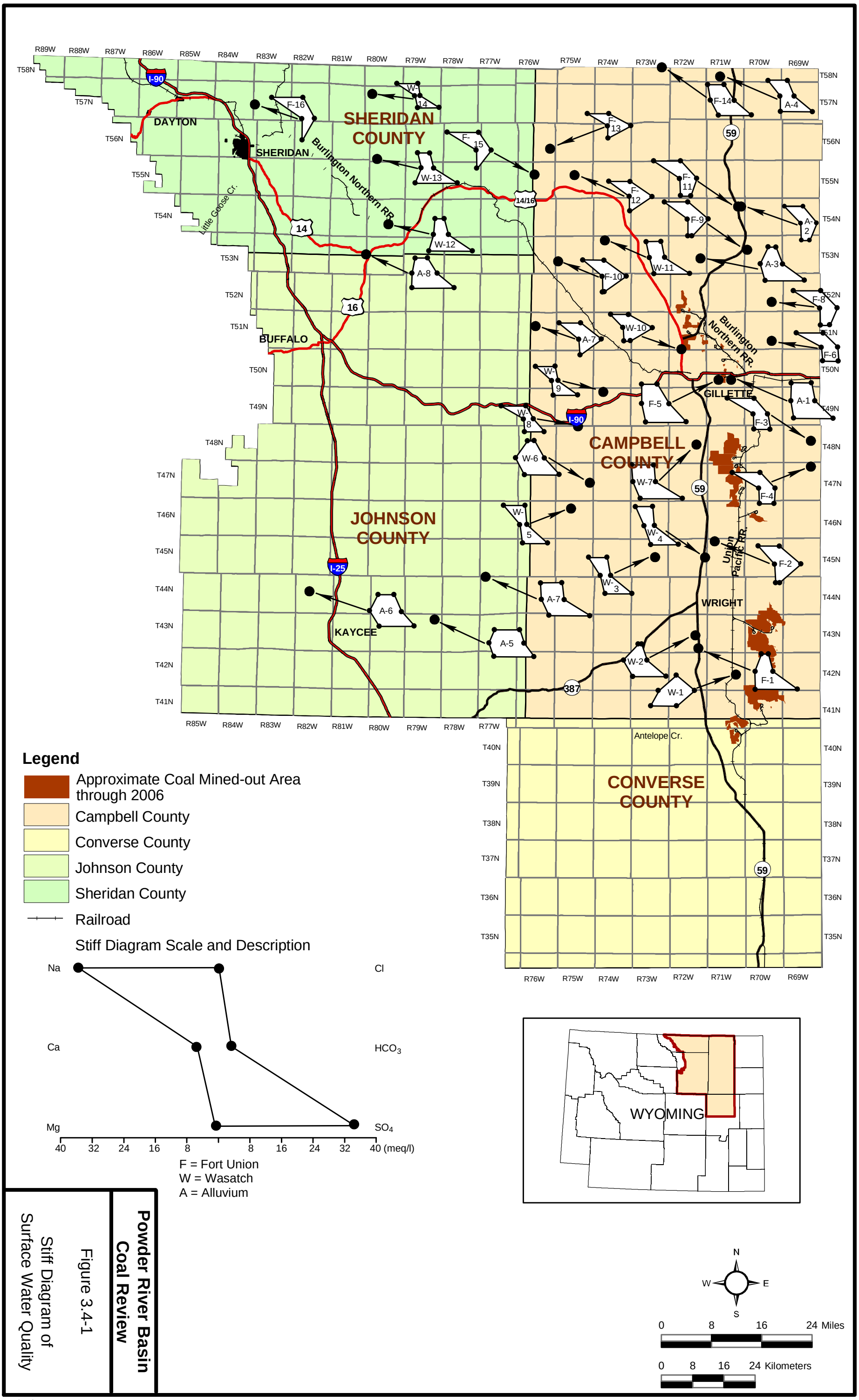
Quaternary Alluvial Aquifer System: This aquifer system is local in nature and is found in alluvium and terrace deposits near the major drainages of the Powder/Tongue River Basin. The thickness of alluvium ranges up to approximately 100 feet. Well yields of 50 to 300 gpm are possible in local areas, and the transmissivity can range up to 20,300 gpd/ft. TDS 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.

Water quality data for the Fort Union, Wasatch, and Quaternary Alluvial aquifers are presented in Appendix B. These data were compiled from studies conducted by the USGS. **Figure 3.4-1** displays groundwater quality in the PRB as selected Stiff diagrams (diagrams showing the relative percent of major ions to depict water quality) to illustrate the distribution of sodium, sulfate, bicarbonate, and calcium. **Figure 3.4-2** summarizes groundwater quality in the PRB using Piper diagrams (trilinear diagrams that provide a visual comparison of several water types). These diagrams illustrate the regional variation in water quality for the Fort Union, Wasatch, and Quaternary Alluvial aquifers. As the diagrams show, the Fort Union is elevated in sodium and bicarbonate, especially in the central or deeper parts of the basin. The Wasatch Formation tends to have locally elevated sulfate. Water quality in the alluvium is quite variable.

3.4.2.2 Northeast Wyoming River Basins

There are six main aquifers underlying the river basins of northeastern Wyoming. These are listed below in order from oldest to youngest. **Table 3.4-10** summarizes the hydrologic properties of stratigraphic units in the Northeast Wyoming River Basins. The Arikaree Aquifer is not within the PRB, but it is discussed briefly below for completeness.

- Madison Aquifer System
- Dakota Aquifer System
- Fox Hills/Lance Aquifer System
- Fort Union/Wasatch Aquifer System
- Tertiary Arikaree Aquifer (Niobrara Basin)
- Quaternary Alluvial Aquifer System



Powder River Basin Coal Review

Figure 3.4-1

Stiff Diagram of Surface Water Quality

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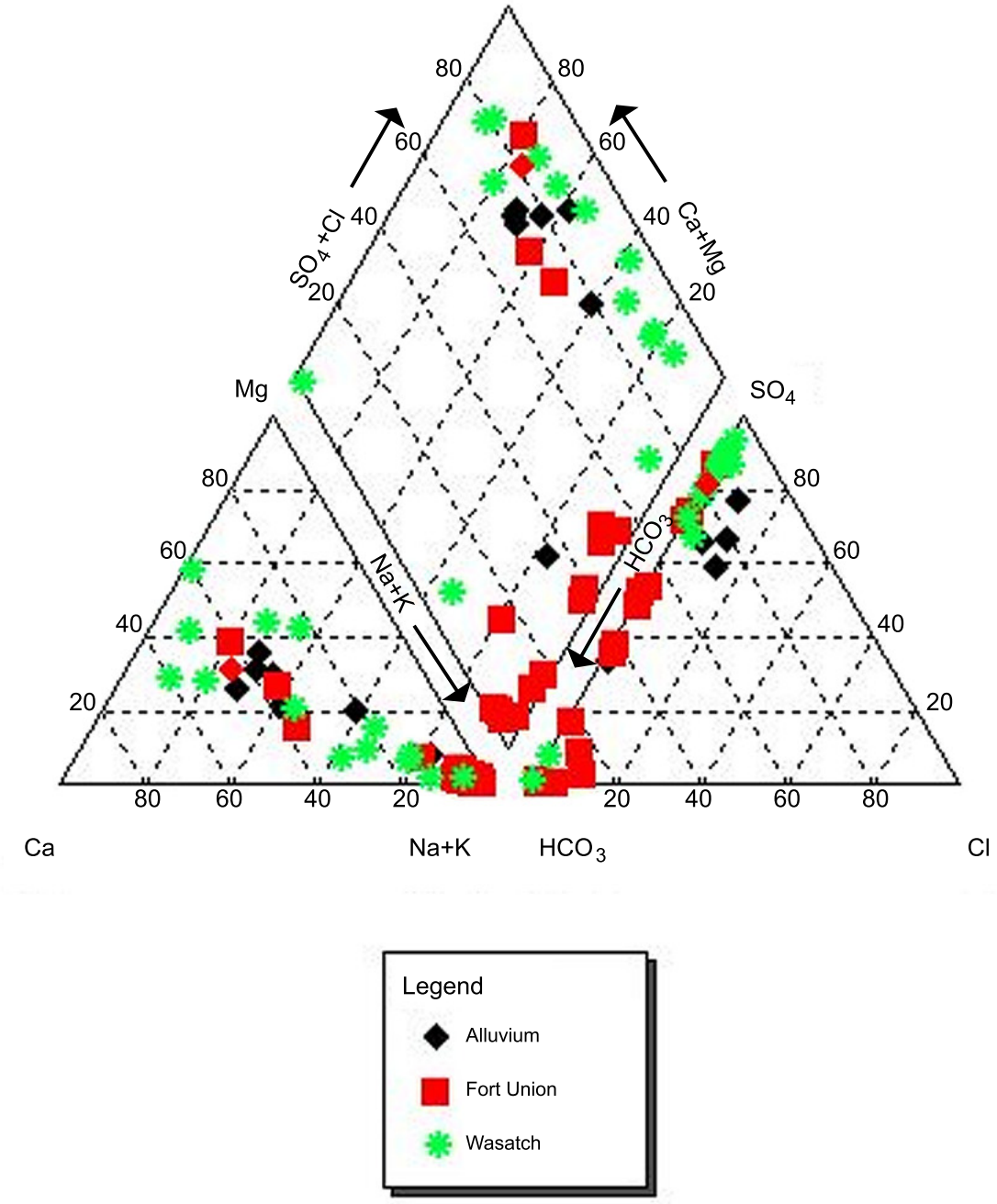
Madison Aquifer System: The Madison Aquifer along the central and eastern flanks of the PRB consists of four water-bearing formations. From oldest to youngest these are the Whitewood Dolomite, Englewood Limestone, Pahasapa Limestone (equivalent to the Madison Limestone in the northern part of the PRB), 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; however, locally it 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 about 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



Powder River Basin Coal Review

Figure 3.4-2

Piper Diagrams for Selected Wells in the PRB

Table 3.4-10
Summary of Groundwater Availability/Development Potential of Major Aquifer Systems, Northeast Wyoming River Basins

Major Aquifer System	Geologic Unit	Thickness (feet)	Lithologic Character	Hydrological Character[1,2]	General Water Quality	Availability/Development Potential[3]	Remarks
Quaternary Alluvial Aquifer System	Alluvium and Terrace Deposits	0 to 100+	Clay rich sandy silt, silt, sand and gravel; unconsolidated and interbedded; present along most streams. Thickness generally less than 50 feet but may be thicker. Coarser deposits in valleys of the Belle Fourche and the Cheyenne rivers. Alluvium overlying formations of Tertiary-age generally is fine- to medium-grained in central part of basin (Hodson et al. 1971).	Yield of 1,000 gpm possible, often through induced recharge. Terraces topographically high and often drained. Specific capacity 0.3 to 18 gpm/ft; porosity 28 to 45 percent; permeability 0.1 to 1,100 gpd/ft^2; transmissivity 15 to 64,000 gpd/ft; specific yield 2 to 39 percent. Coarser deposits have better aquifer properties.	TDS content generally ranges from approximately 100 to >4,000 mg/L, and chemical characteristics of water differ geographically. Chemical type and mineralization of the water can be expected to vary depending on underlying rock types and the nature and degree of interconnection with underlying bedrock aquifers as well as surface water. Moderate to high mineralization tolerable for stock and domestic use. Suitability for irrigation generally limited to salt-tolerant crops. Water in the alluvium in Black Hills generally is better quality than central part of basin (Hodson et al. 1971).	Historical source for domestic and stock use. Production has ranged from 1 to 900 gpm. Groundwater development potential generally better in coarse-grained deposits and poorer in fine-grained materials. Yields in the high end of the above range might be possible for optimally located and properly designed wells if induced infiltration from surface water can be tolerated (Belle Fourche, Cheyenne, and Niobrara river basins). Potential source for irrigation, municipal/public, and industrial sources where more than 40 feet of saturated well-sorted sand and gravel are present.	Quaternary alluvial aquifers generally in hydraulic connection with all bedrock aquifers in outcrop areas and also with surface waters. Alluvial aquifers in larger valleys provide hydraulic interconnection between otherwise hydraulically-isolated bedrock aquifers (Whitcomb 1965). Alluvial aquifers also serve as interchange point and storage for groundwater in the hydrologic cycle (Davis and Rechard 1977; Davis 1976). Induced recharge from surface waters is probable in areas of extensive development.
Middle Tertiary Aquifer	Arikaree Formation	0 to 500 (Southeast only)	Tuffaceous sandstone, fine-grained with silty zones, coarse sand lenses, and concretionary zones.	Yields up to 1,000 gpm; specific capacity up to 232 gpm/ft; porosity 5 to 24 percent; permeability <1 to 300 gpd/ft^2; transmissivity up to 77,000 gpd/ft.	TDS content of water ranges from 261 to 535 mg/L. Composition mainly calcium bicarbonate (Whitcomb 1965). Median TDS content in samples from 12 wells in Niobrara County 321 mg/L (Larson 1984).	Historical source for municipal/public, industrial, domestic, stock, and irrigation supply with tested production ranging as high as 195 to 730 gpm (Whitcomb 1965). Yields of 1,000 gpm might be possible for optimally located and properly-designed wells.	Water level data available from two observation wells located east and southeast of Lusk in Niobrara County (32-62-05-baa01 and 32-62-32-bbb01). Water levels have shown approximately 6 to 13 feet of decline in water levels in the aquifer since the 1970s, with possibly some stabilization and slight recovery since early to mid 1990s (USGS 2001).
Fort Union/Wasatch Aquifer System	Wasatch Formation	Up to 1,600	Fine- to coarse-grained lenticular sandstones interbedded with shale and coal, coarser in south.	Yields generally <15 gpm, locally flowing wells exist. Yields historically could be expected to range from 10 to 50 gpm in the northern part of the basin, with the possibility of higher yields up to 500 gpm in the southern part of the basin (Hodson et al. 1973). Specific capacity 0.10 to 14 gpm/ft (Hodson et al. 1973); porosity 28 to 30 percent; permeability 0.01 to 65 gpd/ft^2; and transmissivity average 500 gpd/ft and range 1 to 4,000 gpd/ft.	TDS content of waters is variable and ranges from <200 to >8,000 mg/L (Hodson et al. 1973). Sodium sulfate and sodium bicarbonate are general dominate water types. Major ion composition varies with depth and shows more sodium and bicarbonate content with depth. Radium 226 + 228 may be of concern near uranium deposits.	Historical source for municipal/public, domestic, and stock supply. Yields ranging from 10 to 50 gpm in the northern part of the basin can be expected, with the possibility of higher yields up to 500 gpm in the southern part of the basin (Hodson et al. 1973).	Water level data available from two observation wells located in Campbell County (50-72-21-aba01 and 42-71-35-aaa01) and one observation well in Converse County (37-70-10-cbb01). Water levels in the aquifer have shown approximately a 40-foot rise between 1983 and 2000 in Gillette and approximately 40 to 50 feet of decline southeast of Wright in Campbell County. Water levels in the aquifer in northwestern Converse County have shown a rise of approximately 7 feet between 1988 and 1999 after a decline of approximately 6 feet between 1986 and 1988 (USGS 2001).

Table 3.4-10 (Continued)

Major Aquifer System	Geologic Unit	Thickness (feet)	Lithologic Character	Hydrological Character[1,2]	General Water Quality	Availability/Development Potential[3]	Remarks
Fort Union/Wasatch Aquifer System (continued)	Fort Union Formation	1,100 to 2,270	Sandstone, fine- to medium-grained, lenticular, interbedded with siltstone, coal, and shale. Middle part may be shalier in north, upper part siltier in south. "Clinker" associated with coal outcrops.	Flowing yields of 1 to 60 gpm where confined. Yields up to 250 gpm with several hundred feet of drawdown. Specific capacity 0.1 to 2 gpm/ft; permeability 0.01 to 100 gpd/ft^2; transmissivity 1 to 5,000 gpd/ft. Coal and clinker generally have better aquifer properties than sandstones. Locally, clinker transmissivity up to 3,000,000 gpd/ft; anisotropy and leaky confining layers are common.	TDS content and major ion composition of Fort Union Formation waters as above. Water co-produced with CBNG is predominantly sodium bicarbonate type with TDS content and SAR (32 samples) of 270 to 1,170 mg/L (mean of 653 mg/L) and 5.7 to 12 (mean of 7.85), respectively (Rice et al. 2000). BLM Wyodak EIS assumed average TDS concentration of 764 mg/L (BLM 1999a,b). High radionuclide content of concern in areas near uranium ore zones.	Historical source for municipal/public, domestic, and stock supply. Maximum expected yields of approximately 130 to 150 gpm (Hodson et al. 1973; Wester-Wetstein and Associates, Inc. 1994). Exploration and development of new Fort Union well field including conjunctive use/recharge of CBNG production water under consideration for the City of Gillette.	Source for approximately 14 municipal and public water supply systems including the City of Gillette and adjacent districts, joint powers boards and privately owned water systems, and water users associations in Campbell County. City of Gillette mixes Fort Union Formation water with that from the Madison and Fox Hills/Lance system for municipal/public water supply. Total of 5,285 CBNG wells permitted with WSEO in planning area as of 12/31/00. Maximum, minimum, and mean depths and range of actual yields listed on permits were 138 to 5,507 (mean 772) feet below ground surface, and 1 to 120 (mean 27) gpm, respectively. Range of depths to main water bearing zone listed on WSEO permits were 124 to 1,558 (mean 124) feet below ground surface. BLM Wyodak EIS assumed average expected water production to be 12 gpm over the estimated 12 year life of each CBNG well (BLM 1999a,b). BLM Wyodak Drainage EA assumed average water production for each CBMG well to be 11.1 gpm (BLM 2000).
Fox Hills/Lance Aquifer System	Lance Formation	500 to 1,000 (North) 1,600 to 3,000 (South)	Sandstone, fine- to medium-grained, lenticular, interbedded with sandy siltstone and claystone.	Yields up to 350 gpm but with large drawdowns and long well completion intervals. Locally flowing wells exist. Specific capacity 0.05 to 2 gpm/ft; permeability 6 to 35 gpd/ft^2; transmissivity 170 to 2,100 gpd/ft.	TDS content in waters at Foxhills/Lance System outcrops north of Niobrara County range from 600-1,500 mg/L, and in Niobrara County range from 1,000 to 3,300 mg/L. Composition mainly sodium, bicarbonate, and sulfate. Fluoride enrichment is characteristic of Fox Hills/Lance Formation waters. Possible high sodium and radionuclide content could be of concern in some areas.	Lance Formation historical source for municipal/public, domestic, and stock supply. Generally yields less than 20 gpm, but yields of several hundred gallons per minute may be possible from complete section 5 of the formation (Hodson et al. 1973).	High fluoride content is of concern for development as source for municipal/public water systems.
	Fox Hills Sandstone	150 to 200 (North) 400 to 700 (South)	Sandstone, fine-to medium-grained, interbedded with shale and siltstone.	Yields up to 705 gpm but with large drawdowns and long well completion intervals. Locally flowing wells exist. Specific capacity 0.05 to 2 gpm/ft; permeability 34 gpd/ft^2; transmissivity 76 to 1,600 gpd/ft for wells also completed in Lance.	Similar to Lance Formation.	Historical source for municipal/public, industrial, domestic, and stock supply. Tested yields of Gillette municipal/public supply wells have ranged from 85 to 705 gpm (Wester-Wetstein and Associates, Inc. 1994).	High fluoride content is of concern for development as source for municipal/public water systems. Has been used for oil well water flooding operations. Water level data available from one observation well completed in the aquifer southeast of Gillette in Campbell County (49-70-31bbb01) has shown approximately 50 feet of decline since 1983 (USGS 2001).

Table 3.4-10 (Continued)

Major Aquifer System	Geologic Unit	Thickness (feet)	Lithologic Character	Hydrological Character[1,2]	General Water Quality	Availability/Development Potential[3]	Remarks
Dakota Aquifer System	Newcastle Sandstone	0 to 60 (Northeastern Basin) 0 to 100 (Southeastern Basin)	Sandstone, fine- to medium-grained, locally conglomeratic, lenticular, with interbedded siltstone, shale, and claystone.	Minor unit of Dakota Aquifer System exploited near outcrop only; often excessive pumping lift. Oil field data: porosity 5 to 27 percent; permeability <11 gpd/ft^2; and transmissivity 0 to 140 gpd/ft.	Waters at Dakota System outcrop generally contain over 1,000 mg/L TDS. TDS content 180 to 3,200 mg/L in 17 samples in Weston County (Larson 1984). Composition changes basinward from calcium, magnesium, and sulfate at outcrop to sodium and sulfate, to sodium and bicarbonate. Deep basin waters >10,000 mg/L TDS and are enriched to sodium and chloride. Possible high fluoride, selenium, and radionuclide content could be of concern in some areas.	Dakota Aquifer System historical source for domestic and stock use.	Few reported wells in northern Black Hills (1958) due to excessive drilling depths except in outcrop areas. Yields typically adequate for stock and domestic purposes. Historically, wells typically have been completed in both the Lakota and Fall River formations to obtain maximum production (Whitcomb et al. 1958). Water level data available from one observation well completed in the aquifer (Lakota Formation) northeast of Lusk in Niobrara County (36-62-28ab02) has shown approximately 23 feet of decline between 1974 and 2000 (USGS 2001).
	Fall River Formation	95 to 150 (Northeastern Basin) 35 to 85 (Southeastern Basin)	Sandstone, fine- to coarse-grained with interbedded shale and siltstone.	Flowing yield 1 to 10 gpm; wells often also completed in Lakota Formation. Specific capacity <0.5 gpm/ft. Oil field data: porosity 11 to 23 percent; permeability 0 to 36 gpd/ft^2; and transmissivity 1 to 900 gpd/ft.	--	--	--
	Lakota Formation	45 to 300 (Northeastern Basin) 115 to 200 (Southeastern Basin)	Sandstone, fine- to coarse-grained, in places conglomeratic, very lenticular, irregularly interbedded with shale which becomes dominant at top (Fuson Shale).	Flowing yield 1 to 10 gpm, up to 150 gpm. Water well data: specific capacity 0.01 to 1.4 gpm/ft; permeability 2 to 14 gpd/ft^2; and transmissivity 220 to 810 gpd/ft for two wells also in Fall River.	--	--	--
Madison Aquifer System	Minnelusa Formation (Hartville Formation)[4]	600 to 800 (Northeastern Basin) 1,000± (Southeastern Basin)	Sandstone, fine- to coarse-grained, interbedded with limestone, dolomite, and shale, locally gypsiferous, especially at top.	Upper part has historically been considered part of Madison Aquifer System, middle is aquitard, lower is minor aquifer in hydraulic connection with Madison. Flowing yields of over 200 gpm possible; specific capacity 1 to 5 gpm/ft. Oil field data: porosity 6 to 25 percent; permeability <0.1 to 18 gpd/ft^2; and transmissivity 2 to 900 gpd/ft.	Similar to Madison Formation waters at outcrop (TDS < 600mg/L, predominantly calcium, magnesium, and bicarbonate type water). TDS content 230 to 2,450 mg/L from 26 samples in Crook County with median and mean of 520 and 773 mg/L, respectively (Larson 1984). Some east basin waters near outcrops show TDS up to 3,000 mg/L (calcium and sulfate enrichment). Deep basin waters TDS >10,000 mg/L (mainly sodium and chloride type water). Fluoride enrichment characteristic of Madison System waters throughout the basin. Concentrations of radionuclides could be of concern in some areas.	Historical source for municipal/public water supply, domestic, and stock use.	Large quantities of water produced from flowing wells at Huelett (1958). Generally deeply buried (>600 to 700 feet minimum) in area (northern Black Hills - 1958) (Whitcomb et al. 1958). Subject of USGS investigation with Pahasapa/Madison Limestone (Ogle 2001). Water level data available from one observation well located in Crook (44-62-36-cbb02) and one in Niobrara (36-62-28-bbd01) counties. Water levels have risen approximately 2 feet (since 1998) and 15 feet (since 1995), respectively, in the two observation wells (USGS 2001).

Table 3.4-10 (Continued)

Major Aquifer System	Geologic Unit	Thickness (feet)	Lithologic Character	Hydrological Character[1,2]	General Water Quality	Availability/Development Potential[3]	Remarks
Madison Aquifer System (continued)	Pahasapa Limestone (Madison Limestone)[4]	550 to 990 (Northeastern Basin) 250± (Southeastern Basin)	Massive fine-grained limestone and dolomitic limestone, locally cherty or cavernous.	Principal unit of Madison Aquifer System. Flowing or pumped yields up to 1,000 gpm; specific capacity 0.5 to 50+ gpm/ft, flow-dependent; and transmissivity 1,000 to 60,000 gpd/ft locally to 300,000 gpd/ft+.	Waters at outcrop (TDS <600mg/L, predominantly calcium, magnesium, and bicarbonate type water). TDS increases basinward to >3,000 mg/L, sodium, sulfate, and chloride predominating. Fluoride enrichment characteristic of Madison System waters throughout the basin. Concentrations of radionuclides could be of concern in some areas.	Probably the most important high-yield aquifer in Wyoming. Historical source for municipal/public water supply, industrial, irrigation, and stock use. Several fish hatcheries use Pahasapa/Madison aquifer as a water source. Base flow and spring discharge from the Pahasapa/Madison aquifer form part of the surface run-off in the Black Hills area (Ogle 2001). Tested pumping rate of seven City of Gillette Pahasapa/Madison aquifer wells ranged from 535 to 900 gpm (Wester-Wetstein and Associates, Inc. 1994).	Subject of USGS investigation with the Minnelusa Formation (Ogle 2001). Water level data available from nine observation wells located in Crook (56-67-28-aab01; 56-67-28-aab02; 53-65-18bbd02; 52-63-25-dcd01; 49-62-36-cbb01); Weston (48-65-35ccb01), (46-66-25dbb01; 44-63-26cac01); and Niobrara (36-62-28-ab01) counties. Water levels generally have risen from 13 to 40 feet in some of the observation wells since 1995 (USGS 2001). Total estimated recharge to the Madison Limestone in the PRB in 1973 was approximately 75,000 acre-feet per year (WSEO 1976).
	Englewood Limestone (Gurnsey Formation, part)[4]	30 to 60 (Northeastern Basin) 0 to 50± (Southeastern Basin)	Thin-bedded limestone, locally shaley.	Minor unit of Madison Aquifer System; USGS test: porosity 15 to 18 percent; and permeability <0.1 gpd/ft^2.	--	--	Generally no groundwater development in area (Northern Black Hills - 1958). Formations may contain some water in permeable zones, but generally are considered to be too deeply buried to be considered important aquifers (Whitcomb et al. 1958).
	Whitewood Dolomite	50 to 60 (Northeastern Basin) Absent (Southeastern Basin)	Massive bedded dolomite, locally cherty.	Minor unit of Madison Aquifer System; the few existing wells also produce from the Madison aquifer. USGS test: porosity 10 to 25 percent; specific capacity 15 gpm/ft; permeability <0.1 to 11 gpd/ft^2; and transmissivity 6,400 gpd/ft.	--	--	--

[1] Reported yields may reflect development needs rather than aquifer capability; higher yields can sometimes be expected, with corresponding drawdown increases. Reported water well transmissivities or permeabilities may be for wells completed in two aquifers.
[2] Oil field (and USGS test) data are variously derived resulting in internal inconsistencies in this compilation. Permeabilities are measured on cores or derived from other data, and transmissivities are from drill stem tests or calculated from permeability.
[3] Actual development potential would require site-specific office and field investigations to define aquifer capability and constraints unique to each project and site.
[4] Nomenclature for equivalent strata exposed in the Hartville uplift on the southeastern basin flank (Feathers et al. 1981).

Taken from: Feathers, Libra, Stephenson, and Eisen 1981, *Occurrence and Characteristics of Groundwater in the Powder River Basin, Wyoming*

Source: HKM Engineering et al. 2002b.

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 14 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; however, they can range up to 500 gpm in the southern part of the PRB. The transmissivity ranges up to 4,000 gpd/ft and 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.

Middle Tertiary Arikaree Aquifer: The Arikaree Formation generally is found south and southeast of the Powder River structural basin, mainly in Niobrara County and, thus, is not a water supply aquifer within the PRB itself (HKM Engineering et al 2002b). This unit is a tuffaceous sandstone up to 500 feet in thickness that can yield up to 1,000 gpm to wells. The transmissivity of the aquifer ranges up to 77,000 gpd/ft. The TDS of the water ranges from 260 to approximately 535 mg/L, and the water is mainly calcium bicarbonate. The water is used in Niobrara County for municipal and public water supply, industrial water supply, irrigation, and stock water.

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; however, it usually is 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, due to 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 for irrigation and stock water.

Water quality data for selected wells screened in the Fort Union, Wasatch, and Quaternary Alluvial aquifers are presented in **Tables B-1** through **B-4** in Appendix B. These data were compiled from studies conducted by the USGS. These aquifers are the main aquifers used for water supply in the Northeast Wyoming River Basins and the aquifers most affected by coal mining and CBNG development. **Figures 3.4-1** and **3.4-2** summarize groundwater quality in the PRB, including the

Northeast Wyoming River Basins, using Stiff and Piper diagrams. For reference, surface and groundwater quality standards for Wyoming are available on the WDEQ website (WDEQ 2004).

3.5 Coal Bed Natural Gas Water Use

3.5.1 Introduction

CBNG development began in earnest around 1990 in the southern part of the Wyoming PRB to the west of the operating coal mines. Natural gas trapped in the coal units of the Fort Union Formation was developed by depressurizing the coal bed aquifers of the formation to facilitate the release of the gas. Shallow coal units to the west of the operating coal mines were exploited early in the 1990s in the drainages of the Belle Fourche and Cheyenne rivers. Beginning in approximately 1995, CBNG development expanded to the west and to the northwest in the PRB to access the natural gas in deeper stratigraphic members of the Fort Union Formation.

CBNG development requires depressurization of the Fort Union Formation coal bed aquifers through dewatering of those aquifers to a level that allows for the release of gas from the coal. CBNG wells are regulated both by the WOGCC as oil and gas wells and by the WSEO as water production wells. Discharge of water by these wells is regulated by the WDEQ for both quantity and quality of water discharged either to surface drainages or to surface impoundments. WDEQ regulates discharges into both in-channel and off-channel impoundments. WSEO regulates the design of in-channel impoundments due to the potential effect on water rights. On public lands administered by the BLM, CBNG development also is regulated by the BLM through permit requirements associated with applications for permit to drill (APDs) and NEPA analyses. The BLM also regulates CBNG wells and water discharge where public minerals are involved beneath private lands. The WOGCC regulates impoundments constructed on private and state lands. The WDEQ requires that all impoundments must have monitoring wells to evaluate the impacts of water stored in the impoundments on alluvial groundwater if the 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 present beneath the impoundment is Class III or better water quality (TDS less than 10,000 mg/L).

3.5.2 CBNG Water Production

As of late 2001 and early 2002, there were approximately 14,550 CBNG wells permitted in the Wyoming PRB (HKM Engineering et al. 2002a,b). Approximately 9,390 of these wells were in the northwestern part of the basin in the Powder/Tongue River Basin, and approximately 5,160 of the wells were in the area west of the coal mines of the eastern PRB, in the Northeast Wyoming River Basins. Most of the CBNG wells west of the coal mines were in the drainages and subdrainages of the Belle Fourche and Cheyenne rivers. The general location of the CBNG wells is shown in **Figure 3.3-5**. Data from the files of the WOGCC presented in **Table 3.5-1** had approximately 12,000 permitted CBNG wells in the Wyoming PRB prior to January of 2002.

Most of the permitted CBNG wells 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 297 million barrels per year in the Northeast Wyoming River Basins (Upper Belle Fourche and

Upper Cheyenne River basins) and approximately 216 million barrels per year in the Powder/Tongue River Basin (Upper and Middle Powder River, Little Powder River, and Upper Tongue River) as shown in **Table 3.5-1**. During 2002, CBNG water production in the Northeast Wyoming River Basins was approximately 258 million barrels, mostly in the upper Belle Fourche River watershed; CBNG water production in the Powder/Tongue River Basin in 2002 was approximately 310 million barrels. Average CBNG water production per well increased steadily from approximately 50 to 400 barrels per day from 1990 to 1996 and then remained at that peak level until approximately 2000. By early 2002, production per well was declining and was around 300 barrels per day per well (BLM 2003a). CBNG wells have an average life expectancy of approximately 7 years, with the majority of water production coming in the first few years to get the coal bed aquifer depressurized. Once methane production is underway, dewatering of the coal bed aquifer is at a reduced and usually steady rate in the range of 1 to 5 gpm. Over time, the water production from an individual CBNG well declines and eventually reaches a level of approximately 1 to 2 gpm. Water quality from CBNG wells in the Fort Union Formation is summarized in **Table 3.5-2**.

Table 3.5-1
Water Production by CBNG Wells in the PRB

Subwatershed	Number of Pre-2002 CBNG Wells[1]	2000 Water Production (barrels)[2]	2001 Water Production (barrels)[2]	Number of Wells in 2002	2002 Water Production (barrels)[3]
Upper Tongue River	819	6,290,722	26,984,948	1,258	67,158,341
Upper Powder River	2,808	42,736,739	90,426,440	2,210	122,389,945
Crazy Woman Creek	150	28,706	9,862	5	30,821
Clear Creek	389	43,877	301,126	171	6,611,551
Middle Powder River	727	7,563,589	19,034,451	670	30,431,564
Little Powder River	1,814	66,667,649	79,325,493	1,817	84,610,410
Antelope Creek	251	1,769,502	7,209,092	189	20,475,248
Upper Cheyenne River	401	48,491,981	46,919,356	344	33,824,899
Upper Belle Fourche River	4,659	200,409,537	242,735,454	4,032	203,251,653
Middle North Platte River	6	0	524	6	64,873
Total	**12,024**	**374,302,302**	**512,946,746**	**10,702**	**568,848,805**

[1]Pre-2002 wells include all wells drilled or authorized and projected for completion by 2002. Water production shown for 2000 and 2001 comes from these wells. Not all pre-2002 wells produced during 2000 or 2001.
[2]Data were compiled from WOGCC 2001, 2002.
[3]2002 data compiled from WOGCC 2005.
Note: One barrel equals 42 gallons.

Source: BLM 2003a; WOGCC 2005.

3.5.3 CBNG Water Discharge

Groundwater produced by CBNG wells primarily is discharged directly to the surface in Wyoming, generally without treatment. The water in the northwestern part of the PRB usually 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. The water quality in the coal bed aquifers varies with location and depth in the Wyoming PRB. Thus, groundwater quality in the PRB is highly variable and generally elevated to some degree in TDS, sodium, calcium, sulfate, and bicarbonate. In the eastern part of the PRB, however, groundwater discharged by the CBNG wells is generally low in TDS and sodium and often of better quality than surface water. The key issues for regulation of

CBNG water discharge are TDS and SAR levels. TDS is often expressed in terms of EC measured directly in the field. **Figure 3.5-1** shows the distribution of EC and SAR in CBNG waters in the PRB.

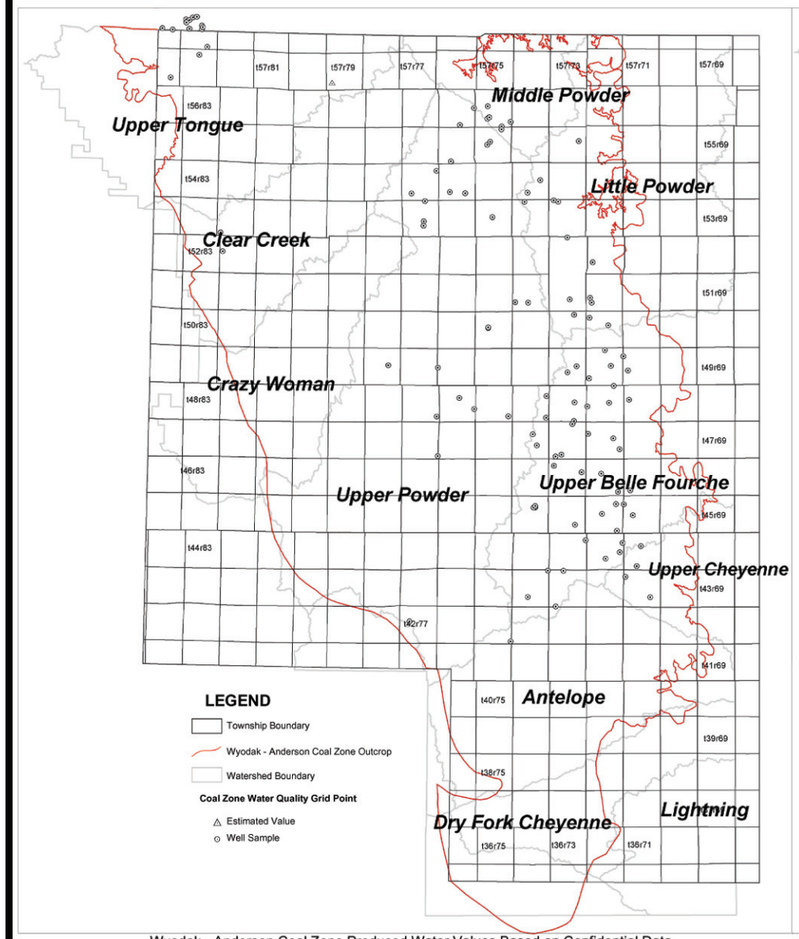
Table 3.5-2
Average Water Quality Data for CBNG-produced Water from the Fort Union Formation

Parameter (units)	MRL	Minimum	Maximum	Median	Detection Ratio (detections/total samples)	DWS
Temperature (˚C)	--	12	29	19	--	--
pH (standard units)	--	6.8	8	7.3	--	6.5-8.5
TDS (mg/L)	--	270	2,720	838	--	500
Calcium (mg/L)	--	1.8	68.9	26.3	--	--
Magnesium (mg/L)	--	1.6	45.7	14	--	--
Sodium (mg/L)	--	109	1,000	270	--	--
Potassium (mg/L)	--	3.1	48	7.3	--	--
Bicarbonate (mg/L)	--	289	3,134	952	--	--
Sulfate (mg/L)	--	<0.3	16.7	X	--	250
Chloride (mg/L)	--	5.1	64.6	10.6	--	250
Fluoride (mg/L)	--	0.4	4.13	1.1	--	2
Iron (mg/L)	--	0.02	4.9	0.38	--	0.3
Manganese (mg/L)	--	0.0014	0.0914	0.0136	--	0.05
Barium (mg/L)	--	0.14	1.6	0.6	--	2
SAR	--	5	68.7	8.8	--	--
Aluminum (µg/L)	<50	--	<50	--	0/70	50 to 200
Silver (µg/L)	<1	--	<1	--	0/70	100
Arsenic (µg/L)	<0.2	--	2.6	--	38/70	50
Boron (µg/L)	<0.1	--	390	--	24/70	--
Beryllium (µg/L)	<0.1	--	<0.1	--	0/70	--
Bismuth (µg/L)	<20	--	46	--	30/70	--
Cadmium (µg/L)	<0.1	--	<0.1	--	0/70	5
Cerium (µg/L)	<0.1	--	14	--	2/70	--
Cobalt (µg/L)	<0.1	--	0.24	--	19/70	--
Chromium (µg/L)	<1	--	1.8	--	10/70	--
Cesium (µg/L)	<0.1	--	0.78	--	30/70	--
Copper (µg/L)	<0.1	--	29	--	70/70	1,000
Mercury (µg/L)	<0.1	--	0.25	--	1/70	2
Lanthanum (µg/L)	<10	--	<10	--	0/70	--
Lithium (µg/L)	<10	--	208	--	70/70	--
Molybdenum (µg/L)	<0.2	--	4.1	--	32/70	--
Nickel (µg/L)	<0.5	--	35	--	66/70	100
Lead (µg/L)	<0.1	--	0.43	--	5/70	--
Rubidium (µg/L)	<0.1	--	38	--	70/70	--
Antimony (µg/L)	<2	--	<2	--	0/70	6
Scandium (µg/L)	<0.1	--	3	--	66/70	--
Selenium (µg/L)	<2	--	<2	--	0/70	50
Tin (µg/L)	<0.1	--	5.5	--	7/70	--
Strontium (µg/L)	<0.1	--	1,900	--	70/70	--
Thorium (µg/L)	<20	--	<20	--	0/70	--
Thallium (µg/L)	<0.2	--	0.34	--	1/70	--
Uranium (µg/L)	<0.1	--	<0.1	--	0/70	--
Vanadium (µg/L)	<0.2	--	1.1	--	1/70	--
Tungsten (µg/L)	<20	--	51	--	4/70	--
Yttrium (µg/L)	<20	--	<20	--	0/70	--
Zinc (µg/L)	<1	--	80	--	39/70	5000
Zirconium (µg/L)	<50	--	<50	--	0/70	--

Note: --- = no recommended value
˚C = degrees centigrade
DWS = drinking water standard (primary or secondary maximum contaminant level)
µg/L = micrograms per liter
mg/L = milligrams per liter
MRL = minimum reporting limit
X = less than minimum reporting

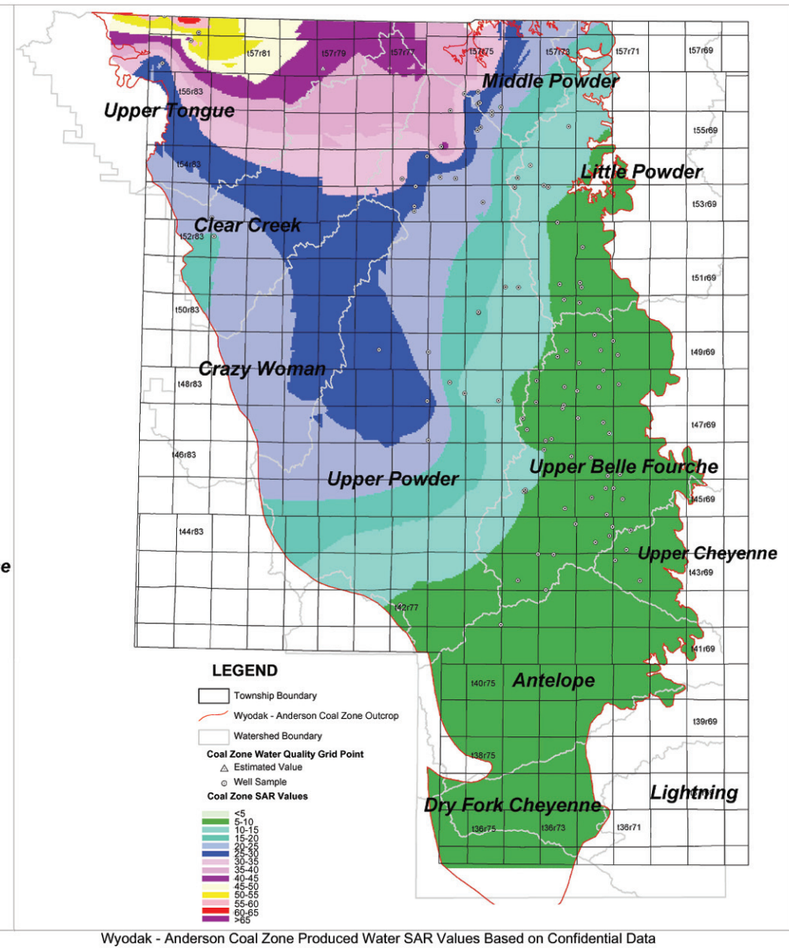
Source: BLM 2003a.

LOCATIONS OF WELLS SAMPLED



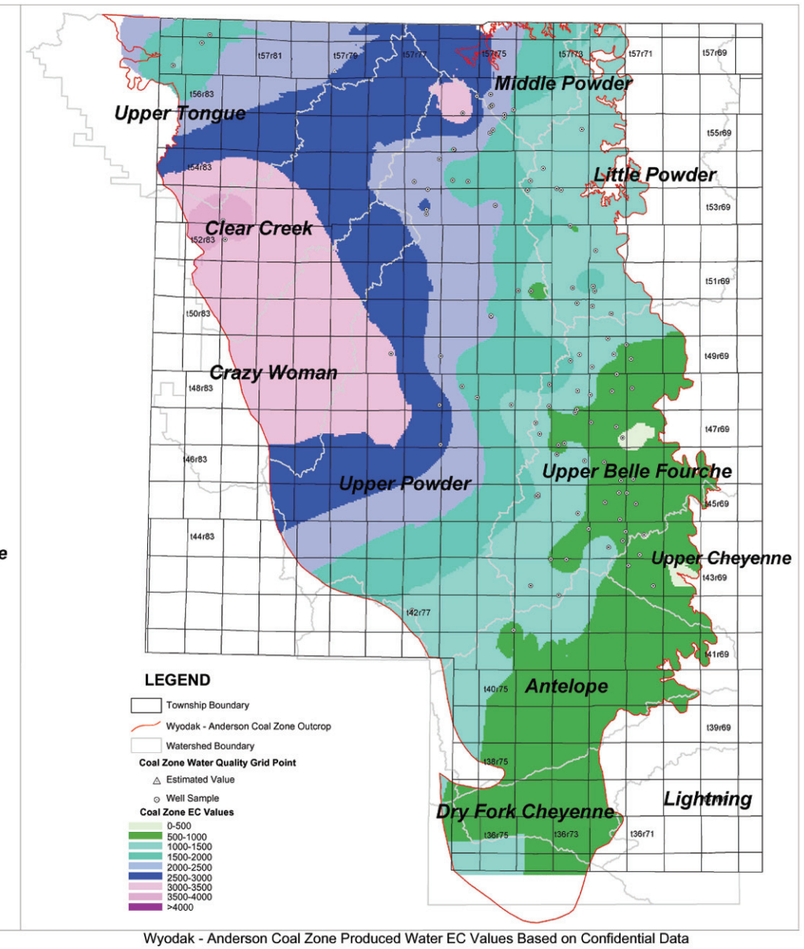
Wyodak - Anderson Coal Zone Produced Water Values Based on Confidential Data

PRODUCED WATER SAR VALUES



Wyodak - Anderson Coal Zone Produced Water SAR Values Based on Confidential Data

PRODUCED WATER EC VALUES



Wyodak - Anderson Coal Zone Produced Water EC Values Based on Confidential Data

SAR and EC Values by Subwatershed

	Little Powder		Upper Belle Fourche		Upper Cheyenne		Dry Fork Cheyenne		Antelope Creek		Upper Tongue		Clear Creek		Crazy Woman Creek		Middle Powder River		Upper Powder River		Salt Creek	
	SAR	EC	SAR	EC	SAR	EC	SAR	EC	SAR	EC	SAR	EC	SAR	EC	SAR	EC	SAR	EC	SAR	EC	SAR	EC
Maximum	23.0	1807	13.4	1828	8.1	1104	7.6	1067	9.0	1230	64.7	3712	42.3	3891	29.8	3455	41.9	3042	43.3	3408	13.1	1883
Minimum	7.7	930	6.1	397	5.6	448	5.5	600	5.8	506	22.6	1413	19.0	2334	19.7	2430	13.2	1182	7.7	785	6.2	974
Mean	11.1	1271	8.2	970	6.4	599	6.7	872	7.1	905	38.7	2406	29.2	3022	24.8	3129	27.8	2077	19.5	2163	9.7	1415
Median	10.3	1230	8.0	977	6.3	558	6.9	877	7.0	921	40.0	2424	28.8	2968	25.2	3169	26.1	1984	19.4	2142	9.5	1388

Source: BLM 2003a.

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Figure 3.5-1

SAR and EC Values for CBNG-produced Water by Subwatershed

07/30/09

As of early 2002, there were approximately 3,565 permitted CBNG outfalls for water discharge in the PRB (see **Figure 3.5-2**). These outfalls are summarized in **Table 3.5-3**. Approximately 43 percent of these outfalls were in the Upper Belle Fourche and Cheyenne River basins, approximately 21 percent were in the Upper Powder River drainage, and approximately 16 percent were 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 ranged from 1 to approximately 25 gpm. Many outfalls are linked to approximately 5 to 7 CBNG wells. The discharge water comes not only from the coal bed aquifer being dewatered, but also from interbedded and overlying sand units in the coal-bearing sections of the Fort Union Formation. Multiple outfalls can be covered by one discharge permit. Thus, the number of discharge permits does not correspond to the number of outfalls in **Table 3.5-3**.

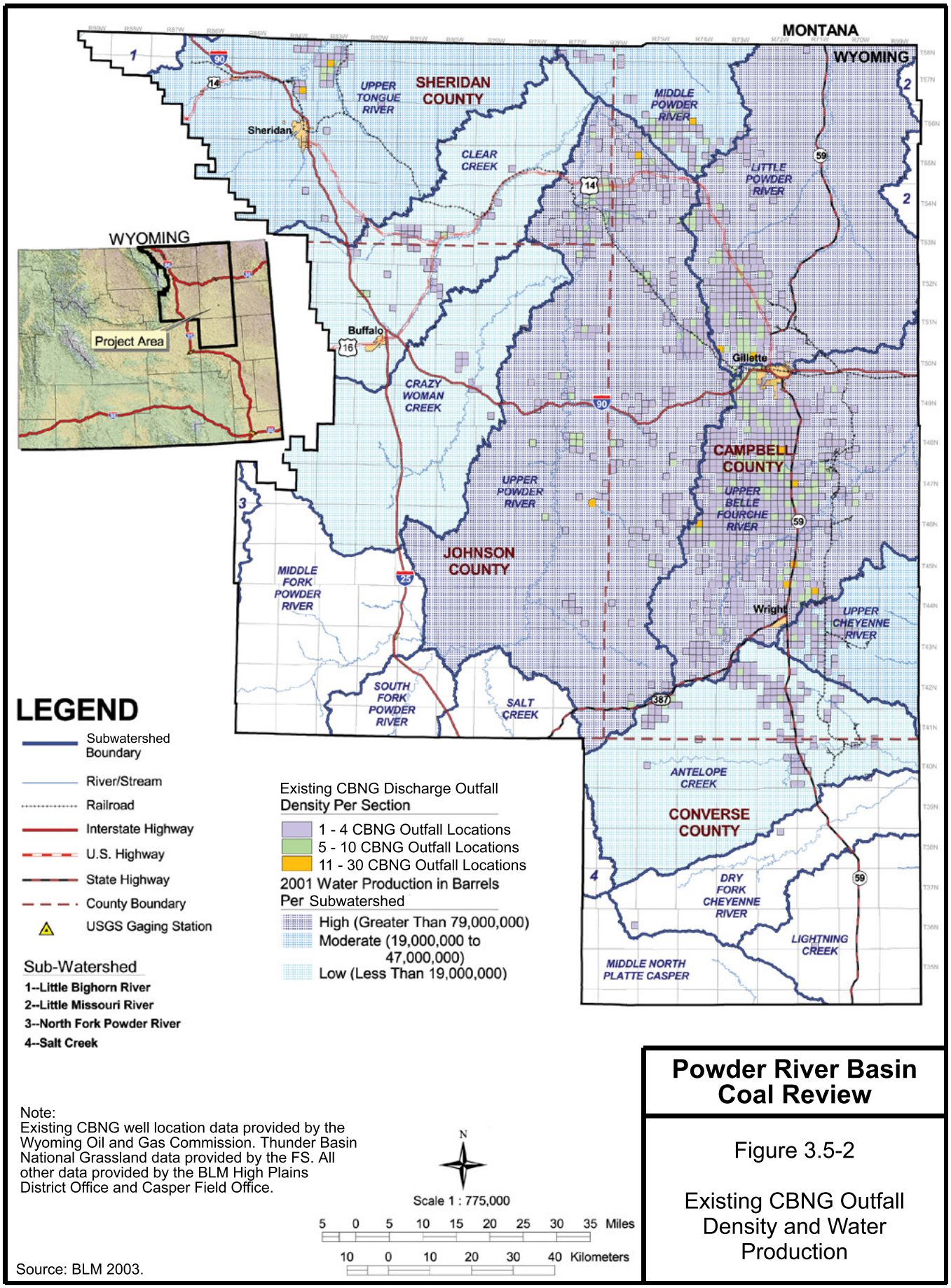
Table 3.5-3
Permitted CBNG Outfalls in the PRB

Subwatershed	Number of Existing CBNG Discharge Permits	Number of Existing CBNG Discharge Outfalls	Year 2001 CBNG Dischages		Estimated Discharge per Outfall	
			(cfs)[1]	(gpm)	(cfs)[1]	(gpm)
Upper Tongue River	22	105	4.8	2,154	0.05	22.4
Upper Powder River	160	760	16.1	7,226	0.02	9.0
Clear Creek	18	67	0.05	22.4	0.0007	0.31
Crazy Woman Creek	4	10	0.002	0.90	0.00022	0.10
Middle Powder River	38	184	3.4	1,526	0.02	9.0
Little Powder River	118	561	14.1	6,328	0.002	0.90
Antelope Creek	59	223	1.3	583.4	0.006	2.7
Upper Cheyenne River	37	125	8.4	3,770	0.07	31.4
Upper Belle Fourche River	290	1,530	43.2	19,388	0.03	13.5
Total	**746**	**3,565**	**--**	**--**	**--**	**--**

[1]cfs = cubic feet per second.

Source: 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. Impacts to surface water flow and quality are thus 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.



Note:
Existing CBNG well location data provided by the Wyoming Oil and Gas Commission. Thunder Basin National Grassland data provided by the FS. All other data provided by the BLM High Plains District Office and Casper Field Office.

Source: BLM 2003.

Powder River Basin Coal Review

Figure 3.5-2

Existing CBNG Outfall Density and Water Production

07/30/09

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 that are regulated by the WOGCC, WDEQ, BLM, and WSEO (in-stream impoundments). 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 relative to water quality 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 the 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 present is Class III or better in quality (TDS less than 10,000 mg/L). These requirements apply regardless of the location or type of impoundment. 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 WSEO regulates the design of in-channel impoundments to ensure water rights are protected. Off-channel impoundments must be at least 500 feet from a drainage. The WDEQ regulates discharges into both off-channel and in-channel impoundments. In addition, BLM review and approval of impoundment design is part of the APD and NEPA process for permitting of CBNG wells. The WOGCC regulates CBNG wells as oil and gas wells and, thus, also plays a role in regulating impoundments on private and state lands.

Studies of the potential impacts to surface water and groundwater quality from infiltration of CBNG water currently are underway by the BLM, USGS, and private research groups funded by the 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 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 (T44N, R76W), 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).

Thus, as of early 2002, discharge of CBNG water to ephemeral drainages and to impoundments had not produced any measurable impacts to surface water flow or quality beyond a few miles from the discharge outfall, due to high conveyance losses. In addition, discharge to impoundments had not appeared to affect groundwater or surface water beyond approximately 25 feet from the unlined impoundments. The PRB Oil and Gas Final EIS (BLM 2003a) specified in the Record of Decision the type of discharge allowed in each of the drainages of the Wyoming PRB. Except for the Belle Fourche and Cheyenne River drainages, most discharge must be to impoundments, to reinjection wells, or to water treatment facilities. In the Belle Fourche and Cheyene River drainages, CBNG wells can discharge produced water directly to ephemeral drainages (BLM 2003a).

3.6 Coal Mine Water Use

3.6.1 Introduction

Coal mining has been a major part of the economy of the PRB since the early 1970s. Coal in the Fort Union Formation is exposed along the eastern side of the PRB from Gillette, Wyoming, south to near Wright, Wyoming. Many of the coal bed outcrops burned due to ignition of methane gas thousands of years ago. These burned areas are now clinker zones that allow for recharge to the coal bed aquifers due to the high permeability of the fractured clinker.

The coal mines in the eastern PRB of Wyoming are shown in **Figure 1-1**. These coal mines are strip mines that remove low sulfur coal from coal beds in the Tongue River member of the Fort Union Formation. Many of the coal areas are overlain by the Wasatch Formation. This formation in the eastern PRB is a local aquifer, containing water in the more sandy and permeable beds. This stratigraphic unit is removed by the mines before mining of the coal can begin. In addition, dewatering of the coal bed aquifers in the Fort Union Formation is required to facilitate mining. The coal beds of the Fort Union Formation dip to the northwest, requiring the coal mines to mine progressively to the northwest and to mine deeper as they expand their mines to follow the PRB coal beds. CBNG development in the eastern PRB extracts natural gas from the same coal beds mined by the coal companies. As a result, the CBNG wells located near the lease boundaries of the current coal mines would be mined through as the coal mines expand to the northwest over the next 20 years.

3.6.2 Coal Mine Water Production

Coal mine water use is determined by three main factors: 1) the tons of coal mined per year; 2) the depth of the coal; and 3) the permeability of the Wasatch and Fort Union members mined through during coal removal. Coal mine dewatering and disposal of pumped water is regulated by the: 1) WSEO for the permitting of dewatering wells and 2) WDEQ for water disposal via WYPDES permits. The WDEQ/LQD division regulates coal mining in general, and the BLM regulates coal mining through its leasing of federally-owned coal beneath private and public lands in Wyoming.

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) released to ephemeral and intermittent drainages through WYPDES permits. 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 (WSEO 2004) (**Table 3.6-1**). Most mines pumped between 300 and 920 acre-feet of groundwater in 2002, while one mine pumped 1,228 acre-feet of waterand a few mines were dry and had no groundwater pumpage (WSEO 2004). As shown in **Table 3.6-1**, 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.

Table 3.6-1
Permitted Groundwater Use for Wyoming PRB Coal Mines

Coal Mine Subregion	Year (acre-feet)									
	1976	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**
Subregion 1	6.14	0	92.1	276.3	61.4	6.14	92.1	184.2	153.5	307
Subregion 2	61.4	61.4	18.42	0.03	0.012	0.921	92.1	122.8	144.29	178.06
Subregion 3	61.4	9.21	6.14	9.21	3.07	1.535	92.1	184.2	24.56	276.3
Total	**128.9**	**70.6**	**116.7**	**285.5**	**64.5**	**8.6**	**276.3**	**491.2**	**322.4**	**761.4**

Coal Mine Subregion	Year (acre-feet)									
	1986	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**
Subregion 1	614	61.4	61.4	184.2	1,075	1,228.2	1,781	1,151.3	890.3	921
Subregion 2	73.68	184.26	184.2	245.6	862.7	693.82	1,627	1,096	1,261.8	626.28
Subregion 3	214.9	307	245.6	307	629.4	1,320.1	1,873	1,565.7	2,456	1,228
Total	**902.6**	**552.7**	**491.2**	**736.8**	**2,567**	**3,242.2**	**5,280**	**3,812.9**	**4,608.1**	**2,775.3**

Coal Mine Subregion	Year (acre-feet)						
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Subregion 1	2,977.9	3,991	2,456	1,842	1,535	951.7	1,504
Subregion 2	2,149	896.44	1,964.8	709.17	2,213	1,749.9	1,965
Subregion 3	3,684	3,499.8	4,881.3	4,850.6	3,684	2,824.4	3,991
Total	**8,810.9**	**8,387.2**	**9,302.1**	**7,401.8**	**7,433**	**5,526**	**7,460**

Source: WSEO 2004.

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 negatively alter the water quality of the drainage or produce flows that would 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 is conveyed 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.

3.6.3 Coal Mine Backfill Water

When coal mines are reclaimed, the overburden is returned to the mined-out portion of the pit as backfill, and the mined area is reclaimed to approximate original conditions for slope and drainage. In the Wyoming PRB, the backfill material gradually resaturates with water as groundwater from the Wasatch Aquifer and the Fort Union coal bed aquifers enters the backfill material. Backfill can take anywhere from 50 to 200 years to resaturate (GAGMO 2001). The water quality in the resaturated backfill usually is high in TDS, sulfate, sodium, and other metals and anions. Monitor wells in coal mine backfill material 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 backfill is 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 backfill improves over time and becomes similar to that found in these aquifers near the coal mines. The time to flush the backfill and improve the water quality varies considerably, based on the permeability of the backfill and groundwater flow rates in the aquifers. The time required to flush water from backfill can vary from a few tens to a few hundreds of years (Martin et al. 1988). This estimate was based on an evaluation of coal mines in the vicinity of Gillette, Wyoming.

3.6.4 Surface Drainages Near Coal Mines

Coal mines 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 often are not replaced (Martin et al. 1988). Studies of coal mines near Gillette, Wyoming 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 (Martin et al 1988) 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.

3.6.5 Groundwater Levels Near Coal Mines

Groundwater drawdown near the coal mines of the eastern PRB is the result of coal mine dewatering and CBNG depressurization of the coal beds. It is often difficult to separate the effects of coal mine dewatering from that of nearby CBNG dewatering in the Fort Union Formation. Coal mine dewatering has resulted in groundwater level declines in the Wasatch of 20 to 100 feet within and up to a distance of approximately 1 to 3 miles from the mine boundaries (GAGMO 2001). In the Fort Union Formation, combined CBNG and coal mine dewatering drawdown of 40 feet or greater usually occurs within approximately 3 to 5 miles of the coal mines, and drawdown of up to 5 feet can occur at a distance of up to 11 miles from the coal mines (GAGMO 2001). Section 4.3, Groundwater Modeling Results for Current Conditions, of this report presents a discussion of the relative effects of CBNG pumping and coal mine dewatering on the Fort Union and Wasatch formations.

Groundwater level declines in the Fort Union Formation within and near the coal mines of the eastern PRB are available in the GAGMO (2001) 20-year report that summarizes groundwater data for these coal mines from 1980 to 2000. Data and maps presented by GAGMO (2001) show that for most mines, groundwater level declines in the mine area over the same 20-year period were in the range of 20 to 60 feet. A maximum drawdown of 120 feet was observed near the northern end of the Subregion 1 coal mines, and one mine in Subregion 2 and one mine in Subregion 3 had maximum water level declines of 100 feet within 1 mile or less of their permit boundaries (**Table 3.6-2**). CBNG fields near these coal mines have been active since approximately 1995, and groundwater level declines in the Fort Union Formation in these fields have been in the range of 100 to 240 feet. Many of these CBNG fields are within 2 miles or less of the coal mine permit boundaries. Thus, the current groundwater levels near the coal mines are a combined effect of CBNG development and coal mine dewatering, with groundwater level declines beyond approximately 2 miles from the coal mines being substantially influenced by CBNG development. The GAGMO (2001) data and interpretative contours are based on water level declines in individual monitor wells, not on average water level declines over broad areas such as a square mile. As such, these declines and interpretative contours would be expected to differ from water level declines modeled with a numerical groundwater flow model. The results of numerical modeling conducted for this study are presented in Section 4.3, Groundwater Modeling Results for Current Conditions.

Table 3.6-2
Eastern PRB Estimated and Actual Groundwater Level Drawdown in the Fort Union Aquifer

Coal Mine	Mine Area Water Level Decline 1980 – 2000[1] (feet)	CBNG Field Water Level Decline[1] (feet)	Distance to CBNG Field[1] (feet)	USGS 1988 Estimated Distance to 5-foot Drawdown Contour[2] (feet)	Measured Distance to 5-foot Drawdown Contour[1] (feet)	Comments
Subregion 1-North Of Gillette						
Buckskin	20 to 120	180 to 240	3,000-6,000	50,000	Up to 2,000	Affected by CBNG drawdown
Rawhide	40 to 60	100 to 200	6,000	60,000	Up to 10,000	Affected by CBNG drawdown
Eagle Butte	10 to 40	60 to 200	2,000	64,000	CBNG	CBNG obscures drawdown
Dry Fork	40	No CBNG field	--	Not used	Not used	--
Wyodak	40 to 60	No CBNG field	--	60,000	Up to 3,000	No CBNG influence
Subregion 2-South Of Gillette						
Caballo	20 to 40	100 to 240	10,000	50,000	Up to 3,000	5-foot drawdown measured east of mine near clinker.
Belle Ayr	80 to 100	100 to 240	1,000	40,000	Up to 5,000	5-foot drawdown measured east of mine near clinker.
Cordero-Rojo	20 to 60	160 to 240	15,000	Not used	Not used	--
Cordero	20 to 40	100 to 180	6,000	50,000	Up to 3,000	5-foot drawdown measured east of mine near clinker.
Coal Creek	10 to 60	60	8,000	60,000	Up to 5,000	5-foot drawdown measured east of mine near clinker.
Subregion 3-Wright						
Jacobs Ranch	20 to 40	80 to 100	2,000	28,000	Up to 12,000	5-foot drawdown measured east of mine near clinker.
Black Thunder	60	100 to 200	6,000	30,000	Up to 10,000	5-foot drawdown measured east of mine near clinker.
North Rochelle	20 to 40	No CBNG	--	50,000	Up to 2,000	5-foot drawdown measured east of mine near clinker.
North Antelope/Rochelle	60 to 100	No CBNG	--	40,000	Up to 15,000	5-foot drawdown measured east of mine near clinker.
Antelope	5 in Anderson; 40 Canyon	No CBNG	--	40,000	Up to 3,000	5-foot drawdown measured east of mine near clinker.

[1]GAGMO 2001.
[2]Based on Martin et al. 1988.

Note: Five-foot drawdown contour measured to east of mines where it is obscured to west by CBNG field drawdown. Measurement approximate and maximum distance given in table.
Measurements made on GAGMO (2001) maps and are estimates resulting from averages in different directions from mines.
Measurements made from mine lease boundary.