SECTION 41

PROBABLE HYDROLOGIC CONSEQUENCES

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LIST OF EXHIBITS

EXHIBIT NUMBER	EXHIBIT TITLE
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LIST OF REVISIONS DURING PERMIT TERM

REV. NUMBER	REVISION DESCRIPTION	DATE APPROVED

SECTION 41 PROBABLE HYDROLOGIC CONSEQUENCES

This section provides an assessment of the potential for adverse hydrologic impacts from proposed mining and reclamation at the Pinabete Mine Plan permit area (permit area). The primary focus of the probable hydrologic consequences (PHC) is to predict the effects of proposed mining and reclamation activities on the prevailing hydrologic balance with respect to the quality and quantity of water in surface water and groundwater systems both during mining and after reclamation. The PHC assessment builds on the baseline hydrologic and geologic information contained in the permit application package (PAP) and observations of hydrologic consequences of mining at the adjacent Navajo Mine. The PHC also couples those data with detailed SEDCAD™ 4 (SEDCAD) modeling of surface flows and sediment yields, spoil leaching test results, and groundwater flow and chemical transport modeling in order to develop projections about potential hydrologic impacts in the permit area.

Disruption of the geomorphic surface and underlying geologic strata together with the associated surface and groundwater flow systems is necessary in order to extract the coal resource by surface mining. Surface coal mining and reclamation operations may affect the hydrologic balance in a several ways, including:

- changing groundwater levels, recharge rates, and flow directions as a result of removal of geologic strata by mining and by backfilling mine pits with overburden and interburden materials;
- exposing unweathered mineral surfaces in the geologic strata to weathering processes during mining and backfilling operations;
- changing the water quality of alluvial groundwater due to changes in groundwater flow patterns, groundwater levels, and transport of groundwater from mine backfill
- changing the quantity and quality of surface runoff and stream flows due to disturbances from mining including construction and operation of diversions, sediment control structures, and other best management practices (BMPs);
- altering surface topography and stream channels during mining and reclamation; and
- modifying stream channel characteristics due to changes in the flows and sediment relationships downstream of mining.

The PHC is a process for identifying these potential changes in the hydrologic balance that may result from proposed mining and reclamation. The PHC also identifies the appropriate preventive and remedial measures required to minimize the impacts to water resources and water uses. Any unavoidable impacts on existing water uses and water rights must be replaced subject to existing state, federal, and Navajo Nation water rights laws. The PHC lays the groundwork for the monitoring plans described in Section 35 (Hydrologic Reclamation Plan) and Section 42 (Monitoring, Maintenance, Inspections, and Examinations).

41.1 Acid-Forming and Toxic-Forming Materials

The assessment of potentially acid- or toxic- forming materials (PATFM) indicates an overall net alkaline environment for overburden and interburden materials that will be removed during mining and used to backfill the mine pit. This assessment draws on the detailed characterization of overburden and interburden materials provided in Section 17 (Geologic Information). This section summarizes the results of overburden and interburden sampling and analyses performed within the permit area. Statistical analysis of overburden and interburden quality data is provided in Appendix 17.E. In summary, the sampling and analysis results show that there is no widespread occurrence of PATFM overburden or interburden materials within the permit area.

The characterization has identified some limited locations within the permit area, where the acid-base potential values within interburden intervals are outside the root-zone criteria limits. These locations are limited and the intervals are thin compared to the total thickness of interburden to be excavated during mining such that the mine backfill will remain net alkaline (Section 17, Geologic Information). The plans for removal and backfilling of interburden materials, that ensure adequate blending and mixing of these thin strata so that zones of PATFM will not occur within mine backfill, are described in Section 20 (Mining Operations) and Section 34 (Post Reclamation Topography).

The assessment of PATFM also draws on the detailed testing of mine spoils that are planned to be placed in the mine backfill to help achieve approximate original contour requirements for mine reclamation. Leaching tests of mine spoils are provided in Appendix 41.A and are summarized in Table 41.1-1. The relevant criteria used for interpretation of leaching test results include the livestock watering criteria and the aquatic and wildlife habitat use criteria included in the Navajo Nation Surface Water Quality Standards promulgated by the Navajo Nation Environmental Protection Agency (NNEPA) (2008) and the livestock water quality criteria for total dissolved solids (TDS), sulfate and fluoride provided by Lardy et.al. (2008). The Lardy et.al. livestock use criteria and the Navajo Nation Surface Water Quality Standards are not enforceable standards for groundwater but are ~~included~~ used as guidelines for suitability of groundwater supplies for livestock use.

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These leaching tests included 18-hour batch leaching tests of composite mine spoils performed in accordance with the U.S. Environmental Protection Agency (USEPA) Synthetic Precipitation Leaching Procedure (SPLP, SW-846 Method 1312) and with the Synthetic Groundwater Leaching Procedure (SGLP). Also, the long-term leaching (LTL) procedure consisting of 45-day leaching tests was performed along with the standard 18-hour leaching procedure, in order to assess any changes associated with longer exposure to the leachant. The SGLP and the LTL procedure were developed at the Energy and Environmental Research Center (EERC) at the University of North Dakota and have been used for over 25 years to predict leaching behavior of solid waste materials under field conditions (Hassett et.al. 2003).

Composite spoil samples were obtained from Navajo Mine Area 3 in accordance with the regraded spoil sampling plan (Navajo Mine Permit Application Package, OSM Permit No. NM-0003F, Chapter 12) (BNCC 2009). A composite sample of coal seam water was comprised of equal proportions of water extracted from the No. 8 coal seam well KF2007-01 and from the No. 3 coal seam well KF98-02, located south and upgradient of the permit area. Two duplicate samples of the composite coal seam water were obtained and analysis results are presented in Table 41.1-1 as "Initial Coal Water Sample" and "Initial Coal Water DUP." The coal seam water sample was used for leaching the composite spoil sample for both 18-hour SGLP tests (Spoil Leachate 1 and Spoil Leachate 1 DUP) and a 45 day LTL test (Spoil 45-Day).

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Synthetic precipitation was prepared in the laboratory and used as a surrogate for field site precipitation that could percolate through the spoil backfill and provide recharge to groundwater and potentially surface water discharge. The prepared solution is highly purified water with strong solvating properties. The water quality is presented in Table 41.1-1 under the heading "Initial Synthetic Precipitation". This synthetic precipitation sample was used in the 18-hour leaching test of spoil (Spoil SPLP) that was performed in accordance with the SPLP method

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The leaching test results of mine spoils using both synthetic precipitation and site groundwater indicate that the pH of leachate remains neutral to alkaline. Thus, low pH values that are often a factor in enhanced trace metals transport would not occur within mine backfill. This finding is supported by data collected and conclusions reported for site wide geologic and hydrologic conditions in Section 17 (Geologic Information) and Section 18 (Water Resources), respectively. The synthetic precipitation leaching solution started with an initial pH of 5.0 and increased to a pH of 7.5 for spoil 18-hour batch samples. This indicates the buffering influence of spoil materials to slightly alkaline conditions. Based on the leaching test results, the concentrations of sulfate, calcium, magnesium, sodium, TDS, boron, and manganese are expected to initially increase in surface water infiltration or groundwater as they saturate mine spoils (~~Table 41.1-1~~Table 41.1-1). Nevertheless, the concentrations observed in mine spoil leachates are also within the range of concentrations observed in background groundwater within and near the permit area.

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Fluoride, sulfate, and TDS concentrations were also above the relevant livestock watering criteria in background groundwater collected from Pictured Cliffs Sandstone (PCS), alluvial deposits, and the Fruitland Formation (Section 18, Water Resources). However, fluoride concentrations were attenuated in mine spoil leaching tests. These results showed fluoride concentrations dropping from 2.4 mg/L in the composite coal seam water used for leaching to concentrations of 1.6 and 1.5 mg/L in the in 18-hour and 45-day spoil leachates, respectively.

41.2 Probable Hydrologic Consequences During Mining and Reclamation Operations

The PHC relies heavily on baseline hydrologic information and focuses particularly on the water resources that need to be preserved to support intended post-mining land uses. The detailed baseline groundwater and surface water information is presented in Section 18 (Water Resources) and is briefly summarized in this assessment.

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41.2.1 Groundwater Changes During Mining and Reclamation Operations

~~BHP Navajo Coal~~Navajo Transitional Energy Company (~~BNCC~~NTEC) has performed baseline monitoring of the groundwater quality of the alluvium in Pinabete and Cottonwood Arroyos. These results indicate poor water quality in the alluvium with TDS concentrations ranging from 1,500 to over 15,000 mg/L (Section 18, Water Resources). The alluvial groundwater in both Pinabete Arroyo and Cottonwood Arroyo is used for stock watering, although the TDS, sulfate, and fluoride concentrations in groundwater often exceed guidelines for livestock use (Lardy, et.al. 2008). Limited groundwater quality baseline data are also provided by Thorn (1993) for the Chaco River alluvium. The results indicate that the groundwater quality of the Chaco River alluvium is quite variable, with TDS concentrations ranging from 742 to 11,900 mg/L, sulfate concentrations ranging from 350 to 6,600 mg/L, and fluoride concentrations ranging from 0.4 to 1.7 mg/L. TDS concentrations in the Chaco River alluvium generally increase from south to north, i.e. in the down gradient direction.

The groundwater resource within and adjacent to the permit area supports marginal stock water use. One stock water well (W-0345) is completed in alluvium of Pinabete Arroyo within the permit area (Section 18, Water Resources). Another stock water well (W-0343) is completed in the alluvium of a tributary to Pinabete Arroyo adjacent to the Burnham Road (Section 18, Water Resources). This well is recharged by an adjacent manmade pond and is equipped with a hand pump. Several livestock water wells are also completed in alluvium of Cottonwood Arroyo north of the permit area, within the alluvium of the Chaco River west of the permit area, and within the alluvium of Pinabete Arroyo south and east of the permit area (Section 18, Water Resources). The saturated thicknesses and yields at these alluvial wells are quite low and vary spatially and with time. The alluvial groundwater levels are sufficient to provide stock water via windmill driven pumps at several of the dug wells during normal and wet years. However, groundwater levels are generally too low to supply water to any of the dug wells during very dry years.

There are no water supply wells completed in the Fruitland Formation within or adjacent to the permit area and there is one stock water well (13-15-1), located south of the permit area that may be completed in the PCS (Section 18, Water Resources). However, the completion zone for this well is uncertain and the well has been capped and welded shut. The groundwater yields from wells completed in the Fruitland Formation and in the PCS, which underlies the Fruitland Formation, are quite low and wells are typically pumped dry during testing and well purging for sampling. Also, the water quality in the PCS and Fruitland

Formation is poor and is generally unsuitable for domestic use or livestock use (Section 18, ~~Water~~ Water Resources).

The potential impacts to the groundwater balance that are addressed in this section include:

- disruption of the Fruitland Formation by mining,
- pit inflows from the coal seams and the PCS,
- drawdown of water levels in the adjacent alluvial aquifers, the Fruitland Formation coal seams, and PCS due to mining within the permit area, and
- changes in groundwater quality resulting from mining and reclamation operations

41.2.1.1 Groundwater Quantity Changes During Mining and Reclamation Operations

41.2.1.1.1 Impacts to Alluvial Groundwater

Baseline information indicates that saturated conditions occur within portions of the alluvium of Pinabete Arroyo and Cottonwood Arroyo. Drawdown of water levels in the Fruitland Formation adjacent to proposed mining operations could result in drawdown of groundwater in the alluvium of the South Fork Cottonwood Arroyo. However, for this to occur, the saturated strata in the Fruitland Formation must be directly connected to the saturated alluvium. Based on the nested wells along Pinabete Arroyo, it has been shown that in some locations the saturation in the alluvium is perched above unsaturated bedrock and is not hydraulically connected with the saturated strata in the Fruitland formation. Nevertheless, there may be some locations along the South Fork of Cottonwood Arroyo where drawdown of alluvial groundwater levels could occur as a result of the proposed mining. Likewise, the mine pits at Navajo Mine may also induce groundwater flow from the Cottonwood Arroyo alluvium, which would temporarily diminish groundwater flow in the alluvium downstream of mining. There are two livestock wells in the Cottonwood alluvium down gradient of the permit area that could be impacted by temporary reductions in alluvial groundwater flow. Neither well is currently used for livestock watering. Well W-0618 (#35) is a collapsed well located near alluvial monitoring well QACW-2. Well QACW-2 was usually dry during baseline monitoring. Well QACW–2B (#126) is a dug well that was monitored by ~~BNCC~~NTEC from 1986 to 1999 for baseline conditions. There was usually sufficient water in this well for sampling, but the groundwater at this well was found to exceed the recommended livestock use criteria for sulfate and TDS (Section 18, Table 18.2-11).

Drawdown of water levels in the Fruitland Formation adjacent to proposed mining operations are expected to have minimal impact on the groundwater in the Pinabete Arroyo alluvium. Perched alluvial groundwater was observed in nested wells along Pinabete Arroyo (Section 18, Water Resources), where the alluvium is closest to planned mining operations. Stock water well W-0345 is completed in the alluvium of Pinabete Arroyo at this location, but is not expected to be directly affected by proposed mining. Also, based on the perched groundwater in the alluvium at this location, proposed mining is not expected to result in a

drawdown of groundwater in the alluvium. Nevertheless, the well is within the permit area so livestock use of water from this well will be temporarily suspended throughout mining and reclamation. Planned mining will directly disturb the stock water well W-0343, which is completed in the alluvium of a tributary to Pinabete Arroyo. Section 32 (Temporary Structures and Facilities Removal and Reclamation) describes the plans for abandonment of wells prior to mining.

41.2.1.1.2 Groundwater Level Drawdown- in the Fruitland Formation and PCS

Open mining pits act as a drain to drawdown groundwater levels in the overburden/interburden and coal seams of the Fruitland Formation located adjacent to the pit. The amount of groundwater encountered during proposed mining is expected to be limited based on observations from exploration drilling and monitoring wells within and adjacent to the permit area area. Likewise, observations during mining at Navajo Mine Area 3 found that groundwater in the coal seams and overburden was insufficient to sustain pit inflows except on the south end of Dixon Pit adjacent to the Cottonwood Arroyo alluvium. There seepage from the highwall face in progressive strips has been sufficient to pool within the pit. At all other locations where seepage was observed along the face of the highwall, the seepage was removed by evaporation and did not pool within the mine pit.

The calibrated steady-state groundwater model of Area 4 North, Area 4 South and Area 5 of the BNCCNTEC's mining lease was used to simulate drawdown and recovery of groundwater levels during and after mining and reclamation (Appendix 41.BAppendix 41.B). The calibrated groundwater model was applied to perform transient simulations for mine pits advancing in 5-year increments as depicted in Figure 41.2-1Figure 41.2-1. The first increment in the sequence represents planned mining within Area 4 North in accordance with the Navajo Mine PAP (BNCC 2009). The other five year mining blocks for years 1 through 25 are for planned mining within the permit area.

Figure 41.2-2 shows the 5-feet drawdown in the No. 3 coal seam after 5-years that was provided in the Navajo Mine PAP based on simulations of 1-year pit progressions for the planned mining within Area 4-4 North in that permit. This figure also shows estimated 5-feet drawdown in the No. 3 coal seam at the end of mining in Area 4 North in accordance with the Navajo Mine PAP based on model simulations using a 5-year pit progression. Figure 41.2-3 provides a similar comparison for the simulated 5-feet drawdown in the PCS the end of mining within Area 4 in accordance with the Navajo Mine PAP based on 1-year and 5-year mine pit progressions. These results show that the extent of the 5-feet drawdown is greater for the simulation using the 5-year mine pit progression as compared to the simulation using 1-year pit progressions. Five-year pit progressions are performed for the subsequent simulations due to the time and effort required to manually enter each change in the mine pit during the transient simulations. Furthermore, the drawdown projections using 5-year pit progression are considered to be conservative or worst-case projections of the extent of drawdown. The 5-feet drawdown in these figures that are based on simulations

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with the 5-year pit represent the estimated initial condition at the start of mining within the permit area for the subsequent model simulations of the proposed 25-year mine plan.

The estimated 5-feet drawdown in the No. 8 coal seam in Year 25 at the completion of planned mining in the permit area is provided in Figure 41.2-4. The corresponding 5-feet drawdown in the No. 3 coal seam and in the PCS at the completion of mining in Year 25 are provided in Figure 41.2-5 and Figure 41.2-6, respectively. The No. 8 coal seam is representative of the upper coal seams (coal seams 6 through 8) while the No. 3 coal seam is representative of lower coal seams (coal seams 2 through 4). No water supply wells are located in the Fruitland Formation within the study area. Thus, the expected drawdown in the Fruitland Formation during mining will not affect any existing or anticipated future use. Likewise, the projected drawdown in the PCS will not affect any existing or anticipated future use. The layer of shale separating the bottom of the lowest coal seam and the PCS should serve to restrict groundwater inflow from the PCS during mining. The thickness of shale layer varies and has been included in the geologic model that has been used to define the layers in the groundwater model. No noticeable upward seepage from the PCS through the shale has been observed in the mine pits at the Navajo Mine and at the San Juan Mine even though the potentiometric levels in the PCS are typically above the pit floor. Therefore, the projected drawdown in the PCS will not affect any existing or anticipated future use. Drawdown in the Fruitland Formation is also not expected to affect water levels in the Pinabete Arroyo alluvium because groundwater in Pinabete Arroyo alluvium is beyond the estimated 5-feet drawdown extent and the alluvial groundwater is perched above unsaturated bedrock (Figure 41.2-4 and Figure 41.2-5).

Although the model predictions are hypotheses based on current data that will need to be re-examined as mining and reclamation proceeds, the modeling results are useful in predicting the likely range of changes in hydrologic conditions and the likely time frames that might be associated with these changes. An uncertainty and error analysis has been included in the model simulations to provide indications of the likely ~~affect~~effect of model error on the PHC predictions (Appendix 41.B). This PHC analysis of drawdown and recovery has relied on the best estimate for model parameters with sensitivity analysis adjustments in order to assess model prediction error and uncertainty in accordance with guidelines provided by the U.S. Army Corps of Engineers (USACE) (USACE 1999).

An error analysis on the effects of specific storage values for the various hydrogeologic units on the predicted extent of the 5-feet drawdown was presented in the groundwater modeling report (~~Appendix 41.B~~Appendix 41.B). The extent of the 5-feet drawdown was greater using the best estimates of specific storage of 2.8×10^{-5} per foot for the coal layers and 3.8×10^{-6} per foot for the non-coal layers as compared to the results using the FEFLOW default specific storage value of 10^{-4} per foot. Those results also showed that the drawdown extent in the deeper coal seams and the PCS was more sensitive to changes in the specific storage.

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Additional error analysis was performed for this assessment to compare the extent of the 5-feet drawdown for the base case determined using the best estimates with four other scenarios performed with variations in backfill recharge rates, backfill hydraulic conductivity, Fruitland Formation hydraulic conductivity, and specific yield of units as outlined in Table 41.2-1. Sensitivity of the results to specific storage was not performed in this analysis but was included in the groundwater modeling report (Appendix 41.B). All but scenario 4 were modeled using the parameters from the steady-state baseline model calibration. In scenario 4, the hydraulic conductivity of the Fruitland Formation layers were increased by 5 times the values obtained from model calibration.

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The 5-feet drawdowns at the completion of mining in Year 25 for scenarios 1 through 4 are provided in Figure 41.2-7 for the PCS, in Figure 41.2-8 for the No. 3 coal seam and in Figure 41.2-9 for the No. 8 coal seam. The drawdown results in the PCS and in the coal seams were similar to the results for the base case for all scenarios, indicating that predictions of drawdown extent are not sensitive to variations in backfill recharge rates, backfill hydraulic conductivity, and specific yield of non coal units. Previous results show that the extent of drawdown is more sensitive to the pit progression interval and the specific yield and specific storage of the coal seams.

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The extent of drawdown was not sensitive to the hydraulic conductivity of the Fruitland Formation layers as indicated by comparison of Scenario 4 with the other results. However, the initial heads in this scenario were significantly different from the other scenarios and from the steady-state calibration targets. When model parameters values are changed from the calibrated values the model provides a poorer representation of hydrogeologic conditions and the model results may not be reliable. This demonstrates that the error analysis for model predictions should not focus on the calibrated model parameters. Instead, the model error analysis should address the error or uncertainty in the storage parameters used for transient simulations and the hydraulic conductivity and recharge values for the backfill as these parameters were not calibration parameters in the steady-state model.

Modeling results and model error analysis indicate that the extent of drawdown of potentiometric levels in the Fruitland Formation coal seams and in the PCS is limited, although the extent is sensitive to the time interval for pit progression and to the specific storage value for the coal seams and the PCS. The base case results are believed to provide an upper bound estimate of the extent of drawdown because they are based on a 5-year pit progression. The extent of drawdown in these units has limited adverse impact to existing or future groundwater use. Drawdown of water levels in the Fruitland Formation could also result in drawdown of water levels in the Cottonwood Arroyo alluvium at limited locations where the alluvium is hydraulically connected to the saturated portions of the Fruitland Formation at locations adjacent to the mine pit.

41.2.1.2 Groundwater Quality Changes During Mining and Reclamation Operations

Groundwater quality changes beyond the active mine area will be minimal during mining and reclamation operations. During active mining, hydraulic gradients and groundwater flow directions in the adjacent Fruitland Formation and within portions of the underlying PCS will be toward the mine pits and backfill areas. Thus, it is expected that there will be little change in the quality of groundwater beyond the limits of the mine pit and mine backfill during mining and reclamation operations.

The water quality in the mine backfill materials will evolve as these materials begin to resaturate with recharge from groundwater inflows from the adjacent Fruitland Formation coal seams and from the underlying PCS. Dissolved solids present in the pore water of mine overburden and interburden materials (spoil) that are removed and backfilled may be concentrated by evaporation during mining. Also, there may be some enhanced weathering of the minerals within the newly fractured and broken interburden strata that are exposed during mining.

The characteristics of the overburden and interburden in the permit area were determined from an extensive drilling, coring, and testing program described in Section 17 (Geologic Information). Test results include analyses of saturated paste extracts of overburden and interburden samples. McWhorter and Landers (1985) have found that the results of saturation extracts from overburden samples correlate well with the antecedent pore water that is displaced in the first flush from backfill material in column leach tests. Electrical conductivity (EC) in saturated paste extracts of overburden and interburden materials indicates considerable variability. In-situ acid-base potential (ABP) characterization indicates a net alkaline environment for the majority of interburden layers across the permit area. Also, the leaching tests of mine spoil presented in Table 41.1-1 show~~s~~ that acid generation is not likely in the post-mine spoil water as pH increased in the SPLP to 7.5 from the pH of 5 for the synthetic precipitation. A pH of 8 was observed in the leaching tests using coal water (Table 41.1-1).

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The average values from the various interburden layers indicate a general decline in EC with depth from the overburden layer (I8) above the No. 8 (S8) coal seam to the lowest interburden layer (I2) above the No. 2 (S2) coal seam as summarized in Table 41.2-2. Higher EC is observed in the shallower overburden above the No. 6 coal seam (S6) as a result of increased weathering and oxidation. The influence of weathering and associated EC values decreases with depth. The mean plus one standard deviation of the EC values for the interburden units I6, I7, and I8 located above the No. 6, No. 7, and No. 8 coal seams, respectively, of 4.2 to 5.2 mmhos/cm provides a reasonable range for the EC that might occur in the first flush of pore water from weathered mine spoils placed in the backfill materials. The EC estimate based on the mean plus one standard deviation is considered to be representative for weathered and oxidized backfill materials because it eliminates the lower EC values that may correspond with unweathered material in

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these interburden units. Assuming a TDS/EC ratio of about 700 based on coal and alluvial groundwater in the permit area and the EC in saturated paste extracts from weathered overburden, the TDS concentrations in initial mine backfill waters would be expected to be on the order of 2,940 mg/L to 3,640 mg/L within the permit area.

Resaturation of the mine backfill will develop from precipitation recharge, lateral inflow from the coal seams and interburden of the Fruitland Formation, and upward flow from the PCS. The summary in ~~Table 41.2-3~~Table 41.2-3 provides spoil leaching test results for synthetic precipitation and for coal seam water. The TDS estimate of 1,200 mg/L for synthetic precipitation is thought to be too low for the initial mine spoils for the following reasons. First, the saturated paste test results from sampling of weathered overburden, as presented in Table 41.2-2, indicate TDS concentrations in initial mine backfill waters in the range from 2,940 mg/L to 3,640 mg/L. Also, the initial water source for the mine backfill will include much larger fractions of coal seam water and PCS water when water levels recover in the backfill. The TDS concentrations in these water sources will be considerably higher than the TDS concentrations leached from precipitation or in the SPLP leaching tests.

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At the Navajo Mine, the TDS concentration in the representative coal seam water used for the leaching tests was 9,800 mg/L. The TDS leaching test results of two spoil samples using this coal seam water were 11,000 and 12,000 mg/L (Navajo Mine Permit Application Package, OSM Permit No. NM-0003F, Chapter 11, Table 11-14b) (BNCC 2009). These results are also reasonably consistent with the TDS concentrations of 12,000 and 14,600 mg/L observed in spoil-water monitoring wells in the Bitsui Pit, as indicated in Table 11-14a of the Navajo Mine PAP, Chapter 11 (BNCC 2009). The consistency between the leaching test and field monitoring results supports the use of the leaching test results using coal seam water to predict initial backfill water TDS concentrations at the permit area.

Although the TDS concentrations observed at the wells completed in the spoils at the Bitsui Pit at Navajo Mine were considerably higher than the TDS observed in spoil leaching tests using coal seam water from the permit area, the mine backfill water source at the Bitsui Pit at Navajo Mine is from water sources with higher initial TDS concentrations. These sources include the No. 8 coal seam water with TDS levels of 5,000 to 10,000 mg/L near the Bitsui mine pit and groundwater seepage from adjacent Navajo Agricultural Products Industry (NAPI) irrigation plots. The TDS in seepage from NAPI irrigation plots is not known and is likely to be quite variable. In some cases, the TDS in irrigation seepage approaches TDS concentrations in mine spoil water due to leaching of soluble salts from weathered and unweathered materials in the Fruitland Formation. In contrast, the TDS concentration in the coal seam water at the permit area is lower and on the order of 3,000 mg/L.

Leaching tests were performed on Navajo Mine spoils using synthetic precipitation and a composite sample of coal seam water as described in Section 41.1. All of the constituents in coal seam water that increased in concentration after leaching through mine spoils are summarized in Table 41.2-3. The test results for spoil leached with coal seam water are believed to provide the best estimates for the groundwater source concentrations for long-term post-reclamation transport modeling as discussed in Section 41.3.1.2.

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41.2.2 Surface Water Changes During Mining and Reclamation Operations

Precipitation runoff from reclaimed areas might be reduced slightly from pre-mine levels due to lower slopes, enhanced vegetative growth from the use of better quality soils, engineered geomorphic drainage designs, and the use of other sediment-control BMPs that operate to retain water in the reclaimed areas.

41.2.2.1 Surface Water Quantity Changes During Mining and Reclamation Operations

Cottonwood Arroyo and Pinabete Arroyo will not be mined under the mine plan described in Section 20 (Mining Operations). Mining operations will temporarily intercept precipitation runoff from the tributary drainages that flow into the Cottonwood Arroyo and Pinabete Arroyo from the permit area. No stream diversions are anticipated to b~~th~~e needed for the proposed mine plan. The upgradient areas that drain to the mine pits are quite small and will either be intercepted by the mine pit or captured in temporary pit protection ponds located up gradient of mining. Precipitation runoff collected in the pit or in the pit protection ponds may be utilized for dust suppression, other mine needs, or will naturally diminish from evaporation and seepage (Section 25, Sediment Control Plan). Once reclamation is completed within the permit area, precipitation runoff from these reclaimed areas will flow through reclaimed channels to Cottonwood Arroyo, Pinabete Arroyo, and the unnamed tributary to the Chaco River and then into the Chaco River (Section 35, Hydrologic Reclamation Plan).

SEDCAD modeling was performed to evaluate peak flows and storm volumes under pre-mine, operational, and post-reclamation conditions on Pinabete Arroyo, Cottonwood Arroyo, and the unnamed tributary to the Chaco River. This tributary is located south of Cottonwood Arroyo and north of Pinabete Arroyo and originally drain~~s~~ed an area of about 0.45 square miles on west side of the permit area (Exhibit 41.2-1). The Chaco tributary now drains an area of 0.98 square miles under the revised post-mining topography. SEDCAD is a commercially available software package with routines derived from the Natural Resources Conservation Service Technical Release No. 55 (NRCS 1986). Application of the SEDCAD program involves subdivision of the drainage Area into subwatersheds and establishment of a linked network of routing between the watersheds. Designation of subwatersheds with relatively uniform surface characteristics enhances the application of model assumptions and improves the estimation of results. SEDCAD calculates the runoff response to a given precipitation event for specific surface topography, soil, and vegetative cover conditions. Curve numbers were assigned to subwatersheds based on their soil and cover characteristics. Information is designated for physical characteristics of channel segments that may

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affect flow-routing within channels. A medium hydrologic response class was utilized on all model runs. The 2-year, 10-year, 25-year, 50-year, and 100-year 6-hour (100yr-6hr) events were modeled with SEDCAD. Pre-mine modeling may be reviewed in Appendix 18.B. Operational and post-reclamation modeling may be reviewed in ~~Appendix 41.C~~Appendix 41.C and Appendix 41.D, respectively.

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Prior to reclamation, ~~BNCC~~NTEC plans to contain all mine disturbed area drainage in the mine pit or in designed runoff containment structures. The bermed containment structures and the mine pit function to contain the runoff from a 100yr-6hr precipitation event or larger. During reclamation, sediment ponds are designed to retain at a minimum the volume of runoff from a 10yr-24hr plus addition volume for sediment storage. Sediment ponds are used to contain and treat water until approval is obtained for use of alternative sediment controls in accordance with 40 CFR Part 434 Subpart H. This subpart applies to alkaline mine drainage from reclamation areas, brushing and grubbing areas, topsoil stockpiling area, and regraded areas at western coal mines. It allows operations to employ alternative sediment controls that are established in accordance with a sediment control plan that is designed to prevent an increase in the average annual sediment yield from pre-mined undisturbed conditions.

Peak flows and runoff volumes to Pinabete Arroyo and to Cottonwood Arroyo will be reduced during operations with worst-case projections shown in Table 41.2-4. The worst-case results in this table are based on no discharge up to the flows from a 100yr-6hr precipitation event from the mine area. Full containment of surface runoff over the entire mine area is unlikely to occur as some of the sediment ponds on reclaimed areas may discharge during precipitation runoff for events greater than a 10yr-24hr event and some areas may be approved for use of alternative sediment controls before containment systems are constructed for all of the planned mine disturbance area.

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It is anticipated that Stevenson's Well Pond will be mined through along with Pond 4N/4S and ~~one unnamed p~~Pond 4N located ~~within the northwest portion of the permit area on a tributary to Cottonwood Arroyo~~ (Exhibit 18.1-2). Pond 4N/4S, Pond 4N and the Stevenson's Well Pond are all located on tributaries to Pinabete Arroyo. The Gilmore Depression shown on Exhibit 18.1-2 will also be mined through. The Gilmore Depression rarely has water even after large precipitation events. There are no surface water right filings within the permit area, although there may be occasional use of these ponds by livestock and wildlife when water is available. Sections 41.3.2.3 and 41.4 provide~~s~~ further discussion of the potential short-term and long-term impacts to surface water sources that may be used for livestock ~~and~~, wildlife and aquatic life in the permit area.

41.2.2.2 Erosion and Sediment Yields During Mining and Reclamation Operations

Under baseline conditions, sediment in the Chaco River, Pinabete Arroyo, and Cottonwood Arroyo is derived from a variety of natural sources, including:

- erosion of soils on the hillsides, particularly from badland areas;
- erosion from roads and disturbed areas; and
- erosion of bed or banks of the stream channels.

The erosion, sedimentation, and landscape evolution in semiarid drainage basin systems is unique in comparison with fluvial systems in more mesic environments. Several studies of basin sediment yield in the Southwest have found that channel incision and stream-bank erosion of alluvial channels contribute the majority of the total sediment yield from the drainage basin (Rosgen 2001). Ultimately, however, the primary source of the sediments in channel erosion is surface erosion from the contributing watershed. Sediments delivered to the valleys from the hill slopes and first-order drainage swales are typically carried only short distances within ephemeral streams during storm flow events. Sediments stored within the ephemeral stream valley result in progressive steepening of the valley slope. Also, ephemeral streams often deposit fans of material upon entering a larger valley with lower valley slopes. These fans of material can extend across the valley from the mouth of tributary drainages, resulting in convex valley segments. This deposition of sediments continues until flushing of the sediment takes place by gullying (Schumm et.al. 1980).

Thus, gullying and channel instabilities are common natural features in arid and semiarid landscapes. The cycle of incision and filling is called arroyo evolution (Schumm et.al. 1984; Gellis et.al. 1991). Arroyos are incised channel systems that carry large volumes of sediment during ephemeral flow events. Following channel incision, an arroyo evolves through time from a narrow, V-shaped gully with low width-to-depth ratios to a wide U-shaped channel. Sediment deposition and channel aggradation increase with the increase in channel width. With channel aggradation, a floodplain and small channel system develop within the wide U-shaped channel. Channel aggradation within the ephemeral stream valley results in steepening of the valley slope that continues until channel incision occurs with a repeat of the cycle of arroyo evolution. The stage within the arroyo evolution cycle varies spatially along an ephemeral stream valley, with channel incision occurring within some segments and channel aggradation occurring in other segments. This process of arroyo evolution with segments of channel incision and head cutting and segments of channel aggradation is a common phenomenon throughout the Southwest and is evident in the unnamed tributary to Chaco located on the west side of the permit area and in the reach of No Name Arroyo between the Burnham Road crossing and its confluence with the Chaco River.

Section 25 (Sediment Control Plan) provides a description of the plans and measures to be taken to control sediment and erosion during surface coal mining and reclamation operations. While these measures prevent additional contributions of suspended solids to stream flow outside of the permit area, these activities will not function to prevent the natural off-site erosion and stream channel evolution processes that currently exist downstream of the permit area.

~~BNCC~~NTEC will route all disturbed area runoff to sediment ponds or implement alternative sediment controls, as described in the sediment control plan in Section 25. Sediment ponds and BMPs for sediment control will stay in use through bond release period or until demonstrations that runoff from the disturbed areas will not contribute quantities of suspended solids greater than those generated pre-mining. Water management techniques, as described below, will reduce the impact of mine disturbance on off-site sediment transport to surface waters down gradient of the permit area. A National Pollutant Discharge Elimination System (NPDES) Multi-Sector General Permit (MSGP) Sector H, Stormwater Pollution Prevention Plan (SWPPP) will be maintained during the construction and operational phases of mining and reclamation. This SWPPP will be maintained and available to the regulatory authority for review at the mine site.

Mine development will be initiated with the establishment of transportation features. Maximum road disturbances will be surveyed and storm-water BMPs will be employed. These may include but are not limited to the use of silt fences, rock check dams, straw wattles or fiber logs, straw bales, and soil berms between the disturbed area and down gradient channels or adjacent undisturbed areas. Topdressing materials will be salvaged and placed in protected stockpiles aligned and shaped to minimize wind and water erosion. Protection will consist of a drainage berm around the base of the stockpile and the surface stabilized to prevent the loss of topdressing material and the additional contribution of sediment from these stockpiles. Refer to Section 22 (Support Facilities) and Section 25 (Sediment Control Plan) for additional control measures and the operation of stockpiles.

Road construction will include the establishment of road fill embankments and associated road drainage structures, such as culverts across drainage swales and road ditching adjacent to primary roads. Diversion ditches may be established above road cuts to minimize flow across the cut. Berms, ditches, or downdrain pipes will be installed along the groin of road fills to safely pass water from the crest of the embankment to the toe. Energy dissipating BMPs will be utilized to control velocity at outlets of culverts, along steep slopes associated with embankments, and in areas exhibiting visual evidence of down cutting. Further discussion on road design and sediment and drainage control plans is found in Section 23 (Roads), Section 25 (Sediment Control Plan), and Section 26 (Drainage Control Plan).

Temporary sediment control will also be utilized during the construction of sediment ponds, most often through the use of containment berms, silt fences, or straw waddles. Suitable topdressing materials will be removed from areas disturbed for sediment ponds and ditch construction and placed in topdressing stockpiles (Sections 20, Mining Operations; Section 22, Support Facilities; Section 25, Sediment Control Plan; and Section 36, Post-Reclamation Soil).

Sediment ponds will be engineered to retain either a 10yr-24hr or 100yr-6hr storm event plus additional storage for sediment (Section 26, Drainage Control Plan). Spillway outlets will be armored with riprap, if necessary, to reduce erosive velocities during discharge. Sediment ponds will be used within the permit area to capture and/or treat surface water runoff from disturbed areas, including mine spoils, areas undergoing topdressing stripping, ancillary support facilities, and other disturbed areas within the permit area. Runoff from some of these disturbed areas may be intercepted by the active mine pit. Excess water in the mine pit during large storm events may be collected in pit sumps and pumped to one or more of the sediment ponds or managed as described in Section 25 (Sediment Control Plan).

Coal will be hauled by truck on haul roads to coal handling facilities outside of the permit area. Drainage control BMPs will predominantly include berms, side ditches along the roads, with ditch relief drains located at low points. If the flow velocity in a ditch channel or ditch relief drain exceeds the erosive velocity, an appropriate type of BMP will be utilized for controlling sediment and erosion (Section 26, Drainage Control Plan).

The perimeter 69-kV power line will also include a construction/maintenance road that will utilize culverts or low-water crossings to minimize the potential for vehicle travel through flowing channels (Section 23, Roads). Subsequent disturbances for ancillary facilities will be developed using the principles described above. The outside disturbance perimeter will be marked and down gradient areas will be protected from disturbed area runoff initially with earthen berms, silt fences, straw wattles/fiber logs or brush dams, and then sediment ponds capable of containing either the 10yr-24hr or 100yr-6hr storm event will be constructed. Water from these disturbed areas may alternatively be directed toward a mine pit, which will eliminate all potential for off-site discharge (Section 25, Sediment Control Plan, and Section 26, Drainage Control Plan). Areas disturbed during construction but not needed for operations and maintenance will be reclaimed in accordance with Section 37 (Post-Reclamation Vegetation).

In summary, erosion and sediment control for mine disturbance will employ BMPs to minimize erosion and the migration of sediment. Sediment yields from the mine area will be lower during mining and reclamation as disturbed area runoff and associated sediments are retained in sediment ponds, within berms, and within the mine pit. Excess water in the pit resulting from extreme precipitation events may be pumped to one or more of the sediment ponds. However, discharge from sediment ponds is expected to be rare based on large design capacities and the operational experience at the nearby Navajo Mine. Consequently, there will be little contribution of sediment to surface waters outside the permit area, as the sediment and runoff from all but the occasional extreme event (much larger than the 10yr-24hr event) are retained within the mine pit and sediment ponds. In addition, any such discharges will be further managed under applicable provisions of ~~BNCC~~NTEC's NPDES permit and applicable NPDES regulations.

SEDCAD modeling was performed to evaluate sediment generation under pre-mine, operational, and post-reclamation conditions for drainages traversing or intersecting the permit area. Projections on sediment yield are developed based on storm-specific flows and six parameters associated with sediment yield: soil texture, soil erodibility constants, representative slopes of overland flow within the watershed, representative lengths, cover, and management practices. Soil samples were acquired from selected representative soil types around the mining lease and sent to the University of Kentucky for assessment of the erodible particle size textural distribution (Appendix 18.B). These data were applied to mapped soil types within the permit area and adjacent watersheds and utilized to develop representative particle size distributions for use within the SEDCAD model. The results, coupled with applicable county soil survey textural information or texture data from soil mapping at the adjacent Navajo Mine were also employed to assign soil erodibility constants. Slope and length information were acquired from ArcGIS™ slope analyses of the watersheds. Cover information was applied to the subwatersheds from vegetation mapping and the management factor was assigned a value of 1 for all subwatersheds. Copies of pre-mine SEDCAD runs are provided in Appendix 18.B. Exhibit 18.B-1 shows the subwatersheds associated with the pre-mine SEDCAD drainage network delineation. Copies of operational and post-reclamation SEDCAD runs are provided in Appendix 41.C and Appendix 41.D, respectively. Exhibit 41.2-1 displays the subwatersheds associated with the post-reclamation models. This exhibit also identifies the subwatersheds that will contain storm runoff during mining operations.

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Operational and pre-mine sediment yield projections from SEDCAD modeling are summarized and compared in Table 41.2-5. Results are quantified by sediment yield in tons/event. The effects are assessed with the modeling of Pinabete Arroyo at the confluence with the Chaco River, Cottonwood Arroyo at the confluence with the Chaco River, and the unnamed tributary to Chaco River downstream of the permit boundary as shown on Exhibit 41.2-1. Sediment yields reaching the Chaco River from Pinabete Arroyo, Cottonwood Arroyo, and the Unnamed Tributary to Chaco River are lower under operational conditions in comparison with the pre-mine baseline yields as shown in Table 41.2-5.

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41.2.2.3 Surface Water Quality Changes During Mining and Reclamation Operations

Interaction between storm water runoff and newly exposed overburden, interburden, coals, and mine spoils may result in increases in TDS, sulfate, and manganese in surface runoff as suggested by the SPLP leaching tests of mine spoils presented in Table 41.1-1. Also, the SPLP leaching test of mine spoil shows that acid generation is not likely in the surface runoff from disturbed areas and spoil water as pH increased in the SPLP to 7.5 from the pH of 5 for the synthetic precipitation. Surface runoff from disturbed areas will be retained in the mine pit, sediment ponds, or berms. Thus, potential changes in surface water quality are expected to be negligible in Pinabete Arroyo, Cottonwood Arroyo, and the Chaco River during mining and reclamation operations as mine water is unlikely to reach these arroyos except during extreme precipitation events that exceed the designs of the containment structures. Mine disturbance will also generate

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additional sediment, but the water and sediment control measures, as outlined in Section 41.2.2.2, will prevent additional contributions of sediment to streams outside the permit area.

Motor fuel storage and equipment maintenance will be provided at the Navajo Mine facilities located outside of the permit area. Nevertheless, equipment repair may on occasion need to be conducted within the active mining or reclamation areas. ~~BNCC~~NTEC maintains and implements a Spill Prevention, Control, and Countermeasure (SPCC) plan that identifies areas of risk, specifies appropriate controls for bulk storage areas, identifies control strategies for managing potential spills, and lists procedures for safely disposing of any contaminated materials.

Federal and state or tribal water quality standards will be met during surface coal mining and reclamation operations at the permit boundary, due to the use of perimeter berms and sediment ponds to contain runoff within the permit area. The NNEPA has designated four uses~~-~~ for surface waters ~~of drainages~~ within the permit area~~, including~~: livestock watering (LW), aquatic and wildlife habitat (A&WHbt), fish consumption (FC), and secondary human contact (ScHC) (NNEPA 2008). Baseline surface water quality meets livestock and secondary human contact criteria (Section 18.1). The baseline water quality in a couple of the surface water and pond samples exceeded the fish consumption criteria for cadmium and mercury. The chronic aquatic and wildlife criteria are more often exceeded in the ~~B~~baseline surface water ~~quality~~results. The samples from the ponds and from Pinabete Arroyo and No Name Arroyo occasionally exceed~~s~~ the chronic aquatic and wildlife criteria~~standards~~ for aluminum, cadmium, copper, mercury, selenium, and zinc ~~in Pinabete Arroyo and in No Name Arroyo~~ (Section 18, Water Resources). ~~Also~~Although mercury is reported as less than detection in a number of samples, the ~~-~~chronic aquatic ~~criteria~~ criterion for mercury is below the detection limit of the analytical method used to analyze surface water samples. There is no numeric surface water use criterion for total suspended solids (TSS). However, the baseline results show very high TSS concentrations in the ephemeral stream ~~When~~ flows. ~~occur, sediment loss results in significant concentrations of total suspended solids (TSS).~~ ~~-~~Section 41.4 discusses the short-term and long-term impacts to surface water resources.

41.2.3 Changes to the Hydrologic Balance During Mining and Reclamation Operations

The mine will be developed in a planned, orderly progression to facilitate development of the operation while protecting the hydrologic balance. Mine planning incorporates the use of BMPs into all development activities potentially impacting water. BMPs may include but are not limited to minimizing inflow into the project area, eliminating traffic through flowing channels, and routing disturbed area runoff generated by storm events into either the mining pit or into sediment ponds.

The primary changes in the hydrologic balance during the surface mining and reclamation operations will be changes in ephemeral stream flows in Pinabete Arroyo and Cottonwood Arroyo that occur as a result of

the containment of surface runoff within the mine area. These changes in flow are not expected to measurably affect the Chaco River due to the ephemeral nature of tributary flows and the relatively small drainage area of the tributaries relative to the drainage area of the Chaco River. The drainage areas of Pinabete and Cottonwood Arroyos represent only 1.4% and 1.8%, respectively, of the total Chaco River drainage basin

Groundwater within the mine areas will also be affected by the drawdown of potentiometric levels in the Fruitland Formation coal seams and the PCS adjacent to the permit area. The groundwater in the Chaco River alluvium will not be directly affected by mining and is beyond the projected drawdown of water levels in the Fruitland formation and PCS that is expected to occur as a result of mining. The drawdown in the Fruitland formation and PCS during mining is also unlikely to affect the groundwater levels in the Pinabete Arroyo alluvium due to the limited drawdown in the bedrock below the Pinabete Arroyo alluvium (~~Figure 41.2-2~~Figure 41.2-2, Figure 41.2-3, Figure 41.2-4, Figure 41.2-5, and Figure 41.2-6) and the occurrence of perched groundwater within portions of the Pinabete Arroyo alluvium. Drawdown in the bedrock units during mining could affect water levels in the Cottonwood Arroyo alluvium where the groundwater is not perched. Thus, the alluvial groundwater flow along Cottonwood Arroyo might diminish downstream of mining during mining operations. Based on the valley gradient for Cottonwood of about 0.5%, an average hydraulic conductivity of 51 feet/day for the alluvium, the average saturated thickness of 2.5 feet estimated from monitoring wells and the estimated width of alluvium 500 feet, the steady-state groundwater flow in the alluvium is only about 1.7 gallons per minute (gpm). Some alluvial groundwater flow is likely to continue due to recharge from surface runoff and periodic release of flows from the irrigation canals associated with the NAPI. The potential effect of the predicted reduction in Cottonwood Arroyo alluvial flows on Chaco River alluvial flows is low.

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Baseline groundwater flows in the Chaco River alluvium are estimated to be between one and two orders of magnitude higher than the groundwater flows from the Cottonwood Arroyo alluvium. Assuming that the hydraulic conductivity of the Chaco River alluvium is the same as the 51 feet/day value obtained for the Pinabete Arroyo alluvium and that the saturated thickness of the Chaco River alluvium is only 6.7 feet as observed at a well completed in the alluvium of the Chaco River southwest of the permit area by Metric Corporation (1991), the flow in the Chaco River alluvium is estimated at approximately 18 gpm or about 11 times the estimated alluvial flow in the Cottonwood Alluvium. The average width of the alluvium was estimated at 3,998 feet based on the average width of the mapped alluvium in the Geologic Map of New Mexico (Anderson and Jones 1994) for the segment of the Chaco River valley west of the permit and the slope of the potentiometric surface in the Chaco River alluvium was assumed to be the same as the valley gradient of 0.25% measured from the topographic map of the Chaco River valley segment west of the permit area. The groundwater flow rate in the Chaco River alluvium could be as much as an order of

magnitude higher if the hydraulic conductivities and saturated thickness are greater than the estimates assumed in the calculations presented above.

It is also expected that the groundwater flow rates in both the Cottonwood Arroyo alluvium and Chaco River alluvium vary seasonally and from year to year. Existing water use of the Chaco alluvium is limited. The inventory of water wells in Exhibit 18.2-1 shows four livestock water wells completed in the alluvium of the Chaco River down gradient from the Cottonwood Arroyo confluence. A reduction in alluvial groundwater flow on the order of 1 to 10% is low relative to the year-to-year fluctuation observed in the alluvial groundwater wells that have been monitored and would not be expected to materially affect the water supply for these wells.

41.3 Post-reclamation Probable Hydrologic Consequences

41.3.1 Post-reclamation Groundwater Changes

The mine pits will be backfilled and reclaimed following the extraction of the coal resources, and the groundwater regime within and adjacent to the permit area will start to move towards a final equilibrium. The groundwater chemistry will also evolve over time as resaturation of the mine backfill occurs through recharge from precipitation, lateral inflow from the coal seams and interburden of the Fruitland Formation, and upward flow from the PCS. The potential impacts to the groundwater balance that are addressed in this section include:

- The rate and extent of saturation of the mine backfill;
- The rate and magnitude of recovery of water levels in the Fruitland Formation coal seams, and the underlying PCS;
- Potential changes in groundwater recharge rates, flow directions, and flow rates; and
- Possible changes in groundwater quality resulting from flow through the spoil backfill of the mine pit

41.3.1.1 Post-reclamation Groundwater Quantity Changes

The mining and reclamation of the Fruitland Formation will result in the removal of the individual coal seams and the backfilling of the mine pit with overburden and interburden materials (spoil) removed during mining. Under baseline conditions the coal seams have higher hydraulic conductivities than the interbedded shales, resulting in large downward vertical potentiometric gradients through the Fruitland Formation (Section 18, Water Resources). Lateral flow within the Fruitland Formation occurs primarily in the coal seams (Section 18, Water Resources). One of the primary hydrogeologic changes to occur as a result of mining is the removal of the coal, the interbedded shales, and the sandstone strata, resulting in more homogeneous and isotropic conditions within the mine backfill. The overburden and interburden material placed in the mine pit as backfill will be broken up during mining and will have higher porosity and hydraulic conductivity than in-situ interbedded sedimentary deposits of the Fruitland Formation.

Laboratory measurements of pre-mine overburden core indicate porosity values of about 0.35 while porosity of mine spoils is on the order of 0.4. The higher porosity of the backfill is also expected to result in a higher hydraulic conductivity in comparison with the same material in its pre-mine setting.

Horizontal hydraulic conductivity values of pre-mine overburden and interburden strata are expected to range from 8.63×10^{-3} feet/day to 2.8×10^{-5} feet/day based on regional information from Kaiser et.al. (1994) and Frenzel (1983). The hydraulic conductivity estimates from laboratory measurements of two pre-mine overburden samples from the Navajo Mine are within this range. A horizontal hydraulic conductivity of 5.0×10^{-4} feet/day was found to best estimate for the unweathered interburden materials from model calibration.

A hydraulic conductivity value of 5.63×10^{-2} feet/day has been used in the post-reclamation Base ~~model~~ Model for the mine spoils in the backfill below 10 feet of the final reclaimed surface. This estimate for hydraulic conductivity of mine spoils was between the average of 1.13×10^{-2} feet/day estimated from laboratory tests on five mine spoil samples from the Navajo Mine and the estimate of 2.27×10^{-1} feet/day obtained by Rehm et.al. (1980) from the geometric mean of 40 hydraulic conductivity values measured for mine spoils in the Northern Great Plains. Often well test measurements of saturated hydraulic conductivities are higher than the values obtained from laboratory analysis of samples. Thus, the value selected as the best estimate for the hydraulic conductivity of mine spoils was higher than the estimates obtained from laboratory tests but well within the range of estimates provided by Rehm (1980) for western mine spoils. The results from Rehm et.al. (1980) are relevant because they include measurements from well tests of saturated spoils and they provide relevant information concerning the range and average values of hydraulic conductivities saturated mine spoils generated at western mines for a range of lithologies and a range of mining and recontouring methods. For the model layer representing the upper 10 feet within the mine backfill, the hydraulic conductivity value was increased by ten times to represent the hydraulic conductivity of weathered spoil and topdressing material.

Hydraulic parameters for mine spoils that were used for modeling post-reclamation conditions are summarized in Table 41.3-1. Given some degree of uncertainty in the ultimate hydraulic conductivity of mine spoils, the value selected for steady-state modeling was considered to be a reasonable upper bound for the hydraulic conductivity of the spoils over the long term. This value is approximately 5 times higher than the average of the laboratory measurements on representative spoil samples, 10 times higher than the model calibrated hydraulic conductivity of the weathered overburden and 100 times higher than the model calibrated hydraulic conductivity of the unweathered interburden material. The hydraulic conductivity of 1.13×10^{-2} feet/day estimated from laboratory tests on Navajo Mine spoils was considered to be a reasonable lower-bound estimate for hydraulic conductivity of mine spoils and was used to represent mine spoils in the transient model. As discussed below, this lower-bound estimate of backfill hydraulic conductivity provides

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a higher magnitude of water recovery in the mine backfill than those determined using higher estimates for the hydraulic conductivity of the backfill.

The recharge rate estimates used for modeling post-reclamation conditions are summarized in ~~Table 41.3-1~~Table 41.3-1. Lower slopes and placement of topdressing materials within reclaimed areas are expected to result in higher recharge than the range from 0.002 to 0.03 inches per year obtained from the estimates from Stone (1987) assigned to the pre-mine surfaces based on slope categories. A recharge rate of 0.04 in/year determined by Stone (1987) as the mean recharge rate for reclaimed areas at Navajo Mine excluding depressions was used as a reasonable estimate of recharge rate for reclaimed mine areas over the long term following reclamation. This recharge rate is approximately twice the average pre-mine rate and reflects the improved surface and soil conditions resulting from mine reclamation. Stone (1987) estimates a recharge rate of 0.16 in/year for depressions during mine reclamation and the 0.4 in/year for final reclamation. A recharge rate of 0.10 in/year was used for mine spoils during mine reclamation in the transient modeling. This recharge rate represents an average rate for the mine backfill in various stages of reclamation.

The extent of drawdown at the end of mining in the No. 8 coal seam, the No. 3 coal seam and the PCS were presented in Section 41.2.1.1. The same transient model simulations of the mine pit progression and backfill sequence (Base Model and scenarios 1 to 3) were applied to simulate the drawdown and the rate and magnitude of recovery of water levels in mine backfill and in the Fruitland Formation coal seams and in the PCS at the various prediction locations in study area. Scenario 4 was not used in the analysis of recovery for reasons discussed previously. The variations in hydrologic parameters for the Base Model and Scenarios 1, 2 and 3 are discussion in Section 41.2 and summarized in Table 41.2-1.

Figure 41.3-1 shows a plan view of the location of mine spoil placement and the location of the five prediction points selected for presenting the modeled transient water level response. Two prediction locations are within areas of proposed mining and backfilling, two are at well locations near the proposed mining area, and one is at a well location upgradient of proposed mining (Figure 41.3-1). Model simulation results of drawdown and recovery presented in ~~subsequent figures~~ Figure 41.3-2, Figure 41.3-3, Figure 41.3-4, and ~~through~~ Figure 41.3-5 show that ~~it could take longer than 1,000 years for~~ groundwater levels ~~to~~ recover in the backfill to ~~a~~ near steady-state conditions within 1,000-years.

Base Model simulation of drawdown and recovery at locations within the backfilled mine show larger drawdown from the pre-mine potentiometric levels at the CW-2 location compared to the GM-19 location (Figure 41.3-2). GM-19 is located near the western edge of proposed mining where the base of the mine pit is at a higher elevation. At location CW-2, the maximum drawdown of approximately 175 feet was

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observed relative to the pre-mine potentiometric elevation in the No. 8 coal seam. The drawdown was less in the lower units (e.g., 115 feet in the No. 3 coal seam and 100 feet in the PCS) (Figure 41.3-2).

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The head recovery shown in Figure 41.3-2 ~~for the No. 8 and No. 3 coal seams~~ is ~~the recovery in the backfill at~~approximately the same elevation ~~corresponding to the pre-mine elevation~~ for both the PCS and the layers within the backfill corresponding to the elevation of each coal seam prior to mining~~.~~. The recovery heads at the prediction locations within the backfill are ~~similar for the two~~at nearly the same elevation for both the backfill and ~~s and similar to the head recovery in~~ the PCS. The plots indicate a slight downward gradient in heads at the GM-19 location and an upward gradient from the PCS to the mine backfill for about the first ~~150~~ 100 years after start of mining at the CW-2 location. Thus, based on these simulation results the groundwater from the PCS will be one source for resaturation of the mine backfill for a relatively long period following mining until heads recover in the backfill to the level where the vertical gradients are negligible~~reverse~~. The recovery of potentiometric heads in the mine backfill at both prediction locations is below the pre-mine heads in No. 8 coal seam. Removal of the interbedded coals and shale strata by mining and placement of more uniform mine backfill eliminates the large downward potentiometric gradients that are observed under baseline conditions. The modeling does indicate that ~~a slight downward~~the vertical hydraulic gradients ~~is maintained~~ in the mine backfill at both locations ~~during the entire~~is negligible at the end of the ~~-~~1,000 year simulation. The model simulations show gradual recovery of potentiometric heads that are ~~still recovering to~~approaching a steady-state level at the end of the 1,000 year simulation.

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Figure 41.3-3, Figure 41.3-4, and Figure 41.3-5 show the drawdown and recovery at the same prediction locations within the backfilled and in the underlying PCS for scenarios, 1, 2 and 3, respectively. The hydraulic conductivity of the backfill for scenario 1 is higher than the estimate used for the base modeling scenario. For scenario 3 the backfill conductivity is the same as scenario 1 and the recharge in the mine backfill is 1.6 times larger than the Base Model. The recovery of potentiometric head in the mine backfill is ~~similar~~ slower for scenario 1 (Figure 41.3-3) ~~and~~ compared to scenario 3 (Figure 41.3-5). For ~~both of these scenarios based on the higher estimate for the hydraulic conductivity of the backfill,~~ Scenario 1 there is ~~no~~ little recovery in heads in the backfill at the GM-19 location~~. This shows~~, indicating that if the hydraulic conductivity is higher than estimated for the base model the backfill may remain dry within the western portion of the permit area near the Fruitland Formation outcrop unless backfill recharge rates are higher as in Scenario 3~~.~~.

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Heads recover in the backfill within the eastern portions of the permit area but the magnitude of recovery in the mine backfill for Scenario 1 is considerably lower than estimated by the Base Model (~~Figure 41.3-2~~Figure 41.3-2). The heads predicted in scenario 3 are ~~slightly~~ higher than the heads predicted in scenario 1, indicating that the magnitude of recovery will be higher if recharge is higher than assumed in the Base Model. However, comparisons of all three figures shows that the hydraulic conductivity of the backfill

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controls the recovery of heads to a ~~much~~ greater extent than recharge rates for the expected error bounds in these parameters. Finally, comparison of results in Figure 41.3-4 for scenario 2 with the Base Model in Figure 41.3-2 shows that the rate and magnitude of recovery in heads in the backfill will be higher if the specific yield of the coal and non-coal layers and hydraulic conductivity of the backfill are~~is~~ lower than the estimates used for the base modeling scenario.

Drawdown and recovery curves from the Base Model simulation at locations GM-28 and VWP2007-01 are shown on Figure 41.3-6. Figure 41.3-7, Figure 41.3-8, and Figure 41.3-9 show the drawdown and recovery curves for scenarios 1, 2 3, respectively. The results for Base Model and for scenarios 1 and 3 are similar and similar to the backfill results. They show that the hydraulic conductivity of the backfill controls the recovery of heads in the adjacent coal seams and PCS to a much greater extent than recharge rates for the expected error bounds in these parameters. Likewise, the results for scenario 2 in Figure 41.3-8 show that the rate and magnitude of recovery in heads in the coal seams and the PCS will be higher if the specific yield of the coal and non-coal layers and the hydraulic conductivity of the mine backfill ~~is~~ are lower than the estimates used for the Base Model scenario. The potentiometric heads in the No. 3 coal are similar to or slightly above the heads in the PCS at the VWP-2007-01 location throughout the simulation. At the GM-28 location immediately north of mining the heads in the coal seams decline below the heads in the PCS during and after mining but recover after about 200 years with downward vertical gradients between the coals and the PCS that are larger than observed under baseline conditions.

Figure 41.3-10 shows the drawdown and recovery curves from the Base Model simulation at VWP2007-02 located upgradient of the proposed mine. These results show only slight changes in heads. The potentiometric head in the No, 8 coal seam declines to a ~~steady state~~ level approximately ~~4~~ 5 feet below the pre-mining level and then recovers to a level approximately 2 feet below the pre-mining level at the end of the simulation. The heads in the No. 3 coal seam and PCS drawdown approximately ~~3~~ 4 feet below the pre-mining level and recover to levels slightly above the pre-mining level at the end of the simulation.

Drawdown and recovery curves at location VWP2007-02 are shown on Figure 41.3-11, Figure 41.3-12, and Figure 41.3-13 for scenarios 1, 2 and 3, respectively. These results also show relatively slight changes in heads, although there is an overall drawdown in heads in the coal seams and the PCS if the hydraulic conductivity of the backfill is higher as assumed in scenarios 1 and 3. The results for scenario 2 presented in Figure 41.3-12 are similar to the results for the base model simulation although rate and magnitude of recovery in heads in No. 3 coal seam and in the PCS is slightly higher compared to the base modeling results in Figure 41.3-10.

Base Model post-reclamation steady-state potentiometric surfaces for the No. 8 coal seam, the No. 3 coal seam, and the PCS are shown on Figure 41.3-14, Figure 41.3-15, and Figure 41.3-16, respectively. The

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Base Model parameters (Table 41.3-1) are considered to be the best estimates. The backfill hydraulic conductivity of 0.056 feet/day was between the bounds used in sensitivity scenarios for transient drawdown and recovery.

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The modeled post-mine potentiometric surface for the No. 8 coal seam shown on Figure 41.3-14 indicates that post-reclamation flow in the through the southern arm of the mine backfill will be to the north with a hydraulic gradient of about one half that of pre-mining conditions due to the higher hydraulic conductivity of the mine backfill compared to the hydraulic conductivity of the No. 8 coal seam for the pre-mining condition. The hydraulic gradient from the mine backfill is northwest toward Cottonwood Arroyo with a northeast gradient along the northeast boundary of the backfilled area. This differs from pre-mining conditions in which the overall gradient was to the northeast with a northwest gradient along the northwest boundary.

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The post-reclamation potentiometric surfaces for the No. 3 coal seam (Figure 41.3-15) and for the PCS (Figure 41.3-16) indicate that gradients through the southern arm of the backfilled area will be predominantly to the north with some outward gradient along the east and west boundaries. The gradients in the northern portion of the backfilled area will be to the northwest toward Cottonwood Arroyo in the western portion of the mine backfill and to the northeast in the eastern portion of the mine backfill. Pre-mining gradients for the No. 3 coal seam and PCS in this area is predominantly to the north with a slight northwest component. There is also a post-mine gradient from the backfill toward the topographic low elevations along Pinabete Arroyo.

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Under steady-state post-reclamation conditions there will also be a vertical downward potentiometric gradient and flow from mine backfill to the PCS within the southern portion of the mine area. The vertical gradients are negligible in the northern portion of the mine area as indicated by the comparison of the potentiometric surface in the PCS in Figure 41.3-15 with the potentiometric surface at the No. 3 coal seam elevation in the mine backfill as presented in Figure 41.3-14.

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41.3.1.2 Post-reclamation Groundwater Quality Changes

Resaturation of mine backfill will develop from precipitation recharge, lateral inflow from the Fruitland Formation, and upward flow from the PCS. For some time following resaturation, there will be no flow from the mine backfill and each of these sources for resaturation of the backfill will influence the quality of the water in the backfill. Once water levels rise sufficiently in the backfill to reverse the upward gradient from the PCS, groundwater will flow at a very slow rate from the backfill into the PCS and toward the topographic lows along Cottonwood Arroyo. The modeling results presented in Section 41.3.1.1 show that the rate of groundwater recovery in the mine backfill will be very slow and may take more than 1,000 years before the final steady-state potentiometric levels and groundwater flow systems become established.

It is expected that TDS and sulfate concentrations will increase in the mine spoil relative to the baseline concentrations in the Fruitland Formation coal seams based on both spoil leaching tests results and the water quality analysis of spoil water samples taken from the Bitsui Pit at the Navajo Mine (BNCC 2009). Also, acid generation is not likely in the post-mine spoil water. As indicated in Section 17, the overburden and interburden materials that will be used to backfill the pit show a substantial net alkaline environment. The mining process for removal and backfilling of overburden and interburden materials provides sufficient blending and mixing of the strata so that acidic spoil water conditions will not occur within mine backfill. This conclusion is supported by the neutral to alkaline pH levels observed in the Bitsui spoil monitoring wells (Chapter 11 of BNCC, 2009) and by the pH increase from 5 to 7.5 in the SPLP tests (~~Table 41.1-1~~Table 41.1-1). The leaching test results summarized in Table 41.2-3 indicate that the major cations and the trace constituents aluminum, barium, boron, iron, lithium, manganese, and molybdenum may also increase in concentration but other trace constituents are expected to remain below detection limits or comparable to the concentrations observed in the baseline coal seam water. TDS is the only constituent that exceeded relevant livestock use criterion in the leaching tests.

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The results for spoil leached with composite coal seam water were selected as a reasonable but lower bound estimate of 3,550 mg/L for TDS concentrations in the backfill. The geochemistry in mine spoils is complex and the TDS and sulfate concentrations in the spoil water in the permit area could be higher than the estimates from the leaching tests. Consequently, an upper bound estimate of 11,500 mg/L for the TDS concentration in the mine spoils was also used in the model simulations to account for the uncertainty in the post-mine spoil concentrations and provide more robust results for this PHC analysis. The upper bound estimate of 11,500 mg/L was the TDS concentration observed in the Bitsui-5 backfill well at Navajo Mine (BNCC 2009).

A chemical transport model was applied to the steady-state post-reclamation groundwater flow conditions to assist in the predictions of long-term post-reclamation groundwater quality. The FEFLOW™ software used for groundwater flow modeling includes features that simulate both conservative and reactive transport. The FEFLOW™ transport routines were applied to simulate the transport of TDS from the mine spoil backfill. The steady-state post-reclamation groundwater flow and transient transport simulations include the influence of mine backfill within Area 4 of the Navajo Mine PAP as well as the mine backfill for the permit area.

TDS was assumed to behave conservatively, that is with no attenuation due to adsorption or chemical transformation. Based on the observations at the Bitsui-5 spoil well, sulfate concentrations are expected to comprise about 43% of the TDS in spoil water. The results of leaching tests using composite coal seam water as summarized in Table 41.1-1 indicate sulfate fraction of TDS of 23% and 28% while the SPLP

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results indicate a sulfate fraction of about 56% of the TDS. For lateral transport from the mine spoil to the Cottonwood Arroyo alluvium, sulfate may be assumed to vary with TDS concentrations based on the sulfate-TDS ratio in the mine spoil source (i.e., Bitsui-5 well). Sulfate reduction is not likely to occur to a measurable degree because the shallow groundwater is likely to remain oxygenated near recharge areas along the alluvium and within the mine backfill. Sulfate reduction could occur where anoxic coal seam water enters mine spoil or in the coal seams down gradient of mine spoils after dissolved oxygen and nitrate in the groundwater have been depleted by the oxidation of organics. For this PHC assessment it is assumed that the TDS and sulfate transport from mine spoil to the Cottonwood Arroyo alluvium behaves conservatively with no measurable attenuation of sulfate by sulfate reduction.

The transport model solves advection-dispersion equations for constituent transport processes in groundwater flow. The transport modeling assumed that the TDS source concentrations remained constant throughout the 500-year transport modeling period, an environmentally conservative assumption. Natural background concentrations were not included in the transport modeling because the objective of the transport modeling is to simulate the direction and rate of transport of modeled constituents from the mine spoils, including the magnitude of attenuation due to dispersion. However, natural background concentrations have been considered in the subsequent interpretations drawn from the transport modeling results.

Several transport scenarios were performed to evaluate the sensitivity of transport results to changes in groundwater flow parameters. The transport scenarios are summarized in ~~Table 41.3-2~~Table 41.3-2. Transport sensitivity scenarios specified the upper bound TDS source concentration of 11,500 mg/L that remained constant throughout the 500-year transport modeling period. An additional sensitivity scenario assuming the lower bound TDS source concentration of 3,550 mg/L was run with the most likely configuration of groundwater flow parameters.

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The 500-year transport simulations were performed using the post-mine steady-state groundwater flow conditions as the initial condition for transport modeling. A 500-year simulation period was considered reasonable for modeling the fate and transport from a constant TDS source concentration in the backfill. After 500 years it is expected that the source concentrations in the mine backfill will decline as groundwater flows through the mine backfill and flushes salts that may have been concentrated in the mine spoils as a result of weathering and evaporation during mining and backfilling operations.

FEFLOW™ transient modeling results are presented for the following selected model layers:

- L1 - corresponding with the alluvium and upper 10 feet of soil and overburden in unmined areas and soil and backfill in mined areas;

- L4 - corresponding with the No. 8 coal seam in unmined areas and same elevation as the No. 8 coal seam in the mine backfill areas;
- L20 - corresponding with the No. 3 coal seam in unmined areas and same elevation as the No. 3 coal seam in the mine backfill areas;
- L28 - corresponding with the PCS throughout the model domain.

The results of the simulations at the end of the 500-year simulation period for L1 are presented in ~~Figure 41.3-17~~Figure 41.3-17, ~~Figure 41.3-18~~Figure 41.3-18, ~~Figure 41.3-19~~Figure 41.3-19, ~~Figure 41.3-20~~Figure 41.3-20, and Figure 41.3-21 for each of the model transport sensitivity scenarios listed in Table 41.3-2. The results of all scenario runs for the upper bound TDS source concentration of 11,500 mg/L show that the TDS concentrations above 5,000 mg/L remain near the mine backfill and do not extend beyond the permit boundary. The primary horizontal direction of TDS migration from the mine spoil in L1 is toward the alluvium and topographic lows along Cottonwood Arroyo. The TDS concentrations decline during transport from the mine backfill.

The L28 simulation results for TDS transport in the PCS at the end of the 500-year simulation period are presented in Figure 41.3-22, Figure 41.3-23, Figure 41.3-24, Figure 41.3-25, and Figure 41.3-26 for each of model transport sensitivity scenarios listed in Table 41.3-2. These results show that the primary direction for TDS transport from the mine spoils is vertically into the PCS. Thus, the primary direction for spoil water migration is into a water-bearing zone that has TDS concentrations similar to, if not higher than, the TDS levels expected for spoil water. The results for the upper bound TDS source concentrations show that the TDS concentrations in the PCS directly below the mine spoils are generally in the range of 5,000 to 10,000 mg/L. The higher TDS concentrations occur where the shale separating the backfill from the PCS is the thinnest or absent. Groundwater flow and TDS transport in the PCS in the vicinity of the mine backfill is predominantly laterally toward the alluvium and topographic low along Cottonwood Arroyo. TDS transport in the PCS to the north and east is limited as shown in these figures.

The simulation results at the end of the 500-year simulation period for the No. 8 coal seam (L4) are presented in Figure 41.3-27, Figure 41.3-28, Figure 41.3-29, Figure 41.3-30, and Figure 41.3-31 for each of the scenarios listed in Table 41.3-2. Likewise, TDS results at the end of the 500-year simulation period for No. 3 coal seam (L20) are presented in Figure 41.3-32, Figure 41.3-33, Figure 41.3-34, Figure 41.3-35, and Figure 41.3-36. These results show groundwater flow and TDS transport from the mine spoil to the north toward the Fruitland Formation outcrop along Cottonwood Arroyo. Lateral transport to the northeast in the No. 8 coal seam is restricted due to the lower heads in the mine backfill relative to the heads in the No. 8 coal seam prior to mining. Lateral transport in the No. 3 coal seam is also restricted despite the higher heads in the backfill relative to the heads in the No. 3 coal seam prior to mining. TDS transport in the No.

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3 coal seam is restricted due to the lower permeability of the No. 3 seam coal relative to the No. 8 coal seam.

It should also be noted that the modeled post-reclamation TDS concentrations do not include any contribution of TDS to the alluvium from outside the mine backfill within Areas 4 North and 4 South. Transport modeling was performed to assess the fate of mine spoil water. The groundwater transport model shows that spoil water from the mine backfill will disperse laterally and vertically and that a component of flow and transport will be toward the alluvium within the topographic low along valley of Cottonwood Arroyo, where it will mix with groundwater flow in the Cottonwood alluvium.

Mixing calculations were performed using post-reclamation modeled concentrations together with actual background concentrations to arrive at better estimates of the post-reclamation groundwater concentrations in the alluvium at the mouth of Cottonwood Arroyo for each of the transport model scenarios. In order to perform the mixing calculations it was necessary to estimate the increase in the steady-state flow in the Cottonwood Arroyo alluvium resulting from mining and reclamation and the increase in TDS mass transport to the Cottonwood Arroyo alluvium from the mine spoils.

The estimated change in the steady-state groundwater flow in the alluvium was determined from the difference between the groundwater flow estimates the in the alluvium near the mouth of Cottonwood Arroyo from steady-state pre-mine calibrated model and the steady-state post-reclamation model. ~~Table 41.3-3~~Table 41.3-3 provides the model predictions of pre-mine steady-state groundwater flow in the alluvium at the mouth of Cottonwood Arroyo and the post-reclamation steady-state flow in the Cottonwood alluvium for the various transport scenarios. For all but scenario 2, the steady-state groundwater flow increased under post-reclamation conditions due to the higher recharge rate estimated for these post-reclamation scenarios. Scenario 2 used the pre-mine recharge rate. In this scenario the steady-state alluvial groundwater flow declined relative to pre-mine results.

Table 41.3-3 also provides the modeled TDS concentrations in the alluvium at the mouth of Cottonwood Arroyo after 500 years based on the transport simulations for each of the model scenarios listed in ~~Table 41.3-2~~Table 41.3-2. It should be noted that the post-reclamation potentiometric surfaces indicate gradients toward the Pinabete Arroyo alluvium. ~~However, t~~The transport simulations ~~do not~~ show some ~~measureable~~ transport of TDS to ~~the~~ a tributary of Pinabete Arroyo ~~alluvium~~, however, the transport simulations do not show measurable transport of TDS to the Pinabete Arroyo alluvium.

The estimates in Table 41.3-3 of the post-reclamation concentrations in the alluvium at the mouth of Cottonwood Arroyo were obtained by adding the estimated concentration in the alluvial groundwater flow determined from the model-predicted post-reclamation TDS mass flux in the alluvium at the mouth of

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Cottonwood Arroyo to the pre-mine TDS concentration of 3,015 mg/L estimated for the alluvium near the mouth of Cottonwood Arroyo. The TDS concentration of 3,015 mg/L was obtained from the median of the baseline monitoring of Cottonwood Arroyo alluvial well QACW-2B located in the Cottonwood Arroyo alluvium west and down gradient of the permit Area.

Comparisons of the estimated post-reclamation concentrations in the alluvium at the mouth of Cottonwood Arroyo with the baseline estimates are provided in Table 41.3-3. These results show that the estimated changes in TDS concentrations in alluvium at the mouth of Cottonwood Arroyo range from an increase of ~~87~~ 91 mg/L in scenario 5 to an increase of ~~942~~ 965 mg/L in scenario 3. Scenarios ~~4~~ 1 and 5 represent the most likely ~~case of~~bounds for likely TDS concentrations based on the ~~flow~~ flow bounds related to hydraulic conductivity in the backfill and ~~parameters and~~ the bounds in TDS source concentrations. Based on scenarios ~~4~~ 1 and 5, the post-reclamation TDS concentration is predicted to increase over baseline estimates ~~by 611~~ within the range from ~~293 mg/L and by 87~~ 91 mg/~~L~~ to 634 mg/L~~, respectively~~. The predicted change in TDS concentrations is within the variability in TDS concentrations observed in the baseline results for monitoring wells completed in the Cottonwood Arroyo Alluvium. For instance, at well QACW-2B located in the alluvium down gradient of the permit area baseline TDS concentrations ranged from 2,590 to 3,800 mg/L. Wider ranges in TDS concentrations were observed at other wells completed in the alluvium of Cottonwood Arroyo and its tributaries.

Based on these results, changes in long-term post-reclamation TDS concentrations in the alluvial groundwater of Cottonwood Arroyo down gradient of the mine area may be expected. Upper bound source concentrations (scenario ~~4~~1) indicated TDS concentration increases on the order of ~~20~~21% while the simulation results with the lower bound source concentrations for mine spoil (scenario 5) indicate TDS concentrations increased on the order of 3%. The results for scenarios ~~4~~ 1 and 5 are based on the most likely ~~values~~ bounds ~~for~~ for source concentrations and backfill ~~recharge~~ conductivity~~and specific storage and specific yield~~.

An increase in TDS concentrations of the magnitude predicted by this PHC assessment is not expected to materially impact the suitability of the alluvial groundwater for livestock use because the predicted TDS increase is within the range of natural variability in the alluvium of Cottonwood Arroyo. Also, the Cottonwood Arroyo alluvium is an unreliable supply for stock water and the quality is a poor source for livestock supply due to high baseline TDS and sulfate concentrations. The median baseline TDS concentration at well QACW-2B was 3,015 mg/L, which is slightly above the livestock suitability guideline of 3,000 mg/L recommended by Lardy et.al. (2008) (Table 18.1-11). The median baseline TDS concentration of 15,210 well GM-17 is far above the livestock suitability guideline while the median baseline TDS concentration in well QACW-2 is 2,305 mg/L, which is more suitable for livestock use but this well is often dry. The median baseline sulfate concentrations in all of the Cottonwood Arroyo alluvial

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wells is well above the livestock suitability guideline of 1,000 mg/L recommended by Lardy et.al. (2008) (Table 18.1-11). Finally, the alluvial groundwater flows in Cottonwood are extremely low and vary with space and time. Water levels obtained during baseline monitoring of the wells in the Cottonwood Arroyo alluvium demonstrate that the groundwater in the alluvium is an unreliable supply. The wells were often dry or had very limited saturated thickness, which limits its potential for livestock use.

In summary, the mine spoils are expected to have higher concentrations of TDS and sulfate than the pre-mine Fruitland Formation coals. Concentrations of aluminum, boron, iron, and manganese may also increase in the spoils but concentrations would be well within relevant criteria for livestock use. Estimates from mixing calculations indicated TDS concentrations in the Cottonwood Arroyo alluvium are likely to increase over the long-term but not sufficiently to materially impact potential groundwater use.

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41.3.2 Post-reclamation Surface Water Changes

41.3.2.1 Post-reclamation Surface Water Quantity Changes

~~BNCC~~NTEC's objective in establishing the post-reclamation topography is to generally replicate the pre-mine relief at the site, to replace or improve the drainage density, and to enhance vegetation production to support the post mining land use. These measures will reduce surface erosion and sediment yield (~~Section~~ Section 34, Post-Reclamation Topography; Section 35, Hydrologic Reclamation Plan; and Section 38, Post-Reclamation Surface Stabilization and Sediment Control). ~~BNCC~~NTEC has designed the post-reclamation topography and drainages to conform with existing drainages along the perimeter of the mine in order to safely convey water from upstream, off-lease watersheds to either Pinabete Arroyo or Cottonwood Arroyo. ~~BNCC~~NTEC will use appropriate channel types, slopes, and drainage densities to construct landforms appropriate to the area and based on reference watersheds, as described in Section 38 (Post-Reclamation Surface Stabilization and Sediment Control). Additional details on the post-reclamation topography may be reviewed in Section 34 (Post-Reclamation Topography).

~~BNCC~~NTEC modeled surface water flows in Pinabete Arroyo, Cottonwood Arroyo, and the unnamed tributary to the Chaco River using SEDCAD. Pre-mine surface water flow predictions are provided in Section 18 (Water Resources). SEDCAD was also applied to the post-reclamation drainage configuration and watershed conditions to predict post-reclamation flows. These SEDCAD event-based flow results for Pinabete, ~~and~~ Cottonwood, and Chaco post-reclamation conditions are provided in Appendix 41.D. Comparisons of pre-mine and post-reclamation event-based peak flow results are provided in Table 41.3-4. Results show ~~little~~ slight differences between pre-mine conditions and post-reclamation conditions, except for the unnamed tributary to the Chaco River. There post-reclamation ~~flows~~ volumes increase due to an increase in drainage area following reclamation (Table 41.3-4). The accuracy of SEDCAD modeling is easily less than five percent, and the variation within the modeling runs is within that range.

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The hydrologic reclamation plan presented in Section 35 is predicated on the use of geomorphic principles that have been employed to create the reconstructed landforms, drainage density, and channels (Section 38, Post-Reclamation Surface Stabilization and Sediment Control). Although many of the pre-mine channels are incised with little or no active floodplain, reclaimed channels for higher-order drainages are designed for long-term stability with a low-flow or pilot channel capable of accommodating average annual peak flows or flows from a 2yr-6hr event and a floodplain to contain more extreme flows, as appropriate, based on slope (Section 38, Post-Reclamation Surface Stabilization and Sediment Control). Post-reclamation channels for first-order drainages are typically designed as vegetated swales.

~~BNCC~~NTEC is planning to reclaim all of the sediment and drainage control ponds utilized during the operation. At a future date, the Navajo Nation may request that some or all of the ponds remain. Future discussions with the Navajo Nation will ~~may result in the retention or~~ address the locations and designs for ~~construction of~~the ponds constructed to replace the original livestock ponds that will be mined through (Section 18, Water Resources, and Section 35, Hydrologic Reclamation Plan). ~~Should pond retention occur, p~~Ponds located on-channel will modify the hydrograph associated with each storm event by lowering the peak flows, extending the runoff over a longer period of time, and reducing storm runoff volumes. For small runoff events, the ponds may retain all of the storm runoff from upstream. Pond reconstruction will be performed to approximate the storage capacity and surface area of the original pre-mine impoundments. Specific discussions of temporary and permanent sediment ponds and the replacement of surface water sources are presented in Section 35 (Hydrologic Reclamation Plan).

41.3.2.2 Post-reclamation Erosion and Sediment Yields

It is difficult to obtain reliable measurements of baseline erosion and sediment yield, due to the infrequency of the transport events in ephemeral stream systems like those in the permit area. Consequently, event-based sediment yields have been estimated using the SEDCAD model. SEDCAD model estimates of sediment yields for pre-mine and post-reclamation conditions are summarized in Table 41.3-5. The results suggest that the replacement of poor quality sodic soils with suitable topdressing materials will result in no change or a reduction~~e~~ in sediment generation from pre-mine to post-reclamation levels, within the five percent accuracy of the model.

~~The exception to this appears in the Pinabete Arroyo watershed, where the additional drainage area combined with a slight increase in the slope/length factor resulted in slightly larger sediment yields.~~

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The sediment control plan and the surface stabilization and sediment control plan in Section 25 and Section 38, respectively, include a description of the sediment control measures that will be used on the reclaimed lands to prevent additional contributions of suspended solids to stream flow.

41.3.2.3 Post-reclamation Surface Water Quality Changes

Reclamation of disturbed areas and replacement of poor quality sodic soils with suitable topdressing materials is not anticipated to impair water quality, and may ~~expected to~~ result in improvement in surface water quality under post-reclamation conditions. SEDCAD modeling results presented in the previous section indicate reductions in post-reclamation sediment yields relative to baseline conditions. Groundwater flow and transport modeling presented in ~~Section~~ Section 41.3.1.2 project the transport of dissolved solids toward the topographic lows along Cottonwood Arroyo. The rates of groundwater flow, however, are very slow and are retained in the bedrock and the alluvium. Cottonwood Arroyo is an ephemeral stream and there is no groundwater contribution to surface flows.

Following reclamation, surface water quality in Cottonwood Arroyo and Pinabete Arroyo is not anticipated to be impaired as a result of mining operations and may be an ~~will probably be improved~~ improvement from pre-mine water quality for the following reasons:

- Sediment contribution from reclaimed areas is likely to decrease relative to baseline due to the overall reduction in slopes and improvement in the permanent vegetation cover.
- Sediment contribution from channel erosion is likely to decrease as incised unstable channels are replaced by stable channel and floodplain configurations.
- Poor quality and sodic soils will be buried within the backfill, and overland flow from the reclaimed areas is expected to exhibit lower concentrations of sodium and TDS.
- Aluminum concentrations should decline with the reduction in suspended solids associated with reduced surface and channel erosion.

Baseline monitoring of water quality of the streams and ponds in the permit area shows all the pH values within the range from 7.0 to 8.6 (Section 18.1). The pH levels during mining and after reclamation are expected to remain within this range. The SPLP leaching test of mine spoil shows that acid generation is not likely in the surface runoff from disturbed areas and spoil water. Also, after re-vegetation of mining disturbed areas, the runoff from these areas is expected to exhibit pH values similar to baseline conditions.

Four ephemeral impoundments within the permit area will also be disturbed by planned mining operations (Exhibit 18.1-2). Livestock watering is the primary use for the impoundments although the impoundments can also provide aquatic and wildlife habitat. The use of the impoundment for livestock and for aquatic and wildlife habitat is limited by the availability of sufficient water from precipitation events. Baseline information on the impoundments is provided in Section 18.1.

The analytical results from these ponds are summarized in Table 18.1-19. The concentrations observed in baseline samples from these ponds are below the relevant livestock use criteria specified in Table 18.1-11. However, the baseline water in the ponds generally exceeds the chronic aquatic and wildlife criteria for

aluminum and mercury and occasionally exceeds the estimated hardness dependent chronic aquatic and wildlife criteria for cadmium and copper. The concentrations of lead and selenium in one sample from the ponds also exceeded the relevant chronic aquatic and wildlife criteria.

The water quality at the reconstructed ponds should be comparable to or better than pre-mine conditions due to improvements in post-mine topsoil and vegetation. Also, the SPLP leaching tests of mine spoil presented in Appendix 41.A found no constituents at concentrations above livestock or chronic aquatic and wildlife habitat criteria, although the detection limits for lead, mercury and selenium were above the relevant chronic aquatic and wildlife habitat criteria for these constituents. These results suggest that the concentrations of trace constituents in precipitation runoff from regarded mine spoil should be similar to if not better than the concentrations in the baseline impoundments. The constituent concentrations in the pond water can be expected to increase as a result of evaporation between pond filling events. Data for the No Name Impoundment in Table 18.1-19 showed a decline in the concentrations of TDS, major ions and the trace constituents boron, iron and zinc when the pond filled following summer precipitation events. Nevertheless, the water in the No Name Impoundment met livestock watering use criteria even when concentrated by evaporation during storage. Occasional the chronic aquatic and wildlife use criteria can be expected to be exceeded when the water in the reclamation ponds is concentrated by evaporation between filling events.

Section 41.4 addresses the potential short-term and long-term impacts to surface water sources.

41.3.3 Post-reclamation Changes to the Hydrologic Balance

The groundwater within the alluvium of Cottonwood Arroyo and Pinabete Arroyos is the only groundwater source within the permit area and adjacent area that is adequate to support limited use for livestock water. One of the potential changes in the hydrologic balance after reclamation is the potential for an increase in groundwater flow toward the topographic lows along Cottonwood Arroyo if long-term recharge rates are higher for reclaimed areas as compared to pre-mine conditions.

Groundwater in mine spoils is expected to have higher concentrations of TDS and sulfate than the pre-mine Fruitland Formation coal seams. This water is expected to contribute to higher TDS and sulfate concentrations in the Cottonwood Arroyo alluvium. However, any increase in the post-reclamation concentrations of TDS and sulfate or in the trace constituents of aluminum, boron, iron, and manganese in the Cottonwood Arroyo alluvium are estimated to be minor and well within the variation measured baseline concentrations of these constituents in alluvial monitoring wells (~~Section~~ Section 41.3.1.2).

The SEDCAD modeling presented in Section 41.3.2 shows little change in surface flows and sediment yields following reclamation relative to baseline conditions. Minor changes in ephemeral flow may occur

if some of the sediment and drainage control ponds are converted to permanent replacement livestock water ponds at the request of the Navajo Nation or the local water user (Section 35, Hydrologic Reclamation Plan).

41.3.4 Post-reclamation Hydrologic Model

As previously discussed, a groundwater model of the post-reclamation hydrologic regime has been developed to support the PHC evaluations. The multilayer, numerical groundwater flow and transport model was developed and calibrated to baseline conditions as described in Appendix 41.B. This appendix includes a description of the conceptual model of both the baseline and post-reclamation groundwater flow system. A conceptual groundwater model is a complex hypothesis of the characteristics and functions of a hydrogeologic system, including recharge and discharge relationships, groundwater flow within and between hydrogeologic units, and the expected properties of these hydrogeologic units. The modeling results are presented in Section 41.3.1.

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The constrained model calibration lends greater confidence in using the model results for prediction. Nevertheless, the 3-dimensional, multilayer saturated-unsaturated flow model is a simplified representation of a complex physical system. The calibrated model is useful and helps provide a better understanding of the likely short-term and long-term groundwater changes that are expected to occur within and adjacent to the permit area. The usefulness of the model must be considered in the context of the uncertainty in the model predictions and the consequences of making decisions based on erroneous model predictions. In the context of a PHC assessment, performance monitoring is used to adjust and modify model predictions over time so that adaptive measures can be taken to prevent material damage to the hydrologic balance

The USACE (1999) describe five approaches for dealing with uncertainty in model execution and interpretation of results. The first two, best estimate and worst case estimates are single value results that need to be used to some extent due to the large number of inputs and parameters required by complex models. However, these approaches do not lend much assurance as to the uncertainty of accuracy of the model predictions. The uncertainty in using the best estimates is reduced by constrained model calibration. This PHC has relied on the third and ~~forth~~fourth approaches for the more sensitive model parameters in order to assessing model prediction error and model uncertainty:

- Best estimate with sensitivity analysis adjustments and
- Bracketed ranges

The bracketed range is used to assess the uncertainty in the predictions of TDS transport in mine spoil. Best estimate with sensitivity analysis adjustments has been used to assess the uncertainty in the calibrated steady-state model and to characterize the uncertainty in model parameters required for prediction. These

include the reclamation recharge rate, the backfill hydraulic conductivity, and the values for specific storage and specific yield.

Model results indicate that the extent of drawdown of potentiometric levels in the Fruitland Formation coal seams and in the PCS is limited, although the extent is sensitive to the actual specific storage in the coals and in the PCS. The extent of drawdown in the Fruitland Formation coal seams and in the PCS is also sensitive to the actual time step used in modeling the pit progression. The 5-year pit sequence used for these simulations estimates greater extent of drawdown compared to an annual pit sequence. Nevertheless, the rate and extent of drawdown has limited adverse impact to existing or future use. It is primarily of concern with respect to the potential for induced drawdown of water levels in the Cottonwood Arroyo alluvium.

Estimates of changes in TDS concentrations in the Cottonwood Arroyo alluvium from model predictions using bracketed ranges and best estimates with sensitivity analysis and from mixing calculations adjustments indicate that TDS concentrations in the Cottonwood Arroyo alluvium are likely to increase over the long-term. The predicted magnitude of change is sensitive to the estimate of TDS concentrations in the mine spoil, the values for specific storage and specific yield, the estimate for the reclamation recharge rate, and the backfill hydraulic conductivity. Nevertheless, the magnitude of the predicted increase in TDS concentrations is within the variability in TDS concentrations observed in the baseline monitoring or wells in the Cottonwood Arroyo alluvium.

While the model predictions are useful in identifying the direction of groundwater flow, the likely magnitude of change and the time frames that might be associated with these changes, the model predictions are hypotheses that will need to be re-examined as mining and reclamation proceed. Consequently, monitoring will be performed assess model predictions and to verify that material damage does not occur. It is anticipated that a monitoring well will be installed in the mine backfill after backfilling of a significant portion of the mine pit. Monitoring of this well would provide information on the actual TDS concentrations that develop within the mine spoil water. Likewise, it is anticipated that Cottonwood Arroyo alluvial well QACW-2B or comparable alluvial well will be monitored and that a monitoring well would be installed in the Fruitland Formation between the mine backfill and the Cottonwood Arroyo alluvium. Monitoring of water levels and TDS concentrations in these wells will provide information on drawdown, recovery, and water quality that can be used to adjust and modify the PHC model predictions if monitoring indicates significant change in the assumptions from which the model predictions were derived.

41.4 Impacts to Surface Water and Groundwater Availability

During surface coal mining operations there may be a temporary reduction in surface water flows in Pinabete Arroyo and Cottonwood Arroyo. ~~Three~~ Four ponds located within the permit area will also be removed by mining operations. There could also be a temporary reduction in groundwater levels and groundwater flows in the alluvium of Cottonwood Arroyo. Also, one livestock water supply well (13-15-2) completed in the alluvium of a tributary to Pinabete Arroyo (Section 18, Water Resources) will be removed by mining operations. Another livestock water well (W-0345) completed in alluvium of Pinabete Arroyo is within the permit area but will not be affected by mining. Livestock grazing will not occur within permit area during active mining. Alternate water supply will be provided for any off-lease livestock grazing that have used these stock water supply wells and ponds located within the permit area.

Groundwater flows in the Cottonwood Arroyo alluvium down gradient of the mine may diminish during active mining. Groundwater flows and TDS concentrations may increase in the Cottonwood Arroyo alluvium in the long-term after reclamation is complete. The groundwater modeling performed for the PHC assessment indicates that it could be many decades if not several centuries after mining and reclamation for any measurable increase in TDS concentration to develop along within the Cottonwood Alluvium down gradient of mining. The magnitude of any increase is predicted to be within the range of variation in TDS concentrations observed during baseline monitoring at monitoring wells completed in the alluvium of Cottonwood Arroyo. The Cottonwood Arroyo alluvium is currently a poor source of livestock water supply due to TDS and sulfate concentrations above recommended livestock use criteria. Furthermore, the quantity of water in the Cottonwood alluvium is limited and several of the baseline water monitoring wells in the alluvium are occasionally dry.

Following reclamation, the water supplies for existing livestock use will be replaced (Section 35, Hydrologic Reclamation Plan). Plans to replace water supplies for existing wells that will be impacted by mining have been included in Section 35 (Hydrologic Reclamation Plan).

Potential future use of groundwater within the reclaimed mine is negligible, due to the low permeability of the spoil and poor water quality. In addition, the potential use of groundwater from the PCS and Fruitland Formation near the site is limited, due to the low permeability and poor water quality observed in these sources in the baseline hydrology assessment (Section 18, Water Resources). As indicated in Section 18 (Water Resources), there are no known water supply wells completed in either the Fruitland Formation or PCS Formation within the permit area and adjacent area.

The ponds found in the permit areas during the baseline surveys do not appear to have water-right filings (Section 18, Water Resources); however, the small basins are periodically utilized by livestock and wildlife when water collects in them following a storm. Pond reconstruction~~, if executed,~~ will be performed to

generally reproduce the storage capacity and surface area of the original impoundment (Section 35 Hydrologic Reclamation Plan). The water availability at the reconstructed ponds should be comparable to pre-mine conditions. SEDCAD modeling presented in Section 41.3.2 shows little change in surface flows and sediment yields following reclamation relative to baseline conditions. Additional water supplies may be available if new ponds are constructed or some of the sediment and/or drainage control ponds are converted to permanent stock water use at the request of the Navajo Nation or local water users (Section 35, Hydrologic Reclamation Plan).

41.5 Probable Hydrologic Consequences Analysis

The probable hydrologic consequences analysis was developed with the support of site-specific data and modeling. Surface water and sediment modeling was performed using SEDCAD. Key assumptions on soil and cover were derived from soil and vegetation mapping at the site with contributions from erodible particle size data collected from depositional zones around the site. Geochemical and mineralogical characteristics of mine spoils were determined from chemical analysis of spoil materials and by the use of x-ray diffraction (XRD). The assessment of the long-term leaching from mine spoils was based on batch testing of mine spoil materials leached with groundwater collected from coal seams near the permit area and with synthetic precipitation. These results were evaluated using PHREEQC, public domain geochemical modeling software. Laboratory tests of geologic strata and mine spoils, well response tests, information from the literature, and model calibration provided the basis for the FEFLOW™ modeling, which was utilized to characterize groundwater flow and potentiometric conditions during and following mining. The chemical transport module in FEFLOW™ was also employed to assess the long-term transport of TDS concentrations from mine spoil materials.

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