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Task 3B Report for the Powder River Basin Coal Review Summary of Cumulative Water Resources Effects

List of Acronyms

ACE	Anderson Consulting Engineers, Inc.
amsl	above mean sea level
BLM	Bureau of Land Management
CBNG	coal bed natural gas
ESI	Environmental Simulations, Inc.
PRB	Powder River Basin
RFD	reasonably foreseeable development

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1.0 Introduction

The Powder River Basin (PRB) Coal Review is a regional technical study for assessing the existing conditions and the projected future cumulative impacts associated with energy-related past, present, and reasonably foreseeable development (RFD) in the Wyoming PRB and, for specific resources, the Montana PRB. This study is being conducted by AECOM, INC. dba AECOM Environment (AECOM) under the direction of the Bureau of Land Management (BLM) High Plains District Office and Wyoming State Office.

This Task 3B Report for the PRB Coal Review provides a summary of the cumulative groundwater resources effects in the Wyoming PRB study area for future years 2020 and 2030 as a result of ongoing coal mine dewatering and coal bed natural gas (CBNG) development. Groundwater recovery following the cessation of coal mine dewatering and CBNG pumping and water discharge also is described. Cumulative effects for air quality, social and economic conditions, and other environmental resources are presented in individual stand-alone Task 3 reports. Cumulative effects to surface water quality and channel stability as a result of CBNG water discharge are discussed in the stand-alone report prepared by Anderson Consulting Engineers, Inc. (ACE) (2012).

For the purpose of this study, the Wyoming PRB study area comprises all of Campbell County, all of Sheridan and Johnson counties less the Bighorn National Forest lands to the west of the PRB, and the northern portion of Converse County (see **Figure A-1** in **Appendix A**). It includes all of the area administered by the BLM Buffalo Field Office, a portion of the area administered by the BLM Casper Field Office, and a portion of the Thunder Basin National Grasslands, which is administered by the U.S. Forest Service (see **Figure A-2** in **Appendix A**).

2.0 Methodology

The PRB Phase II groundwater model, a numerical groundwater flow model, was developed for this study to analyze base year (2008) groundwater level impacts and future year (2020 and 2030) cumulative groundwater level impacts associated with coal mine dewatering and CBNG development in the Wyoming PRB study area. Recovery of groundwater levels following the cessation of coal mine and CBNG pumping also was modeled. A summary of the PRB Phase II groundwater model is presented in the Task 1B report (AECOM 2014). Detailed discussions of model development and calibration are presented in the Groundwater Model Protocol (AECOM 2011b) and the Model Calibration Report (Environmental Solutions, Inc. [ESI] 2014).

For future year 2020 and 2030 groundwater modeling purposes, estimations of future CBNG development and coal mine dewatering through 2030 were based on data and information compiled for the Task 2 report (AECOM 2011a). Projected CBNG well numbers, locations, depths, and pumping and discharge rates were determined in coordination with the BLM Wyoming Reservoir Management Group. The coal mine dewatering rates were projected based on data obtained from the Wyoming State Engineers Office and the coal mine operators. Projected locations of coal mine pits over time were provided by the BLM (2012).

For purposes of recovery modeling, the end of CBNG-related pumping and coal mine dewatering in the Wyoming PRB, as determined in coordination with the BLM, was assumed to be years 2040 and 2050, respectively. The assumption relative to CBNG development was based on the currently projected rate of CBNG development through 2030 and the expected decline in gas reserves in the coal seams in the Wyoming PRB. The assumption relative to coal mining was based on the currently projected rate of coal

mining through 2030 and the lack of available geologic data needed to extend coal mining projections much beyond 2050. For modeling purposes, the projected 2030 CBNG and coal mine pumping rates were held constant through years 2040 and 2050, respectively. Recovery modeling is discussed further in the Groundwater Model Protocol (AECOM 2011b) and the Calibration Report (ESI 2014).

3.0 Groundwater Model Results

3.1 Introduction

The purpose of the PRB Phase II groundwater model is to provide a method for estimating the regional cumulative impacts of coal mine dewatering and CBNG development on groundwater levels in the Wyoming PRB study area for base year (2008) and future years 2020 and 2030. The model was not designed to estimate local impacts around an individual mine pit or to private wells near CBNG well fields. As a result, the modeled groundwater levels, drawdown, mounding, and recovery resulting from projected ongoing coal mine dewatering and CBNG pumping and water discharge in the Wyoming PRB are only approximate and should be used only as a general guide for any given modeled year.

An overview of the PRB Phase II groundwater model layers is presented below to provide context for the analyses presented in this Task 3B report.

- Layer 1 includes the Wasatch Formation and the sand-rich zone of the upper Tongue River Member of the upper Fort Union Formation. The Wasatch Formation does not constitute a regional aquifer. Rather, it is a sedimentary formation that contains local water-saturated sand lenses that can be locally extensive but not hydraulically interconnected with other sand lenses due to the considerable clay content of the Wasatch. Model Layer 1 also includes the seasonally saturated alluvium along streams, which represents local zones of sand and gravel along stream beds. For purposes of this regional analysis, the units that comprise model Layer 1 collectively are referred to as the Wasatch Formation.

  Recharge to Layer 1 comes from precipitation (less evapotranspiration water loss) and CBNG water discharge. The recharge rate is higher on the clinker zones near the coal mines in the eastern Wyoming PRB, in the area between Buffalo and Sheridan in western Wyoming, and in portions of the Montana PRB (**Figure A-3** in **Appendix A**). Groundwater discharge primarily is via vertical downward leakage to the underlying geologic unit, base flow to streams, and CBNG pumping.

- Layer 2 includes the lower coal-rich portion of the upper Tongue River Member of the upper Fort Union Formation, referred to for purposes of this analysis as the upper Tongue River Member. The coal-rich unit of the upper Tongue River Member includes the Wyodak-Anderson and Big George coals. The Wyodak-Anderson is the primary coal mined in the Wyoming PRB study area. Both the Wyodak-Anderson and Big George are primary targets for CBNG development.

  Recharge to Layer 2 comes from precipitation along the outcrop areas (inclusive of clinker zones) of the upper Tongue River Member, and via vertical groundwater flow from adjacent geologic units. Groundwater discharge is via coal mine dewatering, CBNG pumping, vertical downward leakage to the underlying geologic unit, and base flow to stream segments that cross the Layer 2 outcrop areas (**Figure A-3** in **Appendix A**).

- Layer 3 includes the deep coals in the lower Tongue River Member of the upper Fort Union Formation, referred to for purposes of this analysis as the lower Tongue River Member. The deep coals in this layer are used for CBNG development, although to a lesser degree than the main coals of the upper Tongue River member.

Recharge to Layer 3 comes from precipitation along the outcrop areas (inclusive of clinker zones) and vertical groundwater flow from adjacent geologic units. Groundwater discharge is via vertical leakage to adjacent geologic units, CBNG pumping, base flow to stream segments that cross the Layer 3 outcrop areas (**Figure A-3** in **Appendix A**), and coal mine pumping where mines need to depressurize the zone below the coals being mined.

- Layers 4 and 5 represent the Lebo Shale and Tullock members, respectively, of the lower Fort Union Formation. Recharge to these layers comes from precipitation along their respective outcrop areas and vertical groundwater flow from adjacent geologic units. Discharge from Layers 4 and 5 is via vertical leakage to adjacent geologic units, outflow to the north, and base flow to stream segments that cross their outcrop areas (**Figure A-3** in **Appendix A**). Discharge from Layer 5 also is via pumpage from municipal water supply wells for the City of Gillette and Town of Wright. This pumpage is described in HDR et al. (2009) and Stetson Engineering and Wester Wetstein & Associates (2009), respectively.

  These geologic units are included in the Phase II groundwater model to avoid the arbitrary use of a no-flow or general head boundary on the bottom of Layer 3. They are distinct geologic and hydrologic units below the lower extent of the coal mine and CBNG development activity in the Wyoming PRB. Therefore, they are not discussed further in this analysis.

The modeling results for the Wasatch Formation and the upper and lower Tongue River Members of the upper Fort Union Formation for future years 2020 and 2030 and recovery are presented in the figures in **Appendix B** and discussed below. The groundwater level changes for 2020 and 2030 are discussed relative to both 1990 and base year 2008 conditions. Comparison to 1990 conditions is included to present the cumulative groundwater level changes since the onset of CBNG development and since the increase in coal mine dewatering in the Wyoming PRB. Comparison to base year 2008 conditions is included to present the changes in groundwater levels since 2008, a time period of major CBNG pumping. The model results for base year 2008 are presented in the Task 1B report (AECOM 2014).

3.2 Modeled Cumulative Coal Mine- and CBNG-related Groundwater Impacts for Year 2020

3.2.1 Wasatch Formation

See Section 3.1 for an overview of the PRB Phase II groundwater model layers as related to the Wasatch Formation and the upper and lower Tongue River members of the upper Fort Union Formation (model Layers 1 through 3, respectively).

3.2.1.1 Wasatch Formation 2020 Groundwater Levels

Figure B-1 shows the modeled groundwater levels in the Wasatch Formation for year 2020. Based on the model results, groundwater elevations generally decrease from approximately 5,300 feet above mean sea level (amsl) in the south to approximately 3,600 feet amsl in the north. In the southern part of the Wyoming PRB (south of the Converse/Campbell county line), groundwater in the Wasatch Formation flows to the north/northeast, except near Antelope Creek and the southern end of the Subregion 3 coal mines. In this location, Antelope Creek acts as a drain as is evident in the groundwater level depressions. There also is an isolated depression in groundwater levels adjacent to the southern group of mines in Subregion 3 due to coal mine pumping. From the Converse/Campbell county line northward, groundwater flow in the Wasatch Formation generally is to the north.

3.2.1.2 Wasatch Formation 1990 to 2020 Cumulative Groundwater Impacts

The 1990 to 2020 model results for the Wasatch Formation are shown in **Figures B-2** through **B-4**. As shown in **Figure B-4**, dewatering at the Subregion 3 coal mines would result in localized groundwater drawdown up to 50 feet adjacent to the west side of the southernmost mines in this subregion. At the

Subregion 1 coal mines, mine dewatering would result in up to 25 feet of drawdown. No groundwater drawdown is anticipated at the Subregion 2 coal mines. CBNG water discharge would result in localized areas of groundwater mounding in Converse County ranging up to 100 feet. No CBNG-related groundwater drawdown is anticipated in the Wasatch Formation. (Note: The apparent differences in coal mine-related drawdown between **Figures B-2** and **B-4** are due to the change in contour intervals.)

3.2.1.3 Wasatch Formation 2008 to 2020 Cumulative Groundwater Impacts

The 2008 to 2020 model result for the Wasatch Formation are shown in **Figures B-5** through **B-7**. As shown in **Figure B-7**, cumulative groundwater impacts as a result of coal mine and CBNG pumping would be the same as described above for the modeled 1990 to 2020 time period, with the exception of reduced drawdown at the Subregion 1 coal mines. (Note: The apparent differences in coal mine-related drawdown between **Figures B-5** and **B-7** are due to the change in contour intervals.)

3.2.2 Upper Tongue River Member of the Upper Fort Union Formation

3.2.2.1 Upper Tongue River Member 2020 Groundwater Levels

Figure B-8 shows the modeled groundwater levels in the upper Tongue River Member for year 2020. Based on the model results, groundwater elevations generally decrease from approximately 4,700 feet amsl in the south to approximately 3,500 feet amsl in the north. The gradients vary throughout the basin in response to the variation of effective hydraulic conductivity in the groundwater model. The variation of hydraulic conductivity is a result of combining the percentage of sand, clay, and coal at each location as determined from Flores' geologic cross sections and the calibrated values of hydraulic conductivity assigned to each type of material at that location. In the southern part of the Wyoming PRB (south of the Converse/Campbell county line), groundwater in the upper Tongue River Member flows to the north/northeast. In the central part of the Wyoming PRB, there are numerous groundwater depressions along the Johnson/Campbell county line resulting from CBNG pumping, with associated groundwater elevations ranging from approximately 3,400 to 3,925 feet amsl. Immediately to the east and west of the groundwater depressions, groundwater flows to the northwest and northeast, respectively. To the west of the Subregion 3 coal mines, there are minor groundwater depressions resulting from the combined effects of coal mine and CBNG pumping, with associated groundwater elevations of approximately 4,450 feet amsl. Groundwater flow in the northern Wyoming PRB generally is to the north. Exceptions to this flow pattern occur in the vicinity of the eastern Wyoming PRB coal mines and in the northwestern and northeastern parts of the Wyoming PRB. In these locations, the groundwater flow patterns reflect the influence of precipitation-related recharge and (except in the northwest) base flow discharge to streams (primarily Little Powder River, Belle Fourche River, and Antelope Creek) in the upper Tongue River Member outcrop areas.

3.2.2.2 Upper Tongue River Member 1990 to 2020 Cumulative Groundwater Impacts

The 1990 to 2020 model results for the upper Tongue River Member are shown in **Figures B-9** through **B-11**. Drawdown in the coal mine areas in the eastern Wyoming PRB and to the west of Wright reflects the combined effects of coal mine dewatering and CBNG pumping. As shown in **Figure B-11**, drawdown of up to 150 feet would occur in the Subregion 3 coal mine areas, with a drawdown cone of 200 feet to the west of the northern mines in this subregion. Drawdown in the Subregion 2 coal mines would range up to approximately 100 feet. In Subregion 1, the drawdown cone at the central mines in this subregion would reach approximately 150 feet. CBNG-related drawdown would extend over most of the remainder of the Wyoming PRB, with the exception of the area south of Antelope Creek. CBNG-related drawdown would reach approximately 550 to 700 feet in the numerous drawdown cones in the central part of the Wyoming PRB, with drawdown cones of approximately 150 feet located to the northwest. CBNG-related drawdown along the west side of the Wyoming PRB would range from approximately 100 to 300 feet.

3.2.2.3 Upper Tongue River Member 2008 to 2020 Cumulative Groundwater Impacts

The 2008 to 2020 model results for the upper Tongue River Member are shown in **Figures B-12** through **B-14**. Groundwater drawdown and rebound at the coal mine subregions reflect the combined effects of coal mine dewatering and reduced CBNG pumping in the eastern Wyoming PRB. As shown in **Figure B-14**, drawdown to the west of the southern group of coal mines in Subregion 3 would be approximately 75 feet and groundwater rebound in the southern mines of this subregion would be approximately 100 feet. Minor drawdown and rebound are evident on the west side of the Subregion 2 coal mines, with isolated drawdown up to 100 feet and rebound up to 75 feet in Subregion 1. CBNG-related groundwater drawdown and rebound throughout the remainder of the Wyoming PRB are reflective of the projected general westward migration of CBNG development in the Wyoming PRB. Based on the model results, groundwater rebound in the south central, central, and northwestern portions of the Wyoming PRB would be up to approximately 200, 375, and 300 feet, respectively. CBNG-related drawdown cones in the south and north central portions of the Wyoming PRB would range from approximately 325 to 375 feet, with drawdown of approximately 50 to 150 feet in the northwest.

3.2.3 Lower Tongue River Member of the Upper Fort Union Formation

3.2.3.1 Lower Tongue River Member 2020 Groundwater Levels

Figure B-15 shows the modeled groundwater levels in the lower Tongue River Member for year 2020. Based on the model results, groundwater elevations generally decrease from approximately 4,525 feet amsl in the south to approximately 3,500 feet amsl in the north. In the southern part of the Wyoming PRB (south of the Subregion 3 coal mines), groundwater in the lower Tongue River Member flows to the north/northeast. In the central part of the Wyoming PRB, there is a groundwater depression in the vicinity of Crazy Woman Creek resulting from CBNG pumping, with an associated groundwater elevation of approximately 3,525 feet amsl. Immediately to the east, south, and west of the groundwater depression, groundwater flows to the northwest, north, and northeast, respectively. North of the Johnson/Sheridan county line, flow is generally to the north. Exceptions to this flow pattern occur in the vicinity of the eastern Wyoming PRB coal mines. In these locations, the groundwater flow patterns reflect the influence of precipitation-related recharge and base flow discharge to streams (primarily Little Powder River, Belle Fourche River, and Antelope Creek) in the lower Tongue River Member outcrop areas, in addition to the combined effects of coal mine and CBNG pumping.

3.2.3.2 Lower Tongue River Member 1990 to 2020 Cumulative Groundwater Level Impacts

The 1990 to 2020 model results for the lower Tongue River Member are shown in **Figures B-16** through **B-18**. Drawdown in the coal mine areas in the eastern Wyoming PRB and west of Wright reflects the combined effects of coal mine dewatering and CBNG pumping. As shown in **Figure B-18**, drawdown of up to 150 feet would occur in the Subregion 3 coal mine area, with a drawdown cone of approximately 225 feet to the west of the northern mines in this subregion. Drawdown in the Subregion 2 coal mines would range up to approximately 125 feet, with two drawdown cones of up to 275 feet on the west side of the mine areas. Drawdown in the Subregion 1 coal mines would be approximately 50 feet, with localized drawdown reaching approximately 350 feet at the northern mines in this subregion. CBNG-related drawdown would extend throughout most of the remainder of the Wyoming PRB. In the central part of the Wyoming PRB, CBNG pumping would result in a cone of depression of approximately 500 feet in one localized area, with a widespread cone of depression of 400 feet that primarily would extend over much of the eastern half of Johnson County. Drawdown along the west side of the Wyoming PRB would range from approximately 50 to 300 feet.

3.2.3.3 Lower Tongue River Member 2008 to 2020 Cumulative Groundwater Level Impacts

The 2008 to 2020 model results for the lower Tongue River Member are shown in **Figures B-19** through **B-21**. Groundwater drawdown and rebound at the coal mine subregions reflect the combined effects of coal mine dewatering and reduced and/or cessation of CBNG pumping over most of the eastern half of

the Wyoming PRB. As shown in **Figure B-21**, groundwater drawdown in the coal mine subregions would be limited to isolated areas within or adjacent to the mines, with isolated areas of groundwater rebound. Adjacent to the west side of the Subregion 3 coal mines drawdown would reach approximately150 feet, with up to approximately 50 feet of drawdown occurring in the mine areas. The 25-foot drawdown contour would extend approximately 12 miles to the west of the coal mines in Subregion 3. Two drawdown cones are evident on the west side of the Subregion 2 coal mines, with associated drawdowns up to approximately 175 feet. Localized drawdown areas would occur at the Subregion 1 coal mines, with drawdown ranging from 125 feet at the southern mines to 325 feet at the northern mines. Localized areas of groundwater rebound of approximately 25 to 100 feet are evident at all three subregions. CBNG-related drawdown would extend across the central and west central portions of the Wyoming PRB, with drawdown of approximately 250 feet to the east of Buffalo and approximately 100 feet to the west of Wright. Groundwater rebound primarily would occur north of Wright, in the central part of the Wyoming PRB west of Gillette, and north of Sheridan due to the reduction and/or cessation of CBNG pumping in these areas. Groundwater rebound in these areas would range up to 100 feet, with the greatest rebound in the central Wyoming PRB. This pattern is reflective of the general east to west migration of CBNG development that is projected in the Wyoming PRB.

3.3 Modeled Cumulative Coal Mine- and CBNG-related Groundwater Impacts for Year 2030

3.3.1 Wasatch Formation

3.3.1.1 Wasatch Formation 2030 Groundwater Levels

Figure B-22 shows the modeled groundwater levels in the Wasatch Formation for year 2030. Based on the model results, groundwater levels and flow patterns would be the same as shown in **Figure B-1** and discussed in Section 3.2.1.1 for year 2020.

3.3.1.2 Wasatch Formation 1990 to 2030 Cumulative Groundwater Impacts

The 1990 to 2030 model results for the Wasatch Formation are shown in **Figures B-23** through **B-25.** As shown in **Figure B-25**, dewatering at the Subregion 3 coal mines would result in localized groundwater drawdown up to 50 feet adjacent to the west side of the southernmost mines in this subregion. At the Subregion 1 coal mines, mine dewatering would result in up to 25 feet of drawdown within the mine areas. No groundwater drawdown is anticipated at the Subregion 2 coal mines. CBNG water discharge in the Wyoming PRB would result in localized areas of groundwater mounding in Converse County ranging up to 125 feet. No CBNG-related groundwater drawdown is anticipated in the Wasatch.

3.3.1.3 Wasatch Formation 2008 to 2030 Cumulative Groundwater Impacts

The 2008 to 2030 model results for the Wasatch Formation are shown in **Figures B-26** through **B-28**. As shown in **Figure B-28**, cumulative groundwater impacts as a result of coal mine and CBNG pumping would be similar to those described above for the modeled 1990 to 2020 time period. (Note: The apparent differences in coal mine-related drawdown between **Figures B-26** and **B-28** are due to the change in contour intervals.)

3.3.2 Upper Tongue River Member of the Upper Fort Union Formation

3.3.2.1 Upper Tongue River Member 2030 Groundwater Levels

Figure B-29 shows the modeled groundwater levels in the upper Tongue River Member for year 2030. Based on the model results, groundwater elevations generally decrease from approximately 4,700 feet amsl in the south to approximately 3,500 feet amsl in the north. In the southern part of the Wyoming PRB (south of the Converse/Campbell county line), groundwater in the upper Tongue River Member flows to the north/northeast. CBNG pumping in the western half of the Wyoming PRB would result in groundwater depressions with associated groundwater elevations ranging from approximately 3,375 feet

amsl west of Buffalo to 4,000 feet amsl southwest of Wright. To the east, south, and west of the groundwater depression near Buffalo, groundwater flows to the northwest, north, and northeast, respectively. North of the Johnson/Sheridan county line, groundwater elevations and flow patterns are reflective of CBNG pumping. To the west of the Subregion 3 coal mines, the combined effects of coal mine and CBNG pumping are reflected in the groundwater elevations and flow patterns. In the vicinity of the eastern Wyoming PRB coal mines and in the northwestern and northeastern parts of the Wyoming PRB, the groundwater flow patterns reflect the influence of precipitation-related recharge and base flow discharge to streams (primarily Little Powder River, Belle Fourche River, and Antelope Creek) in the upper Tongue River Member outcrop areas.

3.3.2.2 Upper Tongue River Member 1990 to 2030 Cumulative Groundwater Impacts

The 1990 to 2030 model results for the upper Tongue River Member are shown in **Figures B-30** through **B-32.** Drawdown in the coal mine areas in the eastern Wyoming PRB and to the west of Subregions 2 and 3 reflects the combined effect of coal mine dewatering and CBNG pumping. As shown in **Figure B-32**, drawdown of up to approximately 150 feet would occur in the Subregion 3 coal mine area, with a drawdown cone of 300 feet adjacent to the west of the northern mines in this subregion. This drawdown cone would extend to the west with the 200 foot contour extending approximately 5 miles to the north and up to 15 miles to the west of the coal mines in Subregion 3. A more isolated drawdown cone of up to approximately 225 feet is evident adjacent to the west of the southern mines in this subregion. Drawdown in the Subregion 2 coal mines would range up to approximately 125 feet. In Subregion 1, the drawdown cone at the northern group of mines would reach approximately 150 feet. CBNG-related drawdown would extend over most of the remainder of the Wyoming PRB. CBNG-related drawdown would result in a drawdown cone of approximately 550 feet southwest of Wright and a drawdown cone of approximately 700 feet to the east of Buffalo. Numerous other smaller drawdown cones are evident in the western half of the Wyoming PRB.

3.3.2.3 Upper Tongue River Member 2008 to 2030 Cumulative Groundwater Impacts

The 2008 to 2030 model results for the upper Tongue River Member are shown in **Figures B-33** through **B-35.** Groundwater drawdown and rebound at the coal mine subregions reflect the combined effects of coal mine dewatering and reduced and/or cessation of CBNG pumping in the eastern half of the Wyoming PRB. As shown in **Figure B-35**, drawdown to the west of the Subregion 3 coal mines would be approximately 175 feet, with the100-foot contour of this drawdown cone extending to Wright. Isolated areas of groundwater rebound in the southern mines of Subregion 3 would be approximately 125 feet. Both groundwater drawdown and rebound at the Subregion 2 coal mines would be isolated and less than 50 feet. Isolated areas of groundwater drawdown and rebound at the Subregion 1 mines would range up to approximately 100 feet. CBNG-related groundwater drawdown and rebound throughout the remainder of the Wyoming PRB are reflective of the projected general westward migration of CBNG development in the Wyoming PRB. Based on the model results, groundwater rebound in most of the eastern half of the Wyoming PRB and in the northwest would range up to approximately 550 and 250 feet, respectively. CBNG-related drawdown cones to the southwest of Wright and east of Buffalo would range from approximately 300 to 550 feet, respectively. Numerous other smaller drawdown cones are evident in the western half of the Wyoming PRB.

3.3.3 Lower Tongue River Member of the Upper Fort Union Formation

3.3.3.1 Lower Tongue River Member 2030 Groundwater Levels

Figure B-36 shows the modeled groundwater levels in the lower Tongue River Member for year 2030. Based on the model results, groundwater elevations generally decrease from approximately 4,525 feet amsl in the south to approximately 3,500 feet amsl in the north. In the southern part of the Wyoming PRB (south of the Subregion 3 coal mines), groundwater in the lower Tongue River Member flows to the north/northeast. In the central part of the Wyoming PRB, there is a groundwater depression in the vicinity of Crazy Woman Creek resulting from CBNG pumping, with an associated groundwater elevation of

approximately 3,400 feet amsl. Immediately to the east, south, and west of the groundwater depression, groundwater flows to the northwest, north, and northeast, respectively. North of the Johnson/Sheridan county line, flow is generally to the north. Exceptions to this flow pattern occur in the vicinity of the eastern Wyoming PRB coal mines. In these locations, the groundwater flow patterns reflect the influence of precipitation-related recharge and base flow discharge to streams (primarily Little Powder River, Belle Fourche River, and Antelope Creek) in the lower Tongue River Member outcrop areas, in addition to the combined effects of coal mine and CBNG pumping.

3.3.3.2 Lower Tongue River Member 1990 to 2030 Cumulative Groundwater Impacts

The 1990 to 2030 model results for the lower Tongue River Member are shown in **Figures B-37** through **B-39.** Drawdown in the coal mine areas in the eastern Wyoming PRB and to the west of Subregions 2 and 3 reflects the combined effect of coal mine dewatering and CBNG pumping. As shown in **Figure B-39**, drawdown of up to 150 feet would occur in the Subregion 3 coal mine area, with a drawdown cone of 350 feet to the west of the northern mines in this subregion. The 200-foot contour line of this drawdown cone would extend approximately 4 miles west of Wright. A second drawdown cone of approximately 275 feet is evident on the western side of the southern mines in Subregion 3. Isolated rebound of approximately 50 feet is evident to the east of Subregion 3. Drawdown in the Subregion 2 coal mines would range up to approximately 300 feet, with two drawdown cones of 200 and 325 feet to the west of the mine areas. Drawdown in the Subregion 1 coal mines would be approximately 75 feet, with several areas of localized drawdown reaching approximately 175 to 325 feet. CBNG-related drawdown would extend throughout most of the remainder of the Wyoming PRB. To the east of Buffalo, the CBNG-related drawdown cone would reach approximately 650 feet.

3.3.3.3 Lower Tongue River Member 2008 to 2030 Cumulative Groundwater Impacts

The 2008 to 2030 model results for the lower Tongue River Member are shown in **Figures B-40** through **B-42.** Groundwater drawdown and rebound at the coal mine subregions reflect the combined effects of coal mine dewatering and reduced and/or cessation of CBNG pumping over most of the eastern half of the Wyoming PRB. As shown in **Figure B-42**, drawdown in the Subregion 3 coal mines would be up to approximately 50 feet, with a drawdown cone of 225 feet to the west of the northern mines in this subregion. The 100-foot contour line of this drawdown cone would extend westward to Wright. A second drawdown cone of approximately 200 feet is evident on the western side of the southern mines in Subregion 3. Two drawdown cones are evident adjacent to the west side of the Subregion 2 coal mines, with associated drawdowns of approximately 100 and 200 feet. Two areas of localized groundwater rebound of up to approximately 100 feet also are evident in this subregion. Localized drawdown and rebound of up to 275 and 100 feet, respectively, are evident at the Subregion 1 coal mines. CBNG-related drawdown would extend across the western portion of the Wyoming PRB, with drawdown of approximately 500 feet to the east of Buffalo. A CBNG-related drawdown cone of approximately 75 feet also is evident to the southwest of Wright. CBNG-related groundwater rebound primarily would occur in the central portion of the Wyoming PRB from Wright to U.S. Highway 14/16 due to the reduction and/or cessation of CBNG pumping. Groundwater rebound in these areas would range up to 200 feet, with the greatest rebound in the central Wyoming PRB. This pattern is reflective of the general east to west migration of CBNG development that is projected in the Wyoming PRB.

3.4 Modeled Groundwater Recovery

Groundwater recovery for the Wasatch Formation and upper and lower Tongue River members of the upper Fort Union Formation was modeled relative to year 1975. This date reflects the time before the coal mines began substantial pumping of groundwater and before CBNG development in the Wyoming PRB. Thus, 1975 represents near steady-state for the aquifers in these formations. As discussed in Chapter 2.0, the end of CBNG-related pumping and discharge and coal mine dewatering in the Wyoming PRB for recovery modeling purposes was assumed to be years 2040 and 2050, respectively. Recharge sources for the Wasatch Formation, upper Tongue River Member, and lower Tongue River Member (model Layers 1, 2, and 3, respectively) are discussed in Section 3.1.

3.4.1 Wasatch Formation

Modeled groundwater levels and groundwater level changes for the Wasatch Formation for years 2050, 2100, 2150, and 2250 are presented in **Figures B-43** through **B-50**. Based on the model results, groundwater drawdown and mounding as a result of CBNG-related pumping and discharge would diminish by 2050 (**Figure B-44**) and no longer be evident by 2150 (**Figure B-48**). Groundwater drawdown associated with coal mine dewatering would diminish through 2250, with minor localized drawdown remaining at the southern group of coal mines in Subregion 3 (**Figure B-50**). As a result, modeling indicates that groundwater levels in 2250 (following 200 years of recovery) (**Figure B-49**) would approximate steady-state conditions.

3.4.2 Upper Tongue River Member of the Upper Fort Union Formation

Modeled groundwater levels and groundwater level changes for the upper Tongue River Member for years 2050, 2100, 2150, and 2250 are presented in **Figures B-51** through **B-58**. Based on the model results, CBNG-related groundwater drawdown in the western half of the Wyoming PRB would begin to rebound by 2050 (**Figure B-52**) and groundwater levels would recover by 2150 (**Figure B-56**). Thus, it is estimated that groundwater levels in the western half of the Wyoming PRB would reach steady-state conditions in approximately 100 years (**Figure B-55**). In the eastern half of the Wyoming PRB, groundwater drawdown resulting from the combined effects of coal mine and CBNG pumping is projected to diminish through 2250 (**Figure B-58**). As a result, it is anticipated that basin-wide groundwater levels in 2250 (following 200 years of recovery) (**Figure B-57**) would approximate steady-state conditions, with the exception of minor recovery continuing in the vicinity of the Subregion 3 coal mines.

3.4.3 Lower Tongue River Member of the Upper Fort Union Formation

Modeled groundwater levels and groundwater level changes for the lower Tongue River Member for years 2050, 2100, 2150, and 2250 are presented in **Figures B-59** through **B-66**. Based on the model results, CBNG-related groundwater drawdown in the western half of the Wyoming PRB would begin to rebound by 2050 (**Figure B-60**) and groundwater levels would recover by 2150 (**Figure B-64**). Thus, it is estimated that groundwater levels in the western half of the Wyoming PRB would reach steady-state conditions in approximately 100 years (**Figure B-63**). In the eastern half of the Wyoming PRB, groundwater drawdown resulting from the combined effects of coal mine and CBNG pumping are projected to diminish through 2250 (**Figure B-66**). As a result, it is anticipated that basin-wide groundwater levels in 2250 (following 200 years of recovery) (**Figure B-65**) would approximate steady-state conditions, with the exception of minor recovery continuing in the vicinity of the Subregion 3 coal mines.

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