ATTACHMENT 16-2

GROUNDWATER AND SURFACE WATER RESTORATION DESIGNS FOR LEE COULEE
ATTACHMENT 16-2

GROUND WATER AND SURFACE WATER RESTORATION DESIGNS FOR LEE COULEE

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GROUND WATER AND SURFACE WATER RESTORATION DESIGNS FOR LEE COULEE

17.24.314(1)

Introduction

This Attachment has been prepared pursuant to the plans and objectives set forth in Tab 16 to design reclamation plans that will ensure re-establishment of hydrologic functions and related biologic communities and land uses on postmining Lee Coulee in Area B. Lee Coulee has been the subject of special hydrologic and biologic studies since a Stream Study Buffer Zone was established around the "wet reach" of the stream during the permitting of Area B. The results of these studies, together with the restoration performance standards that were developed through analysis of the study data, are presented in Tab 7 (Vol. 4). By reference to topographic cross sections surveyed on the native drainage bottoms, the postmining drainage designs presented in this document emphasize re-establishment and replication of the geomorphic variability of the native channel, floodplain and low terrace dimensions. The guideline entitled "Reclamation of Drainage Basins and Channels Disturbed by Surface Coal Mining" prepared by the Industrial and Energy Bureau of the Montana Department of Environmental Quality (Nov. 2001) was employed in preparing the designs presented under this cover.

In year 2002, Big Sky Mine revised its coal recovery projections to include mining further upstream on Lee Coulee and Gamble's Well Tributary within the previously defined Affected Area Boundary. The additional Mining Disturbance Boundary is factored into the reclamation plans presented for Lee Coulee in this Attachment. In keeping with the relatively recent guideline on stream channel and drainage basin reclamation criteria referenced above, reconstruction designs for Gamble's Well Tributary have been prepared following the same approach employed with Lee Coulee of replicating premining channel and overbank
dimensions. The new reclamation designs for Gamble’s Well are presented in Tab 20.

Backfilling and Grading.

The Stream Study Buffer Zone on Lee Coulee encompasses some 156 acres of the stream and valley floor. Premining baseline studies identified approximately 53.1 acres of subirrigated land within the Buffer Zone on Lee Coulee and about 8.9 acres of subirrigated land on the mouth of Marmot Mound tributary adjacent to the buffer zone. Premining subirrigation within Area B was associated with high water table conditions supplied by ground water discharges from overburden units. Ground water flow in the overburden is from north and northwest of Area B, with a likely recharge source being East Fork Armells Creek lying immediately north of the Lee Coulee drainage. The high water table conditions of the Buffer Zone also maintained open water potholes and marshy channel conditions in Lee Coulee that were determined important to the biologic diversity of the buffer zone. Based on field inventories conducted in 1989 alone, before mining began significantly lowering the local water table, the open water area was estimated to occupy about 1.5 acres and store about 0.4 acre-feet of water.

Mining and pit reclamation activities will remove about 82.7 acres of the buffer zone holding some 19.7 acres of premining subirrigated land on Lee Coulee. All of the 8.9 acres of subirrigated land at the mouth of Marmot Mound tributary will also be removed by mining. Some 77.8 acres of the buffer zone containing about 33.4 acres of naturally subirrigated land lies downstream of mining and pit reclamation where mining disturbances will be only surficial, being limited to the construction and reclamation of various access roads, settling ponds and related runoff control facilities. Background information on the Stream Study Buffer Zone designation and on the nature of the hydrologic and biologic studies conducted in the Stream Study Buffer Zone is provided in the main text of Tab 16 (Vol. 12), in Appendix 10-4 of Tab 10 (Vol. 8), and in Tab 7 (Vol. 4).
The designs, specifications and analyses presented in this Attachment draw upon the results of the Stream Study Buffer Zone hydrologic, biologic and other baseline studies and have as their objective the restoration of geomorphic and topographic features of the premining valley floor and utilization of postmining ground and surface waters for re-establishment of open water reaches and natural subirrigation. The subirrigated acreage and length of channel having open water that will be restored under these plans will be nearly equivalent to premining conditions. The restoration of open water reaches, subirrigated acreage and conveyance of natural streamflow will ensure establishment of the biologic diversity and land uses that existed prior to mining.

This Attachment develops a hydrologic budget for premining Lee Coulee with the finding that annual streamflow volumes through the subirrigated reach were much less than the volume of water annually consumed by subirrigated vegetal species within the reach. This finding is supported by high (shallow) water table elevations recorded in the historic database of monitoring wells located within the wet reach. Open water conditions and natural subirrigation in premining Lee Coulee were obviously supplied primarily by ground water resources, where the stream valley acted as a discharge reach for regional ground water flow. Open water reaches and natural subirrigation in Lee Coulee will be restored per the plans presented in this Attachment by the construction of a stream channel and valley floor that are critically positioned with respect to predicted postmining ground water elevations in the reclaimed mine backfill. In addition to being positioned with respect to postmining water table elevations, the channel and floodplain have also been designed to be hydraulically stable under a wide range of peak flow rates and to closely duplicate the premining geomorphic diversity of the valley floor. Full restoration of open water reaches in Lee Coulee and the development of natural subirrigation in the postmining valley floor will not occur, however, until the resaturation of the reclaimed backfill reaches quasi-equilibrium elevations over broad portions of Big Sky's Area B. To attain up-front restoration of open water conditions and to thereby rapidly re-establish the related biologic diversity of the stream channel, this Attachment also provides plans and specifications for one or more ground water wells that will be used to
sustain open water conditions until ground water resaturation in the backfill reaches invert elevations of the reconstructed stream channel. The methodology used to predict postmining water table elevations in Lee Coulee valley is fully presented in this Attachment together with analyses of backfill resaturation rates and ground water quality characteristics that are based on historic monitoring records from Big Sky's Area A. The basic geomorphic characteristics of the postmining drainage basin, valley floor and stream channel of Lee Coulee are also presented and compared to the same premining parameters.

The hydraulic design of the postmining channel and valley floor of Lee Coulee provides conveyance of a wide range of streamflow rates with nonerosional velocities. Design floodplain widths and the valley and channel alignments have been made variable to match premining conditions. The stream channel and valley floor have been designed to tie into upstream and downstream elevations at the mining disturbance boundary with no "nick" points.

With the exception of Gamble's Well Tributary, the channel and floodplain designs that follow in this Attachment differ from the techniques described in Attachment B of Tab 20 for designing other postmining drainages at Big Sky. The salient difference is that the morphology of postmining Lee Coulee (and Gamble's Well Tributary) will very closely match premining conditions with respect to the variability and form of stream channel and low floodplain dimensions.

17.24.314(1c)(2c), 17.24.501(3a), 17.24.634(1), 17.24.751(2g)(2h)

Premining Hydrologic Budget for Lee Coulee

The hydrologic descriptions provided in Tab 7 combined with the baseline soils and vegetation surveys provided in Tabs 8 and 9, respectively, and the assessments of alluvial valley floor characteristics presented in Tab 11 concluded that premining Lee Coulee and the lower reach of Marmot Mound Tributary have 62 acres of subirrigated land. The subirrigated acreage
along the main stem of Lee Coulee alone amounted to 53 acres. Vegetation in the subirrigated acreage was mapped primarily as riparian grass and riparian deciduous tree types (see Exhibit 9-1, Tab 9). Soils of the floodplains and low benches of the valley floors were described as deep to very deep, having coarse-loamy (Glendive), fine-loamy (Havre), and fine-silty (Greenhalgh) textural families (map unit 2B, Exhibit 8-1, Tab 8). The lowest-lying soils in the Stream Study Buffer Zone, however, were found to be particularly wetter than other sections of Lee Coulee and were described as somewhat poorly drained. These soils were mapped as Villy Variant (map unit 4B, Exhibit 8-1). Subirrigation in the Stream Study Buffer Zone, as defined by riparian vegetal species, is generally restricted to the Villy Variant soil. Exhibit 16-2-1 of this text illustrates the Stream Study Buffer Zone, which encompasses most of the area of subirrigation on premining Lee Coulee, along with the positions of Big Sky Mine’s streamflow monitoring stations and premining drainage basin boundaries.

Hydrologic restoration criteria for postmining Lee Coulee were developed by solving the hydrologic budget for consumptive water uses within subirrigated areas of the Buffer Zone and comparing this volume to estimated and recorded volumes of monthly and annual streamflow. The findings of this assessment were used to determine whether ground water or surface water sources, or a combination thereof, would provide the best reclamation design option for ensuring restoration of natural subirrigation and open water conditions in Lee Coulee. The hydrologic budget of the subirrigated reach was solved under the assumption that all consumptive water uses not supplied by direct precipitation minus runoff (soil moisture) were supplied by ground water sources. The variables needed for this approach were average precipitation values and estimates of potential or actual evapotranspiration rates applicable to the subirrigated species.

Table 16-2-1 compiles monthly precipitation values recorded at Big Sky from January 1981 through September 1996. Average monthly values for the period of record at Big Sky are listed on the right side of the table next to average monthly values recorded by the U.S. Weather Service at Colstrip. From 1981 through 1995 the mean annual precipitation at the
mine has been 13.12 inches, compared to 14.70 inches at Colstrip in the period July 1948 through June 1996.

Table 16-2-2 is the solution of the approximate hydrologic budget for the subirrigated reach of premining Lee Coulee that is derived from the monthly potential evapotranspiration (PET) calculations of Appendix 7-7 (Tab 7), the average monthly precipitation values of Table 16-2-1 and the available holding water capacity for the Villy Variant soil taken from Table 8.A.2 of Appendix 8-A (Tab 8). Table 16-2-2 arithmetically balances PET values with precipitation and potential runoff to derive actual monthly evapotranspiration values (ET) expressed in units of acre-feet (ac-ft), percent monthly to total annual ET, and monthly ET per acre. The critical assumptions implicit in the calculations are: 1) that water was always available so that the subirrigated vegetation utilized water at maximum rates that were independent of water availability, and; 2) that all water not supplied by soil moisture derived from direct precipitation was derived from ground water sources. The infiltration of channel and overbank flow in Lee Coulee was ignored in this analysis.

The net result of the calculations provided in Table 16-2-2 is that the 53 acres of subirrigated land in Lee Coulee valley within the Buffer Zone consumptively used about 81 acre-feet of ground water per year. This translates to a unit consumptive use rate of some 1.5 ac-ft per year per subirrigated acre. Actual evapotranspiration use rates are probably some 25 to 30 percent lower than this, based on observations made elsewhere in the Powder River Basin. As an example, Buckskin Mine near Gillette, Wyoming, found an actual unit ET value of 1.18 acre-feet/year/acre over 59 acres of subirrigated land (Triton Coal Company, 1994). Similarly, an actual average evapotranspiration rate of 12.7 inches (1.06 feet as opposed to 1.52 feet) was found for the 1978 growing season from measurements taken at 12 sites within the Powder River Basin, including sites near Brandenberg, Otter and Moorhead, Montana (Lenfest, 1987). The PET calculations of Appendix 7-7 (Tab 7) are based on the Blaney-Criddle Equation, wherein the seasonal growth coefficient, K, can be adjusted according to the composition of the subirrigated plant community, percentage of ground cover, density of the
vegetation and depth to ground water. Plant community composition, vegetal density and monthly ground water elevation data were apparently not used to adjust the “K” values applied in Appendix 7-7 (Tab 7), and it is likely for this reason that the unit ET rate of Table 16-2-2 (1.52 feet) seems anomalously high. The infiltration of channel flows in premining Lee Coulee, albeit infrequent, probably also contributed some water to support the subirrigated acreage, and this phenomenon is also not accounted for in Table 16-2-2. Despite these limitations, the results of the calculations in Table 16-2-2 were deemed adequate for the purposes of the valley floor reconstruction planning.

Exhibit 16-2-2 illustrates the longitudinal channel profile of premining Lee Coulee and the average ground water table elevation profile representative of the center of the premining valley approximately beneath the channel thalweg. The water table profile is based on Big Sky’s alluvial monitoring well water level records through November 1989, before mine dewatering affected the shallow groundwater table, while the channel profile itself is a product of land surveys completed in July 2000 and October 2001. Horizontal and vertical coordinates in the state plane coordinate grid were computed for each channel point in the recent channel surveys. The reader is also referred to a similar channel survey completed in the mid-1980s and presented as Exhibit 7-9c in Tab 7. This older profile, derived by chaining distances, also contains notes regarding potholes, headcuts and channel water conditions. Although the older profile presents valuable information relating to channel conditions and hydrology, no horizontal coordinates were computed with the survey; consequently, its horizontal stationing does not correlate well with the stationing of the two land surveys. The notes from Exhibit 7-9c were translated onto Exhibit 16-2-2 as accurately as possible. Exhibit 16-2-2 shows that ground water elevations were generally about three feet above to two feet below channel thalweg elevations throughout the premining wet reach. Logically, consumptive ground water losses and the propensity for open water conditions in the channel were greatest where the water table was above the channel floor.
Statistical Analysis of Streamflow Monitoring Records. Annual streamflow volumes at gaging
station sites on Lee Coulee were evaluated to determine the availability, and hence relative
importance, of streamflow in meeting the objectives of the hydrologic restoration design. The
second step in preparing the conceptual valley floor design was to sort and statistically analyze
all streamflow data available from Big Sky’s continuous recording stations on Lee Coulee and
Fossil Fork. Stations having discontinuous (grab sample) streamflow measurements were not
analyzed because the data would be temporally and volumetrically of insufficient accuracy for
design purposes. Stations on Lee Coulee having continuous recordings and which were
statistically analyzed for this assignment include: Station BPSFL (Peep Site), having a drainage
area of 2.23 square miles; Station BRTFL (Randy Thomas), having a drainage area of 3.82
square miles, and; Station BMMFL (Marmot Mound), having a drainage area of 5.14 square
miles. Records from one station are available for Fossil Fork, Station BLFFL (Lower Fossil
Fork), with a drainage area of 2.88 square miles. Station locations are illustrated on Exhibit
16-2-1 accompanying this Attachment.

Tables 16-2-3 through 16-2-6 present the results of the data sorting and statistical analyses
performed for Peep Site, Randy Thomas, Marmot Mound and Lower Fossil Fork stations,
respectively. The data sets were all reduced following the same technique and format, with
total annual flows shown at the bottom of the data columns and average monthly flows shown
on the right side of each table. All units are in acre-feet, unless otherwise noted. Average,
maximum and minimum annual flow volumes are shown near the bottom of each table along
with notes that describe the calendar dates over which these values were computed. Variable
periods of record were used for the statistical summaries in some cases in order to avoid the
error that would be caused by including missing data. At the Randy Thomas and Marmot
Mound stations (Tables 16-2-4 and 16-2-5, respectively), limited periods of record were used
for the statistical compilations in order to avoid potential effects on streamflows caused by
mine pit developments. The average annual unit runoff volume, in units of acre-feet per year
per square mile, that is based on the average annual runoff volume computed from the records
of each station, is shown on the second-last row near the bottom of each table.
Tables 16-2-3 through 16-2-5 show computed unit runoff volumes on Lee Coulee ranging from 2.5 ac-ft/yr/sq. mi. for the Peep Site station to 4.5 ac-ft/yr/sq. mi. for the Marmot Mound station. With a drainage area of 2.88 square miles, the computed annual unit runoff volume for Lower Fossil Fork (3.85 ac-ft/yr/sq. mi., Table 16-2-6) is the same as computed for the Randy Thomas site even though the drainage area at Randy Thomas is nearly one square mile larger than what it is at the Lower Fossil Fork station (3.82 sq. mi. versus 2.88 sq. mi.).

With the exception of Lower Fossil Fork, the streamflow monitoring data show a direct relationship between drainage area and average annual unit runoff. Specifically, the unit runoff value increases with drainage area. This finding is the direct inverse of what is normally reported for drainage basins according to Hadley and Schumm (1961)—that is, unit runoff rates normally decrease with increasing drainage area. Because of this disparity and because of the potential importance of streamflow availability in meeting the hydrologic restoration objectives, a relationship developed by Hadley and Schumm (1961) between drainage area and mean annual runoff was used to estimate annual unit runoff rates at each station. These estimates are shown on the bottom row of Table 16-2-3 through 16-2-6. The runoff relationships reported by Hadley and Schumm are based on their study of 55 reservoirs within a 9,000-square mile area lying in the upper Cheyenne River Basin of eastern Wyoming, southern South Dakota and northwestern Nebraska. As applied to Tables 16-2-3 through 16-2-6, mean annual unit runoff rates for the gaging stations on Lee Coulee and Fossil Fork should range from about 10 to 12 ac-ft/sq. mi., with the highest values representing the smallest drainage areas.

Based on the statistical analyses of Big Sky's streamflow records and the adjustment of these findings per the unit runoff relationship reported by Hadley and Schumm (1961), an average annual unit runoff rate of 11 ac-ft/sq. mi. is applied to Lee Coulee at the Randy Thomas station approximately in the center of the Stream Study Buffer Zone. This is equivalent to an annual runoff volume of about 42 acre-feet at the Randy Thomas site. From Table 16-2-3, note that the large runoff volume of August 2, 1985 was excluded from the record of the Peep...
Site station because of the uniqueness of the event and because the true runoff volume could only be approximated. By adding the runoff volume of some 69.4 acre-feet estimated that day back into the record, the mean annual unit runoff volume over the entire period at record at Peep Site is recomputed as 5.1 ac-ft/sq.mi. This not only shows that the unit runoff calculation is very sensitive to extreme events when computed with relatively short periods of record, but also that the estimates applied with the findings of Hadley and Schumm may be reasonable. According to the Section Water Availability in Tab 11 (Alluvial Valley Floors), approximately 150 acre-feet of runoff annually can be predicted for a two to three square mile watershed area. While the streamflow records of Tables 3 through 6 do not support such a large runoff estimate, annual runoff volumes of 10 to 12 ac-ft/sq. mi. have been observed at the Randy Thomas site and have been reasonably approximated at the Marmot Mound station.

The data presented in Tables 16-2-2 through 16-2-6 show that, with an estimated unit runoff of between 5 and 11 ac-ft/yr/sq. mi., the availability of streamflow in Lee Coulee is small compared to premining subirrigated consumptive losses. Postmining annual runoff volumes at the Randy Thomas station can be expected to average between only about 19.5 to 42 ac-ft/yr, as compared to a premining total consumptive loss rate of 81 ac-ft/yr over the subirrigated acreage of the Buffer Zone. A low-lying, broad floodplain could be designed for the Lee Coulee reconstruction reach to promote frequent overbank flooding and to thereby maximize runoff infiltration, but only some two to three percent of the annual flow of the stream could be expected to infiltrate through the restored soil horizon to a medium specially designed to store water for seasonal vegetal uses. The maximum volume of water that could be stored through channel and overbank infiltration would amount to only some 1.3 ac-ft/yr, which would sustain only about one acre of subirrigation having a consumptive use rate equivalent to premining conditions (1.5 ac-ft/yr; see Table 16-2-2). Based on this finding, it is concluded that restoration of the hydrologic functions of premining Lee Coulee must be ground water dependent and will require re-establishment of a shallow water table lying beneath a broad, relatively flat valley floor. The elevation of the water table must locally be above the invert.
elevation of the reconstructed channel in order to provide open water reaches similar to premining conditions.

17.24.634(1)(2)(4)
Stream Channel and Floodplain Reclamation Design

Design Criteria. The channel and floodplain of postmining Lee Coulee have been designed to meet the specific hydrologic and geomorphic criteria set forth below:

To restore natural subirrigation and open water pooling that will be supplied by ground water lying at a shallow depth beneath the valley floor floodplain and above reaches of the reconstructed channel floor;

To convey a wide range in peak flow rates with nonerosional flow velocities as computed using standard engineering practices with conservative input values;

To re-establish the premining geomorphic diversity of the channel and floodplain to the extent possible and to ensure that the topography of the reclamation reach blends vertically and horizontally with the undisturbed channel and floodplain upstream and downstream of the reclamation reach.

The reach of Lee Coulee that will actually be mined and fully reclaimed is shown on Exhibit 16-2-3, which illustrates the alignment of the stream and valley floor in the postmining topography. The length of the reconstructed stream channel will be 6,689 feet, as compared to a premining stream length of approximately 6,778 feet over the same valley floor reconstruction reach. This means that the postmining stream channel will align nearly perfectly (within nearly 99 percent) over the original, premining course of the stream. Upstream and downstream of the reconstruction reach, disturbances to the stream channel and valley floor will be only surficial and limited to activities such as the construction and
reclamation of sedimentation ponds, runoff control ditches and roads. The reclamation (regrading) of these surficial disturbances will be completed so as to blend in with the natural channel and overbank configurations.

Channel and Floodplain Design Methodology. Seven topographic sections (profiles) were surveyed in July 2000 and October 2001 across the premining channel and floodplain of Lee Coulee within the proposed valley floor reconstruction reach to provide data on basic geomorphic parameters for use as the basis of the reclamation designs. The geomorphic factors of approximate bankfull depth, approximate bankfull width and approximate flood prone area width, all as defined by Rosgen (1998), were measured on the seven surveyed sections. Exhibit 16-2-3 shows the locations of the sections (Cross Sections A-A' through G-G') in the postmining topography. The positions of the sections on the premining and postmining longitudinal channel profiles of Lee Coulee are illustrated on Exhibits 16-2-2 and 16-2-5, respectively. The topographic forms and relief of each premining section are shown on Exhibits 16-2-4a, 16-2-4b and 16-2-4c, which also provide plots of proposed postmining topography in profiles drawn along the same horizontal stationing as the premining sections. When comparing the premining cross sectional profiles to the postmining profiles at the same respective locations on Exhibits 16-2-4a, 16-2-4b and 16-2-4c, the reader is advised that the vertical exaggeration is 10:1, and if the profiles were drawn at a scale of 1:1, vertical differences along the channel floor and overbanks between the premining and postmining scenarios would typically be nearly imperceptible.

Bankfull depths measured from the surveyed premining profiles range from a low of approximately 0.2 feet at Sections B-B' and F-F' to a high of approximately 1.1 feet at Section C-C' (west channel). Premining bankfull widths range from about 9 feet at Section G-G' to about 17 feet at Sections A-A' and B-B'. Premining flood prone area widths, defined as the width measured at an elevation which is determined at twice the maximum bankfull depth, range from approximately 25 feet at Section F-F' to 58 feet at Section C-C' (west channel). Entrenchment ratios, defined as the ratio of the width of the flood prone area to the bankfull
surface width of the channel, range from about 1.8 at Section D to 4.0 at Section D. Width/depth ratios, defined as the ratio of the bankfull width to the bankfull depth, range from 15 at Section G to 85 at Section B.

Rosgen (1998) uses the basic geomorphic data compiled above together with the stream sinuosity ratio and channel slope as delineative criterion to group streams into classes of consistent and distinctive morphology. In its premining state Lee Coulee has a sinuosity ratio of about 1.5 and an average gradient of 0.0087 ft/ft within the proposed channel/valley floor reconstruction reach shown on Exhibit 16-2-3. Based on the basic geomorphic factors compiled above for the premining sections combined with the stream’s sinuosity and gradient values, Lee Coulee appears to best fit Rosgen’s C6 stream type. According to Rosgen (1998), the C6 stream type occurs in broad valleys and plains areas with a history of riverine, lacustrine and eolian deposition. They are found in very low relief interior lowlands and in the great plains. C6 stream channels display low width/depth ratios due to the cohesive nature of stream bank materials. The stream banks are generally composed of silt-clay and organic materials, with the stream beds exhibiting little difference in pavement and sub-pavement material composition. Rates of lateral adjustment in C6 streams are influenced by the presence and condition of riparian vegetation and the streams are very susceptible to shifts in both lateral and vertical stability caused by direct channel disturbance and changes in the flow and sediment regimes of the contributing watershed. The broad range in width/depth ratios found for the seven surveyed sections may be a result of lateral and vertical adjustments in the stream resultant from man’s activities, most particularly the potholes that were dug in the channel for agricultural purposes (see Tab 7).

The postmining topography at the seven sections (profiles) shown on Exhibits 16-2-4a, 16-2-4b and 16-2-4c has been designed specifically to replicate the premining bankfull and flood prone area widths, excluding the large width-to-depth ratio outliers found at premining Sections A, B and F. The channel and flood prone area will be constructed in three segments to provide geomorphic diversity through the reconstruction reach. From Sections A through D the
Postmining entrenchment ratio will be approximately 2.3, compared to a premining range in entrenchment ratios of 1.8 to 3.9. Within this same reach the channel width/depth ratio will be about 27, compared to values ranging from 14 to 85 in the native channel. In the vicinity of postmining Section E the entrenchment ratio will be increased to approximately 3.2 and the width/depth ratio will be decreased to about 20, compared to the same respective premining values of 4 and 30. At postmining Sections F and G the channel and active floodplain will be constructed with entrenchment and width/depth ratios of 2.8 and 25, respectively, compared to the same respective premining values ranging from 2.3-3.3 and 15-55. The channel will be constructed with 4H:1V side slopes throughout and with bottom widths of approximately 14 feet from Sections A through D, approximately 10 feet in the vicinity of Section E and approximately 8 feet through Sections F and G. No guide channel will be constructed across the lowest portion of the reconstructed valley below the plane of the design bankfull width. Changes in the channel and floodplain dimensions through the reconstruction reach and at the tie-ins of the reconstructed channel at the regraded mining disturbance boundary will be made as smooth transitions. As mentioned at the beginning of this section, the alignment of the lowest topography beneath the design bankfull width will nearly perfectly match the premining channel alignment. A minor guide channel may naturally develop on the revegetated, reclaimed soil across the lowest portion of the reconstructed valley below the plane of the design bankfull width.

The postmining topography illustrated at Sections A through G on Exhibits 16-2-4a, 16-2-4b and 16-2-4c will be the control for reclaiming Lee Coulee valley throughout the reconstruction reach. Adjustments to the morphology of these channel and overbank designs between the section locations and, as necessary to blend the topography to the upstream and downstream tie-in points, will be made in consultation with and approval of the DEQ.

The adequacy of postmining Sections A through G to convey runoff from the 100-year, 24-hour storm event with acceptably small (nonerosional) velocities was assessed as a final check on the channel and overbank designs. Peak flow rates from the 100-year, 24-hour
precipitation event were computed using the SEDCAD 4 program described in Tab 20 Postmining Drainage Channels at points corresponding to the upstream and downstream reconstruction limits shown on Exhibit 16-2-3 (see Attachments B-5 and B-6 of Tab 20). The postmining drainage basin at the upstream reconstruction limit will be about 1,635 acres while the downstream reconstruction limit will drain approximately 2,350 acres. The 100-year event calculations of Tab 20 utilize a rainfall quantity of 3.80 inches for the 24-hour duration storm. A runoff curve number of 69, developed in Attachments B-5 and B-6 of Tab 20, was used in all runoff modeling. The postmining curve number determined for upper Lee Coulee in Attachment B-5 (69) is identical to that originally determined for lower Lee Coulee at the downstream affected area boundary in Attachment B-6; consequently, use of this same number for the channel reconstruction reach alone seems justified for both premining and postmining conditions. The SEDCAD modeling yielded peak flow rates of 455 cubic feet per second (cfs) at the upstream site and 499 cfs at the downstream site. For the purposes of computing peak flow rate velocities described below, the larger flow rate (499 cfs) was applied to Section A while the average of the upstream and downstream flow rates (477 cfs) was applied to Sections B through E. The upstream flow rate (455 cfs) was applied to Sections F and G. The reader is advised that the runoff modeling completed for postmining Lee Coulee utilizes a premining drainage area of 2352 acres at the downstream reconstruction limit. Since the postmining drainage area on lower Lee Coulee will be essentially equivalent to premining (2350 acres postmining versus 2352 acres premining), the effect on the accuracy of the calculations is negligible.

Peak flow velocities, flow depths and other basic hydraulic properties associated with the 100-year, 24-hour rainfall runoff event at postmining cross sections A through G are printed on Exhibits 16-2-4a, 16-2-4b and 16-2-4c. These results were computed utilizing standard uniform flow theory in open channel hydraulics set forth by Chow (1959). Premining flow velocities and related parameters could not be computed for Section D because the section, as surveyed, cannot hold the 100-year, 24-hour runoff event. At Sections A, B, F and G, postmining peak flow velocities are less than premining for both low and high vegetal conditions.
retardance conditions. At Sections C and E, the postmining velocities are predicted to be higher than premining, but in both cases well below five feet per second (fps), the maximum velocity beyond which erosion of even vegetated channels can normally be expected. At Section D where premining peak flow velocities were not computed, the postmining velocities will be well below five fps. At Section F, the postmining peak flow velocity is shown to be greater than five fps under low vegetal retardance conditions but significantly less than premining which is 5.75 fps for the same vegetal retardance assumption. With respect to channel flow velocities alone, the proposed valley bottom topography/morphology is deemed adequate as designed, and for the majority of the sections, superior to premining conditions.

Exhibit 16-2-5 is a drawing of the postmining longitudinal profile for Lee Coulee channel through the reconstruction reach shown on Exhibit 16-2-3. The profile shows that the flat channel floor beneath the bankfull plane will be constructed along an approximate constant slope of 0.0089 ft/ft, which is essentially equivalent to the average premining gradient of the stream through the same reach (0.0087 ft/ft). Exhibit 16-2-5 is of the same scale and of essentially the same horizontal stationing as the premining longitudinal profile of Lee Coulee, Exhibit 16-2-2. Differences in horizontal stationing between Exhibits 16-2-2 and 16-2-5 amount to only 89 feet and are partly the result of the graphical “smoothing” of the surveyed premining channel alignment that was digitally conducted to create the postmining channel alignment. When viewed in the perspective of Area B as a whole, the profile of Exhibit 16-2-5 is concave upward but with none of the numerous headcuts (profile nickpoints) that existed within the proposed reconstruction reach under native conditions. Figure 16-2-15 compares the premining and postmining alignments of Lee Coulee channel in plan view.


Postmining Ground water Conditions

Ground water Elevations and Seepage Rates in Postmining Valley Floor – Artificial Cut Method. A series of analytical solutions developed by Abdel-Aziz I. Kashef (Ground-Water
Movement toward Artificial Cuts, 1969, in Water Resources Research, Vol. 5, No. 5) were used to estimate ground water elevations and ground water seepage rates to postmining Lee Coulee within and downstream of the reconstruction reach. The objective of this work was to determine whether or not the postmining longitudinal profile of the stream or the side slopes of the valley will potentially intercept the postmining ground water table in the backfill after the ground water table has fully recovered to equilibrium conditions. Restoration of reaches of open water in the postmining channel floor and shallow water table conditions across the valley floor are necessary for the re-establishment of premining biologic diversity and vegetal productivity and for the re-establishment of associated premining land uses. In general, Kashef’s solutions are similar to conventional techniques described in engineering and ground water textbooks for computing phreatic surfaces and flow rates through earthen dams. Kashef’s solutions are applicable to open channels and highway cuts, but as opposed to many conventional “seepage face” solutions, are not limited only to cuts fully penetrating the contributing aquifer. The author’s developments simulate conditions where cuts fully penetrate aquifers as well as conditions where cuts lie above the floors of aquifers. Kashef’s solutions for partially penetrating cuts simulate material lying below the cut and above the aquifer floor as tailwater, whether the material is a pool or saturated strata.

Figure 16-2-1 illustrates the analytical solution used for computing the position of the phreatic surface and groundwater flow rate through mine backfill to postmining Lee Coulee. Printed at the base of the drawing are the equations used to compute the height of the seepage face “D” and the height “Dx” of the phreatic profile above the floor of the spoils at distances “L” and “x”, respectively, from the nearest final highwall to specific points in the valley floor. Information needed to define elevations on the sub-Rosebud coal shale were taken from the cross sections of Tabs 6 and 20 and from Exhibit 6-3, Rosebud Top of Coal Contours. The extrapolated depth of the shale floor (i.e., the interburden) below the valley floor and resultant angle “B” on Figure 16-2-1 are based on extrapolating the side slopes of the valley walls specified in the postmining topographic sections shown on Exhibits 16-2-4a, 16-2-4b and 16-2-4c and as shown by the postmining topography contours of Exhibit 16-2-3. For water table
elevation solution test sites that fall on native stream channel and valley floor terrain, the valley side slopes were extrapolated to the subcoal shale base by reference to digital topographic files having 5-foot elevation contour intervals. The salient assumption in the conceptual model is that ground water elevations in overburden will recover to premining levels at the positions of the final mine highwalls. Premining ground water elevations in overburden were therefore assigned to the approximate final highwall locations lying nearest to the valley floor analytical solution sites, as illustrated on Figure 16-2-1. The locations of the ground water elevation analytical solution sites are shown on the postmining topography map, Exhibit 16-2-3. The assumption that ground water elevations in overburden outside the mine block will return to premining levels seems entirely logical because: 1) ground water recharge sources for the coal and overburden obviously lie distance from Big Sky Mine toward the west and northwest where the predominate recharge source is probably East Fork Armells Creek, and; 2) Big Sky Mine is positioned near the downstream end of flow in the coal and overburden. Consequently, the mine will not affect upgradient aquifer recharge sources that probably acted as quasi-constant head sources to the ground water discharges that occurred within premining Lee Coulee valley.

Ground water seepage rates to the postmining valley floor were computed according to Kashef’s equation shown on Figure 16-2-1 that solves for the ratio “q/k”. A range of potential hydraulic conductivity values for the spoils was obtained from Colstrip area studies reported by Van Voast and Reiten (1988) and by Van Voast et al. (1977) in the Montana Bureau of Mines and Geology Memoir 62 and Bulletin 102, respectively. The range reported in these publications is approximately 0.9 ft/day to 2.3 ft/day, which converted as required for Kashef’s solutions, is equivalent to 1.063E-5 to 2.662E-5 ft/sec.

Table 16-2-7 presents the results of the analytical solutions described above for estimating ground water elevations at six sites and ground water seepage rates at five sites within postmining Lee Coulee valley. A seepage rate is not computed for Site 0 because the calculation at this site is only for the height “Dx” of the phreatic surface above the subcoal
shale elevation at distance “x” from the final pit wall upgradient from seepage face elevation solution Site No. 1. Table 16-2-7 shows that the ground water elevations at Sites 1 through 5 will potentially range from one foot to five feet above the postmining channel thalweg. At Site 0, near the upstream affected area boundary, the ground water is predicted to lie six feet below the channel floor.

A postmining groundwater table profile drawn on the water table elevations projected by Kashef’s artificial cut method is shown on Exhibit 16-2-5. This profile may be compared to the premining water table profile of Exhibit 16-2-2 by direct superimposition of the two drawings. The premining water table profile was drawn on average values recorded through November 1989 at wells BAL2011 (upstream of the plotted profile and stream study buffer zone), BAL9011, BAL2321, BAL9091, BAL9031, BAL9041 and BAL2411 (downstream of the profile and stream study buffer zone). Water level records collected after November 1989 were not used in the computation of average, premining values because mine dewatering began to influence shallow water table elevations after that time. Monitoring well locations are illustrated on Exhibit 7-1 of Tab 7.

In comparing Exhibits 16-2-2 and 16-2-5, the postmining water table profile of the artificial cut method is seen to typically lie three to four feet above the premining water table profile throughout the wet reach. At groundwater solution test Site 0 (Station 1,250 feet), upstream of the wet reach and upstream of premining subirrigation noted on Exhibit 16-2-2, the premining and postmining water table elevations agree to within approximately one foot. That the projected postmining water table is elevated above the average premining water table through the wet reach is due to the fact that Kashef’s method does not account for losses that perennially and seasonally depressed the premining water table throughout the subirrigated valley floor. These losses included evaporation, vegetal transpiration and groundwater drainage to the channel itself. The agreement between the water table elevation projected by the Kashef method and the premining water table at solution test Site 0 where premining
groundwater losses were probably negligible is considered strong evidence of the accuracy of the Kashef method.

The sensitivity of the analytical solutions employed for determining postmining ground water elevations to large errors in estimating distance “L” from the postmining valley floor to a specific postmining overburden ground water elevation, hence the validity of the assumption stated above regarding recovery of ground water elevations in overburden at sites beyond the mining boundary, was investigated by recalculating the solution for Site No. 1. Specifically, distance “L” was increased 978 feet to a point where the phreatic projection would approximately intercept the same postmining ground water elevation 3362 feet used in the initial solution for Site No. 1 if mining were to permanently cause 10 feet of drawdown in overburden. Stated another way, if the water table in overburden is permanently depressed 10 feet beyond the boundaries of mining, distance “L” of Site No. 1 increases 978 feet from 2260 feet to 3238 feet. Resolving Kashef’s equations with all other variables remaining the same yields a seepage height “D” of 79 feet, which corresponds to a ground water elevation of 3354 feet in the valley floor. This compares to an elevation of 3357 feet computed for a distance “L” of 2260 feet. At elevation 3354 feet the ground water table would still lie about one foot above the adjacent postmining stream channel elevation shown on Table 16-2-7. The ground water seepage rate under this revised solution would be 0.24 ft³/day/ft, as compared to 0.29 ft³/day/ft for the first solution where “L” is 2260 feet.

The sensitivity of the analytical solutions to errors made in estimating postmining ground water elevations in undisturbed overburden at the final mine highwalls was again tested by changing the value “h” (see Figure 16-2-2) for the solution already made at solution site No. 2. At this site the solution shown on Table 16-2-7 is for a distance “L” of 1,977 feet, a postmining water table height “h” in undisturbed overburden above the sub-Rosebud coal layer of 78 feet, and a postmining valley floor height “b” of 54 feet above the sub-Rosebud coal layer. Reducing the value of “h” 10 feet to 68 feet and resolving the equations yields a value of the seepage height “D” at the postmining valley floor of 56.7 feet, which is equivalent to a
ground water elevation of 3334 feet. This compares to a predicted postmining ground water elevation of 3335 feet for “h” equals 78 feet shown on Table 16-2-7. The ground water seepage rate for this revised solution would be 0.35 ft³/day/ft, as compared to the seepage rate of 0.69 ft³/day/ft shown on Table 16-2-7. Clearly, the two sensitivity analyses demonstrate that the analytical solutions for seepage height elevation are not especially sensitive to gross errors in estimated values of distance “L” and moderate errors in estimated values of postmining overburden ground water elevation height “h”. The calculated seepage rate is also relatively insensitive to errors in distance “L” but is moderately sensitive to errors in ground water elevation height “h”.

Subsequent to the preparation of Table 16-2-7, Big Sky Mine expanded its mine plan to include additional coal recovery for a distance of about 1850 feet further upstream on Lee Coulee than previously planned. The expanded mining will remove the upstream-most segment of the stream study buffer zone, measuring about 650 feet along the valley floor, that would not have been removed under the previous plans. Analytical solution Site No. 1 of Exhibit 16-2-1 lies within the revised coal recovery area whereas before it was upstream of planned mining and regrading. Solution Site 0 lies about 100 feet upstream of the revised coal recovery limit. The postmining groundwater elevations shown for Sites Nos. 0 and 1 on Table 16-2-7 are not significantly affected by the expanded coal recovery plan because: 1) Lee Coulee channel within the expanded mining reach will be reconstructed virtually exactly on its premining alignment and profile (see Figure 16-2-15 and Exhibits 16-2-2 and 16-2-5); 2) the expanded mining areas will be moving up the premining and, hence, assumed postmining water table gradient in the overburden, meaning that the aquifer head above the sub-coal shale “h” used in the analytical equation will increase proportionally with distance “L” (see Figure 16-2-1. The effect of both variables increasing in the analytical solution is to negate changes in the calculated postmining valley floor water table elevation “D” or “Dx” that would otherwise occur if head “h” did not increase proportionally with distance “L”. Conversely, moving the postmining valley floor or stream channel from their premining positions could
affect the accuracy of the original calculations summarized on Table 16-2-7, but this is not the case in the proposed reclamation plan.

**Ground Water Elevations in Postmining Valley Floor – Finite Element Model Results.** Postmining water table elevations in Lee Coulee valley developed in the previous text section were derived through equations that solve for phreatic profiles and seepage face elevations independent of the hydraulic conductivity of the aquifer media (mine spoils and undisturbed overburden). The equations require assigning values for source head water elevations outside of and upgradient of the valley floor and this was done under the assumption that postmining ground water elevations will return to premining elevations at distances well outside the mine block. Changes in hydraulic conductivity within the regional postmining flow system, such as those potentially caused by mine spoils, could, however, affect final equilibrium ground water elevations not only in the spoils but also in aquifers surrounding the mine block. The sensitivity analyses performed with the equation variables “L” and “h” in the previous text section address the effects on postmining valley floor water table elevations caused by radical differences in final equilibrium head elevations in overburden surrounding the mine block.

The effects of widely variable spoil hydraulic conductivity values on final equilibrium ground water elevations in postmining Lee Coulee valley were further investigated through solution of a finite element ground water model. The model employed was FLONET/TRANS (© May 1997), marketed by Waterloo Hydrogeologic, Inc. This model uses the dual formulation of hydraulic potentials and stream functions (E. O. Frind and Mantaga, 1985) to solve the steady-state saturated flow equation through a hydrogeologic cross section. FLONET/TRANS simulates multi-layered stratigraphy of variable thicknesses with variable finite element mesh configurations, and allows input of spatially variable hydraulic properties for heterogeneous and anisotropic media under confined or unconfined conditions. The mathematical development of the model is well documented and its accuracy tested against various proven analytical solutions.
The FLONET/TRANS model was originally run for a smaller coal recovery area that was expanded in year 2002 to include plans for mining about 1850 feet further upstream in Lee Coulee valley. Under the original model, premining and postmining ground water conditions were simulated beginning nearly 4,000 feet upstream of the mining limit, but under the expanded plan the mining limit will fall about 1,900 feet downstream of the model’s up-valley terminus. The original model has not been revised and its results are retained below. The reader is referred to additional text added at the bottom of this section describing the effects of the proposed, expanded coal recovery area on the original model results.

The first step in employing the FLONET/TRANS model was to construct a hydrogeologic cross section to scale along the line shown on Figure 16-2-2. The section extends 7,820 feet from the upstream permit boundary crossing on Lee Coulee to a point nearly 1000 feet downstream of the proposed valley reconstruction reach. Drill holes used as control in defining the stratigraphy of the section are shown on the figure. At its up-valley terminus, the section contacts thick overburden sands that are believed to recharge the alluvium. The overburden sands are in turn believed to be recharged by the East Fork Armells Creek ground water/surface water system; consequently, postmining ground water elevations at the upstream limit of the model section are expected to fully recover to premining elevations.

Figure 16-2-3 illustrates the stratigraphy loaded into the ground water model at an exaggerated scale of 56.37 vertical to one horizontal (56.37V:1H). The figure was plotted with this exaggeration for viewing purposes only: when plotted with a vertical exaggeration of 10V:1H, the individual strata layers are scarcely discernible on the figure. The uppermost line on the cross section is the premining water table profile taken from Exhibit 16-2-2 and taken from the water table contour map, Exhibit 7-2 of Tab 7. The model was structured to simulate the alluvium, overburden and Rosebud coal as one aquifer system with one phreatic profile because of the absence of any confining layers hydraulically separating the three stratigraphic units. The finite element mesh of the model cross section is divided into 84 cells where each
After inputting the stratigraphy and phreatic surface of the cross section into the FLONET/TRANS model, the model was then hydraulically calibrated. The objective in the calibration was to find the unique arrangement of aquifer hydraulic conductivity values that, when executing the model, result in a phreatic profile that closely matches the premining input profile. This was accomplished by repetitively running the model and adjusting the conductivity values between model runs as needed to position the phreatic surface. Input starting values for hydraulic conductivity and aquifer storativity were taken from Table 7-3 of Tab 7. In each trial simulation the convergence criterion of the model (the minimum accuracy for which the model computes heads between numerical iterations) was set at 0.01 feet. Hydraulic values determined for the final calibrated model are printed on Figure 16-2-3. In the calibrated file the alluvium is divided into 10 zones having conductivity values ranging from 0.9 to 9.0 ft/day and a uniform storativity of 0.10. The conductivity and storativity of the overburden and Rosebud coal were globally set at 0.70 ft/day, 0.01 and 0.30 ft/day, 0.005, respectively, based on the aquifer testing results of Table 7-3. Figures 16-2-4 and 16-2-5 illustrate output from the calibrated model in stratigraphic and equipotential views, respectively. The position of the phreatic profile on these two figures very closely matches the profile position of Figure 16-2-3 with a maximum error (input head elevations minus output head elevations) of approximately 2.2 feet. The mass flux water balance error in the calibrated model is -0.42 E-11 percent. Output heads in the calibrated model tend to be up to 2.2 feet lower than the input heads between stationing 0 and 2,500 feet, less than two feet lower than input heads between 4,500 and 5,500 feet and less than two feet between approximately 6,400 and 7,000 feet. Over the remainder of the model the calibrated file output heads are equivalent to the input heads to within approximately ± 0.5 feet.

After it was calibrated to premining conditions, the cross sectional ground water model was suitable for simulating the effects of various spoil hydraulic conductivity values on postmining
water table elevations within and adjacent to the reconstructed valley floor. To accomplish this, the mine plan was superimposed on the horizontal stationing of the model and the alluvium, overburden and Rosebud coal were converted to spoils within the mine block. This is shown on Figure 16-2-6. Having revised the model stratigraphy to include the mine spoils block, the model was run with spoil hydraulic conductivity values of 0.09, 0.9 and 9.0 ft/day. This range of values is equivalent to one-tenth, equal to, and ten times the minimum value reported for Colstrip area spoils by the Montana Bureau of Mines and Geology, as cited above. The storativity of the spoils was set at 0.06, which is the average of values reported for Area A mine spoils shown on Table 16-2-9.

Output from the FLONET/TRANS mine spoils simulation runs are presented as Figures 16-2-7 through 16-2-12. Figures 16-2-7 and 16-2-8 illustrate phreatic conditions and equipotential lines computed for a mine spoils conductivity of 0.09 ft/day. In this case the phreatic profile would be stacked high above the premining profile throughout and upgradient of the mine block and there would be a steep water table gradient throughout the mine block. Figures 16-2-9 and 16-2-10 illustrate the model output for a mine spoils conductivity of 0.9 ft/day. Under this scenario the phreatic profile and equipotential distribution would be very similar to premining conditions. By overlaying Figure 16-2-9 on Figure 16-2-4, it can be seen that the postmining profile would be up to about two feet lower than the premining profile of the calibrated model between model stationing 2,500 to 5,700 feet. Figures 16-2-11 and 16-2-12 illustrate the mine simulation output for a spoil conductivity of 9.0 ft/day. In this case the postmining phreatic profile would be much lower than premining within and upstream of the mine spoil block and the equipotential elevations (Figure 16-2-12) would be steeply stacked upgradient of the mine block. The hydraulic conditions under the scenario of 9.0 ft/day spoil conductivity are so radically different than premining that it was necessary to allow the model to deform the stratigraphy of the model input across all model layers. Without allowing this deformation the model could not solve for continuity of ground water flow through the cross section even with a convergence criterion of 2.0 feet.
According to the results of the FLONET/TRANS model, there would be significant changes in groundwater table conditions within a large portion of the postmining valley reach of Lee Coulee coincident with the premining "wet reach" if it is assumed that the entire postmining spoil block beneath the valley floor will be characterized by a hydraulic conductivity of 9.0 ft/day. This assumption cannot be made with any certainty, however, and as described below, the hydraulic conductivity of the backfill in the postmining valley floor is expected to more closely match the hydraulic characteristics of the premining overburden than the premining alluvium. With the backfill having an assumed hydraulic conductivity of 9.0 ft/day, the FLONET/TRANS model shows the postmining equilibrium water table to be up to about 25 feet lower than premining at the beginning of the channel/valley floor reconstruction reach (at approximately station 4,500 feet on Figures 16-2-11 and 16-2-4). This can be seen by overlaying Figures 16-2-11 and 16-2-4. Similarly, at the upstream limit of the premining wet reach (approximately at station 3,000 feet on both figures), the postmining water table would lie about 12 feet below the premining water table and at the affected area boundary upstream of the premining wet reach (approximately at station 1,100 feet on both model figures) the postmining water table would lie about four feet below the premining water table. Under the same assumption, the modeling results indicate that the postmining water table would lie about 14 feet below the premining water table near the center of the reconstructed valley reach (approximately at model station 5,750 feet on Figures 16-2-4 and 16-2-11). The 9.0 ft/day conductivity modeling results indicate that postmining water table elevations would be equivalent to premining water table elevations beginning at the end of valley floor reconstruction (approximately at station 7,000 feet on the model figures) and extending downstream from there.

In summary, the results of the FLONET/TRANS modeling conducted for a spoil hydraulic conductivity of 9.0 ft/day indicate that there would not be wet channel conditions or valley floor subirrigation in the postmining environment beginning upstream of the historic wet reach and extending downstream from there to the downstream terminus of valley floor reconstruction. Postmining water table elevations would be equivalent to premining water...
table elevations beginning at the downstream valley floor reconstruction limit and extending downstream from there to the terminus of the historic wet reach (from approximately station 7,450 feet to 12,400 feet on Exhibit 16-2-2), meaning that approximately the lower 5,000 feet of the premining wet reach characteristics would still exist after final groundwater recovery.

Although the final, steady-state conductivity of the Area B spoils cannot be predicted with absolute certainty, logically, the spoils can be expected to assume the character of the overburden since the overburden will constitute the great majority of the spoils’ volume. The alluvium of Lee Coulee will comprise relatively little of the backfill volume and, by the nature of the mining and backfilling methods, the alluvium will be intermixed with overburden consisting of sand, silt and clay. The average hydraulic conductivity of the spoils is expected to ultimately be similar to that found for the premining overburden, after the spoils have naturally re-compacted. On Table 7-3 (Tab 7), the hydraulic conductivity of Area B overburden is reported to range from 0.73 to 0.97 ft/day. The postmining water table profile and gradient computed by the FLONET/TRANS model for a spoil conductivity of 0.9 ft/day and shown on Figures 16-2-9 and 16-2-10 are believed to be far more representative of steady-state postmining conditions than are the results computed for spoil conductivities of 0.09 and 9.0 ft/day.

The postmining water table profiles that have been computed under this Section Postmining Groundwater Conditions by the artificial cut method and by the FLONET/TRANS model (hydraulic conductivity of 0.9 ft/day) are plotted together with the postmining channel profile on Exhibit 16-2-5. This drawing may be compared directly to Exhibit 16-2-2 showing the premining channel profile and average water table profile because both drawings are plotted to the same scale and both have essentially the same horizontal stationing. The generation of these drawings is explained in more detail in the Section Channel and Floodplain Design Methodology.
Although the postmining groundwater profile predicted by the FLONET/TRANS model lies up to nine feet below (typically five feet below) the profile predicted by the artificial cut method on Exhibit 16-2-5, the two sets of results are felt to be in remarkable agreement given the widely variable approaches of the two predictive efforts. Of the two profiles on the exhibit, that predicted by the artificial cut method is felt to be the most reliable for the following reasons:

1. As explained under the Section *Groundwater Elevations and Seepage Rates in Postmining Valley Floor – Artificial Cut Method*, the water table profile computed via this method is biased high with respect to the premining water table where the premining water table was influenced by consumptive vegetal losses and groundwater drainage to the channel within the premining wet reach. It is not biased high where the premining water table was relatively deep below land surface, such as at the solution test Site No. 0 analyzed with the technique. That the solution at Site No. 0 nearly identically matches the average premining water table elevation there is considered strong evidence of the accuracy of the technique.

2. The shallow water table in premining Lee Coulee valley was recharged by groundwater in permeable overburden sands whose potentiometric surface graded upward from Lee Coulee valley toward East Fork Armells Creek north and northwest of Big Sky Area B. Since the elevations and alignment of postmining Lee Coulee will be nearly identical to premining and because the topographically-high recharge sources associated with East Fork Armells Creek will not be disturbed by Big Sky Mine, it can be expected that the regional groundwater flow system dominated by the two streams will persist after mining with postmining Lee Coulee continuing to serve as a local groundwater sink. The artificial cut method numerically addresses Lee Coulee valley’s function as a local groundwater sink in the regional groundwater flow system.
As previously mentioned, the water table elevations and profiles predicted by the artificial cut method and by the FLONET/TRANS model are considered to be in remarkably close agreement. This is especially true when, with respect to point No. 1 above, it can be concluded that the postmining water table profile predicted by the artificial cut method should be offset lower in elevation to account for premining groundwater losses. This would result in the two profiles agreeing even more closely than what is shown on Exhibit 16-2-5. It should be noted that the water table profile generated by the FLONET/TRANS model cannot be expected to be biased high with respect to the premining average water table profile because it was calibrated to the premining water table profile. Indeed, as stated in the Section *Groundwater Elevations in Postmining Valley Floor – Finite Element Model Results*, the calibrated heads of the finite element model used as input for the spoil simulation modeling were typically about two feet lower than the input (average water table profile) heads. Because of this, the output water table profile generated by the FLONET/TRANS model can be expected to be biased at least two feet low.

As mentioned at the beginning of this section, Big Sky Mine has revised its coal recovery plan to propose mining about 1850 feet further upstream in Lee Coulee valley than was originally simulated with the FLONET/TRANS model. Since the model was used to simulate only conceptual, order-of-magnitude assumptions in the postmining spoil conductivity values, the results of the model are still entirely applicable for projecting postmining groundwater conditions for the expanded mining area. Specifically, for assumed spoil hydraulic conductivity values of 0.09 ft/day and 9.0 ft/day, the postmining water table profiles within Lee Coulee valley would be stacked high above and far below, respectively, the premining water table profile throughout and upstream of the mine block. There would be no wet channel conditions and subirrigation in the reconstructed postmining valley floor if the entire spoil block beneath the valley floor is characterized by a hydraulic conductivity of 9.0 ft/day. Conversely, if the hydraulic conductivity of the backfill averages about 0.9 ft/day, as is projected to be the case, postmining water table elevations and gradients will be very similar to premining throughout the reconstructed valley floor inclusive of the expanded mining area.
Under this scenario, postmining water table elevations predicted by the FLONET/TRANS model, unadjusted for being biased about two feet low, can be expected to lie about five feet or more below the postmining channel upstream of the stream study buffer zone through the expanded valley floor reconstruction limit shown on Exhibit 16-2-5.

**Ground Water Flow to Postmining Lee Coulee.** Since, as described above, the postmining water table profile predicted by the artificial cut method is biased high while the profile predicted by the FLONET/TRANS model is biased low because of model error, the channel reach that will ultimately experience seasonal pooling might best be estimated by averaging the two profile results. Doing this visually on Exhibit 16-2-5, subirrigation/channel pooling is predicted to begin approximately 300 feet downstream of Gamble's Well Tributary (approximately at station 2,600 feet) and extend continuously downstream from there to the end of the profile generated by the FLONET/TRANS model at station 8,800 feet on the exhibit. Based on the profile generated by the artificial cut method alone, subirrigation/channel pooling can be expected to extend downstream of the FLONET/TRANS profile to approximately station 12,600 feet on Exhibit 16-2-5. The total length of reconstructed and native channel expected to experience seasonal groundwater pooling is therefore about 10,000 feet. This compares very favorably with the stationing on the premining channel profile (Exhibit 16-2-2), where wet channel conditions extend from approximately 1,900 feet to 12,400 feet. As described later in the section *Interim Reclamation for Immediate Restoration of Open Water Conditions*, shallow potholes will be formed in the reconstructed channel floor in replacement of premining potholes that seasonally stored water. Being slightly below the channel profile elevation, these postmining potholes will ensure prolonged periods of open water pooling.

The projected postmining valley floor water table elevations of Table 16-2-7 (artificial cut method results) were plotted on Exhibit 16-2-3 to derive the approximate zone of subirrigation that can be anticipated with full resaturation of the Area B backfill. The area shown as subirrigated is approximately equivalent to where the water table elevations projected by the

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artificial cut method will be equal to postmining topography final ground elevations over the stream channel and/or adjacent flood prone area. Exhibit 16-2-3 shows approximately 46 acres of subirrigated land within the reconstructed valley floor and adjoining reaches, which compares favorably with the 53 acres of natural premining subirrigation lying within the Stream Study Buffer Zone on Lee Coulee.

17.24.314(1c), 17.24.644(1)

Restoration of Ground Water Recharge Rates.

Postmining ground water recharge rates in Area B are estimated in this section by reference to recharge rates observed to date in Area A and by review of an aquifer test that was completed in 1983 for the purposes of evaluating the feasibility of developing Area A spoils as a source of ground water supply for mine dust suppression and other miscellaneous uses. Using Area A as an example for predicting ground water recharge rates and aquifer hydraulic values in Area B is considered valid, if not somewhat conservative, inasmuch as "prelaw" Area A was reclaimed without development of specific reclamation plans of the type prepared for Area B that are tailored to maximize re-establishment of premining recharge rates and other hydrologic functions. The reader is also directed to the main text of Tab 16 and to Tabs 17 and 18 for discussions of the anticipated recharge capacity of Area B spoils.

Table 16-2-8 is a compilation of historic water level recovery rates observed in selected Area A wells beginning with the dates that the wells were initially monitored. Wells selected for this inventory were those having consistent water level trends and wells not under the drawdown influence of spoil well ASPW1, which is pumped for extended periods each spring and summer to supply water for mine dust suppression. The water is conveyed via pipeline from the well to the mine's main facility area where the water is used for dust suppression and for washing trucks. In addition to well ASPW1 itself, spoil monitor wells ASPW2, ASPP5, ASPP6, ASP46, ASP47, ASP48 and ASP65 are all likely under the influence of drawdown caused by the pumping of well ASPW1.
Table 16-2-8 shows that ground water levels in most Area A spoil wells not only recovered relatively rapidly, but also that water table elevations reached apparent equilibrium conditions in most wells even while mining was still ongoing in Area A. Coal removal activities began in Area A in 1969 and ceased in September 1989. Ground water recovery rates have been at least as high as 4.9 feet per year (well ASP28) and probably higher, since some of the spoil wells were installed after there was already some spoil resaturation. As would be expected, there is also some correlation between the lowest water table recovery rates of Table 16-2-8 and wells having inferior spoil water quality that are identified in the section Quality of Ground Water Contributing to Postmining Lee Coulee. This correlation is expected under the logic that areas of spoils having low ground water recovery rates also have low rates of ground water movement and, hence, have slower flushing rates of soluble salts. An example of this correlation can be seen in wells ASP22, ASP49, ASPS15 and ASPP18 which are all identified in the section Quality of Ground Water Contributing to Postmining Lee Coulee as having relatively poor water quality with respect to TDS and sulfate concentrations sometime in their sampling histories. All four wells also have some of the lowest ground water recovery rates shown on Table 16-2-8. Well ASP36 seems to be the only "poor" water quality well not fitting this correlation, since it has experienced a moderate ground water recovery rate as shown on Table 16-2-8. With 13 sulfate and 11 TDS analyses in its historic water quality sampling database, however, well ASP36 has had maximum sulfate and TDS concentrations that have exceeded livestock use criteria by only 30 mg/l and 110 mg/l, respectively (see Section Quality of Ground Water Contributing to Postmining Lee Coulee). Livestock use water quality criteria are listed on Table 16-2-10.

Based on data summarized in Table 16-2-8, it is concluded that the Area A spoils have certainly not acted as a barrier to ground water flow but have instead been readily recharged by ground water invading from surrounding undisturbed aquifers and, to a smaller extent, possibly recharged by infiltration of direct precipitation and runoff. Aquifer pump test data are presented below which show very large spoil hydraulic conductivity values at one Area A
site and which demonstrate that the resaturated spoils can be developed for long-term, beneficial water uses.

Area A Spoil Aquifer Test Results. Table 16-2-9 presents analytical results from an aquifer pumping test conducted September 22 and 23, 1983, on seven Area A spoil monitoring wells. The purpose of the test was to determine the sustainable yield of well SPW-2, thereby assisting Big Sky Mine in its study of the feasibility of using the spoils aquifer for a long-term water supply. The testing report is on file at Big Sky Mine. Figure 16-2-13, copied from the original report, identifies the wells of the testing program and the relative positions of the observation wells from the pumped well, well SPW-2. Subsequent to the aquifer test, all Area A wells were assigned new identification labels. The new labels are shown in parentheses by the old well identification labels on Figure 16-2-13.

The spoil well aquifer test had a pumping period of 24.95 hours and a time-weighted average discharge rate of 94.59 gpm. The actual discharge rates ranged from 75 to 100 gpm throughout the test. The lower discharge rates occurred late in the test and were the result of coarse-grained to very coarse-grained sand and coal chips that passed through the well’s perforations and clogged the screen on the pump’s intake section. Water levels in the pumping well and in all observation wells but wells BS-46 (ASP46) and P-6 (ASPP6) were measured during testing to the nearest 0.01 feet using electric tapes. Continuous float recorders were installed on wells BS-46 (ASP46) and P-6 (ASPP6) to provide continuous records of drawdown and recovery values during testing. Water level recovery measurements were taken for approximately six hours following cessation of pumping and again on the morning following the day pumping ended. Maximum drawdowns recorded in the wells ranged from 14.97 feet at the pumped well to 0.0 feet at observation well BS-48 (ASP48), as shown on Table 16-2-9. Saturated spoil thicknesses ranged from 51.1 feet at the pumped well to 3.1 feet at well BS-48 (ASP48), which was completed only in the upper spoil sequence. The test drawdown data were analyzed by the Jacob method (after Lohman, 1979) and following Boulton’s (1963) methods for analysis of unconfined aquifer tests under delayed yield.}

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conditions. All drawdown data were adjusted for the effects of partial aquifer dewatering by the method prescribed by Walton (1962). Post-test recovery data were analyzed according to a method prescribed by Johnson, UOP Inc. (1975). The drawdown and recovery data were descriptive of extreme aquifer heterogeneity (zones of mixed permeability), which was most evident in the fact that the well nearest to the pumped well, well BS-48 (ASP48) at 12.7 feet from the pumped well, experienced no drawdown.

The results of the spoil aquifer test summarized in Table 16-2-9 show very large permeabilities (hydraulic conductivities) and a specific capacity for the pumped well of 6.32 gallons-per-minute-per-foot of drawdown. The testing report concludes that the average permeability of the spoils in the well field is about 70 gal/day/ft² and the average transmissivity is about 3100 gal/day/ft. The maximum storage coefficient of 0.18 found by the test was felt to be most representative of the aquifer as a whole. The long-term sustainable yield of pumped well SPW-2 (ASPW2) was computed to be between 55 and 79 gpm. To put the Area A spoil test results into perspective, the maximum hydraulic conductivities found in the premining aquifers of Area B were from five pumping tests conducted in alluvium of Lee Coulee at rates of 12 to 50 gpm and that yielded a geometric mean hydraulic conductivity of 12.13 ft/day (90.7 gal/day/ft²) and a geometric mean transmissivity of 225.5 ft²/day (1687 gal/day/ft; see Tables 7-3 and 7-4 of Tab 7). All other Area B aquifer tests in all other stratigraphic units (overburden, interburden, Rosebud coal, McKay coal and sub-McKay units) yielded hydraulic conductivities less than one ft/day (less than 7.48 gal/day/ft²). Only the alluvium of Area B has hydraulic conductivities as great or greater than those found in the Area A spoils test, but the transmissivity (hence overall available well yield) of the spoils is greater than that of the alluvium because the saturated thickness of the spoils is several times greater than that of the alluvium.

Big Sky Mine has utilized spoil well SPW-1 (ASPW1) as a source of water supply during the peak demand months of spring and summer for some 10 years since the Area A spoil aquifer test was completed in 1983. As shown in Tab 17, the overall texture and geochemistry of
Area B strata are not significantly different than the overall texture and geochemistry of Area A; consequently, there is no reason to anticipate that postmining ground water recharge rates and yields in Area B will be less than those found in Area A. The facts for Area A alone, as they relate to the rapid ground water recovery rates in spoils, the existence of relatively large spoil hydraulic conductivities at one test site, and the proven capacity of the spoils to sustain ground water pumping for long periods, all suggest that Area B spoils will have recharge capacity and yields similar to premining conditions and which are adequate to support postmining land uses.

17.24.314(1)(a), 17.24.643(2)

Quality of Ground Water Contributing to Postmining Lee Coulee.

The quality of ground water contributing to postmining Lee Coulee is predicted in this section by reference to ground water quality data collected in Area A through water year 1996. Tab 17 previously analyzed probable postmining ground water quality characteristics of Area B based largely on spoil ground water quality data collected in Area A through 1986. The following narrative is intended to complement and update the predictions made in Tab 17, especially in regard to the potential quality of ground water that will restore vegetal productivity, biologic and open water functions of premining Lee Coulee.

Several qualitative and quantitative approaches are taken in Tab 17 to predict postmining ground water quality in Area B. These include comparison of predominate soluble parameter concentrations in Areas A and B overburden from saturated paste data, comparison of textural data from Areas A and B core samples, and calculation of the net increases in chemical constituent concentrations in ground water from premining undisturbed aquifers in Area A to the spoil ground water in Area A. The first two approaches provide qualitative evidence that the postmining ground water quality of Area B should not be inferior to that of Area A, but in fact, probably superior. As part of the third approach, average, flow weighted constituent concentrations in premining Area B ground water are adjusted by the ratio of their respective
increases from premining to postmining conditions in Area A to derive a quantitative estimate of postmining ground water quality in Area B. The reader is referenced to Tables 17-8e and 17-8f of Tab 17 for these calculations. With respect to total dissolved solids (TDS) concentrations alone, these results show that the postmining TDS concentration in Area B spoils should range from 2,400 mg/l to 3,000 mg/l, based on the assumption that the Area B constituent concentrations will increase by the same percentage over undisturbed (premining) mean background levels as the spoil water did in Area A. The ratio of postmining mean TDS to premining mean TDS in Area A was calculated to be 1.58, based on samples taken from 14 spoil monitoring wells through 1986.

In the period 1986 through water year 1990 the spoil ground water quality database in Area A expanded from 14 wells to 19 wells, but after water year 1990 nine spoil wells were deleted from monitoring as part of a revision to Big Sky’s monitoring schedule. The criteria used to select wells that were deleted from monitoring beginning in water year 1991 was consistent (stable) water quality and/or proximity to other wells that were retained in the monitoring program. Locations of wells included in the current monitoring schedule are shown on Exhibit A of the 1993 water year Area A Annual Hydrology Report. Taken as a whole, the historic database for Area A spoil ground water samples through water year 1996 consists of 19 wells having sampling frequencies that range from one event up to 23 events. For the entire historic database there are as many as 217 values available to define concentrations of certain critical chemical parameters, such as sulfate, chloride, boron and pH. Ground water quality and water level data collected each water year from Area A spoils have been reported in Big Sky’s annual reports.

The technique used in Tab 17 to predict postmining ground water quality in Area B is sensitive to the data population used to derive average constituent concentrations in Area A spoil ground water. Since the spoil ground water quality database has grown considerably in the period 1986 through 1996, it is appropriate to verify the conclusions made in Tab 17 by reference to the expanded spoil database. Table 16-2-10 has been prepared to show values of mean

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concentrations and ranges of concentrations of selected chemical constituents in Area A spoil ground water, based on the entire population of samples collected through water year 1996. The constituents reported on the table are those used to define suitability of water for livestock consumption, as taken from Table 3 of Big Sky Mine’s 1996 annual report. The livestock consumption criterion for mercury is not included on Table 16-2-10 because, of the 217 analyses for mercury, only one sample (well ASP35) had a concentration at the laboratory detection limit of 0.001 mg/l. At 0.001 mg/l the concentration was still only one-half the regulatory limit of 0.002 mg/l for inorganic mercury set by the U.S.E.P.A. for public drinking water supplies. The livestock criterion for nitrite-nitrogen is also not included on Table 16-2-10 because this constituent was not specifically analyzed in the monitoring program; however, of the 203 samples analyzed for nitrate plus nitrite as nitrogen, none exceeded the U.S.E.P.A. regulatory limit of 10 mg/l for nitrate alone established for public drinking water supplies. Clearly, neither mercury nor nitrite-nitrogen is of concern in Area A spoil ground water.

In examining Table 16-2-10 it is important to recognize that the statistical summaries have been developed for the entire database without regard to temporal changes in water quality at any site. Temporal changes in ground water quality are discussed in the 1996 annual report where it is concluded that TDS concentrations in ground water of Coalbank Coulee are still rising, whereas in Miller Coulee TDS levels have stabilized or are declining. The annual report further concludes that ground water in Area A spoils is suitable for livestock consumption with the exception of wells ASP22, ASP49 and ASP50A where sulfate and TDS concentrations still exceed livestock use criteria. The 1996 sample from well ASP50A was noted as being highly suspect, however, since its water level and water quality were substantially different from previous values. Table 16-2-10 shows that even with respect to minimum values, concentrations of sulfate and TDS exceed livestock use criteria in wells other than ASP22 and ASP49, including wells ASP63 and ASP67. Well ASP63, however, was sampled only once, in October 1984, while well ASP67 was sampled only twice, once in October 1984 and again in June 1985.
The salient finding shown on Table 16-2-10 is that, at 4641 milligrams/liter (mg/l), the mean TDS concentration of all ground water samples in Area A spoils is in close agreement with the mean value reported in Tab 17 (Table 17-8a), 4201 mg/l, for samples collected only through 1986. The updated value is biased high, however, by the extreme solute concentrations in well ASP22, which as described in the 1996 annual report, is believed to be influenced by a localized plume of highly mineralized water. If data from well ASP22 is deleted as an outlier from the database, the average TDS value reduces to 3982 mg/l, the average sulfate concentration reduces to 2328 mg/l and the maximum sulfate and TDS concentrations reduce to 4740 mg/l and 7420 mg/l, respectively. Both average values are well within their respective livestock use criteria shown on Table 16-2-10. From Table 17-8a, the mean premining TDS of Area A undisturbed aquifers was 2651 mg/l. The ratio of the spoil mean TDS value of 4201 mg/l to the computed premining aquifer mean TDS value in Area A of 2651 mg/l is 1.58, and similarly, the ratio of the mean TDS value of 4641 mg/l on Table 16-2-10 to the same premining TDS value is 1.75. Similarly, the ratio of the mean TDS value of Table 16-2-10 without well ASP22 (3982 mg/l) to the computed premining mean TDS value for Area A is 1.5. Under the conservative assumption that the Area B spoil ground water TDS values will increase over premining values according to the same ratios as did Area A, the mean TDS in Area B spoil ground water will range from 1.5 to 1.75 times the premining mean TDS value. In Table 17-8e of Tab 17 the mean, flow-weighted TDS value of premining aquifers in Area B is computed to be 1541 mg/l. Applying the range in multipliers of 1.5 to 1.75, the mean postmining TDS concentration in Area B ground water is then predicted to be between about 2310 mg/l to 2700 mg/l (1.5 x 1541 mg/l to 1.75 x 1541 mg/l). These values are significantly less than the 5000 mg/l upper limit set for livestock consumption.

Based on the developments presented in Tab 17 for spoil ground water quality data collected in Area A through 1986, the mean sulfate concentration in spoils was computed to be 2450 mg/l. Premining aquifers in Area A were found to have a mean, flow-weighted sulfate concentration of 1487 mg/l; meaning that the concentration of this constituent increased about 65 percent...
from premining to postmining environments. Inclusive of well ASP22, the mean sulfate concentration in Area A spoil ground water shown on Table 16-2-10 is 2745 mg/l, but exclusive of well ASP22 the mean sulfate concentration is 2328 mg/l. Relating these values to the mean premining sulfate concentration in Area A, as described above for TDS values, yields ratios ranging from 1.57 to 1.85 for premining versus postmining environments. In Table 17-8e of Tab 17 the mean, flow-weighted sulfate concentration in premining Area B aquifers is reported to be 763 mg/l. Multiplying this premining average concentration by the range of multipliers found in Area A yields predicted values of mean postmining sulfate concentrations in Area B of between 1200 mg/l and 1400 mg/l. These values are significantly less than the upper limit of 3000 mg/l for sulfate established for livestock consumption.

The results of updating the predictive analyses of Tab 17 with 10 years of additional spoil ground water quality data clearly support the conclusion made before that the average ground water quality of Area B will support the postmining land use of livestock grazing and associated livestock water consumption. Very likely, Area B spoil ground water will exhibit evolutionary trends in quality throughout the reclaimed area with water quality improving over time as antecedent moisture in the backfill is replaced with ground water invading from the undisturbed aquifers. Isolated areas of elevated solute concentrations may exist for some time in Area B backfill similar to what has been recorded at well ASP22 in Area A. Conversely, however, some areas of spoils may contain ground water of relatively low solute concentrations as may be the case ongoing in Area A. As an example, Table 16-2-11 is an analysis of a grab sample collected from the DNR impoundment in Area A in March 1997. Although in its position against a final highwall the impoundment is obviously recharged by ground water from undisturbed overburden and coal units, the impoundment also likely receives some ground water from spoils since saturated spoils occupy one side of the impoundment. Despite the hydraulic connection of the DNR impoundment with saturated spoils, the analysis of Table 16-2-11 shows water quality that is significantly superior to average premining concentrations in both Areas A and B.
As shown in the previous sections, postmining ground water elevations in Lee Coulee are expected to be very similar to premining conditions. Lee Coulee is predicted to experience ground water seepage into the reconstructed channel and valley floor over a channel distance of approximately 10,000 feet. The valley floor will intercept the top of the water table in resaturated spoils, and accordingly, ground water seepage to the postmining channel and valley floor can generally be expected not to begin until spoil saturation is in approximate equilibrium with potentiometric elevations in undisturbed aquifers surrounding Area B. Stated another way, seepage to Lee Coulee will not begin until the spoil volume is saturated from the bottom up. Ground water seepage to postmining Lee Coulee will occur late in the re-establishment of hydraulic equilibrium in the spoils after the majority of the spoil volume has been flushed with invading “fresh” ground water. As result, it is logical to expect from the evolutionary improvement of ground water quality documented in Area A that the quality of ground water ultimately discharging to Lee Coulee will be of superior quality to what will be observed during the initial resaturation of Area B spoils. In light of this conclusion and in consideration of the fact that average concentrations of principal solutes in Area B ground water are predicted to be about half of their respective livestock use criteria shown on Table 16-2-10, the final conclusion is reached that the quality of ground water discharging to Lee Coulee can conservatively be expected to be suitable for all postmining livestock and wildlife uses.

Similar to the natural increases of TDS concentrations in open water within premining Lee Coulee that were due to seasonal evapotranspiration of ground and surface waters, as is documented for the Turtle Pond in Tab 17, salts will seasonally accumulate in open waters that will exist in postmining Lee Coulee with final resaturation of spoils and the natural re-establishment of ground water seepage zones. The same processes of natural ground water seepage and subirrigation are being restored in postmining Lee Coulee; accordingly, some seasonal accumulation of salts in open waters and soils of the channel topography is inevitable regardless of the quality of the postmining spoil ground water. Salts that accumulate in the channel and low overbank of postmining Lee Coulee will, however, be flushed away each
average runoff year by natural runoff events that typically occur in spring and early summer.

Channel reconstruction designs for Lee Coulee provide for nonerosional conveyance of runoff while at the same time provide for approximately as broad an area of overbank flooding as existed in the premining landscape.

17.24.634(1)

Interim Reclamation for Immediate Restoration of Open Water Conditions

As stated in the previous section, the development of high water table conditions with related channel pools and open water reaches in postmining Lee Coulee will not take place until the Area B backfill has resaturated to near equilibrium potentiometric elevations. The resaturation sequence has not been estimated, but it may be on the order of decades, as has been observed in Area A backfill. Pit pumpage discharge rates from Area B have averaged about 170 gpm since early 1990 and it seems logical to expect that the ground water recovery rates in Area B will be at least as great as has been recorded in Area A.

A special interim reclamation plan has been prepared for Lee Coulee to ensure the immediate recreation of open water pooling upon completion of final valley floor reseeding activities. As mentioned in the section Channel and Floodplain Design Methodology, the channel and flood prone area of postmining Lee Coulee have been designed to replicate the natural variability of the stream. The interim reclamation plan involves the construction of one or more water supply wells in overburden sandstone units and the seasonal conveyance of water via pipelines from the well(s) to small “potholes” located at opposite ends of the reconstruction reach. Four potholes and the initial water supply well will be positioned approximately where shown on Exhibit 16-2-3. The potholes will be field fitted in the bottom of the stream channel in consultation with DEQ after the valley floor has been topsoiled and seeded. Each pothole is expected to be between approximately one to two feet deep beneath the reconstructed channel floor and some 10 to 50 feet long. As shown on Exhibit 16-2-3, Biostation 3 (BBIO3) will be located at or near the premining location. Finally, off-channel excavations will be constructed.
as replacement features for “Pond 1” and “Pond 2”. “Pond 1” and “Pond 2” are shallow, seasonal ponds located near the upstream end of the stream study buffer zone and were monitored during baseline monthly “wet-reach” surveys. The replacement ponds will be sized and located in manner similar to “Pond 1” and “Pond 2”.

Figure 16-2-14 illustrates the stratigraphy of the proposed interim water supply well and provides details for the conceptual well design. The well will penetrate a thick sequence of overburden sand that has consistently yielded water to BSCC’s nearby operating pit. The well will be constructed immediately outside of the mine’s regrading limit, as approximately shown on Exhibit 16-2-3. The well is expected to yield between five and 10 gallons per minute. If additional wells are needed, they may be constructed east of the initial well site where thick overburden sands are known to exist. Water will be conveyed from the well(s) to the reconstructed channel via pipelines laid on grade on the reclaimed topography. Additional pipeline segments will be added as needed to ensure that all channel potholes seasonally store water.

Big Sky Mine will operate the water supply well(s) and maintain water in the channel potholes during the growing season period of April through mid-September. If possible, the potholes will be kept full so that overflow from them may also create open water conditions through intervening reaches of Lee Coulee channel. Big Sky Mine will artificially recharge the reconstructed Lee Coulee channel with the following terms and considerations:

A) The artificial recharge process will begin only after the DEQ’s surface water hydrologist approves the plans for the artificial recharge;

B) In consultation with DEQ, the recharge quantity will be monitored with the existing monitoring network to assure that too much recharge is not introduced into Lee Coulee.

BSCC will operate and maintain the interim water supply well(s) and channel potholes until data are available to indicate that pools and open water reaches similar to premining Lee
Coulee have naturally developed in the reconstructed stream system. If the ground water and surface water resource in Lee Coulee has not recovered sufficiently at bond release, BSCC will establish a trust fund, in consultation with and as required by the Department, to maintain supply (production) wells, ponds, and/or other surface water or ground-water resource alternatives to support hydrologic recovery and approved postmine land uses. Data collected during each season's operation of the interim open water restoration system will be available to DEQ for review. In consultation with DEQ and after open water conditions have naturally developed in Lee Coulee, the interim supply well(s) and pipelines will be reclaimed or portions of them may be retained for postmining agricultural uses.

17.24.634(1)
Premining Versus Postmining Channel Characteristics

Table 16-2-12 compares premining versus postmining average channel slope, total channel relief and length characteristics on Lee Coulee for the proposed valley floor reconstruction reach. Only surficial disturbances will occur to the stream channel and valley floor outside of the reconstruction reach. Table 17-13 of Tab 17 and Table 20-2 of Tab 20 provide other premining versus postmining comparisons of basic channel and valley geomorphic characteristics, such as drainage basin areas, valley lengths, valley slopes and stream sinuosities.

Table 16-2-12 shows that the conceptual postmining channel length will be essentially identical to the surveyed premining channel length within the proposed valley reconstruction reach. The channel relief across the reconstruction reach will remain the same at 59 feet for the premining versus postmining scenarios, since the reconstructed channel will be tied-in to the premining channel floor elevations upstream and downstream of the reconstruction reach. All channel and valley floor disturbances upstream and downstream of the reconstruction reach will be only surficial and, with local regrading, will not affect the geomorphic/geometric characteristics of the stream/valley floor system. The gradient of the postmining channel
within the reconstruction reach will be essentially the same as premining. As described under the section Stream Channel and Floodplain Reclamation Design, the channel and overbank forms of the reconstruction reach have been designed to closely replicate the premining topography, most particularly premining geomorphic dimensions of bankfull width, bankfull depth and flood prone area width. The reconstructed channel and flood prone areas will be erosionally stable under the 100-year storm event.

Figure 16-2-15 visually compares the premining and conceptual postmining channel alignments of Lee Coulee. The alignment shown on the figure for premining conditions was taken primarily from horizontal and vertical coordinate surveys of the channel completed in July 2000 and October 2001. The figure is approximately centered on the reconstruction reach of the stream. Channel reaches upstream and downstream of the reconstruction reach are not shown because they will only be surficially disturbed by mine-related activities, if disturbed at all. The salient conclusion that can be reached with Figure 16-2-15 is that the postmining channel alignment nearly identically matches the pattern of the premining channel alignment. The wavelengths, amplitudes and curvature radii of the postmining meander loops therefore closely emulate the premining meanders. It is also noted that the normal streamflow in premining Lee Coulee is around the meander having the largest amplitude on the figure. Higher flows tend to “short circuit” across the top of this premining channel meander through the straight channel course shown on the figure. The conceptual postmining channel alignment purposely restores the meander of the largest amplitude because this particular meander conveys the normal flow of the stream.

As described in the section Channel and Floodplain Design Methodology, a minor guide channel may develop naturally on the design channel floor. The channel floor below the bankfull channel width has been designed to range in width from approximately 8 feet over the upstream segment of reconstruction to about 14 feet over the downstream segment of reconstruction. This will add to the geomorphic diversity of the stream. The final alignment
and length of the guide channel may ultimately vary slightly from the values shown on Table 16-2-12 for restoration of the bankfull width alignment.

17.24.304(5), 314, 645, 646

Hydrologic Monitoring Plan for Postmining Lee Coulee

The objective of the hydrologic monitoring plan for postmining Lee Coulee will be to assess ground water recovery rates and ground water quality and to monitor the quantity and quality of streamflow entering and leaving the valley floor reconstruction reach. Under the current mine and reclamation plan, a number of existing monitoring wells within and adjacent to Lee Coulee will be removed by mining. BSCC will add new backfill wells to replace those removed by mining at locations selected in consultation with DEQ. Some wells will be located so as to monitor ground water conditions within the reconstructed valley floor while other wells will be located so as to monitor ground water conditions in upland spoils up the ground water gradient from the valley floor. Water levels in new wells will be monitored on a quarterly basis and the new wells will be sampled semi-annually for analysis of the standard analytical suite recommended by DEQ. By comparing Exhibit 7-1 (Tab 7), Hydrology Monitoring Site Location Map, to the mine and reclamation plan sequence maps of this permit application, it can be seen that a number of existing monitoring wells lying near the reconstructed valley will remain after final reclamation. These include 100 series, 200 series and 2000 series monitoring wells, and stock well BUN 9110. The monitoring of these wells will provide an understanding of the rate of ground water recovery and ground water quality in units that are contiguous to and that will act as recharge sources to Area B backfill.

The Peep Site (BPSFL) and Marmot Mound (BMMFL) streamflow monitoring stations, which are far above and below the proposed valley floor reconstruction reach on Lee Coulee (see Exhibit 7-1, Tab 7) are not expected to be disturbed by mining activities. These stations will continue to be monitored after reclamation to assess the quantity and quality of streamflow entering and leaving the reconstructed reach. Randy Thomas station (BRTFL), located at the
downstream terminus of valley floor reconstruction, should not be disturbed by mining but
will be relocated near its present site after reclamation if necessary. Monitoring at all three
flume sites will continue after reclamation following the same schedule and procedures that
have been followed for the operational hydrologic monitoring program. In addition, monthly
water level measurements and quarterly water quality analyses (field parameters and laboratory
TDS measurements) will be collected at the post-mining pond/pool features established in Lee
Coulee. Finally, "wet reach" surveys similar to those conducted previously to quantify the
pre-mine upper Lee Coulee surface water resource (see Attachment 15-4) will be made to
assess post-reclamation conditions. BSCC will consult with the Department regarding the
timing, scope and frequency of the postmining "wet reach" surveys prior performing them.

Summary. A reclamation plan for postmining Lee Coulee has been presented that will ensure
the re-establishment of hydrologic functions and their associated biologic communities and
land uses. Hydrologic restoration will be accomplished following two approaches: 1) As part
of the permanent reclamation plan, the premining geomorphic dimensions that define bankfull
width, depth and alignment and flood prone area width will be restored, and a small guide
channel may develop naturally within the lateral dimensions of the bankfull area width; 2) The
utilization of one or more ground water supply wells to provide seasonal pooling in channel
potholes during an interim period beginning immediately after reclamation until ground water
recovery in the backfill is substantially complete. After resaturation of the valley floor backfill
is fully complete, the postmining water table will intercept the stream channel over a reach
approximately 10,000 feet long, which will be essentially equivalent to the length and position
of the premining wet reach. The quality of ground water in the backfill is not expected to be
substantially different than the quality of the premining ground water, based on observations
made at Big Sky's Area A.

16-2-46 Revised Sept. 2002


Johnson Division, UOP Inc., 1975, Ground Water and Wells: Johnson Division, UOP, Inc., Saint Paul, MN.


Triton Coal Company, 1994, Buckskin Mine Permit to Mine Application: Files of Wyoming Department of Environmental Quality, Land Quality Division, Sheridan, WY.


Table 16-2-7 Results of Analytical Solutions to Estimate Groundwater Elevations and Valley Floor Seepage Rates in Postmining Lee Coulee

<table>
<thead>
<tr>
<th>(1) Site No.</th>
<th>(2) Easting (Ft MSL)</th>
<th>Northing (Ft MSL)</th>
<th>(3) Approx. Premining Alluvial Water Table Elev. (Ft MSL)</th>
<th>(4) Premine/Postmine Overburden Water Elev. at Highwall (Ft MSL)</th>
<th>(5) Calculated Postmine Valley Floor Water Table Elev. at Site (Ft MSL)</th>
<th>(6) Calculated Flow Rate to Post-Mine Channel or Valley Floor (Ft³/day/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2711526</td>
<td>676477</td>
<td>3365</td>
<td>3360</td>
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<td>3359</td>
</tr>
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<td>2712558</td>
<td>675628</td>
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<td>3353</td>
<td>3362</td>
<td>3357 ?</td>
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<td>3333</td>
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<td>3</td>
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<td>3320</td>
<td>3306</td>
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<tr>
<td>5</td>
<td>2717746</td>
<td>672985</td>
<td>3285</td>
<td>3285</td>
<td>3310</td>
<td>3290</td>
</tr>
</tbody>
</table>

1. Sites are located on Exhibit 16-2-3.
2. The postmining longitudinal profile of Lee Coulee channel also showing a profile of groundwater elevations derived from this table is presented as Exhibit 16-2-5.
3. Approximate average premining alluvial water table elevations were taken from Exhibit 7-2 and from water level monitoring records compiled by Big Sky Mine.
4. The analytical solution for water table elevation (next column) is based on the assumption that overburden groundwater levels will recover to premining elevations outside the mining disturbance boundary. Overburden water elevations were taken from Exhibit 7-3.
5. Calculated valley floor water table elevations do not take into account the effect of evapotranspiration in depressing groundwater elevations.
6. This is the seepage rate to the postmining channel or to the valley walls above the channel in units of cubic feet per day per linear foot of seepage face. The calculations are based on an assumed value of 1.063E-5 Ft/sec for spoil hydraulic conductivity (0.90 ft/day). The water table elevation shown for Site 0 was calculated at a point on the phreatic profile upgradient of seepage Site No. 1, therefore a seepage flow rate cannot be calculated for Site 0.
Table 16-2-12 Premining and Conceptual Postmining Channel Lengths and Gradients on Lee Coulee

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>PREMINING 1</th>
<th>POSTMINING 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profile Distance Within Valley Reconstruction Reach</td>
<td>6,778 Ft</td>
<td>6,689 Ft</td>
</tr>
<tr>
<td>Total Channel Relief Within Valley Reconstruction Reach</td>
<td>59.2 Ft</td>
<td>59.2 Ft</td>
</tr>
<tr>
<td>Average Channel Gradient Within Valley Reconstruction Reach</td>
<td>0.0087 Ft/Ft</td>
<td>0.0089 Ft/Ft</td>
</tr>
<tr>
<td>Drainage Area At Downstream Limit Of Valley Reconstruction Reach</td>
<td>2352 Acres</td>
<td>2350 Acres</td>
</tr>
</tbody>
</table>

1. Premining and postmining channel and groundwater table longitudinal profiles are presented as Exhibits 16-2-2 and 16-2-5, respectively.

2. Taken from longitudinal surveys of the natural channel completed in July 2000 and October 2001.

3. A small guide channel may develop naturally across the lowest topographic plane beneath the bankfull width that defines the alignment of the reconstructed channel; consequently, the length (and alignment) of the final guide channel in the reconstruction reach may be somewhat different than the values shown here.
FIGURE 16-2-14 ANTICIPATED STRATIGRAPHY AND PROPOSED WELL CONSTRUCTION DETAILS FOR POSTMINING OPEN WATER REACH SUPPLY WELL

Seal Plate For Seasonal Above-Ground Well Discharge

Casing Top 18" Abv. Grd.

Concrete or Cement Grout Seal

5" ID Sch. 40 PVC Casing

Sch. 80 PVC Drop Pipe To Submersible Pump (Install Timer And Liquid Level Control Units On Pump Circuitry For Seasonal Well Operation)

Bentonite Chip Seal

No. 10-20 U.S. Standard Sieve Washed Silica Sand

No. 20 Slot PVC Screen

Blank PVC Casing

Total Depth Cased

PVC Slip Cap

Base of Coal Approx. 130'-150'

ROSEBUD COAL

NTS

STRATIGRAPHY EXTRAPOLATED FROM DRILL HOLES NOS. 5057E AND 5094E

file: Fig16_2-14.dwg

16-2-73

Revised September 2002
LEGEND

- AFFECTED LANDS BOUNDARY
- MINING DISTURBANCE BOUNDARY
  (BACKFILLING, GRADING AND HIGHWALL REDUCTION ACTIVITIES)
- PERMIT BOUNDARY
- DRAINAGE
- SURFACE CONTOUR
- TREND OF HYDROGEOLOGIC SECTION WITH CONTROL DRILL HOLE

FIGURE 16-2-2
HYDROGEOLOGIC CROSS SECTION LOCATION USED TO MODEL GROUNDWATER ELEVATIONS IN POSTMINING LEE COULEE

NOTE: TOPOGRAPHY SHOWN IS THAT OF THE FUT