CHAPTER 6

GROUNDWATER HYDROLOGY

6.1 AQUIFER DELINEATION

The Navajo Mine is located on the western flank of the San Juan Structural Basin in northwestern San Juan County approximately 15 miles west of Farmington, New Mexico. The geologic formation dips gently to the east toward the center of the basin at an angle of one to two degrees and steepens toward the outcrop areas where a fairly abrupt monocline (Hogback) can be observed. A more thorough description of the regional and localized geology of Navajo Mine is provided in CHAPTER 5.

The mine and adjacent areas are underlain by the Pictured Cliffs Sandstone Formation, Fruitland-Kirtland Formation, and unconsolidated alluvial deposits in the valleys of the San Juan River, Chaco River, and the Chinde and Cottonwood Arroyos. A number of ground water monitoring wells have been completed (Exhibit 6-1, Appendix 6.G Exhibit 6.G-1, Exhibit 11-166) in the geologic formations on and near the permit area. The BNCC coal lease monitoring wells for Resources Areas III, IV, and V are shown on Exhibit 6.G-1 and are described in APPENDIX 6.G. Additional baseline data were also obtained from monitoring wells and vibrating wire piezometers (VWPs) installed in the Fruitland coals and in the underlying Pictured Cliffs Sandstone Formation for baseline hydrogeology characterization of Area IV and Area V of the BHP Navajo Coal Company (BNCC) coal lease. The data from these wells and VWPs are provided in Appendix 6.G along with a charaacterization of the groundwater aquifers within the Area 4 North resource area of the BNCC lease area. This Appendix also provides the baseline data that are used to support the development and calibration of multilayer, numerical, groundwater flow model of the hydrogeologic system of Areas IV and V of the BNCC lease.

To obtain hydrologic information, a piezometer installation program was conducted throughout the mine area to estimate the water-bearing potential of the above geologic formations.

Information on the water-bearing zones within these formations was obtained during drilling by monitoring fluid return, air injection pressure, and lithology.

Aquifers were delineated using two different methods. The first approach treated the individual coal seams in the Fruitland Formation as separate aquifers. This resulted in the potentiometric surface maps for the major coal seams (EXHIBITS 6-2 through 6-5). Since the coal seams are discontinuous through the formation, an alternate approach for delineation was considered which utilized United States Geological Survey (USGS) data and treated the coal seams and interbedded lithologic units of the Fruitland Formation as a single aquifer. The single aquifer approach was previously evaluated (Billings, 1987) A copy of the Billings (1987) report

TABLE 6-1 AQUIFER DISCHARGE CHARACTERISTICS

			Total Depth							
Well Name	Location	Casing I.D.	Elev.	Depth	type Test	Transmissivity	Permeability	Saturated Thickness	Formation*	Remarks
SJKF84#3	N 2089324.18	2.0 in.	4990.18	120	(1)	1.42 ft^2/d	0.08 ft/d	18.0 ft.	No. 8	Q=1 gpm; VCW=18.06 gal.
	E 3355493.72				(2)	0.71 ft^2/d	0.04 ft/d			Secondary Permeability
SJKF84#4	N 2086566.75	2.0 in.	5046.67	71	(1)	1.45 ft^2/d	0.08 ft/d	18.0 ft.	No. 8	Q=0.3 gpm; VCW=11.77 gal.
	E 333233.40				(2)	1.03 ft^2/d	0.06 ft/d			Secondary Permeability
SJKF84#5	N 2084412.50	2.0 in.	5092.00	180	(1)	2.08 ft^2/d	0.12 ft/d	18.0 ft.	No. 8	Q=0.1 gpm; VCW=5.52 gal.
	E 331410.00				(2)	0.07 ft^2/d	0.004 ft/d			Secondary Permeability
KF8420(c)	N 2017120.64	2.0 in.	5213.92	190	(1)	1.28 ft^2/d	0.26 ft/d	5.0 ft.	No. 7	Q=0.2 gpm; VCW=8.1 gal.
	E 304307.65				(2)	0.01 ft^2/d	0.002 ft/d			Secondary Permeability
KF8420(a)	N 2017128.35	2.0 in.	5163.78	240	(1)	0.12 ft^2/d	0.012 ft/d	10.0 ft.	No. 2	Q=0.2 gpm; VCW=13.9 gal.
	E 304306.50				(2)	0.009 ft^2/d	0.001 ft/d			Secondary Permeability
KF8421(c)	N 2012188.62	2.0 in.	5219.66	75	(1)	9.08 ft^2/d	1.82 ft/d	5.0 ft.	No. 7	Q=0.5 gpm; VCW=6.12 gal.
	E 302693.56				(2)	0.04 ft^2/d	0.008 ft/d			Secondary Permeability
KF8422(b)	N 2009513.79	2.0 in.	5204.10	140	(1)	0.76 ft^2/d	0.152 ft/d	5.0 ft.	No. 7	Q=0.13 gpm; VCW=9.94 gal.
	E 307829.36				(2)	0.02 ft^2/d	0.003 ft/d			Secondary Permeability
KF8422(c)	N 2009528.55	2.0 in.	5142.50	202	(1)	0.04 ft^2/d	0.006 ft/d	7.0 ft.	No. 4-6	Q=0.03 gpm; VCW=18.37 gal.
	E 307841.20				(2)	0.01 ft^2/d	0.0014 ft/d			Secondary Permeability
KF8422(d)	N 2009525.42	2.0 in.	5124.20	220	(1)	0.71 ft^2/d	0.14 ft/d	5.0 ft.	No. 3	Q=0.17 gpm; VCW=19.82 gal.
	E 307832.96				(2)	0.01 ft^2/d	0.002 ft/d			Secondary Permeability
KF8422(e)	N 2009531.93	2.0 in.	5107.80	237	(1)	0.15 ft^2/d	0.015 ft/d	10.0 ft.	No. 2	Q=0.08 gpm; VCW=22.65 gal.
	E 307820.38				(2)	0.01 ft^2/d	0.001 ft/d			Secondary Permeability

* Fruitland (KF) Formation
(1) Standard Recovery
(2) Modified Recovery

6.2.2.3 No. 4-6 Coal Seam

As was the case for the No. 7 Seam, the No. 4-6 Coal Seam extends from Area III to the south, and northward to just south of the North Area (Area I) where it thins out completely. FIGURE 6-14 shows the results of aquifer testing on the No. 4-6 Coal Seam. The No. 4-6 Coal Seam has an average thickness of seven feet and outcrops to the west of the permit area. No. 4-6 Coal Seam, as with the other coal strata, exhibits extremely low levels of transmissivity and permeability with values of 0.025 ft^2/day and 0.0037 ft/day, respectively. EXHIBIT 6-4 shows the potentiometric surface of the No. 4-6 Coal Seam. As observed, flow from the no. 4-6 Seam is both northeasterly and southwesterly toward the Cottonwood Arroyo discharge area. Flow gradients within the seam range from 0.0001 ft/ft to 0.001ft/ft and flow velocities range from 7.4 x 10^{-6} ft/day to 4.0 x 10^{-5} ft/day.

6.2.2.4 No. 2-3 Seam

The No. 2-3 Seam extends from Area III to the south, and northward to just above Area III, where the coal unit gradually thins and eventually disappears. The No. 2-3 Coal Seam an average thickness of 5 to 10 feet throughout Area III and outcrops to the west of the permit area. Secondary permeability predominates in the No. 2-3 Coal Seam with average transmissivity and permeability values of 0.16 ft^2/day and 0.00075 ft/day, respectively. FIGURE 6-15 through 6-17 provide the results of aquifer testings. EXHIBIT 6-5 shows the potentiometric surface on this seam. Flow from the No. 2-3 seam within the permit area is generally toward its discharge area in the Cottonwood Arroyo. The flow gradient is relatively flat (0.0003 ft/ft) with only two foot decline over a 7000 foot distance. This low gradient and permeability translates into a flow velocity of only 4.5 x 10^{-5} ft/day (0.01 ft/year).

6.3 GROUNDWATER QUALITY

As previously stated, groundwater exists within the Pictured Cliffs Sandstone, in selected lenticular coal strata of the Fruitland Formation, and in the Chinde Arroyo and Cottonwood Arroyo alluvial deposits. In order to obtain representative baseline water quality information from the deposits, the piezometers were purged at least twenty-four hours prior to sampling. The piezometers were sampled, preserved, shipped and analyzed in accordance with EPA guidelines (Guidelines Estimating Test Procedures for the Analysis of Pollutants 40 CFR Part 136). A summary of laboratory results for Fruitland Formation coal wells is provided in TABLE 6-2. Also, baseline water quality monitoring results for the Pictured Cliffs and Quaternary Alluvial Deposits are found in APPENDIX 6.C and APPENDIX 6.G. The results for each are briefly summarized below. The results presented in TABLE 6-2 are the median concentrations for the period of record, except for Baseline Fruitland Coals wells within the BNCC coal lease. The median baseline concentrations for the Fruitland Coals wells within coal lease are presented for the monitoring period only. For the coal monitoring wells within Areas II and III of the coal lease the baseline period was assumed to end at the end of year 2001 consistent with the period of record used for the calculation of reference criteria. Median concentrations were calculated based on all but rejected sample results including field splits and non detected results Less than detection results were estimated at 1/2 the detection limit for calculating the median concentration. When the calculated median is found to be at one half the value of a detection limit, the detection limit is shown as the median in the table if it is lower than any detected result.

Based on the limited seasonal water quality data available, it is evident that analytical parameters do not fluctuate seasonally within the bedrock water-bearing units. The lack of seasonality is typical for aquifers with very low transmissivities and constant static water levels.

6.3.1 <u>Pictured Cliffs Sandstone</u>

Water within the Pictured Cliffs is of poor quality and is classified as a sodium sulfate water type with high concentrations of chloride and abundant hydrogen sulfide gas evident during sampling.

Generally, water quality improves near the outcrop or recharge areas and quickly declines down dip to near connate conditions. Since 1986, data has been submitted to the Office of Surface Mining (OSM) on a quarterly basis (see APPENDIX 6C for copies of analyses from 1975 to 1985).

Table 6-2
Groundwater Quality Summary Table

well category	Well	Monitoring Period*	pH (SU)		TDS -180° (mg/L)		Bicarbonate as HCO_3 (mg/L)		Carbonate as CO_3 (mg/L)		Chloride (mg/L)		Sulfate (mg/L)		Calcium (mg/L)		Magnesium (mg/L)		Potassium (mg/L)	
			n	median	n	median	n	median	n	median	n	median	n	median	n	median	n	median	n	median
Baseline Fruitland Coals within coal lease (median concentrations)	KF2007-01 (No. 8)	2007-2008	5	8.75	5	3460	5	1818	5	156	5	3385	6	740	5	3.2	5	1.7	6	17.9
	KF98-02 (No. 3)	1998 2007-2008	6	7.95	6	3130	6	1512	6	30	6	940	6	107	6	6.1	6	0.9	8	12.1
	KF84-21a (No 2)	1984-2001	30	7.9	30	8375	30	1197	17	<1	30	4445	30	63	30	13.3	30	14.9	30	13.3
	KF84-21c (No 7)	1984	1	8.08	1	8505	1	919	1	68.4	1	3980	1	184	1	14.6	1	14.9	1	15.0
	KF84-22a (No 8)	1984-2001	22	8.0	22	4650	22	1170	12	<1	22	290	22	2140	22	15.3	22	3.5	22	6.8
	KF84-22b (No 7)	1984-2001	26	7.4	26	6115	25	854	15	<1	25	3220	26	<10	26	45.0	26	13.4	26	11.9
	KF84-22d (No 3)	1984	1	7.94	1	8610	1	830	1	46.8	1	3420	1	<10	1	27.4	1	18.7	1	15.8
	KF84-22e (No 2)	1984	2	7.98	2	8155	2	814	2	52.8	2	4185	2	24.5	2	35.6	2	17.5	2	16.3
	KF84-20A (No 3)	1984-2001	26	7.93	26	7260	26	1090	23	<1	26	3715	26	<10	26	18.4	26	11.0	26	11.9
	KF84-20C (No 7)	1984-2001	23	7.9	23	2770	23	1562	21	<1	23	715	23	7	23	9.6	23	2.8	23	5.9
	KF84-18b (No 8)	1984-2001	25	7.1	25	9300	25	1030	13	<1	25	4900	25	<10	25	114.0	27	24.3	25	15.0
	KF84-18a (No. 6)	1984-2001	26	7.47	26	13400	26	450	14	<1	26	7900	26	5.5	26	157.0	26	50.6	26	22.5
Baseline Coal downgradient (median)	SJKF#2	1984	1	7.03	1	43035	1	944	1	<1	1	23800	1	<10	1	515	1	222	1	56
	SKJF#3	1984	1	7.29	1	50810	1	673	1	<1	1	28200	1	<10	1	700	1	278	1	61
	SJKF#4	1984	1	8.06	1	7370	1	3232	1	276	1	2210	1	<10	1	26.5	1	9.18	1	13.5
Potentially Affected Coal Wells (median)	Bitsui-2	1995-2010	26	8	26	5145	26	3233	18	2.75	26	1160	26	165	26	6.21	26	2.4	25	7
	Bitsui-3	1995-2009	21	7.6	17	7960	21	3123.2	12	<1	21	2820	21	317	21	22.4	21	9.4	20	11
	KF83-1	1983-2002	41	7.8	41	7100	40	3092.7	12	138	41	2255	41	340	41	19.4	41	6.9	40	9.35
	KF84	1985-2000	27	7.8	26	7760	27	1420	7	44.4	27	323	27	3860	27	47.5	27	25.9	27	8.6
	KF84-16	1985-2002	32	7.6	32	9955	32	2797.2	7	120	32	4551	32	15.5	32	38.2	32	14.95	32	16.3
	SJKF#5	1984	1	8.12	1	4470	1	3770	1	230	1	360	1	<10	1	5.57	1	2.27	1	11.1

*Monitoring period is period of record, except for Baseline Fruitland Coals wells within coal lease

Median calculation based on all but rejected sample results including field splits and non detected results

Rejected samples include: samples with no sampling or analysis date, samples with pH>11, samples that are clearly inconsistent with results of other samples
uncaracterized metals results included as dissolved metals in statistical summray

For less than detection limit, 1/2 the detection limit used for summary unles the median is a detection limit that is lower than any detected result

6.3.2.1 No. 8 Coal Seam

The No. 8 Coal Seam water can be classified as a sodium bicarbonate – chloride type with high concentrations of fluoride and high concentrations of sulfate in shallow wells near the recharge area and low concentrations of sulfate in deeper wells and wells near groundwater discharge locations. Median concentrations of total dissolved solids (TDS) range from 3,460 mg/l to 50,010 mg/l and median pH ranges from 7.03 to 8.75. Generally, better water is observed closer to the mine area and extremely poor water is seen at potential discharge locations, e.g. San Juan River.

6.3.2.2 No. 7 Coal Seam

The No. 7 Coal Seam water is also classified as a sodium-bicarbonate-chloride type with high concentrations of carbonate and nitrates. Median concentrations of total dissolved solids range from 2,770 mg/l to 8,505 mg/l and pH ranges from 7.48 to 8.08.

6.3.2.3 No. 4-6 Coal Seam

The No. 4-6 Coal Seam water is classified as sodium – chloride type with high concentrations of iron and manganese. A median total dissolved solids concentration of 13,400 mg/l and median pH of 7.4 was observed in the analytical results for the No. 6 coal seam well KF84-18a.

6.3.2.4 No. 2-3 Coal Seam

The No. 2-3 Coal Seam is classified as sodium–chloride–bicarbonate type with high concentrations of carbonates. Median concentrations of total dissolved solids range from 3,130 mg/l to 8.610 mg/L and the median pH ranges from 7.9 to 7.98.

6.3.3 Quaternary Alluvium

As previously stated, within the permit area water occurs in the alluvial deposits of the Chinde Arroyo, Cottonwood Arroyo, drainages. Since 1986, data has been submitted to OSM on a quarterly basis (see APPENDIX 6C for copies of data from 1975 to 1985). Water quality within these fill deposits can generally be described as poor with total dissolved solid (TDS) concentrations at well QAC-1 (Chinde alluvium) ranging from 7,700 to 17,200 mg/l, with a mean of 12,340 mg/l. The elevated TDS is the result of high concentrations of sodium, sulfate and chloride, (sodium chloride-sulfate water type) which is typical of these ephemeral wash alluvial aquifers. The concentrations for the major ions are: sulfate ranges form 500-5,520 with a mean of 4,150 mg/l; sodium ranges from 1,410-4,460 mg/l with a mean of 3,669 mg/l; chloride ranges from 1,200-4,900 mg/l with a mean of 3,397 mg/l.

Weak seasonal correlation is evident at well QAC-1 for static water levels, pH sulfate and manganese; however, it does not appear to fluctuate consistently from year to year, and in some years no seasonality is apparent. Seasonal fluctuations in the water quality are related to the changes in water quantity, as recorded by changing static water levels. Generally the water quantity increases in the winter and spring during the period of low evapotranspiration and greater recharge from snow melt runoff. In Chinde Wash, discharge rates by NAPI may dictate to a larger degree fluctuations in water chemistry than seasonality.

It is not possible to determine seasonal water quality fluctuations in Cottonwood Arroyo alluvium due to the insufficient number of samples caused by frequent dry well conditions. Data to support seasonal fluctuations can be found in the annual and quarterly hydrology reports. Median concentrations from baseline monitoring of Cottonwood alluvial wells are summarized in APPENDIX 6.G Table 6.G-1.

TABLE 6-4

NAVAJO MINE

GROUNDWATER SAMPLING PARAMETER LIST

(BEDROCK AND ALLUVIAL WELLS)

CATEGORY	PARAMETER
GENERAL	Temperature
	Water level
WATER QUALITY	Carbonate
	Bicarbonate
	Sulfate
	Chloride
	Fluoride
	Total Dissolved Solids (TDS)
	Conductivity
	pH
METALS	Selenium
	Calcium
	Magnesium
	Sodium
	Potassium

TABLE 6-6

Analytical Methods and Detection Limits

PARAMETERS	EPA METHOD	DETECTION LIMITS
Temperature	170.1	0.2^0 C
Total Dissolved Solids (TDS)	160.1	10 mg/L
Conductivity	120.1	10 μmh/cm
pH	150.1	0.5 S.I. units
Water level	(*)	0.01 feet
Calcium	200.7	0.10 mg/L
Magnesium	200.7	0.05mg/L
Sodium	200.7	0.50 mg/L
Potassium	200.7	0.50 mg/L
Carbonate	310.1	2.00 mg/L
Bicarbonate	310.1	2.00 mg/L
Sulfate	300.0	1.00 mg/L
Chloride	300.0	1.00 mg/L
Selenium	270.3	0.01 mg/L
Fluoride	A4500-F C	1.5 mg/L

* RCRA Ground Water Monitoring Technical Enforcement Guidance Document, 1986

APPENDIX 6E

WATER SUPPLY WELLS & SPRINGS

WITHIN AND ADJACENT TO THE NAVAJO MINE LEASE

(UPDATED FROM 1989 APPENDIX 12D)

This appendix contains information pertaining to water supply wells and springs that exist in and adjacent to the mine lease area. The original data was collected by Utah International for the Navajo Mine permit developed in 1985, and summarized in Appendix 12D. Norwest Corporation supplemented the previous information with data summarized by the New Mexico Office of the State Engineer (2010) Navajo Settlement Agreement, which enumerated the extent of known existing and historic water uses on Navajo Lands. Nine sites are improved springs (Table 6E-1). A total of 50 wells have been identified within a two-mile radius of the mine operation. Twenty-nine wells were identified as alluvial wells. In addition, one well (13-AW) located within the Chaco River valley was identified as alluvium-artesian. This well is described as 530-foot deep oil and gas well converted to livestock use and is not completed in the Chaco River alluvium. Fifteen wells were identified with an unknown completion. Three of these well with an unknown completion are identified as dug well and are likely completed in the alluvium. No well were identified with completions in the Fruitland Formation. One well was identified with a completion in the Kirtland Formation and four wells were identified as completed in the Pictured Cliffs Sandstone. Eight of the 50 wells were identified as being equipped with windmills to pump water. Most of the wells are used for stock water, although the use was listed as unknown for fifteen of the wells and two of the wells (#90 and SJ00248) also were also listed as domestic use. One well (13-7-2) is identified as abandoned. No wells or springs have been ground truth checked. It is not known whether wells, other than 13-7-2) are still in existence, or have been abandoned and plugged.

Location, ownership, type and amount of water, depth of water, usage, well completion zone(s), well yield, well depth, and water quality information were collected and enumerated where available for the wells and springs included in the BAI inventory. These results are provided in the Addendum 12-D-A, which is now attached to Appendix 6.E. Information for the BAI inventory was compiled using an approximate border of the coal seam outcrops on the west to two miles east of the permit boundary extending north to the San Juan River. Generally, five data sources were examined; UII record (previous Chapter 12-PAP), Navajo Nation files, United States Geological Survey computer data base WATSTORE, New Mexico State Engineer files, and scientific publications. A database was developed from an area larger than that defined above to facilitate collection, tabulation and presentation. Development of these types of data bases typically require triangulation coordinates which include, but extend beyond the area of concern. Consequently, many of the wells/springs presented in the Addendum 12-D-A, lie outside the region defined above. The inventory in the Addendum also includes information on Navajo Mine (UII) monitoring wells at the time of the BAI study.

Tabulation of collected information is given in Addendum 12-D-A. The identified well/spring locations are shown on Figure 12-02, with a BAI number of classification. The UII (Navajo Mine) well numbers are 95-143, and 157.

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Table 6E-1: Water Supply Wells and Springs Adjacent to the Navajo Mine

Site Name	Type	Owner	Completion	Construction	Status	Primary Use	Water Quality Data	Depth to Water	Total Depth (ft)
G8	Seep					Unknown	Available	NA - Spring	
#52	Spring	Navajo				Unknown	Available	NA - Spring	
#53	Spring	Navajo				Unknown	NA	NA - Spring	
#54	Spring	Navajo				Unknown	Available	NA - Spring	
#56	Spring	Navajo	PCS			Unknown	NA	NA - Spring	
13R-104	Spring					Unknown	NA	NA - Spring	
Little Geyser Spring (G9)	Spring					Unknown	Available	NA - Spring	
S-0127 (13R-103)	Spring	Navajo Trust		Improved Spring		Stock Water	NA	NA - Spring	
S-0767	Spring	Navajo Trust		Improved Spring		Stock Water	NA	NA - Spring	
S-0846 (U-30)	Spring	Navajo Trust		Improved Spring	No Access		NA	NA - Spring	
#38	Well	Navajo	PCS	NA		Unknown	Available	470	1505
#41	Well	Unknown	Kirtland (Farmington.)	NA		Unknown	NA	40	60
#44	Well	Navajo	PCS	NA		Unknown	Available	475	804
45 (#34)	Well	Navajo	Pinabete/ Chaco Alluvium	NA		Unknown	NA	8	8
#46	Well	Navajo	Alluvium	Dug Well		Unknown	Available	7.3	9
#51	Well	Navajo	Alluvium	Dug Well	Dry	Unknown	NA		8
#57	Well	Navajo	San Juan Alluvium	Drilled		Unknown	Available	7	27
#70	Well	Navajo	Alluvium	Dug Well		Unknown	Available	7	9
#90	Well	Navajo	PCS	NA		Stock, Domestic	NA		131
#146	Well	Unknown. Likely the same well as W-0593	San Juan Alluvium	NA		Unknown	Available	3	9
13-15-4 (#60)	Well	Unknown	Chaco Alluvium	Concrete collar; wooden lid, bucket operated	Unpermitted	Unknown	NA	8	11
13-7-2	Well	Unknown	PCS	7" steel casing w/ windmill on 8'x8' concrete pad	Abandoned	Unknown	NA		Unknown
13-7-4	Well	Navajo Trust	Unknown	Hand dug w/ hand pump	Permitted	Unknown	NA		Unknown
13-AW (13T-513, #58)	Well	Unknown	Alluvium - Artesian	NA	Unpermitted	OG well converted to Livestock	Available	11	530
46 (W-0618,13R-28, #35)	Well	Navajo Trust	Cottonwood Alluvium	NA		Stock Water	NA	5	16
G5	Well	Unknown	Chaco Alluvium	NA		Unknown	Available		Unknown
GM-22 (13R-38)	Well	Unknown	Pinabete Alluvium	Dug well w/concrete pad & windmill	Permitted	Monitoring/ Livestock	NA	11	47
GM-32 (13-15-7)	Well	Unknown. Likely the same well as W-0202	Chaco Alluvium	Block & Concrete dug well, formerly hand pump operated; 10'x10' concrete pad	Unpermitted	Monitoring/ Livestock	NA	8	9
GM-35	Well	Unknown	Unknown	Dug well w/concrete pad operated by portable hand pump	Unpermitted	Unknown	NA		Unknown
GM-36 (13-7-5)	Well	Unknown	Unknown	Dug well w concrete well head; bucket operated	Unpermitted	Livestock & Monitoring	NA		Unknown
R.A. French (#150)	Well	Unknown	San Juan Alluvium	NA		Unknown	Available	Unknown	37
SJ 00248 (G7, #6)	Well	Unknown	San Juan Alluvium	NA		DOM	Available	10	35
SJ 00264 (#7)	Well	Unknown	San Juan Alluvium	NA		Stock Water	NA	10	35
W-0146	Well	Navajo Trust	Unknown	NA		Stock Water	NA		

Table 6E-1: Water Supply Wells and Springs Adjacent to the Navajo Mine

Site Name	Type	Owner	Completion	Construction	Status	Primary Use	Water Quality Data	Depth to Water	Total Depth (ft)
W-0147	Well	Navajo Trust	Unknown	NA		Stock Water	NA		Unknown
W-0148	Well	Navajo Trust	Unknown	NA		Stock Water	NA		Unknown
W-0202	Well	Navajo Trust	Chaco Alluvium	NA		Stock Water	NA		7
W-0203 (13-15-5)	Well	Navajo Trust	Chaco Alluvium	NA	Unpermitted	Stock Water	NA		8
W-0204 (13-15-6)	Well	Navajo Trust	Chaco Alluvium	Dug well; 8'x8' concrete pad; sides eroding into well	Unpermitted	Stock Water	NA		14
W-0313	Well	Navajo Trust	Unknown	NA		Stock Water	NA		Unknown
W-0342	Well	Navajo Trust	Unknown	NA		Stock Water	NA		Unknown
W-0343 (13-5-1, Stevenson, 13-15-2)	Well	Navajo Trust	Alluvium	5" steel casing; well cap welded shut	Permitted	Stock Water	NA		Unknown
W-0344 (#93)	Well	Navajo Trust	Pinabete Alluvium	NA		Stock Water	Available	7	9
W-0345 (13R-48, 13-15-3)	Well	Navajo Trust	Pinabete Alluvium	Dug well; concrete well head; wooden cover	Permitted	Stock Water	NA	7	10
W-0346 (13R-37, 13-8-4)	Well	Navajo Trust	Pinabete Alluvium	Dug well w/ concrete pad over well; hand pump operable	Unpermitted	Stock Water, Use Unknown	NA	6	8
W-0348 (13-8-1)	Well	Navajo Trust	Pinabete Alluvium	Open well; concrete well head	Unpermitted	Stock Water	NA	9	13
W-0517	Well	Navajo Trust	Unknown	NA		Stock Water	NA		Unknown
W-0519 (13R-31 #17, G4, 13-14-7)	Well	Navajo Trust	Chaco Alluvium	NA	Unpermitted	Stock Water	Available	16	16
W-0520 (G-3, #36)	Well	Unknown	Unknown	NA		Stock Water	Available		Unknown
W-0593	Well	Navajo Trust	Unknown	Windmill		Stock Water	NA		Unknown
W-0603	Well	Navajo Trust	Unknown	Windmill		Stock Water	NA		Unknown
W-0606 (13-15-1)	Well	Navajo Trust	Unknown	5" steel casing w/ 8' x 8' concrete pad; Windmill	Unpermitted	Stock Water	NA		Unknown
W-0607	Well	Unknown	Alluvial	Windmill		Stock Water	NA	18	25
W-0644 (13R-28A, QACW-2B, CWAP-1, #126)	Well	BIA	Cottonwood Alluvium	Hand dug w/ hand pump		Stock Water	Available	Unknown	11
W-0645 (13R-29, #61, 13-14-6)	Well	Navajo Trust	Chaco Alluvium	NA	Permitted	Stock Water	Available	12	16
W-0686	Well	Navajo Trust	Unknown	Windmill		Stock Water	NA		Unknown
W-0691 (13-15-8)	Well	Navajo Trust	Chaco Alluvium	Dug well, 5'x5' concrete pad; equipped w/hand pump	Unpermitted	Stock Water	NA		Unknown
W-0695 (G-2)	Well	Navajo Trust	San Juan Alluvium	NA		Stock Water	Available		Unknown
W-0768 (#10)	Well	Navajo Trust	Unknown	Windmill		Stock Water	NA		Unknown
Wesleyan Navajo Mission (#147)	Well	Unknown	San Juan Alluvium	NA		Unknown	Available	9	19

PCS - Pictured Cliffs Sandstone
- BAI - Numbering System from Historic Addendum 12-D-A prepared by Billings and Associates, Inc. 1985
Source of Navajo Trust information - New Mexico Office of the State Engineer. 2010. Notice of Navajo Nation Expedited Inter Se Proceeding. Hydrographic Survey, Appendix M. Acquired from the Internet August 17, 2011 from http://www.ose.state.nm.us/water-info/NavajoSettlement/Notice2010/AppendixM.pdf

Appendix 6.G

Baseline Groundwater Update for Navajo Mine Area IV North

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6.G-1 Introduction

This Appendix has been prepared to summarize and interpret the additional baseline data obtained from monitoring wells and vibrating wire piezometers (VWPs) that were installed in the Fruitland coals and in the underlying Pictured Cliffs Sandstone (PCS) for baseline hydrogeology characterization of Area IV and Area V of the BHP Navajo Coal Company (BNCC) coal lease. Completion diagrams and lithologic logs for these monitoring wells and VWPs are provided in Attachment 6.G-1. The data from these wells and VWPs locations provide additional information on groundwater levels, aquifer characteristics, and groundwater quality within and adjacent to the Navajo Mine permit area. Geologic information as well as data from monitoring wells installed in Area III of the BNCC lease are also included in this Appendix to support the hydrogeologic interpretations. This Appendix also provides the baseline data that are used to support the development and calibration of the multilayer, numerical, groundwater flow model of the hydrogeologic system of Areas IV and V of the BNCC coal lease.

The hydrogeologic units within and adjacent to Navajo Mine Area IV North include:

- The alluvial groundwater of the Chaco River, Pinabete Arroyo, and Cottonwood arroyo
- The coal seams of the Fruitland Formation
- The Pictured Cliffs Sandstone (PCS), located below the Fruitland Formation

The location of baseline monitoring wells and VWPs completed within or adjacent to Areas III, IV and V of the BNCC coal lease are shown in Exhibit 6.G-1. This exhibit also provides hydrogeologic sections, depicting the various coal seams of the Fruitland Formation and the top of the PCS. Water level elevations measured in the monitored coal units and in the underlying PCS are plotted in the hydrogeologic sections in Exhibit 6.G-5 to depict both horizontal and vertical gradients.

6.G-2 Alluvial Groundwater

Alluvial fill deposits occur in the valley bottom of Cottonwood Arroyo within the permit area and along the Chaco River and Pinabete Arroyo, to the west and south of the permit area. However, these deposits are not considered Alluvial Valley Floors (AVF). Refer to of Chapter 6.5 for information on the negative determination for AVF within and adjacent to the permit area. The Chaco River alluvium is saturated and provides limited stock water supply at several dug wells. Likewise, portions of the alluvium of Cottonwood and Pinabete Arroyos are saturated and will yield water to wells, as evidenced by the dug wells completed in the alluvium of both Cottonwood and Pinabete Arroyos as indicated in Appendix 6.E.

Baseline monitoring of the alluvium of Cottonwood Arroyo was conducted at four alluvial well monitoring locations shown on Exhibit 6.G-1. Baseline water quality information obtained prior to year 1983 from the monitoring wells GM-17 and QACQ-2 (GM-18) are included in Appendix 6-C. Well GM-17 is completed in the alluvium of North Fork of Cottonwood Arroyo. A dug well, GM-18, completed in the alluvium of Cottonwood Arroyo west of the permit area, was converted for use as a monitoring well and is designated as QACW-2 in Exhibit 6.G-1. This well was included in the Navajo Mine quarterly monitoring program. However, the well is usually dry and relatively few samples have been obtained during baseline monitoring. Water quality samples could not be obtained from alluvial monitoring well QACW-1 because it was dry or had insufficient water for sampling during baseline monitoring from 1987 through 1998. The well was subsequently removed by the advance of mining operations in Area III. BNCC has also performed baseline monitoring of well QACW–2B completed in the alluvium of Cottonwood Arroyo west of the permit area as shown in Exhibit 6.G-1. This well is a dug well that has been used for stock water supply and is not owned by BNCC.

The baseline water quality monitoring results for these Cottonwood alluvial wells are summarized in Table 6.G-1. These results show the water quality of the alluvium of Cottonwood Arroyo to be a sodium-sulfate type with variable TDS concentrations. TDS, sulfate, fluoride, iron, and manganese concentrations in the groundwater within the Cottonwood alluvium exceed the relevant groundwater use criteria listed Table 6.G-2. The use criteria in Table 6.G.2 are not enforceable standards with respect to groundwater and are included only as a reference for the suitability of the groundwater quality for domestic water supply and for livestock use. These use criteria are mostly derived from the Navajo Nation surface water quality criteria for domestic water supply and for livestock watering use. Lardy, G., C. Stoltenow, and R. Johnson (2008) provide relevant livestock watering criteria for TDS, sulfate, and fluoride but do not provide a livestock use criterion for chloride. Based on these relevant use criteria, the water in the alluvium of the mainstem of Cottonwood is a poor source of supply for livestock watering use. Fluoride, sulfate, and TDS concentrations often exceed relevant criteria for livestock use (Table 6.G-2). Also, the alluvium is variably saturated and often will not yield sufficient water for sampling.

Two alluvial monitoring wells, PA-1 and PA-2, were installed in 1998 within the alluvium of Pinabete Arroyo at the locations shown in Exhibit 6.G-1. Table 6.G-3 summarizes the baseline water level readings and aquifer test results are summarized in Table 6.G-4. The estimated hydraulic conductivities for the Pinabete Arroyo alluvium of 51.3 ft per day (ft/day) (1.8×10^{-2} cm per second (cm/sec)) and 10.7 ft/day (3.8×10^{-3} cm/sec) are within the range expected for clean sand and are considerably higher than the bedrock values in the area. Well yields from the alluvium, however, are limited by a very low saturated thickness of about 5 ft or less.

Water quality analytical results from the baseline sampling of alluvial wells PA-1 and PA-2 are provided in Table 6.G-5 and Table 6.G-6, respectively. These results show the water quality to be a sodium-sulfate type with TDS concentrations ranging from 1,500 to 4,310 mg/L. Water within the alluvium is unsuitable for drinking water use due to TDS, sulfate, fluoride, iron, and manganese concentrations above drinking water criteria. The water is also a poor source of supply for livestock watering use. TDS, sulfate, and fluoride concentrations usually exceed relevant criteria for livestock use (Table 6.G-2).

Some information on the baseline water quality in the Chaco River Alluvium is provided in the well inventory included in Appendix 6-E-Addendum 12-D-A of the PAP. The available water quality information from this well inventory show TDS concentrations ranging from 1,950 mg/l to 3,110 mg/l and sulfate concentrations ranging from 1,100 to 1,790 mg/l at wells located west of Areas II, III and IV at the Navajo Mine. Limited groundwater quality baseline data are also provided by Thorn (1993) for the Chaco River alluvium. The results show considerable variability in the alluvial water quality with TDS concentrations ranging from 742 to 11,900 mg/L, sulfate concentrations from 350 to 6,600 mg/L, and fluoride concentrations ranging from 0.4 to 1.7 mg/L.

6.G-3 Fruitland Coal Seams

Groundwater is also found in the coal units of the Fruitland Formation and in the PCS, which underlies the Fruitland Formation at the Navajo Mine site. The geologic strata within the permit and adjacent area dip gently to the east toward the center of the San Juan Basin at an angle of 1 to 2 degrees as depicted in the cross sections provided in Exhibit 6.G-1. Based on both regional and site-specific information, the Fruitland Formation and associated coal units, and the PCS are unsaturated or partially saturated near the outcrop of these units on the western side of the Navajo Mine permit area but become saturated to the east and down dip of the outcrop. The pre-mine groundwater in the Fruitland Formation throughout most of the BNCC coal lease will not support beneficial use because of the very low well yields and poor water quality. There are no known water supply wells completed in the Fruitland Formation within or adjacent to the BNCC coal lease.

Based on baseline information obtained from water level elevations measured in the wells and piezometers, the general groundwater flow directions in the Fruitland Formation within Areas III, IV and V of the BNCC coal lease are vertically downward through the interbedded shale and coal units of the Fruitland Formation and into the PCS and laterally within individual coal seams toward the north-northeast with some localized flow toward the topographic lows along Cottonwood and Pinabete Arroyos. Direct recharge rates measured by chloride mass balance methods on undisturbed areas at the Navajo Mine ranged from 0.002 to 0.09 in/yr (Stone 1987). The highest recharge rate of 0.09 in/yr was for valley terraces while the lowest recharge rate of 0.002 in/yr was for badland areas. Recharge from upland flats averaged 0.03 in/yr. Recharge is expected to be higher from saturated alluvium and surface impoundments. Although Stone's research (1986 and 1987) did not include recharge estimates for surface impoundments, it does provide an estimate of an average recharge rate of 0.16 in/yr from depressions within reclaimed mine areas at the Navajo Mine.

Based on the previous mining experience at the Navajo Mine, the coals, the overburden, and the interburden in the Fruitland Formation are not expected to yield much water during mining. The mine pit has remained dry except on rare occasions when surface flows are captured. Groundwater seeps are rarely observed along the highwall as any groundwater in the Fruitland overburden and coals is consumed by evaporation along the highwall. The few seeps that have been observed during mining were at locations within Area I where the highwall was near Navajo Agricultural Products Industry (NAPI) irrigation plots. NAPI irrigation plots do not occur within the drainages associated with proposed Area IV mining, although Cottonwood Arroyo does receive direct discharges of water from irrigation canals. The direct discharges occur when an over supply of water in the canal is released directly to the stream channel. Direct discharge is highly variable, occurs quickly, and can last up to 12 hours. However, usually there is no flow in Cottonwood Arroyo and it retains the characteristics of an ephemeral stream

One conceptualization of the hydrogeology of the Navajo Mine site is to consider the Fruitland Formation as a single hydrogeologic unit. The single hydrogeologic unit approach was previously proposed by Billings and Associates (Appendix 6.D) for modeling groundwater at the Navajo Mine because of the complexity of the individual coal seams, which often split or pinch out. This conceptualization has been used for predicting steady-state post mining flow in the Fruitland Formation from the Navajo Mine to the discharge locations along the subcrop with the San Juan River alluvium. This conceptualization may be best for regional modeling and is the appropriate conceptualization when baseline hydrogeologic information does not exist to calibrate a more complex hydrogeologic model.

However, given the extensive baseline hydrogologic information that was available within areas IV and V of the BNCC lease, a conceptual hydrogeologic model and the numerical groundwater model that delineates the coal beds as distinct hydrogeologic units was developed to assess the baseline hydrogeologic conditions and to simulate the effects of mining within Area IV North. This conceptualization supports the calibration of a numerical model because the potentiometric information is developed from monitoring wells and piezometers completed in specific coal units. This conceptualization is also better for evaluating local influences and the potential changes in vertical and horizontal groundwater flows that may occur as a result of mining and reclamation.

The potentiometric elevations in the specific coal units decline with depth within Areas III, IV and V of the BNCC lease as shown in Exhibit 6.G-1, indicating a vertical downward component of flow through the Fruitland Formation. One of the primary hydrogeologic changes to occur as a result of mining is the removal of the coals, interbedded shales, and sandstone strata, thus resulting in more homogeneous and isotropic conditions within the mine backfill. This change is expected to result in a steady-state post-mining water table that is lower than pre-mining but steady-state potentiometric elevations at the base of the mine backfill that are higher than the potentiometric elevations that occurred in the lowest coal seam prior to mining. The result of this change would be an increase in vertical flow from the mine backfill into the PCS under steady-state post-mining conditions relative to the vertical flow from the Fruitland Formation to the PCS prior to mining.

However, these changes would not be expected within Area I. The pre-mine vertical downward gradient may not have occurred in the Fruitland Formation within Area I because of its closer proximity to the San Juan River, a location for regional groundwater discharge where upward gradients would be expected. Also, Morgan Lake has increased potentiometric elevations in the PCS, which further limits the potential for downward flow into the PCS from the Fruitland Formation.

The PCS, the first hydrogeologic unit below the Fruitland Formation, has been included in the groundwater flow model. The top of the Lewis Shale, the first hydrogeologic unit below the PCS, has been included as the base of the model domain. The delineation of these hydrogeologic units within the model domain was created from the extensive geologic and groundwater information developed for Areas IV and V. Information was also obtained from a variety of sources to help delineate the hydrogeologic units and define groundwater conditions for the portions of the model domain that are beyond the limits of Areas IV and V. Norwest Corporation (2011) provides a description of the hydrogeologic model that was developed to characterize the baseline hydrogeology and to support the probable hydrologic consequences assessment.

Baseline potentiometric elevations measured in the wells and in the VWPs completed in specific coal seams within Areas IV and V are summarized in Table 6.G-7. The potentiometric surface for the No. 3 coal seam is provided in Exhibit 6.G-2. This potentiometric surface was constructed from the baseline potentiometric elevations for the No. 3 coal seam presented in Table 6.G-7 and the July 1989 baseline potentiometric elevations measured in the No. 3 coal wells located within Area III. The modeled baseline potentiometric surface for the No. 3 coal in Figure 6.G-2 was also used to estimate the potentiometric contours beyond the limits of the monitoring data. The potentiometric gradient in the No. 3 coal indicates groundwater flow components toward the north-northeast with local gradients toward Pinabete Arroyo and Cottonwood Arroyo. The lower coal seams pinch out and do not extend north of Area III. The groundwater moving along the potentiometric gradients to the northeast flows through the undifferentiated Fruitland Formation into either the upper coal units or into the underlying PCS.

Potentiometric gradients in the other coal seams within Areas III, IV, and V of the BNCC coal lease are expected to be generally toward the northeast, similar to the gradients shown for No. 3 coal. However, the upper coal seams (No. 6, No. 7, and No. 8) outcrop to a greater extent within the valleys of Pinabete Arroyo, No Name Arroyo, and Cottonwood Arroyo within the BNCC coal lease. The groundwater associated with these upper coal seams is expected to show greater local influence from the topographic lower elevations along the arroyos. The baseline hydrogeologic model generated to support the probable hydrologic consequences assessment simulated local potentiometric gradients toward the topographic lows along Pinabete Arroyo, No Name Arroyo, and Cottonwood Arroyo in all of the Fruitland coal units. The local influence of topography on potentiometric gradients was greatest for the shallowest coal, the No. 8 seam (Norwest Corporation, 2011). Field observations of salt deposits and enhanced vegetation production also indicate that local discharge may occur from the No. 8 coal at the coal outcrop along Pinabete Arroyo. Baseline groundwater model simulations in Figure 6.G-3 and potentiometric elevations at wells KF-2007-01, KF84-22A, and KF83-10A were used to prepare the potentiometric surface of the No. 8 coal seam that is provided in Exhibit 6.G-3.

A displacement (slug) test was performed at well KF-98-02 and bailed recovery tests were conducted at wells KF-98-03 and KF-98-04 to determine transmissivity and hydraulic conductivity in the No. 3 coal seam within Area IV South. The test results are summarized in Table 6.G-8 and show very low hydraulic conductivity values for the No. 3 coal consistent with the low hydraulic conductivity values reported in Table 6-1 for the No. 2, No. 3, and No. 4-6 coal seam wells located within Area IV North. A pumping test of the No. 8 coal seam well KF2007-01 was also performed and interpreted using the Papadopulos-Cooper method as shown in Table 6.G-8. The higher hydraulic conductivity for the No. 8 coal seam relative to the No. 3 seam is consistent with the results in Table 6-1, which show higher hydraulic conductivities for the No. 7 and No. 8 coal units relative to the lower coal units.

In a separate set of tests, the transmissivity and hydraulic conductivity values calculated from the observation well response during a pumping test of the No. 8 coal seam well, G-20, located at the San Juan Mine were 0.017 ft^2/day and 0.001 ft/day (3.5×10^{-7} cm/sec), respectively (San Juan Coal Company, 2009). These results for the hydraulic conductivity from G-20 are lower than the values from well tests at Navajo Mine. However, the observation well response from well G-20 pumping test is useful because it provides a reliable estimate for the storage coefficient (4.2×10^{-4}) associated with the No. 8 coal seam.

Water quality monitoring data from Fruitland Formation coal wells at the Navajo Mine and BNCC coal lease monitoring locations show that baseline groundwater in the coals is very saline. Table 6.G-9 provides a summary of the baseline water quality obtained from coal wells located within Areas II, III, and IV at the BNCC coal lease. This table provides median baseline concentrations measured at the coal wells along with the number of baseline analyses obtained for each constituent at each well. Given the variability in some of the analytical results, the median provides a good representation of baseline water quality at each well location. The median, unlike the mean, is not biased by an anomalous value resulting from analytical or transcription errors or by a sample that may not be representative due to sampling method or impact by drilling fluids or annular grout seal.

The TDS concentrations in Table 6.G-9 for the coal water at the Navajo Mine monitoring locations exceed relevant criteria for both drinking water and livestock use (Table 6.G-2). The chloride concentrations also exceed the drinking water use criterions in most of the wells. Fluoride concentrations are quite variable but the median values in several of the wells exceed the relevant criteria for both drinking water and livestock uses. Sulfate is also quite variable among coal wells with concentrations above relevant drinking water and livestock use criteria in the shallow coal wells near the outcrop but very low sulfate concentrations in the coal water in the deeper coal units and down dip of the outcrop. The low sulfate in these deeper coals is due to apparent sulfate reduction in the groundwater.

Groundwater monitoring results in Table 6.G-9 show that sodium is the dominant cation in the coal water and that bicarbonate and chloride are typically the dominant anions except for the relatively high sulfate in the shallow coals near the outcrop. The TDS concentrations in the coal units at the Navajo Mine typically increase from south to north and from shallow to deep. Furthermore, baseline TDS concentrations in excess of 40,000 mg/L have been reported in Table 6-2 of Navajo Mine Permit Application for the Fruitland coal monitoring wells SJKF84#2 and SJKF84#3 installed in the No. 8 coal northeast of the Navajo Mine as shown in Exhibit 6-6 of the Navajo Mine Permit Application.

Groundwater chemistry can change or evolve along its flow path from the recharge area to the discharge area. Precipitation is low in TDS, is naturally weakly acidic, and contains bicarbonate due to the solution of carbon dioxide in the air. In this portion of the San Juan Basin, the precipitation reaching the ground is immediately neutralized and acquires sodium, sulfate, and other ions. Water that has only a short residence time in the ground is still typically high in TDS concentrations, with sodium, sulfate, and bicarbonate the dominant ions as indicated by both the surface water and alluvial groundwater samples. Calcium is also present due to dissolution of calcium carbonate, but at concentrations that are considerably lower than sodium. Chloride concentrations in precipitation are low. Chloride concentrations in groundwater increase due to evapotranspiration and are typically lower in groundwater in the alluvium and in shallow bedrock near recharge areas. As groundwater migrates through the saturated zones it is no longer in contact with atmospheric carbon dioxide and its capacity to dissolve carbonates diminishes. The chemistry of the groundwater continues to evolve as other soluble minerals dissolve and cation exchange processes reduce the proportion of calcium and increase the proportion of sodium in solution. Sulfate reduction also appears to occur when groundwater transitions from oxidizing to reducing conditions, particularly within the coal units.

6.G-4 Pictured Cliffs Sandstone

The PCS is a well-cemented, low-permeability, marine sand and is the first water-bearing unit below the Fruitland Formation. Based on the geologic information presented in Section 5 of the Navajo Mine Permit, the PCS is approximately 110 to 120 ft thick and follows the structure of the Fruitland Formation, dipping to the east at approximately 2 degrees, although the structure varies locally. The PCS conformably overlies the Lewis Shale, with the contact marked by a zone of interbedded sandstones and mudstones in the lower part of the PCS (Stone et al. 1983). It outcrops just west of the mine lease and east of the Chaco River. The PCS is a marginal water resource due to low permeability, poor water quality, gas production, and low yields (Stone et al. 1983). The PCS is also a natural gas reservoir in the San Juan Basin. Stone et al. (1983) state that the PCS cannot be considered a major aquifer and it is important only because it is the water-bearing horizon immediately underlying the coals in the Fruitland Formation.

Well KPC-98-01 was installed in 1998 near the PCS outcrop at the location shown in Exhibit 6.G-1. In 2007, wells KPC2007-01, KPC2007-02, and KPC2007-03 were completed in the PCS at locations around the perimeter of Area IV South (Exhibit 6.G-1). VWPs were installed in the PCS at four of the five VWP locations as shown on Exhibit 6.G-1. A VWP was not installed in the PCS at the VWP2007-03 location because monitoring well KPC2007-02 was installed in the PCS at this location. Potentiometric elevations measured at the PCS wells and the VWPs are summarized in Table 6.G-10.

The water levels measured in the PCS well KPC2007-01 at the VWP2007-01 location show elevations in the PCS monitoring well that are consistently about 6 feet lower than the potentiometric elevation measured in the PCS at the VWP. The VWP in the PCS at this location is installed at the top of the PCS, while the well screen and filter pack extends through about 75 ft of the PCS. The difference between the two measurements suggests that hydrostatic heads are higher at the top of the PCS at this location and decline with depth. Thus, downward gradients are believed to continue through the PCS at this location.

Historical water level data are also available for six PCS wells that were completed within or adjacent to BNCC lease Areas IV and V during the mid-1970s. Data from these well are included in a report by Science Application, Inc. (1979) that was prepared for a proposed coal gasification project. These PCS monitoring wells are designated as the GM wells with water elevations shown on Exhibit 6.G-4. These PCS monitoring wells and piezometers were plugged and abandoned in 1994.

The modeled baseline potentiometric surface for the PCS in Figure 6.G-1 together with the baseline potentiometric elevations from the PCS wells and VWPs were used to prepare the PCS potentiometric surface provided in Exhibit 6.G-4. The measurements of the baseline potentiometric elevations for the abandoned GM wells were obtained in June 1989. The potentiometric surface for the PCS shows overall gradients to the north. The highest potentiometric elevations for the PCS shown in Exhibit 6.G-4 correspond with a structural high in the PCS located within the southeast portion of Area V of the BNCC coal lease. There are also local gradients toward the topographic lows along No Name Arroyo, Pinabete Arroyo and Cottonwood Arroyo.

Water yields are quite low from these PCS monitoring wells completed around BNCC lease Area IV South. Two of the PCS wells were quickly pumped or bailed dry during conventional sampling. The yield from one of the PCS wells was sufficient to sustain a rate of about 0.4 gallons per minute (gpm) during a constant rate pumping test. The fourth PCS monitoring well was pumped dry after about 140 minutes during a constant-rate pumping test at a rate of about 1 gpm.

An aquifer test was also conducted in 1975 at well T4-1 installed in the PCS near the western side of the Navajo Mine lease boundary as shown in Exhibit 6.G-4. The drawdown and recovery measurements were recorded at the pumped well and at observation well GM30A, located 55.8 ft from the pumping well, and at observation well T4-2 located 12.5 ft from the pumping well (Science Application Inc. 1979). The results of this aquifer test and those performed at the PCS monitoring wells installed within or adjacent to Area IV South are summarized on Table 6.G-11.

Water quality analytical results from the baseline sampling of KPC-98-01 are provided in Table 6.G-12. The initial sample collected from this well in 1998 showed some influence from drilling fluids based on elevated pH and nitrate in the well sample results (Table 6.G-12). It is suspected that the well was not fully developed due to low permeability and limited saturation. Sampling results starting in 2007 are more consistent and representative of baseline conditions within the PCS at this location. Based on the recent samples, the PCS groundwater at this location is a sodium-sulfate type with TDS concentrations slightly above 6,000 mg/L.

The baseline water quality results from PCS well KPC2007-01 are summarized in Table 6.G-13. The PCS groundwater at this location is similar to the groundwater at well KPC-98-01 with TDS concentrations slightly below 6,000 mg/l. Baseline water quality information was also collected during the mid-1970s from PCS wells GM-19, GM-20, GM-30A and GM21 located within or in close proximity to the BNCC coal lease as shown in Exhibit 6.G-1. Water quality data from these wells are summarized in Tables 6.G-14 through 6.G-17. Baseline water quality data for these PCS monitoring wells indicate a sodium-sulfate type with TDS concentrations between 5,000 and 9,000 mg/l. The water quality results are consistent with the results from wells KPC-98-01 and KPC2007-01, although the initial well samples from a number of the PCS wells is suspect due to either poor ion balance or insufficient well development.

In summary, groundwater quality data from monitoring wells located within and adjacent to the Navajo Mine indicate that the groundwater in the PCS has high TDS concentrations, ranging from 5,000 mg/L to over 9,000 mg/L. Sulfate is the dominant anion, although the concentrations of chloride and bicarbonate are also relatively high. Sodium is the dominant cation. Magnesium and calcium concentrations are quite low and are typically less than the potassium concentrations. Generally, water quality changes are observed in the first few samples obtained from PCS monitoring wells, apparently due to the difficulty in developing these low-yield wells. Thus, samples obtained after the initial two samples are believed to provide a better representation of baseline conditions.

The groundwater in the PCS groundwater within Areas IV and V of the BNCC coal lease is unsuitable for either domestic or livestock use. The concentrations of TDS, sulfate, chloride, and boron in the PCS wells are considerably higher than the domestic use criteria provided in Table 6.G-2. The TDS and sulfate concentrations in the PCS are also considerably higher than the livestock use criteria provided in Table 6.G-2. The low permeability and low yield of the PCS also limits the potential for groundwater use from the PCS. There are no known water supply wells completed in the PCS within or adjacent to Navajo Mine Permit Area.

6.G-5 Hydrologic Model

Conceptual and numerical groundwater models are useful to support the interpretation of baseline hydrogeologic information. Furthermore, conceptual or numerical groundwater models are required for the predictive evaluations needed to prepare a probable hydrologic consequence (PHC) assessment of proposed mining and reclamation activities. Groundwater models used for a PHC assessment can range from conceptual depictions, to simple empirical equations, to complex numerical computer simulations of groundwater flow and chemistry.

Site-specific data or data representative of the site conditions are needed to apply groundwater models. Numerical groundwater flow models can help develop a better understanding of the hydrogeologic system, including the groundwater flow relationships between hydrogeologic units and between surface water and groundwater. Extrapolation of data from adjacent or nearby areas or using typical values for parameters from similar hydrogeologic environments is often used in developing numerical flow models. Model calibration can also serve to revise the conceptual model of the groundwater system and provide a better assessment of the properties of hydrogeologic units on a regional scale that cannot be obtained solely from local pumping testing results.

The first step in developing a groundwater model is to establish the objectives of the study. The primary objectives for the development of a groundwater model for Area IV North mine permit revision application:

- To provide a better understanding of the baseline groundwater flow systems within and adjacent to the proposed mine area.
- To provide a better understanding of the likely groundwater changes that are expected during and after mining.

Potentiometric elevations in the monitored coal units and in the underlying PCS are plotted in the hydrogeologic sections in Exhibit 6.G-1, to depict vertical gradients. Quarterly monitoring performed on many of these wells and VWPs show no seasonal changes but occasional fluctuation in some wells due to slow recovery following bailing, purging and sampling. Results show downward potentiometric gradients through the Fruitland formation. Generally the gradients are downward from the Fruitland to the PCS except at locations VWP2007-02 and VWP2007-05. The slightly higher potentiometric elevation in the PCS at these locations indicates a slight upward gradient from the PCS to the No. 2 and 3 coal units of the Fruitland Formation.

6.G-6 Numerical Groundwater Model

A multilayer, numerical, groundwater flow model has been developed to model the groundwater flow systems within and adjacent to Navajo Mine Area IV. Norwest Corporation (2011) provides a detailed description of the numerical groundwater flow model. This numerical model is based on the conceptual model of the hydrogeology of the Fruitland coals, the PCS and the alluvial groundwater systems within and adjacent to Navajo Mine Area IV. A conceptual groundwater model is a complex hypothesis of the characteristics and functions of a hydrogeologic system, including recharge and discharge relationships, groundwater flow within and between hydrogeologic units, and the expected properties of these hydrogeologic units. An essential part of both the conceptual and numerical models is a graphical representation of the horizontal and vertical boundaries of the hydrogeologic system (the model domain) and the delineation of the hydrogeologic units within the model domain that are believed to have the primary controlling influence on groundwater flows. Another element of the conceptual model is to define, to the extent possible, the properties of these hydrogeologic units, including the thickness, hydraulic conductivities, and storage characteristics across the model domain. The conceptual model also includes the hydrogeologist's understanding of spatial relationships between and approximate rates of recharge and discharge, including the groundwater inflows and outflows from the model domain.

The delineation of the hydrogeologic units within and adjacent to Navajo Mine Area IV was based on the extensive geologic and groundwater information obtained from a variety of sources, including the baseline information presented in this Appendix. The multilayer groundwater model was calibrated to obtain a good match with potentiometric surfaces and water levels established from the baseline groundwater information while maintaining consistency with the site-specific recharge estimates from Stone (1986) and the range of hydraulic conductivities associated with each hydrogeologic unit. During model calibration, hydraulic conductivities were applied only for the entire hydrogeologic unit and not spatially within a unit. Without a consistent geologic basis, spatial adjustments in hydrologic conductivities would lead to over-parameterization of the model to match modeled potentiometric levels with observed values. Although some of the differences between the modeled and observed potentiometric levels may be associated with spatial variation in hydrogeologic properties within a hydrogeologic unit, the chosen method for model calibration allows for the overall groundwater flow within each hydrogeologic unit and between units to be represented by the calibrated groundwater model.

Generally, a shale zone such as the Lewis Shale would be considered as an impermeable boundary. However, given the low recharge rates at the Navajo Mine site, the overall low permeability of the Fruitland Formation shales and coals, and the relatively low permeability of the PCS, the flow conditions at the boundary between the PCS and Lewis Shale were found to be significant for calibrating the groundwater flow model. Providing for downward flow from the PCS into the Lewis Shale was required in order to reach an adequate calibration with recharge rates consistent with the measurements from Stone (1987). Downward flow and downward gradients are also indicated by hydrogeologic studies and tests of the Lewis Shale and the PCS immediately west of Area V of the Navajo Mine lease (Science Application, Inc. 1979). Also, as discussed in Section 6.G-4, the water levels measured in the PCS well KPC2007-01 and in the PCS VWP2007-01 at the same location show that downward gradients continue through the PCS at this location.

Table 6.G-18 shows the relationship between the modeled recharge rates and the measurements by Stone (1987). Outside of the alluvial valleys, recharge rates were adjusted by slope within the range of estimates from Stone (1987) for badland areas and for upland flats. The modeled potentiometric surface for the PCS, the No. 3 coal seam, and the No. 8 coal seam are provided in Figure 6.G-1, Figure 6.G-2, and Figure 6.G-3, respectively. These results are consistent with the baseline potentiometric elevations obtained from monitoring wells completed in these hydrogeologic units. However, the modeled potentiometric surfaces extend beyond the limits that could be depicted from well measurements. These potentiometric surfaces and flow patterns are consistent with the conceptual model and all the geologic and hydrogeologic information and the specified boundary conditions.

The results in Figure 6.G-1 show a component of groundwater flow from the PCS to the topographic lows along the west side of the model domain in the valleys of Brimhall Wash, No Name Arroyo, Pinabete Arroyo, and Cottonwood Arroyo. The results for the No. 3 coal seam in Figure 6.G-2 also show a component of groundwater flow to the topographic lows along the west side of the model domain in the valleys of No Name Arroyo, Pinabete Arroyo, and Cottonwood Arroyo. The No. 3 coal seam is not present over a portion of the Brimhall Wash drainage or along the western portion of the model domain. Also, the No 3 coal seam is unsaturated in areas along the western outcrop and remains unsaturated in the modeled potentiometric surface as indicated in Figure 6.G-2. A similar pattern is observed in Figure 6.G-3 for the No. 8 coal seam, although this coal is not present over a large portion of the Brimhall drainage or within a large portion of the No Name, Pinabete, and Cottonwood valleys within the BNCC coal lease. In addition to the flow toward the topographic lows, there is a component of flow down dip to the northeast. Portions of the No. 8 coal seam near the western outcrop are unsaturated. Not shown in these figures for individual hydrogeologic units are the overall downward gradients and downward flow between units. In fact, the model predicts perched groundwater conditions in the shallower coals along the western portion of the lease area as depicted by the north-south section in Figure 6.G-4.

The calibrated numerical model helps confirm the conceptual model. The numerical model is well constrained and consistent with the recharge rates measured by Stone (1987) and with the hydraulic conductivities and heads measured within the various hydrogeologic units in the model domain.

6.G-7 References

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Appendix 6.G Figures

Figure 6.G-1. Modeled Potentiometric Surface for the PCS

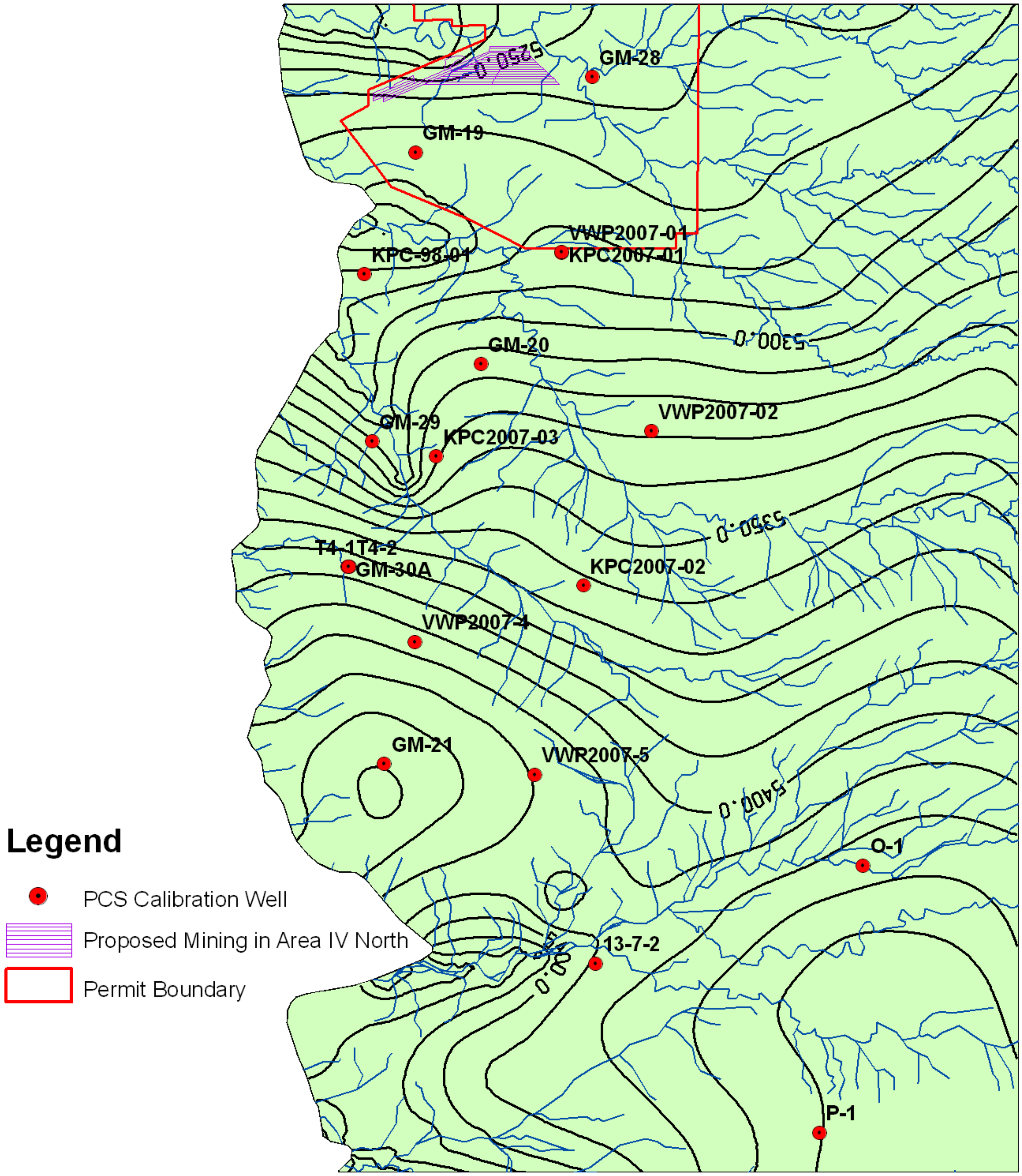


Figure 6.G-2. Modeled Potentiometric Surface for the No.3 Coal

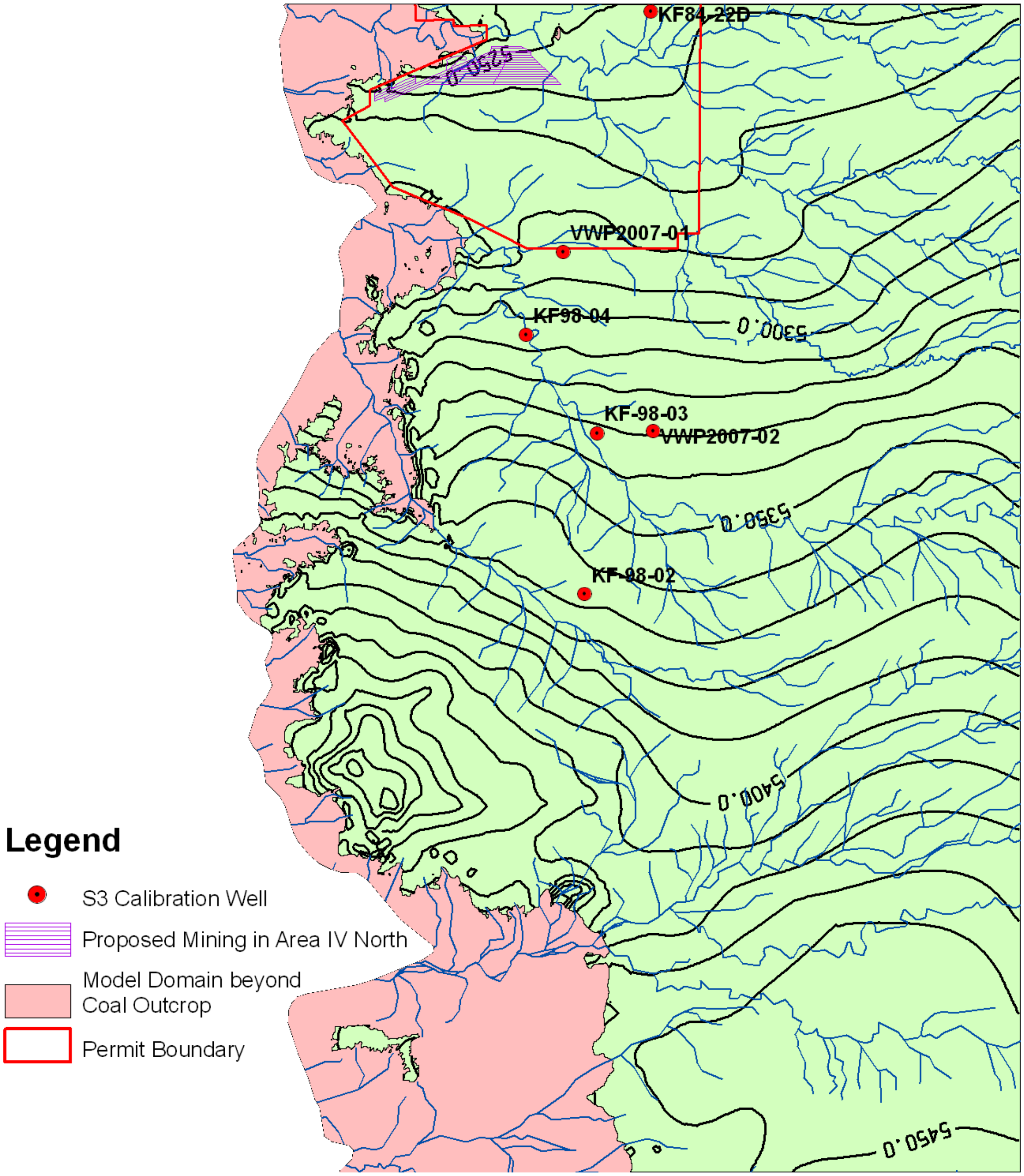


Figure 6.G-3. Modeled Potentiometric Surface for the No. 8 Coal

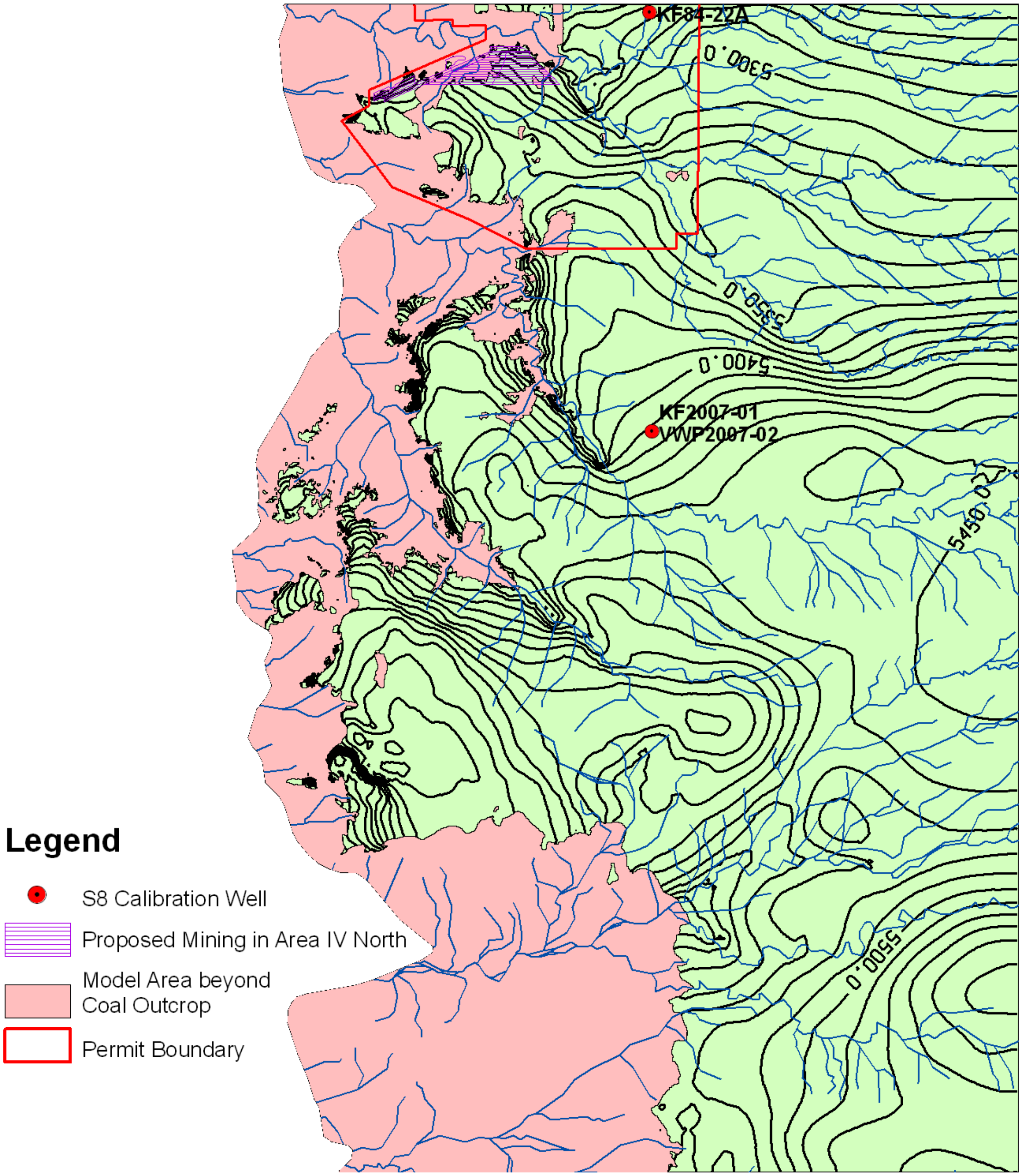
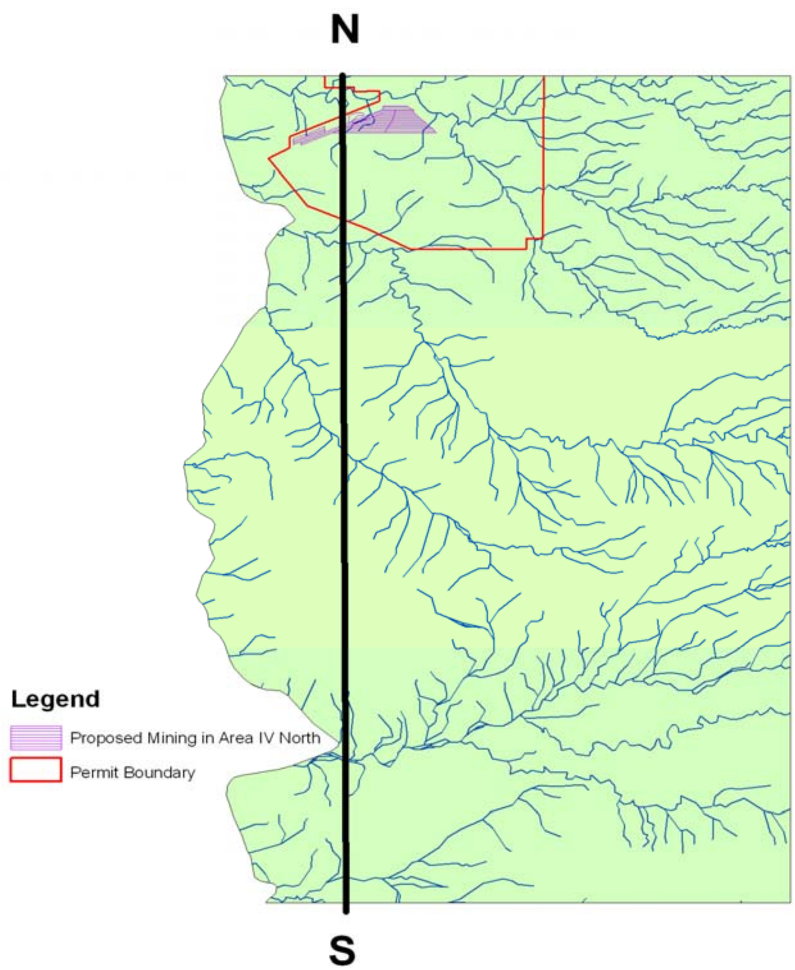
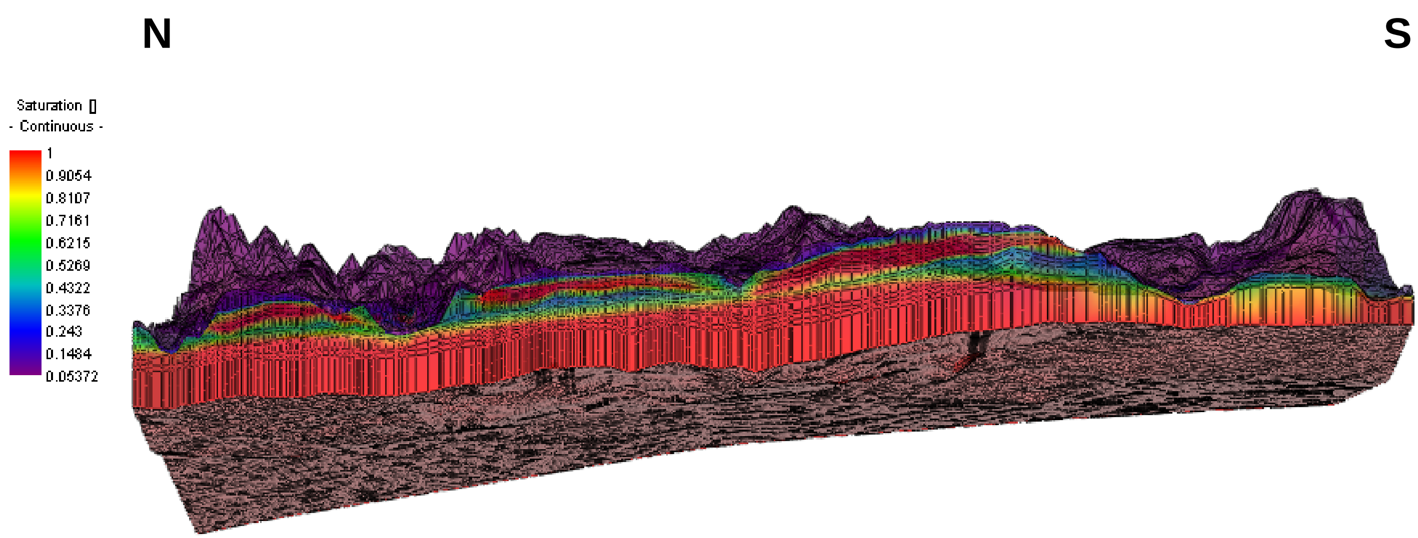


Figure 6.G-4. Modeled Saturation for a N-S Section





Appendix 6.G Tables

Table 6.G-1 Baseline Water Quality at Cottonwood Arroyo Alluvial Wells

		Cottonwood Alluvial Well		
Parameter		QACW-2	QACW-2B	GM-17
Baseline Monitoring Period		1974 - 2008	1986 - 1999	1975 - 1982
pH (SU)[1]	n	9	33	7
	median	7.9	7.8	6.9
TDS -180° (mg/L)	n	14	32	11
	median	2,305	3,015	15,210
Bicarbonate (as HCO3 mg/L)	n	9	32	2
	median	310	375.2	767
Carbonate (as CaCO3 mg/L)	n	2	15	0
	median	24	0.5	NA
Chloride (mg/L)	n	14	33	11
	median	28.2	138	113
Sulfate (mg/L)	n	14	32	11
	median	1,227	1,605	9,308
Calcium (mg/L)	n	9	33	8
	median	113	154	375
Magnesium (mg/L)	n	11	33	10
	median	16.2	22.7	145.0
Potassium (mg/L)	n	5	32	6
	median	2.0	6.5	25.5
Sodium (mg/L)	n	9	33	8
	median	451	778	4,510
Fluoride (mg/L)	n	14	33	11
	median	2.35	1.38	0.30
Nitrate as N (mg/L)	n	7	7	11
	median	0.18	0.09	1.03
Boron (mg/L)	n	13	32	11
	median	0.11	0.13	0.28
Iron, total (mg/L)	n	4	16	9
	median	0.03	1.04	0.62
Iron, diss.(mg/L)	n	14	33	11
	median	0.18	0.10	0.09
Manganese, total (mg/L)	n	3	16	8
	median	0.02	0.37	1.765
Manganese, diss. (mg/L)	n	14	33	11
	median	0.10	0.11	1.02
Selenium. (mg/L)	n	9	33	11
	median	0.0030	0.0025	0.0004

[1]Lab pH included in summary only when no field pH data are available for the well
QACW-2 include 1974 through 1979 samples from GM-18

Table 6.G-2. Relevant Groundwater Quality Use Criteria

Parameter (units)	Livestock Watering Criteria [1]	Domestic Water Supply Criteria for Surface Water by 2007 Navajo Nation Standards	EPA Secondary Drinking Water Standards[2]
Arsenic (mg/L)	0.2	0.01	
Barium (mg/L)		1	
Boron (mg/L)	5	0.63	
Cadmium (mg/L)	0.05	0.005	
Chloride (mg/L)			250
Chromium (mg/L)	1	0.1	
Copper (mg/L)	0.5(D)	1.3	1
Fluoride (mg/L)	2*	4	2
Total iron (mg/L)	-		0.3
Lead (mg/L)	0.1	0.015	
Total manganese (mg/L)	-		0.05
Mercury (mg/L)	0.01	0.002	
Nitrate (mg/L-N)	0.132	10	
pH (su)	6.5-9.0	5.0-9.0	6.5-8.5
Potassium (mg/L)			
Radium-226 (pCi/L)	30**	5**	
Radium-228 (pCi/L)	30**	5**	
Selenium (mg/L)	0.05	0.05	
Silver (mg/L)		0.035	0.1
Sulfate (mg/L)	1000*		250
Total dissolved solids (TDS) (mg/L)	3000*		500
Uranium (mg/L)		0.03	
Zinc (mg/L)	25	2.1	5

[1] Based on Navajo Nation Environmental Protection Agency Water Quality Program, 2008, Navajo Nation Surface Water Quality Standards 2007, passed by Navajo Nation Resources Committee on May 13, 2008 and on other cirteria for livestock use as noted

[2] http://water.epa.gov/drink/contaminants/secondarystandards.cfm

* Although there are no Navajo Nation livestock watering criteria for TDS, sulfate and fluoride, TDS concentrations above 3,000 may adversely affect growing/young livestock and waters with sulfate concentrations above 1,000 mg/l and fluoride concentrations above 2 mg/l are not recommended for livestock use (Lardy, G., C. Stoltenow, and R.

** 30 pCi/L criteria for Ra-226 + Ra-228

mg/L - milligram per liter

Table 6.G-3 Water Levels in Pinabete Alluvial Monitoring Wells

Well Name	PA-1		PA-2	
Measuring point elevation (ft msl)	5352.9		5431.43	
Date	Water level (ft)	Elevation (ft msl)	Water level (ft)	Elevation (ft msl)
3/26/1998	-	-	7.61	5423.82
3/29/1998	11.35	5341.55	7.69	5423.74
4/30/1998	11.42	5341.48	-	-
5/12/1998	11.46	5341.44	7.94	5423.49
6/11/1998	11.63	5341.27	8.16	5423.27
7/21/1998	12.04	5340.86	8.38	5423.05
8/20/1998	11.87	5341.03	8.24	5423.19
9/30/1998	11.7	5341.20	8.09	5423.34
11/8/1998	11.4	5341.50	7.88	5423.55
12/17/1998	11.18	5341.72	7.63	5423.8
8/22/2007	11.85	5341.05	8.78	5422.65
9/4/2007	11.95	5340.95	8.76	5422.67
10/4/2007	12.1	5340.80	NA	-
11/5/2007	12.14	5340.76	-	-
11/15/2007	-	-	8.76	5422.67
12/3/2007	12.09	5340.81	-	-
12/5/2007	-	-	8.7	5422.73
1/17/2008	12.0	5340.90	8.6	5422.83
2/19/2008	-	-	8.6	5422.83
2/21/2008	11.7	5341.20	-	-
3/20/2008	11.6	5341.30	8.3	5423.18
4/24/2008	11.5	5341.40	5.5	5425.93
5/27/2008	11.0	5341.90	5.0	5426.43
6/24/2008	12.0	5340.90	8.2	5423.23
7/24/2008	12.2	5340.70	9.0	5422.43
8/19/2008	-	-	9.2	5422.23
8/20/2008	11.2	5341.70	-	-
9/30/2008	11.0	5341.90	9.0	5422.4

ft msl - feet above mean sea level
(-) no measurement taken

Table 6.G-4 Alluvial Monitoring Well Summary and Aquifer Test Results

Well	Location (ft)		ID (in)	Elevation (ft)	Well depth (ft)	Test type	Transmissivity (ft^2/day)	Hydraulic conductivity		Saturated thickness (feet)
	Northing	Easting						(ft/day)	(cm/sec)	
PA-1	1990260.34	300409.2	2.1	5351.2	15.2	2.0 gpm pumping test	230.7	51.3	1.8E-02	4.5
PA-2	1980956.93	306702.8	2.1	5429.6	9.6	0.75 gpm pumping test	53.6	10.7	3.8E-03	5

ft^2/day - square feet per day
cm/sec - centimeter per second
NA - information not available
ID - inside well casing diameter

Table 6.G-5 Water Quality at Pinabete Arroyo Alluvial Well PA-1

Parameter (units)	3/29/1998	5/15/1998	8/20/1998	11/8/1998	6/15/2004	11/5/2007	2/21/2008	5/27/2008	8/20/2008	11/21/2008
Total Alkalinity as $CaCO_3$ (mg/L)	300	297	282	301	302	304	314	310	224	344
Arsenic (mg/L)	<0.005	<0.005	<0.005	<0.005	-	0.0008	<0.0005	0.0007	<0.0005	0.0008
Barium (mg/L)	0.05	0.03	0.9	0.03	-	0.0161	0.0144	0.0262	0.0164	0.0174
Bicarbonate as HCO_3 (mg/L)	365	362	344	367	368	371	383	378.2	216	344
Boron (mg/L)	0.17	0.2	0.2	0.22	-	0.787	0.2	0.2	0.2	0.2
Ion balance (%)	6.77	0.89	3.88	2.38	-	5.99	1.06	1.78	0.85	1.64
Cadmium (mg/L)	<0.001	<0.001	<0.001	<0.001	-	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
Calcium (mg/L)	85.4	68.5	103	90.6	102	110	116	137	139	101
Carbonate (mg/L)	<1	<1	<1	<1	<10	<10	<10	<10	<10	<10
Chloride (mg/L)	25	22	29	16	14	14	17	36	25	18
Chromium (mg/L)	0.03* (total)	<0.01	<0.01	<0.01	-	0.005	0.004	0.004	<0.001	<0.001
Electrical conductivity (EC) (uS/cm)	2540	2410	2310	2150	2480	2380	2380	2680	3050	2520
Copper (mg/L)	<0.01	<0.01	<0.01	<0.01	-	0.0106	0.0151	0.0101	0.0094	0.0079
Fluoride (mg/L)	2.49	2.36	2.39	2.53	-	2.2	2.2	2.1	2.2	3
Hydroxide (mg/L)	<1	<1	<1	<1	<10	<10	<10	<10	<10	<10
Iron (mg/L)	0.99	0.06	<0.02	<0.02	-	<0.05	<0.05	<0.05	<0.05	<0.05
Total iron (mg/L)	41.9	3.07	4.43	0.25	-	16.7	17.5	53.2	1.39	3.88
Lead (mg/L)	<0.005	<0.005	<0.005	<0.005	-	<0.0001	<0.0001	0.0002	0.0002	0.0003
Magnesium (mg/L)	15.4	13.4	16.5	13.8	15.8	16.3	17.9	22.3	22.3	16.4
Manganese, D (mg/L)	0.138	0.005	0.017	<0.01	-	0.118	0.057	0.488	0.218	0.087
Manganese, T (mg/L)	1.31	0.843	0.37	0.03	-	0.487	0.302	3.56	0.350	0.142
Mercury (mg/L)	<0.001	<0.001	<0.001	<0.001	-	<0.0002	<0.0002	0.0002	<0.0002	<0.0002
Nitrate (mg/L-N)	0.66	0.72	<0.05	NM	-	0.05	0.03	0.04	0.10	0.05
pH (su)	7.6	7.5	7.5	7.7	7.67	7.61	7.54	7.53	7.48	7.78

Table 6.G-5 Water Quality at Pinabete Arroyo Alluvial Well PA-1

Parameter (units)	3/29/1998	5/15/1998	8/20/1998	11/8/1998	6/15/2004	11/5/2007	2/21/2008	5/27/2008	8/20/2008	11/21/2008
Potassium (mg/L)	9.8	1.8	1.7	2.9	1.4	1.4	1.3	2.7	1.7	1.7
Radium-226 (pCi/L)	<1.69	5.78	NM	0.91	-	2.9 ± 0.9	0.42 ± 0.34	1.3 ± 0.4	0.6 ± 0.42	0.10 ± 0.22
Radium-228 (pCi/L)	<1.9	5.77	NM	11.74	-	1.5 ± 0.7	0.60 ± 0.40	1.1 ± 0.6	0.53 ± 0.49	0.48 ± 0.38
Selenium (mg/L)	0.005	0.005	<0.005	<0.005	0.014	0.006	0.004	0.006	0.003	0.006
Silver (mg/L)	<0.01	<0.01	<0.01	<0.01	-	<0.00005	<0.00005	0.00006	<0.00005	<0.00005
Sodium (mg/L)	375	458	374	377	464	418	457	511	503	445
Sulfate (mg/L)	893	833	875	805	920	1040	1060	1140	1280	980
Total dissolved solids (TDS) (mg/L)	1610	1640	1730	1500	1660	1680	4310	1950	2030	1750
Uranium (mg/L)	-	-	-	-	-	0.01010	0.01080	0.01350	0.01620	0.01230
Zinc (mg/L)	0.053	0.037	<0.025	0.043	-	0.007	0.002	0.002	0.002	0.007

(-) s no analysis performed

mg/L - milligram per liter

µS/cm - microsiemens per centimeter

su - standard units

pCi/L - picocuries per liter

Table 6.G-6 Water Quality at Pinabete Arroyo Alluvial Well PA-2

Parameter (units)	3/30/1998	5/15/1998	8/20/1998	11/11/1998	6/15/2004	11/15/2007	2/21/2008	5/27/2008	8/19/2008	11/20/2008
Total alkalinity as $CaCO_3$ (mg/L)	293	281	315	327	286	410	308	328	405	430
Arsenic (mg/L)	<0.005	<0.005	<0.005	<0.005	-	0.0012	0.0007	0.0018	0.0008	0.0027
Barium (mg/L)	0.04	0.02	<0.2	0.02	-	0.0107	0.0129	0.0195	0.0143	0.0119
Bicarbonate as HCO_3 (mg/L)	357	342	384	398	349	451	376	400	405	430
Boron (mg/L)	0.19	0.2	0.22	0.31	-	0.2	2.1	0.2	0.3	0.2
Ion balance (%)	4.27	2.64	1.65	3.2	-	16	6.5	5.57	0.61	8.18
Cadmium (mg/L)	<0.001	<0.001	<0.001	<0.001	-	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
Calcium (mg/L)	56.8	61	101	95	87.5	95	96.0	96.8	90.8	92.3
Carbonate (mg/L)	<1	<1	<1	<1	<10	24	<10	<10	<10	<10
Chloride (mg/L)	22	65	51	35	22	38	30	32	42	45
Chromium (mg/L)	0.03* (total)	<0.01	<0.01	<0.01	-	0.006	0.004	0.003	<0.001	0.009
Electrical conductivity (EC) (uS/cm)	4390	4510	4530	4520	4040	4600	4410	4110	5010	4860
Copper (mg/L)	<0.01	<0.01	<0.01	<0.01	-	0.0508	0.0116	0.0225	0.0226	0.0220
Fluoride (mg/L)	2.47	2.81	3.06	2.91	-	2.8	2.4	2.5	3.1	3.3
Hydroxide (mg/L)	<1	<1	<1	<1	<10	<10	<10	<10	<10	<10
Iron (mg/L)	0.11	<0.02	<0.02	0.04	-	<0.05	<0.05	<0.05	<0.05	<0.05
Total iron (mg/L)	63.9	2.88	6.55	0.13	-	1.86	5.61	3.03	1.86	3.19
Lead (mg/L)	<0.005	<0.005	<0.005	<0.005	-	<0.0001	<0.0001	0.0001	0.0002	0.0001
Magnesium (mg/L)	12	11	16	15	13.2	0.0277	15.5	16.7	15.5	16.7
Manganese (mg/L)	1.33	0.456	0.22	0.11	-	0.0277	0.090	0.141	0.128	0.135
Total manganese (mg/L)	3.71	0.525	0.88	0.24	-	0.552	1.27	0.599	0.551	0.748
Mercury (mg/L)	<0.001	<0.001	<0.001	<0.001	-	<0.0002	<0.0002	0.0002	<0.0002	<0.0002
Nitrate (mg/L-N)	0.27	0.32	<0.05	NM	-	0.06	0.08	0.08	0.11	0.05
pH (su)	7.9	7.4	7.3	7.5	7.62	7.19	7.41	7.5	7.21	7.31

Table 6.G-6 Water Quality at Pinabete Arroyo Alluvial Well PA-2

Parameter (units)	3/30/1998	5/15/1998	8/20/1998	11/11/1998	6/15/2004	11/15/2007	2/21/2008	5/27/2008	8/19/2008	11/20/2008
Potassium (mg/L)	5	2	3	5.4	1.8	2.1	2.0	2.4	3.3	3.2
Radium-226 (pCi/L)	<1.69	27.9	-	0.48	-	0.67 ± 0.43	0.40 ± 0.39	0.45 ± 0.34	0.60 ± 0.40	2.5 ± 0.7
Radium-228 (pCi/L)	<1.9	1.74	-	9.02	-	0.62 ± 0.48	1.4 ± 0.6	0.19 ± 0.56	1.2 ± 0.5	0.55 ± 0.37
Selenium (mg/L)	0.0007	0.006	<0.005	<0.005	0.012	0.012	0.009	0.014	0.010	0.018
Silver (mg/L)	<0.01	<0.01	<0.01	<0.01	-	<0.00005	<0.00005	0.00009	<0.00005	<0.00005
Sodium (mg/L)	781	981	872	891	839	809	850	907	966	1000
Sulfate (mg/L)	1670	1760	1690	1940	1550	2200	2100	2150	1950	2400
Total Dissolved Solids (TDS) (mg/L)	2990	3150	3600	3420	2780	3500	3070	3030	3540	3580
Uranium (mg/L)	-	-	-	-	-	0.01230	0.01120	0.01350	0.01160	0.01170
Zinc (mg/L)	0.051	0.025	<0.025	0.18	-	0.003	0.008	0.009	0.004	0.008

(-) no analysis performed
mg/L - milligram per liter
µS/cm - microsiemens per centimeter
su - standard units
pCi/L - picocuries per liter

Table 6.G-7. Potentiometric Elevations in Coal Monitoring Wells and Piezometers

Well/VWP Name	KF-98-02	KF-98-03	KF-98-04	KF2007-01	VWP 2007-01 (yellow)	VWP 2007-01 (green)	VWP 2007-01 S6 (white)	VWP 2007-02 (yellow)	VWP 2007-02 (white)	VWP 2007-02 (blue)	VWP 2007-02 (green)	VWP 2007-03 (yellow)	VWP 2007-03 (red)	VWP 2007-05 S2 (blue)
Coal Unit	S3	S3	S3	S8	S2a/S2b	S3	S6	S2	S3	S7	S8	S3	S2	S2
Date	Potentiometric Elevation (ft msl)													
4/30/1998	5325.75	5294.77	5289.62	-	-	-	-	-	-	-	-	-	-	-
5/12/1998	5331.00	5294.95	5289.59	-	-	-	-	-	-	-	-	-	-	-
6/11/1998	5340.83	5292.87	5289.03	-	-	-	-	-	-	-	-	-	-	-
7/21/1998	5349.56	5293.74	5289.07	-	-	-	-	-	-	-	-	-	-	-
11/8/1998		5293.78	5288.83	-	-	-	-	-	-	-	-	-	-	-
12/17/1998	5315.64	5292.75	5288.85	-	-	-	-	-	-	-	-	-	-	-
8/22/2007	-	5292.21	-	5392.33	5275.44	5278.48	5331.54	5292.06	5288.98	5372.05	5394.32	5366.22	5360.25	-
9/4/2007	5352.12	5292.37	-	5392.60	5273.72	5278.78	5331.85	5291.73	5288.58	5371.69	5394.47	5367.05	5357.72	-
10/4/2007	5354.47	-	5288.48	-	-	-	-	-	-	-	-	-	-	-
10/9/2007	-	-	-	5392.81	5273.44	5278.79	5330.39	5291.30	5287.63	5371.25	5393.71	5367.63	5357.26	-
11/5/2007	5356.16	-	-	-	-	-	-	-	-	-	-	5367.88	5357.23	5410.91
11/15/2007	-	-	-	5392.86	5273.37	5278.69	5329.97	5290.94	5288.21	5370.93	5393.77	-	-	-
12/3/2007	-	-	-	-	-	-	-	-	-	-	-	5367.74	5357.60	-
12/5/2007	5323.44	5291.94	-	5392.01	-	5278.56	5329.88	5291.09	5287.85	5370.81	5393.67	-	-	5410.61
1/17/2008	5329.14	5292.73	-	5393.06	-	-	-	-	-	-	-	-	-	-
1/31/2008	-	-	-	-	5273.42	5278.79	5329.84	5291.91	5288.15	5370.74	5393.81	5368.04	5357.83	5410.71
2/19/2008	5332.94	5291.73	-	5393.36	5273.05	5278.62	5330.05	5289.57	5287.20	5370.63	5393.56	5368.70	5357.74	-
3/20/2008	5328.04	5292.13	-	5392.96	5273.15	5278.39	5330.09	5289.18	5286.96	5370.63	5393.71	5366.44	5385.30	-
4/24/2008	5331.34	5292.83	-	5393.26	5273.23	5278.30	5330.11	5289.12	5286.86	5370.60	5393.67	5366.52	5385.50	5410.22
5/27/2008	-	-	-	5393.06	-	-	-	-	-	-	-	-	-	-
5/28/2008	5332.54	-	-	-	5273.42	5286.86	5330.11	5289.70	5286.86	5370.54	5390.11	5365.97	5385.40	5410.27
6/24/2008	5299.04	5291.73	-	5393.06	5273.47	5278.62	5330.15	5287.02	5287.02	5370.59	5390.11	5365.97	5385.40	5410.33
7/24/2008	5303.84	5293.43	-	5365.96	5273.30	5278.76	5330.17	5289.63	5286.89	5370.51	5390.05	5366.05	5385.50	5410.33
8/19/2008	5305.84	-	-	5392.96	5273.42	5278.56	5330.17	5286.99	5287.51	5370.45	5393.48	5366.19	5358.26	5410.33
8/20/2008	-	5293.03	-	-	-	-	-	-	-	-	-	-	-	-
9/30/2008	5300.24	5292.73	-	5392.76	5273.45	5278.53	5330.42	5287.63	5287.42	5370.51	5393.36	5366.14	5358.11	5410.39

ft msl - feet above mean sea level
VWP - vibrating wire piezometer
(-) no measurement taken

Table 6.G-8. Coal Monitoring Well Summary and Aquifer Test Results

Well	Location (ft)[1]		Coal seam	Ground Elevation (ft)	Well depth (ft)	Test type	Transmissivity (ft^2/day)	Hydraulic conductivity		Saturated thickness (feet)
	Northing	Easting						(ft/day)	(cm/sec)	
Kf-98-02	1974601.45	2526796.60	#3	5505.9	216.5	Displacement Test	0.0010	0.0001	4.6E-08	7.5
Kf-98-03	1984332.35	2527508.40	#3	5423.5	133.9	Bailed Recovery Test	0.010	0.002	7.1E-07	5
Kf-98-04	1990225.42	2523277.83	#3	5351.8	64.8	Bailed Recovery Test	0.010	0.001	3.5E-07	10
Kf2007-01	1995163.61	2525504.37	#8	5557.2	118	Papadopulos-Cooper Pumping Test	1.398	0.056	2.0E-05	25

ft^2/day - square feet per day

cm/sec - centimeter per second

[1] Coordinate system - State Plane New Mexico West, NAD 1983

Table 6.G-9. Baseline Water Quality in the Fruitland Coals at the BNCC Coal Lease

Well	Well Depth (feet)	Baseline Monitoring Period	pH (SU)		TDS -180° (mg/L)		Bicarbonate as HCO_3 (mg/L)		Carbonate as CO_3 (mg/L)		Chloride (mg/L)		Sulfate (mg/L)		Calcium (mg/L)		Magnesium (mg/L)		Potassium (mg/L)	
			n	median	n	median	n	median	n	median	n	median	n	median	n	median	n	median	n	median
KF2007-01 (No. 8)	118	2007-2008	5	8.75	5	3460	5	1818	5	156	5	3385	6	740	5	3.2	5	1.7	6	17.9
KF98-02 (No. 3)	216.5	1998 2007-2008	6	7.95	6	3130	6	1512	6	30	6	940	6	107	6	6.1	6	0.9	8	12.1
KF84-21a (No 2)	118	1984-2001	30	7.9	30	8375	30	1197	17	<1	30	4445	30	63	30	13.3	30	14.9	30	13.3
KF84-21c (No 7)	75	1984	1	8.08	1	8505	1	919	1	68.4	1	3980	1	184	1	14.6	1	14.9	1	15.0
KF84-22a (No 8)	125	1984-2001	22	8.0	22	4650	22	1170	12	<1	22	290	22	2140	22	15.3	22	3.5	22	6.8
KF84-22b (No 7)	140	1984-2001	26	7.4	26	6115	25	854	15	<1	25	3220	26	<10	26	45.0	26	13.4	26	11.9
KF84-22d (No 3)	220	1984	1	7.94	1	8610	1	830	1	46.8	1	3420	1	<10	1	27.4	1	18.7	1	15.8
KF84-22e (No 2)	237	1984	2	7.98	2	8155	2	814	2	52.8	2	4185	2	24.5	2	35.6	2	17.5	2	16.3
KF84-20A (No 3)	190	1984-2001	26	7.93	26	7260	26	1090	23	<1	26	3715	26	<10	26	18.4	26	11.0	26	11.9
KF84-20C (No 7)	240	1984-2001	23	7.9	23	2770	23	1562	21	<1	23	715	23	7	23	9.6	23	2.8	23	5.9
KF84-18b (No 8)	133	1984-2001	25	7.1	25	9300	25	1030	13	<1	25	4900	25	<10	25	114.0	27	24.3	25	15.0
KF84-18a (No. 6)	181	1984-2001	26	7.47	26	13400	26	450	14	<1	26	7900	26	5.5	26	157.0	26	50.6	26	22.5

Well	Well Depth (feet)	Baseline Monitoring Period	Sodium (mg/L)		Fluoride (mg/L)		Nitrate as N (mg/L)		Boron (mg/L)		Iron, total (mg/L)		Iron, diss.(mg/L)		Manganese, total (mg/L)		Manganese, diss. (mg/L)		Selenium, diss. (mg/L)	
			n	median	n	median	n	median	n	median	n	median	n	median	n	median	n	median	n	median
KF2007-01 (No. 8)	118	2007-2008	5	1180	5	2.70	5	0.25	5	0.33	5	0.290	5	<0.05	5	0.017	5	0.008	5	0.005
KF98-02 (No. 3)	216.5	1998 2007-2008	6	1210.0	6	1.65	6	0.03	8	0.4	6	0.530	6	0.038	8	0.018	6	0.018	6	0.008
KF84-21a (No 2)	118	1984-2001	30	3080	30	1.56	5	0.1	30	0.61	21	0.100	30	0.100	21	0.020	30	0.0255	29	<0.005
KF84-21c (No 7)	75	1984	1	2858	1	1.79	1	394	1	0.63	1	-	1	0.015	1	-	1	0.3800	1	<0.001
KF84-22a (No 8)	125	1984-2001	22	1600	22	2.19	3	0.53	22	0.27	19	0.420	22	0.080	19	0.020	22	0.0143	22	<0.005
KF84-22b (No 7)	140	1984-2001	26	2210	25	0.89	1	0.08	25	0.39	23	1.130	26	0.195	23	0.300	26	0.300	26	<0.005
KF84-22d (No 3)	220	1984	1	2866	1	1.28	1	-	1	0.5	1	-	1	0.006	1	-	1	0.016	1	<0.001
KF84-22e (No 2)	237	1984	2	2803	2	1.23	2	-	2	0.51	2	-	2	0.005	2	-	2	0.140	2	<0.001
KF84-20A (No 3)	190	1984-2001	26	2690	26	1.39	2	0.115	26	0.55	17	2.730	26	0.235	17	0.180	26	0.100	26	<0.005
KF84-20C (No 7)	240	1984-2001	23	1040	23	1.74	2	0.18	21	0.42	16	0.640	23	0.180	16	0.075	23	0.082	23	<0.005
KF84-18b (No 8)	133	1984-2001	25	3380	25	0.44	3	0.1	25	0.73	17	11.900	25	<0.5	16	0.380	25	0.380	25	<0.005
KF84-18a (No. 6)	181	1984-2001	26	4640	26	0.66	2	0.1	26	0.72	17	3.80	26	0.25	17	1.33	26	1.32	19	<0.005

Median calculation based on all but rejected sample results including field splits and non detected results

Rejected samples include: samples with no sampling or analysis date, samples with pH>11, samples that are clearly inconsistent with results of other damples

For less than detection limit, 1/2 the detection limit used for summary unles the median is a detection limit that is lower than any detected result

uncaracterized metals results included as dissolved metals in statistical summray

Table 6.G-10 Water Depths and Potentiometric Elevations in the Pictured Cliffs Sandstone Monitoring Wells and Piezometers

	Well or Piezometer Name											
	KPC-98-01		KPC2007-01		KPC2007-02		KPC2007-03		VWP 2007-01 Kpc (blue)	VWP 2007-02 Kpc (red)	VWP 2007-04 Kpc	VWP 2007-05 Kpc (red)
Measuring point elevation (ft msl)	5366.46		5355.71		5515.06		5470.23					
Date	Water depth (ft)	Elevation (ft msl)	Water depth (ft)	Elevation (ft msl)	Water depth (ft)	Elevation (ft msl)	Water depth (ft)	Elevation (ft msl)	Potentiometric elev (ft msl)	Potentiometric elev (ft- msl)	Potentiometric Elev. (ft- msl)	Potentiometric Elev. (ft- msl)
3/29/1998	91.31*	5275.15	-	-	-	-	-	-	-	-	-	-
4/30/1998	86.62	5279.84	-	-	-	-	-	-	-	-	-	-
5/12/1998	84.84	5281.62	-	-	-	-	-	-	-	-	-	-
6/11/1998	106.37	5260.09	-	-	-	-	-	-	-	-	-	-
7/21/1998	97.27	5269.19	-	-	-	-	-	-	-	-	-	-
11/8/1998	80.30	5286.16	-	-	-	-	-	-	-	-	-	-
12/17/1998	89.81	5276.65	-	-	-	-	-	-	-	-	-	-
8/22/2007	-	-	93.61	5262.10	217.55	5297.51	-	-	5270.44	-	-	-
8/23/2007	75.09	5291.37	-	-	-	-	128.66	5341.57	-	5298.44	-	-
9/4/2007	79.35	5287.11	93.68	5262.03	169.11	5345.95	128.03	5342.20	5268.35	5297.90	-	-
10/4/2007	77.56	5288.90	93.65	5262.06	-	-	-	-	-	5297.37	-	-
10/9/2007	-	-	-	-	-	-	-	-	5267.89	-	-	-
11/5/2007	76.51	5289.95	93.78	5261.93	183.30	5331.76	130.67	5339.56	-	-	5393.83	5411.60
11/15/2007	-	-	-	-	-	-	-	-	5268.14	-		
12/5/2007	78.15	5288.31	93.71	5262.00	163.16	5351.90	133.71	5336.52	5268.26	5296.81	5397.48	5411.26
1/31/2008	-	-	-	-	-	-	-	-	5268.09	5297.32	5393.68	5411.54
2/19/2008	-	-	-	-	-	-	-	-	5268.91	-	-	-
2/21/2008	-	-	-	-	-	-	-	-	-	5296.42	-	-
3/20/2008	89.80	5276.66	96.80	5258.91	158.80	5356.26	128.30	5341.93	5268.95	5296.48	5401.50	5410.79
4/24/2008	85.00	5281.46	94.10	5261.61	156.40	5358.66	123.50	5346.73	5268.78	5296.42	5401.82	5410.76
5/27/2008	81.50	5284.96	98.50	5257.21	155.90	5359.16	126.50	5343.73	-	-	-	-
5/28/2008	-	-	-	-	-	-	-	-	5269.01	5296.28	5402.20	5410.82
6/24/2008	79.90	5286.56	94.10	5261.61	157.10	5357.96	127.10	5343.13	5269.04	5296.48	5402.40	5410.88
7/24/2008	79.20	5287.26	94.00	5261.71	156.30	5358.76	126.70	5343.53	5268.76	5296.39	5402.86	5410.85
8/19/2008	-	-	-	-	157.80	5357.26	-	-	5268.83	5296.14	5402.95	5410.85
8/20/2008	78.40	5288.06	94.10	5261.61	-	-	126.70	5343.53	-	-	-	-
9/30/2008	77.70	5288.76	94.40	5261.31	155.20	5359.86	126.80	5343.43	5268.66	5296.25	5403.30	5410.94

ft msl - feet above mean sea level
*1 day after well development
(-) no measurement taken

Table 6.G-11 Pictured Cliffs Sandstone Monitoring Well Summary and Aquifer Test Results

Well	Location (ft)[1]		Elevation (ft)	Well Depth (ft)	Test type	Transmissivity (ft^2/day)	Hydraulic conductivity		Saturated thickness (ft)	Storage coefficient
	Northing	Easting					(ft/day)	(cm/sec)		
KPC-98-01	1993802	290787	5366.46	125.7	0.4 gpm pumping test	0.79	0.020	7.1E-06	39	NA
KPC2007-01	1995103	302596	5355.71	208.84	NA	0.576	0.0074	2.6E-06	78	NA
KPC2007-02	1975119	303891	5515.06	320.98	NA	NA	0.0001	3.5E-08	NA	NA
KPC2007-03	1982885	295091	5470.23	138.4	NA	NA	0.0040	1.4E-06	NA	NA
Pumping test well T4-1	1976250	289850	5520	228	0.15 gpm pumping	0.1203	0.0014	4.9E-07	84	0.00032
Recovery test well GM-30A	1975811	290347	NA	191.6	NA	0.1337	0.0016	5.6E-07	84	0.00034

[1] Coordinates State Plane New Mexico West NAD 1983
[2] 18.3 gpm for 8.7 min

ft^2/day - square feet per day
cm/sec - centimeter per second
gpm - gallon per minute
NA - information not available or not determined

0.0E+00

Table 6.G-12 Water Quality at Pictured Cliffs Sandstone Monitoring Well KPC-98-01

Parameter (units)	3/29/1998	11/8/1998	8/23/2007	11/5/2007	2/21/2008	5/27/2008	8/20/2008	11/21/2008
Total Alkalinity as $CaCO_3$ (mg/L)	131	581	750	930	900	870	740	850
Arsenic (mg/L)	<0.005	<0.005	0.0042	0.00193	0.0019	0.002	0.0017	0.0035
Barium (mg/L)	0.02	0.02	0.0138	0.0101	0.0123	0.0236	0.0132	0.0126
Bicarbonate as HCO_3 (mg/L)	132	709	891	1135	1098	1061	903	1037
Boron (mg/L)	0.12	0.61	0.6	1.11	0.7	0.7	0.6	0.7
Ion balance (%)	2.13	3.71	4.6	8.3	2.17	0.49	6.89	1.61
Cadmium (mg/L)	<0.001	<0.001	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
Calcium (mg/L)	26.5	33.1	28	25.2	26.8	30.8	28.4	28.6
Carbonateas CO3 (mg/L)	14	<1	12	<10	<10	<10	<10	<10
Chloride (mg/L)	39	177	310	212	234	244	220	236
Chromium (mg/L)	<0.01* (total)	<0.01	0.018	0.124	0.012	0.004	0.001	0.021
Electrical conductivity (EC) (uS/cm)	1380	6550	5510	8250	8250	8250	8730	8700
Copper (mg/L)	<0.01	<0.01	0.0396	0.026	0.0571	0.43	0.0468	0.0807
Fluoride (mg/L)	2.29	1.13	1.3	1.4	1.4	1.3	1.5	1.5
Hydroxide (mg/L)	-	-	<10	<10	<10	<10	<10	<10
Iron (mg/L)	0.46	1.51	0.68	<0.05	<0.05	<0.05	<0.05	<0.05
Total iron (mg/L)	2.51	1.74	0.68	29.5	7.60	2.71	0.16	0.51
Lead (mg/L)	<0.005	0.005	0.0001	<0.0001	0.0003	0.0003	0.0002	0.0001
Magnesium (mg/L)	2.7	5.7	8.2	6.8	7.7	8	7.4	7.7
Manganese (mg/L)	0.013	0.08	0.063	0.0673	0.058	0.051	0.037	0.039
Total manganese (mg/L)	0.038	0.1	0.073	0.111	0.183	0.082	0.044	0.045
Mercury (mg/L)	<0.001	<0.001	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Nitrate (mg/L-N)	1.54	-	<0.02	2.29	1.94	4.46	2.68	1.92
pH (su)	9.1	8	7.78	7.76	7.70	7.79	7.73	7.87
Potassium (mg/L)	8.2	17.3	9.2	7.1	8.6	10	8.5	8.1
Radium-226 (pCi/L)	<1.69	3.92	0.92 ± 0.49	1.0 ± 0.5	1.2 ± 0.5	1.5 ± 0.5	0.76 ± 0.44	0.61 ± 0.36
Radium-228 (pCi/L)	<1.9	5.42	1.2 ± 0.5	1.6 ± 0.6	1.1 ± 0.4	1.2 ± 0.5	1.2 ± 0.5	1.3 ± 0.4
Selenium (mg/L)	<0.005	<0.005	0.005	0.00346	0.006	0.005	0.005	0.011
Silver (mg/L)	<0.01	<0.01	<0.00005	0.00006	<0.00005	0.00007	<0.00005	<0.00005
Sodium (mg/L)	202	1490	2150	1790	1930	2270	1690	1980
Sulfate (mg/L)	350	2680	3900	3350	3300	3800	3300	3400
Total dissolved solids (TDS) (mg/L)	800	4830	6640	6060	6050	5900	5820	6360
Uranium (mg/L)	-	-	0.01901	0.01230	0.01220	0.00952	0.01000	0.01010
Zinc (mg/L)	0.093	0.365	0.002	0.201	0.018	0.022	0.019	0.027

(-) analysis not performed for parameter

mg/L - milligram per liter

µS/cm - microsiemens per centimeter

su - standard units

pCi/L - picocuries per liter

Table 6.G-13 Water Quality at Pictured Cliffs Sandstone Monitoring Well KPC2007-01

Parameter (units)	8/16/2007	11/15/2007	2/19/2008	5/28/2008	8/20/2008	11/20/2008
Total alkalinity as CaCO3 (mg/L)	1480	1870	1900	1280	1600	1440
Arsenic (mg/L)	0.006	0.0058	0.0052	0.0234	0.0025	0.0051
Barium (mg/L)	0.0342	0.0096	0.0214	0.0341	0.0191	0.0173
Bicarbonate as HCO3 (mg/L)	1732	866	415	1488	756	1293
Boron (mg/L)	0.3	0.429	0.5	0.6	0.4	0.5
Ion balance (%)	9	10.4	11.1	6.13	17.9	7.82
Cadmium (mg/L)	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
Calcium (mg/L)	13.4	3.6	2.4	18.6	3	11.6
Carbonate as CO3 (mg/L)	36	696	936	36	588	228
Chloride (mg/L)	320	304	292	374	365	580
Chromium (mg/L)	0.005	0.025	0.040	0.008	0.002	0.063
Electrical conductivity (EC) (uS/cm)	8240	8260	8070	7950	8560	9250
Copper (mg/L)	0.0934	0.104	0.0785	0.2470	0.0369	0.0412
Fluoride (mg/L)	1.7	1.5	1.5	1.8	1.6	1.6
Hydroxide as CaCO3 (mg/L)	<10	<10	<10	<10	<10	<10
Iron (mg/L)	<0.05	<0.05	<0.05	0.13	<0.05	<0.05
Total iron (mg/L)	1.11	0.0892	0.93	533	0.17	1.57
Lead (mg/L)	<0.0001	<0.0001	<0.0001	0.0004	0.0002	0.0002
Magnesium(mg/L)	7.3	0.0056	4.2	9.4	4.4	7.1
Manganese (mg/L)	0.034	0.0244	<0.005	0.022	<0.005	0.0785
Total manganese (mg/L)	0.055	0.024	0.022	9.73	0.006	0.137
Mercury (mg/L)	<0.0002	<0.0002	<0.0002	0.001	<0.0002	<0.0002
Nitrate (mg/L-N)	<0.02	<0.02	0.03	0.05	0.65	0.07
pH (su)	8.19	9.82	10.3	8.35	9.85	9.14
Potassium (mg/L)	18.1	76.9	73.3	14.3	35.2	16.2
Radium-226 (pCi/L)	0.18 ± 0.28	0.61 ± 0.39	0.01 ± 0.28	2.0 ± 0.7	0.33 ± 0.32	0.10 ± 0.22
Radium-228 (pCi/L)	0.86 ± 0.57	0.19 ± 0.44	0.37 ± 0.57	0.42 ± 0.45	0.50 ± 0.47	0.37 ± 0.43
Selenium (mg/L)	0.008	0.003	0.004	0.006	0.004	0.008
Silver (mg/L)	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	0.0001
Sodium (mg/L)	1720	2020	1920	1840	1600	2020
Sulfate (mg/L)	2750	2500	2000	2900	2350	2800
Total dissolved solids (TDS) (mg/L)	5820	5820	5650	6790	5640	6280
Uranium (mg/L)	0.00187	0.00149	0.00065	0.00472	0.00080	0.00089
Zinc (mg/L)	0.006	0.004	0.001	0.012	0.003	0.008

mg/L - milligram per liter
μS/cm - microsiemens per centimeter
su - standard units
pCi/L - picocuries per liter

Table 6.G-14 Water Quality at Pictured Cliffs Sandstone Monitoring Well GM-19

Parameter (units)	11/16/1974	8/5/1976	8/8/1977	9/10/1979
Arsenic (mg/L)	<0.5	<0.001	<0.05	0.33
Barium (mg/L)	-	<0.1	<0.5	0.08
Boron (mg/L)	1.03	0.3	1.0	0.88
Cadmium (mg/L)	0.016	<0.001	<0.01	<.01
Chromium (mg/L)	-	0.001	<0.01	<.01
Copper (mg/L)	0.015	0.001	0.02	0.02
Iron (mg/L)	0.4	0.005	<0.05	0.01
Lead (mg/L)	<0.05	0.001	<0.05	0.1
Manganese (mg/L)	0.245	0.088	0.06	0.11
Mercury (mg/L)	<0.0005	<0.0004	<0.001	-
Selenium (mg/L)	<0.05	<0.01	<0.01	0.002
Silver (mg/L)	-	<0.001	<0.05	<.01
Zinc (mg/L)	0.240	0.031	0.07	0.42
Total iron (mg/L)	-	-	-	0.01
Total manganese (mg/L)	-	-	-	0.12
pH (su)	8.1	7.83	7.9	7.5
Electrical conductivity (EC) (uS/cm)	-	-	-	-
Total dissolved solids (TDS) (mg/L)	9172	8437	7810	9270
Fluoride (mg/L)	1.7	0.76	0.9	1.49
Bicarbonate as HCO3 (mg/L)	1000	-	-	-
Carbonate as CO3 (mg/L)	-	-	-	-
Chloride (mg/L)	1020	534.8	668	1077
Sulfate (mg/L)	4050	3685	4000	4535
Calcium (mg/L)	43	13.2	200	-
Magnesium (mg/L)	19	3.83	38	-
Potassium (mg/L)	-	-	-	-
Sodium (mg/L)	3040	1610	2200	-
Hydroxide (mg/L)	-	-	-	-
Total alkalinity (mg/L)	-	-	-	-
Nitrate (mg/L-N)	-	-	1.2	-
Ion balance (%)	2.4	-	-	-

(-) analysis not performed for parameter
mg/L - milligram per liter
μS/cm - microsiemens per centimeter
su - standard units

Table 16.G-15 Water Quality at Pictured Cliffs Sandstone Monitoring Well GM-20

Parameter (units)	11/16/1974	6/27/1975	5/18/1976	10/6/1976	8/22/1977	12/20/1977	9/10/1979
Arsenic (mg/L)	<0.5	-	0.01	0.03	<0.01	<0.01	<0.001
Barium (mg/L)	-	-	0.24	<0.1	<0.5	<0.1	0.1
Boron (mg/L)	0.68	-	0.88	0.2	0.9	1.2	2.24
Cadmium (mg/L)	<0.010	-	0.001	<0.001	<0.01	0.001	<0.1
Chromium (mg/L)	-	-	0.013	0.019	<0.01	0.012	0.01
Copper (mg/L)	0.025	-	0.016	0.006	0.01	0.008	0.03
Iron (mg/L)	0.15	-	0.64	0.066	<0.05	0.35	0.01
Lead (mg/L)	<0.05	-	0.035	0.034	<0.05	<0.001	0.10
Manganese (mg/L)	0.035	-	0.026	0.008	<0.001	0.16	0.29
Mercury (mg/L)	<0.0005	-	<0.0004	<0.0004	<0.001	<0.0004	-
Selenium (mg/L)	<0.05	-	<0.01	<0.01	<0.01	<0.01	0.001
Silver (mg/L)	-	-	<0.001	<0.001	<0.05	<0.01	<.01
Zinc (mg/L)	0.08	-	0.08	<0.001	<0.05	0.04	1.06
Total iron (mg/L)	-	-	-	-	-	-	0.03
Total manganese (mg/L)	-	-	-	-	-	-	0.29
pH (su)	11.8	10.8	9.3	8.6	8.7	7.3	7
Electrical conductivity (EC) (uS/cm)	-	8755	-	-	-	-	-
Total dissolved solids (TDS) (mg/L)	5033	-	5711	5822	5880	5050	5260
Fluoride (mg/L)	-	-	-	-	-	-	-
Bicarbonate as HCO3 (mg/L)	192	290	475	-	462	269	-
Carbonate as CO3 (mg/L)	471	272	105	-	-	-	-
Chloride (mg/L)	1030	-	2118	1280	1430	757	803
Sulfate (mg/L)	1880	-	1725	1830	2050	2380	2250
Calcium (mg/L)	11	-	10.6	8.5	11	9.3	-
Magnesium (mg/L)	0.7	-	4.32	4.56	7	19	-
Potassium (mg/L)	-	-	-	-	-	-	-
Sodium (mg/L)	1640	-	2000	1690	2020	1600	-
Hydroxide (mg/L)	-	-	-	-	-	-	-
Total alkalinity (mg/L)	-	-	-	-	-	-	-
Nitrate (mg/L-N)	-	-	-	0.08	0.6	0.2	-
Ion balance (%)	9.5	-	9.8	-	0.9	2.5	-

(-) analysis not performed for parameter
mg/L - milligram per liter
µS/cm - microsiemens per centimeter
su - standard units

Table 6.G-16 Water Quality at Pictured Cliffs Sandstone Monitoring Well GM-30A

Parameter (units)	5/19/1976	8/22/1977	9/10/1979
Arsenic (mg/L)	<0.01	<0.01	0.0019
Barium (mg/L)	0.4	<0.5	0.03
Boron (mg/L)	0.46	0.6	0.96
Cadmium (mg/L)	<0.001	<0.01	<.01
Chromium (mg/L)	0.010	<0.01	0.01
Copper (mg/L)	0.007	0.01	<.01
Iron (mg/L)	0.49	<0.05	0.01
Lead (mg/L)	0.20	<0.05	0.13
Manganese (mg/L)	0.07	0.04	<.01
Mercury (mg/L)[1]	<0.0004	<0.001	-
Selenium (mg/L)[2]	<0.01	<0.01	0.002
Silver (mg/L)	<0.001	<0.05	<.01
Zinc (mg/L)	0.09	<0.05	0.16
Total iron (mg/L)	-	-	0.02
Total manganese (mg/L)	-	-	0.05
pH (su)	7.6	7.5	7.5
Electrical conductivity (EC) (uS/cm)	-	-	-
Total dissolved solids (TDS) (mg/L)	6573	6930	7070
Fluoride (mg/L)	-	-	-
Bicarbonate (mg/L)	171	210	-
Carbonate (mg/L)	-	-	-
Chloride (mg/L)	1215	1120	1203
Sulfate (mg/L)	422	3100	3105
Calcium (mg/L)	30.8	102	-
Magnesium (mg/L)	17.7	22	-
Potassium (mg/L)	-	-	-
Sodium (mg/L)	2070	2110	-
Hydroxide (mg/L)	-	-	-
Total alkalinity (mg/L)	-	-	-
Nitrate (mg/L-N)	0.51	0.4	-
Ion balance (%)	34	4.5	-

(-) analysis not performed for parameter
mg/L - milligram per liter
µS/cm - microsiemens per centimeter
su - standard units

Table 6.G-17 Water Quality at Pictured Cliffs Sandstone Monitoring Well GM-21

Parameter (units)	11/16/1974	8/4/1976	8/22/1977	9/10/1979
Arsenic (mg/L)	<0.5	<0.01	<0.01	<.0001
Barium (mg/L)	-	<0.1	<0.5	0.05
Boron (mg/L)	0.88	0.7	1.0	1.10
Cadmium (mg/L)	0.081	<0.001	<0.01	<.01
Chromium (mg/L)	-	0.005	<0.01	0.03
Copper (mg/L)	0.025	<0.001	0.01	<0.01
Iron (mg/L)	0.2	0.198	<0.05	0.04
Lead (mg/L)	<0.05	0.001	<0.05	0.26
Manganese (mg/L)	0.05	<0.039	0.07	0.03
Mercury (mg/L)	<0.0005	<0.0004	<0.001	-
Selenium (mg/L)	<0.05	<0.01	<0.01	0.001
Silver (mg/L)	-	<0.001	<0.05	<0.1
Zinc (mg/L)	0.447	0.045	0.06	0.62
Total iron (mg/L)	-	-	-	0.41
Total manganese (mg/L)	-	-	-	0.11
pH (su)	7.9	7.2	7.3	7
Electrical conductivity (EC) (uS/cm)	-	-	-	-
Total dissolved solids (TDS) (mg/L)	6923	6624	6370	6140
Fluoride (mg/L)	0.4	0.2	-	-
Bicarbonate (mg/L)	585	-	-	-
Carbonate (mg/L)	-	-	-	-
Chloride (mg/L)	780	646	150	118
Sulfate (mg/L)	3600	2502	2625	3740
Calcium (mg/L)	423	155	414	-
Magnesium (mg/L)	65	148	62	-
Potassium (mg/L)	-	-	-	-
Sodium (mg/L)	1470	920	1440	-
Hydroxide (mg/L)	-	-	-	-
Total alkalinity (mg/L)	-	-	-	-
Nitrate (mg/L-N)	-	-	0.4	-
Ion balance (%)	8.2	-	-	-
Radium-226 (pCi/L)	-	-	-	0.11
Radium-228 (pCi/L)	-	-	-	-

(-) analysis not performed for parameter

mg/L - milligram per liter

µS/cm - microsiemens per centimeter

su - standard units

pCi/L - picocuries per liter

Table 6.G-18 Measured and Modeled Recharge Rates

Surface characterization	Recharge range[1] (in/yr)	Mean recharge[1] (in/yr)	Modeled recharge (in/yr)
Badlands	0.002 to 0.01	0.006	
Slopes > 5%			0.002
Slopes: 2 to 5%			0.01
Upland flat	0.02 to 0.05	0.03	
Upland flat (slope <1%)			0.03
Upland (slope 1 to 2%)			0.02
Alluvial valley	0.09	0.09	0.09

[1]From Stone 1987

Appendix 6.G Exhibits