11.6 PROBABLE HYDROLOGIC CONSEQUENCES

This section provides a detailed assessment of the probable hydrologic consequences (PHC) of mining and reclamation activities at the Navajo Mine. The primary focus of the 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.

Disruption of the surface and geologic conditions and associated surface water 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 several ways, including:

- changing groundwater levels, recharge rates, and flow directions by removal of overburden and interburden materials and mining of the coal and by backfilling mine pits;
- exposing unweathered mineral surfaces in overburden and interburden to weathering processes during mining and backfilling operations;
- past placement of coal combustion by-product (CCB) materials in mine backfill;
- changing the quantity and quality of surface runoff and stream flows by construction of diversions, surface disturbance, sediment control structures, and construction and operation of best management practices (BMPs);
- altering surface topography and stream channels during mining and reclamation; and
- changing sediment loads and concentrations and flow rates within stream channels downstream of mining and thereby altering stream channel morphology.

The PHC is a process for identifying these potential changes in the hydrologic balance that may result from mining and reclamation. This PHC assessment builds on the geologic information, the baseline groundwater information, and the baseline surface water information contained in Chapters 5, 6, and 7 respectively. The baseline hydrologic information also identifies any water resource or water use that could be affected by the proposed mining and reclamation operation.

The PHC also identifies the appropriate preventive and mitigating measures to minimize the impacts to water resources and water uses. Regulations require the replacement of a water supply in use that is contaminated, diminished, interrupted, or destroyed by mining and reclamation activities. Alternate water supplies are identified in the PHC and Section 12.11, Hydrologic Reclamation Plan, to provide a suitable replacement for existing water uses that may impacted by mining and reclamation activities. The PHC lays the groundwork for the proposed monitoring plans.

Literature sources for this study include published and unpublished reports, papers, and data authored or developed by several state and federal natural resource management agencies. Reports published by private consultants and academic institutions were also used. Site-specific data were developed through drilling, monitor/piezometer well installations, and pump testing as described in Chapter 6. Additional data were obtained from past geological investigations, observations made by BHP Navajo Coal Company (BNCC) staff during the day-to-day operations of the mine, and surface water and groundwater monitoring performed in conjunction with historic and on-going mining and reclamation activities at Navajo Mine. The PHC also couples these data with detailed SEDCAD™ 4 (SEDCAD) modeling of surface flows and sediment yields, spoil and CCB leaching test results, and groundwater flow and chemical transport modeling in order to develop projections about potential hydrologic impacts of proposed mining and reclamation at Navajo Mine.

11.6.1 Summary of Probable Hydrologic Consequences

11.6.1.1 <u>Groundwater Summary</u>

Monitoring wells completed in the PCS and Fruitland Formation at Navajo Mine show that well yields are quite low and well are typically pumped dry during sampling. The sampling also shows that the water quality in the PCS and Fruitland Formation is poor and generally not suitable for either livestock or domestic use (Appendix 6-G). Groundwater use in the vicinity of the Navajo Mine is limited in extent and is mostly derived from wells completed within surficial valley-fill deposits of Quaternary age, herein referred to as alluvium. An inventory of wells and springs is included in Appendix 6-E. This inventory was extended several miles beyond the Navajo Mine permit boundary and includes wells completed in the alluvium of the Chaco River and the San Juan River. The inventory found no water supply wells completed in the Fruitland

Formation or the Pictured Cliffs Sandstone (PCS) within or adjacent to the Navajo Mine permit area.

The inventory of wells and springs included in Appendix 6-E also identified a number of water wells completed within the alluvium of the San Juan River, the Chaco River, and Chaco tributaries including Pinabete Arroyo, Cottonwood Arroyo, and Chinde Arroyo. The water wells in the San Juan River alluvium are completed at varying depths and varying yields. Available water quality information provided in the Appendix 6-E Addendum shows that water quality in San Juan River alluvium is also quite variable with TDS concentrations above the EPA drinking water use criterion in all wells sampled. Several water wells completed in the Chaco River alluvium are also shown in Appendix 6-E.. Most of these wells are dug wells and the available water quality information shows variable water quality with TDS and sulfate concentrations often above both the Navajo Nation livestock use criteria and the EPA drinking water use criteria.

The water wells within the Navajo Mine lease completed in the alluvium of Pinabete and Cottonwood Arroyos support marginal stock water use, although the baseline TDS and sulfate concentrations exceed guidelines for livestock use. The baseline fluoride concentrations fluctuate in the alluvial groundwater and are often above Navajo Nation livestock use criterion (Appendix 6-G).

Changes in groundwater flow and groundwater quality will occur as a result of mining and reclamation at Navajo Mine. During mining operations, all strata overlying the Fruitland coal seams are stripped to expose the coal for mining. Each successive open cut serves as a sink for groundwater causing drawdown of potentiometric heads in the adjacent coals. Some drawdown in the potentiometric heads in the underlying PCS may also occur, depending upon the baseline heads in the PCS relative to the base of the mine pit. Model simulations of the advance of proposed open pit mining in Area IV North show very limited extent of drawdown in the Fruitland Coals and underlying PCS as discussed in Section 11.6.2.4. Groundwater inflows to the mine pits in Area II and Area III have been too low to saturate or pond within the mine pit and are seldom observed as seeps along the highwall. The pit floors remain dry except on rare occasions when storm runoff is captured. The alluvium in the North Fork of Cottonwood Arroyo has been mined through in Area III, depleting the groundwater in the North Fork alluvium immediately up gradient and down gradient of the mine. Mining will not occur within the alluvium along the main stem of Cottonwood Arroyo. The advance of the mine pit in Area IV North will result in limited drawdown in the adjacent coal units and the underlying PCS but is not expected to result in a drawdown of groundwater levels in the alluvium within the main stem of Cottonwood Arroyo (Section 11.6.2.4).

As a result of mining and reclamation, the interbedded structure of the pre-mine Fruitland Formation is replaced with backfill spoil of overburden and interburden materials. As discussed in Section 11.6.2.4, the backfill spoil is more homogeneous and has a higher porosity and higher hydraulic conductivity than the pre-mine in-situ interbedded sedimentary deposits of the Fruitland Formation. Mining is also expected to result in higher recharge rates during and following reclamation as a result of removal of the badland topography that occurs over portions of the mine area and placement of topdressing materials within reclaimed areas that permit higher rates of infiltration and groundwater recharge relative to baseline conditions

Despite an increase in recharge rates, the rate of recharge will still be quite low and the time period required for water levels to recover to a near steady-state level in the mine backfill is estimated to be on the order of several centuries or longer unless there is an imported source of water that enhances recharge. One such imported source is irrigation seepage and return flows from the Navajo Agricultural Products Industry (NAPI) irrigation sites located adjacent to Areas I and II. The NAPI irrigation seepage water has resulted in re-saturation of the Bitsui Pit starting in the early 1980's while other backfilled pits that are not located near external sources of water have remained dry.

The mine spoil and CCB materials that are derived from the coal and overburden at Navajo Mine do not exhibit hazardous toxicity as demonstrated by the extraction procedure (EP) toxicity test results presented in Appendix 11-K. Although this toxicity procedure has been replaced by the TCLP test, the results are still a valid indication that the materials are non-hazardous. In addition, the characterization of overburden and interburden materials provided in Section 11.6.2.2 indicates that there is no widespread occurrence of potentially acid-forming overburden or interburden materials. The strata are mostly highly alkaline, although there are some limited locations where the acid-base potential values indicate potentially acid-forming material.

However, 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.

Characterization investigations conducted on mine spoil and CCB materials contained in Appendix 11-K together with analysis of groundwater samples from wells completed in mine spoil and in CCB materials show that TDS and sulfate concentrations are lower in saturated CCBs in comparison with saturated mine spoils. Arsenic, boron, fluoride, and selenium concentrations increased in fly ash leachate and also showed higher concentrations in CCB wells Bitsui-1 and Watson-4 in comparison with the concentrations in spoil wells. Other trace constituents were below detection limits in the majority of the samples from both CCB wells and spoil wells. The leaching tests, reported in Appendix 11-K, show that arsenic, boron, and fluoride are all attenuated in flow through mine spoil. Furthermore, arsenic and selenium were below detection limits in the spoil leaching tests reported in Appendix 11-VV and in all of the Bitsui spoil monitoring wells, including the well immediately down gradient of CCB material. Thus, both the leaching tests and the observations in the Bitsui backfill monitoring wells indicate that, if CCBs become saturated, the probable result is that concentrations of arsenic, boron, fluoride, and selenium may increase above the concentrations present in the water source that saturates the CCB materials. Groundwater flow from the saturated CCB materials will evolve geochemically with changes in pH and redox conditions, chemical precipitation and coprecipitation, adsorption and dispersion. Concentrations of some constituents, such as arsenic, boron, fluoride, selenium, and sulfate may decrease as a result of geochemical processes. This hypothesis appears to be supported by observations in the spoil monitoring wells located downgradient of saturated CCB materials in the Bitsui Pit. Furthermore, TDS and sulfate concentrations are not expected to increase in CCBs that become saturated with spoil water. As a result, the quality of groundwater that migrates from backfilled pits is not expected to measurably change due to the presence of CCB materials in mine backfill.

The concentrations of TDS, sulfate, boron, and manganese are expected to increase in the mine spoil water relative to the concentrations in the recharge water sources. Concentrations of boron in mine spoil are expected to remain below the livestock use criterion of 5 mg/l while the boron concentrations in CCB material exceed the livestock use criterion. TDS and sulfate concentrations in the baseline groundwater exceed drinking water use criteria and exceed published criteria for livestock use. Concentrations of other trace constituents are expected to remain below detection limits or comparable to the concentrations observed in the recharge water sources.

The constituent concentrations in mine spoil water will also vary with the chemistry of the water sources recharging the mine spoil. In Area I these sources include the No. 8 coal seam water with TDS concentrations ranging from 5,000 to 10,000 mg/l and seepage from adjacent NAPI irrigation plots with unknown TDS concentrations. Precipitation recharge rates are very low relative to the other sources of recharge at the Bitsui Pit and probably account for less than 1% spoil water present in this pit. In Areas II through IV recharge from NAPI irrigation will be negligible and the primary sources of recharge of mine spoils include precipitation recharge with low TDS concentrations and inflows from the various coal units which show TDS concentrations ranging from 14,200 mg/l at the No. 2 coal seam well KF84-21A to 2,770 mg/l at the No. 7 coal seam well KF84-20C. Some inflow from the PCS with high TDS concentrations may also occur in Areas II through IV but the inflow will cease once the hydraulic head in the backfill rises sufficiently to reverse the flow from the PCS to the Fruitland Formation.

Section 11.6.2.3.1 provides an assessment of potential transport of spoil water from the mine in Area I through the Fruitland Formation to its discharge location at formation subcrop beneath the alluvium of San Juan River. Based on estimates of groundwater flow velocities, the projected travel time from the mine to the formation subcrop is expected to be on the order of 290 years. Measurable changes in TDS and sulfate concentrations in the San Juan River alluvial groundwater at the Fruitland Formation subcrop are not expected to occur because sulfate reduction in the coal functions to attenuate transport of sulfate and TDS from spoil water. Furthermore groundwater flow in the San Juan River alluvium is more than two orders of magnitude higher than groundwater flow estimated to be discharging to the alluvium from the Fruitland Formation.

When water levels in the mine backfill recover sufficiently, groundwater will migrate from the mine backfill vertically into the PCS and laterally toward potential discharge locations. These discharge locations include the Fruitland Formation subcrop at the San Juan River alluvium, the coal bed methane depressurization areas in the Fruitland Formation and PCS located east and northeast of the mine, the Fruitland Formation and PCS subcrop locations along the Cottonwood Arroyo valley, and Fruitland Formation and PCS outcrop locations to the west of Areas II and III. The discharge at the Fruitland Formation and PCS outcrop will be removed by evapotranspiration like it does under baseline conditions.

Groundwater flow and transport rates are extremely slow as demonstrated in Section 11.6.2.4. Modeling of mine water transport from Area IV North found that long-term post-reclamation TDS concentrations in the groundwater in the alluvium of Cottonwood Arroyo are expected to increase down gradient of the mine area. An increase in TDS concentrations of the magnitude predicted by the PHC assessment is not expected to materially impact the suitability of the alluvial groundwater for livestock use as indicated in Section 11.6.2.4. Furthermore, alluvial groundwater flows in Cottonwood Arroyo are extremely low and vary with space and time. Baseline monitoring of the wells in the Cottonwood alluvium demonstrate groundwater in the alluvium is an unreliable supply, which limits its potential for livestock use.

The TDS and sulfate concentrations in the alluvium of Cottonwood Arroyo down gradient of mining are expected to increase by about 20% over a 500 year period following mining. These changes could impact water supply well QACW–2B (BIA No. 13R-28A) completed in the alluvium of Cottonwood Arroyo west of the permit area as shown on Exhibit 11-166. This is a dug well that has been used for stock water supply. It is not owned by BNCC but has been sampled by BNCC for baseline water quality and water levels. However, the quantity of water in the Cottonwood alluvium is limited and this well and several other water monitoring wells in the Cottonwood alluvium are often dry. Mining activities are not expected to adversely impact any other developed water sources (Section 11.6.2.5).

BNCC has surface water rights on the San Juan River, New Mexico Office of State Engineer Permit 2838, which can be used to offset any adverse impacts to the State of New Mexico and present users. These rights will be maintained throughout the mining operation and a period thereafter, for retirement, if required to any affected San Juan Basin water users. For temporary impacts to water users, unseasonably dry conditions, or lack of potable water supply, BNCC provides water to local permittees in tanks for livestock use in areas around the lease, when requested. BNCC also provides the community potable water at two locations, one near the Navajo North facilities and the other near the Area III facilities. Permanent impacts to surface water users may be mitigated by the construction of impoundments incorporated into the post-mining landscape (Chapter 12 Sections 12.11 Hydrologic Reclamation Plan and 12.3.4.1 Permanent Impoundments).

11.6.1.2 Surface Water Summary

The surface water resources in the mine permit area and adjacent area are described in Chapter 7. Six named naturally ephemeral streams are directly affected by mining. These drain from east to west across the mine permit area and into the Chaco River, located west of the Navajo Mine permit area. Chinde Arroyo, located furthest north, has perennial flows derived from return flows from NAPI. Cottonwood Arroyo, located furthest to the south, exhibits intermittent flows from irrigation returns flows associated with NAPI. Chinde and Cottonwood have the largest drainage areas. The Chaco River is an ephemeral to intermittent drainage until its confluence with the drainage from Morgan Lake. Morgan Lake discharges continually, yielding perennial flows in the lower reaches of the Chaco River, which flows north into the San Juan River.

Surface drainage from the mine permit area is contained until reclamation standards have been met and then will drain via the tributary channels into the Chaco River. Diversions have been constructed on the Chinde and Cottonwood Arroyos to enable flows in these Chaco tributaries to pass through the permit area. The flow in Neck Arroyo also passes through the mine permit area as the main Neck channel and most of its drainage area has not been and will not be affected by mining other than by the transportation corridors. Hosteen Wash, Barber Wash, and Lowe Arroyos have been interrupted by mining and no flow from these drainages passes through the mine permit area. Instead, flows are retained by check dams and containment structures located upstream of mining.

Bitsui Wash, located in the northern portion of Area I outside of the permanent program permit area, drains to the north into the San Juan River. Bitsui receives drainage from pre-law jurisdictional lands on the northern area of the mine lease and starting in the early 1980's irrigation return flow from NAPI. The Bitsui Wash does not receive drainage from the reclaimed areas or from sediment ponds within the Navajo Mine permit area, however the NAPI irrigation return flows contribute intermittent to perennial flows depending upon NAPI activities.

The Chaco River, which flows north into the San Juan River, drains an area of more than 4,000 square miles. Flow in the Chaco River is ephemeral except for the last 12.5 miles of the river, where perennial flow is the result of spillway overflows from Morgan Lake and discharge from the Four Corners Power Plant (FCPP). One other prominent surface water feature adjacent to the Navajo Mine is Morgan Lake, which is manmade and used as cooling water for FCPP. The San Juan River serves as the primary source of water for Morgan Lake. Water from Morgan Lake is also used by BNCC for mine operations.

Prior to mining and the construction of Morgan Lake, surface water use within the Navajo Mine permit area and adjacent area was limited to surface water captured in stock watering ponds, which were constructed to catch surface flows from some of the small tributary drainages. The location of stock watering ponds on and near the permit area is shown on Exhibit 10-3. Due to the unreliable nature of water supplies at stock watering ponds, and the temporary loss of some historical livestock impoundments, BNCC also provides water to local permittees when requested in permanent tanks for livestock use at locations around the lease. BNCC provides potable water from two stations located near the North Facility area and near Area III, but outside the mine lease, as a courtesy to neighboring landowners. Additional information on post-mining water sources is provided in the Hydrologic Reclamation Plan Section 12.11.

Almost all of the surface water use in the vicinity of the Navajo Mine is from the San Juan River. The largest use is for irrigation, which accounts for 78 percent of the water use in San Juan County while power generation and associated mining accounts for only about 10 percent of water use (Blanchard et al. 1993). Other than the San Juan River, surface water is not used for drinking or irrigation.

Surface water impacts associated with mining are related to water quantity, water quality, or water use. Surface water within the area of mine disturbance is contained until reclamation standards and water discharge criteria have been met. Then containment structures are removed and surface runoff from precipitation events will drain to the Chaco River tributaries that cross the permit area. Under baseline conditions, these tributary channels carry very high concentrations of suspended solids and bed loads during storm runoff events. Sediment control measures, as outlined in Section 11.2.10, will prevent additional contributions of sediment to stream flow or to runoff outside the permit area during operations. Surface reclamation plans and associated modeling demonstrate that total suspended solids concentrations and sediment yields may be equivalent or less than pre-mining levels following reclamation.

Changes in peak flows due to the presence of upstream containment berms, diversions and highwall impoundments, coupled with retention of water within pits and down gradient sediment ponds will reduce peak flows and runoff volumes down gradient of the mine during operations. As areas are reclaimed, BNCC expects to see better retention of surface water runoff within the permit area compared with pre-mining conditions, due to lower slopes and the placement of topdressing materials with more permeable textures than occurred naturally pre-mine. Following successful reclamation and stabilization, flows should be comparable with pre-mining conditions with, perhaps, a slight decrease in peak flows and runoff volumes due to the improved infiltration following reclamation (Section 11.6.3).

Prior to mining and before the development of up gradient agricultural lands, surface flows in channels traversing the permit area were predominantly ephemeral. It is anticipated that post-mining flows will also be ephemeral, due to the limited precipitation regime coupled with marginal development of alluvium, unless flows from the upgradient NAPI generate seasonal or perennial flows. Future development of NAPI may continue further east and south of existing development into the headwaters of Cottonwood, and south into the headwaters of the Brimhall and Hunters Wash. The expanded NAPI irrigation plots would be far removed from mining within Area III or Area IV North. The ephemeral surface flows are unpredictable and carry such high sediment loads that essentially no use is made of the water for agricultural or other purposes (Chapters 6 and 7). Stock watering ponds are the principal use of surface water on or near the permit area, and these are not located on the larger tributaries where pond embankments are susceptible to failure due to flash floods.

Surface water quality after mine reclamation is expected to support existing uses prior to mining as a result of the revegetation practices outlined in Section 12.6. As discussed in the previous subsection, the overburden and interburden materials that will be used to backfill the pit show a substantial net alkaline environment. An extensive program of sampling regraded spoils has been developed for Navajo Mine to ensure that the regraded spoils are suitable for revegetation and surface drainage reclamation. Water quality changes that could occur include increases in TDS, sulfate and iron as discussed in Appendix 11-K, Table 11-14f, and Section 11.6.3.

11.6.2 Assessment of Potential Groundwater Changes

The monitoring wells completed in the Fruitland Formation and in the PCS within the study area demonstrate that groundwater yields from the Fruitland Formation and the PCS, which underlies the Fruitland Formation at the Navajo Mine, are quite low and most monitoring wells are pumped dry during sampling. Furthermore, the water quality in the PCS and Fruitland Formation is poor and generally not suitable for either livestock or domestic use (Appendix 6-G). An inventory of wells and springs is included in Appendix 6-E. The results show that there is no known water supply wells completed in the Fruitland Formation or the PCS within or adjacent to the Navajo Mine permit area. All of the water supply wells located within or adjacent to the Navajo Mine are completed within alluvium. There were two PCS wells located several miles east of the permit area that were identified in 1985 in the original Navajo Mine area well inventory by Billings and Associates, Inc (BAI) (1985). These wells will not be affected by mining due to the distance from the mine. The water quality in these wells is poor and unsuitable for use with total dissolved solids (TDS) concentrations above the New Mexico regulatory threshold for current or future use of 10,000 mg/l as referenced in 20.6.2.3101(A) New Mexico Administrative Code (NMAC) and 20.6.2.3103NMAC. Well No. 38 has been abandoned. Spring No. 56 was also reported to be issuing from the PCS at a location adjacent to the San Juan River alluvium. The TDS was 624 mg/l which is acceptable for livestock use but exceeds the Environmental Protection Agency (EPA) Drinking Water Criteria. This spring is located to the north and down gradient of Morgan Lake and may be the result of seepage from Morgan Lake as suggested by its location and the TDS of the water, which is considerably lower than the concentrations observed elsewhere in the PCS as described in Appendix 6-G.

There was one PCS well BAI #90 located several miles west east of BNCC coal lease Area V that was identified in 1985 in the original Navajo Mine area well inventory by Billings and Associates, Inc (1985). This well was described as a Gulf Oil Co. Shot hole with a well depth of 131 feet and no water quality or depth to water information provided. The other PCS well identified in Appendix 6-E is well 13-7-2. This well is located in Burnham several miles south of BNCC coal lease Area V. This was the original Burnham Chapter house well but was abandoned and replaced with a deeper well due to poor water quality and poor yield.

The inventory of wells and springs included in Appendix 6-E identified a number of water wells completed within the alluvium of the San Juan River, the Chaco River, and Chaco tributaries including Pinabete Arroyo, Cottonwood Arroyo, and Chinde Arroyo. The water wells in the San Juan River alluvium are completed at varying depths and have varying yields. Available water quality information provided in the Appendix 6-E Addendum shows that water quality in San Juan River alluvium is quite variable with TDS concentrations ranging from 528 mg/l to 5,880 mg/l. These water quality results are consistent with the data reported by Thorn (1993), which found TDS concentrations ranging from 1,860 mg/l to 3,940 mg/l in four wells completed in the San Juan River alluvium. Several water wells completed in the Chaco River alluvium are shown in Appendix 6-E. Most of these wells are dug wells and the available water quality information shows variable TDS concentrations ranging from 1,950 mg/l to 3,110 mg/l. Limited groundwater quality baseline data for the Chaco River alluvium are also provided by Thorn (1993). The results show considerable variability in the alluvial water quality 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.

The water wells within the BNCC coal lease completed in the alluvium of Pinabete and Cottonwood Arroyos support marginal stock water use, although the baseline TDS and sulfate concentrations exceed published guidelines for livestock use (Lardy, G. and C. Stoltenow, 1999) The baseline fluoride concentrations fluctuate in the alluvial groundwater and are often above the

Navajo Nation water quality criterion for livestock and wildlife use and the EPA drinking water use criterion (Appendix 6-G).

11.6.2.1 Observations During Previous Mining And Reclamation At Navajo Mine

The location of the pits previously mined or currently being mined at the Navajo Mine are shown on Exhibit 11-166. The Bitsui and Watson Pits were mined in the mid-1960s and backfilled in the 1970s before the promulgation of regulations under the Surface Mining Control and Reclamation Act of 1977 (SMCRA). Some of the backfill in this area consisted of CCBs from the FCPP. CCBs were placed at discrete locations within the backfill and surrounded by and covered by overburden removed during mining of the coal. Approximate CCB placement locations within the Bitsui and Watson Pits are shown on Exhibit 11-167. CCB placement within these mine pits also preceded the NAPI irrigation activities which began at locations adjacent to the Bitsui Pit in the early 1980s. The NAPI irrigated plot that is closest to Bitsui Pit is shown on Exhibit 11-167. NAPI irrigation has had a significant influence on both nearby groundwater elevations and flow directions.

Since mining at the Navajo Mine started long before SMCRA became law, baseline hydrologic monitoring data generally does not exist for Area I and portions of Area II of the Navajo Mine. Nevertheless, the “GM-“ monitoring wells shown on Exhibit 11-166 were installed during the period from 1975 to 1977 and provide baseline information for Areas III, IV, V, and portions of Area II. Many of the GM wells have been mined through or abandoned and additional monitoring wells were installed, most in 1983 and 1984. Monitoring wells were installed in 1998 and in 2007 for baseline characterization of Areas IV South and V.

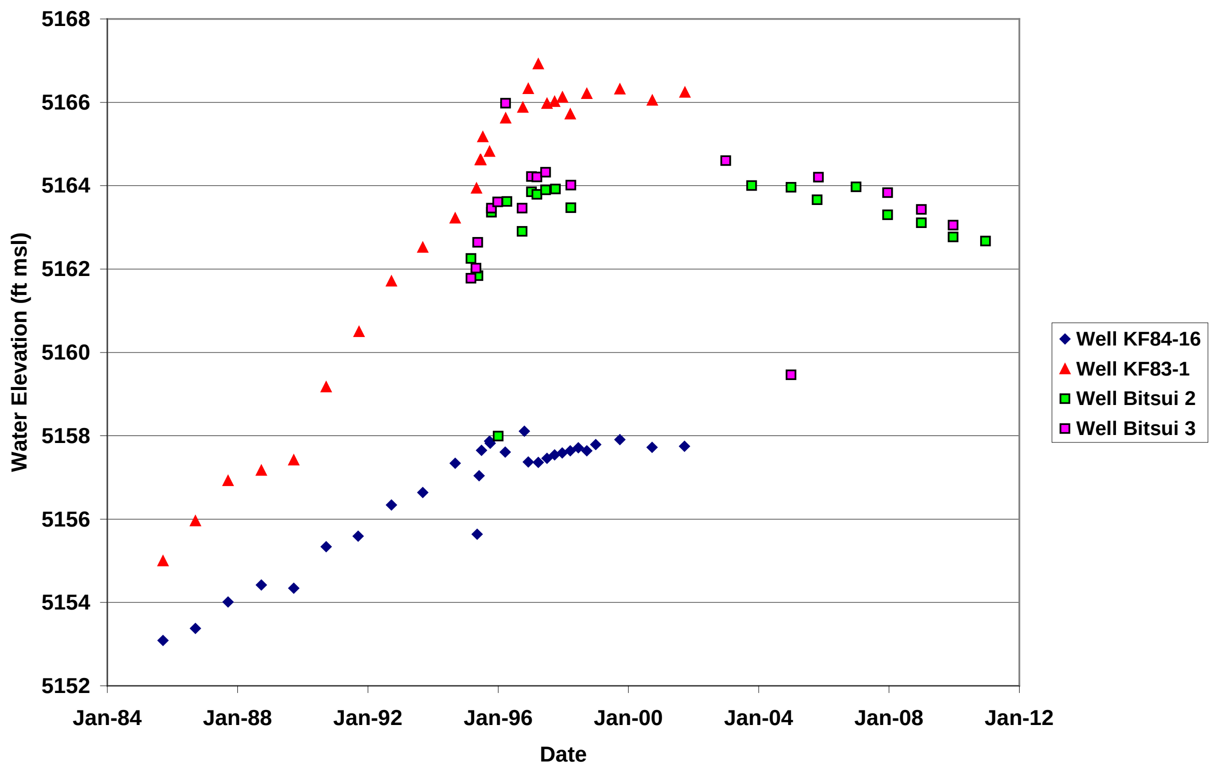
BNCC also collected groundwater data from historic CCB disposal on pre-law and interim lands (Supplemental Groundwater Study (SGS), Appendix 11-MM) to investigate possible impacts to groundwater from mine placement of CCBs at Navajo Mine. The Bitsui Pit is in the northeastern portion of the mine lease area, as shown on Exhibit 11-166. The Bitsui Pit location was selected for the study for the following reasons:

Unlike other CCB placement locations at the mine, the CCBs at the Bitsui Pit were expected to be largely saturated based on the close proximity to center pivot irrigation conducted by NAPI east of the coal lease, and the Bitsui Pit is closest to the San Juan River of all the backfilled pits at Navajo Mine.

The SGS, which was undertaken in 1995, was accomplished by installing six groundwater monitoring wells within mine backfill and CCB disposal areas in the Bitsui Pit. Other wells were installed during the mid-1990s to monitor backfill and CCB placement in locations not influenced by NAPI irrigation. Wells Watson-1 and Watson-4 were installed in the CCBs placed within the Watson Pit and wells Custer 2 and Custer 3 were installed in the CCBs placed in the Custer Pit to monitor the influence of Morgan Lake. Custer 1 was drilled in shallow Fruitland Formation sands west of Custer Pit Ramp 4 to monitor the influence of Morgan Lake. The new wells at the Bitsui, Watson and Custer Pits and No. 8 coal seam wells KF-84, KF83-1 and KF84-16 were monitored for static water levels and water quality on a quarterly basis from 1995 through 1998 and then annually. These wells are shown on Exhibit 11-167 along with other monitoring wells in the vicinity

Navajo Mine also monitored static water level (SWL) and collected water quality samples from several No. 8 seam coal wells in the vicinity of Bitsui Pit starting in 1985 and 1986. Time plots of water elevations measured in the nearest coal wells are provided in Figure 11-30. Over an 11-year period from 1985 to 1996, SWL in the No. 8 coal seam rose 11 feet in well KF83-1, which is near the southeast corner of the Bitsui Pit. During that same period of time, water levels rose 5 feet in well KF84-16, which is also completed in the No. 8 coal seam further east of Bitsui Pit as shown in Exhibit 11-167. The Bitsui-3 well is completed in the No. 8 coal seam east of the Bitsui Pit but west of the well KF84-16. The Bitsui-2 well is completed in the No. 8 coal seam approximately 300-feet north of the Bitsui Pit as shown on Exhibit 11-167. Water elevations initially increased in both the Bitsui-2 and -3 wells after they were installed in 1995. The water levels in these coal wells would have been drawn down considerably during mining at the Bitsui Pit but the magnitude of drawdown and recovery prior to installation of the wells is uncertain. Water elevations in all of these wells appear to have reached an equilibrium stage with relatively little change in water elevations since 1996, as indicated in Figure 11-30.

Figure 11-30. Water Elevations in Coal Monitoring Wells in the Vicinity of the Bitsui Pit



The rise in water levels is associated with NAPI irrigation and the No. 8 Coal recharging the Bitsui Pit. Observations of seepage from nearby NAPI irrigation emerging from the highwall at the northeast end of the Dodge Pit adjacent to and southwest of the backfilled Bitsui Pit support the conclusion that seepage from NAPI irrigation provides a source of the recharge water for the Bitsui Pit and the Dodge Pit. Also, the NAPI irrigation has produced return flows sufficient to maintain perennial flows in Bitsui Wash upstream of the mine and to provide a water source for the perennial pond located on a branch of Bitsui Wash and referred to as "NAPI Pond" on Exhibit 11-166. These sources of water from NAPI irrigation return flows are sufficient to migrate down gradient and saturate the backfilled Bitsui Pit.

Three geologic sections through selected monitoring well locations were prepared to examine groundwater conditions in three dimensions. These geologic sections along with the map showing the locations of the sections are provided Exhibit 11-167. Measured water levels in monitoring wells are shown on the sections.

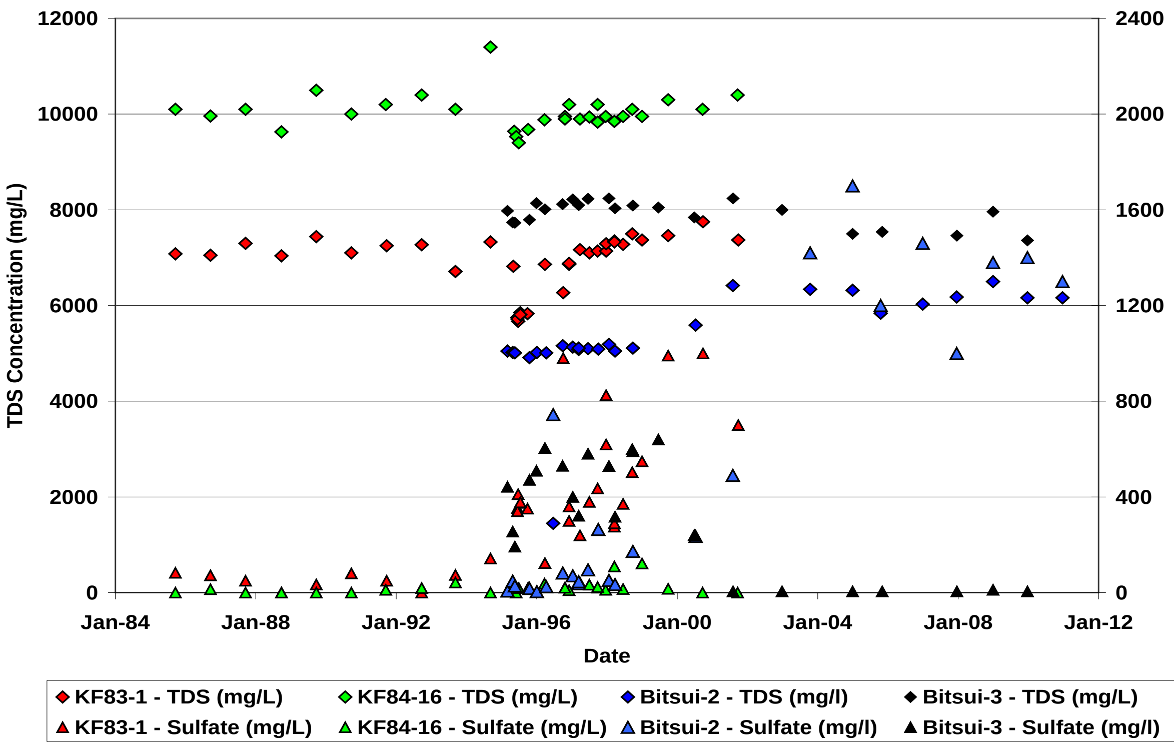
The water level measurements depicted in the geologic sections show minimal influence from Morgan Lake on the adjacent Custer Pit. The wells completed in the CCBs of the Custer Pit remained dry. Approximately one foot of saturation was observed in June 1989 at the No. 8 coal well KF83-2 located adjacent to the Custer Pit. Also, the Custer Pit and ramps remained dry during mining operations. The ten to twenty-five foot thick shale layer separating the bottom of the lowest mineable coal seam and the PCS (see Chapter 6) acts to isolate the mine pits from groundwater in the PCS. No noticeable upward seepage through the mine floor (shale layer) has been observed, even though, prior to backfilling, the mine pits in the vicinity of Morgan Lake were well below the potentiometric levels in the PCS as projected in Exhibit 11-166.

Saturated conditions developed within the backfill of the Dodge Pit as indicated by the water level rise in spoil well KF83-14. The water source for saturation of both the Dodge Pit and the Bitsui Pit is believed to be primarily from NAPI irrigation with perhaps very minor contribution from the PCS, although the dry conditions observed in the backfilled Custer Pit located closer to Morgan Lake indicates little influence from the relatively high potentiometric surface in the PCS near Morgan Lake.

Watson-1 well, completed in the CCBs at the Watson Pit, also remained dry. A couple of feet of saturation was present in the Watson-4 well, which may be the result of upward seepage from the PCS as recharge rates are extremely slow and the well is upgradient of the saturation in the Bitsui Pit and not near NAPI irrigation as shown Exhibit 11-167.

TDS and sulfate concentrations observed in monitoring wells completed in the No. 8 coal seam near the Bitsui Pit are plotted in Figure 11-31. The increase in sulfate in well KF83-1 corresponds with a decrease in alkalinity such that TDS concentrations did not change. TDS concentrations in wells KF84-16 and in Bitsui-3 show no consistent trends, although sulfate concentrations appeared to temporarily increase in both of these wells in the mid-1990’s.

Figure 11-31. Time Series of TDS and Sulfate in Coal Wells Located Near the Bitsui Pit



The increase in sulfate started in 1995 in well KF83-1 and was above 400 mg/l when Bitsui-3 was first sampled in 1996. The sulfate in these wells is thought to be due to migration of spoil water from the adjacent Bitsui Pit. Spoil water migration may have been enhanced by frequent purging and sampling of these wells, which increases gradients toward the monitoring well with corresponding increases in flow velocities in the fractured (cleated) coal. Well KF84-16 is located about 1,400 feet to the east of the Bitsui Pit and has much higher TDS concentrations in comparison with coal wells KF83-1 and Bitsui-3, which are located close to the Bitsui Pit. This is consistent with the baseline characterization, which found that TDS concentrations in the coals increased with depth and distance from the outcrop. The decline in sulfate in these wells may be related to a reduction in gradients and perhaps due to attenuation by sulfate reduction. Sulfate reduction accounts for the absence of sulfate in the deeper coals located further from recharge locations.

Sulfate and TDS both increased in the coal well Bitsui-2, although the magnitude of the TDS increase was less than the magnitude of the sulfate increase. The sulfate and TDS increased at Bitsui-2 and not at Bitsui-3, KF84-16 and KF83-1 because of the closer proximity of Bitsui-2 to the mine spoil and the local direction of ground water flow to the northwest towards Bitusi-2 (Exhibit 11-167). Sulfate concentrations within the background coal wells are very low (median 5 mg/L) and is typical for coal aquifers (Table 11-14g). The sulfate concentrations associated with mine spoil wells are significantly higher with a mean of 7,605 mg/L for the Bitsui-4, Bitsui-5 and Bitsui-6 spoil monitor wells compared to coal wells. However, the sulfate concentration at the coal monitor well Bitsui-2 has sulfate concentrations significantly elevated above coal groundwater values, but not as high as concentrations at the spoil monitor wells (Table 11-14g).

The increase in sulfate in well Bitsui-2 started in 1995 reaching a maximum in year 2004. Sulfate concentrations in this well have fluctuated since year 2004 but have centered around 1,400 mg/l. While the leveling off of sulfate concentrations suggests breakthrough of a sulfate plume, the sulfate concentrations in this well are about 27 percent of the median value of approximately 5,115 mg/l measured in the nearest spoil monitoring well Bitsui-5. The lower and relatively steady concentrations of sulfate measured in coal monitor well Bitsui-2 samples can be related to dispersion and bacterially mediated sulfate reduction and subsequent metal sulfide precipitation resulting in an overall removal of dissolved sulfur species.

Sulfate reduction was found to explain the large reduction in sulfate concentrations in groundwater transport from mine spoil through a coal seam at the West Decker surface coal mine in Montana (Clark, 1995). The geochemical process postulated to explain the observations included bacterial reduction of sulfate utilizing coal as a source of organic matter, reverse ion exchange of sodium for calcium and magnesium ions with transport through the coal, and precipitation of calcium and magnesium carbonates and sulfide metals. These same processes also explain the observations in the coal at the Bitsui-2 well located down gradient of the Bitsui Pit. Sulfate concentrations within the background coal wells are very low (median 5 mg/L) and is typical for coal aquifers (Table 11-14g). The sulfate concentrations associated with mine spoil wells are significantly higher with a mean of 7,605 mg/L for the Bitsui-4, Bitsui-5 and Bitsui-6 spoil monitor wells compared to coal wells. However, the sulfate concentration at the coal monitor well Bitsui-2 has sulfate concentrations significantly elevated above coal groundwater values, but not as high as concentrations at the spoil monitor wells (Table 11-14g).

Ion exchange, carbonate formation and sulfate reduction are processes that explain the observed data trends. These reactions are all reversible and limited within a given area. As a plume migrates the reactions will take place primarily at the leading edge or front of the plume while equilibrium will be approached for these processes behind the front, assuming the source water does not change. These biogeochemical reactions will result in an overall reduction in the observed breakthrough of specific constituents and assuming the source is finite will result in a breakthrough consisting of concentrations lower than those observed at the source.

Bacterially mediated sulfate reduction in groundwater systems is a well known and documented process (Freeze and Cherry, 1979; Drever, 1988; Schwarzenbach et al., 1993; Clark, 1995; Stumm and Morgan, 1996; Clark and Fritz, 1997; Benner et al., 2002; Doshi, 2006; Appelo and Postma, 2007; Praharaj and Fortin, 2008). Overall bacterially mediated sulfate reduction mass action can be described as follows:

$$SO_4^{2-} + 2C_{organic} + 2H_2O = H_2S + 2HCO_3^-$$

The produced hydrogen sulfide is then involved in chemical reaction with metals (Me) resulting in precipitation:

$$H_2S + Me^{+2} \rightarrow MeS + 2H^+$$

Metals that readily form metal sulfide precipitates include cadmium, copper, iron, lead, manganese, mercury, nickel, and zinc. Other metals including arsenic, antimony, and molybdenum can form complex sulfide minerals (Doshi, 2006) and manganese, iron, nickel, copper, zinc, cadmium, mercury, and lead may also be co-precipitation with other metal sulfides (Doshi, 2006). Bacterially mediated sulfate reduction also consumes acidity by generating bicarbonate as a product which in turn raises the pH. The increased pH facilitates the precipitation of metal sulfides (Gadd, 2004).

The sulfide concentrations in the Bitsui-2 monitor well samples vary significantly from non-detect to over 60 mg/l supporting a dynamic system of sulfate reduction and sulfide removal. Additionally, the Bitsui-2 iron and manganese concentrations are several orders of magnitude lower than the concentrations observed in the Bitsui spoil wells. This observation supports the removal of sulfide generated from sulfate reduction as iron and manganese sulfides. Also, the pH values at Bitsui-2 have been maintained at approximately 8.13 on average since October 2003; while the incoming spoil water is lower with median values at spoil monitoring wells Bitsui-4, Bitsui-5, and Bitsui-6 ranging from 6.8 to 7.50, indicating an increase in pH that supports the reduction of sulfate.

Iron and manganese concentrations in background coal monitor wells are low ranging from less than 0.05 to 0.24 and less than 0.01 to 0.03 mg/L, respectively. However, spoil monitor wells Bitsui-1, Bitsui-4 and Bitsui-6 show concentrations of iron and manganese orders of magnitude higher with values on the order of 3.77 mg/L and 7.05 mg/L, respectively. The high metals concentrations are not observed at Bitsui-2. The highest iron concentration measured at Bitsui-2 is 0.14 mg/L and is typically less than detection (0.05 mg/L), similar to coal background groundwater. The highest manganese concentration measured at Bitsui-2 is 0.02 mg/L and is also typically less than detection limits and similar to coal background groundwater. The migration of high sulfate water from the spoil does not show similar relative proportions of iron and manganese. If the observed concentrations of lower sulfate at Bitsui-2 compared to spoil monitor wells were due to dilution with background coal groundwater, the iron and manganese concentrations would be expected to show relatively higher concentrations than observed. Rather the concentrations of iron and manganese are significantly lower supporting the process of sulfate reduction and sulfide metal precipitation.

Bicarbonate values are not increased as expected based on general sulfate reduction processes. Instead bicarbonate concentrations are decreasing. While the calcium concentrations are low (~8 mg/l), the high bicarbonate values (~3,000 mg/l) result in saturation with respect to calcite causing calcite precipitation in order to reach equilibrium and lowering the bicarbonate concentration.

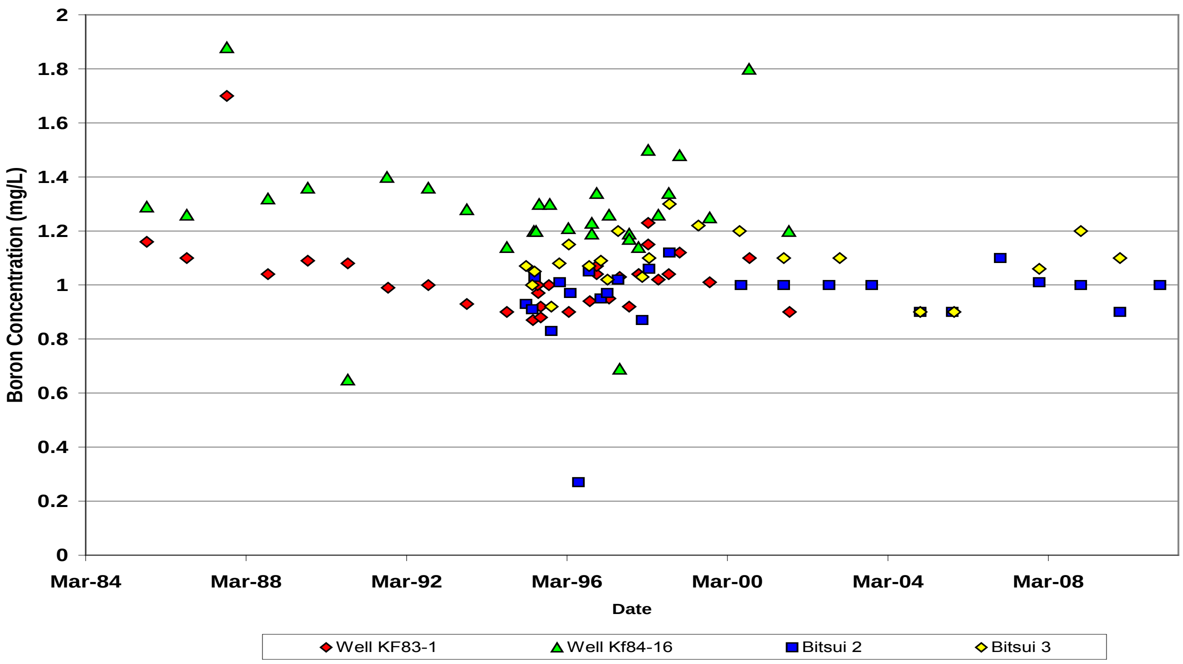
Bacterially mediated sulfate reduction rates are dependent on sulfate concentrations, amount of available organic carbon and temperature (Benner et al., 2002; Appelo and Postma, 2007; Praharaj and Fortin, 2008). The sulfate concentrations at the Bitsui-2 monitor well have sustained values equal to or greater than 1,000 mg/l or 10 milli-moles (mM) since October 2003.

This well is also completed in coal which provides the source of organic carbon necessary for bacterial mediated sulfate reduction. The high sulfate concentrations and large pool of organic carbon result in high sulfate reduction rates (Benner et al., 2002; Appelo and Postma, 2007; Praharaj and Fortin, 2008). The highest rates found in the literature are on the order of 0.92 mM/day which are noted as being achievable under laboratory conditions at sulfate concentrations above 2 mM (Appelo and Postma, 2007). Doshi (2006) also reports sulfate reduction rates between 0.553 mM/day and 1.052 mM/day in laboratory scale bioreactors. However, use of laboratory sulfate reduction rates in transport modeling results in no sulfate reaching the Bitsui-2 well from the Bitsui Pit. Since field conditions are not as favorable as the laboratory experiments, a more realistic reduction rate of 0.11 mM/day was observed in the field (Benner et al., 2002).

A study of geochemical processes in groundwater impacted by coal mine water showed that bacterially mediated sulfate reduction decreased sulfate concentrations from 1,100 mg/l to less than 100 mg/l (Clark, 1995). Clark (1995) also found simultaneously decreasing bicarbonate values from approximately 3,000 mg/l to less than 2,400 mg/l as a result of saturation with respect to calcite and subsequent calcite precipitation. While Clark (1995) does not present a sulfate reduction rate, a rate can be back calculated from the data provided. Using the reduced amount of sulfate (~1,000 mg/l) and the approximate time for sulfate reduction in observation wells of 50 to 228 days, the sulfate reduction rate is estimated to range between 0.21 to 0.046 mM/day similar to those reported by Benner et al (2002). The sulfate reduction rates from field studies have been used to provide bounds for sulfate reduction in the calibration of the sulfate transport model developed in Section 11.6.2.3.1.

Finally, boron, a constituent at elevated concentrations in CCB leachate, shows no concentration change in the coal wells located near the Bitsui Pit as shown in Figure 11-32. Very high concentrations of boron and extremely high concentrations of sulfate may be an indicator of CCB leachate. However, high sulfate concentrations are also associated with spoil materials and sulfate alone does not identify CCB leachate. The use of TDS, boron and sulfate together provide identification of the source and sulfate is ideal for modeling because of the larger difference between background and leachate compared to boron. Backfill, rather than CCBs, is the cause of increased sulfate concentrations in coal wells KF83-1 and Bitsui-2.

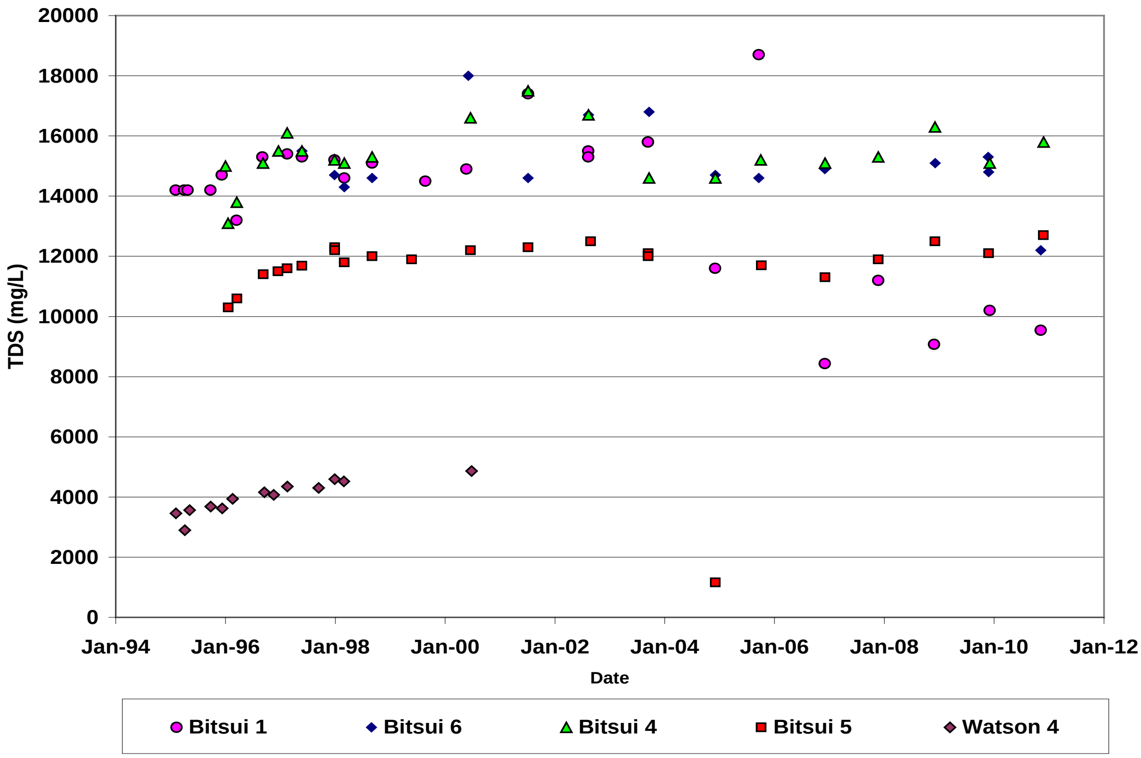
Figure 11-32. Time Series of Boron Concentrations in Coal Wells Located Near the Bitsui Pit



The results of time series plots of TDS, sulfate/chloride, and boron concentrations from the Bitsui backfill monitoring wells and the Watson-4 CCB well are provided in Figures 11-33, 11-34, and 11-35, respectively. The results show similar TDS concentrations in the CCB monitoring well Bitsui-1 and in mine backfill wells Bitsui-4 and Bitsui-6 but lower TDS concentrations in backfill monitoring well Bitsui-5. The Bitsui-5 well has lower concentrations of sulfate and higher concentrations of chloride in comparison with the spoil wells Bitsui 4 and Bitsui-6 as shown in Figure 11-33. These differences may partly be explained by the proximity to water recharge sources. Bitsui-5 is closer to the down gradient coal and may have initially received more recharge of low sulfate and higher chloride water from the down gradient coal. With water level recovery in the backfill, the sulfate concentrations have increased and the chloride concentrations have declined in well Bitsui-5 and are starting to approach the concentrations observed in wells Bitsui-4 and Bitsui-6. Wells Bitsui-4 and Bitsui-6 are completed in the Bitsui Pit mine backfill approximately 280 feet and 170 feet, respectively, north of CCB monitoring well Bitsui-1 as shown in Exhibit 11-167. Water elevations in these three wells show a very slight gradient to the north, estimated at 0.0025 ft/ft between Bitsui-1 and

Bitsui-4. The Bitsui-6 well is completed in the mine spoils at a location approximately 33 feet from an identified CCB backfill placement location.

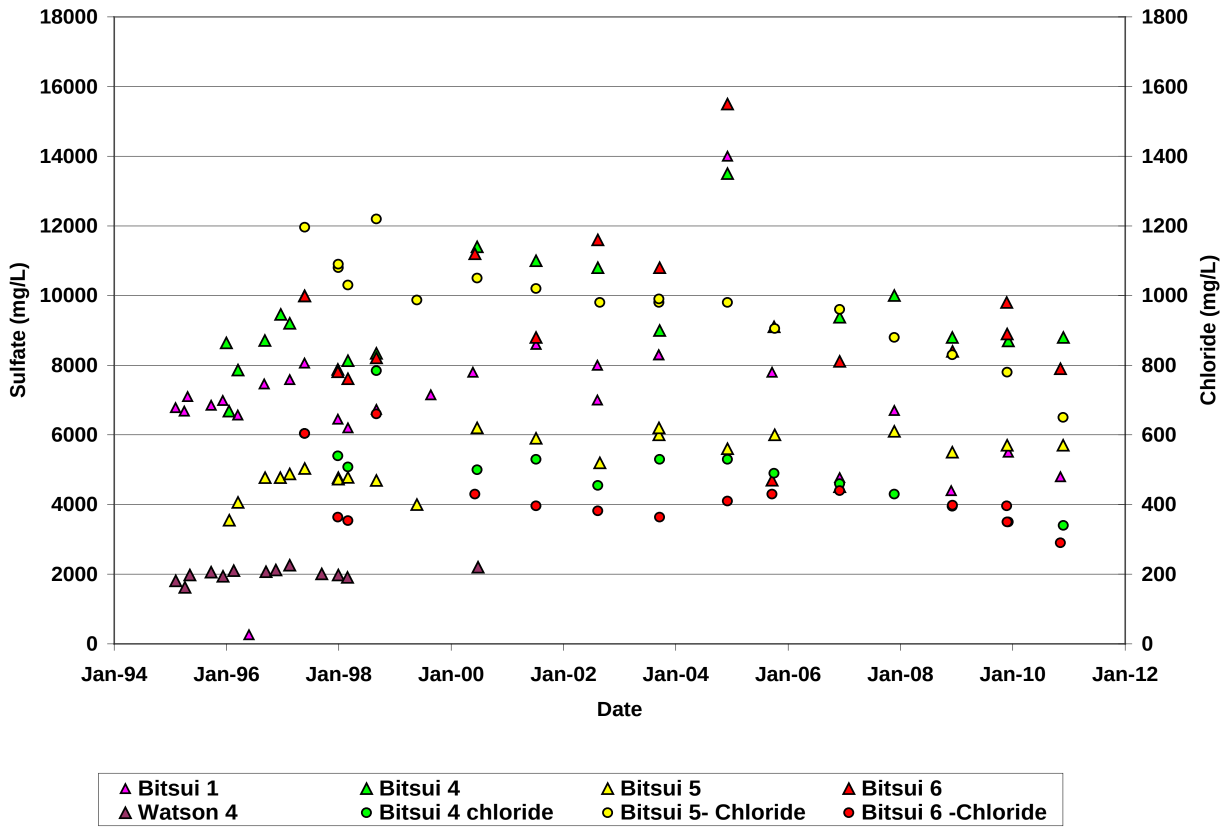
Figure 11-33. TDS Concentrations in Bitsui and Watson Wells



The lowest TDS concentrations were observed in the Watson-4 well, which can be used to characterize leachate from CCB disposal at a location that is not influenced by NAPI irrigation, spoil water, or pit inflows from the coals. The relatively low TDS observed in the Watson-4 CCB well demonstrates that CCBs are not a source for the relatively high TDS observed in spoil monitoring wells Bitsui-4 and Bitsui-6.

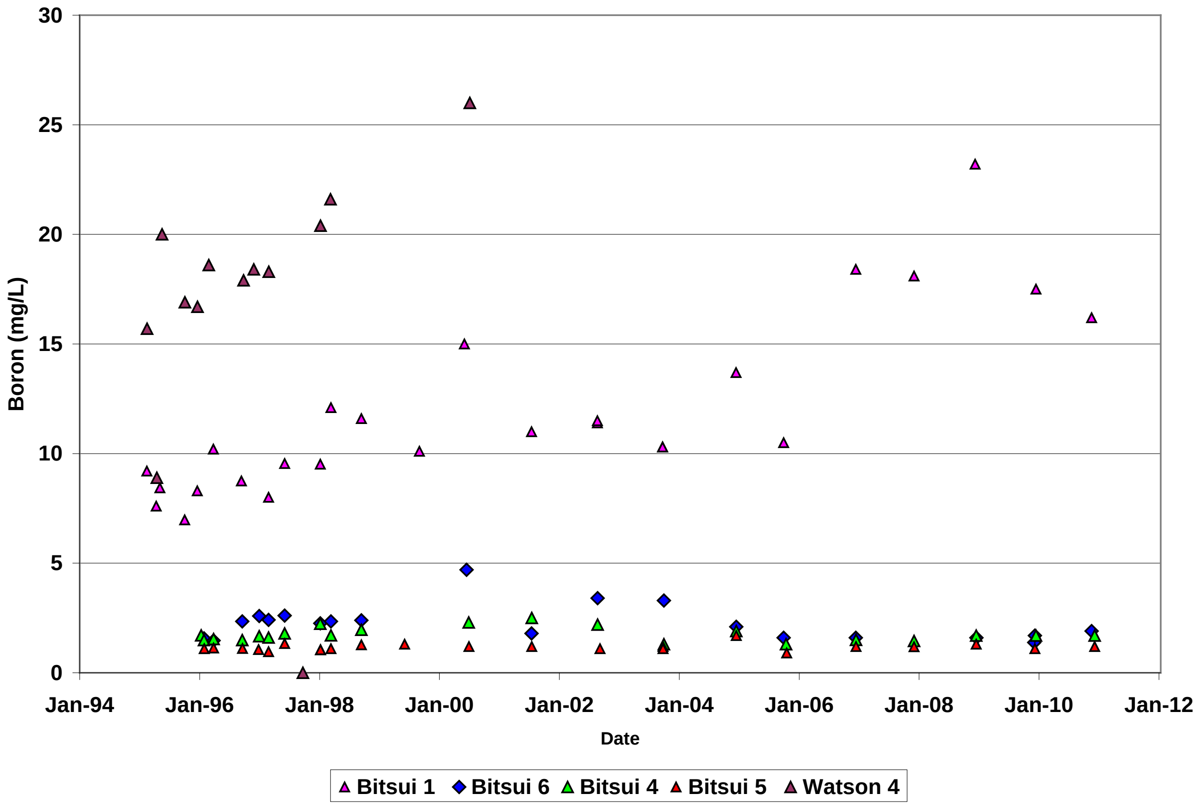
The sulfate concentration plots in Figure 11-34 show highest levels in the mine backfill wells Bitsui-4, and Bitsui-6 and slightly lower levels in the CCB well Bitsui-1 and in spoil well Bitsui-5. The sulfate concentrations observed in the Watson-4 well are much lower than the concentrations observed in the backfill wells, but are higher than the concentrations observed in the nearby coal wells.

Figure 11-34. Sulfate and Chloride Concentrations in Bitsui and Watson Wells



The boron concentrations plotted in Figure 11-35 show highest levels in the Watson-4 CCB well, which can be used to characterize leachate from CCBs at a location that is not influenced by NAPI irrigation or pit inflows from the coals. The boron concentrations in the Bitsui-1 CCB well are significantly higher than in the other backfill wells and in the coal wells (Figure 11-32), but lower than the concentrations observed in the Watson-4 CCB well. On the other hand, the sulfate in Bitsui-1 was similar to the sulfate in the backfill spoil wells. This suggests that mine spoil water is the source of the water in the Bitsui-1 CCB well. The boron concentrations in the mine spoil wells Bitsui-4, and Bitsui-5 are similar to the concentrations observed in the coals and do not show any influence from CCBs. The boron concentrations observed in well Bitsui-6 are slightly higher than the concentration observed in Bitsui-4, and Bitsui-5, indicating possible influence of groundwater from the CCBs located approximately 33 feet south of this backfill monitoring well.

Figure 11-35. Boron Concentrations in Bitsui and Watson Wells



The sulfate, TDS, and boron concentrations are higher in the Bitsui spoil wells in comparison with the concentrations observed from mine spoil leached with surface water and with coal water as presented in Table 11-14c. The higher concentrations in the Bitsui spoils in comparison with the leaching tests may be due to higher concentrations in the NAPI irrigation source water after it has leached the overburden materials between the irrigation site and the Bitsui Pit or it may be due to chemical evolution within the mine spoil linked to ion exchange and precipitation. Calcium and sulfate concentrations increase in spoil leachate from the dissolution of gypsum. Precipitation of calcite and ion exchange of calcium for sodium results in a larger increase in sulfate and a smaller increase in calcium. As shown in Table 11-14a, the calcium concentrations are lower and sodium and sulfate concentrations are higher in spoil wells Bitsui-4, Bitsui-5, and Bitsui-6 in comparison with concentrations observed from mine spoil leached with coal water as presented in Table 11-14b. These results suggest that ion exchange and precipitation in mine spoil permit sulfate concentrations to increase above gypsum solubility limits and above observations from short-term leaching tests.

Table 11-14a also provides a comparison of concentrations in spoil wells, CCB wells and potentially affected coal wells with the median baseline concentrations observed in Fruitland coal wells at the mine site and with median baseline concentrations observed in No. 8 coal wells down dip and down gradient near the subcrop with the San Juan River alluvium. Median concentrations are summarized in Table 11-14a along with the number of analyses available for each constituent at each well for calculating the median. Less than detection results are entered at 1/2 the detection limit for calculating the median concentration.

The baseline concentrations of TDS, calcium, and sodium in wells KF84-18a and KF84-18b were comparable with the concentrations observed in spoil wells, while the baseline concentrations for sulfate and boron were lower. The TDS, calcium, and sodium concentrations in the spoil wells are also lower than the concentrations observed in two of the three down gradient baseline coal wells. Sulfate concentrations in the spoil wells are higher than the baseline sulfate concentrations observed in coal wells. Boron concentrations in spoil wells Bitsui-4 and Bitsui-5 are comparable with the baseline boron concentrations in the down gradient coal wells. As discussed previously, the boron in spoil well Bitsui-6 is higher, due to influence from CCB placement immediately upgradient of this well. Bitsui-1, which is completed in the CCBs at this location, exhibits higher boron concentrations and lower sulfate concentrations in comparison with spoil well Bitsui-6.

Table 11-14a.
Concentrations for Selected Constituents in Navajo Mine Monitoring Wells

Location	Well*	TDS (mg/L)		SO4 (mg/L)		Ca (mg/L)		Na (mg/L)		B (mg/L)	
		n	median	n	median	n	median	n	median	n	median
Baseline Fruitland Coals within coal lease (median concentrations)	KF2007-01	5	3460	5	740	5	3.2	5	1180	5	0.3
	KF98-02	6	3130	6	107	6	6.1	2**	1210	6	0.4
	KF84-18a	25	13400	25	5	25	159	25	4660	24	0.72
	KF84-18b	24	9240	27	5	27	114	26	3365	26	0.73
	KF84-20A	26	7260	26	5	26	18.4	25	2700	26	0.5
	KF84-20C	23	2770	23	7	23	9.6	23	1040	23	0.42
	KF84-21A	31	8370	31	64	31	13.4	30	3095	31	0.6
	KF84-22a	30	4615	30	2050	30	15.5	30	1600	26	0.26
	KF84-22b	25	6010	25	5	25	45	25	2330	22	0.39
	KF84-21C	1	8505	1	184	1	14.6	1	2858	1	0.63
	KF84-22C	1	8035	1	5	1	44.4	1	2716	1	0.46
	KF84-22d	1	8610	1	5	1	27.4	1	2866	1	0.5
	KF84-22e	1	8275	1	44	1	26.8	1	2890	1	0.56
	Median		8035		7		18		2716		0.50
Baseline Coal downgradient (median)	SJKF#2	1	43035	1	5	1	515	1	13456	1	1.23
	SJKF#3	1	50810	1	5	1	700	1	15632	1	1.43
	SJKF#4	1	7370	1	5	1	217	1	2642	1	1.57
	Median		43035		5		515		13456		1.43
Mine spoil (median)	Bitsui-4	20	15150	20	8900	20	290.5	20	4630	20	1.7
	Bitsui-5	21	11800	24	5030	24	59.50	24	3860	24	1.11
	Bitsui-6	20	14850	20	8850	20	368.00	20	4270	20	2.07
CCB wells (median)	Bitsui-1	25	14600	26	6995	26	75.3	26	4845	25	10.5
	Watson-4	6	3620	6	189	6	687.5	6	445	6	17.4
Potentially Affected Coal Walls (median)	Bitsui-2	27	5160	27	235	27	6.4	27	2060	27	1.0
	Bitsui-3	17	7960	21	240	21	22.4	21	3130	21	1.1
	KF83-1	37	7100	37	351	37	19.6	36	2625	35	1
	KF84	24	7760	24	3955	24	48	24	2565	24	1.3
	KF84-16	31	9960	31	16	31	38.6	31	3840	31	1.3
	SJKF#5	1	4470	1	5	1	6	1	1668	1	1.23

* All wells are shown on Exhibit 11-166 except for KF2007-1 and KF98-02 which are shown on Appendix 6-G Exhibit 6-G-1

** In the case of 2 values the median is averaging the data

Table 11-14b.

Selective Results of Batch Leach Tests

Comparison of leaching water (surface water from Chinde Arroyo and groundwater from Coal seam #4-6) and leachate water produced (Data from IT Corporation Leach Report, Appendix 11-K, Tables 27.B13 through 27B.29)

(Concentrations in milligrams per liter).

Water Source	**PH**	**TDS**	**Ca**	**Na**	**Cl**	**SO4**	**Fe**	**Mn**	**B**	**F**	**Se**	**As**	**Cd**
Surface Water from Chinde Arroyo	7.8	1,900	230	280	15	1,200	0.45	0.08	0.31	1.0	<0.001	<0.001	<0.001
Surface Water Leachate:													
Spoils S-4	7.8	4,600	640	850	43	2,700	0.06	0.7	<0.5	0.6	0.20	0.002	<0.001
Spoils S-5	8.2	3,500	320	750	27	2,300	0.02	0.26	<0.5	0.9	0.018	0.002	<0.001
Fly Ash	12.2	2,000	290	380	16	590	0.02	0.02	1.0	1.9	0.09	0.009	<0.001
Bottom Ash	8.5	2,000	260	330	22	940	0.03	0.07	<0.5	0.9	0.046	<0.001	<0.001
CCB w/ S-4	7.7	5,300	670	850	37	3,200	0.02	1.4	<0.5	1.0	0.018	<0.003	<0.001
CCB w/ S-5	8.1	4,500	550	800	29	3,000	0.08	0.39	<0.5	1.8	0.010	<0.003	<0.001
Groundwater from coal seams 4-6 (Composite #4)	8.2	9,800	140	3,500	5,200	120	0.15	0.03	0.53	0.3	0.011	0.015	0.001
Groundwater Leachate:													
Spoils S-4	7.8	12,000	730	3,200	5,500	2,700	0.06	0.7	<0.5	0.5	0.20	0.002	<0.001
Spoils S-5	8.2	11,000	530	3,200	5,600	2,300	0.02	0.26	<0.5	0.6	0.018	0.002	<0.001
Fly Ash	12	10,000	520	3,000	5,600	320	0.02	0.02	6.2	3.1	0.22	0.017	<0.001
Bottom Ash	8.5	8,700	170	3,500	5,500	170	0.03	0.07	0.6	0.7	0.020	<0.001	<0.001
CCB w/ S-4	7.9	12,000	790	3,100	5,700	2,000	0.04	1.3	<0.5	0.9	0.016	0.009	<0.001
CCB w/ S-5	7.9	12,000	740	3,700	5,600	2,000	0.09	0.64	0.9	1.3	0.009	0.008	<0.001

The potentially affected coal wells are all located adjacent to the pre-SMCRA mined locations within Area 1 as shown on Exhibit 11-167. KF84 is located adjacent to the Custer Pit while the other potentially affected coal wells in Table 11-14a are down gradient of the Bitsui Pit. The TDS, calcium, and sodium concentrations in these wells are generally consistent with the corresponding baseline concentrations in the coals while the sulfate and boron concentrations are slightly higher (see Table 11-14a).

Outside of these groundwater level and water quality changes that have been observed in the coals adjacent to the Bitsui Pit, the only other groundwater change that has been observed at the Navajo Mine is the drawdown in water levels in several of the coal wells adjacent to mining within Area II and Area III. The 2006-07 Navajo Mine Hydrology Report (BNCC, 2009) shows declines in water levels in No. 8 coal seam well KF84-18b and No 7 coal seam wells KF84-20C and KF84-22b. Water levels have fluctuated in the No. 8 coal seam well KF84-18b but this well has been dry or has had insufficient water for sampling for most of the monitoring events since year 2003. Water levels in several of the other coal seam wells listed in Table 11-14a have been dry or have insufficient water for sampling since year 2001, these include wells KF84-20C, KF84-22b, KF84-18a, KF84-20B, KF84-20A, and KF84-21A.

Although drawdown effects have been observed prior to year 2002 in several of the baseline coal monitoring wells listed in Table 11-14a, the water quality monitoring through year 2001 at these wells has been selected to represent baseline water quality. There could be no influence from the mine on water quality of these wells because the hydraulic gradients at these well locations would have been toward the mine pit after the start of mining. These baseline coal wells are at locations that are quite distant from NAPI plots and results are not affected by NAPI irrigation unlike the monitoring wells near the Bitsui Pit. The water quality in these wells after reclamation can be compared with the baseline quality to identify any changes that might be due to mining.

During mining operations, all strata overlying the Fruitland coal seams are stripped to expose the coal for mining. Each successive open cut serves as a sink for groundwater causing drawdown of potentiometric levels in the adjacent coals and the underlying PCS. The potential impact of mining activities on groundwater quantity was addressed in Chapter 6. In that analysis, a three dimensional model was used to evaluate hydrologic consequences due to stress propagation from pit advance. The analysis showed that the stress propagation resulted in minimal impacts to the hydraulic regime as drawdown of only two to three feet were computed near the mine area for the coal seams and interbedded lithologic units of the Fruitland Formation. The effects of mining on the water bearing strata decrease by orders of magnitude within a few miles of the mine area (Appendix 6-D).

Average inflow to the entire mine area was estimated to be approximately 239 acre-feet per year over a model simulation time of 12 years. Observations during actual mining have shown that these model estimates of mine inflow were too high. Groundwater inflows to the mine pits in Area II and Area III have rarely been sufficient to be observed as seeps along the highwall. The pit floors remain dry except on rare occasions when storm runoff is captured. It appears that any groundwater flow to the mine pits from the Fruitland Formation is consumed by evaporation from the highwall. Also, no noticeable upward seepage through the pit floor or significant disruption of the mine floor (shale layer) has been observed in the mine pits.

11.6.2.2 Groundwater Impacts due to CCB Placement and Mine Spoil

The mine spoils are the non coal overburden and interburden materials of the Fruitland Formation that are removed to allow access to the coals and then placed within the mined pit to achieve approximate original contour. The overburden and interburden is generally comprised of fine to medium grained sandstones, siltstones, sandy and silty claystones, carbonaceous claystones, and bentonitic claystones, although the mostly tan or gray shale dominates. The clays are commonly highly expansive and are believed to be smectites. The potential to form acidic material from the oxidation of sulfur is not common and pH values are typically highly alkaline (pH > 8.0). Removal and backfilling of overburden and interburden materials provides for adequate blending and mixing of overburden materials ensuring that potential acid forming materials are blended with neutralizing materials such that acidic water will not occur within the mine spoil. This conclusion is supported by laboratory results of acid-base accounting of mine spoil samples, which shows average total sulfur acid base potential of approximately 19.0 tons/kilotons and by the neutral to alkaline pH levels observed in the Bitsui backfill monitoring wells. The laboratory results of the spoil samples were analyzed as part of Navajo Mine's root-zone monitoring program.

Between 1971 and 2008, BNCC placed CCBs from FCPP in mined out pits or ramps at Navajo Mine. BNCC does not have any current operational plans to place CCB materials in the mine backfill for future reclamation within the permit boundary. Historic placement locations are primarily within Area I with limited placement in Area II. As discussed in Section 11.6.2.1, the SGS (Appendix 11-MM) was implemented to assess possible impacts to groundwater from historic mine placement of CCBs at Navajo Mine. BNCC has also completed detailed studies of the constituents leached from CCBs and mine spoil for the PHC determination. The results of these studies are provided in Appendix 11-K. No toxic materials are present in the spoil or CCB as demonstrated by the toxicity tests in Appendix 11-K. Characterization investigations conducted on CCB and mine spoil at Navajo Mine contained in Appendix 11-K show that, except for boron, CCBs and spoil material have similar leaching concentrations. A subsequent spoil testing program was also completed in year 2008 to generate additional information on spoil properties and leaching characteristics of mine spoil. These testing results are presented in Appendix 11-VV and are used to support the PHC assessment for proposed spoil placement as mine backfill within Area IV North at Navajo Mine.

Parameter concentrations (mg/kg) of a solid matrix of CCB and of spoil disposed of at Navajo Mine are presented in Tables 11-14c and 11-14d (taken from the Appendix 11-K, Tables 27-B3 and 27-B4). The only notable parameter differences with the spoil is that fly ash has elevated concentrations of boron, and slightly higher concentrations of selenium and barium. For the remainder of the trace metals, the concentrations of spoil, fly ash, and bottom ash are similar. Both bottom ash and fly ash have lower concentrations of sulfate, sodium, and calcium when compared to spoil.

Per EPA's 1993 final regulatory determination CCB materials (fly ash, bottom ash, boiler slag, and flue gas emission control waste) are exempt from regulation as a hazardous waste under Subtitle C of the Resource Conservation and Recovery Act (RCRA, 58 FR 42466, 9 Aug 1993). Solid samples of fly ash, bottom ash, and spoil were subjected to the Extraction Procedure (EP) Toxicity Test and the extract from this procedure was subsequently analyzed for a suite of metals and general chemistry. The results (Appendix 11-K, Table 27.B11) were all below the limits for EP toxicity used to classify a material as toxic.

Table 11-14b is a comparison of surface and groundwater concentrations before and after they have been leached through different mixtures of spoil and CCB. The data presented in Table 11-14b was selectively extracted from data tables contained in Appendix 11-K. Several general relationships are evident from Table 11-14b for both groundwater and surface water as follows.

1. Surface water and groundwater leached through fly ash or bottom ash had lower TDS than when leached through spoil and is similar to the original concentration of the pre-leach water.
2. In general, the leachates produced do not widely differ from that of coal seam groundwater. TDS concentrations in the leachate have increased (except for bottom ash, which had a lower TDS than the groundwater) due to increases in sulfate, calcium, and chloride concentrations. However, the increased TDS concentration is small in comparison to the concentration of the coal groundwater.
3. Trace constituent concentrations are similar for all the leachates produced, with the exception of fly ash alone, which showed increases in arsenic, boron, and fluoride and selenium concentrations.
4. Spoil serves to attenuate arsenic, boron, and fluoride when concentrations are slightly elevated in fly ash leachate, in baseline surface water and in baseline coal seam water.
5. The iron concentration in both surface water and groundwater decreased following leaching through spoil, CCB, or a mixture of the two. Manganese concentrations increased in both surface and groundwater leaching of mine spoil but not in leaching of fly ash or bottom ash.

Table 11-14c

Coal Combustion By-product (CCB) Analysis Summary

(Table 27-B3, Appendix K)

PARAMETER	UNIT	CCB	
		FLY ASH (No sludge)	BOTTOM ASH
Acidity[1]	mg/kg $CaCO_3$	<100[3]	397
Alkalinity[1]	mg/kg $CaCO_3$	11,577	2,976
Chloride	mg/kg	100	124
Cyanide	mg/kg	0.20	0.22
Fluoride	mg/kg	176	81
Nitrate[1]	mg/kg No_3-N	<1	2
pH		NA[2]	NA
Phenolics	mg/kg	1.29	1.36
Residue:			
Filterable @ 180 ^{0} C	mg/kg	NA	NA
Specific Conductance @ 25 ^{0} C	µmhos/cm	NA	NA
Sulfate[1]	mg/kg SO_4^{-2}	1,667	<100
Metals:			
Aluminum	mg/kg	6,600	2,000
Arsenic	mg/kg	11	0.38
Barium	mg/kg	850	420
Boron	mg/kg	160	10
Cadmium	mg/kg	0.4	<0.1
Calcium	mg/kg	12,000	3,000
Chromium	mg/kg	5	<1
Cobalt	mg/kg	2	1
Copper	mg/kg	0.063	0.023
Iron	mg/kg	5,300	2,100
Lead	mg/kg	26	<1
Magnesium	mg/kg	530	150
Manganese	mg/kg	99	32
Mercury	mg/kg	0.2	<0.1
Molybdenum	mg/kg	<6	<6
Nickel	mg/kg	2	<1
Potassium	mg/kg	162	44
Selenium	mg/kg	6.5	<2[4]
Silver	mg/kg	<0.2	<0.2
Sodium	mg/kg	430	84
Zinc	mg/kg	13	5

(1) Water leachable.
(2) NA – not analyzed.
(3) < - Less than.
(4) Higher detection limits due to matrix interference.

Table 11-14d

Spoils and Overburden Analysis Summary

(Table 27-B4 Appendix K)

PARAMETER	UNIT	S–1	S–2	S–3	S–4	S-5	D-1	D-2
Acidity[1]	mg/kg $CaCO_3$	399	299	197	399	298	399	398
Alkalinity[1]	mg/kg $CaCO_3$	3,293	3,693	3,945	3,593	3,777	7,186	3,877
Chloride[1]	mg/kg	250	150	246	200	248	399	149
Cyanide	mg/kg	0.17	1.18	0.20	0.25	0.20	0.08	0.20
Fluoride	mg/kg	471	463	420	575	503	403	332
Nitrate[1]	mg/kg NO_3-N	29	16	12	20	24	15	20
pH		NA[2]	NA	NA	NA	NA	NA	NA
Phenolics	mg/kg	1.09	1.19	1.09	1.18	1.05	0.90	1.98
Residue:								
Filterable @ 180 ^{0} C	mg/kg	NA	NA	NA	NA	NA	NA	NA
Specific Conductance @ 25 ^{0} C	µmhos/cm	NA	NA	NA	NA	NA	NA	NA
Sulfate	mg/kg SO_4^{-2}	8,982	7,236	6,410	12,724	6,610	1,946	3,529
Metals:								
Aluminum	mg/kg	8,100	7,400	5,500	6,600	6,600	9,200	6,200
Arsenic	mg/kg	6.5	6.0	36	17	4.3	4.5	4.6
Barium	mg/kg	180	42	130	520	150	110	120
Boron	mg/kg	9	8	4	<3[3]	4	<3	<3
Cadmium	mg/kg	1.0	0.9	1.1	0.9	0.8	1.1	0.9
Calcium	mg/kg	16,000	17,000	7,9000	9,500	27,000	14,000	11,000
Chromium	mg/kg	3	3	2	3	3	6	6
Cobalt	mg/kg	7	7	8	7	9	7	6
Copper	mg/kg	11	6	6	15	9	10	0.143
Iron	mg/kg	14,000	13,000	39,000	27,000	14,000	20,000	18,000
Lead	mg/kg	35	32	58	35	32	42	72
Magnesium	mg/kg	2,900	3,100	2,300	2,100	2,900	4,100	6,200
Manganese	mg/kg	200	200	360	190	470	350	250
Mercury	mg/kg	<0.1	<0.1	0.2	0.8	<0.1	0.2	0.2
Molybdenum	mg/kg	<6	<6	<6	<6	<6	<6	<6
Nickel	mg/kg	10	9	13	10	13	10	9
Potassium	mg/kg	1,100	1,400	906	1,200	1,400	903	801
Selenium	mg/kg	<1[4]	<2[4]	<2[4]	<2[4]	<2[4]	<1[4]	<1[4]
Silver	mg/kg	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Sodium	mg/kg	2,600	2,700	2,700	3,500	2,700	2,900	1,400
Zinc	mg/kg	66	63	58	71	69	63	56

(1) Water leachable.
(2) NA – not analyzed.
(3) < - Less than.
(4) Higher detection limits due to matrix interference.

6. Selenium concentrations in surface water and groundwater leached through a mixture of CCB and spoil are similar to the selenium concentrations in leachate produced by spoil alone. Boron concentrations in groundwater leached through a mixture of CCB and spoil are similar to the original concentration of the groundwater. Boron concentrations declined in surface water leached through a mixture of CCB and spoil. Fluoride concentrations also declined in surface water leached through spoil.

These leaching test results together with the data collected from the SGS that were presented in Section 11.6.2.1 show that some increase in TDS concentrations would be expected in mine spoil water in comparison with the TDS concentrations in the original source of water (i.e. groundwater or surface water). The leaching tests indicate that the increase in TDS is due primarily to increases in calcium, sodium, and sulfate while the field monitoring results from the SGS indicate that the increase in TDS is due primarily to increases in sodium and sulfate. Apparently, precipitation of calcite allows sulfate to increase above gypsum solubility limits accounting for the increase in sulfate and decrease in calcium in saturated mine spoils in comparison with leaching test results. The groundwater monitoring data from the Navajo Mine show that baseline groundwater in the coals is very saline. TDS levels have remained at or near baseline concentrations in the potentially affected coal seam wells located near the backfilled mine pits as discussed in Section 11.6.2.1.

The leach study, as well as the data from the SGS, shows that TDS and sulfate concentrations are lower in saturated CCBs in comparison with mine spoils when the source of saturation is surface water or groundwater. Also, TDS and sulfate concentrations do not increase in CCBs that become saturated with spoil water. Arsenic, boron, fluoride, and selenium concentrations increased in fly ash leachate and also showed higher concentrations in CCB wells Bitsui-1 and Watson-4 in comparison with the concentrations in spoil wells (see Table 11-14e). Selenium concentrations in the CCB wells were below the livestock criterion of 0.05 mg/l. Boron and fluoride in the CCB wells were above the livestock criteria of 5 mg/l and 2 mg/l, respectively. Arsenic concentrations in the CCB wells were close to the livestock criteria of 0.02 mg/l. Other trace constituents were below detection limits in the majority of the samples from both CCB and spoil wells and are not listed in Table 11-14e.

Table 11-14e

Trace Constituent Concentrations in Spoil and CCB Wells

Location	Well	As (mg/L)		B (mg/L)		Fe (mg/L)		Mn (mg/L)		F (mg/L)		NO3-N		Se (mg/L)	
		n	median	n	median	n	median	n	median	n	median	n	median	n	median
Mine spoil (median)	Bitsui-4	20	0.0025	20	1.69	20	0.51	20	3.650	20	0.30	19	0.023	20	0.0025
	Bitsui-5	24	0.0025	23	1.11	23	0.11	23	0.108	23	1.00	18	0.125	23	0.0025
	Bitsui-6	20	0.0025	20	2.07	20	0.35	20	4.560	20	0.29	15	0.020	20	0.0025
CCB wells (median)	Bitsui-1	25	0.0210	25	10.50	25	0.10	25	0.200	26	2.25	14	0.025	25	0.0060
	Watson-4	5	0.0200	11	17.40	6	0.01	6	0.025	6	3.63	2	0.070	6	0.0170
Potentially Affected Coal Wells (median)	Bitsui-2	24	0.0025	25	0.97	25	0.025	24	0.006	25	1.70	20	0.033	25	0.0025
	Bitsui-3	20	0.0025	21	1.07	21	0.06	21	0.005	20	1.02	16	0.028	21	0.0025
	KF83-1	19	0.0025	34	1.02	33	0.14	34	0.020	34	1.07	3	6.240	33	0.0025
	KF84	15	0.0025	24	1.30	23	0.20	24	0.134	24	2.70	2	0.080	24	0.0025
	KF84-16	17	0.0025	28	1.27	28	0.145	28	0.057	28	0.69	4	0.080	26	0.0025
	SJKF#5	1	0.0010	1	1.23	1	0.036	1	0.170	1	2.07	1	0.920	1	0.0010

The arsenic, boron, and fluoride concentrations in spoil well Bitsui-6 located immediately down gradient of CCB well Bitsui-1 confirm the leaching tests results which found that spoil attenuates or reduces the concentrations of arsenic, boron, and fluoride. The CCB and spoil well monitoring results in Table 11-14e also indicate likely attenuation of selenium in saturated mine spoils. Attenuation of metals in mine spoil occurs as a result of adsorption associated with the high cation-exchange-capacity (CEC) of mine spoils and geochemical precipitation and co-precipitation. Also, when groundwater containing low sulfate levels interacts with the spoil, sulfate concentrations increase. Laboratory data suggest that colloidal hydroxides are formed when the spoils and water interact. This geochemical interaction and mixing facilitates the adsorption and precipitation of metals, thus reducing their concentrations. The attenuation data from the leach study (Appendix 11-K) also shows that the concentrations of many parameters would be reduced after contact with the coal seam. While cation-exchange and precipitation reactions are finite and reversible processes the source of metals is also a finite process and cation-exchange and sulfide precipitation is expected to significantly reduce metals concentrations in down gradient groundwater.

Sulfate reduction resulting in metal sulfide precipitation results in highly insoluble precipitates (Drever, 1998). The sulfide precipitates will remain in mineral form unless sufficient oxygen is provided to the system. Given the very low recharge and groundwater flow rates at the site the release of metals trapped as sulfides is unlikely and should act as a relatively permanent sink within the system. Additionally, given the large source of sulfate within the system, observed sulfate reduction to sulfide, and the finite source of metals the natural attenuation of metals due to metal sulfide precipitation is likely to reduce metal concentrations down gradient.

The cation-exchange process will only reverse if there is a significant geochemical change in the inflowing water source. One such difference that could cause the release of metals would be a lowering in pH. The lowering of pH increases the hydronium ion concentration and competes for exchange sites with cations. However, as shown in the leachate testing the pH remains neutral to slightly alkaline and the inflowing coal groundwater is very alkaline with a pH of approximately 9. This indicates that over time the groundwater will increase in pH to a value similar to the inflowing groundwater at a pH of 9 and not result in the displacement of metals from exchange sites. Additionally, the metals that are attenuated by cation-exchange would require higher concentrations of other metals or the presence of newly incorporated metals with a greater exchange site affinity to displace those metals on the exchange sites. Thus, the total number of exchange sites and the amount of the finite source will determine whether or not the metals will breakthrough. Once the source is depleted some metals may desorb over time to equilibrate with the new incoming water chemistry while a portion of the metals will remain at the exchange sites resulting in overall reduction and attenuation over time leading to lower trailing concentrations rather than a breakthrough of high metals concentrations.

Mine spoil does not appear to be a source for selenium as concentrations were below the 0.005 mg/l detection limit in the groundwater samples obtained from the three spoil monitoring wells Bitsui-4, Bitsui-5 and Bitsui-6. On the other hand, mine spoil does appear to be a source for manganese, which increased in spoil leachate and also showed higher concentrations in spoil wells in comparison with CCB wells as shown Table 11-14e and with baseline coal wells as shown in Appendix 6-G Table 6.G-9. The concentrations of other constituents in the spoil water are comparable to the concentrations in the baseline groundwater in the PCS and Fruitland coals. The water quality in the mine spoils and in the baseline groundwater are both poor and exceed the chloride, sulfate, and TDS criteria for drinking water and livestock use based on Navajo Nation and EPA standards (Appendix 6-G). Based on the Table 11-14e results, the arsenic, boron, fluoride, and selenium concentrations in the mine spoils are expected to meet livestock use criteria (Appendix 6-G). The fluoride concentrations fluctuate in the baseline groundwater and are often above the water quality criteria for livestock and drinking water use.

Additional leaching tests were performed on Navajo Mine spoils to support the PHC assessment for proposed spoil placement as mine backfill within Area IV North at Navajo Mine. These testing results are presented in Appendix 11-VV These leaching tests included 18-hour batch leaching tests of composite mine spoils performed in accordance with the EPA Synthetic Precipitation Leaching Procedure (SPLP, SW-846 Method 1312) and with the Synthetic Groundwater Leaching Procedure (SGLP). Also, 45-day leaching tests were included along with the standard 18-hour leaching procedure, in order to assess any changes associated with longer exposure to the leachant.

Composite spoil samples were obtained from Navajo Mine Area III in accordance with the regraded spoil sampling plan (Chapter 12 Section 12.3.1). 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 within Area IV. Two duplicate samples of the composite coal water were obtained and analysis results are presented in Table 11-14f as “Initial Coal Water Sample” and “Initial Coal Water DUP.”

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 11-14f under the heading "Initial Synthetic Precipitation".

The composite spoil was leached in duplicate (18-hr tests) with coal well water (Spoil Leachate 1 and Spoil Leachate 1 DUP; a test in which spoil is exposed to coal water for 45 days according to the long-term leaching procedure described above (Spoil 45-Day). Finally, an 18-hour leaching test of spoil was performed using the synthetic leaching fluid described in the SPLP (Spoil SPLP).

The leaching test results indicate that the pH of leachate using the expected field site materials and waters remains neutral to alkaline, indicating that low pH values that are typically responsible for enhanced trace metals transport will not exist with the mine backfill at the Navajo Mine. This finding is supported by data collected and conclusions reported for site wide geologic and hydrologic conditions. The synthetic precipitation leaching solution started with an initial pH of 5.0 and increased to a pH value of 7.5 for the spoil 18-hour batch samples, indicating the buffering influence of these materials to slightly alkaline conditions. An initial flush of salts, principally calcium and sulfate, occurs with leaching of these spoil along with detectable concentrations of some metals and trace constituents as indicated in Table 11-14f.

Fluoride was at a concentration of 2.4 mg/l in the background composite coal groundwater sample used in the leaching test. However, fluoride concentrations are attenuated in mine spoils as demonstrated by the leaching test results of mine spoil, which showed fluoride concentrations dropping from the concentration of 2.4 mg/l in the composite coal 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.

Thus, if spoil water does saturate CCB, the probable result is that concentrations of arsenic, boron, fluoride, and selenium may increase in the CCB material but these concentrations should decrease due to attenuation as this water migrates through the spoil, as supported by observed field and laboratory leachate data. TDS and sulfate concentrations are not expected to increase in CCBs that become saturated with spoil water. The concentrations of sulfate, sodium, TDS, boron, and manganese are expected to increase in spoils that become saturated with surface water infiltration or groundwater. Sulfate concentrations are likely to increase in the coal seam water adjacent to the mine pit as shown in Figure 11-31 for the coal wells adjacent to the Bitsui Pit. TDS would also increase in the coals adjacent to the mine pit but by less than the increase in sulfate as demonstrated in Figure 11-31.

Table 11-14f

Batch Leaching Test Results

Analyte (mg/L)	EPA Drinking Water Criteria	Aquatic & Wildlife Habitat (Acute)[1]	Aquatic & Wildlife Habitat (Chronic)[1]	Livestock (LW)	Initial Coal Water Sample	Initial Coal Water DUP	Initial Synthetic Precipitation	Spoil SPLP	Spoil 45-Day	Spoil Leachate	Spoil Leachate Dup
Al[2]		0.750 mg/L	0.87 mg/L	NCNS	0.13	0.14	0.056	< 0.05	0.38	0.29	0.3
Sb	0.0056				<< 0.0067	<< 0.0067	<< 0.0067	<< 0.0067	<< 0.0067	<< 0.0067	<< 0.0067
As	0.01	0.340 mg/L D	0.150 mg/L D	0.200 mg/L	<< 0.015	<< 0.015	<< 0.015	<< 0.015	<< 0.015	<< 0.015	<< 0.015
Ba	1	NCNS	NCNS	NCNS	0.093	0.088		0.07	0.079	0.25	0.2
Be	0.004				< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
HCO_3					1300	1200		33	960	1000	1000
B	0.63	NCNS	NCNS	5.0 mg/L D	0.31	0.29		0.084	0.36	0.44	0.45
Cd	0.005	Hardness Dependent	Hardness Dependent	0.05 mg/L	<< 0.00051	<< 0.00051	<< 0.00051	<< 0.00051	<< 0.00051	< 0.006, 0.00087*	<< 0.00051
Ca					3.4	3.3	0.27	150	56	64	69
CO_3					260	300	< 7	14	< 7	< 7	< 7
Cl	250[3]	0.019 mg/L	0.011 mg/L	0.011 mg/L	710	700		1.5	600	610	610
Cr (III + VI)	0.1	NCNS	NCNS	1.0 mg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Co		NCNS	NCNS	1.0 mg/L D	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Cu	1.3	Hardness Dependent	Hardness Dependent	0.5 mg/L D	< 0.005	< 0.005	< 0.005	< 0.005	0.053	< 0.005	< 0.005
F	2	NCNS	NCNS	NCNS	2.4	2.5	0.0067	0.54	1.5	1.6	1.6
Fe	0.3				0.067	0.073	< 0.05	< 0.05	< 0.05	0.17	0.18
Pb	0.015	Hardness Dependent	Hardness Dependent	0.100 mg/L	<< 0.011	<< 0.011	<< 0.011	<< 0.011	<< 0.011	<< 0.011	<< 0.011
Li					< 0.1	< 0.1	< 0.1	< 0.1	0.11	0.1	0.1
Mg					1.3	1.2		15	12	13	13
Mn	0.05[3]				< 0.01	< 0.01	< 0.01	0.19	0.098	0.11	0.1
Hg	0.002	0.0024 mg/L	0.000001 mg/L	NCNS	<< 0.00005	<< 0.00005	<< 0.00005	<< 0.00005	<< 0.00005	< 0.00024, 0.0001*	< 0.0002, 0.00008*
Mo		NCNS	NCNS	NCNS	0.012	< 0.01	< 0.01	< 0.01	0.015	0.014	0.014
Ni	0.61	Hardness Dependent	Hardness Dependent	NCNS	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04
pH (standard units)	6.5 - 9.0	6.5 - 9.0	6.5 - 9.0	6.5 - 9.0	9	8.9	5	7.5	8	8	7.9
K					11	10	< 1	7	14	14	14
Se	0.05	0.033 mg/L	0.002 mg/L	0.05 mg/L	<< 0.026	<< 0.026	<< 0.026	<< 0.026	<< 0.026	<< 0.026	<< 0.026
Ag	0.035	Hardness Dependent	NCNS	NCNS	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015
Na					1200	1100	5.7	150	1200	1200	1200
SO_4	250				300	260	3.4	670	930	970	990
Tl	0.0017	0.700 mg/L D	0.150 mg/L D	NCNS	<< 0.011	<< 0.011	<< 0.011	<< 0.011	< 0.4, 0.014*	<< 0.011	<< 0.011
TDS	500				3100	3000	28	1200	3500	3500	3600
V		NCNS	NCNS	0.100 mg/L D	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Zn	5	Hardness Dependent	Hardness Dependent	25 mg/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.0095

[1] Navajo Nation Water Quality Program, **2007**, Navajo Nation Surface Water Quality Standards. (Wildlife standard 0.002 mg/l for total selenium and 0.000012 mg/l for mercury)
<< Reported value is less than the MDL
*Above MDL, but below PQL
[2] pH 6.5 – 9
D – Dissolved
Harness Dependent – Equations for harness dependency found in NN SWQ Standards 2007

11.6.2.3 Potential Migration of Spoil and CCB Leachate in Groundwater From Current Mining and Reclamation Operations

As discussed, re-saturation of a portion of mine spoil within the Bitsui and Dodge pits has occurred over a period of about 25 years due to the contribution of seepage flow from adjacent NAPI irrigation. The Doby Pit is also located adjacent to NAPI irrigation plots. However, BNCC installed the Doby French drain adjacent to the Doby highwall to intercept seepage from the NAPI irrigation plots in order to curtail the resaturation of the Doby Pit. A backfill monitoring well, Doby-1-BF, was completed in the Doby Pit to monitor the rate of re-saturation of the Doby Pit and to assess the effectiveness of the Doby French Drain. The well has been monitored annually since September 2002 and has been dry during every monitoring event.

The rate of re-saturation is expected to be extremely slow at the other mine pits at Navajo Mine. This conclusion is based on the following:

- Groundwater modeling described in Section 11.6.2.4.1 found that resaturation of the backfilled pit within Area IV North will be very slow and will take several centuries or longer to approach steady state post-mining levels.
- Groundwater in the coal monitoring wells KF84-18a and KF84-18b located adjacent to the backfilled Yazzie Pit have remained nearly dry, indicating little or no water level recovery in the backfill.
- Well Doby-1-BF installed in the Doby Pit backfill has remained dry over the period from to 2002 to 2010. The Doby well was installed to assess the effectiveness of the Doby French Drain at intercepting seepage from the adjacent NAPI plots. These results demonstrate that the French Drain was effective and captured seepage from nearby NAPI irrigation. These results also show that without the NAPI seepage influence, the rate of re-saturation of mine backfill will be extremely slow.

The Yazzie Pit is the only pit at Navajo Mine, other than the mine pits within Area I, which is located near a potential source of water in Chinde Arroyo and the Chinde Diversion that could re-saturate the backfill more quickly than the extremely slow rates predicted for the Area IV North mine backfill in Section 11.6.2.4.1. A gain-loss evaluation of Chinde Arroyo and the Chinde Diversion found that there was water loss within Segment 3, the uppermost segment of the Chide Diversion (see Appendix 11-OO). The Chinde Diversion routes flow around the Yazzie Pit. The uppermost segment routes flow to the north along the east side of the Yazzie Pit. It then bends to the west and flows between the backfilled Yazzie and Doby Pits. Chinde Arroyo at the point of the diversion was originally an ephemeral stream but now exhibits perennial flow due to irrigation return flows and seepage along with occasional flows caused by discharge from the Navajo Indian Irrigation Project (NIIP) Ojo Amarillo canal and storm runoff events.

According to the Chinde Wash Surface Water Gain/Loss report (Appendix 11-OO), the water loss within Reach 3 of the Chinde Diversion is largely the result of evapotranspiration losses from the wetlands and salt cedar thickets that exist at the head of the diversion and to a lesser extent the result of seepage from the diversion that can be seen in the Yazzie highwall immediately below this wetland area at the head of the diversion. Although most of this seepage from the Chinde Diversion is currently lost to evaporation, it is likely that a portion of the seepage enters the Yazzie Pit backfill. This seepage contribution could increase the rate of re-saturation of the backfill in the Yazzie Pit, although rates of re-saturation should be slower than was observed for the Bitsui Pit because the seepage contribution is thought to be relatively small based on the following:

- both the Yazzie and Doby Pits, located adjacent to the Chinde Diversion, remained dry during mining and reclamation operations,
- the Doby-1-BF monitoring well installed in the backfill of the Doby Pit adjacent to the Chinde Diversion has remained dry, and
- little recovery of groundwater levels has been observed in coal wells KF84-18a and KF84-18b located adjacent to the Yazzie Pit.

Potentiometric surface maps for the Fruitland coal units (Exhibits 6-2 through 6-5 and Exhibits 6.G-2 and 6.G-3) all show general gradients toward the east in the direction of the dip of the coal and toward the northeast in the direction of the subcrop of the Fruitland Formation with the San Juan River alluvium. Both groundwater modeling and water level measurements from the network of monitor/piezometer wells installed by BNCC also indicate local gradients in the Fruitland coals toward Cottonwood and Pinabete Arroyos within Areas III and IV as shown in Exhibits 6.G-2 and 6.G-3. Potentiometric gradients were found to be quite flat across Area III while the coal units within and adjacent to Area II were dry or nearly dry.

11.6.2.3.1 Area I Groundwater Migration

Based on the potentiometric surface for the No. 8 coal, the discharge locations for the re-saturated mine spoil within Area I are projected to be:

- the subcrop of the No. 8 coal and the Fruitland Formation beneath the alluvium of San Juan River Valley to the northeast of Area I and
- down dip in the No. 8 coal Seam toward the drawdown influences of nearby coal bed methane wells (Exhibit 11-166).

The subcrop of the No. 8 coal seam and the Fruitland Formation beneath the alluvium in the San Juan River Valley occurs at elevations below the water levels in the coal seam to the south. The San Juan River alluvium, herein, refers to the unconsolidated Quaternary deposits of alluvium and Pleistocene outwash materials. The characteristics of the deposit varies but is largely comprised of either a gravel or sand matrix containing varying combinations of boulders, cobbles, pebbles, and silt. The approximate location for the coal subcrop is depicted in Exhibit 11-166. The approximate extent of the San Juan River alluvium along the Fruitland Formation subcrop is also mapped out in this exhibit. This subcrop location along the alluvium of the San Juan River is thought to be the primary discharge location for groundwater in the No. 8 coal and in the undifferentiated Fruitland Formation.

Discharge from the coal seam may also occur as leakage into the units above or below the coal. Although the potential rate of leakage through the shale, mudstone, and siltstones which overlie and underlie the coal seam is very low, the area of contact above and below the coal is sufficiently large that the potential discharge via leakage can be significant. However, the higher predicted potentiometric elevations in the PCS in the vicinity of Morgan Lake, as depicted in

Exhibit 11-166, function to limit or preclude vertical downward leakage into the PCS from the coal and the mine backfill and may even provide a source of water for recharging the backfill. Upward vertical gradients will diminish as water levels rise in the pit backfill. However, it is expected that gradient reversal will be limited to locations more distant from Morgan Lake such that little spoil water within Area 1 will enter the PCS. Lateral groundwater flow is expected to occur from the saturated mine backfill in the direction toward the subcrop in both the No. 8 coal and in the undifferentiated Fruitland Formation.

A groundwater transport model was applied to assess the potential impact of mine spoil and CCB placement within Area 1 on the water quality in the down gradient coal seam and on the water quality in the alluvium of the San Juan River valley. This model represents a simplification of the groundwater flow system. Estimates of hydraulic variables and physical relationships used for the model are based on presently available data. For the purpose of this evaluation, it is assumed that the primary path for groundwater flow from the mine spoil will be through the coal in a north-north east direction toward the coal formation subcrop in the San Juan River alluvial aquifer (see Figure 11-24). Some groundwater flow will also occur through the undifferentiated Fruitland Formation but the rate and magnitude of this flow is expected to be lower than in the coal due to the lower hydraulic conductivity and higher porosity of the undifferentiated Fruitland Formation relative to the coal.

A steady-state MODFLOW model of groundwater flow through the coal was set up to support the groundwater transport modeling. The MT3DMS model was applied in conjunction with the steady state MODFLOW model to simulate advection, dispersion/diffusion, and sulfate reduction in order to estimate transport through the coal to the subcrop location along the San Juan River alluvium. The mass transport parameters for dispersion and decay (sulfate reduction) were estimated based on calibration to the sulfate breakthrough concentrations observed in the down gradient coal well Bitsui-2. Sulfate decay rates estimated from model calibration were found to be at the lower bound of the estimated decay rates reported in the literature.

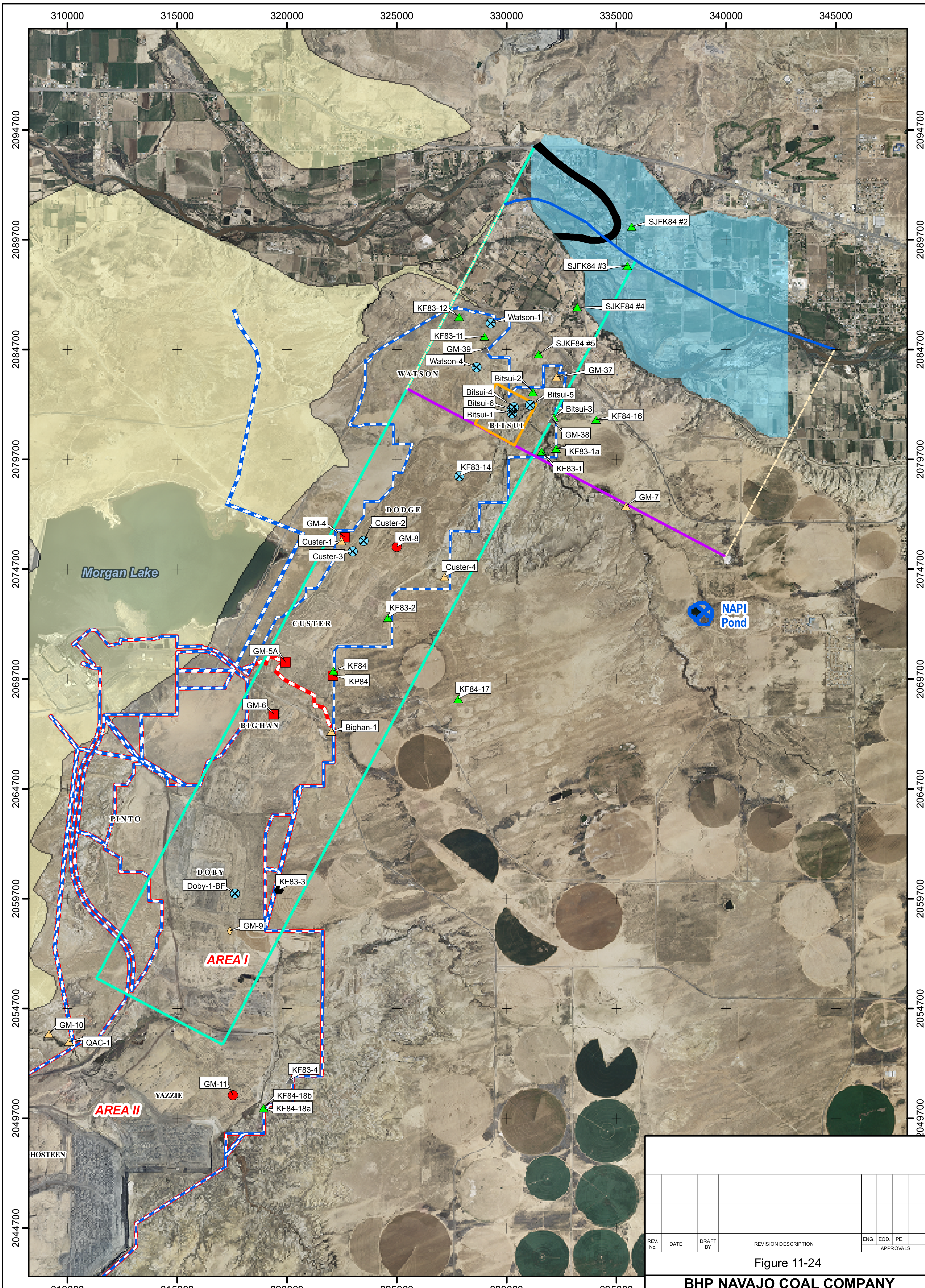
As shown from Figure 11-24, the most northern portion of the mine area, where spoils have been placed, is the Bitsui Pit located more than 5,000 feet from the coal subcrop with the San Juan River alluvial aquifer. Saturation within the Bitsui Pit extends for a distance of approximately 2,000 feet perpendicular to the estimated direction of flow as depicted in Figure 11-24. The water elevation in the Bitsui Pit backfill is estimated at 5,164 feet based on water level measurements in the Bitsui backfill wells. The water elevations in these wells have been within about 1-foot of this estimate over the period from 2001 through 2010. The 5,164 elevation was specified as a constant head in the along the south boundary of the MODFLOW model domain shown in Figure 11-24. Head levels in the coal beneath the San Juan River alluvium along the northern boundary of the MODEFLOW model domain shown in Figure 11-24 were estimated based on the heads in the alluvium. These alluvial heads were estimated to vary linearly from the San Juan River elevation of 5,087 feet at the west end to the river elevation of 5,132 at the east end of the specified head boundary. No flow model boundaries were specified on the west and east sides of the MODFLOW model domain shown in Figure 11-24. The boundary on the west side extends to the approximate outcrop of the coal and beyond limits of saturation in the backfill. The no flow boundary on the east side was set at a sufficient distance from the Bitsui Pit to have minimal influence on the dispersion calculations. The model mass balance is approximately 1%, indicating insignificant mass contribution from beyond the east and west boundaries.

A summary of hydraulic conductivity estimates for the Fruitland Formation coal seams is provided in Table 6-1 (Chapter 6). A hydraulic conductivity of 0.08 feet per day from this table is considered a reasonably conservative estimate for the No. 8 coal based on the test results for wells SJKF84 #3, SJKF84 #4 and SJKF84 #5 located in the coal down gradient of the Bitsui Pit. The porosity of coal seams is primarily associated with cleating and small scale fracturing of the coal. Porosity estimates ranging from 0.02 to 0.007 were obtained for the Fruitland Formation coals from tests conducted for the Western Cretaceous Coal Seam Project (Mavor et al., 1992). An estimate of coal porosity of 0.01 was used for modeling. This estimate also appears to match the rate of transport from the Bitsui Pit to well Bitsui-2 and has been used in the model calibration and simulations.

Sorption of sulfate was assumed to be near zero and was not included in the transport model. The longitudinal dispersivity value of 10 feet was estimated from model calibration using well Bitsui-2 located approximately 300 feet from the Bitsui Pit. Lateral dispersivity was estimated as 0.1 x longitudinal and vertical dispersivity was estimated at 0.01 x longitudinal dispersivity. These are standard dispersivity factors used in transport modeling (Gelhar et al, 1992). The model calibration is not very sensitive to the dispersivity values.

The source concentration of sulfate in the Bitsui Pit was assumed to be constant after resaturation of the Bitsui Pit. A sulfate source concentration of 7,000 mg/l was estimated based on the average of the median sulfate concentrations in backfill wells Bitsui-4 and Bitsui-5, the two backfill wells nearest the Bitsui-2 well.

Sulfate reduction in nature can be described by a second order decay rate that is dependent on both the carbon source and sulfate concentration. However since the aquifer matrix is comprised of coal, the carbon source is considered fixed and the sulfate reduction can be modeled as a pseudo first-order decay rate. The sulfate reduction rate is represented in the MT3DMS model using a first-order decay equation assuming a pseudo first-order process with a constant decay rate throughout the coal unit. The sulfate reduction decay rate of 3x 10^{-4} day^{-1} was estimated by model calibration to the sulfate breakthrough in well Bitsui-2. A comparison of the sulfate concentrations observed at the Bitsui-2 coal well with the predicted sulfate breakthrough curve from the calibrated model is provided in Figure 11-36. The calibrated sulfate reduction decay rate determined by model calibration is near the lower bound of sulfate reduction values found in the literature, including the study of sulfate reduction in coals down gradient of mine spoilt (Clark, 1995). Using data from Clark (1995) for sulfate reduction in groundwater down gradient of mine spoil at the West Decker Mine in Montana, sulfate decay rates were estimated to range from 3 x 10^{-3} day^{-1} to 6 x 10^{-4} day^{-1}.



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				APPROVALS		

Figure 11-24

BHP NAVAJO COAL COMPANY

bhpbilliton

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Navajo Mine Permit

Area I Groundwater Models

PREPARED BY: MD	DRAWN BY: MD	PAPER SIZE: 11"x17"
APPROVED BY: APO	DATE: 04/16/2011	

Data Source:
Aerial Photography (San Juan County) 2009
* NMBMMR RM-19 Beaumont 1998

N

1:48,000

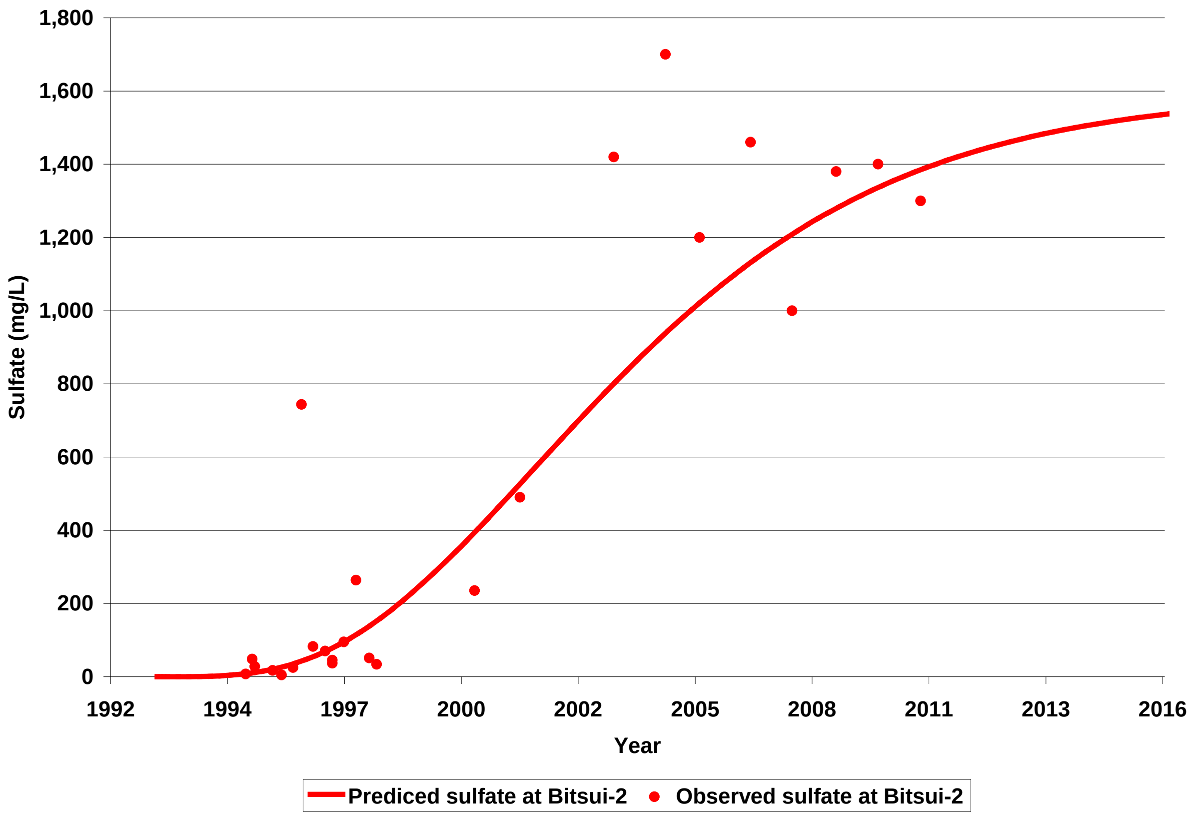
Projection Information:
State Plane New Mexico West
North American Datum 1927
FIPS 3003
feet

0 2,200 4,400 8,800 Feet

Bitsui Transport Model:
- Specified Head Boundary
- Constant Head Boundary
- No Flow Boundary
- Bitsui Pit Source
- Max Mine Water Flow Projection
- San Juan Alluvium above Fruitland Formation Outcrop
- Approximate Coal Subcrop*

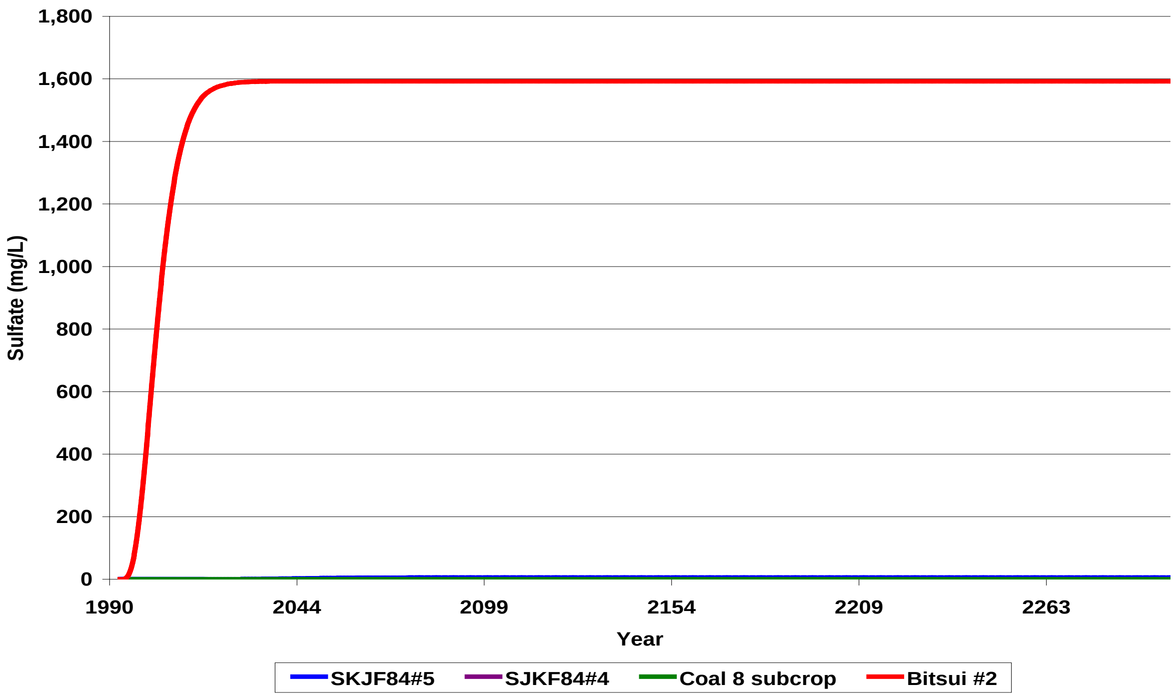
- BNCC Lease Area
- BNCC Permit Area
- Pictured Cliffs Formation (Kpc)
- NAPI Pond
- Abandoned Alluvial Monitoring Well
- Existing Alluvial Monitoring Well
- Well, Coal No. 2, Existing
- No 3. Coal Monitoring Well
- Well, Coal No. 4, Existing
- No 6. Coal Monitoring Well
- No 7. Coal Monitoring Well
- No 8. Coal Monitoring Well
- Fruitland Well or Nested Wells
- Abandoned PCS Monitoring Well
- Existing PCS Monitoring Well
- Backfill Monitoring Well

Figure 11-36. Predicted Sulfate Concentrations at well Bitsui-2



The model predicts sulfate concentrations over time anywhere in the model domain. Prediction points were established at the Bitsui-2 well located down gradient of the Bitsui Pit, at well SJKF84#5, at SJKF84#4 and at the coal subcrop on the model boundary. These prediction locations are shown on Figure 11-24. Predicted sulfate concentrations for the specified prediction points are plotted in Figure 11-37. These results show that sulfate concentrations in the Bitsui-2 well approach a steady state value of about 1,600 mg/l assuming that source concentrations remain at 7,000 mg/l. These results also show that steady state sulfate concentrations remain below the 10 mg/l detection limit at the down gradient coal wells SJKF84#5 and SJKF84#4 and at the coal subcrop with the alluvium at the model boundary.

Figure 11-37. Model Predicted Sulfate Concentrations at Specified Prediction Points



A sensitivity analysis was performed for longitudinal dispersivities and sulfate decay coefficients. These results found that the predicted sulfate results are not sensitive to the dispersivity but the results are sensitive to the sulfate reduction rate. Figure 11-38 shows the sensitivity of sulfate concentrations to changes in sulfate decay rate at Bitsui-2. Figure 11-39 shows the modeled sulfate concentrations at SKJF84 #5 at the corresponding sulfate decay rates. Continued monitoring of sulfate concentrations in the Bitsui-2 and SKJF84 #5 wells will serve to further verify the sulfate decay rate and permit, if warranted, any modifications to the model predictions.

The modeling results indicate that there will be no sulfate transport to the San Juan River. Also, as a result of sulfate reduction, TDS levels are not expected to increase in the coal water at the subcrop with the alluvium. While the TDS concentrations did increase in the Bitsui-2 well as indicated in Figure 11-31, this increase is the result of the increase in sulfate concentrations. Alkalinity and chloride concentrations decreased in this well as a result of transport of water from the mine spoils through the coal. As sulfate reduction is expected to continue under reducing condition in the coal down gradient of the Bitsui-2 well, the magnitude of TDS increase will also drop and is expected to be negligible at the coal subcrop.

Figure 11-38. Predicted Sensitivity of Sulfate Concentration to Sulfate Decay Rate at Bitsui #2

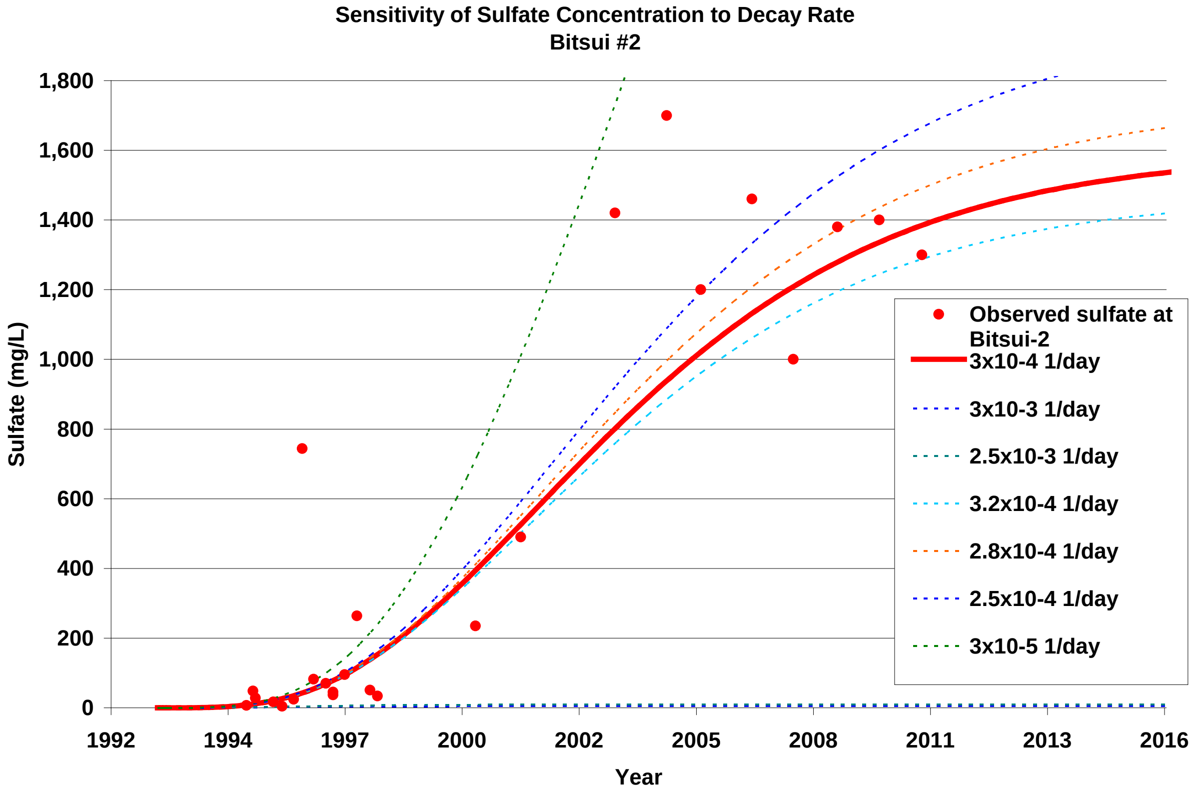
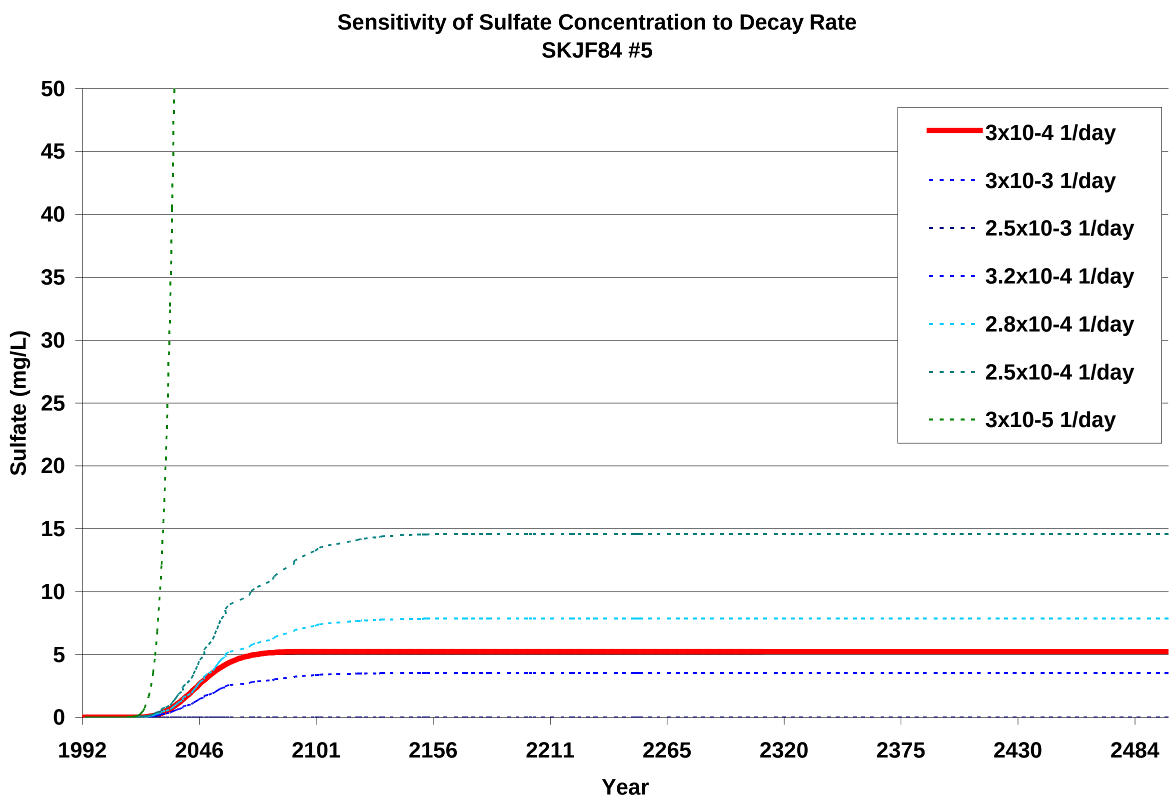


Figure 11-39. Predicted Sensitivity of Sulfate Concentration to Sulfate Decay Rate at SKJF84 #5



Some groundwater transport will also occur through the undifferentiated Fruitland Formation as suggested by Cross Section A-A' in Exhibit 11-167. The undifferentiated Fruitland formation is comprised of interbedded sequences of shales, carbonaceous shales, sandstones, mudstones, claystones, and coal stringers. While carbon sources and reducing environments are present in the undifferentiated Fruitland formation due to the carbonaceous shales and coal stringers, sulfate reduction rates could be lower than in the coal. On the other hand, the rate of groundwater flow is expected to be lower through the undifferentiated Fruitland due to the lower hydraulic conductivity expected for these interbedded sequences of shales, carbonaceous shales, sandstones, mudstones, claystones, and coal stringers in comparison with the coal. Furthermore, groundwater velocities in the undifferentiated Fruitland Formation will be lower because the overall porosity is expected to be higher than in the coal. Thus, even if sulfate reduction rates are lower in the undifferentiated Fruitland formation, transport times are expected to be longer, allowing more time for sulfate reduction.

A simple calculation of flow velocities and transport times has been performed to demonstrate the likely differences that can be expected based on the expected differences in effective porosity. The effective porosity of the coal was estimated to be approximately 1% based on both the literature for the Fruitland coals and the transport model calibrations. The effective porosity in the undifferentiated Fruitland will vary with materials in the Fruitland Formation and is lower in the clays and shales than in the sandstones even though clay has higher porosity than sandstone. Effective porosity can be determined for the specific yield of the material. Johnson (1967) provides a comprehensive review of specific yields for sedimentary materials. The specific yield decreases with the particle size of the sediments. The specific yields were reported to range from 10% to 32% for unconsolidated sands. Johnson (1967) provides a specific yield estimate of 10% for tight and partially cemented sandstones. Johnson (1967) provides average specific yield estimate of 3% for clays and 8% for silts. The effective porosity of coal stringers may be higher than 1% effective porosity estimated for the No. 8 coal, particularly if the shallower stringers are more weathered. Typically, higher porosity is usually present in the shallow coals in the San Juan Basin (Questa Engineering Corporation, 2000). Based on these results an overall porosity of the undifferentiated Fruitland is likely to be on the order of 5% or higher.

An elevation difference of 63 feet is calculated for the water elevation of 5,164 feet measured in the Bitsui Pit and the water elevation of 5,101 feet estimate in the alluvium at the coal subcrop. The distance between the Bitsui Pit and the coal subcrop is approximately 7,300 feet resulting in an average hydraulic gradient between the Bitsui Pit and the groundwater at the coal subcrop of 0.0086 ft/ft.

The average groundwater velocity between the Bitsui Pit and the coal subcrop can be estimated using the following equation:

$$v = kI/ N_e$$

where:

> v = Velocity of groundwater in the Fruitland Formation (feet per day).
>
> N_e = Effective porosity (dimensionless)
>
> K = Hydraulic conductivity (feet per day)
>
> I = Hydraulic Gradient (dimensionless)

Thus, based on the porosity and hydraulic conductivity for the coal, the groundwater velocity is estimated to be 0.069 feet per day and it would take 290 years for water from the mine pit to flow the 7,300 foot distance through the coal from the Bitsui Pit to the coal subcrop with the San Juan River alluvial aquifer. The groundwater velocity in the undifferentiated Fruitland Formation is expected to be at least 5 times lower based on an estimated effective porosity of 5%. Also, the hydraulic conductivity of the undifferentiated Fruitland Formation is expected to be lower based on the extent of shale and claystone within the unit and the observations from mining and exploration drilling that the coals in the Fruitland will typically yield some water while very little water will flow from the undifferentiated Fruitland.

Even if the TDS and sulfate were to increase in the Fruitland Formation at the coal subcrop several hundred years from now, it is unlikely that it would result in a significant increase in the alluvial groundwater due to the much higher flow rates in the alluvial groundwater relative to the flow in the Fruitland Formation. A groundwater mixing calculation has been performed to provide upper bound estimates for the magnitude of the potential increase in TDS concentrations in the San Juan River alluvium. The lateral extent of the Navajo Mine perpendicular to the direction of flow toward the Fruitland Formation subcrop at the San Juan River alluvium is estimated at approximately 6,500 feet as indicated by the mine water flow projection shown in Figure 11-24. The maximum volume of groundwater from the reclaimed mine that can discharge to the San Juan River alluvium can be estimated using the following equation:

$$Q = k\ I.\ L.\ M$$

where:

Q = Estimated discharge of potentially mine-affected groundwater to the San Juan River alluvial aquifer (ft^3/day)

K = Hydraulic conductivity of the Fruitland Formation, which is assumed to be 0.08 ft/day based on the hydraulic conductivity of the coal

I = Hydraulic gradient from the Navajo Mine to the Fruitland Formation subcrop, which is conservatively estimated to be 0.01 ft/ft

L = Lateral extent of the mine normal to the general direction of flow in the coal seam = 6,500 ft

M = Estimated average saturated thickness of the Fruitland Formation between the Bitsui Pit and the San Juan River alluvium estimated to be on the order of 50 to 60 feet as suggested by Cross Section A-A' in Exhibit 11-167.

Assuming a gradient of 0.01 ft/ft based on measurements at the Bitsui Pit and a hydraulic conductivity of 0.08 feet per day for both the coal and the undifferentiated Fruitland Formation, the discharge to the San Juan River alluvium (Q) is estimated as:

$$Q = [0.08 \text{ feet per day}] \cdot [0.01] \cdot [6{,}500 \text{ ft}] \cdot [60 \text{ ft}]$$

$$Q = 312 \text{ feet}^3\text{/day}$$

This is likely the upper bound estimate as the hydraulic conductivity of 0.08 ft/day is considered to be upper bound estimate for combined coal and undifferentiated Fruitland Formation. The results of these calculations, nonetheless, demonstrate that the annual production of mine-affected groundwater that could reach to the San Juan River alluvium is small when compared to the flow in the San Juan River alluvium as discussed below.

The thickness of the San Juan River alluvial deposits varies but appears to range from about 20 to 65 feet based on the alluvial well depths reported in Appendix 6-E. The depth of saturation reported for these wells range from about 10 to 45 feet with most on the order of 15 feet. A conceptual model of the San Juan River and the floodplain alluvium is presented in a report by the United States Department of Energy (2009) for the Shiprock Uranium Mill Tailings Site. This report lists the San Juan River as the major source of groundwater in the alluvial aquifer with less significant sources of alluvial water which include infiltration and recharge of precipitation on the floodplain and discharge of bedrock groundwater to the alluvium. There is also considerable mixing of river water and alluvial groundwater. This occurs seasonally as well as with distance along the length of the river with river water recharging the groundwater system near the downstream end of a pool and then discharging back to the river near the downstream end of the riffle (United States Department of Energy, 2009).

A hydraulic conductivity of the San Juan River alluvium of 85 feet per day was found to provide the best overall estimate for the alluvial aquifer based on a series of groundwater model calibration runs with a uniform hydraulic conductivity (United States Department of Energy, 2009). Hydraulic gradients in the alluvium vary across the floodplain but are approximately the same as the valley gradient. The valley gradient of 0.0034 ft/ft was measured for the San Juan River valley along the Fruitland Formation subcrop as depicted in Exhibit 11-166. An average width of the alluvium of 6,851 feet was estimated by dividing the mapped area of the San Juan River alluvium in Exhibit 11-166 by the length of the valley segment. Using a hydraulic gradient of 0.0034 ft/ft, a valley width of 6,851 feet, a hydraulic conductivity of 85 feet per day, and a saturated thickness of 15 feet, the average flow in the alluvial aquifer is estimated as:

$$Q = [85 \text{ feet per day}] \cdot [0.0034] \cdot [6{,}851 \text{ ft}] \cdot [15 \text{ ft}]$$

$$Q = 29{,}413 \text{ ft}^3/\text{day}.$$

Thus, the ratio of the groundwater discharge from the Fruitland Formation to the alluvium across the maximum mine water flow projection to the groundwater flow in the San Juan River Alluvium is:

$$\text{Ratio} = 312/29{,}413 = 0.0106$$

The existing water quality in the San Juan River alluvial aquifer is quite variable as indicated by the available water quality data from San Juan River alluvial wells provided in Appendix 6-E. TDS, sulfate concentrations, and fluoride concentrations for these wells are provided in Table 11-14g, along with water quality data for San Juan River alluvial well G-7 provided by Thorn (1993). Thorn's report also provides information on boron concentrations in the alluvial groundwater. Table 11-14g provides a comparison of water quality data for San Juan River alluvium, for the baseline coal wells and for the wells in the Bitsui Pit.

The baseline No. 8 coal well SJKF #4 is located closest to the coal subcrop as shown in Exhibit 11-166. The TDS concentration of 7,370 mg/l observed in this well is considered to be representative of the TDS in the coal water reaching the San Juan River alluvial aquifer, although TDS concentrations in excess of 40,000 mg/l have been observed at wells SJKF #2 and SJKF #3 located further down dip. The TDS concentration observed in this well is higher than TDS concentration of 6,160 mg/l observed in the Bitsui-2 well in years 2009 and 2010 so that there would need to be a considerable increase in TDS concentrations along the entire groundwater transport path from the Bitsui Pit to the subcrop in order for mine water transport to increase the TDS loadings to the San Jun River alluvium.

Based on the dilution ratio of 0.01, a TDS increase from the 6,160 mg/l observed in the Bitsui-2 well to 10,370 mg/l across the entire transport zone would result in a TDS increase in the San Juan River alluvium of only 30 mg/L. Not only is such an increase in TDS concentrations unlikely and inconsistent with observations and modeling calculations, but a 30 mg/l change in alluvial concentrations is far below the natural variation observed in the San Juan River alluvial wells as represented by the standard deviation calculated from the alluvial well results presented in Table 11-14g.

Table 11-14g

Water Quality of the San Juan River Alluvium in Comparison with Mine Spoil Water and Coal Water

Location	Well	TDS (mg/L)	SO4 (mg/L)	B (mg/L)	Mn (mg/L)
Baseline Coal	SJKF#2	43,035	5	1.23	2.93
	SJKF#3	50,810	5	1.43	0.71
	SJKF#4	7,370	5	1.57	0.11
	Composite #4*	9,800	120	0.53	0.03
Mine spoil (median)	Bitsui-4	15150	8900	1.69	3.65
	Bitsui-5	11800	5030	1.11	0.11
	Bitsui-6	14850	8850	2.07	4.56
	mean	13,933	7,593	1.62	2.77
Bitsui-2 (Year 2010)		6,160	1,300	1.00	0.01
San Juan River Alluvial Aquifer	G-7	3,940	1,700	0.32	0.02
	BIA# 147	842	310	na	na
	BIA# 148	528	174	na	na
	BIA# 150	5,880	3,600	na	na
	BIA# 151	2,140	1,300	na	na
	BIA# 152	2,140	1,300	na	na
	BIA# 45	1,270	456	na	na
	Average	2,391	1,263	0.32	0.02
	Standard Deviation	1,766	1,095	na	na

*Composite #4 from Coal No 4 and 6 in Table 11-14b

Table 11-14g also provides a comparison of the TDS, sulfate, boron, and manganese concentrations in the San Juan River alluvial groundwater with the concentrations in the Bitsui Pit, in the Bitsui-2 coal well located immediately down gradient of the Bitsui Pit and in the baseline coal water samples.

As discussed earlier, potentiometric surface maps for the Fruitland coal units (Exhibits 6-2 through 6-5 and Exhibits 6.G-2 and 6.G-3) all show general gradients toward the east. Thus, some of the groundwater flowing through Area I mine spoils may not discharge along the San Juan River valley but rather will flow down dip in response to coal depressurization from coal bed methane extraction. For display purposes, approximate locations of coal bed methane wells near the Navajo Mine have been included on Exhibit 11-166.

The data and associated modeling calculations all show that water in the backfill within Area I at the Navajo Mine will not measurably affect the water quality in the San Juan River alluvial groundwater.

11.6.2.3.2 Area II Groundwater Migration

All of Area II coal seams were found to be mostly dry, with minor saturation along the eastern lease boundary. Coal wells KF84-18a and KF84-18b, located near the Yazzie Pit highwall, have been dry or have had limited saturation throughout mining and following mine backfilling. Thus, little groundwater inflow to the backfilled Area II mine pits is expected from the coals adjacent to the highwall. Water sources that could potentially saturate the backfilled mine pits within Area II include precipitation recharge and water flowing in the Chinde Arroyo. Recharge rates are extremely low based on the studies by Stone (1987) and the dry conditions in the Fruitland Formation within Area II prior to mining.

The Chinde Diversion routes flows in Chinde Arroyo around the Yazzie Pit. Chinde Arroyo was originally an ephemeral stream but now exhibits perennial flow due to NAPI irrigation. It is likely that a small portion of the flow in Chinde Diversion seeps into the Yazzie backfill. This seepage contribution is believed to be small because saturation has not been observed in the backfill in the Doby Pit. While the Doby French drain intercepts seepage from NAPI irrigation it does not intercept seepage from the segment of the Chinde Diversion that is adjacent to the Doby Pit. Nevertheless, the potential seepage from the Chinde Diversion is an additional source of water could increase the rate and level of re-saturation of the backfill in the Yazzie Pit and in the Doby Pit.

The potentiometric elevations in the PCS within Area II (Exhibit 11-166) are projected to be at or near the base of the mine pits. As the mine spoils begin to saturate over the long-term, the buildup of heads in the mine spoil will increase the rate of vertical flow to the PCS. A build up of head in the mine backfill would also result in lateral flow into the adjacent Fruitland Formation. Thus, transport directions for mine spoil water would be vertical downward into the PCS and laterally down dip in the Fruitland Formation. Lateral flow through the Fruitland Formation will flow down dip to the east in the direction of coal depressurization from coal bed methane extraction or will flow to the northeast toward the Fruitland Formation subcrop beneath the alluvium of San Juan River valley. This component of flow and transport has been addressed in the Area I assessment in Section 11.6.2.3.1.

Lateral flow through the PCS within Area II is expected to be generally toward the northeast as indicated by the potentiometric surface provided in Exhibit 11-166. There could also be a component of flow west toward the PCS outcrop located east of the Chaco River. Groundwater flow rates through the PCS would be very low due to the very low hydraulic conductivity of the PCS. Any discharge along the PCS outcrop to the west of Area II would be removed by evapotranspiration. Based on pre-mine observations along the PCS outcrop adjacent to Areas III and IV North, flow rates in the PCS are expected to be insufficient to sustain flow at a seep. PCS water may also flow vertically downward into the Lewis Shale as was found in groundwater studies performed within lease Areas IV North and South and V.

11.6.2.3.3 Area III Groundwater Migration

In the southern part of Area III, all of the coal seams, but the No. 8 coal seam, were found to be saturated. As discussed in Chapter 6, the lower coal units (No. 2, No 3) pinch out just north of Area III. Discharge locations for the Fruitland coal seams within Area III include:

- the outcrop locations along the Cottonwood Arroyo valley to the south and the Chaco River valley to the west,
- down dip toward the center of the San Juan Basin where the groundwater flow joins the regional flow to the northeast toward the subcrop at the San Juan River alluvium and the coal bed methane depressurization areas, and
- into the PCS and Lewis Shale via vertical flow from the Fruitland Formation.

Groundwater flow rates through the Fruitland coals within Area III are believed to be extremely low because of the low hydraulic conductivities of the coal and the relatively flat potentiometric gradients.

For a long period following mining within Area III gradients will be toward the mine backfill. As the mine spoils begin to saturate over the long-term, the buildup of heads in the mine spoil will increase reversing the gradients with respect to the mine spoils. Based on model estimates of Area IV North it could take as long as 80 years for gradient reversal to occur. Transport directions for mine spoil water at that time would be laterally down dip in the Fruitland Formation, laterally toward the outcrop areas to the south and west of Area III and vertically into the PCS. Lateral flow from the mine spoils through the Fruitland Formation and PCS will be very low due to the low hydraulic conductivity of these units as indicated by the test results in Appendix -G and due to the relatively flat gradients that can be expected based on pre-mine conditions. Most discharge to the PCS and Fruitland Formation outcrops to the south and west of Area III is expected to be removed by evapotranspiration, although a portion of this groundwater flow could reach the Cottonwood Arroyo alluvium.

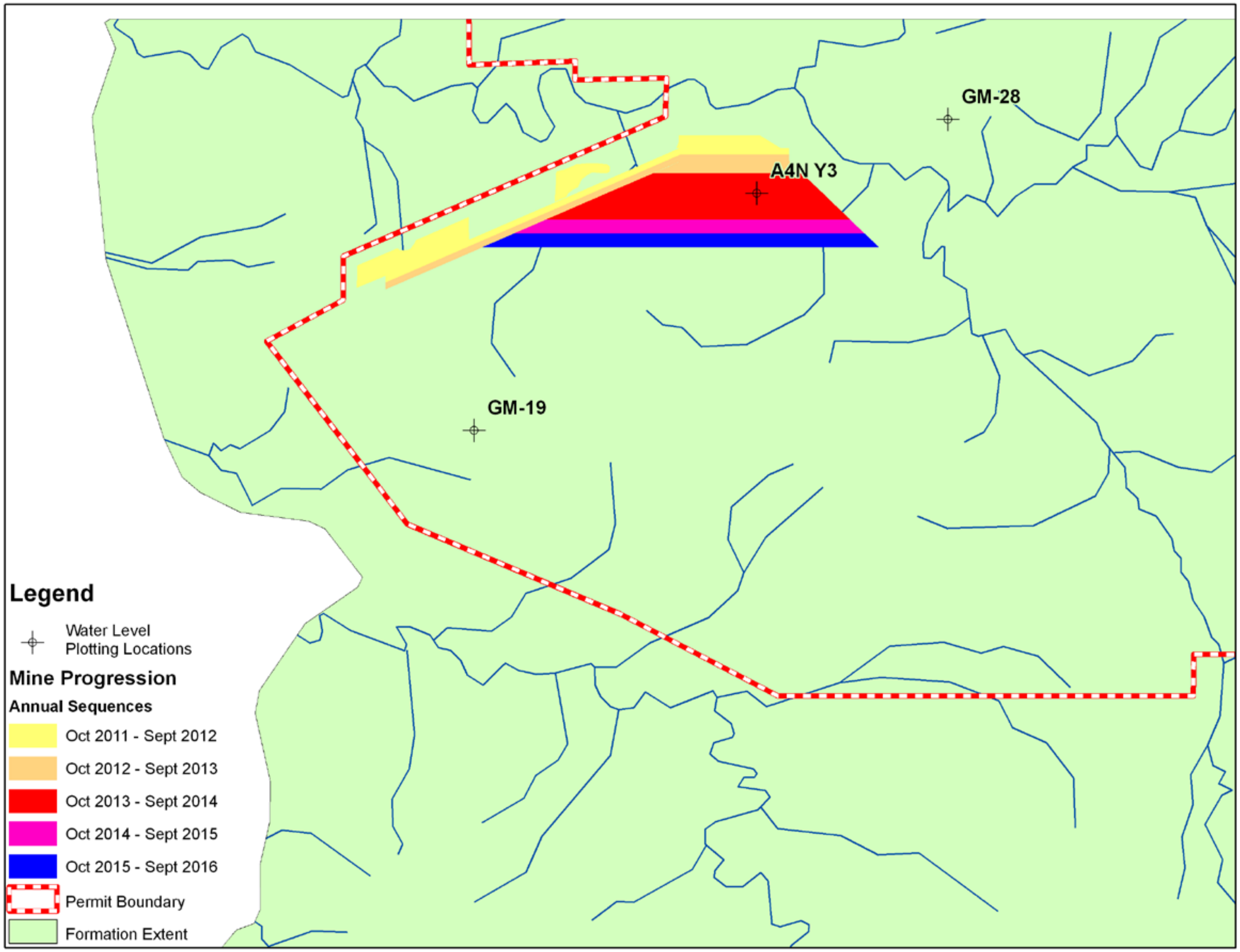
11.6.2.4 Potential Groundwater Impacts from Proposed Mining and Reclamation within Area IV North

BNCC is proposing to conduct surface coal mining and reclamation activities within a 704 acre mining block in Area IV North of its coal lease with the Navajo Nation. The No. 8 coal seam extends over a little more than half of the proposed mine area. Perched groundwater appears to occur in the No. 8 and No. 7 coal seams as indicated in Figure 6.G-4 in Appendix 6-G. Groundwater encountered during mining within Area IV North will be quite small based on observations from exploration drilling within Area IV North and on observations at Area III mining which found that groundwater in the coals and overburden was insufficient to sustain pit inflows during mining. Instead, any groundwater observed as seepage along the face of the highwall was removed by evaporation and did not pool within the mine pit.

The calibrated steady-state groundwater model of Areas IV North and South and V of the BNCC’s coal lease was used to simulate drawdown and recovery of groundwater levels during and after mining and reclamation (Norwest, 2011). Figure 11-40 shows the groundwater model domain and the location for proposed mining within Area IV North.

Groundwater flow in the Fruitland coals and in the underlying PCS in the area of proposed mining is north toward Cottonwood Arroyo as indicated in Figures 6.G-1 through 6.G-3 in Appendix 6-G. However, the rate of groundwater flow from bedrock units to the alluvium along Cottonwood Arroyo is known to be very low because the alluvium is only marginally saturated. Cottonwood alluvial well QACW-2 located west of the permit area was usually dry during baseline monitoring and Cottonwood alluvial well QACW-1 was dry throughout the baseline monitoring from 1989 through 1998.

Figure 11-40. Mining Block Sequences for Proposed Mining in Area IV North



Groundwater was observed during baseline monitoring at well GM-17 completed in the alluvium of North Fork of Cottonwood Arroyo. In the limited areas where partial saturation of the alluvium occurs, groundwater flows are too low to support base flow in the channel at any time. The limited saturation found within the Cottonwood alluvium is recharge from direct precipitation, from ephemeral surface water flows in Cottonwood Arroyo and from periodic discharges of excess flows from the NIIP Ojo Amarillo canal into the North Fork of Cottonwood Arroyo.

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. When broken up during mining, the overburden and interburden material placed in the mine pit as backfill have higher porosity and hydraulic conductivity than the pre-mine 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. These laboratory porosity measurements are consistent with the long-term swell factor of 12% estimated based on experience in mining the same formation at the Navajo Mine. The higher porosity will result in higher hydraulic conductivity in comparison with the pre-mine interburden and overburden material.

Horizontal hydraulic conductivity values of pre-mine overburden and interburden strata are expected to be in the range from 8.63 x 10^{-3} ft/day to 2.8 x 10^{-5} ft/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 also within this range (Physical Testing Laboratory Data provided in Appendix 11-K). A horizontal hydraulic conductivity of 5.0 x 10^{-4} ft/day was used for unweathered interburden and overburden materials in the calibrated model.

A hydraulic conductivity value of 5.63 x 10^{-2} ft/day has been used in the post-reclamation model for the mine spoils in the backfill below 10 ft of the final reclaimed surface at Area IV North.

This estimate of hydraulic conductivity for mine spoils was between the average of 1.13×10^{-2} ft/day estimated from laboratory tests on five mine spoil samples from the Navajo Mine (Physical Testing Laboratory Data provided in Appendix 11-K) and the estimate of 2.27×10^{-1} ft/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. A hydraulic conductivity value of 5.63×10^{-1} ft/day has been used to represent the model layer for the upper 10 ft within the mine backfill, which will be comprised of weathered spoil and topdressing material.

Hydraulic parameters for mine backfill and topdressing materials that were used for modeling post-reclamation conditions are summarized in Table 11-14h. Given some degree of uncertainty in the ultimate hydraulic conductivity of Navajo Mine spoil materials, 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} ft/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. This lower-bound estimate provides more conservative estimates of the water recovery rates in mine spoils.

Another primary hydrogeologic change that is expected to occur as a result of mining in Area IV North is the removal of the badland surfaces that cover much of the proposed mine area and the establishment of reclaimed surface conditions that provide for more groundwater recharge. The recharge rate estimates used for modeling post-reclamation conditions are also summarized in Table 11-14h. Lower slopes and placement of topdressing materials within reclaimed areas are expected to result in higher recharge for reclaimed surfaces compared to the relatively steep slope badland surfaces that currently exist within the proposed Area IV North mine area. The pre-mine recharge rate for this area averages only about 0.0069 in/year based on the estimates from Stone (1987) that were assigned to these pre-mine surfaces based on slope categories.

Table 11-14h.

Recharge Rates and Hydraulic Properties of Mine Spoils for Groundwater Modeling

Surface characterization	Recharge range[1] (in/yr)	Mean recharge[1] (in/yr)	Modeled recharge (in/yr)
Reclaimed areas	0.01 to 0.23	0.04	
Reclaimed depression areas		0.16	
Reclaimed areas-transient			0.1
Reclaimed areas-steady state			0.04
Alluvium- pre-mine and reclaimed	0.09		0.09
Pre-mine surfaces (excluding alluvial terraces)	0.002 to 0.04		0.002 to 0.03

Reclamation materials	Porosity (%)	Ksat (cm/sec)	Ksat (ft/day)
Surface mine spoils (L1)	40.6	2.0E-04	5.6E-01
Mine spoils < L1	40.6	2.0E-05	5.6E-02
Geometric mean of mine spoils in northern Great Plains (Rehm et al. 1980)		8.0E-05	2.3E-01
Lab tests of Navajo Mine spoil samples	40.6	4.0E-06	1.1E-02

[1] Estimates from Stone (1987)
L1- Uppermost layer in model
Ksat - Saturated hydraulic conductivity

For steady-state modeling, the recharge rate of 0.04 in/year measured by Stone (1987) for upland flats was assumed to be a reasonable estimate of recharge rate over the long term following reclamation. This recharge rate is more than five times the average pre-mine rate and reflects the improved surface and soil conditions resulting from mine reclamation. An even higher recharge rate of 0.10 in/year was used for mine spoils in the transient modeling until final reclamation, after which the long-term recharge rate of 0.04 in/year was used for reclaimed areas in the transient model. This recharge rate of 0.10 in/year represents an average rate for the mine backfill in various stages of reclamation and is based on the average between Stone’s estimate of 0.16 in/year for depressions during mine reclamation and the 0.04 in/year for final reclamation.

11.6.2.4.1 Water Level Drawdown and Recovery

The open mine pit acts as a drain for drawdown of any groundwater in the overburden/interburden, in the coal seams, and in the underlying PCS. Model simulations of the advance of proposed open pit mining in Area IV North have been performed to provide estimates of drawdown and recovery in the Fruitland coals and in the PCS during mining and reclamation. These simulations were performed for the proposed annual mining block sequences as depicted in Figure 11-40.

The estimated 5 foot drawdown in the No. 8 coal seam in Year 2016 at the completion of proposed mining is provided in Figure 11-41. The corresponding 5 foot drawdown in the No. 3 coal in Year 2016 is provided in Figure 11-42. Based on the very limited extent of drawdown in the coal units, surface mining in Area IV North is not expected to result in a drawdown in water levels or depletion of water in the alluvium of Cottonwood Arroyo.

There will also be some depressurization of the PCS below the mine pit. Figure 11-43 shows the estimated 5 foot drawdown in the PCS in Year 2016 at the completion of proposed mining in Area IV North. The layer of shale separating the bottom of the lowest coal seam and the PCS serves to restrict groundwater inflow from the PCS during mining. The thickness of shale layer between the No. 2 coal and the PCS averages about 8.7 feet over the Area IV North mine block but is absent in some places. This variation in the shale thickness has been included in the groundwater model and the associated estimates of drawdown within the PCS. Artesian pressures in the PCS occur in the eastern portion of the Area IV North mine block where the shale thickness separating the coal from the PCS is greater. Likewise, the drawdown in the PCS is dampened, particularly in these locations where the shale thickness is greater.

The groundwater model was also applied to simulate the rate of recovery of water levels in mine backfill and the drawdown and recovery of potentiometric levels in the PCS and in the Fruitland coals adjacent to the mining block. The water level drawdown and recovery plots for point A4N Y3, located within the proposed Area IV North mine area, is shown on Figure 11-44. At this location the shale separating the coal from the PCS is projected to be 15.3 feet thick based on the geologic model.

The plot shows the large downward gradients that occur from the No. 8 coal seam to the PCS. With advance of mining to this location in Year 3, the drawdown level in the Fruitland coals is essentially the base of the mine pit at an elevation of about 5,203 feet. Drawdown in the underlying PCS at the same location is damped. Maximum drawdown is less than 17 feet, occurring approximately 30 years following the start of mining. Upward gradients from the PCS to the mine backfill occur until about 85 years after the start of mining. After that time, the recovery in the backfill is sufficient that gradients are vertically downward from the backfill to the PCS.

Figure 11-41. Drawdown in the No. 8 Coal under Proposed Mining in Area IV North

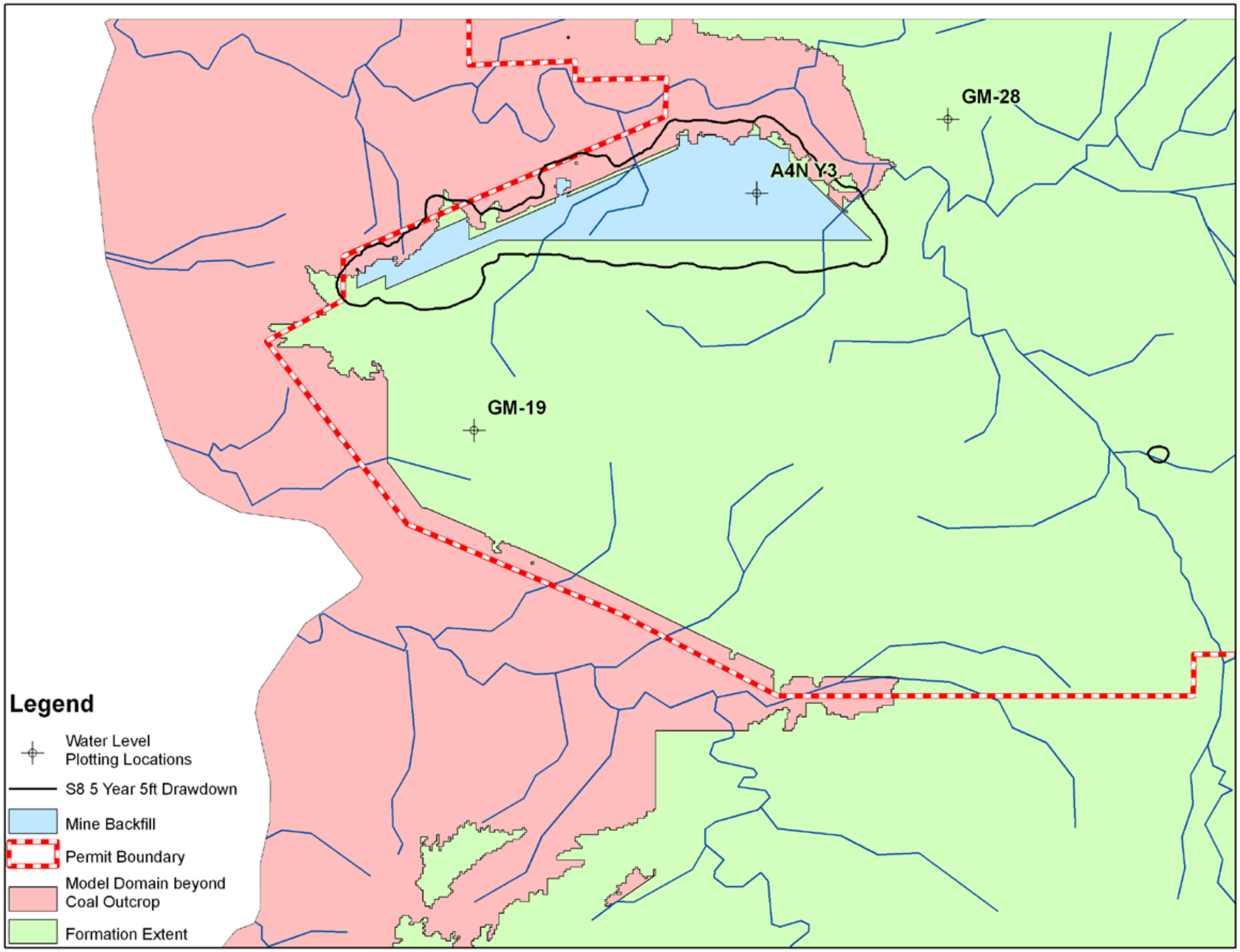


Figure 11-42. Drawdown in the No. 3 Coal under Proposed Mining in Area IV North

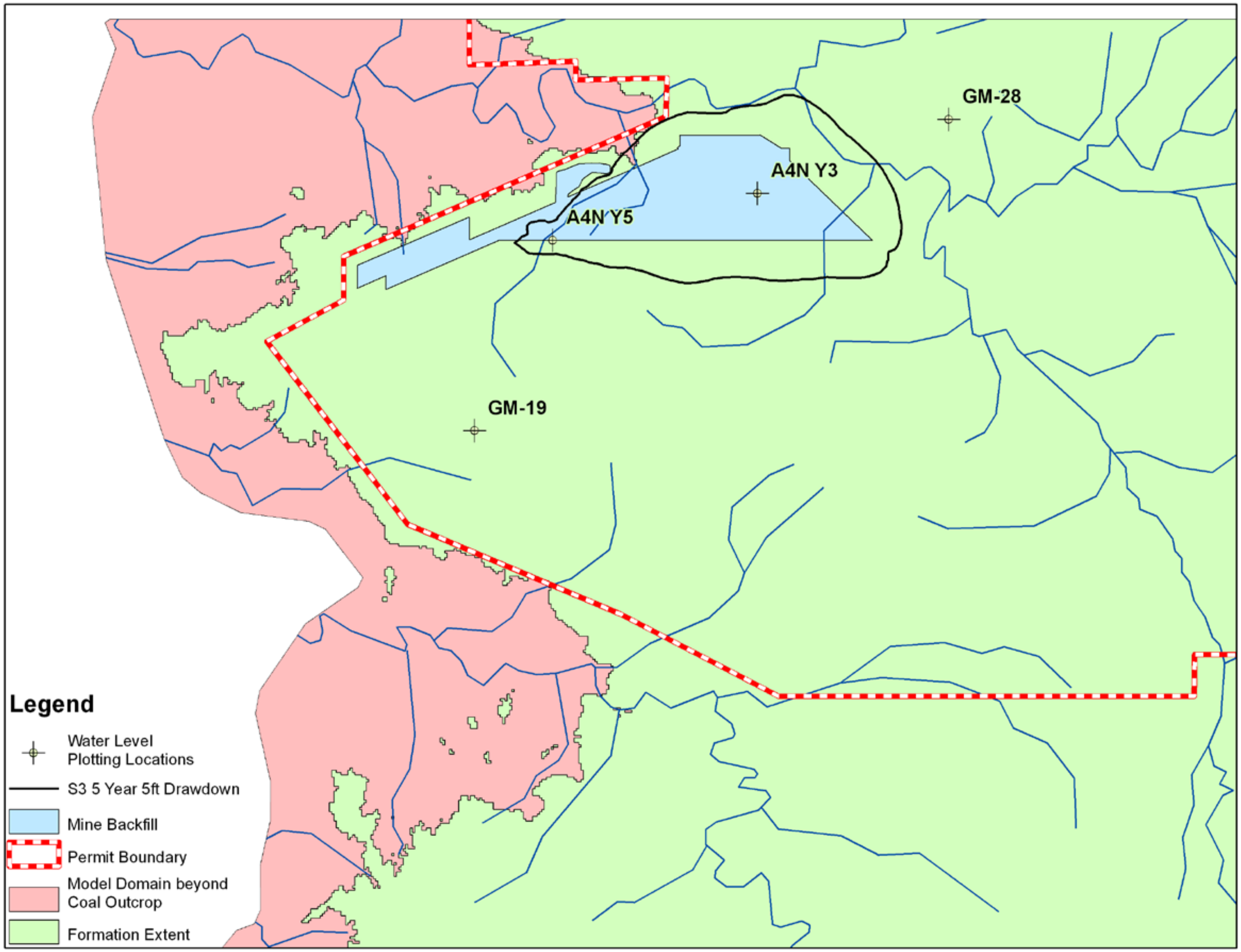


Figure 11-43. Drawdown in the PCS under Proposed Mining in Area IV North

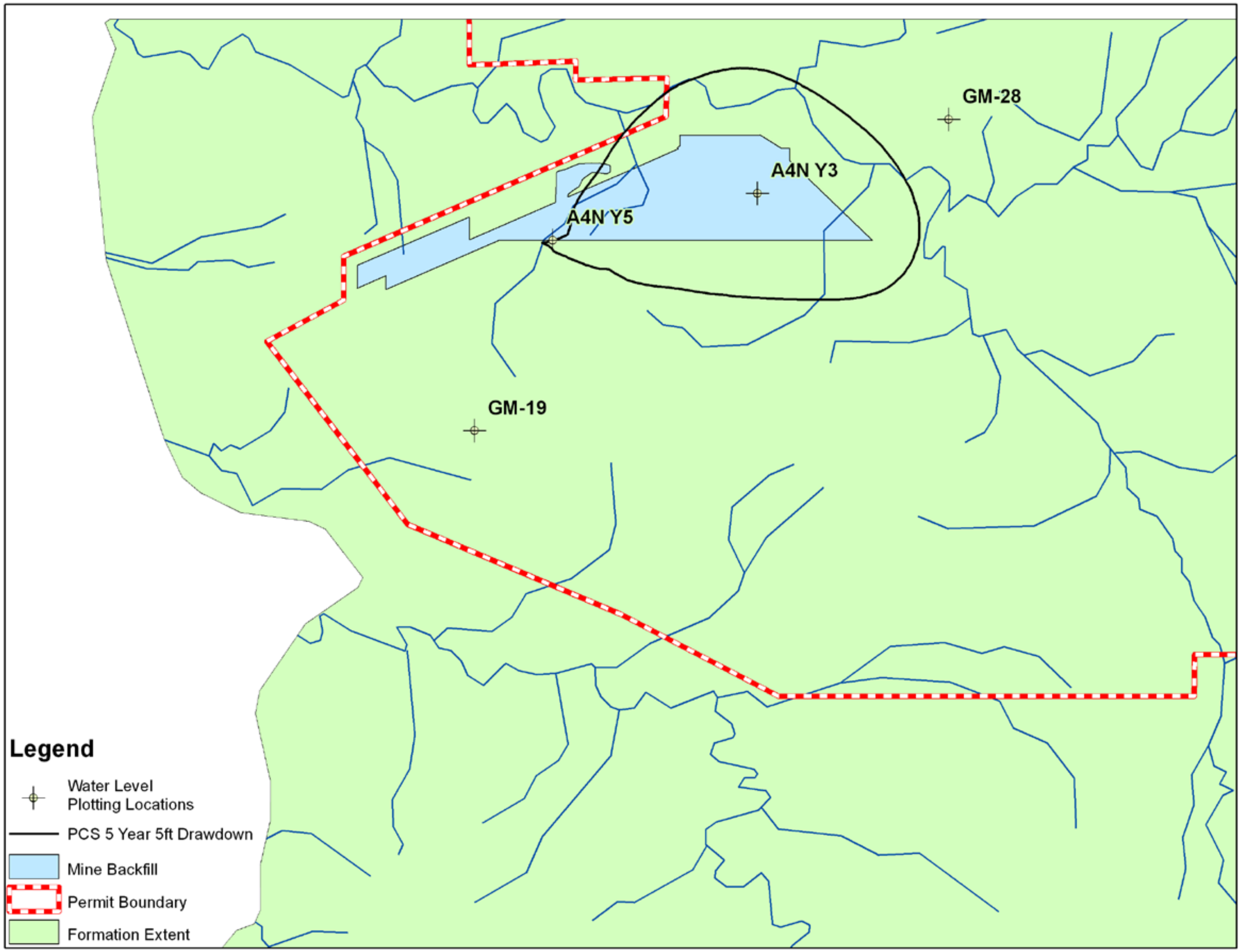
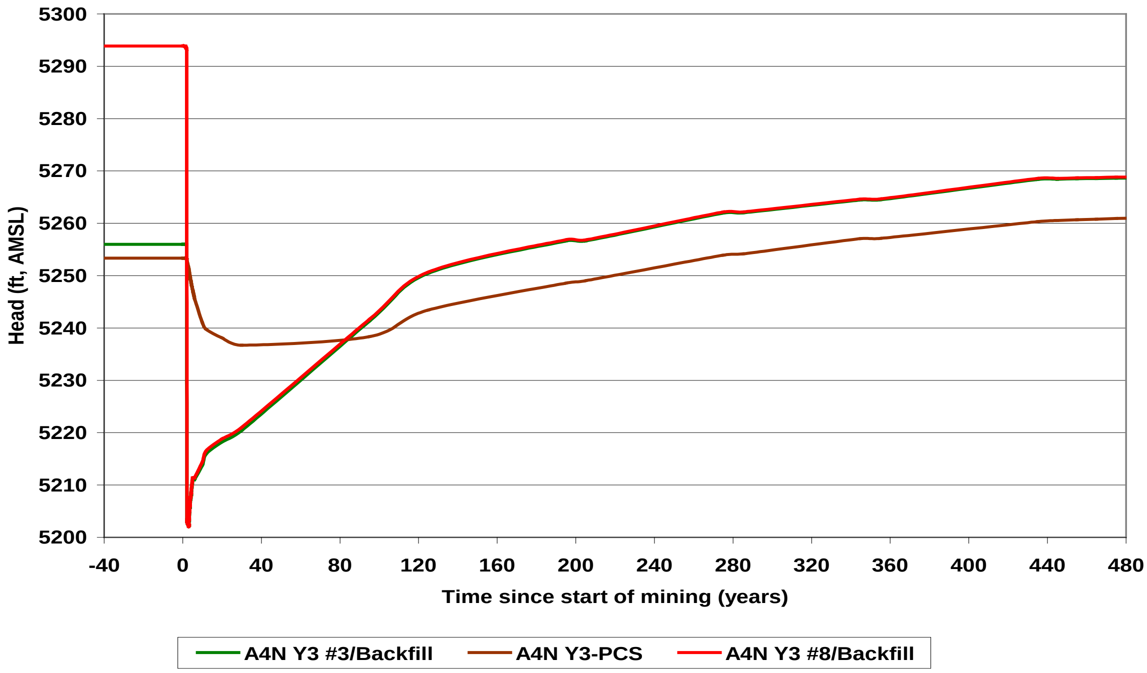


Figure 11-44. Drawdown and Recovery in the PCS and Backfill with Area IV North Mining



The transient model simulations show that it takes over 400 years for recovery of water levels to approach steady-state conditions in the PCS and in the mine backfill. It is possible that actual recovery rates may be slightly faster than the estimates shown in these figures if the recharge rates are higher than the estimates used for modeling. However, it is more likely that recovery rates will be slower than estimated as recharge rates for post-mining may be lower than estimated herein and closer to the pre-mine rates. As discussed previously, the recharge rates used to represent conditions for long-term reclamation were more than five times the average recharge rate for the mine area prior to mining and are believed to be upper-bound estimates based on the recharge measurements by Stone (1987).

The results in Figure 11-44 also show that final steady-state water level in the mine backfill is considerably lower than the pre-mine level of perched groundwater in the No. 8 coal. On the other hand, the final steady-state water level in the mine backfill is higher than the pre-mine potentiometric level in the No. 3 coal at this location. Likewise, the final steady-state water level in the PCS is higher than the pre-mine potentiometric level in the PCS at this location. The heads in the mine spoil are much more uniform with depth, although the vertically downward head gradient between the mine backfill and the PCS is greater than the vertically downward head gradient between the No. 3 coal and the PCS prior to mining. The higher vertical downward gradients and the higher potentiometric levels mean that the vertical downward flows are higher under steady state conditions following mining. The increase in the rate of vertical flow into the PCS from the post-reclamation backfill in Area IV North occurs in response to the increase in the recharge rate that was applied to the reclaimed surface for post-reclamation conditions. As indicated in Table 11-14h, the average recharge rate of 0.04 in/year for post-reclamation conditions within the Area IV North Mine Area is more than five times the average pre-mine recharge rate of 0.0069 in/year estimated based on predominance of badland surfaces at the proposed mine area.

Figure 11-40 shows locations selected as prediction points for presenting water level drawdown and recovery results from modeling, including the A4N Y3 location that was previously discussed. The other two locations correspond with the locations of the now abandoned PCS wells, GM-19 and GM-28. The drawdown and recovery results for the GM-19 and GM-28 locations are provided in Figures 11-45 and 11-46, respectively. These results show very little change in the potentiometric level or head in the No. 8 coal seam, the No. 3 coal seam or in the PCS during and following mining at these locations within the permit area.

These results together with the 5-foot drawdown plots show that the hydrogeologic effects of proposed mining within Area IV North are localized and occur over a long time period. The long-term change resulting from the removal of the interbedded coal, shales, mudstones, and sandstone strata and replacement with a relatively homogeneous and isotropic mine backfill will be an increase in the rate of vertical flow into the PCS from the mine backfill compared with the vertical flow into the PCS from the Fruitland formation prior to mining.

The model simulated steady-state post mining potentiometric surface in the PCS is provided in Figure 11-47. This surface is similar to the pre-mining PCS potentiometric surface in Appendix 6-G Figure 6.G-1 except for the localized increase in the heads in the PCS below the mine backfill within Area IV North. The higher head in the PCS below the mine backfill is due to the higher heads at the base of the mine backfill. Very little change in heads is predicted at locations away from mine backfill, including at the former PCS wells GM-19 and GM-28, located within the permit area at distances of about 3,500 and 3,000 feet from the Area IV North mine pit. This localized increase in heads in the PCS results in an increase in gradients toward the northwest and toward the northeast as depict in Figure 11-47.

Figure 11-45. Drawdown and Recovery in the PCS, the No. 3 Coal and the No. 8 Coal at GM-19

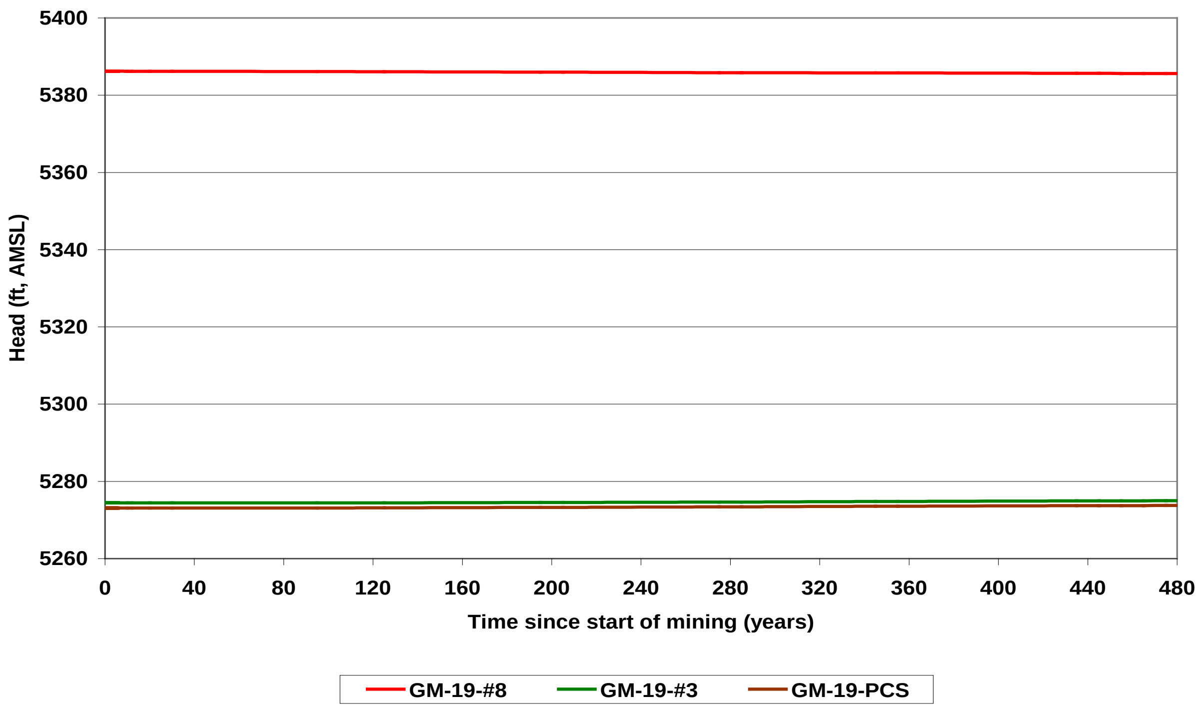
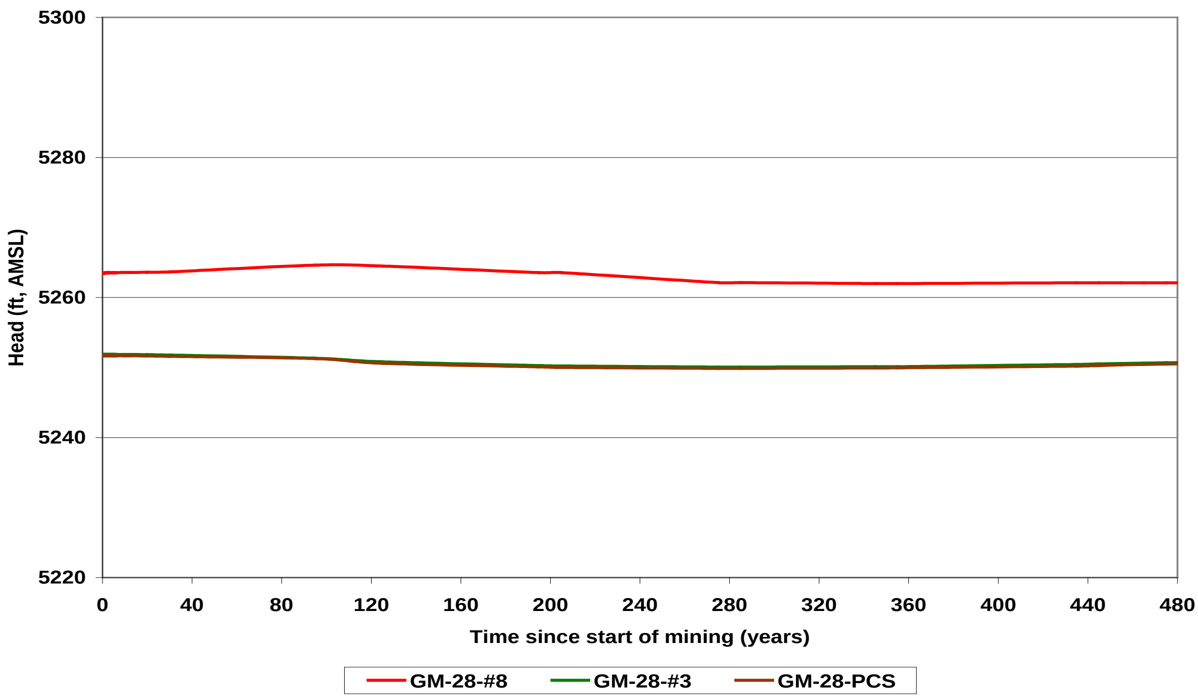


Figure 11-46. Drawdown and Recovery in the PCS, the No. 3 Coal and the No. 8 Coal at GM-28



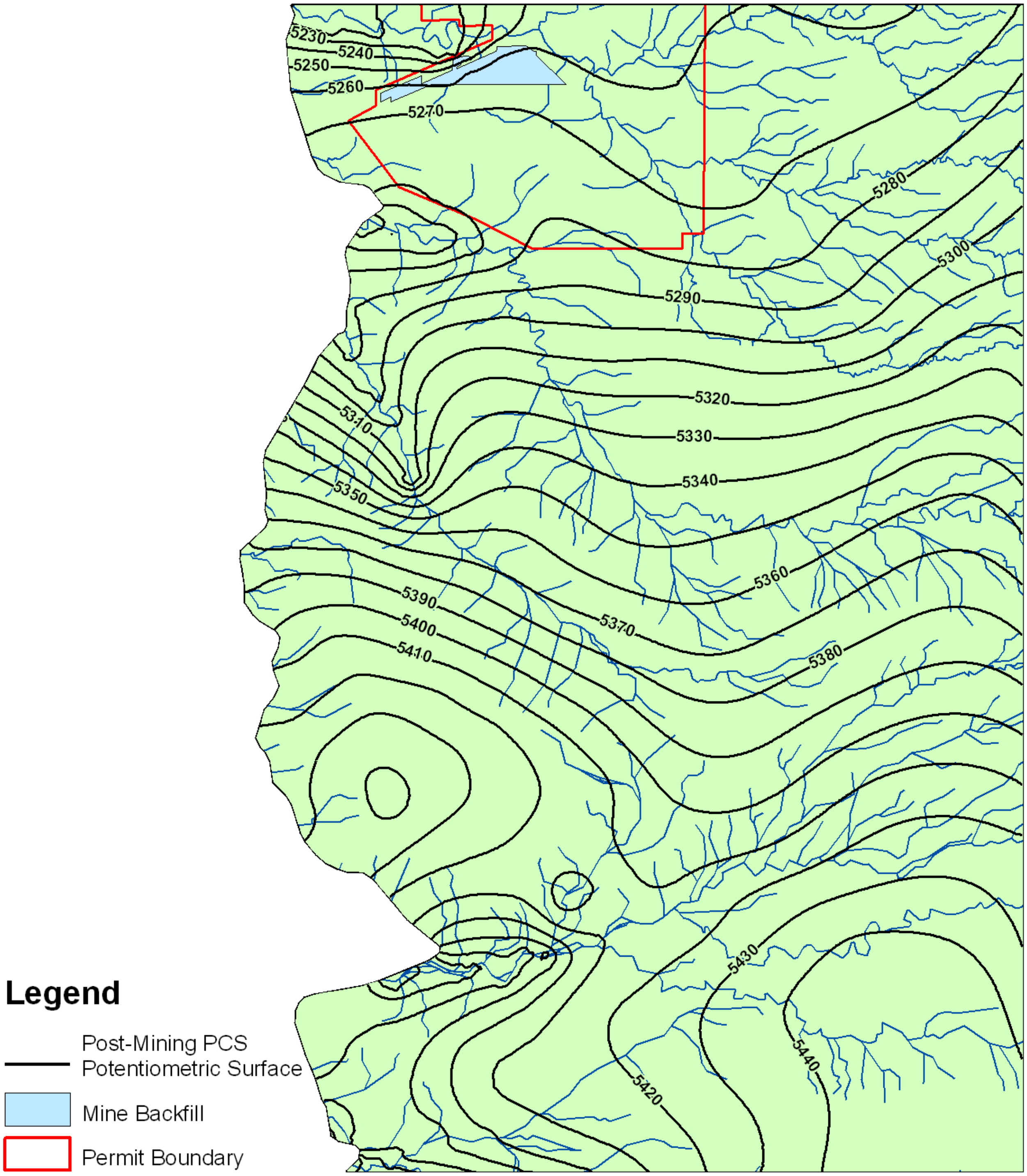
11.6.2.4.2 Potential Impacts to Alluvial Groundwater Flow

In both the pre-mining and post-reclamation groundwater flow models, there is a component of groundwater flow from Area IV North toward the alluvium within the topographic low along Cottonwood Arroyo. The increase in the post-reclamation recharge rate within the mine areas also increases the rate of the groundwater flow in the alluvium. The model estimates for the steady-state post-reclamation alluvial groundwater flow at the mouth of Cottonwood Arroyo is 4.58 gallons per minute (gpm) compared to the pre-mine alluvial groundwater flow estimate of 4.3 gpm.

However, the increase in flow is not expected to measurably change the potential well yield from the alluvium for several reasons. First, the estimated pre-mine steady state groundwater flow on the order of 4.3 gpm in the alluvium and underlying PCS was insufficient to sustain water supply at the two dug wells that were monitored for baseline conditions. Actual groundwater flows in the alluvium are variable in space and time and a modeled steady state flow of 4.3 gpm does not translate into a reliable water supply of 4.3 gpm. Likewise, an increase in the steady state flow by 0.3 gpm does not imply that this increase would be available as a reliable water supply at alluvial wells. Finally, groundwater recovery to the post-mining steady state conditions with the slight increase in groundwater flow is estimated to take more than 400 years.

The road crossings of Cottonwood Arroyo are not expected to affect the groundwater in the Cottonwood alluvium. The alluvium in the North Fork of Cottonwood has been mined through in Area III. Thus, the groundwater in the alluvium of the North Fork Cottonwood has most likely been depleted immediately up gradient and down gradient of the mine. The loss of alluvial groundwater flow from the North Fork may result in a decrease in groundwater flow in the Cottonwood alluvium below the confluence with the North Fork. The alluvium along the main stem of Cottonwood will not be mined through and advance of the pit in Area IV North and drawdown in the coal units and the PCS are not expected to affect groundwater levels in the alluvium of Cottonwood Arroyo.

Figure 11-47. PCS Steady-State Post-Mining Potentiometric Surface



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11.6.2.4.3 Potential Groundwater Quality Changes

Groundwater quality changes beyond the active mine area at Area IV North will be minimal during mining and reclamation operations. During active mining, hydraulic gradients, and groundwater flow directions in the Fruitland Formation and in 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 precipitation and groundwater inflows from the adjacent Fruitland Formation coal seams and from the underlying PCS. Upward flow into the mine backfill from the PCS will be relatively low and will cease once saturation levels in the backfill rise sufficiently to reverse directions of flow after about 85 years following the start of mining. Dissolved solids present in the pore water of mine overburden and interburden materials (spoil) that are used to backfill the pit may be concentrated by evaporation during mining. There may also be some enhanced weathering of the minerals within the newly fractured and broken interburden strata that are removed during mining of the coals and placed within the mine backfill. The characteristics of the overburden and interburden strata within Area IV North were determined from an extensive drilling, coring, and testing program described in Chapter 5.

It is expected that TDS and sulfate concentrations will increase in the Area IV North mine spoil relative to the baseline concentrations in the Fruitland Formation coals based on both spoil leaching tests results and the water quality analysis of spoil water samples taken from the Bitsui Pit as presented in Section 11.6.2.2. Concentrations of boron and manganese may also increase but other trace constituents are expected to remain below detection limits or comparable to the concentrations observed in the baseline coal water.

The TDS concentrations are lower in the Fruitland coals in the vicinity of Area IV North in comparison with the baseline TDS concentrations further north in the vicinity of Areas I and II.

The groundwater leaching test results presented in Table 11-14b showed TDS concentrations of 11,000 and 12,000 mg/L in leachate generated from two spoil samples using composite coal groundwater samples from Area II wells KF84-18a and KF84-18b with a TDS concentration of 9,800 mg/L. A comparable TDS concentration of 11,850 mg/l was observed in spoil water in the Bitsui Pit at well Bitsui-5. This well is most representative of concentrations from spoil only in the Bitsui Pit because it is not located near or down gradient of any CCB placement locations.

The water sources for leaching of mine spoil in the Bitsui Pit in Area I include the No. 8 coal water with TDS concentrations ranging from 5,000 to 10,000 mg/L, seepage from the PCS and from adjacent NAPI irrigation plots with unknown TDS concentrations and some precipitation recharge with low TDS concentrations. The water sources for recharge of the Area IV North mine spoils include:

- inflows from the various coal units with average TDS concentrations of approximately 3,000 mg/l as found for the composite coal sample used in the leaching test results presented in Table 11-14f;
- precipitation recharge with TDS concentrations of approximately 1,200 mg/l based on the SPLP leaching test results presented in Table 11-14f; and
- upward flow from the PCS with average TDS concentrations in the range from 7,800 to 9,200 mg/l based on samples obtained from nearby PCS well GM-19 (Appendix 6-G Table 6.G-14).

Inflow from the PCS is estimated to be very low and temporary so that backfill recharge over the long-term is expected be primarily from the coals and from precipitation recharge. Since the TDS concentrations are lower in the coal water at Area IV North in comparison with the coals near the Bitsui Pit, the TDS concentrations in the spoil water in Area IV North should also be lower than the concentrations observed at the Bitsui spoils or in the Table 11-14b spoil leaching test results.

The spoil leaching test results presented in Table 11-14f using coal water representative of Area IV North may be viewed as a lower bound estimate for the TDS in spoil water in Area IV North.

The TDS and sulfate concentrations in the spoil water at the Area IV North mine may be higher than these leaching test results due to calcite precipitation and ion exchange which results in increased sulfate and sodium concentrations and decreased calcium concentrations in saturated mine spoils in comparison with leaching test results. While the TDS observed in the spoil well Bitsui-5 was within the limits of the TDS in Table 11-14b for the two spoil leaching tests performed using the composite coal groundwater, the sulfate concentrations in Bitsui-5 were about two times the concentrations observed in the spoil leaching tests. For this PHC analysis, the TDS concentrations in the Bitsui-5 well were used as an upper bound estimate for the post-mine TDS concentrations in the mine spoils in Area IV North.

Table 11-14i provides a range of concentrations for constituents of concern that might be expected in Area IV North mine spoils based on leaching tests and water quality monitoring at spoil well Bitsui-5. These results show TDS and sulfate to be the primary constituents of concern with respect to spoil leachate. Arsenic and selenium were below detection in the spoil water sample and in most of the leaching test results. Fluoride is lower in the spoil water than in the coals and is attenuated in flow through mine spoil. Boron and manganese concentrations are elevated in mine spoil but concentrations are below criteria for livestock use.

Table 11-14i.

Estimated Source Concentrations in Mine Spoils

Constituent	Area IV North coal water	Estimated Source Concentrations in Mine Spoils (mg/L)			
		Spoil Well Bitsui #5	Spoil SPLP	Spoil leached with Area IV N coal water	S-4 Spoil leached with coal water
Arsenic	<0.015	<0.005	<0.015	<0.015	0.002
Boron	0.31	1.12	0.084	0.45	<0.5
Calcium	3.4	60	150	67	730
Manganese	<0.01	0.108	0.19	0.11	0.70
Fluoride	2.4	1.0	0.54	1.6	0.50
Sodium	1200	3860	150	1200	3200
Selenium	<0.026	<0.005	<0.026	<0.026	0.2
Sulfate	300	5,115	670	980	2700
TDS	3100	11,850	1200	3550	12000

SPLP= Synthetic Precipitation Leaching Procedure

Consequently, TDS was selected for transport modeling simulations using a lower bound source concentration of 3,550 mg/l and an upper bound TDS concentration of 11,850 mg/l. TDS was assumed to behave conservatively, that is with no attenuation due to adsorption or chemical transformation. Sulfate was not modeled separately but was assumed to vary with TDS based on the sulfate-TDS ratio in the source. Based on the observations at the spoil well Bitsui-5, sulfate concentrations are expected to comprise about 41% of the TDS.

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 Area IV North mine spoil. The chemical transport model was applied to the steady-state post-reclamation groundwater flow conditions to provide predictions of long-term post-reclamation TDS transport from the mine spoil in Area IV North.

The transport model solves advection-dispersion-adsorption equations for constituent transport processes in groundwater flow. Several transport scenarios were performed to evaluate the sensitivity of transport results to changes in groundwater flow parameters. Transport sensitivity scenarios specified the upper bound TDS source concentration of 11,850 mg/l that remained constant throughout the 500-year transport modeling period. An addition 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 (Scenario 5). 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. Table 11-14j summarizes the flow parameters varied in the transport sensitivity runs. Scenarios 4 and 5 in Table 11-14j represent the most likely case of post-mining groundwater flow parameters and the upper and lower bounds of source concentration, respectively (Area IV North Groundwater Water Modeling Report (2011).

Table 11-14j.

Summary of Transport Model Sensitivity Runs

Transport Scenario	Source Concentration (mg/l)	Backfill Recharge Rate (in/yr)	Backfill Hydraulic Conductivity (ft/d)	Specific Storage (1/ft)	Coal Specific Yield (fraction)
1	11,500	0.04	0.056	$1x10^{-4}$	.2
2	11,500	pre-mine	0.56	$3. 8x10^{-6}$ Coal: $2. 8x10^{-5}$	.2
3	11,500	0.04	0.56	$3. 8x10^{-6}$ Coal: $2. 8x10^{-5}$	0.005
4	11,500	0.04	0.056	$3. 8x10^{-6}$ Coal: $2. 8x10^{-5}$	0.005
5	3,550	0.04	0.056	$3. 8x10^{-6}$ Coal: $2. 8x10^{-5}$	0.005

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 TDS from the mine spoils. However, natural background concentrations have been considered in the subsequent interpretations drawn from the transport modeling results.

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

- L1 - corresponding with the alluvium, with the upper 10 ft of soil and overburden in unmined areas and with the upper 10 ft of backfill and topdressing materials in reclaimed areas;
- L4 - corresponding with the No. 8 coal seam in unmined areas and the same elevation as the No. 8 coal in the mine backfill;
- 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, assuming that the constituent source concentrations remained constant throughout the 500-year transport modeling period are presented for the scenarios in Table 11-14j in Figures 11-48 through 11-52,. The results of all scenario runs for the upper bound TDS source concentration of 11,850 mg/l show that concentrations greater than 5,000 mg/l do not extend very far from the mine spoil. The primary horizontal direction of TDS migration from the mine spoil in L1 is toward the alluvium and topographic lows along Cottonwood Arroyo. Elevated TDS concentrations extend down gradient within the alluvium of Cottonwood Arroyo but are less than 1,000 mg/l near the mouth of Cottonwood.

The L28 simulation results for TDS transport in the PCS are presented in Figures 11-53 through 11-57. 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 within the range from 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 Area IV North mine 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 (L4) are presented in Figures 11-58 and 11-62, respectively, for the scenarios listed in Table 11-14j. Likewise, the No. 3 coal (L20) results at the end of the 500 year simulation period are presented in Figures 11-63 and 11-67. 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 is restricted due to the lower heads in the mine backfill relative to the heads in the No. 8 coal prior to mining. Lateral transport in the No. 3 coal is also restricted despite the higher heads in the backfill relative to the heads in the No. 3 coal prior to mining. TDS transport in the No. 3 coal is restricted due to the lower permeability of the No. 3 coal relative to the No. 8 coal.

Figure 11-48. Scenario 1 TDS Transport in the L1 after 500-years with Constant Source of 11,850 mg/l

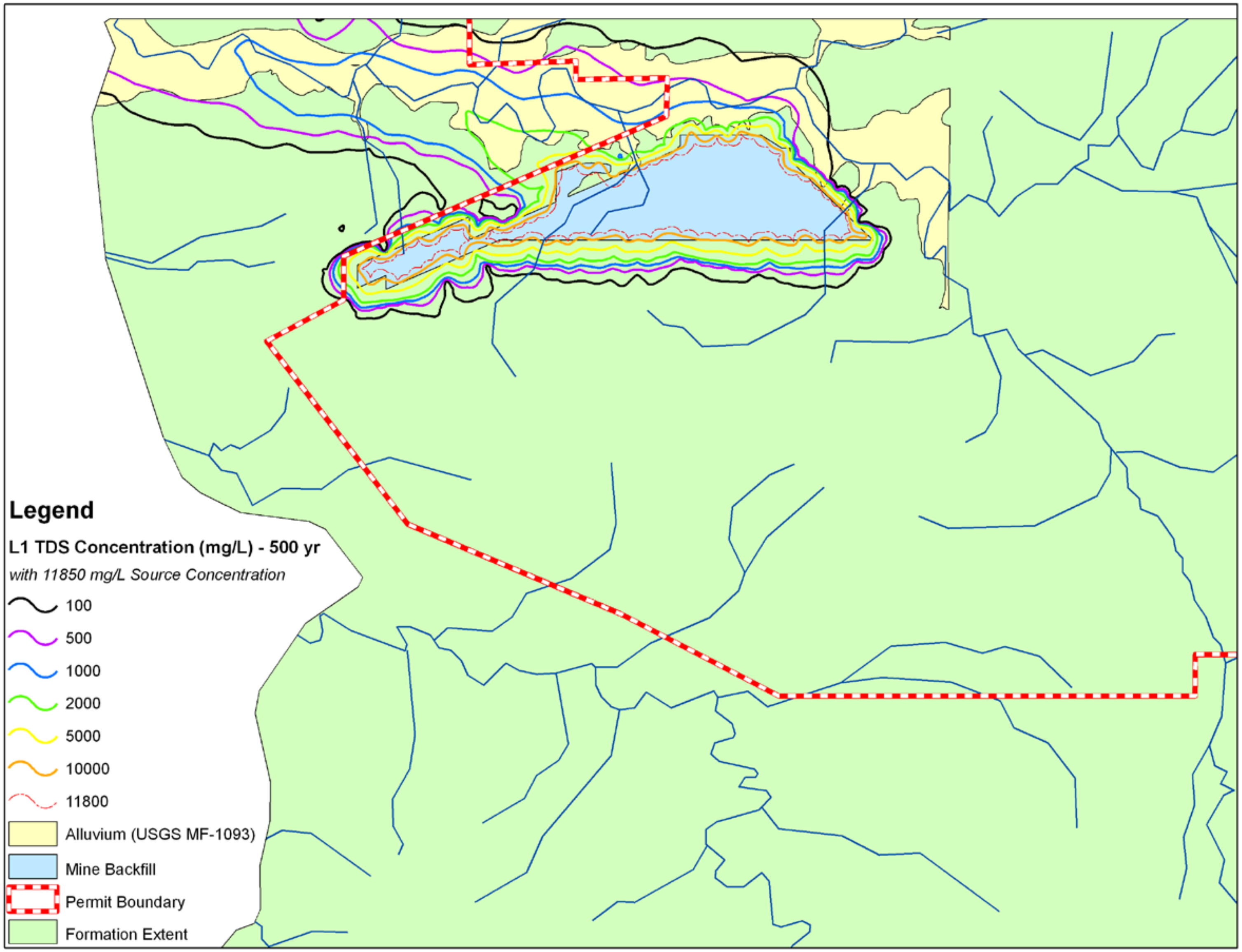


Figure 11-49. Scenario 2 TDS Transport in the L1 after 500-years with Constant Source of 11,850 mg/l

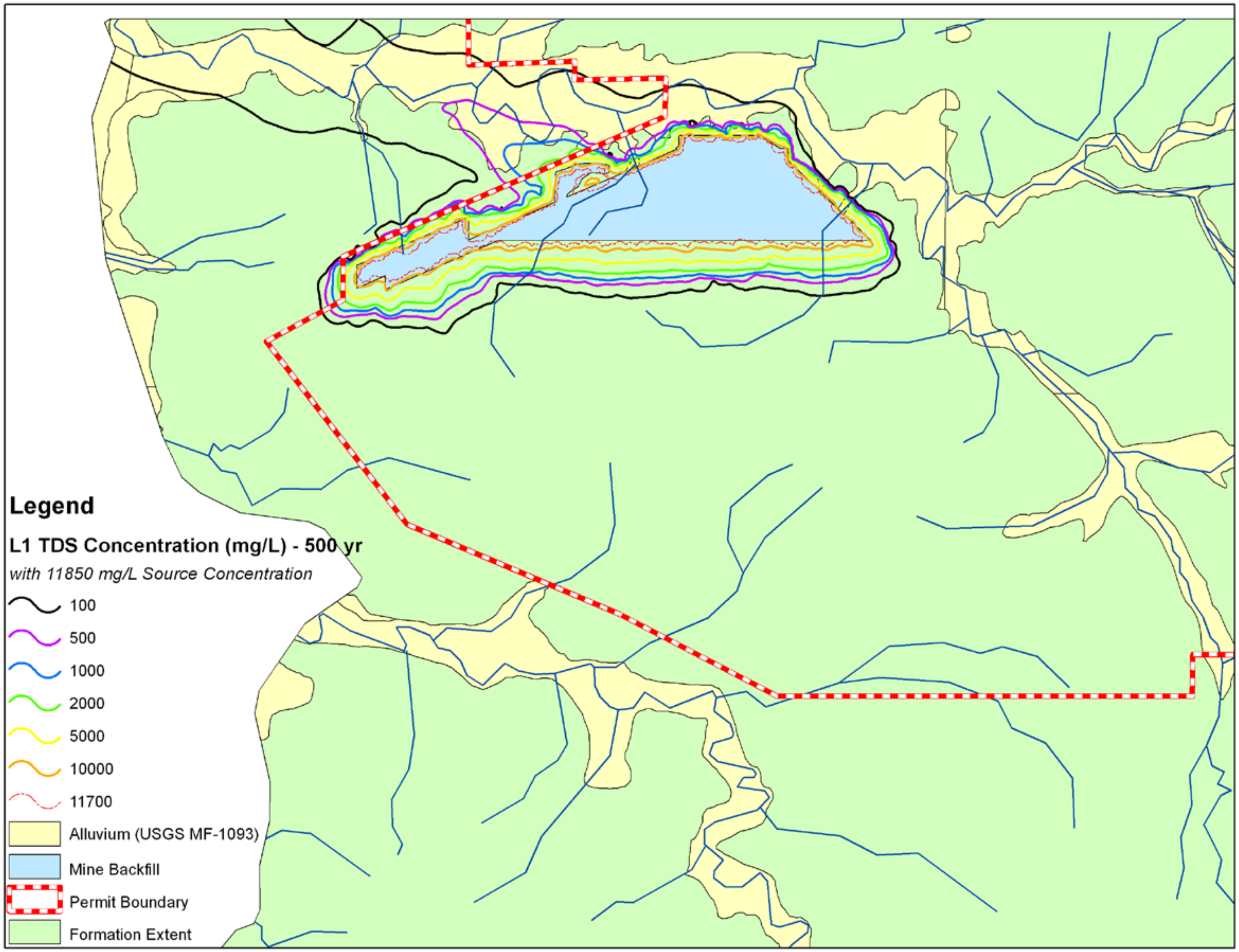


Figure 11-50. Scenario 3 TDS Transport in the L1 after 500-years with Constant Source of 11,850 mg/l

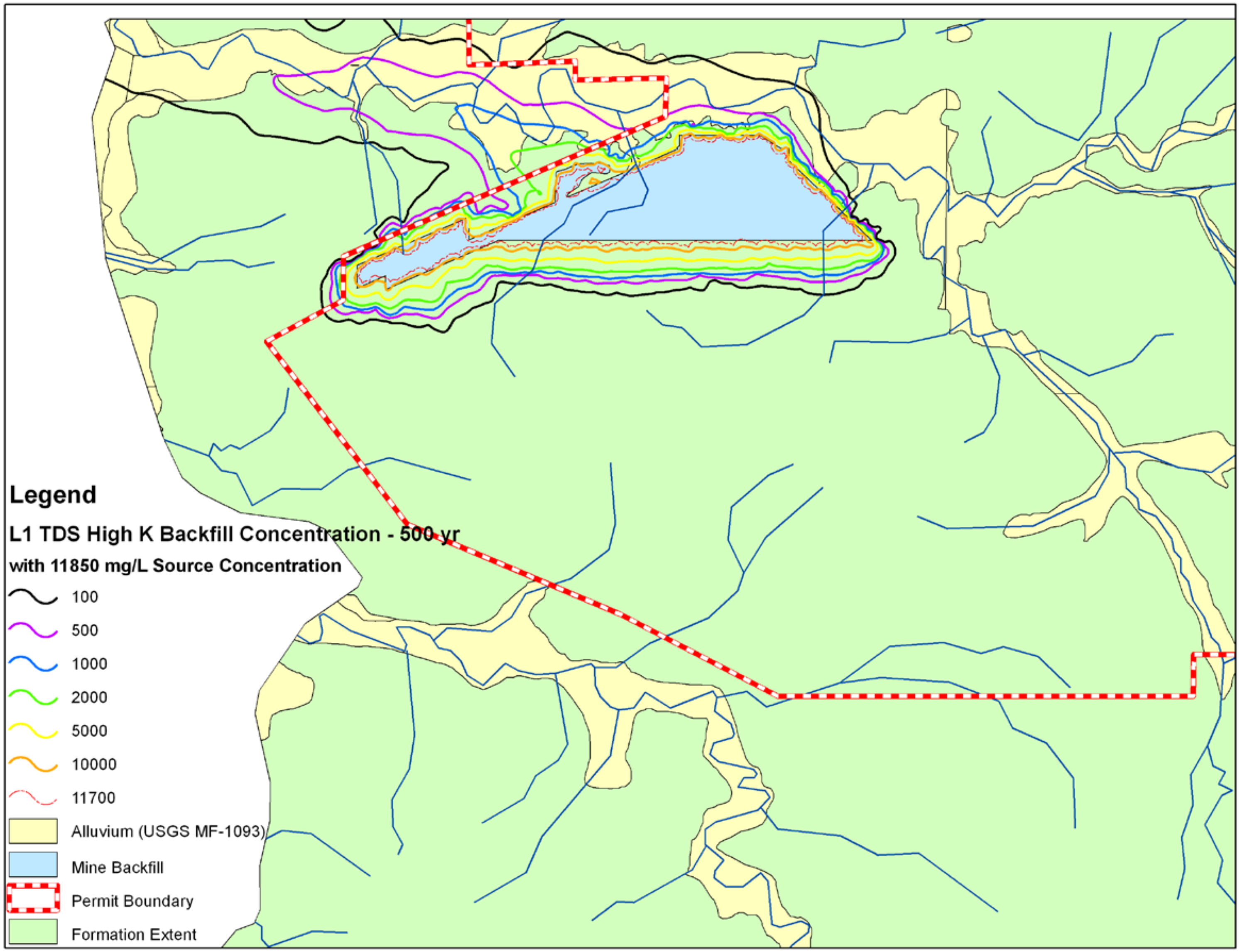


Figure 11-51. Scenario 4 TDS Transport in the L1 after 500-years with Constant Source of 11,850 mg/l

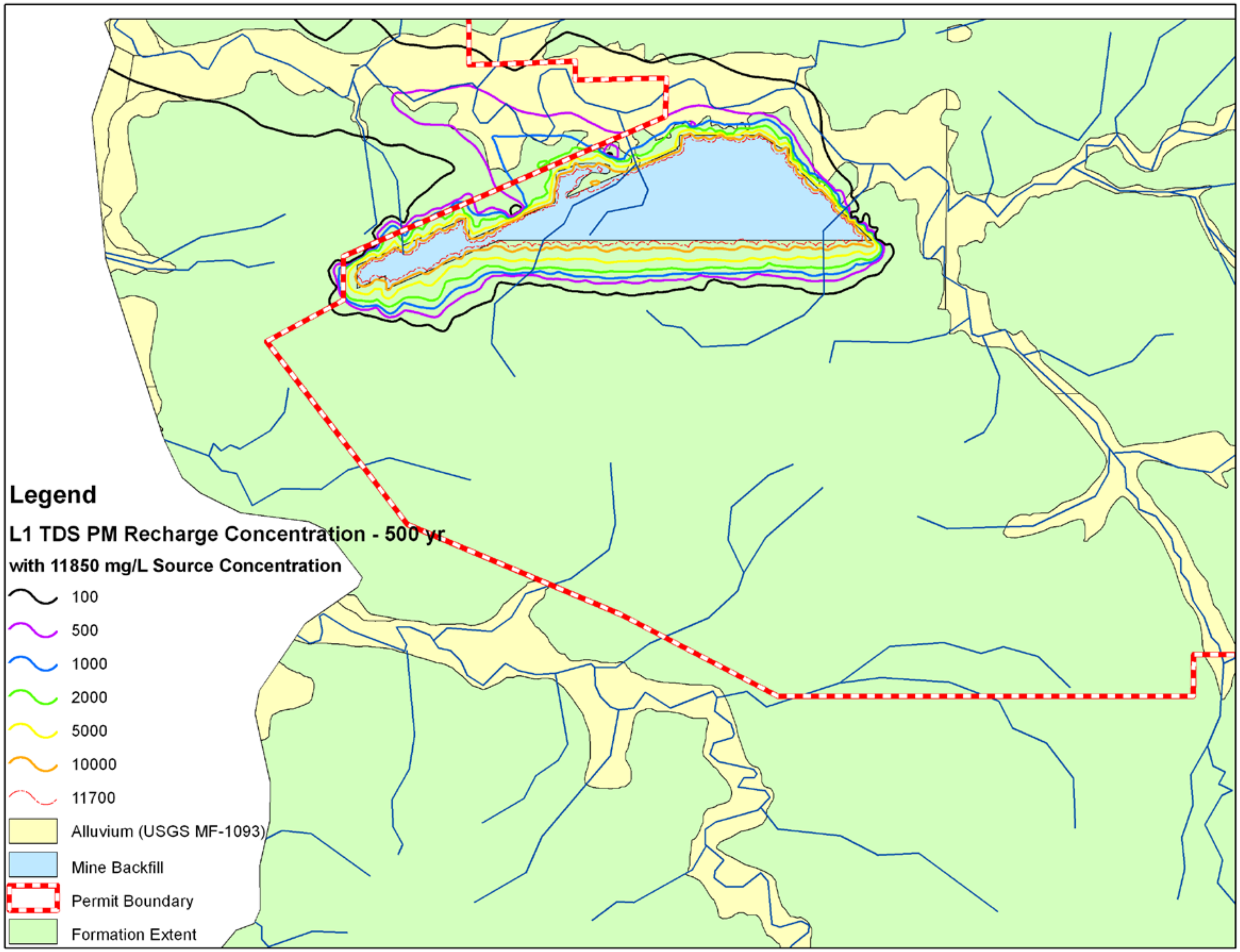


Figure 11-52. Scenario 5 TDS Transport in the L1 after 500-years with Constant Source of 3,550 mg/l

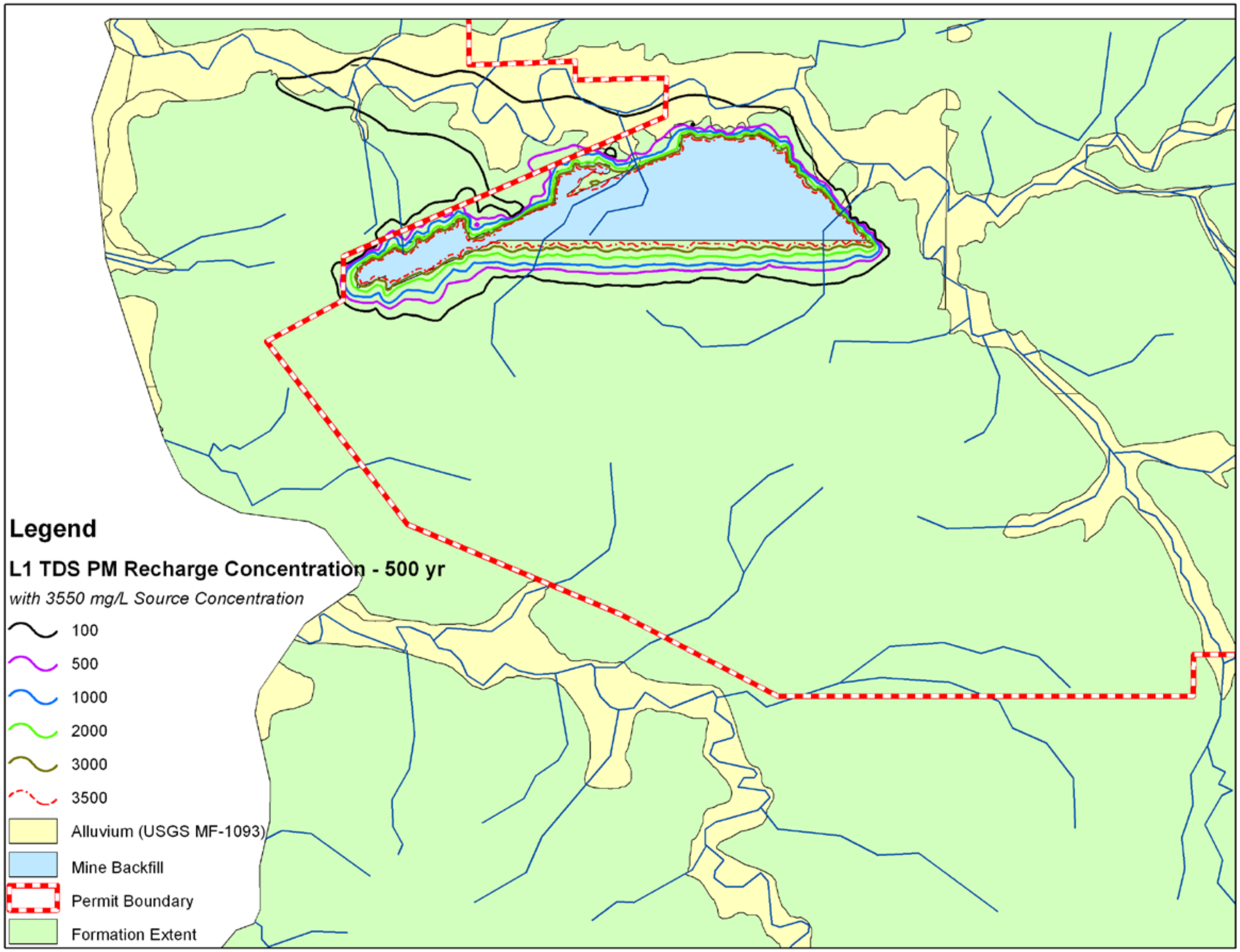


Figure 11-53. Scenario 1 TDS Transport in the PCS after 500-years with Constant Source of 11,850 mg/l

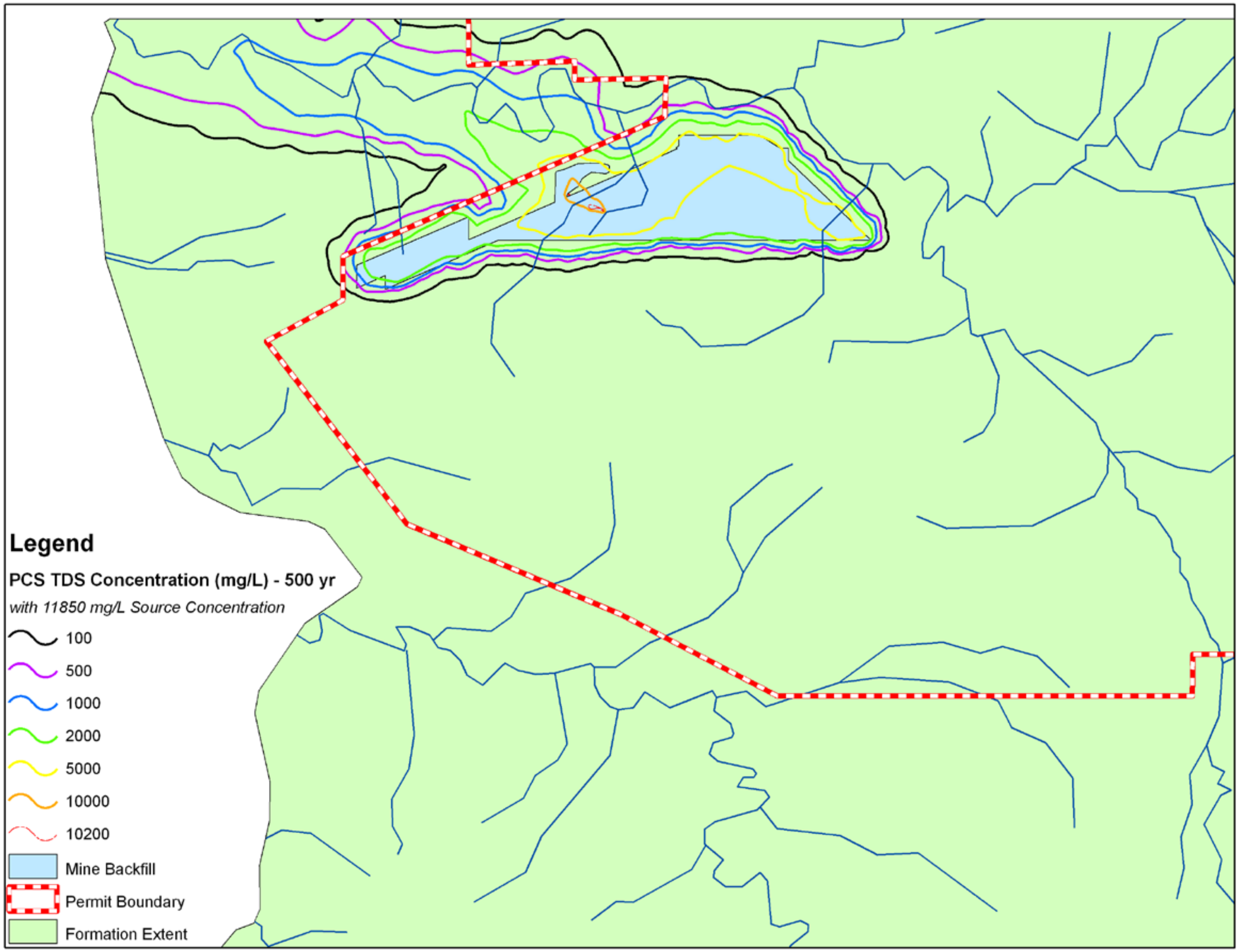


Figure 11-54. Scenario 2 TDS Transport in the PCS after 500-years with Constant Source of 11,850 mg/l

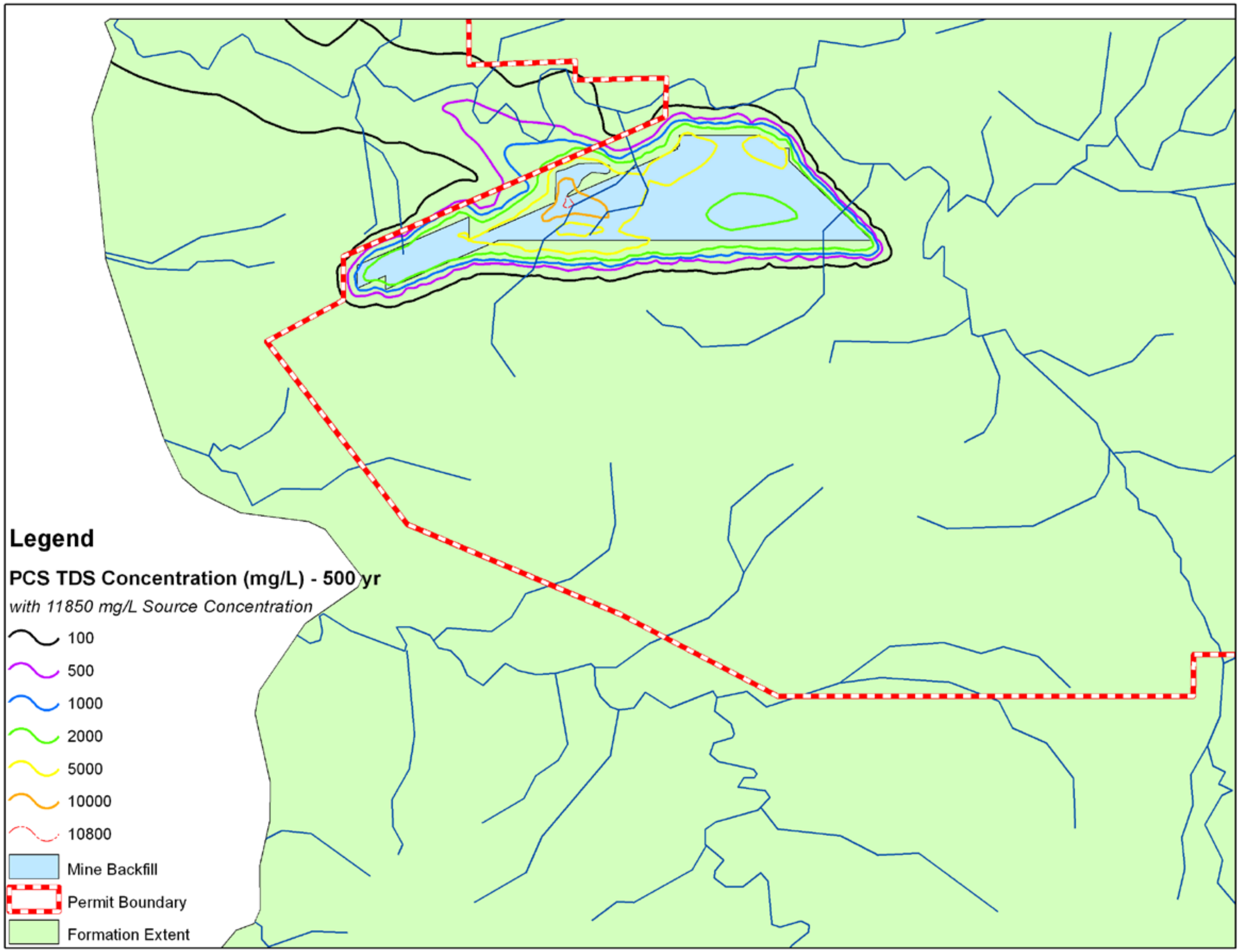


Figure 11-55. Scenario 3 TDS Transport in the PCS after 500-years with Constant Source of 11,850 mg/l

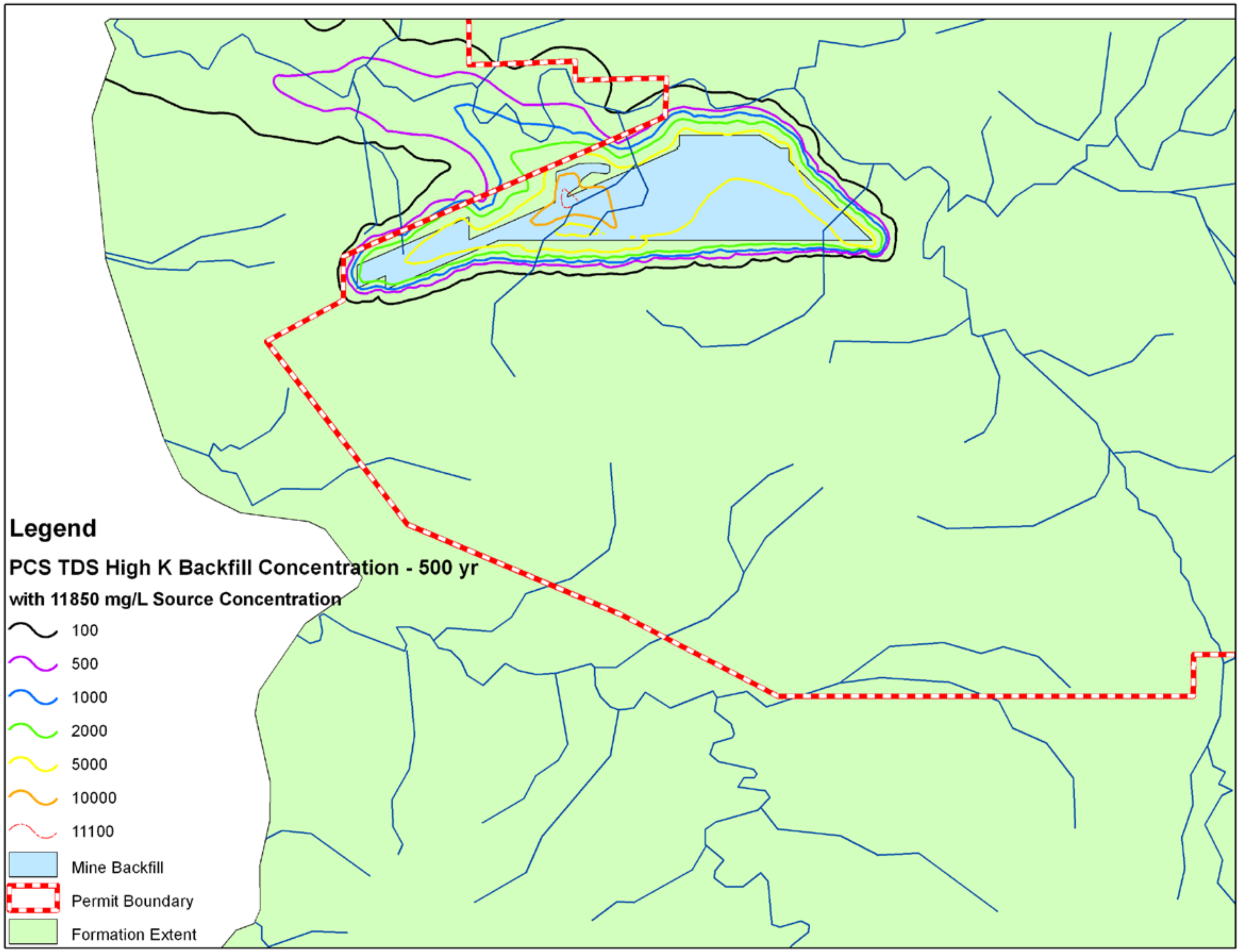


Figure 11-56. Scenario 4 TDS Transport in the PCS after 500-years with Constant Source of 11,850 mg/l

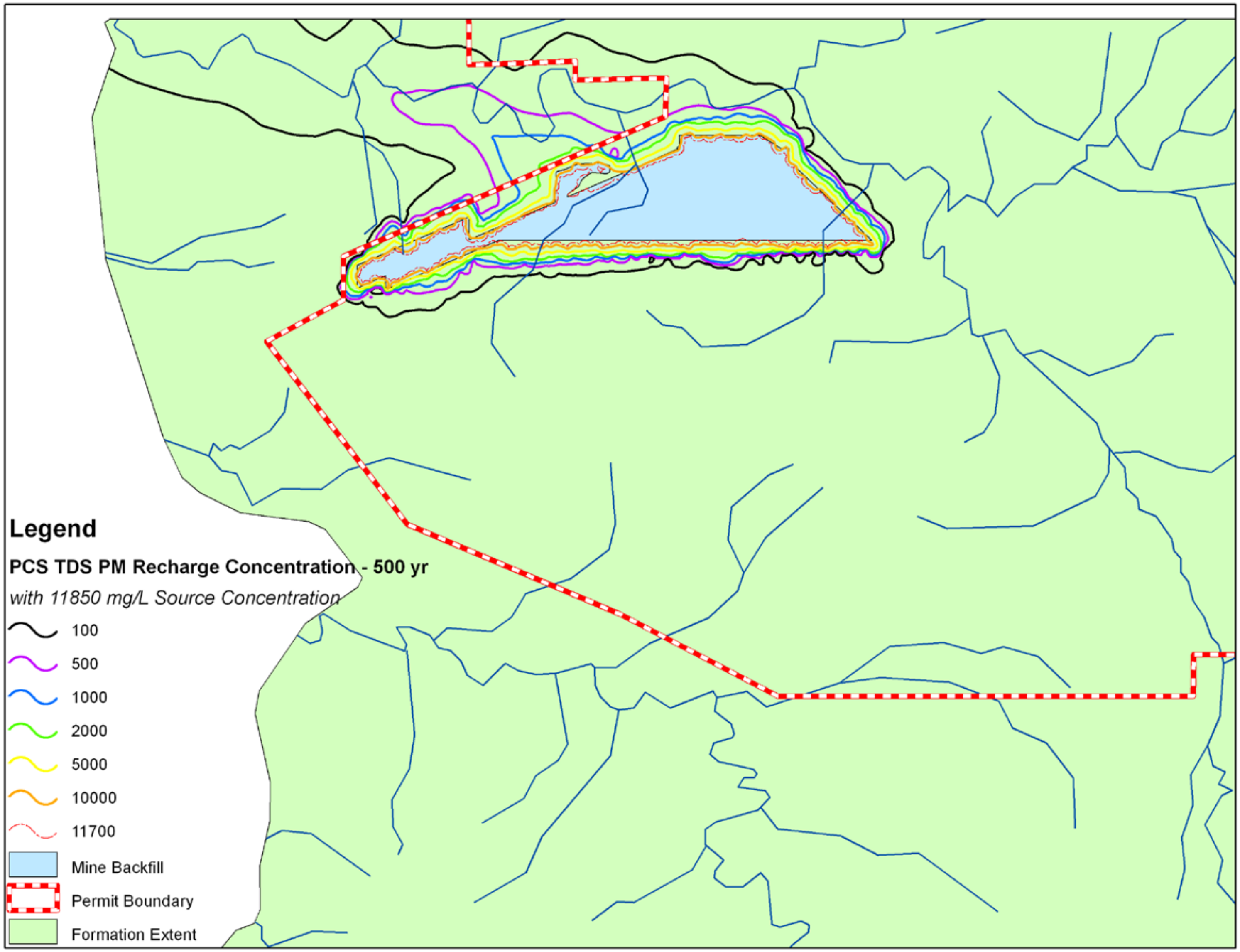


Figure 11-57. Scenario 5 TDS Transport in the PCS after 500-years with Constant Source of 3,550 mg/l

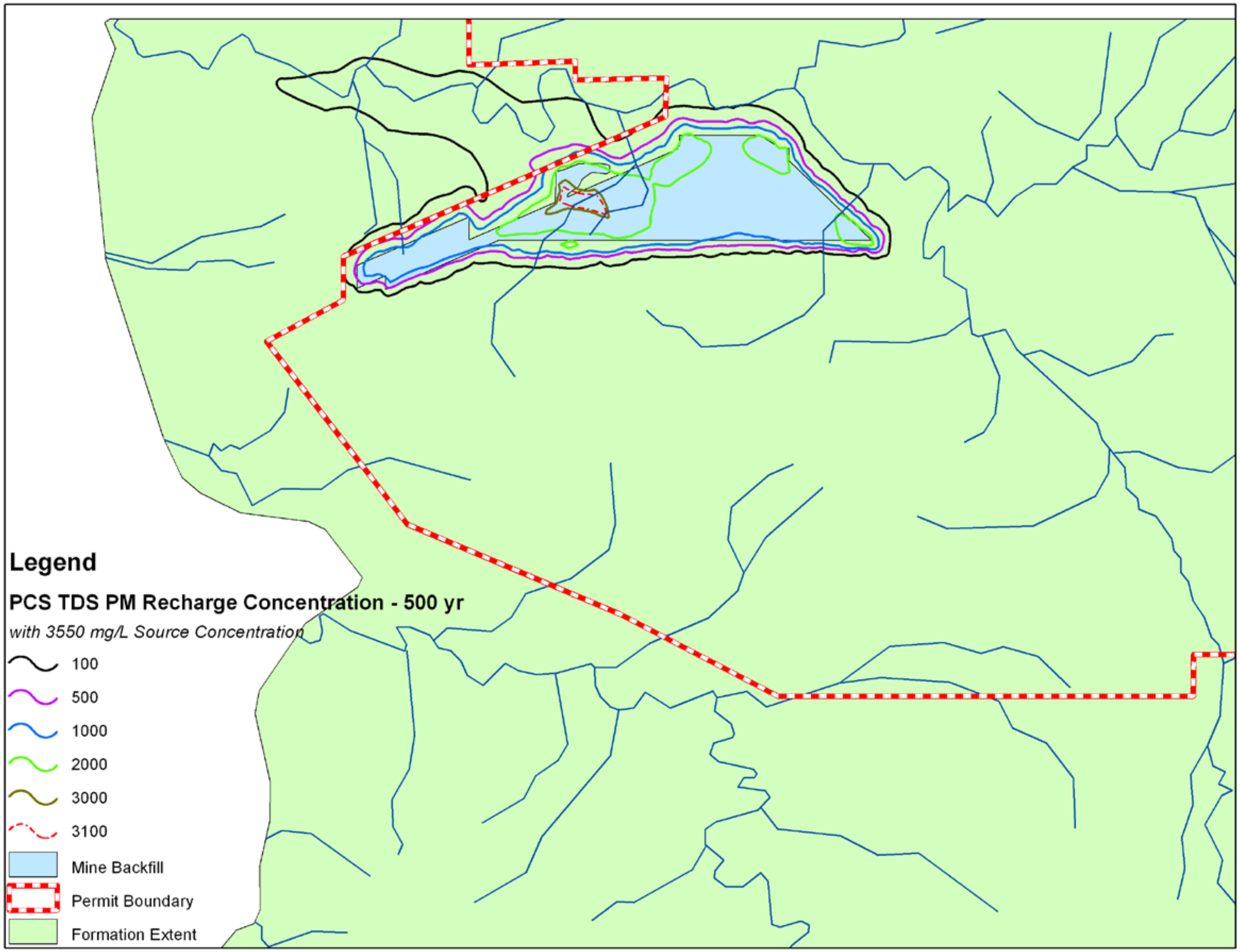


Figure 11-58. Scenario 1 TDS Transport in the No. 8 Coal after 500-years with Constant Source of 11,850 mg/l

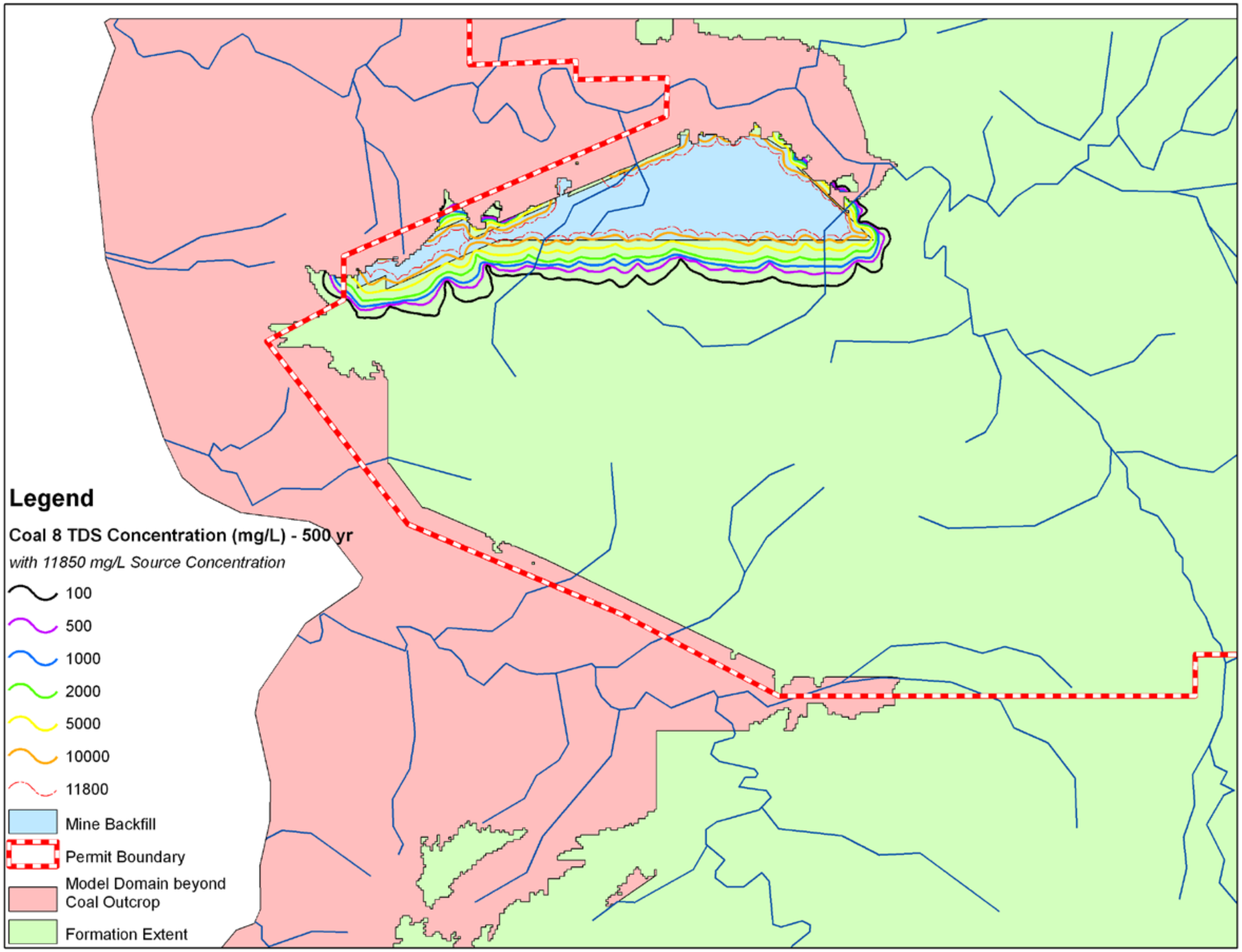


Figure 11-59. Scenario 2 TDS Transport in the No. 8 Coal after 500-years with Constant Source of 11,850 mg/l

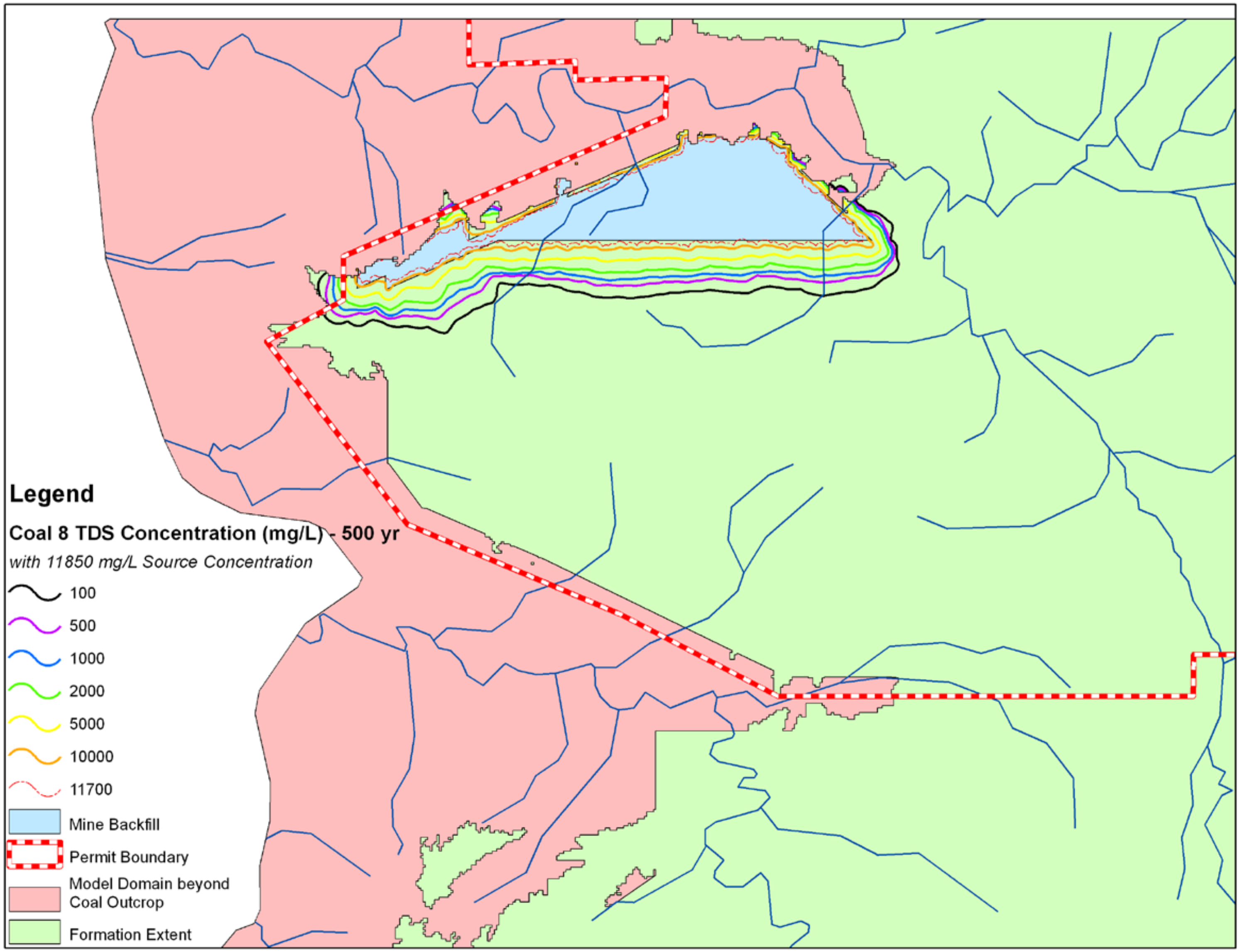


Figure 11-60. Scenario 3 TDS Transport in the No. 8 Coal after 500-years with Constant Source of 11,850 mg/l

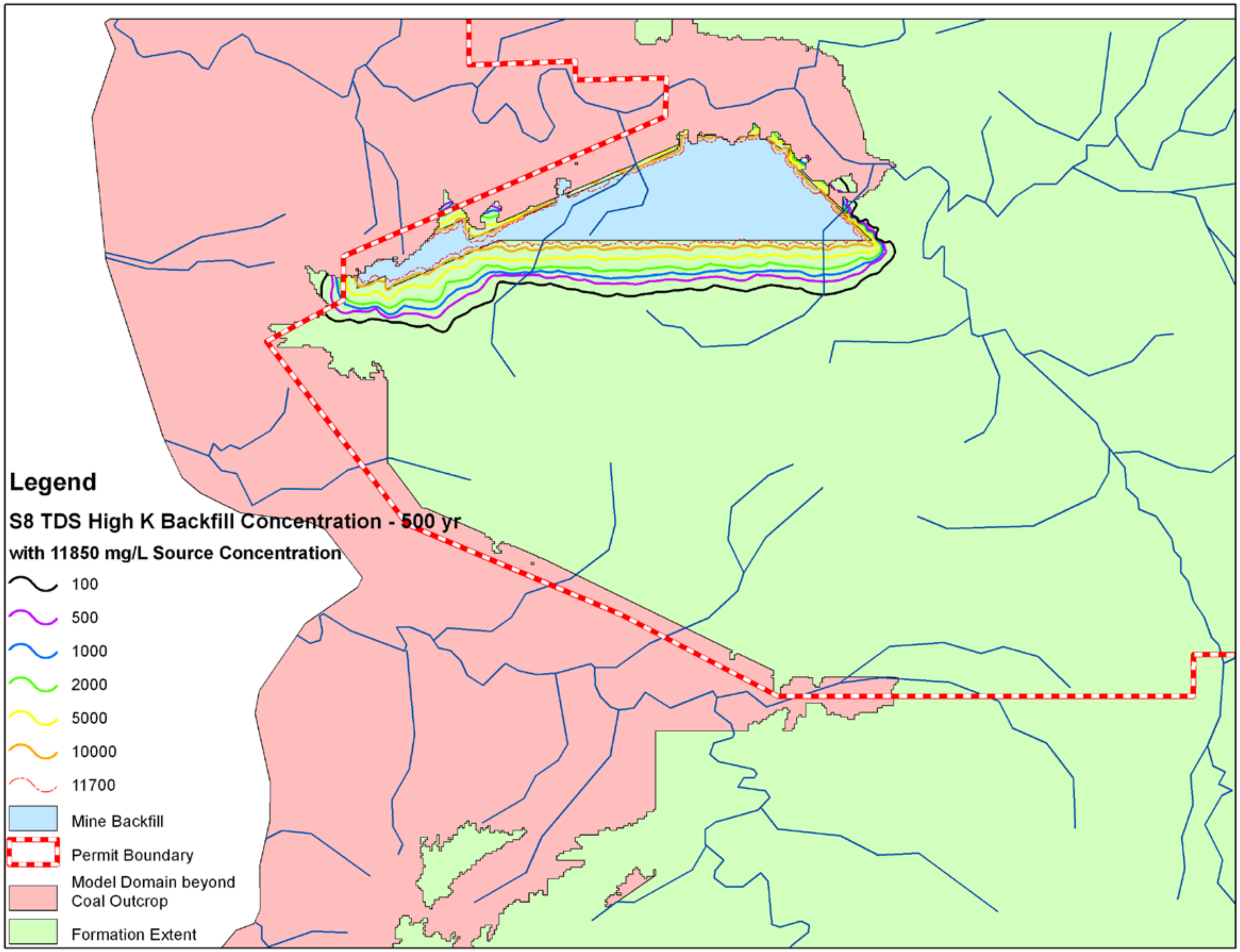


Figure 11-61. Scenario 4 TDS Transport in the No. 8 Coal after 500-years with Constant Source of 11,850 mg/l

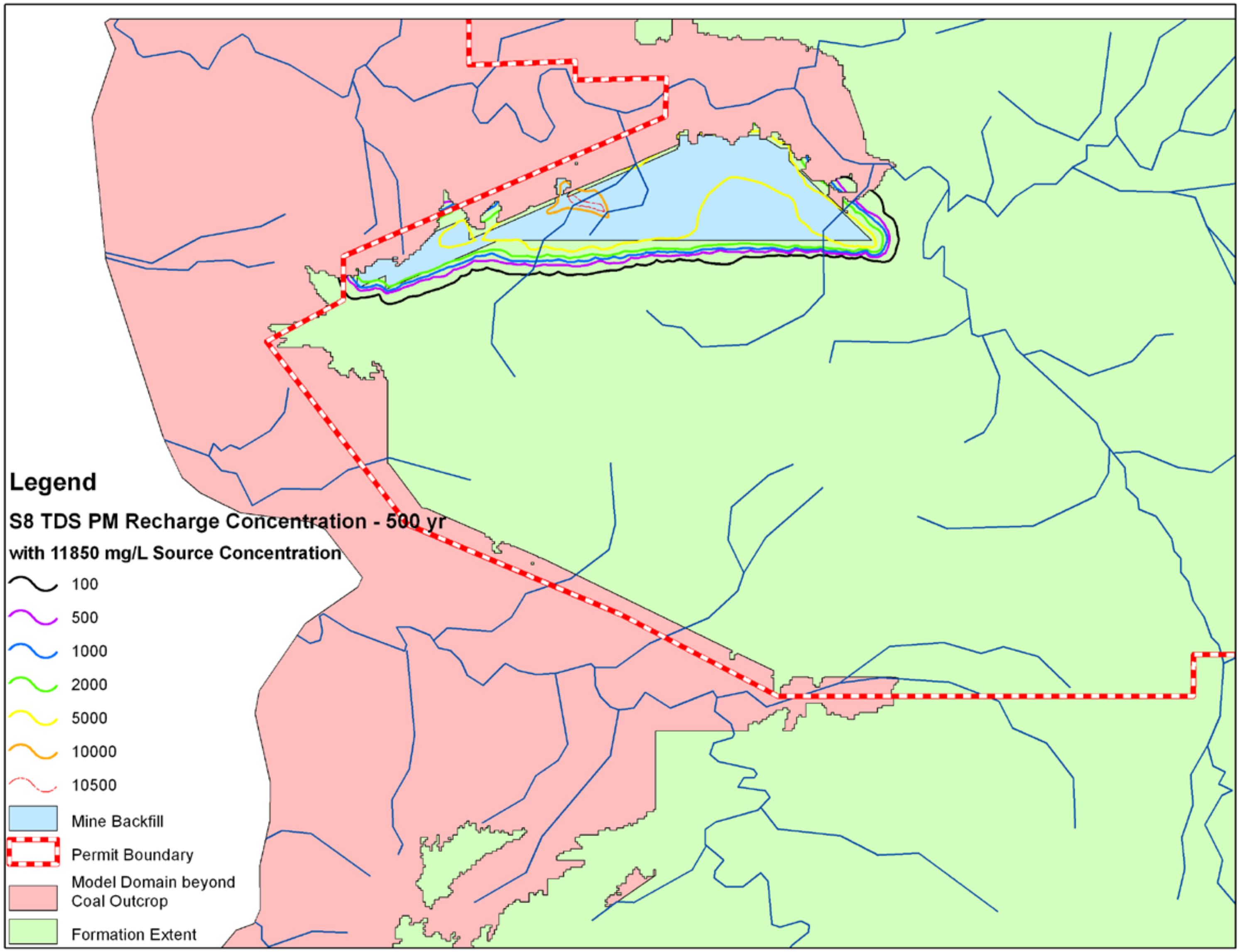


Figure 11-62. Scenario 5 TDS Transport in the No. 8 Coal after 500-years with Constant Source of 3,550 mg/l

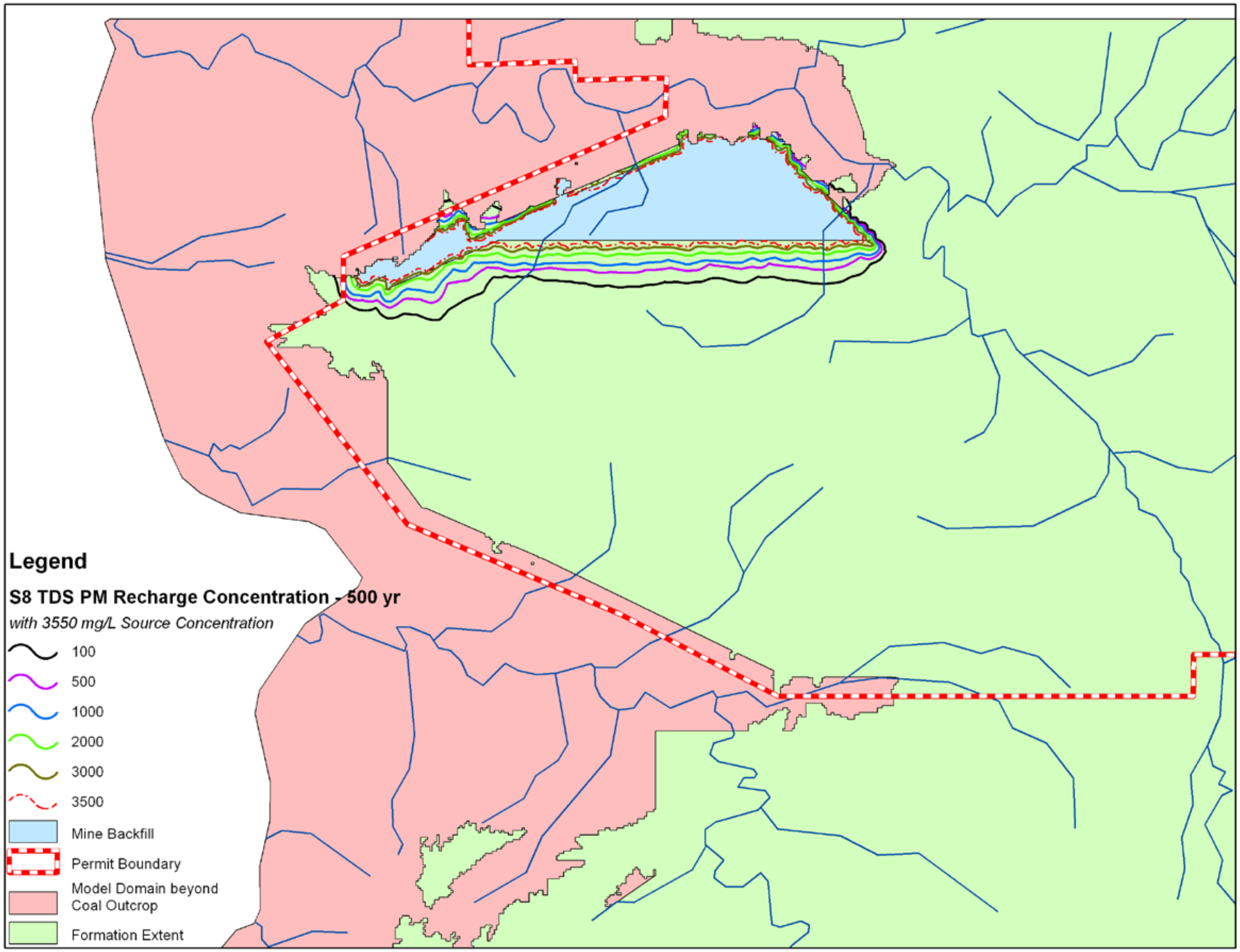


Figure 11-63. Scenario 1 TDS Transport in the No. 3 Coal after 500-years with Constant Source of 11,850 mg/l

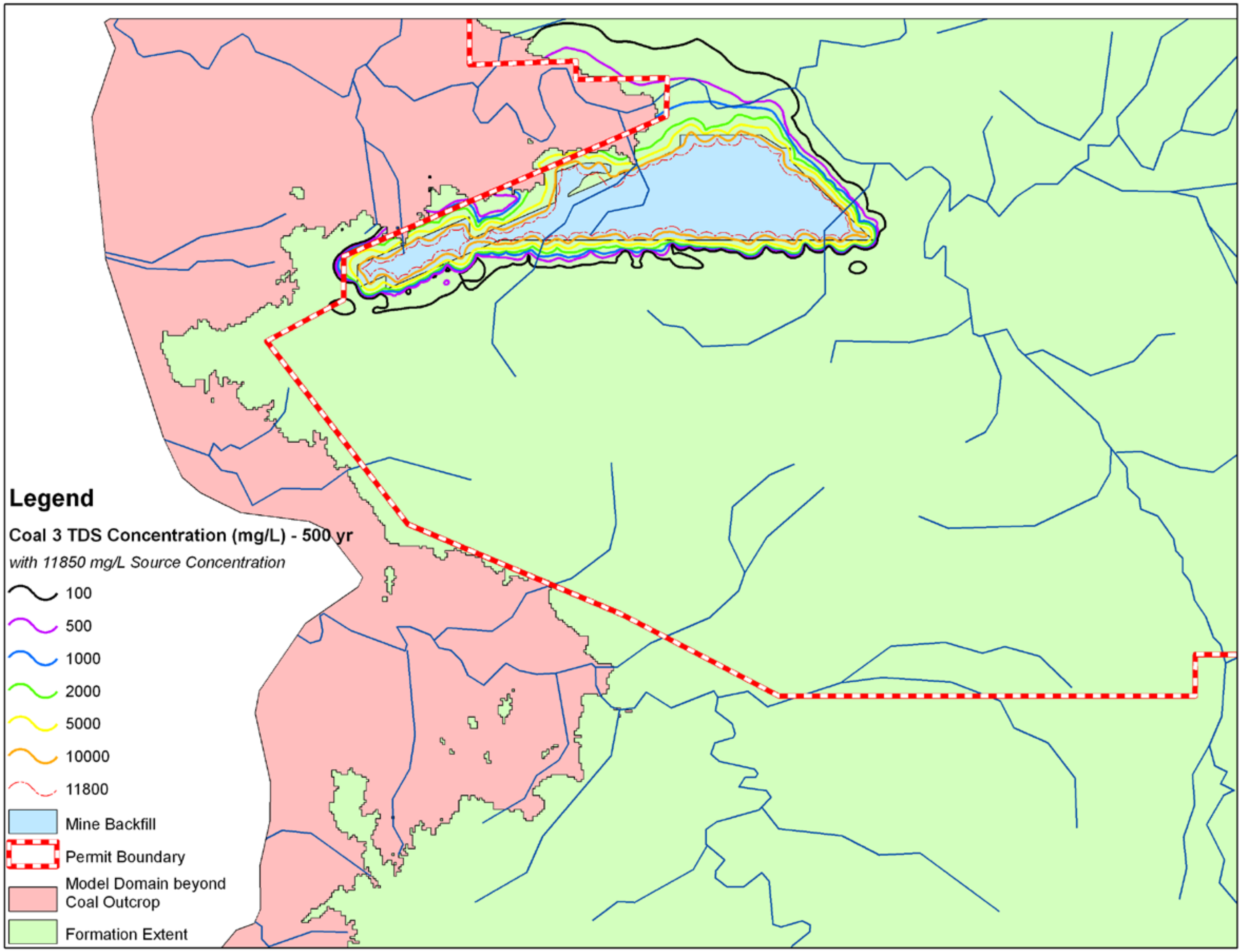


Figure 11-64. Scenario 2 TDS Transport in the No. 3 Coal after 500-years with Constant Source of 11,850 mg/l

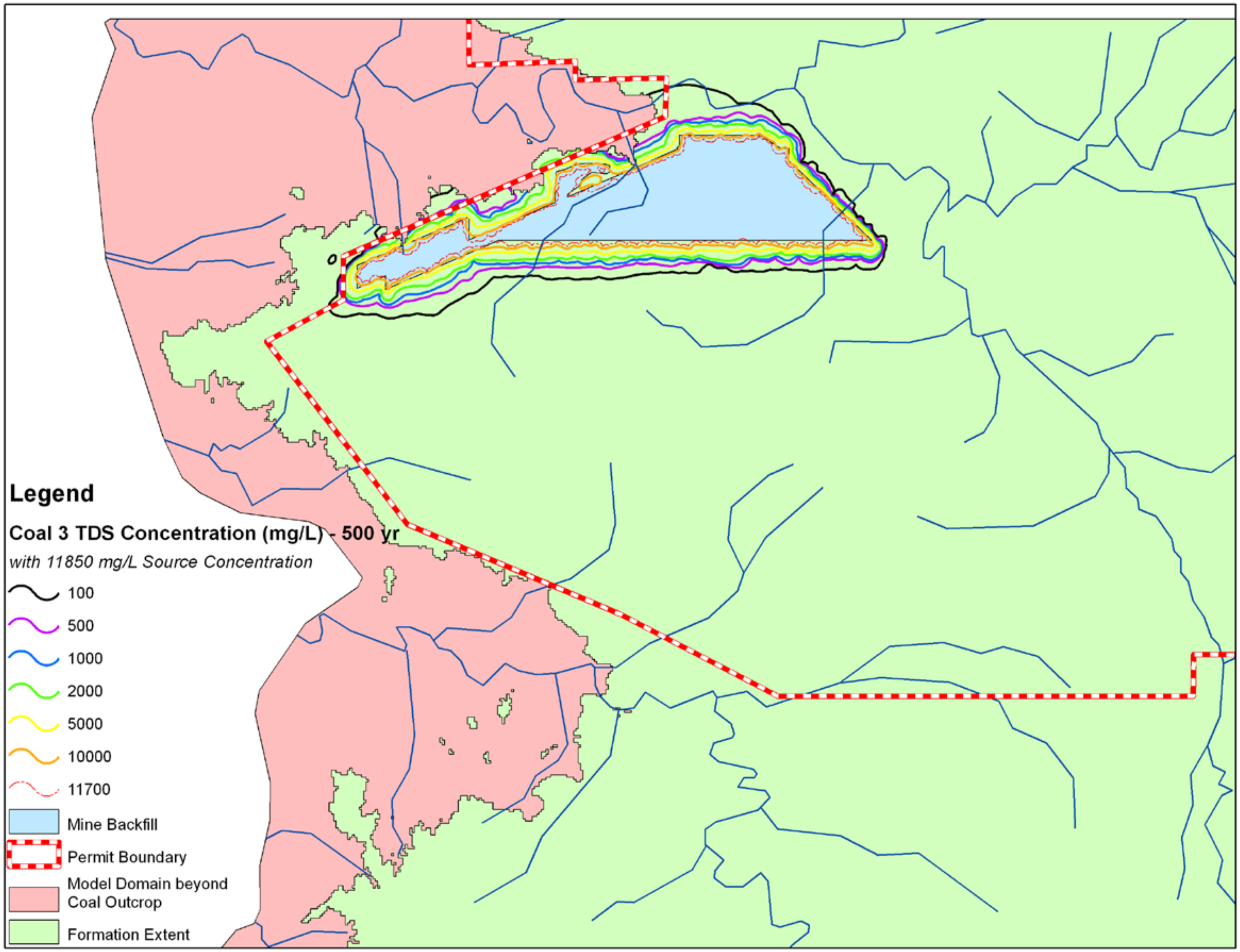


Figure 11-65. Scenario 3 TDS Transport in the No. 3 Coal after 500-years with Constant Source of 11,850 mg/l

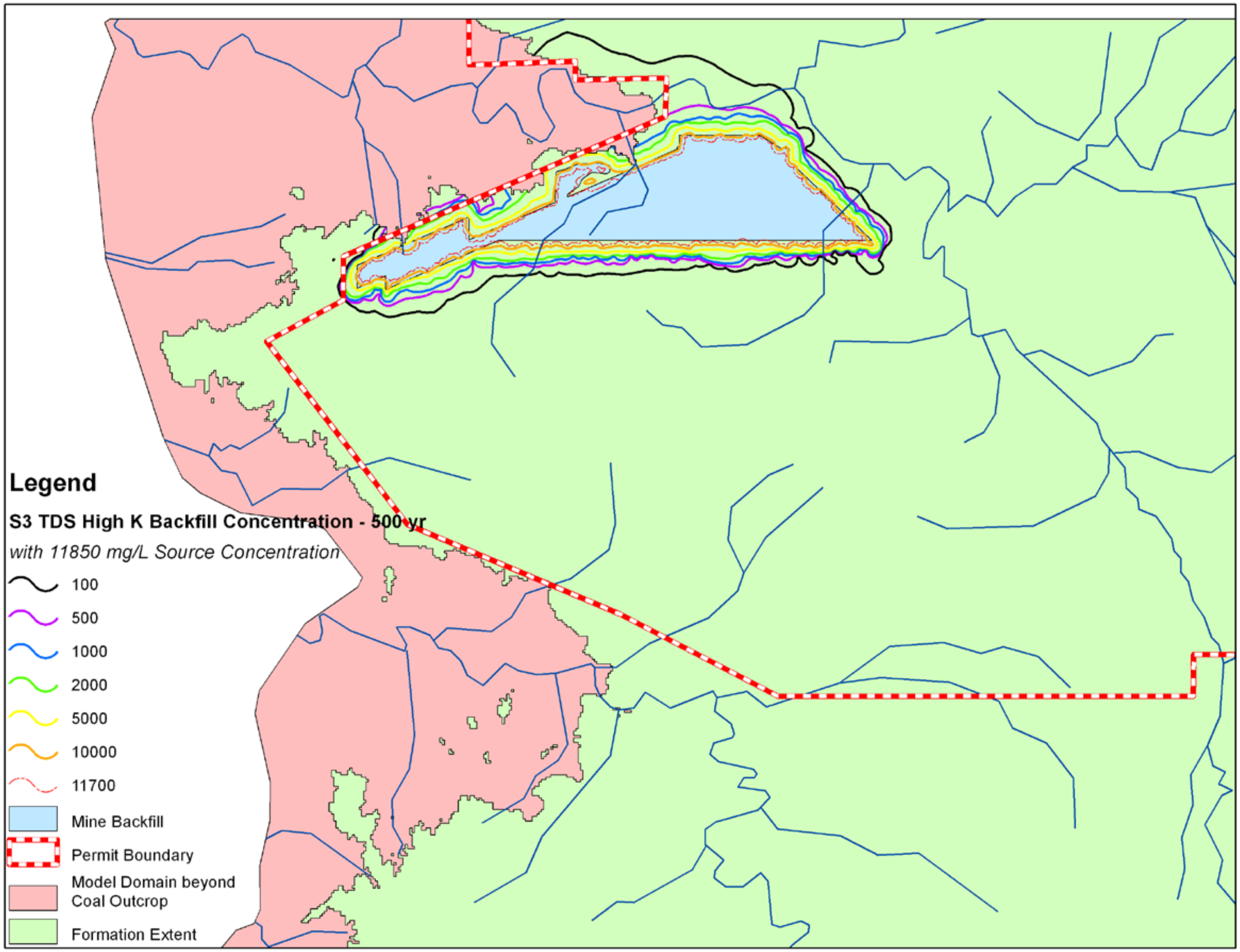


Figure 11-66. Scenario 4 TDS Transport in the No. 3 Coal after 500-years with Constant Source of 11,850 mg/l

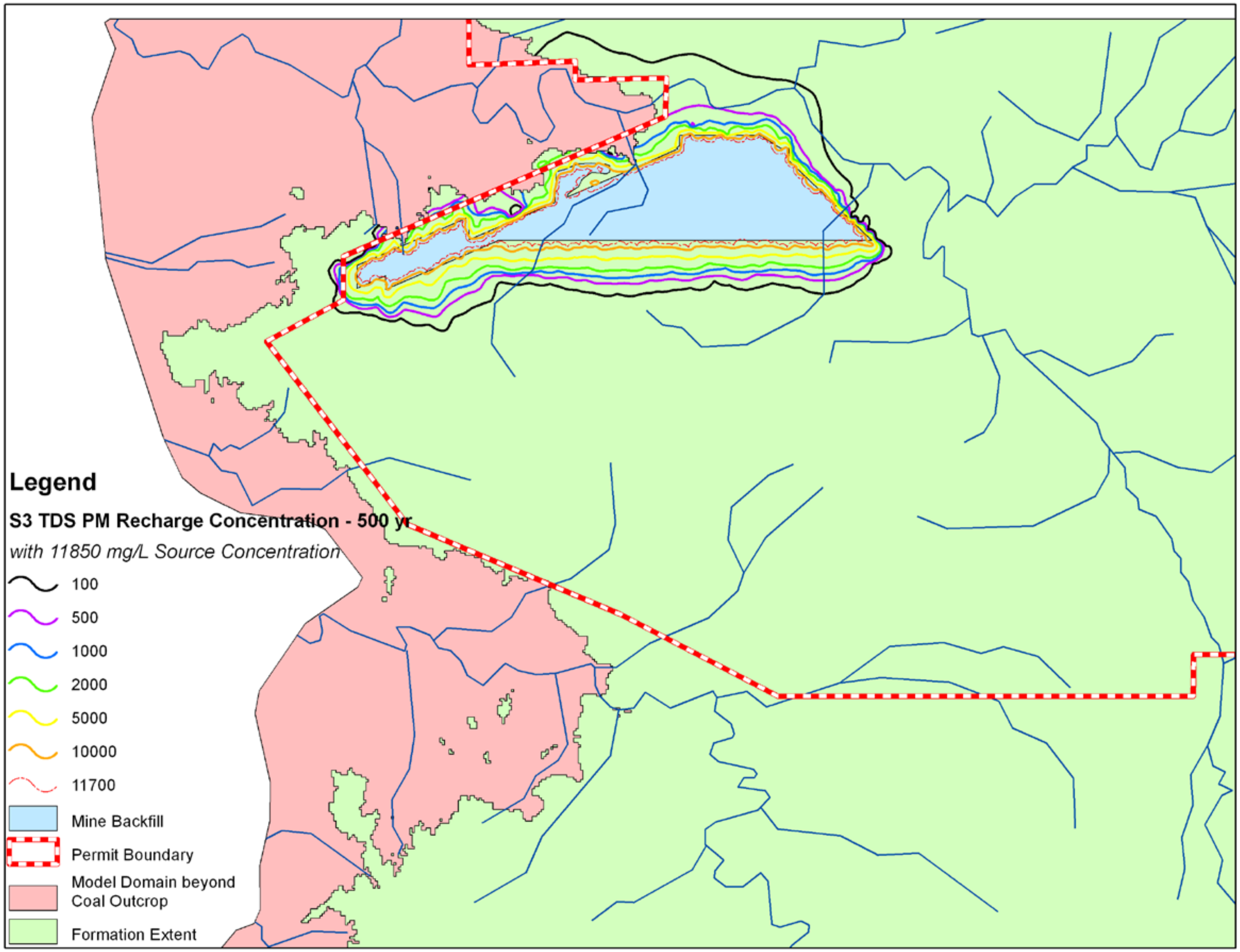
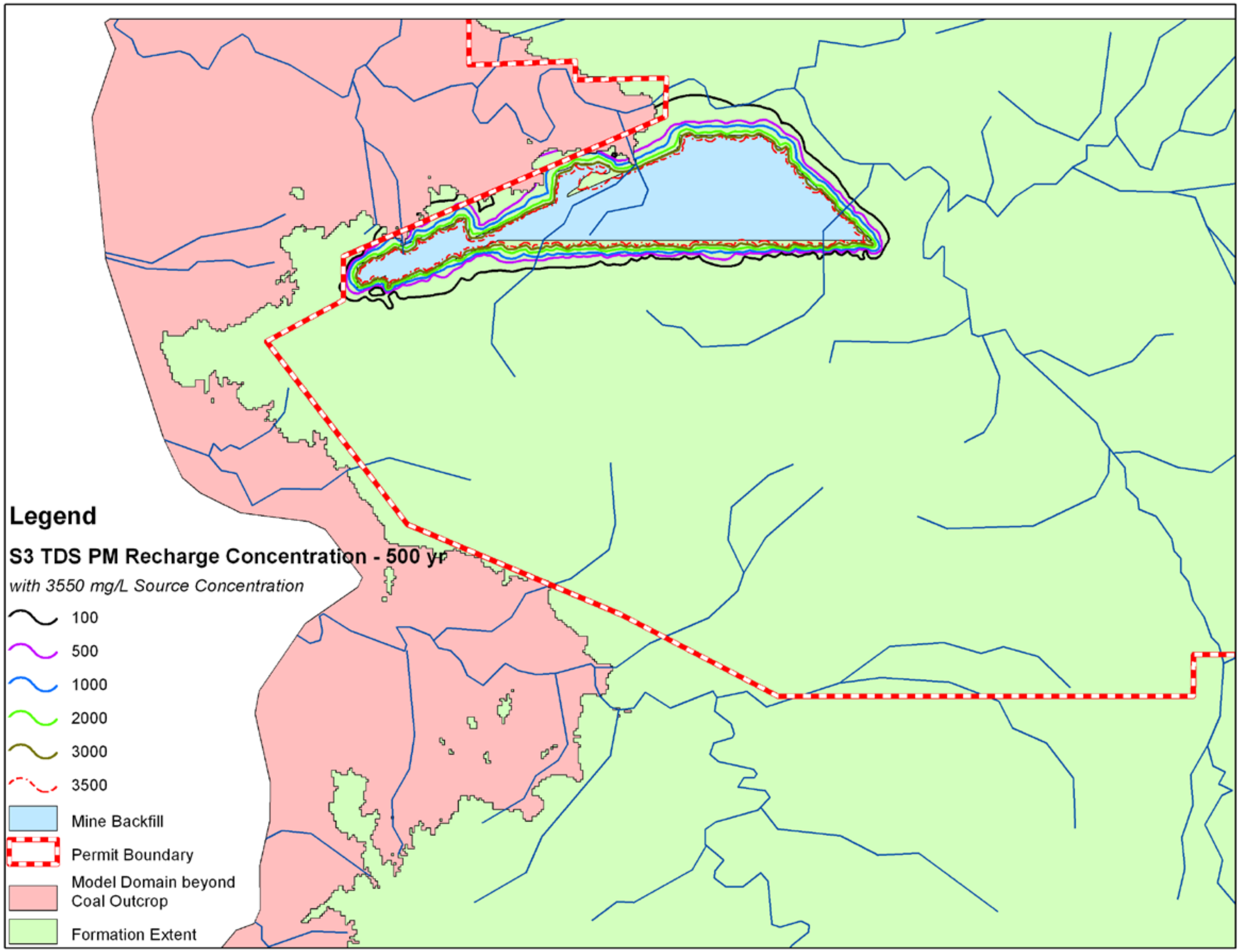


Figure 11-67. Scenario 5 TDS Transport in the No. 3 Coal after 500-years with Constant Source of 3,550 mg/l



The transport modeling simulations show that lateral migration of groundwater flow and constituents from the mine spoil within Area IV North is largely toward the alluvium and the topographic lows along Cottonwood Arroyo. However, there is also a large vertical component of flow and constituent migration from the mine spoils to the PCS, where the baseline TDS concentrations may be similar to or higher than the TDS concentrations in mine spoil.

The steady-state pre-mine calibrated model and the steady-state post-reclamation model were used to provide estimates of groundwater flow in the alluvium at the mouth of Cottonwood Arroyo, where the Cottonwood alluvium meets the Chaco River alluvium. Table 11-14k provides the model predictions of pre-mine and post-reclamation steady-state groundwater flow in the alluvium at the mouth of Cottonwood Arroyo. The increase in the steady state groundwater flow under post-reclamation conditions occurs as the result of the higher recharge rate estimated for post-reclamation conditions. Table 11-14k also provides the modeled TDS concentrations in the alluvium at the mouth of Cottonwood Arroyo after 500 years. The TDS results are shown for model scenarios listed in Table 11-14j.

Table 11-14k.

Modeled Result for Alluvium at Mouth of Cottonwood

	Post-mine model flow	**Pre-mine model flow**
Flow (ft^3/day)	**882**	**827**
Scenario from Table 11-14j	**Post-mine 500-yr concentration (mg/l)**	
1	**860**	
2	**160**	
3	**340**	
4	**210**	
5	**64**	

The results of the transport modeling scenarios shown in Figures 11-48 through 11-67 and in Table 11-14k indicate that modeled post-mining concentration of TDS from mine backfill along the Cottonwood Arroyo drainage is most sensitive to the specific storage and specific yield of the Fruitland Formation coals and interburden (Scenarios 1 and 3) and to the recharge in the mine backfill (Scenarios 2 and 3). The results also show that modeled TDS migration from the mine backfill is relatively insensitive to the hydraulic conductivity of the backfill (Scenarios 3 and 4).

It should also be noted that the modeled post-reclamation TDS concentrations do not include any contribution of TDS to the alluvial and PCS groundwater from outside the mine area. Transport modeling was performed to assess the fate of mine spoil water. It is apparent that spoil water from Area IV North will disperse laterally and vertically but that a major 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. Transport modeling has also demonstrated the large vertical component of groundwater flow and constituents from the mine backfill flow vertically to the PCS, where it will mix with groundwater in the PCS and disperse with components of flow laterally toward the topographic low along the outcrop, laterally toward the northeast in the direction of regional groundwater flow, and vertically into the Lewis Shale.

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. The estimates in Table 11-14l of the post-reclamation concentrations in the alluvium at the mouth of Cottonwood Arroyo were obtained by adding the estimated pre-mine constituent mass flux in the Cottonwood alluvium to the model-predicted post-reclamation constituent mass flux in the alluvium at the mouth of Cottonwood Arroyo, and dividing by the predicted post-reclamation groundwater flow in the alluvium at the mouth of Cottonwood Arroyo. These mixing calculations are expected to slightly overestimate the post-mine concentrations because the baseline mass flux includes the pre-mine mass flux contribution from all areas including the mine area. Thus, the calculated post-mine TDS concentration in the Cottonwood alluvium includes both the TDS contribution from the mine spoils along with the pre-mine TDS contribution from the Fruitland Formation for the mine area.

The median TDS concentration of 3,015 mg/L obtained from baseline monitoring of Cottonwood alluvial well QACW-2B located in the Cottonwood alluvium west and down gradient of the Permit Area was used to estimate the pre-mine constituent mass flux in the Cottonwood alluvium. The Table 11-14l estimates of post-mine TDS concentrations in the alluvium at the mouth of Cottonwood Arroyo were used to estimate the constituent mass flux in the alluvium at the mouth of Cottonwood Arroyo associated from the Area IV North mine spoil for each of the transport model scenarios.

Comparisons of the estimated post-reclamation concentrations in the alluvium at the mouth of Cottonwood with the baseline estimates in Table 11-14l show that the estimated changes in TDS concentrations in alluvium at the mouth of Cottonwood range from a decrease of 124 mg/l in Scenario 5 to an increase of 672 mg/l in Scenario 1. Scenario 4 represents the most likely case of flow parameters and the most conservative case of source concentration. In this scenario, the post-reclamation TDS concentration represents an increase of 22 mg/l over baseline estimates.

Table 11-14l.

Estimated Post-Reclamation TDS in Cottonwood Alluvium

	Flow (ft^3/day)	TDS (mg/l)	mass flux (kg/day)
Pre mine estimates	827	3015	70.61
Mine contribution (Scenario 1)	882	860	21.48
Mine contribution (Scenario 2)	882	160	4.00
Mine contribution (Scenario 3)	882	340	8.49
Mine contribution (Scenario 4)	882	210	5.24
Mine contribution (Scenario 5)	882	64	1.60
Estimated Cottonwood Alluvium (Scenario 1)	882	3687	92.08
Estimated Cottonwood Alluvium (Scenario 2)	882	2987	74.60
Estimated Cottonwood Alluvium (Scenario 3)	882	3167	79.10
Estimated Cottonwood Alluvium (Scenario 4)	882	3037	75.85
Estimated Cottonwood Alluvium (Scenario 5)	882	2891	72.20

Based on these results, slight changes in long-term post-reclamation TDS concentrations in the groundwater in the alluvium of Cottonwood Arroyo down gradient of the mine area may be expected.. Worst-case estimates based on upper bound source concentrations indicated TDS concentration increases on the order of 22%. The most likely case based on upper bound source concentrations (Scenario 4) estimates a TDS concentration increase of less than 1 %. 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. Furthermore, alluvial groundwater flows in Cottonwood are extremely low and vary with space and time. Baseline monitoring of the dug wells in the Cottonwood alluvium demonstrates groundwater in the alluvium is an unreliable supply, 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 boron and manganese may also increase in the spoils but are unlikely to exceed livestock use criteria. Upper- and lower-bound estimates from mixing calculations found TDS concentrations in the Cottonwood alluvium are likely to increase over the long-term but not sufficiently to materially impact the suitability of alluvial groundwater for livestock use.

11.6.2.5 Assessment of Impact on Adjacent Groundwater Users

Wells and springs located on or near the permit area are shown on Figure 6E-1 in Appendix 6-E. Wells and springs which could potentially be impacted by mining are located to the west, east, and north of the permit area. Wells and springs located to the south of the Permit Area cannot be impacted as the groundwater flow directions in the Fruitland Formation and the PCS are toward the northeast with localized flow toward the west near the mouth of the Cottonwood Arroyo.

Wells and springs are evaluated on a case by case basis to assess whether the quantity or quality of the water supply to the well could potentially be affected. Starting from the south, and moving counterclockwise, wells 70, 13-5-1, W-0345, and W-0344 (93) (Appendix 6-E) of Township 26N, Range 16W are non-BNCC wells located south and east of proposed mining in Area IV North. All four are alluvial, hand dug wells. They will not be affected as their source of water is derived from a formation geologically above those potentially impacted by mining (i.e., Fruitland Formation and PCS) in the alluvium.

Numbers 38 and 44 PCS water wells located nearly six miles east of Area III in Township 27N, Range 15W. These wells will not be affected by mining due to the distance from the mine. Well No. 38 was shown to have a total depth of 1,505 feet and completed in both the PCS and the Cliff House Sandstone. The depth of water in the well was listed at 470 feet below ground surface (bgs) and the water quality was poor with a TDS of 18,300 mg/l, a specific conductance of 28,900 uS/cm, and a chloride concentration of 11,000 mg/l. Nearby, Well No. 44 is shown to be completed in the PCS at a total depth of 804 feet. The depth of water was listed at 475 feet bgs and the quality was poor with a specific conductance of 25,600 uS/cm and a chloride concentration of 9,160 mg/l. The yield of this well was reported at 2-3 gpm. Poor water quality in the PCS has caused No. 38 to be abandoned and No. 44 to be classified unfit for human consumption. Well No. 46 is a 9-foot deep hand dug alluvial well located in Township 27N, Range 15W. The well is more than 4.5 miles from the mine. The alluvium at this location is up gradient of mining and will not be impacted. The stock well W-048 is west of #46 approximately one mile closer to the mine. There is no information about this well, but it is adjacent to a crop circle, which undoubtedly affects it far more than the mine. Wells No. 51 and 41 (Township 28N, Range 15W), are several miles east of the permit boundary, and both have been abandoned. One mile north is W-0147, a Navajo stock well for which there is no information.

The Navajo spring S-0767 is located more than 1.5 miles east of the reclaimed Doby Pit and downgradient of NAPI irrigation. Hydrologic influences from NAPI are substantially more likely than impacts from the mining operation. Two miles northeast of the spring is W-0146, a stock well, which is over 3 miles east and upgradient of the Bighan Pit. It is also located among several NAPI crop circles. The stock well W-0313 is located over one mile southeast and upgradient of the reclaimed Bitsui Pit.

Well No. 149 in the BAI survey was located in the southeast corner of Township 29N, Range 15W. This well was listed as Fruitland well PNM GT-2 installed by Public Service Company of New Mexico. Fruitland Well PNM GT-2 is an underground coal gasification test well that was installed by Public Service Company of New Mexico at a location north of the San Juan River and east of the San Juan Mine. This well was mapped at the wrong location and is not shown in Appendix 6-E.

Between the mining area and the San Juan River in Township 29N, Range 15W, there exist only four non-BNCC wells with associated beneficial uses (Wells No. W-0603, the Wesleyan Navajo Mission alluvial well, W-0593, and 146). Wells north of the San Juan River are not considered, as the San Juan River acts as an aquifer discharge point in this vicinity (Chapter 6). Well W-063 is a stock well with a windmill, for which there is no completion information. The alluvial Wesleyan Navajo Mission well (Well No. 147) is 19 feet deep. Well W-0593 is a stock well with a windmill, which may be the same as Well No. 146, an alluvial well, approximately 28 feet deep. Ownership and usage is unknown, but the well appears to be attached to a windmill. The quality and quantity of the groundwater in the San Juan River alluvium that supplies water for this well will not be affected by mining at Navajo Mine as demonstrated in 11.6.2.3.1. Springs No. 54 and 56 are owned by the Navajo Nation. It is unknown whether the springs are currently flowing. Spring No. 56 was reported to be issuing from the PCS at a location adjacent to the San Juan River alluvium. The TDS was reported at 624 mg/l which is acceptable for livestock use but exceeds the USEPA Drinking Water Criteria. This spring is located to the north and downgradient of Morgan Lake. This spring is located more than 2 miles northeast of BNCC's Navajo Mine North Facilities Area. It is unlikely that this spring could be affected by mining because Morgan Lake, which is the likely source of water for this spring, lies between the North Facilities Area and the spring. Spring No. 54 issues from a terrace. The TDS was reported at 703 mg/l which is acceptable for livestock use but exceeds the EPA Drinking Water Criteria. This spring does not appear to derive its water source from the Fruitland Formation because TDS concentrations are more than one order of magnitude lower than the TDS concentrations observed in Fruitland Formation wells located within several miles of this spring. Uses reported for both springs include domestic, stock, and/or irrigation.

G5 is an alluvial well located downgradient of Morgan Lake, and more than three miles from the lease boundary. This well and the nearby Little Geyser Spring (G9) are heavily influenced by the perennial flows from Morgan Lake, and from periodic recharge from flows along Chaco.

There are three stock wells west of the South Barber, Mason, and Neck Arroyo area on the Chaco River, W-0520 (G-3), W-0519 (13R-31, #17, G4), and W-0342. W-0519 is an alluvial well with a depth of 16 feet. There is no depth information on the other two. It is unlikely that these are affected by the mine, as they are located in a broad swath of Chaco River alluvium.

Well W-0618 (#35) in the alluvium of Cottonwood Arroyo west of the permit area is a collapsed well located near alluvial monitoring well QACW-2, which has usually been dry during baseline monitoring. QACW–2B (#126) completed in the alluvium of Cottonwood Arroyo west of the permit area is a dug well that has been used for stock water supply and is not owned by BNCC. This well is shown on Figure 6E-1 sheet 2 and Exhibit 11-166 and appears to correspond with BIA well No. 13-R-28A in the permit file at the Navajo Nation, Water Resource Management office in Fort Defiance, Arizona. The TDS and sulfate concentrations in the alluvium of Cottonwood Arroyo down gradient of mining are expected to increase by about 22% over a 500 year period following proposed mining within Area IV North. The increase in TDS in this well could be greater than estimated due to influences from Area III mining that were not included in the transport model. However, the quantity of water in the Cottonwood alluvium is limited and this well and several water monitoring wells in the alluvium are often dry.

Thus, within the permit area and adjacent area the only water supply wells or springs could be potentially affected by previous or proposed mining at Navajo Mine is well QACW–2B completed in the alluvium of Cottonwood Arroyo west of the permit area.

Further south, there are four alluvial wells along the Chaco River. Well 13-15-4 is 11 feet deep. No use is specified. It appears to be downgradient of the confluence of the Pinabete Arroyo with the Chaco River. It is only 1.5 miles from the permit area, but with the local groundwater gradient, is most likely to be influenced by the Chaco River. Well 45 is 8 feet deep, but further south and upgradient of the Pinabete-Chaco confluence. It is more than 2 miles west or northwest of the Navajo Mine lease boundary. There is no information about the depth of the other two alluvial wells, 13-AW (13T-513) (#58) and W-0691, but they are two miles west of Area IV South.

BNCC has water rights on the San Juan River, New Mexico Office of State Engineer Permit 2838, which can be used to offset any adverse impacts to the State of New Mexico and present users. These rights will be maintained throughout the mining operation and a period thereafter, for retirement, if required to any affected San Juan Basin water users. For temporary impacts to surface water users, BNCC may provide water to local permittees in tanks for livestock use in areas around the lease. Permanent impacts to surface water users may be mitigated by the construction of impoundments incorporated into the post-mining landscape (Chapter 12 Sections 12.11 Hydrologic Reclamation Plan and 12.3.4.1 Permanent Impoundments).

11.6.3 Assessment of Potential Surface Water Changes During Mining and Reclamation Operations

Minimization of impacts to the hydrologic balance are focused on reducing the disturbance footprint to the extent practical, limiting the amount of upgradient water commingled with disturbed area drainage, utilizing BMPs to limit migration of sediment during storm events, and containment or treatment of flows downgradient of the mine site. Hydrologic water management is integrated into mine planning. Stream buffer zones have been demarcated to limit disturbance in channel reaches unaffected by mining. Temporary diversions have been constructed to route upgradient flows around active mining pits into downgradient natural channels, when possible. In other situations, upgradient impoundments have been established to contain upstream water runoff.

There will be periods when precipitation runoff from the drainages that normally flowed across the areas intersected by mining will not make it to the Chaco River during operations, but will either be intercepted by the mine pit or captured in temporary pit protection ponds (highwall impoundments) 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. Once reclamation is completed within the mining area, precipitation runoff from these reclaimed areas will flow through channels in the reconstructed topography and then to the Chaco River. Precipitation runoff from reclaimed areas may be reduced somewhat from pre-mine levels due to any of the following factors: lower slopes, enhanced vegetative growth, engineered traditional or geomorphic drainage designs, and the use of sediment-control BMPs that operate to retain water in the reclaimed areas reducing storm-water runoff to the channels.

There is a direct relationship between the maximum peak flows and total runoff volume and sediment yield; the management of water flow through the site during operations is designed to reduce peak sediment concentrations through the use of storm water management plans and the containment of sediment associated with storm flows. Post-reclamation water management is focused towards establishment of a stable post-mine topography enhanced by vegetative stabilization which will decrease storm water runoff and sediment yield. The post-mine topography is designed to replicate the approximate original contour.

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 to model peak flows, yield and sediment concentrations. Key assumptions on soil and cover were derived from soil and vegetation mapping at the site (Tables 11-15, 11-16, 11-16A, 11-16B, 11-16C, and 11-16D).

11.6.3.1 Stream Buffer Zone Protection

Six major tributaries to the Chaco River have been identified within the Navajo Mine permit area and are discussed in Chapter 7 Section 7.2, and shown on Exhibits 7-3, 7-4, and 7-4C. The six drainages are: Chinde Arroyo, Hosteen Wash, Barber Wash, Neck Arroyo, Lowe Arroyo, and Cottonwood Arroyo. Mining or support activities are projected to occur in all the listed drainages. Mining will not occur in the Neck Arroyo, however, transportation roads and facilities are present.

Diversions are employed to route water around the mining area to minimize impacts to the hydrologic balance. North, in Area I, the Doby North and Dodge diversions route water away from the pit. Further south in Area II, the Chinde and Hosteen diversions are employed. Area III diversions include the North Fork of Cottonwood Arroyo (Section 11.5.5.3).

Those areas identified as stream buffer zones (Exhibits 11-9 through 11-11) outside the approved mining disturbance (see Chapter 12, Exhibits 12-1, 12-2, and 12-3 for scheduled mining disturbance) will not be disturbed by surface mining activities (30 CFR 816.57(b)) and will be marked as described in Section 11.1.1. The remaining drainages will not be marked since none of the sub-watersheds within the identified drainages meet the definition of buffer zone stream.

11.6.3.2 Water Quality Effects during Operations

Potential surface water quality changes that could occur during mining and reclamation operations include the generation of additional sediment. BMPs at the site include the use of perimeter berms and containment features. Topdressing and regolith stockpiles are protected by berms to minimize migration of solids into undisturbed areas. Typical berm cross-sections are shown in Figure 11-9. The coal stockpiles will be partially enclosed and surrounded by containment berms to minimize migration of coal fines (Figure 11-7), and divert surface runoff into either directly into a sediment pond or into a ditch or channel that leads to a sediment pond. In areas subject to containment berms, such as topdressing stockpiles, berms will be able to contain the runoff from a 10-year 6-hour (10-yr 6-hr) storm. See Section 11.5.4.5 for further discussion on containment berms.

When runoff does occur, the newly exposed overburden, interburden, and coals and mine spoils may result in increases in TDS, sulfate, iron, and manganese in surface runoff from these disturbed areas. The analyses of overburden and interburden materials presented in Tables 5-2, Tables 11-14, 11-14b, 11-14c, and Appendix 11-K show that these materials are not acid forming. The water quality of newly exposed strata and mine spoils is best characterized by the SPLP test results for Navajo Mine spoils Table 11-14f. The spoil leachate results presented in Table 11-14f describe TDS and sulfate concentrations of 1,200 mg/l and 670 mg/l, respectively. These concentrations are above the median concentrations observed in surface water baseline samples but are well below the highest concentrations observed in the baseline surface water quality samples (Table 7-7). Surface runoff from disturbed areas will be retained by BMPs and is unlikely to reach the downgradient tributaries to Chaco or the Chaco River itself except during extreme precipitation events that exceed the design requirements of the structures. Trace constituents in SPLP spoil leachate are below detection limits except for fluoride, boron, and barium. These parameters are well below their corresponding Navajo Nation livestock and wildlife use criteria (NNEPA WQP, 2008). Manganese was also detected, but has no livestock and wildlife use criterion (Table 11-14f).

There is the potential for increases in salinity in water that might be flushed from sediment ponds and containment berms during large storm events that produce spillway overflows. However, any increased salinity in water from ponds or berms is unlikely to produce a measurable change in the salinity of flows in tributaries to the Chaco River due to dilution from high flows in the drainages during the storm events.

Motor fuel storage and equipment maintenance will be provided at the industrial facilities areas shown on Exhibits 11-9 through 11-11. Nevertheless, equipment repair may on occasion, need to be performed within the active mining or reclamation areas. BNCC 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 a spill, should it occur, and lists procedures for safely disposing of any contaminated materials. Appendix 11-HH includes hydrologic data for the land farm used to treat materials contaminated with petroleum hydrocarbons.

Federal and state or tribal water quality standards will be met during surface coal mining and reclamation operations at the applicable compliance point, whether that is the furthest down gradient sediment pond or the permit boundary. This is achieved through the use of perimeter berms and sediment ponds to contain or treat runoff within the permit area. The Navajo Nation Environmental Protection Agency (NNEPA) has identified four uses of drainages within the permit area, including livestock and wildlife watering, aquatic habitat, fish consumption and secondary human contact (NNEPA WQP, 2008).

In conclusion, the water and sediment control measures, as outlined in Section 11.5.4, not only prevent additional contributions of sediment but also serve to contain mine water that may have higher concentrations of TDS and sulfate than in the baseline flow in the tributaries to Chaco or in the Chaco River. Thus, these measures also serve to minimize potential changes in water quality of receiving streams outside the permit area.

11.6.3.3 Runoff and Erosion during Mining and Reclamation Operations

Mining and reclamation operations are designed to minimize impacts to undisturbed upland flows through the mining operation and to contain or treat all sediment-laden waters that have interacted with disturbed area runoff. BNCC has engineered the mine plan and supporting facilities to limit effects to the hydrologic balance and surface water quality. Sediment ponds have been constructed downgradient of mining operation disturbances to store or treat and release stormwater runoff. A summary of site sediment ponds is compiled on Table 11-5, with references to permit design information. Additionally, upland flows are routed around mining pits through diversions or impounded in highwall impoundments. Typically these features are located east or south of the mining area.

Diversions associated with Area I include Doby North and Dodge. Further south in Area II are the Chinde and Hosteen diversions. Area III diversions include the North Fork of Cottonwood (Exhibits 11-13E).

Appendix 11-N provides conceptual engineering design data. Designs for the Chinde Diversion crossing are found in Appendix 11-JJ. Engineering designs for the North Fork Cottonwood Diversion are found in Exhibits 11-74, -74A through 74E. The diversion designs are described in Appendix 11-QQ.

Highwall impoundments have also been designed and constructed to prevent water from entering active mining pits. Locations are shown on Exhibits 11-13B through 11-13E. Appendix 11-II includes pre-approved designs as highwall impoundments that do not require approval prior to construction. As-built information is submitted and retained in Appendix 11-II. Highwall impoundment design includes a hazard assessment to ensure the safety of the miners and structures within the pit (Table 11-7). Impoundments are designed to contain the 2-yr 6-hr storm at a minimum, and the 100-yr 6-hr storm whenever possible. It should be noted that water from highwall impoundments will never leave the permit area as surface discharge, as discharged water will be intercepted by the pits. A number of upland ponds protecting the various mine areas are included in Table 11-7.

The PHC analysis includes a characterization and evaluation of reclaimed channels and surface topography. The post-mining topography has been engineered to be stable over time, through the reclamation and establishment of a final surface configuration which includes drainages. From a hydrologic perspective, the post-mining topography is evaluated on the basis of adequate drainage density.

Drainage density is an integrated measure of drainage basin morphology. Drainage density is the length of stream channels per unit area within a drainage basin. The restoration of post-mine drainage networks within the range of pre-mine drainage densities and configurations or regional norms will ensure that pre-mine conditions are achieved.

Drainage densities are calculated by measuring the total stream length in miles and dividing that length by the drainage area in square miles. Pre-mining and post-mining stream lengths were measured for the total drainage area of each stream as well as the area within the lease boundary only. U.S.G.S. 7.5 minute quadrangles were used to determine the pre-mining drainage densities. Post-mining drainage densities were determined from the 1:6000 scale final surface configuration topography maps provided in Chapter 12.

Peak flow, runoff volume, sediment yield, and peak sediment concentrations were predicted for both pre- and post-mine drainages for Chinde Arroyo, Hosteen Wash, Barber Wash, South Barber Drainage, Neck Arroyo, Lowe Arroyo, and Cottonwood Arroyo and the tributaries to the Chaco River that are projected to be disturbed. These estimates were developed using the SEDCAD modeling technique as described in Chapter 7. Pre-mine and undisturbed runoff curve numbers were developed from the soil cover complexes within each drainage. For areas disturbed by mining, an analysis of the available topdressing types and quantities was made to determine an appropriate curve number (Tables 11-15 and 11-16 through 11-16d). This analysis indicated that, as a whole, the available topdressing material has a curve number close to that of the Shiprock Soil Complex "Sk" in Tables 11-15 and 11-16 through 11-16d. The curve number of reclaimed areas was based on this soil type.

The Chinde Arroyo and Cottonwood Arroyo are also impacted by the activities of the NAPI located hydraulically up gradient from the mine. These impacts include direct discharges of water from irrigation canals and indirect discharges from irrigation return flows. The impacts are similar to both streams with the exception that the Chinde is a perennial stream.

TABLE 11-15

TOPDRESSING TYPES AND QUANTITIES (1)

Soil Mapping Unit Symbol	Soil Mapping Units	Percent of Map Unit (3)	Soil volume (cubic yards)					Title of SCS Soil Survey (4)	Hydrologic Group
			Area I	Area II	Area III	Area IV North	Total		
Ba	Badland	-	0	0	0	0	0		
Bb (2)	Bacobi and	39	37,061	20,523	201,579	342,305	601,468	1	C
	Monierco soils	61	57,967	32,101	315,290	535,401	940,759	2	D
Bc	Blancot	-	0	0	664,484	0	664,484	2	B
Bh	Blancot, very hard	-	0	0	307,680	0	307,680	2	B
Fa	Faro and Persayo Soils	-	8,024	83,158	0	161,922	253,104	2	D/D
Gr	Grieta	-	0	0	0	69,104	69,104	3	B
Jc	Jocity -Gilco	-	503,634	183,596	481,270	1,525,313	2,693,813	3	B/B
Jh	Jocity, very hard	-	0	0	103,722	46,339	150,061	3	B
Ma	Mack	-	0	0	1,433,038	176,992	1,610,030	5	C
Mn	Mayqueen	-	295,981	55,176	0	23,851	375,008	2	B
Ms	Mayqueen -Shiprock	-	421,971	341,951	614,672	333,565	1,712,159	2	B
Mv	Mayqueen -Shiprock, very hard	-	85,805	0	61,024	0	146,829	2	B
Na	Nakai	-	0	0	0	53,010	53,010	4	B
Nt	Natrargids	-	0	6,628	0	0	6,628	2	D
Nv	Natrargids, overblown	-	2,159	82,861	97,028	218,490	400,538	2	D
Ra	Razito	-	599,753	521,804	458,595	311,260	1,891,412	5	A
Rh	Razito. very hard	-	73,893	0	21,089	196,707	291,689	5	A
Rl	Redlands Variant	-	19,683	33,505	945,193	331,678	1,330,059	5	B
Rv	Redlands Variant, very hard	-	0	0	105,452	61,901	167,353	5	B
Sc	Shiprock	-	192,636	540,865	868,130	160,006	1,761,637	2	B
Sh	Shiprock, very hard	-	22,430	21,812	67,523	143,239	255,004	2	B
Sl	Shiprock -Blancot	-	278,724	0	23,813	0	302,537	2	B/B
Sv	Shiprock Variant	-	0	0	416,510	70,420	486,930	2	B
Sz	Stumble	-	0	0	15,596	105,082	120,678	2	A
Ta	Trail	-	0	23,210	0	0	23,210	5	A
Th	Trail. very hard	-	0	16,144	0	4,538	20,682	5	A
TOTAL:			2,599,721	1,963,334	7,201,688	4,871,123	16,635,866		

(1) This information was generated from Chapter 8 Soil Resources, Approved PAP for Navajo Mine.

(2) Undifferentiated groups and complex SOil mapping units were delineated if the major components had contrasting hydrologic groups.

(3) Percentages of each major mapping unit component were derived from Chapter 8.5.2 Soil Mapping Unit Descriptions, Approved PAP for Navajo Mine.

(4) 1 = Soil Survey Coconino County, Arizona; 2= Soil Survey San Juan County, New Mexico, Eastern Part; 3= Soil Survey Sandoval County, New Mexico; 4= Soil Survey San Juan County, Utah; 5= Soil Survey Shiprock Area, Parts Of San Juan County, New Mexico and Apache County, Arizona.

Table 11-16

Land Types and Curve Numbers

Land Use/Condition (1)	Curve Numbers for Hydrologic Groups (5)			
	A	B	C	D
Reclaimed Lands (2)	65	78	86	91
Undisturbed Lands (3)	65	78	86	91
NAPI Cultivated lands (4)	67	78	85	89

(1) Land use/conditions and the associated curve numbers were taken from Ms. Pamela J. Schwab and Dr. Richard Warner (1987), "SEDCAD+ User's Manual", Civil Software Design, Table 5.3, pages 110-112.

(2) From reference (1) the land use/condition for reclaimed lands is between "Herbaceous" and "Desert Shrub", each with poor hydrologic condition. The curve numbers were determined by interpolating between the curve numbers associated with the two land use/conditions.

(3) The type of land use/condition for undisturbed areas will be identical to reclaimed lands (same curve numbers).

(4) The type of land use/conditions selected from reference (1) is "Row crops, Straight row" with good hydrologic conditions.

(5) The hydrologic group classification for the soil types will be obtained from the NRCS soil surveys.

TABLE 11-16A

TOPDRESSING TYPE, QUANTITIES, AND CURVE NUMBERS FOR AREA I

Soil Mapping Unit Symbol	Soil Mapping Unit	Volume (cu yds)	Percent (%)	Hydrologic Group (2)	Curve Number (3)	Weighted Value
Bb (1)	Bacobi and	37,061	1.43%	C	86	1.23
-	Monierco soils	57,967	2.23%	D	91	2.03
Bc	Blancot	0	0.00%	B	78	0.00
Bh	Blancot, very hard	0	0.00%	B	78	0.00
Fa	Faro and Persayo Soils	8,024	0.31%	D/D	91	0.28
Gr	Grieta	0	0.00%	B	78	0.00
Jc	Jocity -Gilco	503,634	19.37%	B/B	78	15.11
Jh	Jocity, very hard	0	0.00%	B	78	0.00
Ma	Mack	0	0.00%	C	86	0.00
Mn	Mayqueen	295,981	11.39%	B	78	8.88
Ms	Mayqueen -Shiprock	421,971	16.23%	B	78	12.66
Mv	Mayqueen -Shiprock, very hard	85,805	3.30%	B	78	2.57
Na	Nakai	0	0.00%	B	78	0.00
Nt	Natrargids	0	0.00%	D	91	0.00
Nv	Natrargids, overblown	2,159	0.08%	D	91	0.08
Ra	Razito	599,753	23.07%	A	65	15.00
Rh	Razito. very hard	73,893	2.84%	A	65	1.85
Rl	Redlands Variant	19,683	0.76%	B	78	0.59
Rv	Redlands Variant, very hard	0	0.00%	B	78	0.00
Sc	Shiprock	192,636	7.41%	B	78	5.78
Sh	Shiprock, very hard	22,430	0.86%	B	78	0.67
Sl	Shiprock -Blancot	278,724	10.72%	B/B	78	8.36
Sv	Shiprock Variant	0	0.00%	B	78	0.00
Sz	Stumble	0	0.00%	A	65	0.00
Ta	Trail	0	0.00%	A	65	0.00
Th	Trail. very hard	0	0.00%	A	65	0.00
Totals		2,599,721	100.00%			75.09

(1) Undifferentiated groups and complex soil mapping units were delineated if the major components had contrasting hydrologic groups.
(2) Hydrologic groups were taken from SCS soil surveys, see Table 11-15 for the respective location and title of each survey .

(3) Curve number associated with the hydrological group classification was taken from Table 11-16 (reclaimed).

TABLE 11-16B

TOPDRESSING TYPE, QUANTITIES, AND CURVE NUMBERS FOR AREA II

Soil Mapping Unit Symbol	Soil Mapping Unit	Volume (cu yds)	Percent (%)	Hydrologic Group (2)	Curve Number (3)	Weighted Value
Bb (1)	Bacobi and	20,523	1.05%	C	86	0.90
-	Monierco soils	32,101	1.64%	D	91	1.49
Bc	Blancot	0	0.00%	B	78	0.00
Bh	Blancot, very hard	0	0.00%	B	78	0.00
Fa	Faro and Persayo Soils	83,158	4.24%	D/D	91	3.85
Gr	Grieta	0	0.00%	B	78	0.00
Jc	Jocity -Gilco	183,596	9.35%	B/B	78	7.29
Jh	Jocity, very hard	0	0.00%	B	78	0.00
Ma	Mack	0	0.00%	C	86	0.00
Mn	Mayqueen	55,176	2.81%	B	78	2.19
Ms	Mayqueen -Shiprock	341,951	17.42%	B	78	13.59
Mv	Mayqueen -Shiprock, very hard	0	0.00%	B	78	0.00
Na	Nakai	0	0.00%	B	78	0.00
Nt	Natrargids	6,628	0.34%	D	91	0.31
Nv	Natrargids, overblown	82,861	4.22%	D	91	3.84
Ra	Razito	521,804	26.58%	A	65	17.28
Rh	Razito. very hard	0	0.00%	A	65	0.00
Rl	Redlands Variant	33,505	1.71%	B	78	1.33
Rv	Redlands Variant, very hard	0	0.00%	B	78	0.00
Sc	Shiprock	540,865	27.55%	B	78	21.49
Sh	Shiprock, very hard	21,812	1.11%	B	78	0.87
Sl	Shiprock -Blancot	0	0.00%	B/B	78	0.00
Sv	Shiprock Variant	0	0.00%	B	78	0.00
Sz	Stumble	0	0.00%	A	65	0.00
Ta	Trail	23,210	1.18%	A	65	0.77
Th	Trail. very hard	16,144	0.82%	A	65	0.53
Totals		1,963,334	100.00%			75.72

(1) Undifferentiated groups and complex soil mapping units were delineated if the major components had contrasting hydrologic groups.
(2) Hydrologic groups were taken from SCS soil surveys, see Table 11-15 for the respective location and title of each survey .

(3) Curve number associated with the hydrological group classification was taken from Table 11-16 (reclaimed).

TABLE 11-16C

TOPDRESSING TYPE, QUANTITIES, AND CURVE NUMBERS FOR AREA III

Soil Mapping Unit Symbol	Soil Mapping Unit	Volume (cu yds)	Percent (%)	Hydrologic Group (2)	Curve Number (3)	Weighted Value
Bb (1)	Bacobi and	201,579	2.80%	C	86	2.41
-	Monierco soils	315,290	4.38%	D	91	3.98
Bc	Blancot	664,484	9.23%	B	78	7.20
Bh	Blancot, very hard	307,680	4.27%	B	78	3.33
Fa	Faro and Persayo Soils	0	0.00%	D/D	91	0.00
Gr	Grieta	0	0.00%	B	78	0.00
Jc	Jocity -Gilco	481,270	6.68%	B/B	78	5.21
Jh	Jocity, very hard	103,722	1.44%	B	78	1.12
Ma	Mack	1,433,038	19.90%	C	86	17.11
Mn	Mayqueen	0	0.00%	B	78	0.00
Ms	Mayqueen -Shiprock	614,672	8.54%	B	78	6.66
Mv	Mayqueen -Shiprock, very hard	61,024	0.85%	B	78	0.66
Na	Nakai	0	0.00%	B	78	0.00
Nt	Natrargids	0	0.00%	D	91	0.00
Nv	Natrargids, overblown	97,028	1.35%	D	91	1.23
Ra	Razito	458,595	6.37%	A	65	4.14
Rh	Razito. very hard	21,089	0.29%	A	65	0.19
Rl	Redlands Variant	945,193	13.12%	B	78	10.24
Rv	Redlands Variant, very hard	105,452	1.46%	B	78	1.14
Sc	Shiprock	868,130	12.05%	B	78	9.40
Sh	Shiprock, very hard	67,523	0.94%	B	78	0.73
Sl	Shiprock -Blancot	23,813	0.33%	B/B	78	0.26
Sv	Shiprock Variant	416,510	5.78%	B	78	4.51
Sz	Stumble	15,596	0.22%	A	65	0.14
Ta	Trail	0	0.00%	A	65	0.00
Th	Trail. very hard	0	0.00%	A	65	0.00
Totals		7,201,688	100.00%			79.67

(1) Undifferentiated groups and complex soil mapping units were delineated if the major components had contrasting hydrologic groups.
(2) Hydrologic groups were taken from SCS soil surveys, see Table 11-15 for the respective location and title of each survey .

(3) Curve number associated with the hydrological group classification was taken from Table 11-16 (reclaimed).

TABLE 11-16D

TOPDRESSING TYPE, QUANTITIES, AND CURVE NUMBERS FOR AREA IV NORTH

Soil Mapping Unit Symbol	Soil Mapping Unit	Volume (cu yds)	Percent (%)	Hydrologic Group (2)	Curve Number (3)	Weighted Value
Bb (1)	Bacobi and	342,305	7.03%	C	86	6.04
-	Monierco soils	535,401	10.99%	D	91	10.00
Bc	Blancot	0	0.00%	B	78	0.00
Bh	Blancot, very hard	0	0.00%	B	78	0.00
Fa	Faro and Persayo Soils	161,922	3.32%	D/D	91	3.02
Gr	Grieta	69,104	1.42%	B	78	1.11
Jc	Jocity -Gilco	1,525,313	31.31%	B/B	78	24.42
Jh	Jocity, very hard	46,339	0.95%	B	78	0.74
Ma	Mack	176,992	3.63%	C	86	3.12
Mn	Mayqueen	23,851	0.49%	B	78	0.38
Ms	Mayqueen -Shiprock	333,565	6.85%	B	78	5.34
Mv	Mayqueen -Shiprock, very hard	0	0.00%	B	78	0.00
Na	Nakai	53,010	1.09%	B	78	0.85
Nt	Natrargids	0	0.00%	D	91	0.00
Nv	Natrargids, overblown	218,490	4.49%	D	91	4.08
Ra	Razito	311,260	6.39%	A	65	4.15
Rh	Razito. very hard	196,707	4.04%	A	65	2.62
Rl	Redlands Variant	331,678	6.81%	B	78	5.31
Rv	Redlands Variant, very hard	61,901	1.27%	B	78	0.99
Sc	Shiprock	160,006	3.28%	B	78	2.56
Sh	Shiprock, very hard	143,239	2.94%	B	78	2.29
Sl	Shiprock -Blancot	0	0.00%	B/B	78	0.00
Sv	Shiprock Variant	70,420	1.45%	B	78	1.13
Sz	Stumble	105,082	2.16%	A	65	1.40
Ta	Trail	0	0.00%	A	65	0.00
Th	Trail. very hard	4,538	0.09%	A	65	0.06
Totals		4,871,123	100.00%			79.65

(1) Undifferentiated groups and complex soil mapping units were delineated if the major components had contrasting hydrologic groups.
(2) Hydrologic groups were taken from SCS soil surveys, see Table 11-15 for the respective location and title of each survey .

(3) Curve number associated with the hydrological group classification was taken from Table 11-16 (reclaimed).

NAPI direct discharges are a result of an over supply of water in the canal that is released directly to the wash. NAPI discharge events for both streams are highly variable, occur quickly, and can last up to 12 hours causing significant erosion and sediment transport in the channel. The indirect NAPI related discharges are a result of return flows to the washes caused by the infiltrating irrigation water. The irrigation return waters have changed the Chinde Arroyo into a perennial stream with a base flow containing elevated dissolved solids concentrations from irrigation return waters leaching the unconfined surface formations. The Cottonwood Arroyo is not impacted by perennial flows but increased mineralization is deposited on the stream banks as a result of seeps in the upper reaches that are carried down stream during precipitation flow events. The impacts of the NAPI activities on the baseline hydrologic balance of the Cottonwood Arroyo will be highly variable increases in the flow, discharge, and water quality concentrations of the channel's hydrologic balance. Moreover, these impacts increase the already highly variable hydrologic balance and further decrease the potential for post mining changes to the hydrologic balance as a result of mining. Quantitative data to characterize the NAPI impacts to these drainages is found in Section 11.6.3.2.2.1 and Appendix 11-OO and is also being collected as part of the surface water monitoring plan.

Specific probable hydrologic consequences for each major tributary to the Chaco River are described by watershed in the following sections. Channels are listed from north to south within the permit area.

11.6.3.3.1 Chinde Arroyo

The present watershed area of Chinde Arroyo is about 42.4 square miles (sq mile) (27,130 acres). An area of additional 11 square miles does not contribute to the present Chinde watershed as it is diverted by NIIP's Ojo Amarillo canal into Cottonwood Arroyo. About 4.86 square miles of the Chinde Arroyo drainage basin is disturbed by mining activities (Table 7-9). The post-mining Chinde Arroyo watershed increases in size by 1.7 sq miles (1,124 acres) primarily because of changes in the drainage divide between Hosteen Wash and Chinde Arroyo, and the drainage divide between Dodge Diversion and Chinde Arroyo.

The pre-mining drainage density of Chinde Arroyo was estimated to be 1.4 miles/sq mile for the entire drainage area and 2.8 miles/sq mile for the area disturbed by mining. Higher drainage density within the mine area reflects the greater relief in this area. Post-mining drainage density for Chinde Arroyo is 4.7 miles/sq mile over the area disturbed by mining. Both pre- and post-mining drainage densities appear to be relatively low. However, the calculated drainage density is dependent upon the criteria for measuring drainage length. The criterion used in this analysis was to include only stream channels identified on the topographic maps. Thus, conservatively, contour crenulations associated with badlands topography did not enter into the drainage density measurement, as they reflect an unstable geomorphic regime.

These results indicate a higher post-mining drainage density for the area disturbed by mining. This higher drainage density will be adequate to prevent gullies forming in light of the lower relief associated with the post-mining surface. Final surface configuration designs were developed in Chapter 12 (see Section 12.3, Exhibits 12-5A, 12-6A, and 12-6B). For design of reclaimed channels, see Section 11.6.5.

The largest hydrologic change to Chinde Arroyo is in the Doby reclamation area to the north, where the westward drainages from the off lease undisturbed surface are diverted towards the south via a post-mine channel (Doby North Channel) that runs north to south along the eastern lease boundary. The pre-mine topography had no major channel; the surface sloped down towards the west with primarily sheet flow drainages and some small channels. The post-mine channel also collects surface runoff from a portion of the reclaimed surface to the west and diverts the flow into a tributary of the Chinde Diversion. Refer to Exhibit 11-76A and 12-5A for the location and alignment of the post-mine channel.

Comparison of SEDCAD predictions for pre- (see Chapter 7, Appendix 7-G) and post-mining (see Chapter 11, Appendix 11-BB) flows and sedimentology from a 10-yr 6-hr event are provided in Table 11-17. Sediment yields for the 10-yr 6-hr event at the downstream outlet (Structure 24) are predicted to decline, despite an increase of 1,124 acres in watershed size post-mining, from a pre-mining yield of 8,657 tons to a post-mining yield of 8,159 tons. The predicted decreases in sediment yield are due to the lower slopes and better vegetation cover on reclaimed areas.

The peak flow resulting from a 10-yr 6-hr precipitation event was predicted to decrease from a pre-mining estimate of 715 cubic feet per second (cfs) to a post-mining estimate of 705 cfs for Chinde Arroyo below the lease boundary (Structure 24). The runoff volume was predicted to decline from 502 acre-feet, pre-mining, to 488 acre-feet, post-mining. The post-mining SEDCAD modeling for the 10-yr 6-hr event indicates that although the total sediment is less than the pre-mine, the peak sediment concentration (mg/l) and peak settleable concentration (milliliters per liter or ml/l) increased following mining. The peak sediment concentration increased from 50,387 mg/l to 77,099 mg/l and the peak settleable concentration from 4.16 ml/l to 13.24 ml/l.

Baseline water quality in Chinde Arroyo indicates that TDS, total iron, total manganese, and sulfate concentrations usually exceed drinking water standards, but the average water quality appears to be suitable for livestock watering (see Chapter 7, Table 7-7). Maximum values associated with baseline water quality at CD-1A, the upstream Chinde monitoring site, exceed the Navajo Nation's livestock watering standards for sulfate, and selenium for one of the 93 samples collected between 1999 and 2010. The water quality at CD-1 exceeded the fluoride livestock watering standard of 2.0 mg/l 26 times. Secondary drinking water standards for TDS, fluoride, sulfate, total iron, and total manganese were also exceeded. Sulfate and total iron concentrations exceed the standards more than 50 percent of the samples. The maximum selenium concentration reported exceeded the 0.033 mg/l acute aquatic life standard and the 0.002 mg/l chronic aquatic life standard. This site is influenced by return flows from the NAPI fields upstream which have produced perennial flows in the Chinde Arroyo.

Downstream, at CD-2A, the comparisons of water quality with the standards were similar to the observations described for CD-1A. When contrasting the upstream and downstream sites, average electrical conductivity, TDS, sulfate, and chloride are elevated downstream compared with the upstream samples. Average TSS, total iron, dissolved manganese, fluoride, and boron levels are often lower downstream at CD-2A. In general, it appears that selenium is approximately the same upstream and downstream.

Post-mining concentrations of sulfate, iron, manganese, and TDS parameters may actually decrease slightly, due to more favorable vegetative stabilization associated with better distribution of topdressing over the disturbed areas and lower concentrations of sediment in stream flows. However, any change would be marginal and chemical quality of surface water following mining would be expected to approximate pre-mining conditions. Acid forming or toxic materials are not present in the drainage.

TABLE 11-17

COMPARISON OF PRE- & POSTMINING AREAS, PEAK FLOWS AND SEDIMENT YIELDS
CHINDE ARROYO
10-YEAR, 6-HOUR PRECIPITATION EVENT

Sedcad 4.0 Watershed Designation		**Pre-Mine**				**Post-Mine**				**Difference From Pre-Mine**			
Pre	Post	Area	Peak Flow (cfs)	Sediment (tons)	Yield (tons/acre)	Area	Peak Flow (cfs)	Sediment (tons)	Yield (tons/acre)	Area	Peak Flow (cfs)	Sediment (tons)	Yield (tons/acre)
S24	S24	27,130	715	8,657	0.3	28,254	705	8,159	0.3	1,124	-10	-498	0.0
S17 SW1	S17 SW1	1,100	34	141	0.1	824	40	66	0.1	-276	6	-75	0.0
S15 SW1	S15 SW1	595	43	92	0.2	600	26	45	0.1	5	-17	-47	-0.1
S11	S27	446	172	1,380	3.1	1,726	332	2,757	1.6	1,280	160	1,377	-1.5
S18 SW1	S18 SW1	146	10	24	0.2	120	10	15	0.1	-26	0	-9	0.0

11.6.3.3.1.1 Surface Water Gain/Loss in Chinde Arroyo

The results of a gain/loss study conducted from April 1999 through March 2000 are reported in Appendix 11-OO, Chinde Wash Surface Water Gain/Loss Report. The synoptic, NAPI, and continuous surface water monitoring data collected during the monitoring year for Chinde Arroyo finds that during base flow and NAPI operational spills there is a net loss of surface water from the NAPI discharge point to Navajo Mine monitoring station CD-2A, a distance of nine miles. For example, on April 18, 1999, flow volume declined from 8.0 acre-feet at CD-1A to 0.5 acre-feet at CD-2A during a NAPI operational discharge. Similar instances of flow volume decreases between CD-1A and CD-2A (Chapter 7 Figure 7-2) occurred throughout the year, such as on July 1, 1999 in which CD-1A recorded 11.11 acre-feet and CD-2A recorded only 0.82 acre-feet of volume for the same NAPI operational spill.

However, by dividing this nine-mile reach into smaller reaches and measuring flow between these reaches, the reach (Reach 3) above the Yazzie highwall and upstream of reclaimed lands was identified as losing a significant amount of flow. In addition, the synoptic data documents that surface flows across reclaimed lands consisting of spoil (Reach 4) change very little and in fact are dominated by a slight increase. Thus, the conclusion of the report is that the effects of mining on surface water flow volumes both during and after mining are minimal.

Changes in surface flows are minimal in the regraded spoil reach (Reach 4) because the spoil at Navajo Mine is comprised dominantly of sodic mudstone and siltstone that have a very low permeability. Synoptic monitoring identified that base flow increased across the reclaimed land during three measurements by 119 gpm (202 to 321 gpm), 11 gpm (0 to 11 gpm), and 49 gpm (458 to 507 gpm) and decreased during one measurement by 30 gpm (115 to 85 gpm) along Reach 4. Pit run spoil permeability was determined in the Leach Study (Appendix 11-K) to be 3.97×10^{-6} centimeters/second (cm/sec) (five samples that ranged from 1.66×10^{-6} to 5.4×10^{-6} cm/sec), which is a similar permeability to that of a compacted soil liner. Based on the data from the Chinde Wash Surface Water Gain/Loss Report and permeability values, future surface water losses along the permanent Chinde Arroyo diversion are expected to be negligible.

Losses of surface water from the NAPI discharge point to Navajo Mine monitoring station CD-2A are occurring above the Yazzie highwall due to a large and highly vegetated area upstream of the Yazzie highwall, and to a lesser extent due to seeps along the highwall itself immediately below the diversion. Synoptic monitoring recorded a decrease in flow of surface water during three measurements along Reach 3 for the first three-quarters of the study, (Q2 – Q4 1999) with a decrease in flow of 772 gpm (974 to 202 gpm), 283 gpm (283 to 0 gpm) and 275 gpm (390 to 115 gpm), respectively.

The effect that the large and densely vegetated area has on surface water flow is two-fold: 1) it reduces peak flows, and 2) it enhances surface water loss. Surface water losses occur due to the flows spreading out, creating a larger surface area for infiltration and evaporation. The extensive and dense vegetated area will consume water by transpiration during the majority of the year. In addition, un-quantified seeps have been observed on the Yazzie highwall face beneath the Chinde temporary diversion confirming that surface water is infiltrating in the vegetated area. The cumulative effects of these processes, without an additional source of incoming water, are to reduce the amount of available surface water for downstream flows.

Following backfilling of the Yazzie pit, the periodic seeps on the face of the highwall beneath the temporary diversion will decrease significantly or stop due to the placement of low-permeability spoil against the highwall.

The continuous monitoring data also recorded that during large storm events, for example the events between August 3 and 4, 1999, and August 5 and 6, 1999, there was an increase in flow volume from CD-1A to CD-2A (Figure 7-2). This flow volume increase is typical of an ephemeral channel and is the result of increasing watershed size and contributions of additional flow from tributaries progressively producing an increasing volume of flow downstream.

Synoptic flow measurements and continuous flow data collected and reported in the Chinde Wash Surface Water Gain/Loss Report (Appendix 11-OO) have characterized and documented gains and losses of surface water flows along specific reaches of Chinde Arroyo. Specifically, the data collected support the conclusion that future reconstructed channels built in spoils will not significantly alter surface water flows due to vertical infiltration.

11.6.3.3.2 Hosteen Wash

The Hosteen Wash watershed area is about 9.1 sq miles. Mining activities disturb approximately 3.7 sq miles of this drainage. The Hosteen Wash watershed will decrease in size by 1.7 sq miles or 1,274 acres post-mining. This is largely a result of post-mining changes in the drainage divide between Hosteen and Chinde Arroyo, in which Chinde Arroyo increases by 844 acres.

Pre-mining drainage density for Hosteen Wash was estimated to be 3.18 miles/sq mile for the entire drainage area and 2.8 miles/sq mile for the area disturbed by mining. Post-mining drainage density for Hosteen Wash is 6.1 miles/sq mile over the area disturbed by mining. These results indicate a higher post-mining drainage density for the wash. This higher drainage density is to ensure that gullying would not develop on this watershed due to insufficient drainage.

Final surface configuration designs were developed in Chapter 12 (see Section 12.3, Exhibits 12-6A and 12-6B). For design of reclaimed channels, see Section 11.6.5 and Appendix 11-H. Drainage geometry and grade were selected to maximize stability. Similar to a natural channel, sediment deposition may produce local convexities as a result of the aggrading conditions in the channel. These convexities may be reworked, exhibiting down cutting following larger storm events, and redistributing some of the sediment further downstream. Some channel aggradation or channel degradation are expected to develop from natural conditions, despite the design of a graded longitudinal profile and channel cross-section.

With the post-mining channel, some reworking of channel materials will occur, especially during the large flood events. However, channel aggradation or channel degradation would not develop within the reclaimed channel because the graded profile and channel dimensions will be designed to maintain dynamic equilibrium. See the Reclamation Surface Stabilization Handbook (BNCC, 1992) for information regarding the design of reclamation structures.

Comparison of SEDCAD predictions for pre- (see Chapter 7 Appendix 7-A) and post-mining (see Chapter 11 Appendix 11-CC) flows and sedimentology are provided in Table 11-18. This comparison indicates decreases in flow and sediment yields associated with post-mining conditions. These predicted decreases are due to a reduction in the badlands area and a slightly lower curve number attributed to reclaimed areas.

The peak flow resulting from a 10-yr 6-hr precipitation event is predicted to decline from a pre-mining estimate of 1,417 cfs (Structure 9) to a post-mining estimate of 538 cfs (Structure 18) for the entire Hosteen drainage. The runoff volume was predicted to decline from 247 acre-feet, pre-mining, to 126 acre-feet, post-mining.

The SEDCAD modeling for the 10-yr 6-hr event indicates that the predicted peak sediment concentration for post-mining will decrease and the peak settleable concentration will increase. The peak sediment concentration decreased from 45,433 mg/l to 37,159 mg/l and the peak settleable concentration increased from 1.11 ml/l to 2.30 ml/l. The increase in peak settleable solids is attributable to replacement of pre-mining badland areas (clay-rich) with a post-mining topdressing material, typically a sandy loam soil. The clay rich areas will increase the suspended solids concentration, while sandy loam areas will decrease the suspended solids concentration and increase the settable solids (sand) concentration. The SEDCAD analysis also indicates that the total sediment yield will decrease from a pre-mine yield of 8,658 tons to a post-mine yield of 3,400 tons.

Comparison of pre-mining and post-mining flows and sediment yields resulting from a 10-yr 6-hr precipitation event were performed separately for several sub-watersheds disturbed by mining within the Hosteen Drainage (Table 11-18). In all of the sub-watersheds compared, with one exception, the flows and sediment yields declined as a result of mining, even in sub-watersheds that increased in size following mining.

Baseline water quality in Hosteen Wash should be similar to that of Chinde Arroyo because of the similar soils, geology, and vegetation found within the basins (see Chapter 7). Post-mining concentrations for sulfate, iron, manganese, and TDS should decrease slightly due to reduction of badlands area and better distribution of topsoil over the disturbed areas.

TABLE 11-18

COMPARISON OF PRE- & POSTMINING AREAS, PEAK FLOWS AND SEDIMENT YIELDS
HOSTEEN WASH
10-YEAR, 6-HOUR PRECIPITATION EVENT

Sedcad 4.0		**Pre-Mine**				**Post-Mine**				**Difference From Pre-Mine**			
Pre	Post	Area	Peak Flow (cfs)	Sediment (tons)	Yield (tons/acre)	Area	Peak Flow (cfs)	Sediment (tons)	Yield (tons/acre)	Area	Peak Flow (cfs)	Sediment (tons)	Yield (tons/acre)
S9	S18	5,833	1,417	8,658	1.5	4,518	538	3400	0.8	-1,316	-879	-5,258	-0.7
S2	S11	2,379	640	3,617	1.5	2,264	414	1843	0.8	-115	-226	-1,774	-0.7
S6	S15	1,964	668	3,655	1.9	818	64	181	0.2	-1,146	-604	-3,474	-1.6
S12SW1	S5SW1	279	144	479	1.7	240	15	30	0.1	-39	-129	-449	-1.6
S2SW2	S11SW1	146	79	259	1.8	213	13	31	0.1	67	-66	-228	-1.6
S6SW6	S14SW1	178	79	273	1.5	143	8	18	0.1	-36	-71	-255	-1.4
S6SW5	S13SW1	194	91	269	1.4	94	7	11	0.1	-100	-84	-258	-1.3
S12SW2	S6SW1	107	49	84	0.8	169	13	29	0.2	62	-36	-55	-0.6
S2SW1	S11SW2	203	25	49	0.2	86	14	34	0.4	-117	-11	-15	0.2
S13SW2	S9SW1	275	146	569	2.1	410	20	46	0.1	135	-126	-523	-2.0

11.6.3.3.3 Barber Wash

The Barber Wash watershed area is about 5.3 sq miles. Mining activities disturbs approximately 1.4 sq miles of this drainage. Barber Wash will decrease in size by 1.3 sq miles (849 acres) post-mining. This is largely due to post-mining topography changes at the drainage divide between the Barber and South Barber drainages, in which the South Barber drainage increases by 1.45 sq miles (928 acres) (see Exhibits 7-4C and 11-75A).

Pre-mining drainage density for Barber Wash was estimated to be 1.75 miles/sq mile for the entire drainage area and 1.46 miles/sq mile for the area disturbed by mining. Post-mining drainage density for Barber Wash is 6.7 miles/sq mile over the area disturbed by mining.

These results indicate a higher post-mining drainage density over the area disturbed by mining. The post-mining drainage density may be greater than necessary to achieve a stable topographic condition. The increased drainage density was deemed necessary to avoid excessive overland flow lengths. In the event the drainage network is too extensive for the associated flows and sediment yields, the drainage density would decrease where channel flows are insufficient to transport sediment yield from overland flow and upstream contributions. This may occur in the upper reaches of some channels. As these headwater channels fill with sediment, drainage density will decrease as the channel network approaches equilibrium with the flow and sediment yield regime of the contributing watershed.

Final surface configuration designs were developed in Chapter 12 (Section 12.3 and Exhibits 12-6A and 12-6B). For design of reclaimed channels, see Section 11.6.5. Drainage geometry and grade were selected to encourage stability without causing excess sediment deposition. Sediment deposition may produce local convexities as a result of the aggrading conditions in the channel. These convexities may in turn exhibit down cutting following larger storm events, resulting in migration of re-worked sediments downstream. Natural forces will cause aggregation, degradation and down cutting.

Comparison of SEDCAD predictions for pre- (Chapter 7 Appendix 7-B) and post-mining (Chapter 11 Appendix 11-DD) peak flows and sediment yields resulting from a 10-yr 6-hr precipitation event are provided in Table 11-19. In all cases, the comparison indicates a decrease in flow and sediment yields associated with post-mining conditions. These predicted decreases are due to a reduction in the badlands area and a lower curve number attributed to reclaimed areas.

The peak flow resulting from a 10-yr 6-hr precipitation event was predicted to decline from a pre-mining estimate of 404 cfs to a post-mining estimate of 284 cfs for the entire Barber drainage. The runoff volume was predicted to decline from 101 acre-feet, pre-mining, to 59 acre-feet, post-mining.

The SEDCAD modeling for the 10-yr 6-hr event indicates that the predicted peak sediment concentration for post-mine (24,586 mg/l) decreased compared to pre-mine (27,241 mg/l). Total sediment yields (tons) decreased for post-mining conditions while the predicted settleable solid concentrations increased. Sediment yields declined from a pre-mining yield of 1,672 tons to a post-mining yield of 1,076 tons. The settleable solids concentration for the post-mine is 2.2 ml/l compared to the pre-mine concentration of 0.36 ml/l. The change is attributable to replacement of pre-mining badland areas (clay-rich) with a post-mining topdressing material which is typically a sandy loam soil. The clay rich areas will increase the suspended solids concentration, while sandy loam areas may decrease the suspended solids concentration and increase the settable solids concentration.

The peak concentrations of suspended solids and settleable solids are only order-of-magnitude predictions, it is concluded that there should be no significant change between pre- and post-mining in the peak concentrations of TSS and total settleable solids.

Baseline water quality in Barber Wash should be similar to Chinde Arroyo because of similar soils, geology, and vegetation found within the basins (see Chapter 7). Post-mining concentrations for sulfate, iron, and manganese should decrease slightly due to a reduction of badlands area and better distribution of topsoil over the disturbed areas.

TABLE 11-19
COMPARISON OF PRE- & POSTMINING AREAS, PEAK FLOWS AND SEDIMENT YIELDS
BARBER WASH
10-YEAR, 6-HOUR PRECIPITATION EVENT

Sedcad 4.0 Watershed Designation		**Pre-Mine**				**Post-Mine**				**Difference From Pre-Mine**			
Pre	Post	Area	Peak Flow (cfs)	Sediment (tons)	Yield (tons/acre)	Area	Peak Flow (cfs)	Sediment (tons)	Yield (tons/acre)	Area	Peak Flow (cfs)	Sediment (tons)	Yield (tons/acre)
S2	S9	3,364	404	1,672	0.5	2,515	284	1,076	0.4	-849	-120	-596	-0.1
S7	S8	1,716	285	831	0.5	849	86	336	0.4	-867	-199	-495	-0.1
S6SW1	S5	678	175	503	0.7	437	23	44	0.1	-241	-152	-459	-0.6

11.6.3.3.4 South Barber Drainage

The South Barber Drainage has a watershed of about 0.8 sq miles. Mining activities will disturb approximately 0.03 sq miles (17 acres) of this drainage area. The post-mine topography will increase the South Barber drainage by 928 acres. This is largely due to the post-mining topography changes at the drainage divide between the Barber and South Barber drainages that increases the South Barber drainage by 928 acres. The most significant change from pre-mine is that the upper portion of the Barber drainage will be diverted into the South Barber Channel (see Exhibits 7-4C and 11-75A).

Pre-mining drainage density for the South Barber drainage was estimated to be 5.93 miles/sq mile for the entire drainage area. Post-mining drainage density for the South Barber drainage is 5.98 miles/sq mile over the area disturbed by mining. These results indicate that the post-mining and pre-mining drainage densities are about equal. This along with other erosion control practices on the reclaimed areas will ensure that the sediment yield from the post-mining surface will be equivalent to or less than pre-mine. Final surface configuration designs are presented in Chapter 12 (see Sections 12.3, Exhibits 12-6A and 12-6B). For design of reclaimed channels, see Section 11.6.5. Drainage geometry and grade were selected to maximize stability without causing sediment deposition. Sediment deposition may produce local convexities as a result of the aggrading conditions in the channel. These convexities may in turn develop head cuts and begin to erode.

Comparison of SEDCAD predictions for pre-mining (Appendix 7-N) and post-mining (Appendix 11-EE) flows and sedimentology is provided in Table 11-20 for a 10-yr 6-hr event. The comparison indicates a decrease in the total sediment yield for post-mining and the peak flows remain about equal. The predicted sediment yield is 765 tons for post-mine and 599 tons for pre-mine. The predicted peak flows are approximately equal at 166 cfs. The increase in sediment yield for post-mine condition is primarily due to the increased drainage area; the yield in tons per acre is 1.1 tons/acre for pre-mine and 0.5 tons/acre for post-mine. The SEDCAD modeling also indicates for the post-mine condition a decrease in peak sediment concentration and an increase in peak settleable concentration. The predicted peak sediment concentration is 39,347 mg/l for post-mine and 40,564 mg/l for pre-mine. The predicted peak settleable concentration is 1.36 ml/l for post-mine and 0.0 ml/l for pre-mine. The change is attributable to replacement of pre-mining badland areas (clay-rich) with a post-mining sandy loam soil. The clay rich areas will increase the suspended solids concentration, while sandy loam areas may decrease the suspended solids concentration and increase the settable solids concentration. The comparison indicates there is no significant change between the pre and post-mine peak sediment and peak settleable concentrations. For the same storm event the total sediment yield in tons per acre declined for the post-mine condition.

11.6.3.3.5 Neck Arroyo

The Neck Arroyo watershed area is about 1.88 square miles. Approximately 14 percent of this drainage (0.26 square miles or 168 acres) lies within the permit area. Within the permit area, pit disturbance extends across about three percent of the drainage (0.06 square miles or 36 acres), while about one percent of the drainage (0.19 square miles or 132 acres) will be directly disturbed by the location of roads.

TABLE 11-20
COMPARISON OF PRE- & POSTMINING AREAS, PEAK FLOWS AND SEDIMENT YIELDS
SOUTH BARBER DRAINAGE
10-YEAR, 6-HOUR PRECIPITATION EVENT

Sedcad 4.0 Watershed Designation		**Pre-Mine**				**Post-Mine**				**Difference From Pre-Mine**			
Pre	Post	Area	Peak Flow (cfs)	Sediment (tons)	Yield (tons/acre)	Area	Peak Flow (cfs)	Sediment (tons)	Yield (tons/acre)	Area	Peak Flow (cfs)	Sediment (tons)	Yield (tons/acre)
S2	S6	526	166	599	1.1	1,454	166	765	0.5	928	0	166	-0.6

It is possible that road crossings and rail crossings could slightly alter the flow and sediment equilibrium resulting in either temporary aggrading or degrading conditions developing in the stream channel above or below the road crossing. After removal of the road crossing the affected channel reach will return to the approximate pre-mine condition.

Comparison of SEDCAD predictions for pre- (see Chapter 7) and post-mining flows and sedimentology are provided in Table 11-21. This comparison suggests slight decreases in flow and sediment yields under post-mining conditions. These decreases are due to the lower curve number attributed to reclaimed areas and also lower slopes and better vegetation cover on reclaimed areas.

Table 11-21

Comparison of Pre- & Post-Mining Flows and Sediment Yields Neck Arroyo 10-Year 6-Hour Precipitation Event

SEDCAD Subwatershed				Pre-Mining		Post-Mining		Difference from Pre-Mining	
				Flow	Sediment	Flow	Sediment	Flow	Sediment
J	B	S	SW	(cfs)	(Tons)	(cfs)	(Tons)	(cfs)	(Tons)
1	1	1	1	31.18	348.00	30.79	343.69	-0.39	-4.31
1	1	1	5	31.38	402.34	27.52	361.5	-3.86	-40.84

The peak flow resulting from a 10-yr 6-hr precipitation event was predicted to decline from a pre-mining estimate of 247 cfs to a post-mining estimate of 244 cfs for the entire Neck drainage. Likewise, the runoff volume was predicted to decline from 39.0 acre-feet, pre-mining, to 38.7 acre-feet, post-mining. Sediment yields for the same event declined from a pre-mining yield of 14,351 tons to a post-mining yield of 14,284 tons.

The SEDCAD modeling for the 10-yr 6-hr event indicates that predicted peak concentration of TSS increased slightly from pre-mining to post-mining conditions (426,430 mg/l and 428,223 mg/l, respectively) even though peak settleable solids concentrations and sediment yields decreased. This slight increase in total suspended solid concentrations appears to result from numerical error associated with routing high concentrations of sediment in flood flows. Since the peak concentrations of suspended solids and settleable solids are only order-of-magnitude predictions, it can be concluded that there should be no significant change between pre- and post-mining in the peak concentrations of TSS and total settleable solids.

Comparison of pre-mining and post-mining flows and sediment yields resulting from 10-yr 6-hr precipitation event were performed separately for each sub-watershed disturbed by mining within the Neck Arroyo drainage (Table 11-21). In all cases, the flows and sediment yields remained the same or declined as a result of mining.

Pre-mining drainage density for Neck Arroyo was estimated to be 3.11 miles/sq mile for the entire drainage area and should not change as a result of mining.

11.6.3.3.6 Lowe Arroyo

The Lowe Arroyo watershed area is about 11.00 sq miles. Approximately 4.00 sq miles of this drainage lies within the permit area, and 2.18 sq miles is expected to be disturbed. Final surface configuration and drainage designs have been developed as discussed in Chapter 12 (Section 12.3and Section 11.6.5.1).

Drainage geometry and grade were selected to maximize stability without causing sediment deposition. Such sediment deposition may subsequently develop head cuts and erode as local convexities in the channel develop as a result of aggrading conditions. With the post-mining channel, some reworking of channel materials will occur especially during the large flood events. Similar to natural channels in the area, major channel aggradation or channel degradation may develop within the reclaimed channel despite the engineered graded profile and channel dimensions designed for stability. Channel instabilities could develop as a result of head cuts working upstream from changes in base level on Chaco River or the San Juan River.

The largest hydrologic change is the routing of undisturbed drainages east of the permit boundary. Pre-mine, the drainages east of the permit formed the main branch of the Lowe channel that flowed east to west toward SEDCAD structure 10 (Exhibit 7-4). In the post-mine, these drainages are routed to the south initially before flowing west and north toward SEDCAD structure 11 (Exhibit 11-77). As shown on Table 11-22, the watershed area to Structure 7 decreases by 1,808 acres in the post-mine while the watershed area to Structure 11 increases by 1,584 acres. The outlet for the Lowe Arroyo drainage is the same location (lease boundary) as the pre-mine at Structure 12.

The southern post-mining drainage that flows to Structure 11 differs from the pre-mine channel alignment in order to accommodate a lower gradient in the reclaimed channel. The post mining drainage that flows to Structure 10 has a similar alignment as the pre-mine channel.

In the post-mine, the Lowe Arroyo watershed increases by 93 acres due to a change in the drainage divide with Cottonwood Arroyo. This change in watershed acres occurs along the southern boundary between Lowe and Cottonwood drainages. The shifting of 93 acres from Cottonwood Arroyo to Lowe Arroyo will have no appreciable effect on the peak flows or sediment yields of either watershed due to their large size and reclamation practices.

Comparison of SEDCAD predictions for pre-mining (Appendix 7-D and Appendix11-X) and post-mining flows and sedimentology provided in Table 11-22 for a 10-yr 6-hr event. There is a decrease in peak flow and sediment yields from pre-mining conditions to post-mining at both the lease line and the outlet of the watershed. Sediment yields for the 10-yr 6-hr event at the downstream outlet (Structure 12, lease line) are predicted to decline, despite an increase of 93 acres in watershed size post-mining, from a pre-mining yield of 3,682 tons to a post-mining yield of 3,227 tons. The decline in sediment yields and peak flows is due primarily to a lower curve number resulting from reclaiming with sandy loam topdressing material, better vegetation cover on reclaimed areas and terraces that reduce the slope lengths for the post-mine drainage.

TABLE 11-22

COMPARISON OF PRE- & POSTMINING AREAS, PEAK FLOWS AND SEDIMENT YIELDS
LOWE ARROYO
10-YEAR, 6-HOUR PRECIPITATION EVENT

SEDCAD 4.0 WATERSHED DESIGNATION		Pre-Mine				Post-Mine				Difference From Pre-Mine			
Pre-mine	Post-mine	Area (acres)	Peak Flow (cfs)	Sediment (tons)	Yield (tons/acre)	Area (acres)	Peak Flow (cfs)	Sediment (tons)	Yield (tons/acre)	Area (acres)	Peak Flow (cfs)	Sediment (tons)	Yield (tons/acre)
S5	S5	386	55	76	0.2	2,074	317.93	1,071	0.5	1,688	263	996	0.3
S7	S7	2,087	382	1,132	0.5	279	38.37	63	0.2	-1,808	-344	-1,069	-0.3
S8	S6	609	96	166	0.3	2,599	371.51	1,279	0.5	1,990	276	1,113	0.2
S9	S9	541	241	1,005	1.9	341	124.17	416	1.2	-200	-117	-589	-0.6
S10	S10	4,659	735	2,431	0.5	6,798	490	2,811	0.4	2,139	-245	380	-0.1
S11	S11	1,846	129	246	0.1	3,430	329	1,313	0.4	1,584	200	1,067	0.2
S12 (Lease Line)	S12	7,046	926	3,682	0.5	7,139	514	3,227	0.5	93	-412	-455	-0.1
S13 (Outlet)	S13	7,855	919	3,951	0.5	7,945	527	3,426	0.4	90	-392	-525	-0.1

The peak flow resulting from a 10-yr 6-hr precipitation event was predicted to decrease from a pre-mining estimate of 926 cfs to a post-mining estimate 514 cfs for Lowe Arroyo below the lease boundary (Structure 12). The runoff volume at structure 12 is predicted to decline from 238 acre-feet, pre-mining, to 192 acre-feet, post-mining.

11.6.3.3.7 Cottonwood Arroyo

The Cottonwood Arroyo watershed area is about 80 square miles. The pre-mining watershed areas are shown on Exhibit 7-4A. The final surface topography and drainage configuration has been developed and is discussed in Section 11.6.5.1 and Chapter 12.3.

The primary hydrologic change to Cottonwood Arroyo is the disturbance of the North Fork of Cottonwood Arroyo. Approximately 10,662 feet of the North Fork will be permanently re-aligned from the pre-mine orientation due to reclamation (See Exhibit 11-77). As noted in the discussion of Lowe Arroyo, the Cottonwood Arroyo watershed will slightly increase from the pre-mine but with no appreciable hydrologic effects.

Table 11-23 shows the comparison of flow and sediment yield for the 10-yr 6-hr precipitation event for the portions of Cottonwood tributaries that drain the proposed Area 4 North mine area. These results reflect disturbance conditions for the entire sub-watershed even though proposed mining affects only a portion of the sub-watershed. Yet the differences in sediment yields (tons) and peak flow are negligible between pre and post-mining at the lease line (Structure 36). Sediment yields for the 10-yr 6-hr event at the downstream lease line are predicted to slightly increase from a pre-mining yield of 26,947 tons to a post-mining yield of 27,017 tons (Structure 37). This is essentially no change in sediment yield. The incrementally small changes in the sediment and peak flow figures reflect the small acreage of mining disturbance in the Cottonwood watershed as a whole.

The peak flow resulting from a 10-yr 6-hr precipitation event at the lease line (Structure 36) is predicted to slightly increase from a pre-mining estimate of 2,879 cfs to a post-mining estimate

2,903 cfs. The runoff volume at Structure 36 is predicted to decline from 1,473 acre-feet, pre-mining, to 1,150acre-feet, post-mining.

TABLE 11-23

COMPARISON OF PRE- & POSTMINING AREAS, PEAK FLOWS AND SEDIMENT YIELDS
COTTONWOOD ARROYO
10-YEAR, 6-HOUR PRECIPITATION EVENT

SEDCAD 4.0 WATERSHED DESIGNATION		Pre-Mine				Post-Mine				Difference From Pre-Mine			
Pre	Post	Area (acres)	Peak Flow (cfs)	Sediment (tons)	Yield (tons/acre)	Area (acres)	Peak Flow (cfs)	Sediment (tons)	Yield (tons/acre)	Area (acres)	Peak Flow (cfs)	Sediment (tons)	Yield (tons/acre)
S21	S21	13,492	1,551	11,133	0.8	13,532	1,546	11,417	0.8	40	-5	284	0.0
S34	S34	18,191	674	7,201	0.4	18,279	665	7,298	0.4	88	-9	97	0.0
S36 (lease line)	S36	49,060	2,879	26,803	0.5	49,184	2,903	27,364	0.6	124	24	561	0.0
S37(Outlet)	S37	51,269	2,842	26,947	0.5	51,477	2,855	27,017	0.5	208	13	70	0.0

The pre-mining drainage density for Cottonwood Arroyo was estimated to be 2.64 miles/sq mile for the entire drainage area and 2.33 miles/sq mile for the permit area. Drainage densities will not change significantly as a result of mining. Final surface configuration design for Area III has allowed for a higher post-mining drainage density for the area disturbed by mining (see Exhibit 11-77). Furthermore, the gradient terraces to be installed according the Reclamation Surface Stabilization Handbook (BNCC, 1992) along with the lower relief associated with the post-mining surface should minimize gullies forming on the reclaimed surface.

Baseline water quality data in Cottonwood Arroyo indicate TDS, total iron, total manganese, and sulfate average concentrations usually exceed secondary drinking water standards but generally are suitable for livestock watering (see Chapter 7 Table 7-7). BNCC monitored three sites along the Cottonwood Arroyo between 1997 and 1999. Upstream NAPI discharges heavily influenced the water quality at two of the sites, as the flows were eroding and mobilizing sediment from surficial eolian sand dunes. Active channel widening and head cut development followed discharges from NAPI and storm events. Multiple storm events in 1999 resulted in the destruction of the downstream monitoring station CNS-1. During the monitoring period, when flows occurred, sediment loss resulted in significant concentrations of TSS, which resulted in elevated salinity, iron, and manganese concentrations. Water quality parameter levels were often elevated at CN-1 which is located upstream of the mine on the North Fork of Cottonwood, and at the downstream site CNS-1. Average TSS concentrations ranged from approximately 115,800 mg/l at the upstream site, CS-1, to approximately 131,000 mg/l at the upstream site, CN-1. Average selenium concentrations exceeded chronic aquatic habitat standards. Post-mining concentrations of TDS, total iron, total manganese, sulfate, and TSS may actually decrease slightly due to better distribution of topdressing over the disturbed areas and lower concentrations of sediment in stream flows. However, any change would be marginal and chemical quality of surface water following mining would be expected to approximate pre-mining conditions.

11.6.3.3.8 San Juan River and Chaco River

The San Juan River Basin within the 1408 HUC codes extends across approximately 24,900 sq miles. Approximately 0.21 percent of this drainage lies within the lease area. The Chaco River has a watershed area of approximately 4,570 sq miles within the 14080106 HUC code. The lease occupies about 1.2 percent of the total drainage area.

The San Juan River and Chaco River channels and flood plains will not be directly impacted by mining activities. The only possible impact on these rivers would be through the discharge of surface or groundwater from the mine area or from reclaimed surface and backfill.

The Chaco River does not receive groundwater base flow and thus would not be impacted by changes in groundwater quality. A relatively small amount of groundwater from backfill areas could reach the San Juan River after a period of about 200 years. As explained in Section 11.6.2.3.1, this quantity is so small relative to flows in the San Juan River that little change in the water quality of the San Juan River would be expected. Furthermore, based on leaching studies of overburden and spoils, chemical quality expected from backfill leachate would be very similar to baseline quality in coal seams. Consequently, no change in water quality in the San Juan River would be expected from groundwater from the mine area.

Storm runoff from the active mine area is contained within the mine and is not directly discharged to surface water drainage courses. Consequently there would be no impact on surface water quality of the San Juan and Chaco Rivers as a result of mine water discharges.

Diversion of flows in the major channels such as Chinde Arroyo may result in minor disruption of dynamic equilibrium within the stream channel. These changes could increase or decrease sediment loads along segments of the channel but are usually unlikely to change sediment loads to the San Juan or Chaco Rivers. The diversion of Chinde Arroyo through the Big Fill culvert is one example where flood attenuation may reduce sediment loads downstream to the Chaco River. The hydrologic consequences of such changes are temporary adjustments in channel grade and geometry until a new equilibrium is reached. From field observations it appears that channel adjustments have already occurred downstream of the Big Fill culvert and the channel is approaching equilibrium conditions.

Analysis of impacts of reclamation of drainages and stream channels, as described in Section 11.6.3.1 through 11.6.3.8, indicates only minor changes in flow and sedimentology that are likely to have minimal impact on channel conditions and sediment loads in the San Juan and Chaco Rivers.

11.6.4 Post-Reclamation Probable Hydrologic Consequences

BNCC's objectives in establishing the post-reclamation topography are to restore the affected land to a condition supporting the land uses it was capable of supporting prior to mining. This is achieved by minimizing the disturbance to the hydrologic balance, restoring prominent drainage features of the permit area to approximate the pre-mining conditions, and establishing a diverse, effective, and long lasting vegetative cover of the same seasonal variety as the native vegetation (Chapter 12 Section 12.1). All reclamation strategies are implemented to reduce surface erosion and sediment yield. BNCC 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 area drainages. BNCC will use appropriate channel types, slopes, and drainage densities to construct landforms appropriate to the area.

BNCC is planning to reclaim all of the sediment and drainage control ponds utilized during the operation, except for impoundments designated as permanent impoundments (Chapter 12 Section 12.3.4.1). At some future date, the Navajo Nation may request that some or all of the ponds remain. Future discussions may result in the retention or construction of ponds replacing the original livestock ponds. Should pond retention occur, ponds located on-channel will modify the hydrograph associated with the 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 generally reproduce the storage capacity and surface area of the original pre-mine impoundment. The spoil material at each pond location will be compacted under appropriate moisture conditions in order to reduce permeability and, thereby, prevent excess pond infiltration. Specific discussions of temporary and permanent sediment ponds and the replacement of surface water sources are presented in Chapter 11 Section 11.2.10 and Chapter 12 Section 12.3.4 and 12.11.

The mining and reclamation plan for the Navajo Mine includes the development of a post-mine topography that minimizes the disturbance to the hydrologic balance and restores prominent drainage features of the permit area to approximate the pre-mining conditions. This post-mining topography may incorporate diversion channels developed during operations. BNCC will meet all the regulatory requirements for diversions as specified in 30 CFR 816.43. Ideally, these diversions will not employ channel lining, artificial channel roughness features, or retention basins, unless approved by the regulatory agency. The diversions will not diminish downstream water rights. The ephemeral channels traversing the post-mine topography are designed, located, and constructed to be stable within a condition of dynamic equilibrium, and will not increase the potential for downstream flooding or endanger property or public safety. The channels will be designed to minimize additional contributions of suspended solids to stream flows using features such as appropriate gradients, channel linings, and roughness features. Lastly, these channels will not be constructed to divert water into underground mines.

11.6.4.1 Post-Reclamation Erosion, Sediment Yields, and Water Quality

The Reclamation Surface Stabilization Handbook (BNCC, 1992) includes 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 to meet applicable federal, state, and tribal water quality laws, regulations, and standards.

Mining operations will minimize disturbance to the hydrologic balance within the permit area and prevent material damage outside. Reclamation of disturbed areas and replacement of poor quality sodic soils with suitable topdressing materials is expected to produce better or equivalent surface water quality as pre-mining under post-reclamation conditions. SEDCAD modeling results presented in the previous section indicate equivalent or reductions in post-reclamation sediment yields relative to baseline conditions. TDS, sulfate, iron, and manganese concentrations in surface runoff from reclaimed areas are expected to decline with time to concentrations well below the SPLP leaching test results for mine spoils in Table 11-14f. Also, trace constituents in surface runoff are expected to be well below the SPLP spoil leachate results, which are less than detection limits or livestock watering criteria as shown in Table 11-14f. Groundwater flow and transport modeling presented in Section 11.6.2.4.3 project the transport of dissolved solids and several trace constituents toward the topographic lows along the pre-mining channels. The rates of groundwater flow are very slow relative to storm water runoff volumes, and groundwater flows are expected to be retained within the alluvium and not contribute to surface water.

Following reclamation, surface water quality in drainages throughout the permit area is expected to be equivalent to or an 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 configurations.
- Poor quality and sodic soils will be buried within the backfill, thus overland flow from the reclaimed areas is expected to exhibit lower concentrations of sodium and TDS.
- Trace metal concentrations such as boron or selenium are expected to be reduced, through spoil attenuation as shown in Table 11-14e.
- Dissolved aluminum concentrations should decline with the reduction in suspended solids associated with reduced surface and channel erosion.

Section 11.6.5 addresses the potential short-term and long-term impacts to surface water sources that have existing uses.

11.6.4.2 Site Channels

The reclaimed channels are engineered to have flow velocities equal to or less than the pre-mine channels. Some erosion is anticipated, particularly in the pilot channels shown on Figures 11-27 and 11-29. All natural channels erode because they are in constant state of flux based on the magnitude of flows conveyed. During low flows, deposition will occur in some reaches of the channel and erosion in other reaches. Deposition will occur in reaches of lower slopes or where the channel bed widens and the flow spreads out, thus reducing the velocity. Erosion (down cutting with some lateral movement) will happen in reaches where the channel bed narrows and confines the flow, thereby increasing the velocity. This generally occurs in reaches with increases in channel bed slopes.

During elevated flows the storm deposited sediment from low flows will be washed downstream in natural channels. Some lateral movement of the channel banks is expected as well as some down cutting of the channel bed. This process is also expected to occur in the reclaimed channels. Lateral movement of the low flow pilot channel is projected but will be confined within the banks of the main channel. The pilot channel is expected to resemble the surrounding natural channels in time. It could be incised in some reaches of the channel with depths as deep as 5 feet at the floodplain. The existing, incised channel depths in the existing or natural channels directly downstream of the lease are much deeper (See Exhibit 11-76E). Erosion is expected to occur in the reclaimed channels but the erosion rate will be equivalent or less than pre-mining conditions since the flow velocities in the reclaimed channels are less than the pre-mine (See Tables 11-24 and 11-24a).

Low frequency (10-yr 6-hr or greater) large storm flows with corresponding higher velocities are required to transport coarse materials. Inversely for the higher frequency (2-yr 6-hr) smaller flows, the abundant coarse materials in combination with vegetation will serve to stabilize the grade and minimize erosion and down cutting.

Cut bank depths up to 5 feet deep could result if a 3-foot deep incised pilot channel should migrate and abut against a 1.5 to 2.0 feet thick floodplain bank (See Figure 11-24a). The erosion depth or incised pilot channel depth of three feet was selected based on observations of channel erosion in adjacent, pre-law mine spoils. Usually at a scour depth of three feet or less into the spoil material, a protective shielding of the channel bottom has occurred as the finer-grained sediments are winnowed away. If the incised pilot channel excavates deeper than three feet or should erode beyond the toe of the main channel into the reclaimed slope, the area/erosion will be mitigated by stabilizing the channel. Channel stabilization options include armoring the channel with coarse materials that range in size from pea – sized gravel (>0.63 inches) up to large (3-foot length of the long axis) sandstone cobbles and boulders.

11.6.4.2.1 Area I South Reclaimed Channels

There is one reclaimed channel in the Area I South final surface configuration (FSC) with a watershed larger than 640 acres, which requires detailed designs according to the Reclamation Surface Stabilization Handbook (BNCC, 1992). The reclaimed channel is designated as the Doby North Channel. The alignment of the reclaimed channel is shown on Exhibits 11-85 and 85A.

11.6.4.2.1.1 Analysis of Pre-Mine Channels

In the vicinity of Doby Pit, the pre-mine surface sloped down towards the west with primarily sheet flow drainages and some small channels. The post-mine topography changed the pre-mine drainage pattern by diverting the westward drainages from the off lease undisturbed surface towards the south via a post-mine channel that runs north to south along the eastern lease boundary. The channel also collects surface runoff from a portion of the reclaimed surface to the west.

Since there was no main channel in the pre-mine surface, the pre and post-mine flow velocities cannot be compared. The design of the reclaimed channel was based on maintaining the flow velocity less than the erosive velocity of the channel bed material, which in this case is the spoil material. The spoil material is primarily composed of shale/clay with sandstone cobbles that has an erosive velocity of approximately 5 feet per second (fps). Specifically, the design philosophy was to design a channel that is: 1) stable by demonstrating that the flow velocities are less than 5 fps, and 2) able to safely convey the flow from the 100-yr 6-hr event.

11.6.4.2.1.2 Analysis of Reclaimed Channels

The SEDCAD hydrology software was utilized to design the reclaimed channel. The hydrology for the Doby North Channel was modeled in SEDCAD to simulate the 2-, 10-, 25- and 100-yr 6-hr storm events. The channel was designed to retain the 10-yr 6-hr peak flow without overflowing the banks. The watershed subdivisions used in the model are presented in Exhibit 11-85 and 85A. The results from the SEDCAD runs are presented in Appendix 11-FF. During storms greater than the 10-yr 6-hr event over bank flow will occur at the upper reach of the channel. For all the storm events simulated the flow velocities are less than 5 fps, indicating that the channel will be hydraulically stable.

The profile of the Doby North Channel at the south end of the Doby reclamation area has a significant drop; this reach of channel will require a riprapped drop structure to control erosion. The drop structure will be designed for a 25-yr 6-hr stability and 100-yr 6-hr capacity. The design of the drop structure is included in the SEDCAD hydrology model (Appendix 11-FF).

The location and design details for the Doby North Channel are presented on Exhibit 11-85.

11.6.4.2.2 Area II Reclaimed Channels

Four reclaimed channels in the Area II FSC have watersheds that are larger than 640 acres, which require detailed designs according to the Reclamation Surface Stabilization Handbook (BNCC, 1992). The three reclaimed channels are Chinde Arroyo Branch 1, Hosteen Wash Branch 1, Barber Reclaimed Channel, and South Barber Channel. The alignments of the reclaimed channels are shown on Exhibits 11-75, 11-76, 11-76A, 11-76B, 11-76C and the pre-mine surface configuration with channels is shown on Exhibits 11-76F, 11-76G, and 11-76H.

The design of the reclaimed channels was based on a comparison of pre-mine channel flow velocities with post-mine channel flow velocities using HEC-RAS. Specifically, the design philosophy was to design a channel that is: 1) equally or more stable than the pre-mine channel (by demonstrating that the post-mine flow velocities are less than the pre-mine), and 2) able to convey the 100-yr 6-hr event.

Table 11-24 compares pre-mining and post-mining channel velocities for the entire channel reach that was modeled. Both the maximum and average flow velocities are provided for each of the four drainages modeled. Table 11-24a provides a detailed breakdown between channel reaches (channel stations) by listing the design flows that were input at each station and the corresponding flow velocities for that particular channel reach. For all design storm events, the reclaimed channels have a lower maximum and average flow velocity than the pre-mine channels as noted in Table 11-24. Results of the HEC-RAS analysis also indicate that the reclaimed channels will convey the peak flows generated by the 100-yr 6-hr precipitation event. Complete HEC-RAS output files for all four modeled channels by design storm events (2-, 10-, 25-, 100-yr 6-hr peak flows) are provided in Appendix 11-NN (post-mine) and Appendix 11-PP (pre-mine).

The lower post-mine flow velocities are attributed to lower peak flows and different channel geometries in the reclaimed channel versus the pre-mine channel. The lower peak flows result from replacement of pre-mine badlands with reclaimed areas that have lower curve numbers. Generally, the pre-mine channels that were modeled are incised, which confines the flow and increases the flow depth, producing higher channel velocities than the reclaimed channel. The grades of the pre-mine channels were also steeper. The reclaimed channel section consists of a pilot channel and a main channel or a floodplain (See Figures 11-27 and 11-29, and Exhibit 11-76E). The geometry of the design sections for the reclaimed channels were proportioned from upstream to downstream depending on the magnitude of the flows.

Pre-mine and post-mine channel peak flows were estimated using SEDCAD for the 2-, 10-, 25-, and 100-yr 6-hr events. The supporting documentation for the pre-mine peak flow estimations are in Appendix 7-A (Hosteen Wash), 7-B (Barber Wash), 7-G (Chinde Arroyo) and 7-N (South Barber Channel). The supporting documentation for the post-mine peak flow estimations are in Appendix 11-BB (Chinde Arroyo), 11-CC (Hosteen Wash), 11-DD (Barber Wash), and 11-EE (South Barber Channel).

The pre-mining SEDCAD drainage subdivision for Chinde Arroyo is shown on Exhibit 7-3; the post-mining drainage subdivision is shown on Exhibit 11-75. The pre-mining SEDCAD drainage subdivision for Hosteen, Barber, and South Barber drainages is shown on Exhibit 7-4C, the post-mining drainage subdivision is shown on Exhibit 11-75A.

The peak flows were input upstream of the prediction points or SEDCAD structures for both the pre-mine and post-mine HEC-RAS analysis. Entering the peak flows in this manner will generate conservative results. The results of the HEC-RAS pre-mine analysis for the 2-, 10-, 25-, and 100-yr, 6-hr peak flow for the modeled channels are in Appendix 11-PP, HEC-RAS Results for Area II Pre-Mine Channels.

11.6.4.2.2.1 Analysis of Pre-mine Channels

Due to the lack of detailed cross-sectional channel data within the lease, the development of the pre-mine channel sections used in the HEC-RAS is based on one representative surveyed cross-section. This cross-section is taken from both upstream and downstream of the lease for each respective drainage. The surveyed downstream cross-section was repetitively projected upstream across the lease to a transition zone for that particular channel. Similarly, the surveyed upstream cross-section was repetitively projected downstream across the lease to the transition zone.

The transition zone, 1,300 to 1,500 feet in length, connects the upstream and downstream channel configuration. The length and location of the transition between the upstream and downstream cross-sections was based on topographic information. Natural pre-mine transitions (i.e. incised badland channel to a broad valley channel) are evident from the topography and these approximate locations determined the location of the modeled transitions.

This method of interpolation across the permit area for development of the pre-mine channel for the HEC-RAS analysis was applied for modeling Hosteen Wash Branch 1. Locations of the transitions and the representative upstream and downstream cross-sections used in the HEC-RAS modeling are shown on the pre-mine plan and profile sheets, Exhibit 11-76G.

The channel profiles used in the HEC-RAS pre-mine analysis were extracted from U.S. Geological Survey (USGS) and aerial surveys at 10-foot contours.

11.6.4.2.2.1 Analysis of Reclaimed Channels

The flow velocities in the reclaimed channels were determined by inputting the reclaimed channel sections into HEC-RAS. The reclaimed channel reaches are transitioned into the existing natural channel at the upstream and downstream ends. The transitions of the reclaimed channel to the natural channel generally occurred over a 500 to 700 foot reach. The post-mine peak flows and gradient for that particular drainage dictated the geometry of the reclaimed channel. The reclaimed channel cross-sections are shown on Exhibit 11-76E, Sheet 1. The locations of the transition reaches and the design sections used in the HEC-RAS model are shown on the plan and profile sheets Exhibit 11-76A, 11-76B, and 11-76C.

The reclaimed channel profiles are generally uniform, which was stipulated by the elevation of the channel bottom at the upstream and downstream lease boundaries, except where the reclamation has been completed, such as the downstream reach of the Barber Reclaimed Channel. In this case, the elevation of the channel just up-stream of the completed reclamation and the channel elevation downstream at the lease line will determine the grade.

Due to the completed reclamation in Up Dip Barber the grade of the Barber Reclaimed Channel is set and will not change. Because this area is reclaimed and includes an existing vegetated channel, the necessity of constructing a reclaimed channel and resultant disturbance to the area across the reclamation should be evaluated. Specifically, the natural channel that has developed and which will continue to develop during the time prior to final reclamation will likely have a similar geometry to the reclaimed channel, particularly the pilot channel. The lower reach of the Barber Reclaimed Channel will be monitored for channel development and stability in order to determine if construction of the reclaimed channel is required.

The profile of the Barber Reclaimed Channel just east of the rail line will have a significant drop; this reach of channel will require a riprapped drop structure to control erosion. The drop structure will be designed for a 25-yr 6-hr stability and 100-yr 6-hr capacity. The reclamation of the channel will be done during the final reclamation of the railroad embankment. The embankment material will be used to reduce the grade of the drop structure.

Chinde Branch 1 in the post-mining topography is a tributary of the Chinde Arroyo, which did not occur in the pre-mine topography. The post-mining topography changes the pre-mine drainage pattern by diverting the upstream watersheds of the Hosteen Wash into the Chinde Arroyo watershed. Consequently, the results of the HEC-RAS analysis could not be compared to a corresponding pre-mine channel. However, the flow velocities can be compared to velocities in the other pre-mine channels analyzed. The flow velocities in Chinde Branch 1 are all less than the velocities in the other pre-mine channels, except for the Barber Wash 2-yr 6-hr average velocity (see Table 11-24).

The Chinde Branch 1 Reclaimed Channel converges with the Chinde Arroyo at approximately Station 0+00, see Exhibit 11-76A. The HEC-RAS analysis for Chinde Branch 1 includes this station and the subsequent stations upstream. The channel reach downstream of Station 0+00 to the western permit boundary will be a part of the Chinde Permanent Diversion. The design section for Chinde Branch 1 is shown on Exhibit 11-76E, Sheet 1.

South Barber Channel in the post-mining topography is a tributary to the Neck Arroyo. The post-mining topography changes the pre-mine drainage pattern by diverting the upstream watersheds of the Barber Wash into the South Barber watershed. The reclaimed South Barber Channel will have a riprapped drop structure from Station 13+91 to 20+70. Refer to Appendix 11-EE for riprap size design and Exhibit 11-76C and 11-76E for the profile and typical section. The flow velocities in South Barber Channel are less than or equal to the velocities of the pre-mine channel (see Table 11-24).

11.6.4.2.3 Area III Reclaimed Channels

Seven post-mining or reclaimed channels in the Area III FSC have watersheds that are larger than 640 acres, which require detailed designs according to the Reclamation Surface Stabilization Handbook (BNCC, 1992). The alignment of the seven post-mining/reclaimed channels are shown on Exhibit 11-78 and are designated as Lowe, Lowe North, Lowe North R2, Lowe North R3, Lowe North R4, Lowe South, and North Fork. The pre-mine surface configuration with channels is shown on Exhibit 11-78A.

The design of the reclaimed channel was based on a comparison of pre-mine channel flow velocities with post-mine channel flow velocities using HEC-RAS. Specifically, the design philosophy was to design a channel that is: 1) equally or more stable than the pre-mine channel by demonstrating that the post-mine flow velocities are less than the pre-mine, and 2) able to convey the 100-yr 6-hr event.

Mining has disturbed the main channel and tributaries of Lowe North and Lowe South Branches; therefore detailed cross-sections of the pre-mine channels are not available to perform a HEC-RAS analysis for comparison with the reclaimed channels. In lieu of a comparison with pre-mining channel conditions, the reclaimed channels were designed to have average flow velocities less than 5 fps during the peak flow from a 2-yr 6-hr storm event. The limiting criterion of 5 fps is based on the erosive velocity of the spoils, which is 5 fps. The bottom and banks of the reclaimed channels will be in the regraded spoils. The channel bottoms and banks will not be topsoiled. Only the North Fork pre-mine channel and the downstream reach of the Lowe Arroyo near the western permit boundary were analyzed as pre-mine channels for comparisons with the post-mining channel.

TABLE 11-24

PRE-MINE AND POST-MINING CHANNEL VELOCITIES

Chinde Branch 1

	Pre-Mine		Post-Mining	
Storm Event	Maximum Velocity (fps)	Average Velocity (fps)	Maximum Velocity (fps)	Average Velocity (fps)
2-Year	n/a	n/a	4.43	4.02
10-Year	n/a	n/a	6.80	4.50
25-Year	n/a	n/a	7.62	4.88
100-Year	n/a	n/a	8.09	5.19

Hosteen Wash Branch 1

	Pre-Mine		Post-Mining	
Storm Event	Maximum Velocity (fps)	Average Velocity (fps)	Maximum Velocity (fps)	Average Velocity (fps)
2-Year	9.56	4.81	6.65	5.10
10-Year	12.91	6.23	9.42	4.63
25-Year	14.38	6.92	9.58	4.97
100-Year	15.97	7.62	10.63	5.42

South Barber Channel

	Pre-Mine		Post-Mining	
Storm Event	Maximum Velocity (fps)	Average Velocity (fps)	Maximum Velocity (fps)	Average Velocity (fps)
2-Year	7.65	5.13	7.65	3.53
10-Year	10.25	6.78	10.25	4.41
25-Year	11.05	7.42	11.05	4.85
100-Year	12.25	7.92	12.21	5.30

TABLE 11-24a

HEC-RAS RESULTS

Chinde Branch 1 Post-mining

Flow Change Location (Sta)	2-Year			10-Year			25-Year			100-Year		
		Velocity (fps)			Velocity (fps)			Velocity (fps)			Velocity (fps)	
	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg
192.92	38	3.59	3.47	104	4.92	4.76	149	5.61	4.82	213	6.19	4.85
170.00	101	4.22	4.18	258	6.80	4.31	468	7.62	4.88	511	7.75	4.93
123.00	112	4.43	4.10	332	6.21	4.49	496	7.04	4.92	741	8.05	5.41
37.00	108	4.33	4.19	333	6.17	4.48	503	7.06	4.89	758	8.09	5.36

Hosteen Branch 1 Pre-mine

Flow Change Location (Sta)	2-Year			10-Year			25-Year			100-Year		
		Velocity (fps)			Velocity (fps)			Velocity (fps)			Velocity (fps)	
	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg
104.00	62	6.46	2.20	192	7.91	2.72	286	12.90	3.22	423	8.94	3.23
74.00	135	8.76	4.28	395	10.39	4.91	583	11.00	5.16	854	11.77	5.51
46.00	180	8.79	7.01	511	11.87	9.58	748	13.27	10.70	1,089	14.73	12.17
6.00	226	9.56	8.91	640	12.91	12.16	937	14.38	13.53	1,366	15.97	15.03

Hosteen Branch 1 Post-mining

Flow Change Location (Sta)	2-Year			10-Year			25-Year			100-Year		
		Velocity (fps)			Velocity (fps)			Velocity (fps)			Velocity (fps)	
	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg
86.00	121	6.30	4.83	364	8.43	4.52	540	9.26	4.91	793	10.17	5.37
28.00	125	6.65	6.33	409	9.42	5.16	627	9.58	5.24	951	10.63	5.64

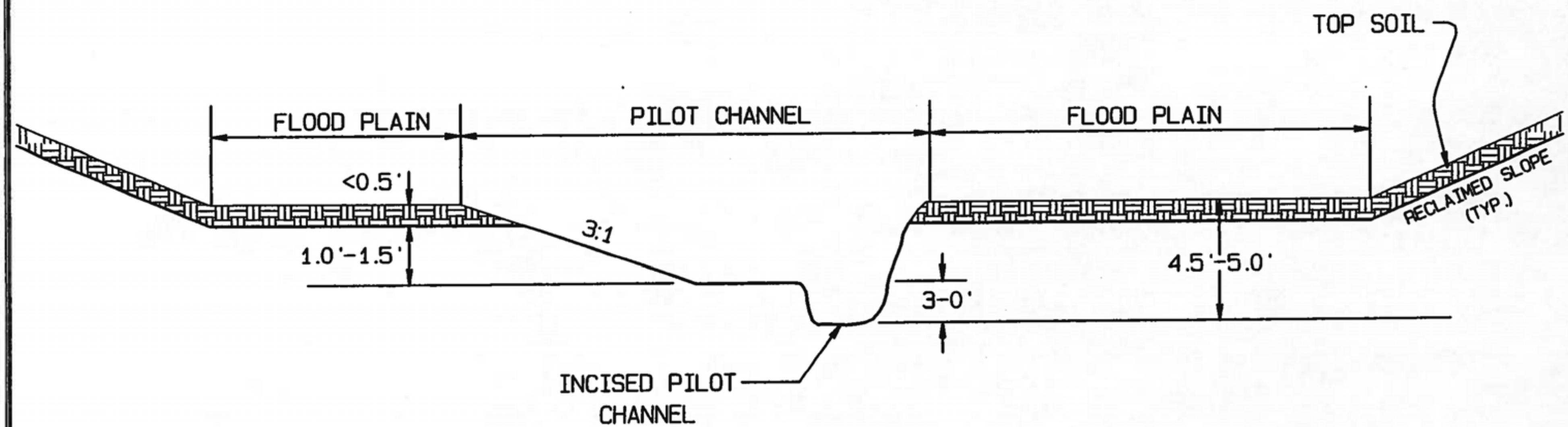
South Barber Channel Pre-mine

Flow Change Location (Sta)	2-Year			10-Year			25-Year			100-Year		
		Velocity (fps)			Velocity (fps)			Velocity (fps)			Velocity (fps)	
	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg
15.42	51	7.65	5.13	166	10.25	6.78	251	11.05	7.42	375	12.25	7.92

South Barber Channel Post-mining

Flow Change Location (Sta)	2-Year			10-Year			25-Year			100-Year		
		Velocity (fps)			Velocity (fps)			Velocity (fps)			Velocity (fps)	
	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg
107.54	24	3.23	3.14	73	4.56	3.76	110	5.28	4.08	164	6.04	4.51
87.54	22	3.16	2.80	78	4.81	3.42	123	5.52	3.82	192	6.27	4.26
27.00	31	2.98	2.87	103	4.43	3.38	159	5.09	3.68	243	5.87	3.97
20.70	51	7.65	5.06	166	10.25	6.58	251	11.05	7.19	377	12.21	7.71

FIGURE 11-27



TYPICAL RECLAIMED INCISED PILOT CHANNEL SECTION
NTS

Table 11-26 compares pre-mining and post-mining channel velocities for the entire channel reaches that were modeled. Both the maximum and average flow velocities are provided for each of the drainages modeled. Table 11-26a provides a detailed breakdown between channel reaches (channel stations) by listing the design flows that were input at each station and the corresponding flow velocities for that particular channel reach. For all design storm events the reclaimed channels have a lower maximum and average flow velocity than the pre-mine channels. For all the reclaimed channels not compared to a pre-mining channel the average flow velocities during the 2-yr 6-hr storm event are less than 5 fps. Results of the HEC-RAS analysis also indicate that the reclaimed channels will convey the peak flows generated by the 100-yr 6-hr precipitation event. The HEC-RAS output files for all the reclaimed and pre-mining channels modeled are provided in Appendix 11-X1 and 11-Y1 (post-mining); and Appendix 11-X2 and 11-Y2 (pre-mining).

The lower post-mine flow velocities are attributed to lower peak flows and different channel geometries in the reclaimed channel versus the pre-mine channel. The lower peak flows result from the replacement of pre-mine badlands with reclaimed areas that have lower curve numbers. Generally, the pre-mine channels that were modeled are incised, which confines the flow and increases the flow depth, producing higher channel velocities than the reclaimed channel. The grades of the pre-mine channels were also steeper. The reclaimed typical channel section consists of a main channel that will retain the 2-yr 6-hr peak flow with a floodplain. The flows larger than the 2-yr 6-hr peak flow will overflow into the floodplain (See Exhibit 11-78C). The geometry of the design sections for the reclaimed channels was proportioned depending on the magnitude of the flows.

Pre-mine and post-mine channel peak flows were estimated using SEDCAD for the 2-, 10-, 25-, and 100-yr 6-hr events. The peak flows were input at the prediction points or SEDCAD structures for both the pre-mine and post-mine HEC-RAS analysis. The supporting documentation for the pre-mining peak flow estimations are in Appendix 7-D (Lowe Arroyo), and 7-H (Cottonwood Arroyo). The supporting documentation for the post-mining peak flow estimations are in Appendix 11-X (Lowe Arroyo), and 11-Y (Cottonwood Arroyo).

The pre-mining SEDCAD drainage subdivision for Lowe and Cottonwood Arroyo is shown on Exhibit 7-4, the post-mining drainage subdivision is shown on Exhibit 11-77.

11.6.4.2.3.1 Analysis of Pre-mine Channels

Prior to the construction of the North Fork Diversion, the North Fork of the Cottonwood Arroyo reach inside the permit boundary was field surveyed to obtain cross-sections on approximately 100-foot intervals. The locations of the cross-sections are shown on Exhibit 11-78A, Sheet 3. The cross-section data and the predicted peak flows from SEDCAD were input into HEC-RAS to obtain pre-mining channel flow velocities and depths. The HEC-RAS results are presented in Appendix 11-Y2 and summarized on Tables 11-26 and 11-26a in this section.

The downstream reach of the Lowe Arroyo at the western permit boundary was also surveyed to obtain cross-sections on approximately 100-foot intervals. Mining has not disturbed this reach of channel. The cross-section data and the predicted peak flows were input into HEC-RAS to obtain both pre-mining and post-mining channel flow velocities and depths for comparative purposes. The HEC-RAS results are presented in Appendix 11-X2 (pre-mining) and Appendix 11-X1 (post-mining) with results summarized on Table 11-26 and 11-26a in this section.

The Manning's roughness coefficients (n) used for the North Fork pre-mine channel in the HEC-RAS analysis were as follows: 0.045 for the floodplain, 0.035 for the channel banks, and 0.030 for the channel bottom. For the Lowe Arroyo pre-mine channel, the reach in the vicinity of the western permit boundary, the n values used were: 0.045 for the floodplain and a composite n of 0.033 for the channel bottom and channel banks.

Due to the lack of detailed cross-sectional data of the North Lowe and Lowe South main channels including its tributaries, the pre-mine HEC-RAS analysis were not performed for these channels.

11.6.4.2.3.2 Analysis of Reclaimed Channels

The flow velocities in the reclaimed channels were determined by entering the reclaimed channel sections into HEC-RAS. The reclaimed channel sections were taken from the Area III FSC on approximately 200-foot intervals. The reclaimed channel reaches are transitioned into the existing natural channel at the upstream and downstream ends. The transitions of the reclaimed channel to the natural channel generally occurred over a 100 to 200-foot reach. The post-mine peak flows and the gradient of that particular drainage channel dictated the geometry of the reclaimed channel. The locations of reclaimed channel cross-sections used in HEC-RAS are shown on Exhibit 11-78, Sheets 2-4. The typical reclaimed channel sections are shown on Exhibit 11-78C and the profiles are shown on Exhibit 11-78B.

The Manning's roughness coefficients (n) used for the reclaimed channels in the HEC-RAS analysis were as follows: 0.045 for the floodplain and a composite n of 0.033 for the channel bottom and channel banks. For the configuration of the reclaimed channels analyzed the composite n is approximately equivalent to a channel having n values of 0.030 for the channel bottom and 0.035 for the channel banks.

Due to lack of detailed cross-sections of the pre-mine channels in the Lowe Arroyo watershed a comparative analysis could not be made between pre-mining and post-mining conditions. In lieu of a comparative analysis, the reclaimed channels in the Lowe drainage area were designed to have flow velocities less than 5 fps during the 2-yr 6-hr peak flow. The gradients of the reclaimed channels in the Lowe drainage area are also generally less than pre-mine, except in the steep reaches where drop structures are required. This coupled with the cross-sectional configuration of the reclaimed channel strongly indicates that the post-mine flow velocities could possibly be less than the pre-mine. The HEC-RAS results for the reclaimed channels within the Lowe watershed are in Appendix 11-X1 and summarized on Table 11-26 and 11-26a.

Drop structures will be utilized in the steep reaches of the reclaimed channels to control erosion. The drop structures will be designed to remain stable during the 25-yr 6-hr peak flow and pass the 100-yr 6-hr peak flow with a 1-foot freeboard. A computer software, Rip-rap Design

Systems, Version 2; WEST Consultants, Inc.; San Diego, Ca, which calculates rip-rap size utilizing seven different methods was used to determine the rip-rap size. Four design methods (ASCE, USBR, Isbash, and HEC-11) were used to determine the D_{50} rock size. For the selected D_{50} rock size refer to the drop structure schedule on Exhibit 11-78C. The supporting design data for the drop structures is presented in Appendix 11-X3. The locations of the drop structures are shown on the plan and profile drawings, Exhibit 11-78, Sheets 2 and 3; and Exhibit 78B, Sheets 1 and 2, respectively.

Tributaries having less than 640 acres of watershed may require rip-rap down drains depending on the grade at the entrance into the main reclaimed channel. The designs for these down drains will be done during the final regrading process and will be presented on reclamation as-built drawings. The as-built drawings will be submitted to the regulatory agency.

TABLE 11-26
PRE-MINE AND POST-MINING CHANNEL VELOCITIES

North Fork

	Pre-Mine		Post-Mining	
Storm Event	Maximum Velocity (fps)	Average Velocity (fps)	Maximum Velocity (fps)	Average Velocity (fps)
2-Year	9.34	5.18	6.42	4.79
10-Year	12.08	6.46	8.71	4.73
25-Year	12.58	6.88	9.47	4.66
100-Year	13.48	7.20	10.73	4.70

Lowe

	Pre-Mine		Post-Mining	
Storm Event	Maximum Velocity (fps)	Average Velocity (fps)	Maximum Velocity (fps)	Average Velocity (fps)
2-Year	8.80	4.46	7.76	3.87
10-Year	11.59	5.95	8.70	5.20
25-Year	12.95	6.55	10.18	5.90
100-Year	14.51	7.13	12.03	6.56

Lowe North

	Pre-Mine		Post-Mining	
Storm Event	Maximum Velocity (fps)	Average Velocity (fps)	Maximum Velocity (fps)	Average Velocity (fps)
2-Year	n/a	n/a	5.58	4.32
10-Year	n/a	n/a	7.94	4.40
25-Year	n/a	n/a	8.38	4.42
100-Year	n/a	n/a	9.35	4.50

Lowe North R1

	Pre-Mine		Post-Mining	
Storm Event	Maximum Velocity (fps)	Average Velocity (fps)	Maximum Velocity (fps)	Average Velocity (fps)
2-Year	n/a	n/a	2.21	2.02
10-Year	n/a	n/a	3.76	3.40
25-Year	n/a	n/a	4.41	3.97
100-Year	n/a	n/a	5.11	4.57

Lowe North R2

	Pre-Mine		Post-Mining	
Storm Event	Maximum Velocity (fps)	Average Velocity (fps)	Maximum Velocity (fps)	Average Velocity (fps)
2-Year	n/a	n/a	3.93	3.83
10-Year	n/a	n/a	5.99	4.11
25-Year	n/a	n/a	7.06	4.03
100-Year	n/a	n/a	8.03	3.98

Lowe North R3

	Pre-Mine		Post-Mining	
Storm Event	Maximum Velocity (fps)	Average Velocity (fps)	Maximum Velocity (fps)	Average Velocity (fps)
2-Year	n/a	n/a	5.24	4.47
10-Year	n/a	n/a	7.15	6.14
25-Year	n/a	n/a	7.98	6.76
100-Year	n/a	n/a	9.09	7.49

Lowe North R4

	Pre-Mine		Post-Mining*	
Storm Event	Maximum Velocity (fps)	Average Velocity (fps)	Maximum Velocity (fps)	Average Velocity (fps)
2-Year	n/a	n/a	n/a	n/a
10-Year	n/a	n/a	n/a	n/a
25-Year	n/a	n/a	n/a	n/a
100-Year	n/a	n/a	n/a	n/a

Lowe South

	Pre-Mine		Post-Mining	
Storm Event	Maximum Velocity (fps)	Average Velocity (fps)	Maximum Velocity (fps)	Average Velocity (fps)
2-Year	n/a	n/a	4.87	3.38
10-Year	n/a	n/a	7.09	3.55
25-Year	n/a	n/a	7.39	3.57
100-Year	n/a	n/a	8.24	3.68

* The reclaimed reach is riprapped.

TABLE 11-26a
HEC-RAS RESULTS

North Fork Pre-mining

Flow Change Location (Sta)	2-Year			10-Year			25-Year			100-Year		
		Velocity (fps)			Velocity (fps)			Velocity (fps)			Velocity (fps)	
	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg
150.00	256.0	9.34	5.18	674.0	12.08	6.46	971.0	12.58	6.88	1,401.0	13.48	7.20

North Fork Post-mining

Flow Change Location (Sta)	2-Year			10-Year			25-Year			100-Year		
		Velocity (fps)			Velocity (fps)			Velocity (fps)			Velocity (fps)	
	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg
142.24	249	6.42	4.79	665	8.71	4.73	962	9.47	4.66	1,393	10.73	4.70
13.03*	1,050	N/A	N/A	2,880	N/A	N/A	4,196	N/A	N/A	6,107	N/A	N/A

* For the flow change the reach is undisturbed.

Lowe Pre-mining

Flow Change Location (Sta)	2-Year			10-Year			25-Year			100-Year		
		Velocity (fps)			Velocity (fps)			Velocity (fps)			Velocity (fps)	
	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg
38.83	253.0	8.80	5.00	735.0	11.59	7.13	1,089.0	12.95	8.07	1,597.0	14.32	9.09
15.95	315.0	7.35	5.77	926.0	10.96	8.05	1,370.0	12.67	9.04	2,017.0	14.51	10.01

Lowe Post-mining

Flow Change Location (Sta)	2-Year			10-Year			25-Year			100-Year		
		Velocity (fps)			Velocity (fps)			Velocity (fps)			Velocity (fps)	
	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg
38.83	127.0	7.76	3.94	386.0	7.09	4.56	578.0	8.25	5.08	859.0	9.66	5.47
33.20	146.0	7.09	3.60	490.0	8.47	5.33	755.0	9.97	6.20	1,156.0	11.21	7.02
15.95	155.0	7.09	3.87	514.0	8.70	5.29	791.0	10.18	6.01	1,206.0	12.03	6.72

Lowe North Post-mining

Flow Change Location (Sta)	2-Year			10-Year			25-Year			100-Year		
		Velocity (fps)			Velocity (fps)			Velocity (fps)			Velocity (fps)	
	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg
90.01	125.00	5.26	4.14	372.0	7.03	4.24	553.0	7.69	4.35	820.0	8.78	4.46
53.09	127.00	5.58	4.73	386.0	7.94	4.77	578.0	8.38	4.59	859.0	9.35	4.58

Lowe North R1 Post-mining

Flow Change Location (Sta)	2-Year			10-Year			25-Year			100-Year		
		Velocity (fps)			Velocity (fps)			Velocity (fps)			Velocity (fps)	
	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg
12.73	17.0	2.21	2.02	77.0	3.76	3.40	126.0	4.41	3.97	202.0	5.11	4.57

Lowe North R2 Post-mining

Flow Change Location (Sta)	2-Year			10-Year			25-Year			100-Year		
		Velocity (fps)			Velocity (fps)			Velocity (fps)			Velocity (fps)	
	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg
14.00	112.0	3.93	3.83	307.0	5.99	4.11	445.0	7.06	4.03	643.0	8.03	3.98

Lowe North R3 Post-mining

Flow Change Location (Sta)	2-Year			10-Year			25-Year			100-Year		
		Velocity (fps)			Velocity (fps)			Velocity (fps)			Velocity (fps)	
	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg
15.89	33.0	5.24	4.04	98.0	7.15	5.42	144.0	7.98	5.96	210.0	9.09	6.60

Lowe North R4 Post-mining

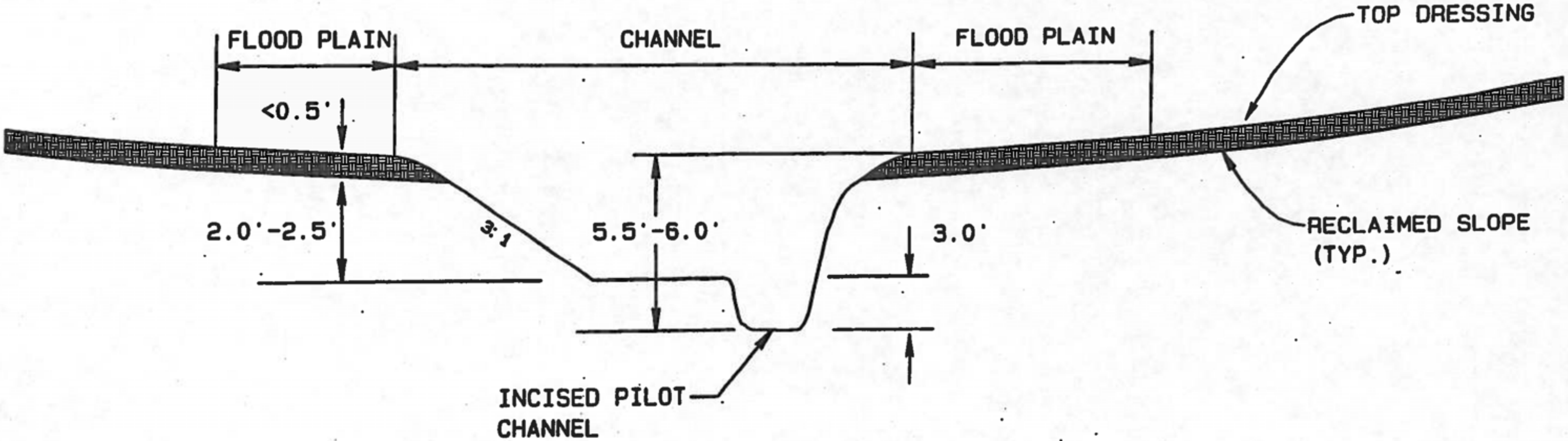
Flow Change Location (Sta)	2-Year			10-Year			25-Year			100-Year		
		Velocity (fps)			Velocity (fps)			Velocity (fps)			Velocity (fps)	
	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg
11.71*	86.0	N/A	N/A	230.0	N/A	N/A	331.0	N/A	N/A	475.0	N/A	N/A

Lowe South Post-mining

Flow Change (Sta)	2-Year			10-Year			25-Year			100-Year		
		Velocity (fps)			Velocity (fps)			Velocity (fps)			Velocity (fps)	
	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg	Q (cfs)	Max	Avg
258.72*	83	N/A	N/A	209	N/A	N/A	296	N/A	N/A	418	N/A	N/A
243.0	106	3.62	3.07	318	5.78	2.98	473	6.32	3.01	701	7.39	3.13
178.00	106	4.87	3.56	329	7.09	3.86	495	7.39	3.89	739	8.24	3.99
33.2*	106	N/A	N/A	490	N/A	N/A	755	N/A	N/A	1,156	N/A	N/A
15.95*	155	N/A	N/A	514	N/A	N/A	791	N/A	N/A	1,206	N/A	N/A

* For the flow change the entire reach is either undisturbed or riprapped.

FIGURE 11-29



TYPICAL RECLAIMED CHANNEL SECTION

N.T.S.

11.6.4.2.4 Ephemeral Stream Diversion Designs

All streams within the Navajo Mine permit area with the possible exception of Chinde Arroyo are hydrologically ephemeral streams. Nevertheless, OSM regulations classify all streams with drainage areas greater than one square mile as intermittent streams regardless of flow conditions. Reclamation features and structures will be designed in accordance with the Reclamation Surface Stabilization Handbook (BNCC, 1992), which provides information concerning design of permanent diversions for ephemeral streams and addresses low order stream segments with drainage areas less than one square mile.

Design flows were developed using the SEDCAD computer model following the procedures and assumptions described in Chapter 7.

11.6.4.2.5 Area IV North Reclaimed Channels

All of the drainage basins in post-mining topography are less than one square mile (640 acres). Per the Reclamation Surface Stabilization Handbook (BNCC, 1992) the channels for these drainage basins will not require detail designs. The detail designs will be developed during the final regrading and reclamation process.

11.6.5 Impacts to Surface Water Availability

Ephemeral surface flows are unpredictable and of such poor water quality that essentially no use is made of the water for agricultural or other purposes (Chapters 6 and 7). Stock watering ponds are the principal use made of water on or near the permit area. Steps are taken to assure that this use is not impaired. During surface coal mining operations there will be a temporary reduction in surface water flows in the mined out drainages.

Following reclamation, the water supplies for existing livestock use will be replaced. Water levels in the alluvium downstream of mining are expected to recover following mining and flows will be equivalent or may actually be higher than in pre-mine conditions due to enhanced recharge rates within reclaimed areas.

The ponds found in the permit areas during the baseline surveys do not appear to have water-right filings (Chapter 7); 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. The water availability at the reconstructed ponds should be comparable to pre-mine conditions, as SEDCAD modeling presented in Section 11.6.3.3 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.

BNCC has designed the Navajo Mine operations plan to minimize impacts to surface water through the use of sediment control measures for storm water runoff. These include reducing the disturbance area footprint, backfilling and stabilizing the pit areas as soon as practicable, and use of multiple hydrologic structures. The structures range from berms established around isolated areas of disturbance and coal stockpiles, to sedimentation ponds downgradient of mining, to armoring of channels in steep gradients. The Navajo Mine operations plan minimizes the potential for upland waters to commingle with runoff from disturbed areas through the diversion of streams upgradient of the operation around the active mining areas, and construction of upgradient or highwall impoundments. In addition, the BNCC implements a stream buffer zone policy to protect perennial and intermittent streams.

Sediment concentrations are predicted to be the same or less than pre-mining, however modeling suggests that post-mining, there may be increases in settleable solids concentrations from the mobilization of fine-grained materials. The best management practices are focused towards minimizing sediment, which will limit the dissolution of salts from fine particles entrained by runoff events. There is the potential for increases in TDS, sulfates, iron, and manganese in waters leaving the permit area, but concentrations of these parameters will not exceed water quality standards and criteria associated with the predominant use of surface waters for livestock watering. In addition, BNCC has an SPCC plan that identifies areas of risk, specifies specific locations for containment structures, and has spill management protocols to minimize impacts from accidental releases of petroleum hydrocarbons.

The mining and reclamation plan re-establishes a final surface configuration which is comparable to the pre-mine topography. The calculated drainage density is equal or greater than the pre-mining topography, except in areas of pre-mine badlands. Reclaimed channels will have a small pilot channel within a floodplain. The reclamation plan has been engineered to minimize the potential for long-term badland development through the design of stable post-mining reclamation channels which have the potential for self-armoring and through the use of topdressing that is a suitable plant growth medium. The latter should better support the establishment of a sustaining and stabilizing vegetative cover. These reclamation strategies will minimize the potential for gully establishment and head cutting should destructive storm flows drain through the reclaimed watersheds. Modeling predicts post-mining peak flows similar or lower than pre-mining flows.

The probable hydrologic projections suggest that mining will not have a deleterious impact on the hydrologic balance within the area, and BNCC will verify this through the hydrologic monitoring program and assessments prepared for bond release.

11.6.6 Hydrologic Monitoring Reporting

Hydrologic monitoring reports will be submitted to OSM on a quarterly frequency and a detailed monitoring report will be submitted twice during the permit term. The quarterly monitoring report will consist of a summary of the data collected and events for the quarter, identification of anomalies, inconsistencies, or non-compliances, and include an electronic copy of the raw analytical data on disk.

In addition to the quarterly hydrologic monitoring report, an in-depth hydrology report will be submitted twice during the permit term to OSM. This detailed hydrologic monitoring report will provide a detailed reduction, analysis, and interpretation of surface water and groundwater data collected to date, in addition to the raw data. The analysis will include plotting hydrographs, parameter concentration vs. time graphs, trilinear graphs, and statistical summaries. The monitoring data is then compared against historical data trends and water quality standards to identify changes in water quality or quantity. Specifically for the detailed report, flow and water quality data will be provided as detailed below.

Flow: For the nearly perennial Chinde Arroyo stations, CD-1A and CD-2A, quarterly hydrographs will be plotted. A comparison of the flow between the upstream and downstream stations will be provided.

Water Quality and Sediment: Stage and discharge corresponding to each sample will be reported along with the measured concentrations. For Chinde Arroyo, summary statistics will include water yield and sediment and analyte concentrations for each month. A comparison of water quality and sediment concentrations between the upstream and downstream stations will be provided.

A comparison will be made between surface water quality concentrations collected and the applicable water quality State of New Mexico for Interstate and Intrastate Streams standards and Navajo Nation Stream Standards for both the biannual report and the quarterly reports.

Discussion on requirements of the Clean Water Act, National Pollutant Discharge Elimination System, (NPDES) and the Stormwater Pollution Prevention Plan (SWPPP) is found in Section 11.2.6.

11.6.6.1 Surface Water Reference Criteria

Surface water reference criteria were developed from 8 years of surface water monitoring data to aid in the evaluation of future surface water monitoring data.

Each reference criteria value at each station (Table 11-27a through 11-27g) was determined by selecting the larger of the mean plus two (2) standard deviations, which was determined from the baseline data, the maximum value in the data set.

Reference criteria were not determined for calcium, magnesium, sodium, potassium, carbonate, bicarbonate, and sulfate because these parameters will be used to calculate an ion balance.

The reference criteria will be adjusted based on changing technical information and regulations and new field data. The criteria will be re-evaluated at permit renewal time.

TABLE 11-27A
SURFACE WATER MONITORING REFERENCE CRITERIA
SATAION CD-1[1,2]

PARAMETER	UNIT	SELECTED CRITERIA	MAX DETECT LIMIT
Conductivity	µmhos/cm	3189	10
pH	Units	8.7	-
TDS	mg/l	2284	25
TSS	mg/l	1265	25
Calcium	mg/l	120	10
Magnesium	mg/l	32.4	10
Sodium	mg/l	586	25
Potassium	mg/l	5.23	0.5
Carbonate	mg/l	44.3	2
Bicarbonate	mg/l	572	10
Sulfate	mg/l	986	10
Chloride	mg/l	139	10
Fluoride	mg/l	4.3	0.1
Iron	mg/l	20.7	0.25
Boron	mg/l	0.90	0.1
Selenium	mg/l	0.015	0.001

(1) Data set includes NAPI irrigation, seasonal seepage, and precipitation runoff samples.
(2) Data set represents samples from 1996-2003

TABLE 11-27b
SURFACE WATER MONITORING REFERENCE CRITERIA
STATION CD-2[1,2]

PARAMETER	UNIT	SELECTED CRITERIA	MAX DETECT LIMIT
Conductivity	µmhos/cm	4187	10
pH	Units	8.5	-
TDS	mg/l	3328	25
TSS	mg/l	365	25
Calcium	mg/l	624	10
Magnesium	mg/l	56.4	10
Sodium	mg/l	727	25
Potassium	mg/l	11.0	0.5
Carbonate	mg/l	36.8	2
Bicarbonate	mg/l	398	10
Sulfate	mg/l	1763	10
Chloride	mg/l	176	10
Fluoride	mg/l	2.14	0.1
Iron	mg/l	6.1	0.25
Boron	mg/l	0.55	0.1
Selenium	mg/l	0.013	0.001

(1) Data set includes NAPI irrigation, seasonal seepage, and precipitation runoff samples.
(2) Data set represents samples from 1996-2003

TABLE 11-27c
SURFACE WATER MONITORING REFERENCE CRITERIA
STATION CN-1[3,4,5]

PARAMETER	UNIT	SELECTED CRITERIA	MAX DETECT LIMIT
Conductivity	µmhos/cm	2019	1
pH	Units	8.6	-
TDS	mg/l	1611	25
TSS	mg/l	293,000	1
Calcium	mg/l	-	0.5
Magnesium	mg/l	-	0.5
Sodium	mg/l	-	0.5
Potassium	mg/l	-	0.5
Carbonate	mg/l	-	2
Bicarbonate	mg/l	-	10
Sulfate	mg/l	-	10
Chloride	mg/l	1500	10
Fluoride	mg/l	1.84	0.1
Nitrate	mg/l	-[5]	0.05
Iron	mg/l	7.0	0.25
Manganese	mg/l	4.0	0.25
Boron	mg/l	0.78	0.1
Selenium	mg/l	0.02	0.001

(3) Data set includes irrigation and precipitation runoff samples.
(4) Data set represents eight (8) years of data collection, 1985-1992
(5) Baseline data collection is not complete, monitoring discontinued May 2000.

TABLE 11-27d
SURFACE WATER MONITORING REFERENCE CRITERIA
STATION CNS-1[3,4, 5]

PARAMETER	UNIT	SELECTED CRITERIA	MAX DETECT LIMIT
Conductivity	µmhos/cm	2300	1
pH	Units	8.7	-
TDS	mg/l	1669	25
TSS	mg/l	1,120,000	1
Calcium	mg/l	-	0.5
Magnesium	mg/l	-	0.5
Sodium	mg/l	-	0.5
Potassium	mg/l	-	0.5
Carbonate	mg/l	-	2
Bicarbonate	mg/l	-	10
Sulfate	mg/l	-	10
Chloride	mg/l	1500	10
Fluoride	mg/l	1.84	0.1
Nitrate	mg/l	-[5]	0.05
Iron	mg/l	7.0	0.25
Manganese	mg/l	4.0	0.25
Boron	mg/l	1.02	0.1
Selenium	mg/l	0.02	0.001

(3) Data set includes irrigation and precipitation runoff samples.
(4) Data set represents eight (8) years of data collection, 1985-1992
(5) Baseline data collection is not complete, monitoring discontinued May 2000.

TABLE 11-27e
SURFACE WATER MONITORING REFERENCE CRITERIA
STATION CS-1[3,4, 5]

PARAMETER	UNIT	SELECTED CRITERIA	MAX DETECT LIMIT
Conductivity	µmhos/cm	5620	1
pH	Units	8.62	-
TDS	mg/l	1240	25
TSS	mg/l	1,030,000	1
Calcium	mg/l	-	0.5
Magnesium	mg/l	-	0.5
Sodium	mg/l	-	0.5
Potassium	mg/l	-	0.5
Carbonate	mg/l	-	2
Bicarbonate	mg/l	-	10
Sulfate	mg/l	-	10
Chloride	mg/l	1500	10
Fluoride	mg/l	1.32	0.1
Nitrate	mg/l	-[5]	0.05
Iron	mg/l	17.6	0.25
Manganese	mg/l	4.0	0.25
Boron	mg/l	1.10	0.1
Selenium	mg/l	0.02	0.001

(3) Data set includes irrigation and precipitation runoff samples.
(4) Data set represents eight (8) years of data collection, 1985-1992
(5) Baseline data collection is not complete, monitoring discontinued May 2000.

TABLE 11-27f
SURFACE WATER MONITORING REFERENCE CRITERIA
STATION NB-1[3,4, 5]

PARAMETER	UNIT	SELECTED CRITERIA	MAX DETECT LIMIT
Conductivity	µmhos/cm	8200	1
pH	Units	8.6	-
TDS	mg/l	8260	25
TSS	mg/l	67,300	1
Calcium	mg/l	-	0.5
Magnesium	mg/l	-	0.5
Sodium	mg/l	-	0.5
Potassium	mg/l	-	0.5
Carbonate	mg/l	-	2
Bicarbonate	mg/l	-	10
Sulfate	mg/l	-	10
Chloride	mg/l	1500	10
Fluoride	mg/l	2.96	0.1
Nitrate	mg/l	-[5]	0.05
Iron	mg/l	7.0	0.25
Manganese	mg/l	4.0	0.25
Boron	mg/l	0.98	0.1
Selenium	mg/l	0.02	0.001

(3) Data set includes irrigation and precipitation runoff samples.
(4) Data set represents eight (8) years of data collection, 1985-1992
(5) Baseline data collection is not complete, monitoring discontinued May 2000.

TABLE 11-27g
SURFACE WATER MONITORING REFERENCE CRITERIA
STATION NB-2[3,4, 5]

PARAMETER	UNIT	SELECTED CRITERIA	MAX DETECT LIMIT
Conductivity	µmhos/cm	4200	1
pH	Units	8.6	-
TDS	mg/l	3840	25
TSS	mg/l	64,500	1
Calcium	mg/l	-	0.5
Magnesium	mg/l	-	0.5
Sodium	mg/l	-	0.5
Potassium	mg/l	-	0.5
Carbonate	mg/l	-	2
Bicarbonate	mg/l	-	10
Sulfate	mg/l	-	10
Chloride	mg/l	1500	10
Fluoride	mg/l	1.86	0.1
Nitrate	mg/l	-[5]	0.05
Iron	mg/l	7.0	0.25
Manganese	mg/l	4.0	0.25
Boron	mg/l	0.75	0.1
Selenium	mg/l	0.022	0.001

(3) Data set includes irrigation and precipitation runoff samples.
(4) Data set represents eight (8) years of data collection, 1985-1992
(5) Baseline data collection is not complete, monitoring discontinued May 2000.

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