4.0 CHANNEL STABILITY EVALUATION

4.1 General

The cumulative impact assessment includes an evaluation of channel stability with respect to the surface water resources within the study area. In general, the impacts to channel stability largely relate to the water quantity associated with the discharges from current or projected coal mining activities, CBNG wells or conventional oil and gas wells compared to the runoff characteristics of the receiving drainages. Of particular importance is the amount of production water or discharge that is directly conveyed to the receiving drainages. As stated in Chapter 2, based on a review of the data available in the Task 1 and Task 2 reports, it is assumed that the production water discharged directly to the receiving drainages is limited to CBNG wells.

Conducting an evaluation for channel stability in relation to potential changes in the hydrologic regime is a difficult task, especially for semiarid and arid regions. For example, runoff from the tributary watersheds is typically considered the primary factor in channel development. In consideration of the smaller watersheds within the semiarid study area, this runoff may be infrequent and only in response to precipitation events. With respect to the study area, a USGS report (Martin, Naftz, Lowham, and Rankl; 1988) concluded that "the fluvial system currently (1987) is stable. Although some gullying and headcutting is occurring, the processes appear to be related to natural rejuvenation of the basins and generally are of a local nature". Consequently, it is likely that active erosion is occurring in some of the ephemeral drainages (in the form of gullying and headcutting).

Given the limited data available to assess channel stability, quantification of the impacts becomes problematic. To the maximum extent possible, the impact to perennial drainages is addressed on a quantitative basis, at the subwatershed level, using regression equations related to discharge and channel width. To support this evaluation in consideration of the limited data, geomorphic relationships have been utilized to provide a qualitative assessment of the impacts associated with the production of CBNG discharge water. These relationships include the following:

$$Q \sim (b, d, 8)/S \qquad \text{(Schumm, 1977)}$$

where Q represents mean annual discharge
b represents channel width
d represents depth

8 represents meander wavelength, and
S represents channel gradient.

$$Q_s d_{50} \sim Q S \qquad \text{(Lane, 1955)}$$

where Q_s represents bed material load
d_{50} represents median sediment size,
Q represents mean annual discharge, and
S represents channel gradient.

These relationships provided a qualitative assessment of the response of the receiving drainages to an increase in discharge provided by the introduction of CBNG well production water.

4.2 Evaluation of Perennial Streams

Examination of United States Geological Survey (USGS) records for the Belle Fourche River below Moorcroft, Wyoming (USGS Gage 06426500) and the Little Powder River above Dry Creek, near Weston, Wyoming (USGS Gage 06324970) provided the basis of the evaluation of perennial streams. The daily discharge data for the Little Powder River indicated that zero discharge occurs less than 3% of the days of record, while the daily discharge data for the Belle Fourche River indicate that a zero discharge occurred about 23% of the days of record. Based on the CBNG discharge data presented in Appendix A, the annual streamflow in the Little Powder River and the Belle Fourche River will increase by a maximum of 2.2 cfs and 4.3 cfs, respectively and may essentially eliminate records of zero streamflow.

Figure 4.2-1 and Figure 4.2-2 provide estimates of peak annual discharge recurrence interval for the Little Powder River and Belle Fourche River, respectively. A common range for the channel forming discharge is between the 1.5-year and 2-year recurrence interval. Using this information, the Little Powder River channel forming discharge is estimated to be in the range of 270 to 420 cfs, and the Belle Fourche River channel forming discharge is estimated to be in the range of 652 to 789 cfs.

Figure 4.2-3 and Figure 4.2-4 present a hydraulic geometry relationship for channel width as a function of discharge for the Little Powder River and Belle Fourche River, respectively. The hydraulic geometry relationships were developed from all data classified as good (G) by the USGS during the data collection efforts. For each field measurement, the USGS crew will report a poor, fair, or good rating of the measurement conditions, which may vary depending on ice or

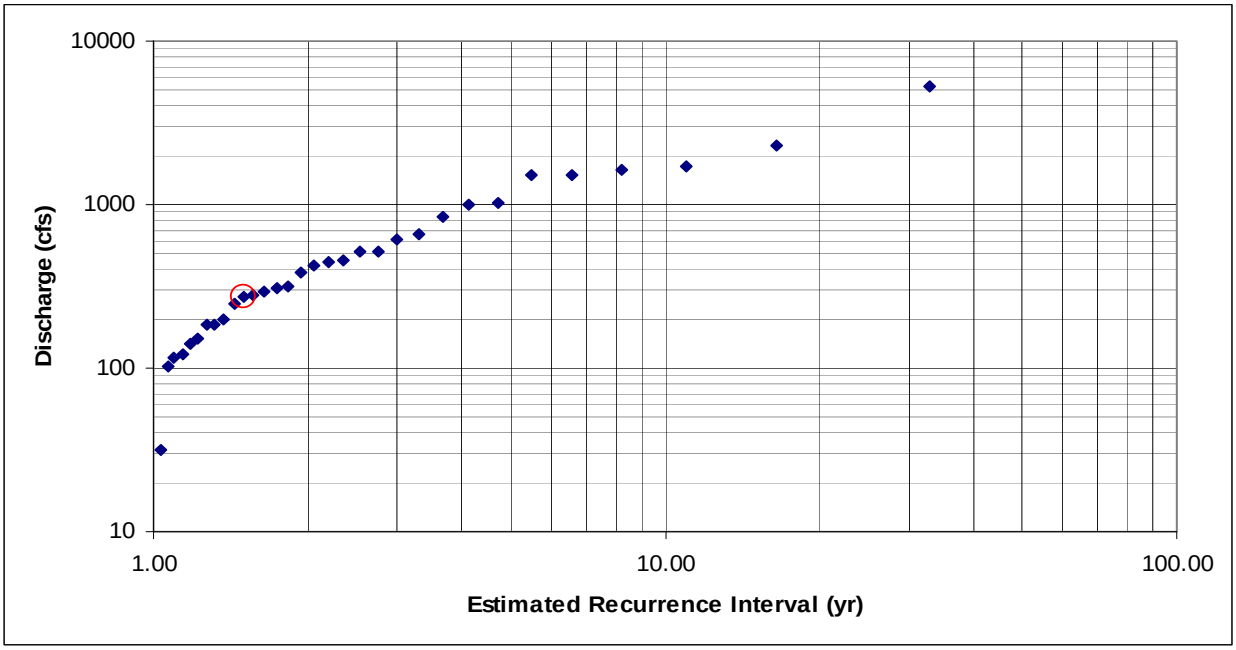

Figure 4.2-1 Estimated Recurrence Intervals for Observed Annual Peak Discharge for the Little Powder River.

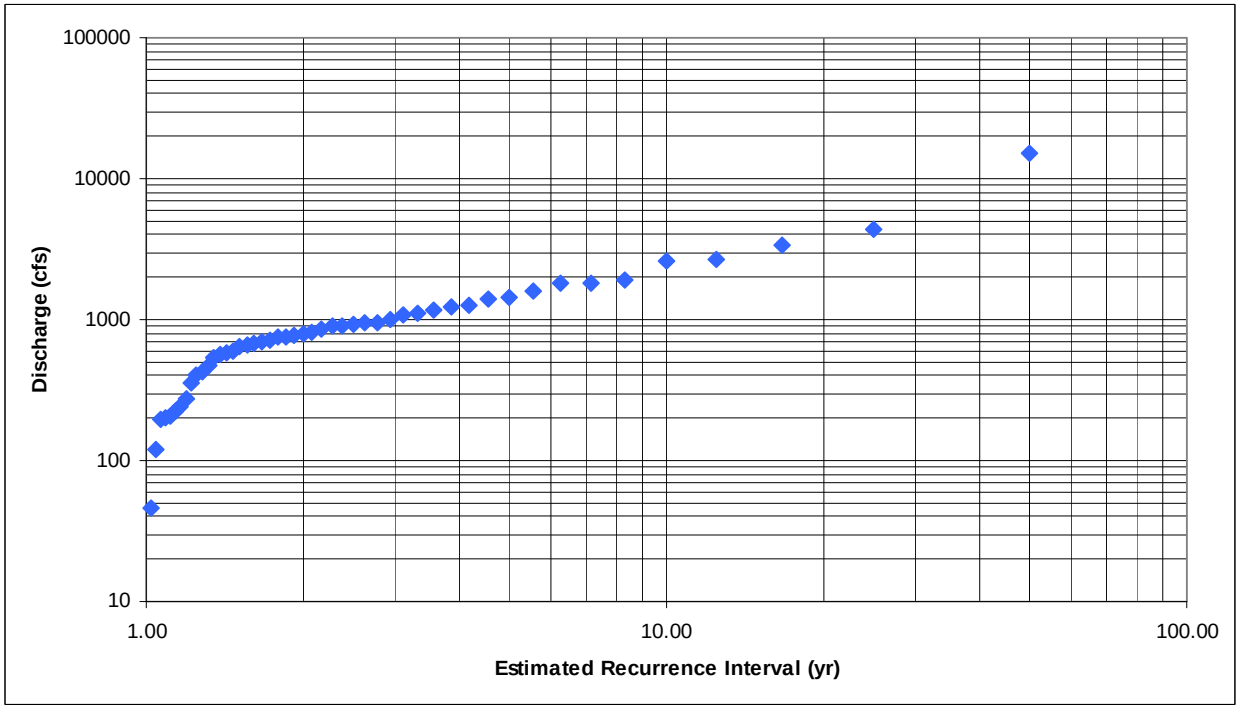

Figure 4.2-2 Estimated Recurrence Intervals for Observed Annual Peak Discharge for the Belle Fourche River.

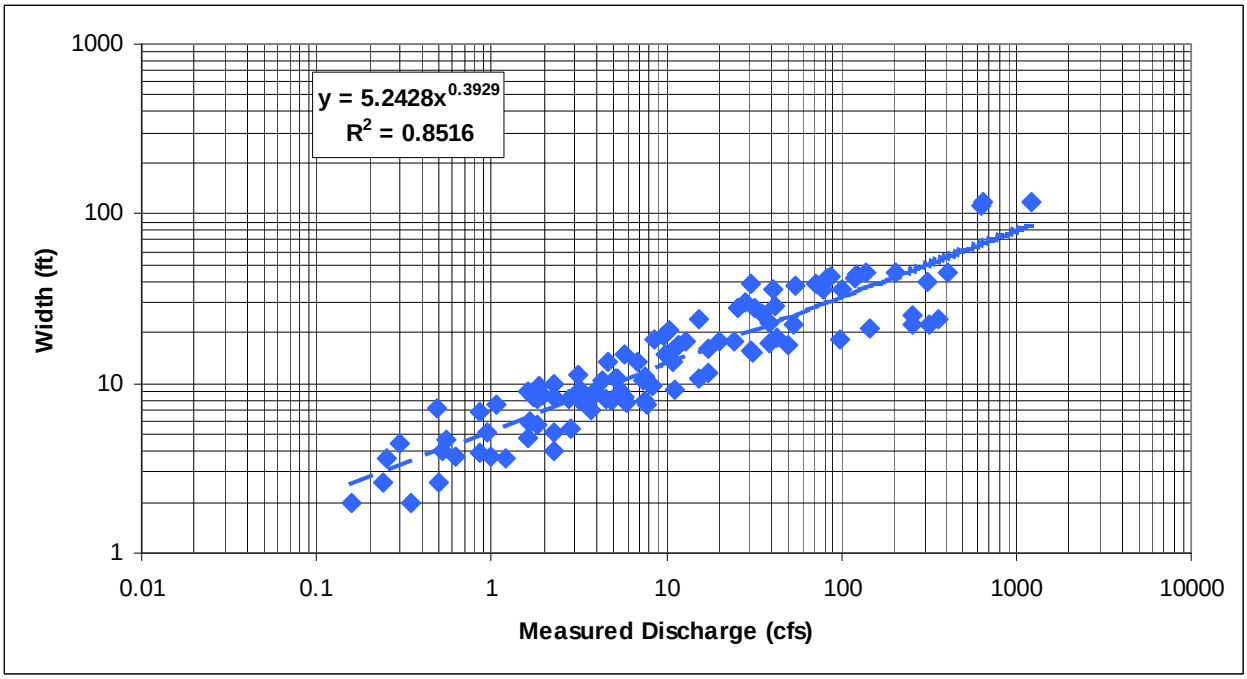

Figure 4.2-3 The Relationship Between Measured Discharge and Channel Width for the Little Powder River.

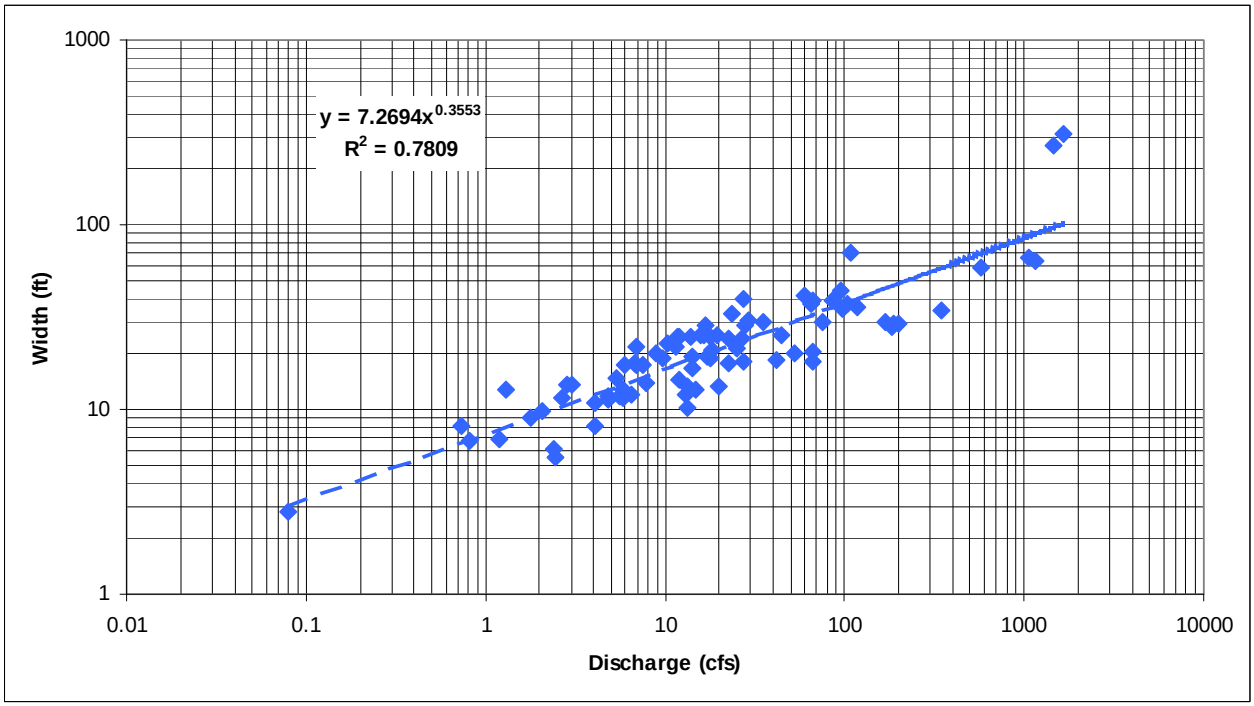

Figure 4.2-4 The Relationship Between Measured Discharge and Channel Width for the Belle Fourche River.

debris accumulation, rapidly changing water levels, or numerous other factors that are beyond control of the field crew. Using the relationships developed, channel width in the range of the channel forming discharge was computed for the existing condition and for the maximum CBNG well production condition by adding the predicted CBNG discharge to the existing condition discharge **(Table 4.2-1)**. The estimated change in width for the Little Powder River was computed to be less than 0.3%, and was less than 0.2% for the Belle Fourche River. These results suggest that for the larger, perennial streams the effect of the CBNG well production water will be minimal.

Table 4.2-1 Impact of CBNG Production Water on Perennial Streams

Location	Channel Forming Discharge [1] (cfs)	CBNG Discharge		Estimated Width		Potential Impact [Increased Width]	
		(cfs)	(%)	Existing Conditions (ft)	Combined Discharge (ft)	(ft)	(%)
Little Powder River above Dry Creek near Weston, Wyoming (USGS Gage 06324970)	270 to 420	2.2	0.5% to 0.8%	47.3 to 56.3	47.4 to 56.4	0.15 to 0.12	0.3%
Belle Fourche River below Moorcroft, Wyoming (USGS Gage 06426500)	652 to 789	3.9	0.5% to 0.6%	66.9 to 72.1	67.0 to 72.2	0.16 to 0.14	0.2%

[1] Discharge associated with the 1.5 to 2 year recurrence interval.

From a qualitative standpoint, the geomorphic relationships also provide insight into the potential impacts of the CBNG production water on the mean annual discharge events. Increasing the discharge in Schumm's relationship (Schumm, 1977) results in the following:

$$Q^{+} \sim (b^{+}, d^{+}, 8^{+})/S^{-}$$

This means that an increase in mean annual discharge may result in potential increases in channel width, depth, and meander wavelength while a decrease in channel gradient may occur. With respect to the Lane relationship, increasing the discharge may result in:

$$Q_s^{+} d_{50}^{+} \sim Q^{+} S^{-}$$

The interpretation of this information reveals that an increase in mean annual discharge may reduce channel gradient or result in an increase in bed material transport or median particle size of the bed material. Given the relatively low increase in mean annual discharge, these trends predicted by the geomorphic relationships are considered to be imperceptible.

4.3 Evaluation of Ephemeral Streams

Limited data on streamflows is available for the smaller, ephemeral drainage channels within the study area that may receive discharges from the CBNG wells. Furthermore, the data related to the predicted CBNG well production water is provided on a subwatershed basis. However, it is reasonable to assume that the CBNG well production water will represent a much higher percentage of the mean annual discharges in some of the ephemeral drainages within the study area. Consequently, the impacts to channel stability will be more readily apparent and may be manifested by an increase in channel erosion, headcutting, and incision.

As stated previously, some of the ephemeral channels through which the CBNG production water will be conveyed are actively eroding. Numerous geomorphologic studies have used data developed from different locations to infer landform development through time, commonly employing a technique termed location-for-time substitution. This technique assumes that by observing channel form as one moves downstream along a channel, the effect of physical processes at one location through time can be predicted; that is, changing location is substituted for changing time. This technique was used to develop a Channel Evolution Model (CEM) for Oaklimeter Creek, an incised stream in northern Mississippi (Schumm *et al.* 1981, 1984). Simon and Hupp (1987) later developed a similar model of channel evolution based on Schumm *et al.* (1981, 1984).

The CEM consists of five channel-reach types **(Figure 4.3-1)**, which describe the evolutionary phases typically encountered in an incised channel. These evolutionary phases range from strong disequilibrium to a new state of quasi-equilibrium. Quasi-equilibrium implies that the system is not static and changes through time, but over a period of years the average condition is one of stability. The model is based on the assumption that moving downstream through the system is equivalent to remaining in place and monitoring changes due to the passage of time. The response at any given location in the channel can then be estimated from the morphology of downstream channel locations.

The channel reach types in the CEM are labeled Types I through V, and are assumed to occur consecutively in the downstream direction. The CEM assumes each channel type will occur in turn at a given location as the channel evolves. Type I reaches are located upstream of the actively degrading reach and have not yet experienced significant bed or bank instabilities. These reaches are generally characterized by U-shaped cross sections with little or no recently deposited sediment stored in the channel bed.

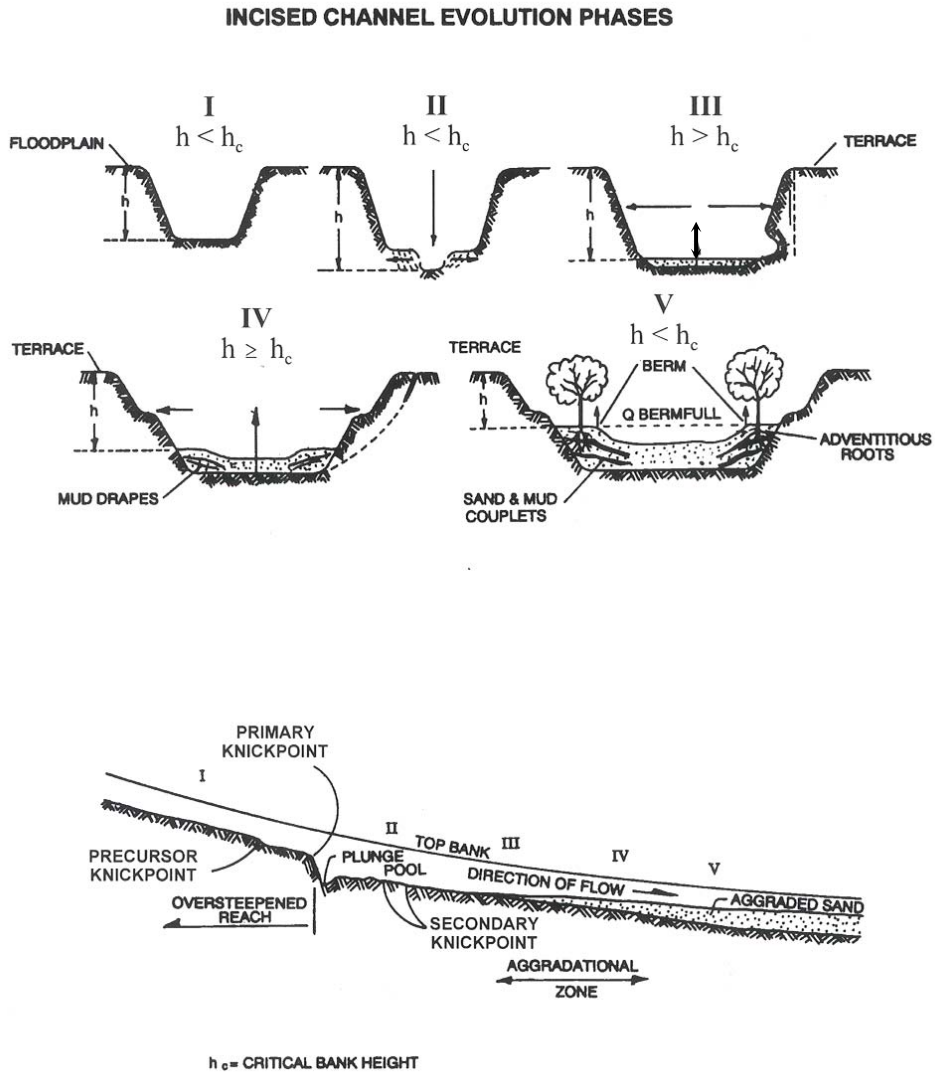

Figure 4.3-1 CEM Channel Types

Type II reaches are encountered immediately downstream of Type I reaches. Bed degradation is the dominant process in the Type II reach. Type II channels are over-steepened reaches where the sediment transport capacity exceeds the sediment supply. Although the channel is actively degrading in a Type II reach, the bank heights (h) do not exceed the critical bank height (h_c) and, therefore, reach-scale geotechnical bank instability is not encountered.

As bed degradation continues, the bank heights and angles continue to increase. When the bank heights exceed the critical bank height for stability in Type III reaches, mass failures

(geotechnical instability) begin. The dominant process in the Type III reach is channel widening. In places, the Type III reach may continue to be slightly degradational. However, the reduced sediment transport capacity resulting from the longitudinal channel slope decreasing combined with increased sediment supply from upstream due to instability and from bank failures within the reach often results in the initiation of sediment deposition on the channel

Type IV reaches are downstream of Type III reaches and represent the first manifestation of the incising channel returning to a new state of dynamic equilibrium. In the Type IV reach, geotechnical bank instabilities and channel widening may continue, but at a much reduced rate. The sediment supply from upstream (Type III) exceeds the sediment transport capacity, resulting in aggradation of the Type IV channel bed. The Type IV reach is also characterized by the development of berms, which are depositional features along margins of the over-widened channel. These berms represent the beginning of a new inner channel with dimensions adjusted to the flow and sediment regime.

Type V reaches represent a state of dynamic equilibrium with a balance between sediment transport capacity and sediment supply. Bank heights in the Type V channel are generally less than the critical bank height and, therefore, reach-scale geotechnical bank instability ceases. However, local bank failures can still exist as part of the meander process, or as the results of constrictions, obstructions, or other local factors. The berms, which were initiated in the Type IV reach have now become colonized by riparian vegetation forming a compound channel within the larger, incised channel. The equilibrium channel of Type V is of a compound shape, with a smaller inner channel bounded by a narrow floodplain. The original floodplain of the Type I channel is now a terrace.

The CEM addresses the channel stability status within a system context. Dynamic equilibrium in a Type V reach simply implies that system stability has been attained. A Type V reach may exhibit considerable erosion that is part of the natural meander process or some other local process, yet still be classified as being in dynamic equilibrium.

The primary value of the CEM sequence is to underpin identification of the evolutionary state of the channel from field reconnaissance. The morphometric characteristics of the channel reach types can also be correlated with hydraulic, geotechnical, and sediment transport parameters (Harvey and Watson 1986; Watson *et al.* 1988). The evolution sequence provides an understanding that while reaches of a stream may differ markedly in appearance, the channel form in one reach is associated with that in adjacent and remote reaches by an evolutionary process.

Fundamentally, the cause for incision (gully formation) is an imbalance between the sediment transport capacity and the sediment supply. For example, urbanization of the watershed increases runoff and increases sediment transport capacity. Urbanization can also decrease the sediment supply from the watershed to the stream, which can also upset the delicate balance. Downstream dredging or channelization decreases the base level and increases transport capacity. Stream sediment transport capacity can be abruptly increased through channelization, an increase in flow velocity or duration as a result of land-use change, or lowering base level. Sediment supplies may be abruptly reduced by sediment trapping in reservoirs, erosion control practices on uplands, and imperviousness. Natural causes such as uplift or subsidence, climate change, and lateral shifting of the stream can also cause the balance to be interrupted.

As stated previously, the discharge of CBNG well production water into the ephemeral drainages may initiate or exacerbate erosion within the conveyance channel. Should erosion be initiated, given the relatively minor flow compared to the typical gully section in the typical ephemeral drainage channel, it is anticipated that a small incision may occur, similar to the CEM Type II model. One must also consider that the sustained nature of the CBNB well production water may also generate and support an increase in diversity and density of the vegetation along the channel. The increase in vegetation may tend to prevent channel erosion or partially stabilize existing erosion within the ephemeral drainage channel.

Similar to the perennial stream channels, the geomorphic relationships were utilized to provide insight into the potential impacts of the CBNG production water on the mean annual discharge events associated with the ephemeral drainages. Increasing the discharge in Schumm's relationship (Schumm, 1977) results in the following:

$$Q^{+} \sim (b^{+}, d^{+}, 8^{+})/S^{-}$$

Given that the relative magnitude of the increase in mean annual discharge is more significant in the ephemeral drainage channel, it is likely that potential increases in channel width and depth will occur along with local reductions in channel slope. With respect to the Lane relationship (Lane 1955), increasing the discharge may result in the following:

$$Q_s^{+} d_{50}^{+} \sim Q^{+} S^{-}$$

Again, an increase in mean annual discharge may reduce channel gradient or result in an increase in bed material transport or median particle size of the bed material. Given the potentially significant increase in mean annual discharge, these trends predicted by the geomorphic

relationships are more likely to occur, especially considering that the increases attributable to the CBNG production water are sustained discharges.

Due to the potential for erosion in the ephemeral drainages, it may be prudent to establish a monitoring and management plan on selected drainages prior to the discharge of CBNG production water. Where an ephemeral drainage may be impacted, erosion monitoring pins can be installed into the bed and banks of the drainage channel at appropriate locations. The pins are typically driven 3 to 4 feet into the soil leaving about an inch exposed, and subsequent measurements are made of the length of exposed pin. Each erosion pin is located via a GPS; however no survey equipment is typically required. Seasonal measurements will yield a data set that quantifies estimated erosion at each point. Where erosion is evident from the visual inspection and evaluation of the data, methods to mitigate the erosion should be considered. Mitigation measures may include placement of small grade control structures at locations of active erosion and headcutting.

Ephemeral drainage channels that are presently experiencing active headcutting and erosion should be identified. Monitoring of the erosion should be conducted as specified above. Where erosion of the channel is considered significant, mitigation measures should be implemented and the channel stabilized. Mitigation measures identified in the Draft EIS for the Seminoe Road Natural Gas Development Project (BLM, 2005) may be worthy of consideration and include grade control structures, check dams, impact basins, channel reconstruction, and other possible engineered erosion control measures.

4.4 Evaluation of Caballo Creek near Belle Ayr Coal Mine

Following the assessment of the impact associated with CBNG well discharge on channel stability as discussed in the previous sections, the BLM and WDEQ requested an additional investigation be conducted with pertinent hydrologic data from an active coal mine in the Powder River Basin. Consequently, data available for Caballo Creek in the vicinity of the Belle Ayr Coal Mine was obtained, reviewed and utilized to complete the assessment of channel stability. The purpose of the channel stability assessment was to evaluate the impact of increased flows (associated with CBNG well discharge) in Caballo Creek on the existing and reclaimed channels as well as the diversion channels and structures constructed in accordance with the mine permit application.

4.4.1 Pertinent Information and Statistics

The Belle Ayr Coal Mine is located about 12 miles south of Gillette, Wyoming along State Highway 59. A USGS water quality sampling site (USGS 06425800-Caballo Creek near Gillette, Wyoming) is located near the crossing of Caballo Creek and the highway. Pertinent statistics associated with the sampling site include the drainage area of 122 square miles (estimated near the *western* mine permit boundary) and a gage datum that is 4520 feet above sea level NGVD29. At or very near the USGS sampling site is the first of two Caballo Creek stream gages associated with the Belle Ayr Coal Mine. The first stream gage, BA-6, is located near the upstream extent of the mine permit boundary. A second gage, BA-4, is located at the downstream extent of the mine permit boundary. North of Caballo Creek near the western boundary of the mine permit is Bone Pile Creek and Duck Nest Creek. Both of these streams are tributary to Caballo Creek. **Figure 4.4-1** presents a location map illustrating the mine permit boundary along with the existing streams and stream gages.

Information for this investigation was obtained from several documents pertinent to the Belle Ayr Coal Mine. Watershed data were obtained from relevant mine permit documents and specifically included a document entitled "***Reclamation Plan for Portions of Caballo Creek, Belle Ayr Mine, Campbell County, Wyoming"*** (Western Water Consultants, Inc. 1997). The watershed vertical relief is 740 feet from the headwaters to the confluence with the Belle Fouche River, with a mainstream channel length of 51 miles. The basin slope is 0.0056 and the average stream gradient is 0.0027, yielding a sinuosity of about 1.8. The 2-year recurrence interval storm was estimated to range from 400 to 441 cfs for the 200-square mile drainage area (estimated at the *eastern* mine permit boundary). An estimate of flow volume per year at the western mine boundary used by the mine is reported to be 1,300 ac-ft per year. The permit documents classified Caballo Creek as an intermittent stream.

4.4.2 Hydrologic Data

Figure 4.4-2 provides summary information related to gage data at BA-4 and BA-6 for the time period extending from 1984 to 2004. The data portrayed in the graph indicates that discharges in both gages began increasing in about 1992. Conversations with representatives of the Belle Ayr Mine, along with data provided in the Belle Ayr Mine annual reports, indicate that the increases in flow noted at that time were consistent with the production of CBNG well discharge water from wells located within the Caballo Creek, Bone Pile Creek and Duck Nest Creek watersheds. The location of the WYPDES discharge points associated with the CBNG wells and a listing of wells within Belle Ayr Mine permit area were documented in the annual reports.

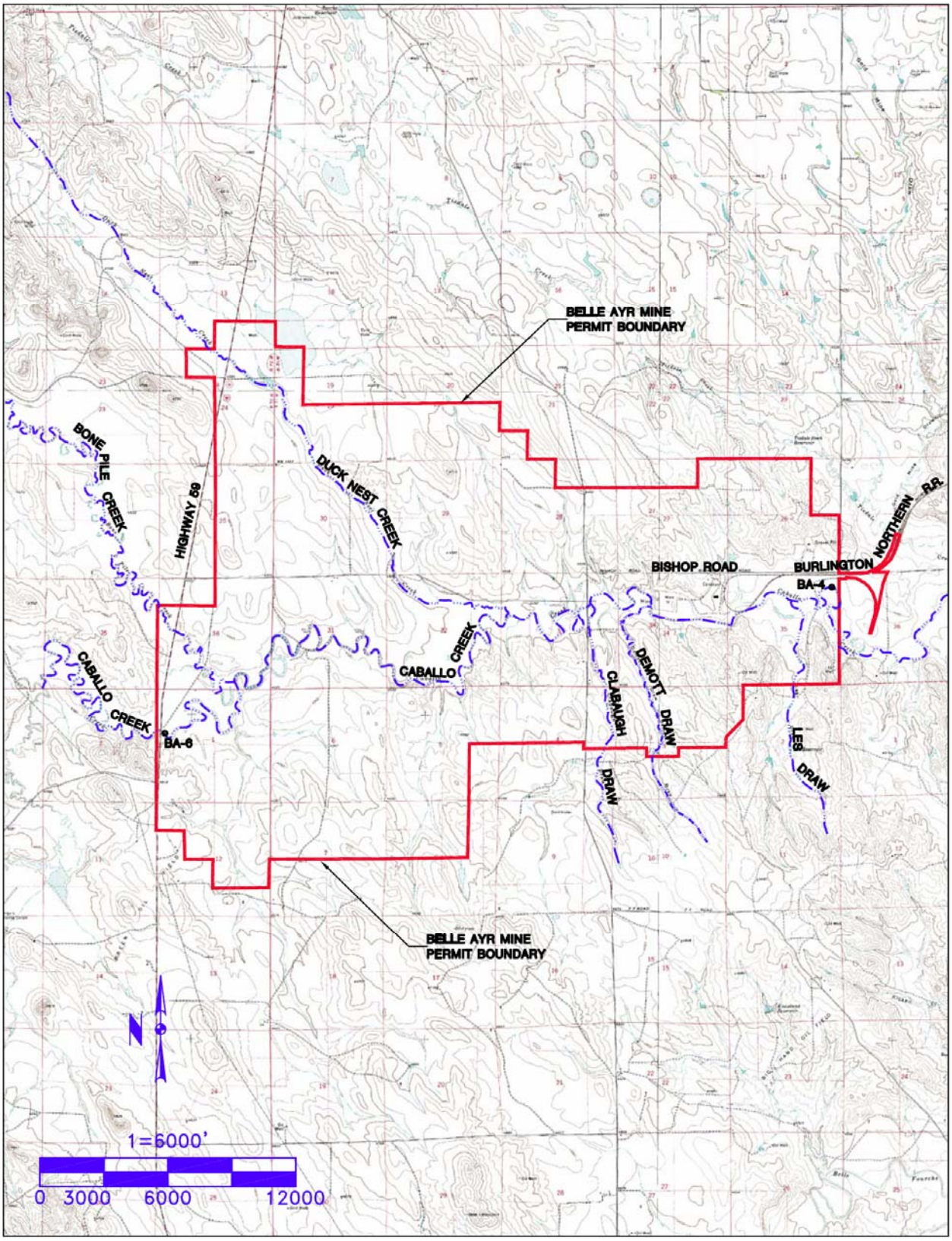

Figure 4.4-1 Vicinity Map

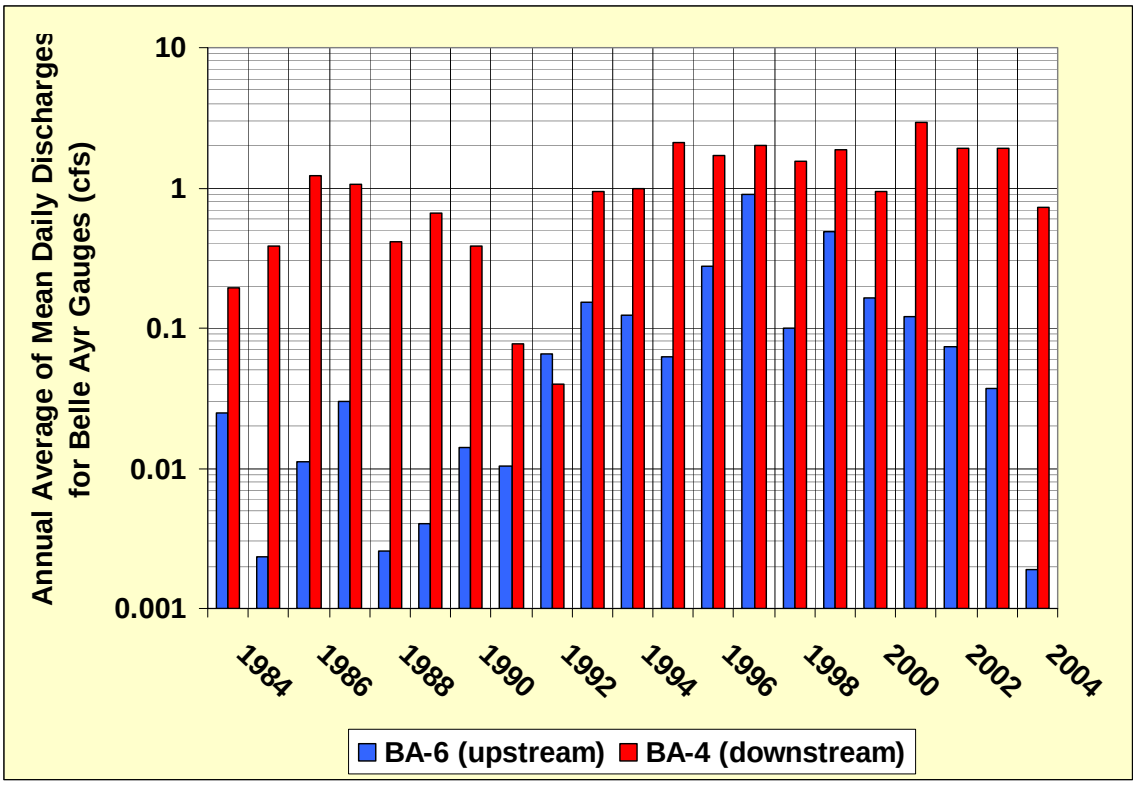

Figure 4.4-2 Hydrologic Data for Caballo Creek (1984-2004)

The information below is derived from a review of the data in **Figure 4.4-2.**

- Both gages may have received CBNG well discharge water for about 10 years.
- The average annual discharge for the BA-4 gage (downstream gage) increased from 0.5 cfs (from 1984 to 1992) to 1.6 cfs (from 1993 to 2004). This represents an increase of 1.1 cfs that is potentially attributable to the contribution of CBNG well discharge water.
- The average annual discharge for the BA-6 gage (upstream gage) increased from 0.02 cfs (from 1984 to 1992) to 0.21 cfs (from 1993 to 2004). This represents an increase of 0.19 cfs that is potentially attributable to the contribution of CBNG well discharge water.

It should be noted that the BA-6 gage is located upstream of the CBNG wells within the Bone Pile Creek and Duck Nest Creek watersheds, thereby reducing the contribution of CBNG well discharge water to this location compared to BA-4. Furthermore, the annual reports provided by the Belle Ayr Mine indicated that the majority of the CBNG well discharge water is contributed from the Bone Pile Creek and Duck Nest Creek watersheds. Consequently, the impact of the CBNG well discharge water will be more evident on the flow data reflected for the BA-4 gage.

The existence of Caballo Reservoir was investigated with respect to its impact on the flow records of Caballo Creek. Caballo Reservoir represented a premining impoundment formed by an earthen dam in the channel of Caballo Creek. Caballo Reservoir was located downstream of the confluence of Bone Pile Creek and Caballo Creek, thereby impacting the flows at the BA-4 gage. Following a period of flooding in 1978, the dam embankment for Caballo Reservoir was breached. Given the period of record chosen for this analysis (1984 to 2004), the existence of Caballo Reservoir did not impact the results illustrated in **Figure 4.4-2**.

During the field reconnaissance visit to the Belle Ayr Mine, areas of ponded water were apparent but no surface flow was evident in either Caballo Creek or Bone Pile Creek west of Highway 59. Reportedly, discharge collected from CBNG wells within the Duck Nest Creek watershed has been historically diverted into Bone Pile Creek. Evidence of historic diversions from Duck Nest Creek into Bone Pile Creek east of Highway 59 was observed during the field reconnaissance visit (see **Figure 4.4-7** and **Figure 4.4-8**). Minimal flow was observed at one of these locations. Since these historic diversions from Duck Nest Creek impact the flow in Bone Pile Creek (located downstream of the BA-6 gage), no impact on the records at the BA-6 gage on Caballo Creek are realized.

The data along with the field observations may reflect the limited precipitation and drought conditions that have existed since the turn of the century. An analysis of precipitation data was conducted to evaluate the impact of potential drought conditions on the hydrologic period of record chosen for this work effort. Data available for a precipitation gage near Gillette, Wyoming was utilized for the evaluation. The results of this work are illustrated in **Figure 4.4-3**. The precipitation data reflects the same general trend as the gage data. A general increase in average annual precipitation exists from a value of 14.36 inches (for the time period from 1984 to 1992) to 18.14 inches (for the time period form 1993 to 2004). This represents an increase of 3.78 inches or 19% in average annual precipitation. Based on a comparative evaluation of the gage data at BA-4, the increase in annual precipitation tends to minimize the impact of the CBNG well discharge on the increase in streamflow observed at the gage.

A further evaluation of the impact of potential drought conditions was conducted through an evaluation of the Palmer Drought Index. The Palmer Drought Index, typically used as a measure of dryness, is based on a supply and demand model of soil moisture. The index has proven most effective in determining long-term drought. The methodology assigns 0 as normal, and drought is shown in terms of minus numbers; for example, minus 2 is a moderate drought, minus 3 is a severe drought, and minus 4 is an extreme drought. For the Belle Fourche drainage basin in Wyoming, the index values (data limited to annual values prior to 2001) are presented in **Figure 4.4-4**. An evaluation of the data in **Figure 4.4-4** results in the following observations:

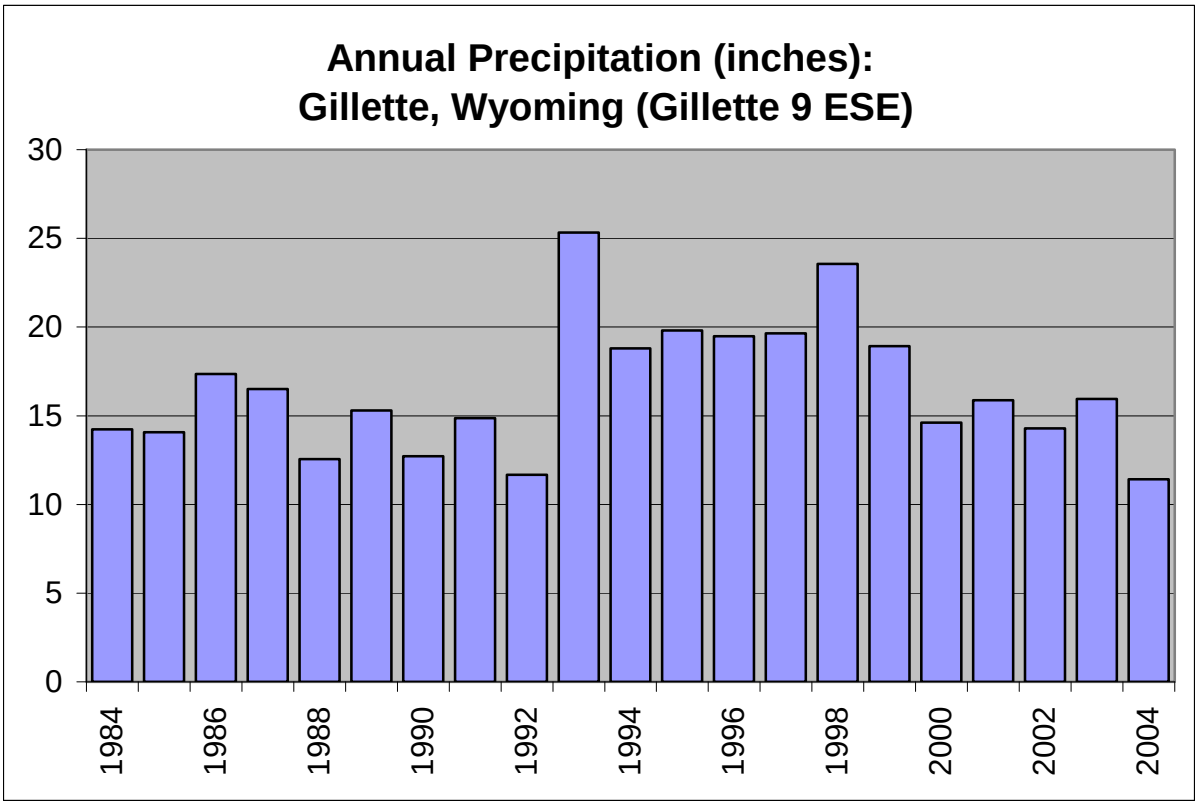

Figure 4.4-3 Average Annual Precipitation Data (1984-2004)

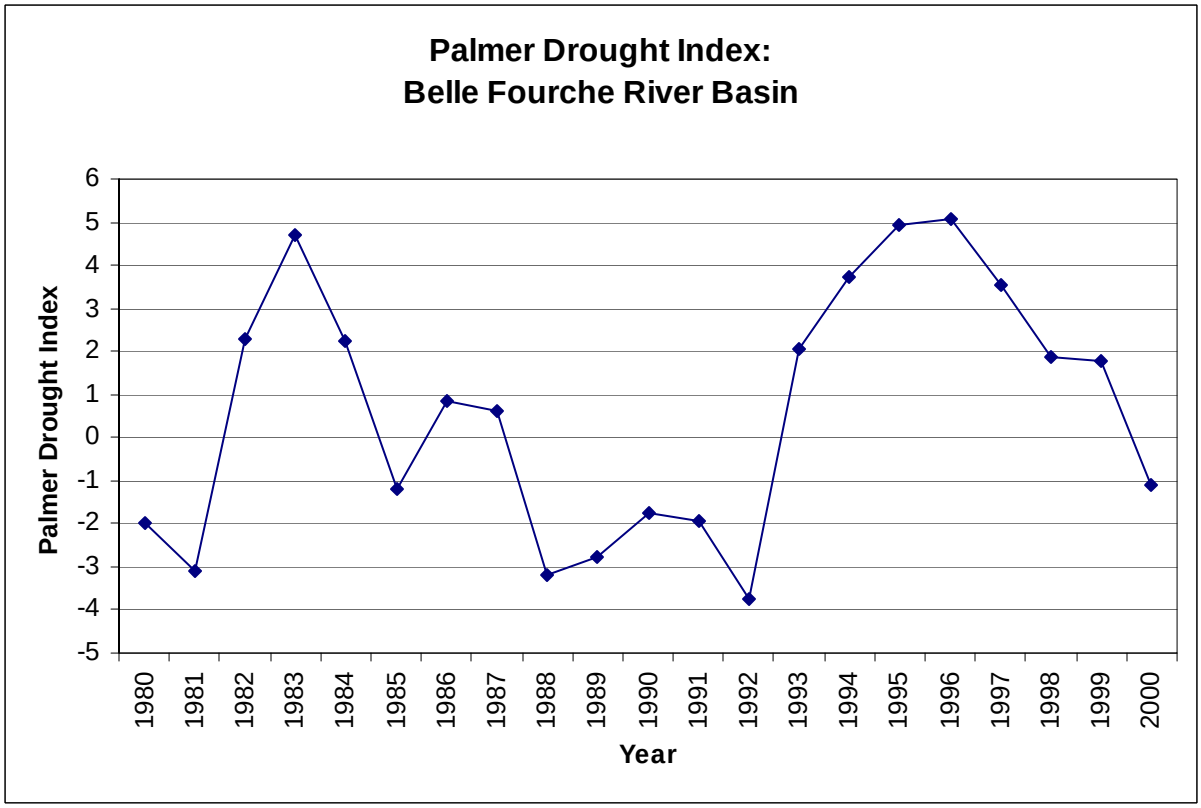

Figure 4.4-4 Palmer Drought Index Data (1980-2000)

- Drought conditions were present during the time period from 1984 to 1992 with noticeable improvement or absence of drought conditions beginning in 1993. Minor drought conditions are evident in 2000, the last year of the available data.

- As expected, there is a correlation between the index values and precipitation data. The increase in annual precipitation beginning in 1993 was manifested in an increase in the Palmer Drought Index and an absence of drought conditions from 1993 to 1999.

- The increase in the Palmer Drought index beginning in 1993 would support a corresponding increase in streamflow within the Belle Fourche drainage basin.

- With the addition of CBNG well discharge into Caballo Creek in 1992, the data for the Palmer Drought Index would tend to minimize the impact of the CBNG well discharge on the increase in streamflow observed at the BA-4 gage.

4.4.3 Channel Stability

The concept of the dominant discharge or channel-forming discharge implies that the natural channel morphology (width, depth, slope and planform) adjusts to a discharge that is largely responsible for that geometry. As previously stated in Section 4.2, the dominant discharge is generally considered to be in the range of the 1.5-year to 2-year recurrence interval. The 2-year peak discharge for Caballo Creek at the eastern mine boundary was estimated to be about 400 cfs. The estimated contribution of CBNG well discharge water of 1.1 cfs represents less than 1% of the 2-year peak discharge. Therefore, it is unlikely that the modest increase in surface flows attributable to CBNG well discharge water would have a systematic effect on the channel morphology associated with the channel-forming discharge. Furthermore, given the relatively flat nature of the channel gradient coupled with the high sinuosity of the channel, a sustained discharge of this magnitude will likely promote an increase in diversity and density of the vegetation along the channel.

These results were confirmed by observations of the existing channels during the field reconnaissance visit. **Figures 4.4-5 to 4.4-12** are provided to document the increase in vegetation and lack of active erosion within the channels.

Figure 4.4-5 This view is looking downstream on Caballo Creek at the BA-6 v-notch weir gauging site.

Figure 4.4-6 This view is looking upstream on Caballo Creek at the BA-4 v-notch weir gauging site. No discernible flow was observed.

Figure 4.4-7 The view is looking upstream on Bone Pile Creek from a pipeline diversion associated with CBNG well production water from the Duck Nest Creek watershed.

Figure 4.4-8 This view illustrates Bone Pile Creek downstream of the location where CBNG well production water is introduced. Vegetation is very dense and no active erosion was noted.

Figure 4.4-9 This view presents a highly sinuous, deeper reach of Caballo Creek along the western permit boundary. Banks are well vegetated and no active erosion was noted.

Figure 4.4-10 This is a view of the confluence of Caballo Creek and Bone Pile Creek.

Figure 4.4-11 The view illustrates the diversion channel immediately downstream of the confluence of Caballo Creek and Bone Pile Creek.

Figure 4.4-12 The view displays Caballo Creek and Bone Pile Creek upstream of highway 59. Banks are stable with significant aquatic vegetation in the stream. No significant flow was observed in either channel.

Qualitatively, these results can also be confirmed by geomorphic relationships. As presented in Section 4.3, increasing the discharge in Schumm's relationship (Schumm, 1977) results in the following:

$$Q^{+} \sim (b^{+}, d^{+}, 8^{+})/S^{-}$$

Assuming the relative magnitude of the increase in mean annual discharge is more significant in the ephemeral drainage channel, it is likely that potential increases in channel width and depth will occur along with local reductions in channel slope. However, it should be noted that contribution of flow from the CBNG well discharges into Caballo Creek (characterized as an intermittent stream) is relatively small in comparison to the channel forming discharge. Furthermore, the existing slope and sinuosity (reported to be 0.0012 ft/ft and 1.81, respectively) of Caballo Creek would require a significant increase in discharge to manifest a noticeable decrease in slope or an increase in sinuosity. Consequently, it is unlikely that the minor contribution from CBNG well discharge to the flow in Caballo Creek will result in any active erosion to the channel.

4.4.4 Summary and Conclusions

Based on the channel stability assessment of Caballo Creek, the following information is provided:

- CBNG well production water has been historically and is presently discharged into Bone Pile Creek, Duck Nest Creek, and Caballo Creek. Based on the hydrologic data, the average annual discharge was estimated to increase from 0.5 cfs to 1.6 cfs (increase of 1.1 cfs) within Caballo Creek at the BA-4 gage. The estimated contribution of CBNG well production water of 1.1 cfs represents less than 1% of the 2-year peak discharge.

- The increase in the data related to average annual precipitation values and the Palmer Drought index beginning in 1993 support a corresponding increase in streamflow within the Belle Fourche drainage basin. With the addition of CBNG well discharge into Caballo Creek in 1992, the data related to average annual precipitation and the Palmer Drought Index would tend to minimize the impact of the CBNG well discharge on the increase in streamflow observed at the BA-4 gage.

- No active erosion was evident within the natural channels associated with Caballo Creek, Bone Pile Creek or Duck Nest Creek. Furthermore, no active erosion was evident within the diversion channels or adjacent to the structures within the diversion channels.

- Field observations noted an increase in vegetation diversity and density within all drainage channels receiving CBNG well production water.

- Given the relative magnitude of the flow contribution from CBNG well production water, geomorphic relationships confirmed the conclusion that the minor contribution from CBNG well production to the flow in Caballo Creek will not likely result in any active erosion to the channel.

Based on the information provided on channel stability, a threshold may exist where the contribution of CBNG well production water may create erosion within the receiving drainage channel. Given the channel slope, sinuosity and watershed area, drainages such as Caballo Creek may not realize an increase in channel erosion and will more likely realize an increase in vegetation along the channel. Smaller drainages, such as Bone Pile Creek (drainage area of 44.4 square miles, slope of 0.0017 ft/ft, sinuosity of 2.14) or Duck Nest Creek (drainage area of 6.63 square miles, slope of 0.002 ft/ft, and sinuosity of 1.92) may be more likely to exhibit channel erosion depending on the magnitude of the flow contribution from CBNG well production compared to the channel forming discharge. However, field observations in these watersheds found similar increases in vegetation along the channels.

To have an impact on channel stability that is manifested in active channel erosion, CBNG well production water will likely have to represent a significant portion of the channel forming discharge in watersheds where the channel slope is steep enough and width/depth/sinuosity low enough to impact channel morphology. Given the magnitude of the discharges, the impact will more likely be evident in small ephemeral drainages that are characterized by steep channel gradients, lower sinuosity, and smaller widths and depths. Otherwise, as drainage area/basins increase, the channel slope typically decreases along with an increase in sinuosity thereby reducing the impact of CBNG well production water on channel stability.