5 HYDROLOGIC IMPACT ASSESSMENTS

Required by 30 CFR 780.21(g), as the regulatory authority, OSMRE shall provide an assessment of the probable cumulative hydrologic impacts of the mining operation upon surface water and groundwater systems in the cumulative impact area. After assessing the PHC presented in the PAP for the operation, and considering cumulative hydrologic impacts from all mining operations, OSMRE shall make a determination of whether or not the mining operation has been designed to minimize disturbances to the hydrologic balance within the permit and adjacent areas, and to prevent material damage to the hydrologic balance outside the permit area.

The assessment presented in Chapter 5 of this document considers available quantity and quality information related to surface water and groundwater potentially affected by the Kayenta Complex operation. The assessment will determine if the potential exists for the operation to create material damage to the hydrologic balance outside the permit area. If the potential exists for material damage to the hydrologic balance outside the permit area, then OSMRE will identify material damage criterion, and precursor material damage thresholds to ensure material damage to the hydrologic balance outside the permit area does not occur.

5.1 Surface Water

OSMRE will evaluate surface water quantity and quality related to the overall hydrologic balance and potential impact of the Kayenta Complex on stream uses and considering in-stream water quality standards (WQS). OSMRE must also evaluate that the operation has been appropriately designed to provide the surface water quantity and quality information necessary to assess potential impacts per 30 CFR 780.21(g). Potential offsite surface water quality impacts are related to WQS for irrigation, livestock, aquatic and wildlife habitat, fish consumption, and secondary human contact.

5.1.1 Surface Water Monitoring Program

Above-mining and below-mining locations were selected on the primary washes transecting the Kayenta Complex (Yellow Water Canyon Wash, Coal Mine Wash, Moenkopi Wash, Dinnebito Wash) in order to identify above-mining and below-mining relationships. Additionally, major tributaries to Moenkopi Wash within the Moenkopi Wash CIA (Reed Valley Wash, Red Peak Valley Wash, and Yucca Flat Wash) were monitored to evaluate potential contributing impacts to Moenkopi Wash. The primary washes, Moenkopi tributaries within the permit area, and corresponding monitoring locations are displayed on Figure 11.

A variety of monitoring techniques and instrumentation were utilized to characterize the surface water hydrologic regime. Surface water quantity monitoring techniques included the use of current meters, slope-area methodology, pulse generators coupled with stilling wells and data loggers, crest-stage gages, portable cutthroat flumes, and visual estimates when flow conditions precluded the use of other measuring devices (PWCC, v.11, ch.16, 2011).

PWCC may request modification to the surface water monitoring program after baseline is defined, surface water and groundwater interaction is characterized, and the magnitude of seasonal or natural variability is documented. When the magnitude and extent of potential impacts exceed hydrologic consequence projections identified in the PHC, the data collection frequency or geographic monitoring locations may need to be expanded. Conversely, when the monitoring program has sufficiently established background conditions and natural or seasonal variability, the frequency and data collection localities may be relaxed. As such, OSMRE approved the reduction of all above-mining and tributary surface water monitoring locations in July of 2001 and July of 2002 since the provided data adequately fulfilled the monitoring objectives. Therefore, above-mining and tributary surface water monitoring locations 14, 16, 18, 35, 37, 50, 78, 85, and 157 were removed from the active monitoring program. PWCC continues to collect surface water quantity information at locations 15, 25, 26, 155, and 34.

Based on the surface water quantity monitoring information collected before the approved monitoring reduction, coupled with the continued monitoring at locations 15, 25, 26, 34, and 155, OSMRE finds that the surface water quantity program is currently sufficient for OSMRE to make the required evaluation for material damage potential in this CHIA. Continued surface water quantity monitoring at locations 15, 25, 26, 34, and 155 is necessary to reinforce hydrologic impact conclusions presented in the PHC of the permit application, and assess potential material damage impact.

5.1.2 Surface Water Quantity

Information from 14 monitoring locations determined multiple peak hydrographs are a characteristic of the area hydrology. PWCC calculated an average annual runoff of 0.15-inches in the Moenkopi CIA (PWCC, v.11, ch.18, 2011). Applying the runoff factor to the area of the Moenkopi CIA yields an estimated average annual baseline runoff of 1,972 ac-ft, and 402 ac-ft for the Dinnebito CIA. Baseline runoff was determined using measured flow data from undisturbed area, and applying the runoff factor to the entire assessment area. Average annual measured surface flow in the Moenkopi CIA from 1987-2008 was 1488 ac-ft. During the 2005 – 2009 monitoring period, discharges reported for NPDES permit #NN0022179 averaged 21.28 ac-ft from surface water impoundments.

5.1.2.1 Impact Potential to Existing and Foreseeable Uses

SMCRA requires that all surface mining and reclamation activities be conducted to minimize disturbance of the hydrologic balance within the permit and adjacent areas, and prevent material damage to the hydrologic balance outside the permit area. In order to protect the surface water hydrologic balance, and following 30 CFR 816.41(d)(1), PWCC shall prevent additional contribution of suspended solids to stream flow outside the permit area to the extent possible using the best technology currently available. Therefore, PWCC constructs surface water impoundment structures adjacent to areas disturbed by mining to capture suspended solids transported during runoff events. Nine Mine Safety and Health Administration (MSHA) sized structures have been constructed on tributaries confluent to Moenkopi Wash, and the PHC predicts that portions of the stream channel above and below the structures will be affected (PWCC, v.11, ch.18, 2011). “The reach immediately above a dam will gradually aggrade headward as more and more water is impounded until a pool level is reached that is in equilibrium with water gains and losses. Channel reaches below the dams will become incised by smaller active meandering channels whose widths are a function of drastically reduced runoff potential, channel gradients and sediment load particle size ranges” (PWCC, v.11, ch.18, 2011). “It is estimated that more than 320 sediment ponds and several permanent internal impoundments have been or will be constructed during the life of the mining operation” (PWCC, v.11, ch.18, 2011). The construction of sediment control structures, and the coordinated removal of temporary structures, assists in minimizing mining impacts. However, the construction of surface water impoundments potentially reduces surface water quantity outside the Moenkopi CIA and Dinnebito CIA during runoff events compared to baseline conditions when only a few local impoundments existed.

Figures 29 and 30 illustrate the total annual acreage potentially generating runoff to impoundments in the Moenkopi and Dinnebito CIAs. The annual acreage generating runoff to impoundments may vary from year to year based on mining and reclamation schedules. The contributing acreage to impoundments reaches a maximum of 47,321 acres for the Moenkopi CIA in 2021, and 3,651 acres for the Dinnebito CIA in 2011. The graphs are scaled to the size of the Dinnebito CIA (33,087 acres) and Moenkopi CIA

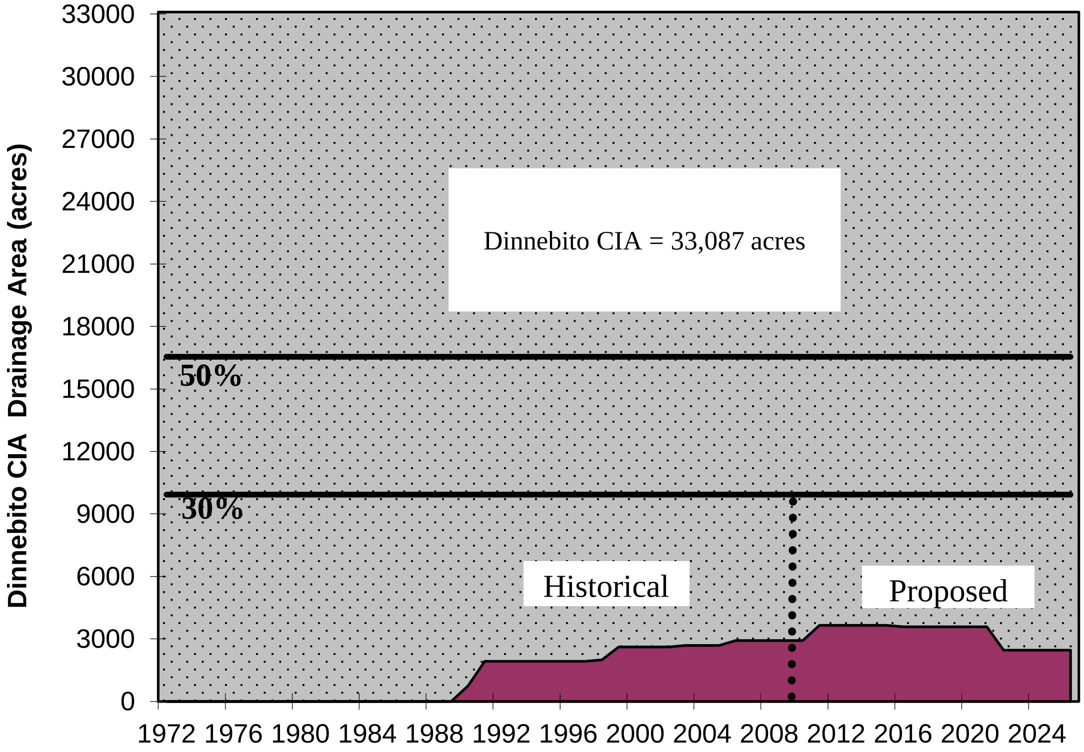


Figure 29: Dinnebito CIA Acres Managed with Impoundments, Kayenta Complex.

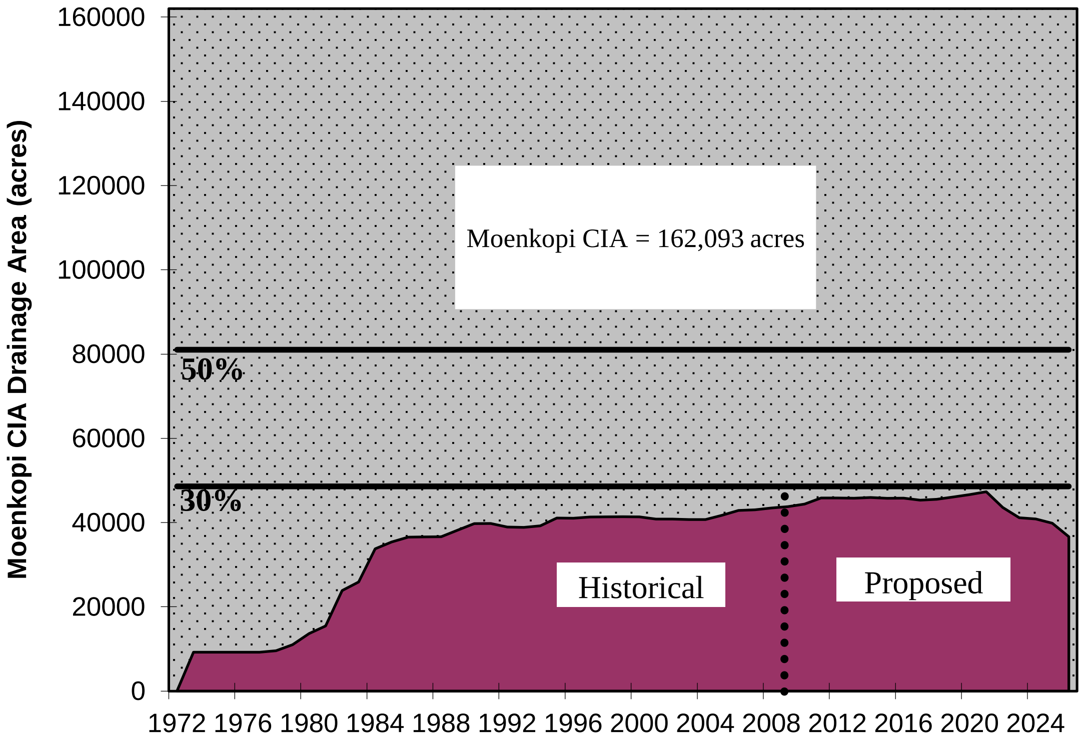


Figure 30: Moenkopi CIA Acres Managed with Impoundments, Kayenta Complex.

(162,093 acres). OSMRE must assess if the surface water quantities potentially generated from these maximum contributing acreages, and retained by impoundments, will impact the downstream irrigation, livestock, or aquatic and wildlife habitat water uses. The PHC concludes "comparisons of average annual runoff estimates indicate the impounded areas through December 2013 have the potential to, on average, reduce average annual runoff in the Dinnebito basin by no more than 1.4 percent, and in the Moenkopi basin by no more than 5.8 percent" (PWCC, v.11, ch.18, 2011).

Surface water for irrigation use was attempted in the Dinnebito (HUC 15020017) near the community of Rocky Ridge; however, conditions limited the retention and use of surface water along Dinnebito Wash for agricultural water use. Variability in annual surface flow rates ranging three orders of magnitude, coupled with high sediment transport rates during flash flood events, likely limit the effectiveness of impoundments for agricultural use on Dinnebito Wash. However, the community of Moenkopi, approximately 70 miles downstream from the Kayenta Complex along Moenkopi Wash, may use water in the alluvial channel for agricultural irrigation. Farmers in the Moenkopi Village area may dig pits in Moenkopi Wash to reach the saturated alluvium, pumping the saturated alluvium for irrigation water when necessary and available (OSMRE, 2011b). Watering of livestock may occur along Moenkopi Wash and Dinnebito Wash at channel pools. However, the location, duration, extent, and quality of the resultant surface water pools the left behind downstream of the Kayenta Complex are unknown.

Moenkopi and Dinnebito washes commonly experience flash flood events. The flash flood events scour the channel bottom, alter and extend the channel banks, and are capable of uprooting tamarisk populations with deep tap roots (OSMRE, 2009). The hydrologic environment of the ephemeral, sand-bed channels along Moenkopi and Dinnebito washes provides limited conditions for the sustainability of aquatic habitat. However, aquatic habitat has the potential for sustainability in a less aggressive environment such as near seeps, springs, and surface water bodies. Therefore, it is likely that the retention of surface water runoff in impoundments within the Kayenta Complex will enhance the potential for successful establishment of aquatic and wildlife species within the permit area, and not create material damage outside the permit area.

The alluvium near the community of Moenkopi supports agricultural irrigation use and is recharged by three mechanisms: direct precipitation, infiltration of surface water runoff to the alluvium, and groundwater discharge to the alluvium. Infiltration from direct precipitation provides the smallest recharge of the three mechanisms since the annual average precipitation is 5.96-inches at Tuba City, adjacent to the community of Moenkopi (PWCC, 1999). Alluvial recharge from surface water runoff infiltration has greater effect based on a flow model simulated release of 644 ac-ft to Moenkopi Wash from the permit area (PWCC, v.11, ch.18, 2011). The results indicate the entire 644 ac-ft volume infiltrated to the alluvium between the permit area and 45 miles downstream (approximately 25 miles upstream of the Village of Moenkopi), or an infiltration rate of 14.5 ac-ft per mile (PWCC, v.11, ch.18, 2011). Essentially,

> Short-term, rapid advance of the streamflow front over the initially dry alluvium occurs until the wetted channel is large enough to allow total infiltration to equal the release rate. Flow over the dry bed is influenced by [the ability of the material to adsorb] which initially pulls water into the dry soil at a higher infiltration rate than occurs under higher saturation conditions. As the materials become more saturated, the infiltration rate decreases, allowing the front to move further downstream. (GeoTrans, 1992).

A third recharge mechanism occurs on Moenkopi Wash approximately 40 miles downstream of the Kayenta Complex, and approximately 30 miles upstream from the community of Moenkopi. In this segment, Moenkopi Wash alluvium is recharged by discharge from the N aquifer system in an area referred to as Blue Canyon in this document (Figure 31). Downcutting and erosion of Moenkopi Wash created a slot canyon exposing the Navajo Sandstone and creating features known locally as "the water caves" (OSMRE, 2011b). The N aquifer hydraulic gradient near Blue Canyon induces groundwater discharge to Moenkopi Wash alluvium, providing a consistent source of recharge to the Moenkopi Wash alluvium. Regional numerical groundwater flow simulation quantifies the annual baseflow discharge to Moenkopi wash at 4,305 ac-ft prior to mining in 1955 (PWCC, 1999).

Figure 31: Blue Canyon on Moenkopi Wash (photo by Paul Clark, 11-8-2002).

The primary recharge mechanisms to the Moenkopi Wash alluvium are from both infiltration of surface water after storm flow events, and from N aquifer discharge at Blue Canyon. PWCC operations influence these two recharge mechanisms to Moenkopi Wash alluvium. One recharge mechanism is associated with surface water runoff, and the second mechanism is associated with groundwater discharge from the N aquifer. N aquifer groundwater discharge impacts to Moenkopi Wash alluvium are further discussed in Section 5.2.4.1. The Moenkopi CIA for surface water runoff is 162,093 acres of the 1,689,600 acre Moenkopi watershed (HUC 15020017). Therefore, PWCC may manage a maximum of 9.6-percent of the Moenkopi watershed (HUC 15020017). OSMRE recognizes that decreases in surface flows are of concern to Moenkopi area farmers relying on sub-flow in Moenkopi Wash alluvium for agricultural irrigation supply water. Therefore, OSMRE will establish a surface water quantity material damage threshold and limit for the amount of surface area managed by surface water impoundments within the Kayenta Complex to minimize potential surface water quantity impact on agricultural irrigation water supply.

5.1.2.2 Surface Water Quantity Material Damage Threshold and Limit

The surface water quantity monitoring program and PAP have provided sufficient information for OSMRE to assess surface water quantity impacts. After assessing the potential surface water quantity impact of the mining operation on existing and foreseeable agricultural irrigation, livestock, and aquatic and wildlife habitat water uses, OSMRE has determined that the operation has been designed to minimize surface water quantity impacts within the permit area and prevent material damage outside the permit and adjacent area by limiting the surface area managed by surface water impoundments. The Kayenta Mine Environmental Assessment (EA) (OSMRE, 2011c), identifies a level of moderate impact if the watershed area controlled by impoundments is between 30 to 50 percent of the total drainage area, and major impacts greater than 50-percent. Therefore, OSMRE defines the surface water quantity material damage threshold at 30-percent of Moenkopi or Dinnebito CIA managed by impoundments. If conditions are above the threshold, then mine plan operations will be regulated to ensure impacts are minimized and a level of material damage not reached. Material damage is defined as greater than 50-percent of the Moenkopi CIA or Dinnebito CIA managed by surface water impoundments.

5.1.3 Surface Water Quality

Several recharge mechanisms influence surface water quality within the permit and adjacent area. Precipitation generates rainfall runoff in the ephemeral washes, entraining sands, silts, and clays, inducing elevated concentrations of total suspended solids (TSS). The elevated TSS concentrations influence the cation exchange capacity, and ultimately the chemical composition of the surface water. Recharge also occurs from baseflow in areas where the Wepo Formation is in hydrologic communication with the alluvium. Wet reaches are typically evident where the Wepo Formation water discharges to the alluvium, and most apparent when precipitation events have not recently occurred. The effect of precipitation on spoil surface area also influences the surface water quality. During mining and through bond release, surface water impoundments capture surface water runoff that was in contact with the spoil material. The impounded surface water may discharge over the spillway during precipitation events exceeding the 10-year 24-hour event design capacity, or infiltrate through the bottom of the impoundments, entering the Wepo Formation and alluvial and surface water systems.

5.1.3.1 Surface Water Quality Monitoring Program

Above-mining and below-mining locations were selected on the primary washes transecting the Kayenta Complex: Yellow Water Canyon Wash, Coal Mine Wash, Moenkopi Wash, Dinnebito Wash (Figure 11). The four primary washes are monitored in order to evaluate compliance with the NNSWQS (NNEPA, 2007) and the HTWQS (Hopi Tribe, 2008). The document entitled: “Guidance for Assessing the Quality of Navajo Nation Surface Waters to Determine Impairment (Integrated 305(b) Reporting and 303(d) listing)” (NNEPA 2008) identifies the minimum number of sample values required to determine support of designated uses. Most WQS require a minimum 5 values in 3 years for use assessment. Dissolved oxygen, pH, suspended sediments, temperature, and turbidity require a minimum 10 values in 10 years for use assessment. Based on previously collected surface water information, coupled with continued monitoring at locations 15, 25, 26, 34, and 155, OSMRE finds the surface water quantity program sufficient for OSMRE to make the required evaluation for material damage potential in this CHIA. Continued surface water quantity monitoring at locations 15, 25, 26, 34, and 155 is necessary to reinforce hydrologic impact conclusions.

5.1.3.2 Impact Potential to Existing and Foreseeable Uses

The surface water quality regime was characterized and monitored by PWCC using 14 monitoring locations in the permit and adjacent area (Figure 11). The monitoring program was established to evaluate surface water quality impacts from overland flow on mine disturbed area to the washes, resulting in the addition of dissolved solids to the surface water system and potential for material damage to the hydrologic balance.

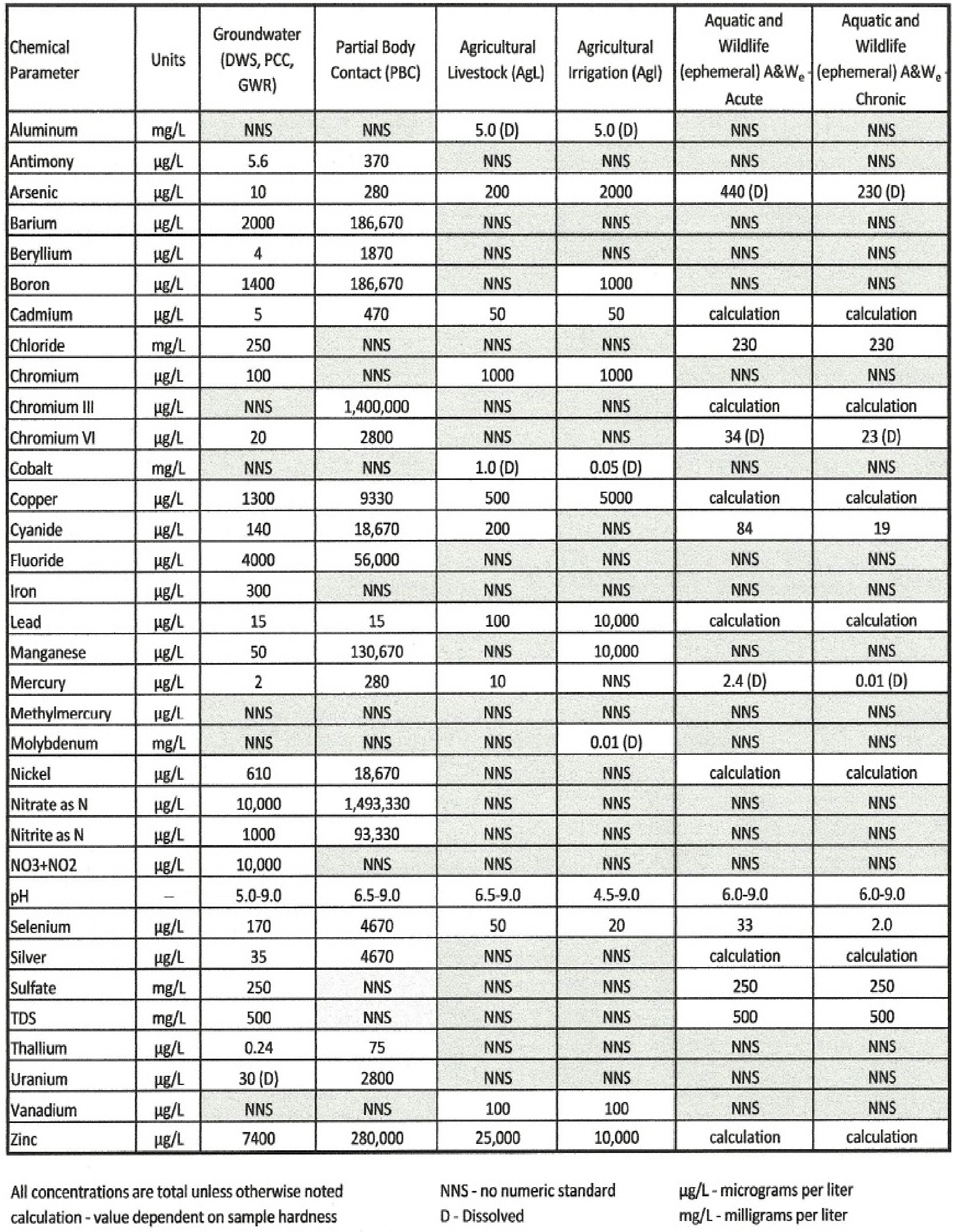
The NNEPA Water Quality Program (WQP) and Hopi Tribe Water Resources Program (WRP) have identified designated uses for Moenkopi and Dinnebito Washes, and identified WQS of chemical parameters which are considered to have the potential to adversely impact the designated water resource use. Moenkopi Wash has the following designated uses: Secondary Human Contact, Agricultural Livestock Watering, Agricultural Irrigation Water Supply, Aquatic and Wildlife Habitat (acute and chronic), and Fish Consumption. Dinnebito Wash has the same water use designations as Moenkopi Wash with the exception of Agricultural Water Supply. The NNEPA WQP developed WQS in 2004, and revised them in 2007, which are the current standards under the CWA (NNEPA, 2007). The Hopi Tribe WRP developed similar WQS in 2008, revised them in 2010, and was approved by the USEPA for implementation in 2011 (Hopi Tribe, 2008). Table 5 provides the HTWQS (Hopi Tribe, 2008) applicable to the Dinnebito and Moenkopi CIAs. Table 6 provides the NNSWQS (NNEPA, 2007) applicable to the Dinnebito and Moenkopi CIAs.

Surface Water Quality Assessment Protocol

The Hopi Tribe WRP and NNEPA WQP are integral components in the protection of the hydrologic balance and surface water quality. As such, OSMRE will work in partnership with the tribes if concentrations of chemical parameters have potential to change the present or potential use outside the permit area.

(1) WQS defined and implemented by the NNEPA WQP and Hopi Tribe WRP are protected by the material damage definition.
(2) Discharges to the surface water are reported to USEPA under point source permit No. NN0022179, and permit No. AZR0F121 issued under the 2008 Multi-Sector General Permit for Stormwater.
(3) Stream channels are monitored for evaluation with water quality criteria (e.g. numeric in-stream) promulgated by the NNEPA WQP and Hopi Tribe WRP.
(4) If monitoring shows that WQS have been exceeded for 4 out of 4 consecutive sampling events, OSMRE will notify the appropriate CWA authority, and request assistance in determining if a persistent water quality violation exists. A frequency of four was selected to account for seasonal variability and consistency with quarterly monitoring required at 30 CFR 816.41.
(5) If the appropriate CWA authority determines a water quality violation exists, OSMRE will evaluate the chemical parameter of concern to determine whether the mining operation caused the violation.
(6) If the mining operation is the cause of the violation, OSMRE will use the appropriate permitting and enforcement procedures to correct the water quality violation.

Table 7 provides summary statistics of downstream monitoring locations for chemical parameters with a WQS applicable to the Dinnebito Wash and Moenkopi Wash CIAs. The summary information considers non-detected concentrations to equal the method detection limit (MDL). For example, if a MDL is 100 mg/L, then the value is included in summary statistics as a detected concentration of 100 mg/L. Although the approach may skew the summary statistics, this approach was applied to both upstream and downstream assessment locations, and provides a method for cursory assessment. The highest reported concentrations at downstream monitoring locations were compared to the most protective WQS. Nine chemical parameters were above the most protective WQS: cadmium, chloride, lead, manganese, mercury, molybdenum, selenium, sulfate, and TDS. The remaining parameters evaluated will not be carried forward for assessment.



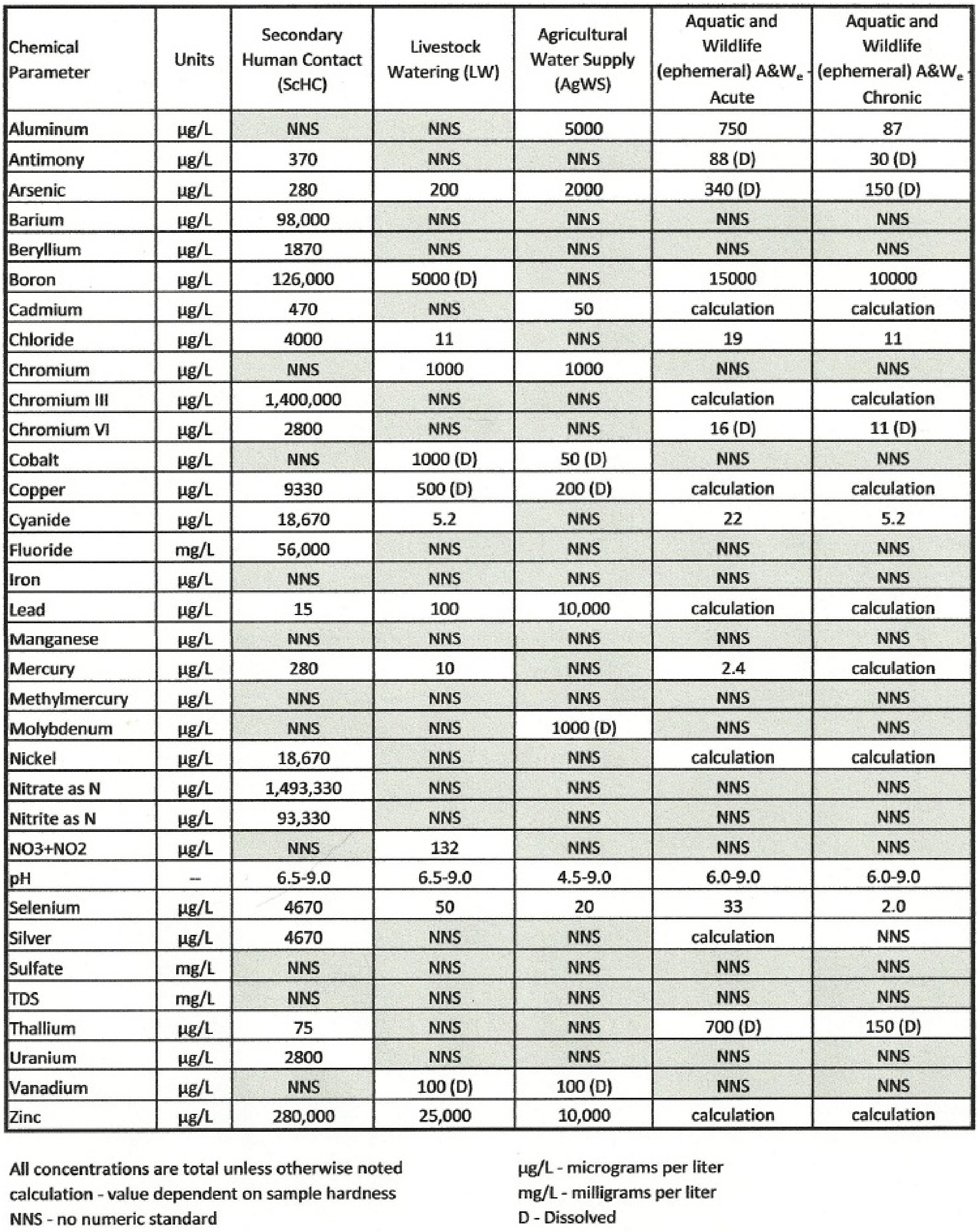
Chemical Parameter	Units	Groundwater (DWS, PCC, GWR)	Partial Body Contact (PBC)	Agricultural Livestock (AgL)	Agricultural Irrigation (Agl)	Aquatic and Wildlife (ephemeral) $A\&W_e$ - Acute	Aquatic and Wildlife (ephemeral) $A\&W_e$ - Chronic
Aluminum	mg/L	NNS	NNS	5.0 (D)	5.0 (D)	NNS	NNS
Antimony	µg/L	5.6	370	NNS	NNS	NNS	NNS
Arsenic	µg/L	10	280	200	2000	440 (D)	230 (D)
Barium	µg/L	2000	186,670	NNS	NNS	NNS	NNS
Beryllium	µg/L	4	1870	NNS	NNS	NNS	NNS
Boron	µg/L	1400	186,670	NNS	1000	NNS	NNS
Cadmium	µg/L	5	470	50	50	calculation	calculation
Chloride	mg/L	250	NNS	NNS	NNS	230	230
Chromium	µg/L	100	NNS	1000	1000	NNS	NNS
Chromium III	µg/L	NNS	1,400,000	NNS	NNS	calculation	calculation
Chromium VI	µg/L	20	2800	NNS	NNS	34 (D)	23 (D)
Cobalt	mg/L	NNS	NNS	1.0 (D)	0.05 (D)	NNS	NNS
Copper	µg/L	1300	9330	500	5000	calculation	calculation
Cyanide	µg/L	140	18,670	200	NNS	84	19
Fluoride	µg/L	4000	56,000	NNS	NNS	NNS	NNS
Iron	µg/L	300	NNS	NNS	NNS	NNS	NNS
Lead	µg/L	15	15	100	10,000	calculation	calculation
Manganese	µg/L	50	130,670	NNS	10,000	NNS	NNS
Mercury	µg/L	2	280	10	NNS	2.4 (D)	0.01 (D)
Methylmercury	µg/L	NNS	NNS	NNS	NNS	NNS	NNS
Molybdenum	mg/L	NNS	NNS	NNS	0.01 (D)	NNS	NNS
Nickel	µg/L	610	18,670	NNS	NNS	calculation	calculation
Nitrate as N	µg/L	10,000	1,493,330	NNS	NNS	NNS	NNS
Nitrite as N	µg/L	1000	93,330	NNS	NNS	NNS	NNS
NO3+NO2	µg/L	10,000	NNS	NNS	NNS	NNS	NNS
pH	–	5.0-9.0	6.5-9.0	6.5-9.0	4.5-9.0	6.0-9.0	6.0-9.0
Selenium	µg/L	170	4670	50	20	33	2.0
Silver	µg/L	35	4670	NNS	NNS	calculation	calculation
Sulfate	mg/L	250	NNS	NNS	NNS	250	250
TDS	mg/L	500	NNS	NNS	NNS	500	500
Thallium	µg/L	0.24	75	NNS	NNS	NNS	NNS
Uranium	µg/L	30 (D)	2800	NNS	NNS	NNS	NNS
Vanadium	µg/L	NNS	NNS	100	100	NNS	NNS
Zinc	µg/L	7400	280,000	25,000	10,000	calculation	calculation

All concentrations are total unless otherwise noted
calculation - value dependent on sample hardness

NNS - no numeric standard
D - Dissolved

µg/L - micrograms per liter
mg/L - milligrams per liter

Table 5. Hopi Tribe Water Resources Program 2008 Water Quality Standards (Hopi Tribe, 2008).



Chemical Parameter	Units	Secondary Human Contact (ScHC)	Livestock Watering (LW)	Agricultural Water Supply (AgWS)	Aquatic and Wildlife (ephemeral) A&W$_e$ - Acute	Aquatic and Wildlife (ephemeral) A&W$_e$ - Chronic
Aluminum	µg/L	NNS	NNS	5000	750	87
Antimony	µg/L	370	NNS	NNS	88 (D)	30 (D)
Arsenic	µg/L	280	200	2000	340 (D)	150 (D)
Barium	µg/L	98,000	NNS	NNS	NNS	NNS
Beryllium	µg/L	1870	NNS	NNS	NNS	NNS
Boron	µg/L	126,000	5000 (D)	NNS	15000	10000
Cadmium	µg/L	470	NNS	50	calculation	calculation
Chloride	µg/L	4000	11	NNS	19	11
Chromium	µg/L	NNS	1000	1000	NNS	NNS
Chromium III	µg/L	1,400,000	NNS	NNS	calculation	calculation
Chromium VI	µg/L	2800	NNS	NNS	16 (D)	11 (D)
Cobalt	µg/L	NNS	1000 (D)	50 (D)	NNS	NNS
Copper	µg/L	9330	500 (D)	200 (D)	calculation	calculation
Cyanide	µg/L	18,670	5.2	NNS	22	5.2
Fluoride	mg/L	56,000	NNS	NNS	NNS	NNS
Iron	µg/L	NNS	NNS	NNS	NNS	NNS
Lead	µg/L	15	100	10,000	calculation	calculation
Manganese	µg/L	NNS	NNS	NNS	NNS	NNS
Mercury	µg/L	280	10	NNS	2.4	calculation
Methylmercury	µg/L	NNS	NNS	NNS	NNS	NNS
Molybdenum	µg/L	NNS	NNS	1000 (D)	NNS	NNS
Nickel	µg/L	18,670	NNS	NNS	calculation	calculation
Nitrate as N	µg/L	1,493,330	NNS	NNS	NNS	NNS
Nitrite as N	µg/L	93,330	NNS	NNS	NNS	NNS
NO3+NO2	µg/L	NNS	132	NNS	NNS	NNS
pH	--	6.5-9.0	6.5-9.0	4.5-9.0	6.0-9.0	6.0-9.0
Selenium	µg/L	4670	50	20	33	2.0
Silver	µg/L	4670	NNS	NNS	calculation	NNS
Sulfate	mg/L	NNS	NNS	NNS	NNS	NNS
TDS	mg/L	NNS	NNS	NNS	NNS	NNS
Thallium	µg/L	75	NNS	NNS	700 (D)	150 (D)
Uranium	µg/L	2800	NNS	NNS	NNS	NNS
Vanadium	µg/L	NNS	100 (D)	100 (D)	NNS	NNS
Zinc	µg/L	280,000	25,000	10,000	calculation	calculation

All concentrations are total unless otherwise noted
calculation - value dependent on sample hardness
NNS - no numeric standard

µg/L - micrograms per liter
mg/L - milligrams per liter
D - Dissolved

Table 6. NNEPA Water Quality Program 2007 Surface Water Quality Standards (NNEPA, 2007).

					Dinnebito Wash CIA				Moenkopi Wash CIA			
					Location 34 Storm Water Samples				Locations 25, 26, and 155 Storm Water Samples			
Chemical Parameter	Most Protective WQS	WQS	Units	Type	# Samples	Low	Median	High	# Samples	Low	Median	High
Aluminum	Aquatic (NN)	0.75 (T)	mg/L	Dissolved	n=20	0.03	0.05	0.45	n=54	0.03	0.05	0.72
Antimony	Aquatic (NN)	88	µg/L	Dissolved	n=10	1	1	10	n=24	1	1	12
Arsenic	Aquatic (HT)	230	µg/L	Dissolved	n=17	0.8	1	5	n=46	0.5	1	51
Barium	Secondary Contact (NN)	98000 (T)	µg/L	Dissolved	n=12	50	70	200	n=32	20	100	270
Bicarbonate	NNS	NNS	mg/L	Dissolved	n=49	43.9	91	614	n=112	57	116	399
Boron	Agricultural (NN)	1000 (T)	µg/L	Dissolved	n=34	20	70	140	n=111	10	70	360
Calcium	NNS	NNS	mg/L	Dissolved	n=49	16	158	520	n=112	16.8	89.2	505
Cadmium	Fish Consumption (NN)	8 (T)	µg/L	Dissolved	n=17	3	5	10	n=50	3	5	10
Chloride	Aquatic (HT)	230 (T)	mg/L	Total	n=34	1	12	55	n=112	2	12	261
Chromium	Agricultural (HT)(NN)	1000 (T)	µg/L	Dissolved	n=18	10	10	10	n=52	10	10	50
Copper	Agricultural (NN)	200	µg/L	Dissolved	n=20	10	10	10	n=55	10	10	50
Fluoride	Secondary Contact (NN)	56 (T)	mg/L	Total	n=34	0.1	0.7	1	n=112	0.1	0.6	1.1
Iron	NNS	NNS	mg/L	Total	n=31	7.22	551.5	2960	n=103	0.05	274	2610
Lead	Secondary Contact (NN)	15 (T)	µg/L	Dissolved	n=16	20	20	60	n=49	20	20	60
Magnesium	NNS	NNS	mg/L	Dissolved	n=49	4	56.5	500	n=112	3	28	511
Manganese	Agricultural (HT)	10 (T)	mg/L	Total	n=31	0.13	12.9	26.4	n=103	0.014	7.96	64
Mercury	Aquatic (HT)	0.01	µg/L	Dissolved	n=15	0.1	0.2	0.2	n=46	0.1	0.2	2.3
Molybdenum	Agricultural (HT)	0.01	µg/L	Dissolved	n=10	1	3	50	n=28	1	1	50
Nickel	Fish Consumption (NN)	4600 (T)	µg/L	Dissolved	n=10	10	20	30	n=29	10	10	20
Nitrate as N	Secondary Contact (NN)	1493 (T)	mg/L	Total	n=34	0.99	2.4	6.1	n=111	0.02	1.5	14.9
Nitrite as N	Secondary Contact (NN)	93.3 (T)	mg/L	Total	n=34	0.01	0.01	0.03	n=111	0.01	0.06	0.37
NO3+NO2	Livestock Watering (NN)	132	mg/L	Total	n=34	0.99	2.5	6.1	n=94	0.02	1.7	15.1
pH	All Uses	< 9.0	s.u.	Total	n=34	6.5	7.7	8.3	n=112	6.5	7.7	8.5
Selenium	Aquatic (HT)(NN)	2	µg/L	Dissolved	n=17	1	2.9	20	n=48	0.7	1	5
Silver	Secondary Contact (NN)	4670 (T)	µg/L	Dissolved	n=10	5	10	10	n=29	5	10	20
Sodium	NNS	NNS	mg/L	Dissolved	n=49	3.9	48	680	n=112	5.4	47	780
Sulfate	Aquatic (HT)	250 (T)	mg/L	Total	n=34	30	660	2118	n=112	20	310	4880
TDS	Aquatic (HT)	500	mg/L	Total	n=34	122	1090	3094	n=112	94	580	7750
Vanadium	Agricultural (HT)(NN)	100 (T)	µg/L	Dissolved	n=20	5	10	16	n=54	5	10	30
Zinc	Agricultural (HT)(NN)	10 (T)	mg/L	Dissolved	n=20	0.01	0.01	0.03	n=55	0.01	0.01	0.18

NNS - No Numeric Standard	mg/L - milligrams per liter	NN - Navajo Nation	CIA - Cumulative Impact Area
WQS - Water Quality Standard	µg/L - micrograms per liter	HT - Hopi Tribe	T- Total

Table 7. Storm water sample ranges for downstream locations, Kayenta Complex (1986-2010).

One dissolved cadmium sample was reported at a value of 10 mg/L at a downstream location in the Moenkopi CIA. A review of the surface water quality data submitted in annual hydrologic monitoring reports (PWCC, 2011b) indicate the elevated value is attributed to an elevated MDL. The median cadmium value for Moenkopi CIA downstream monitoring locations is 5 mg/L (Table 7), and less than the medium upstream monitoring locations for cadmium (Table 2). Therefore, the NNEPA fish consumption designated use does appear to be compromised due to the activities at the Kayenta Complex.

One total chloride sample was reported at a value of 261 mg/L at a downstream location in the Moenkopi CIA. The median chloride value for Moenkopi CIA downstream monitoring locations is 12 mg/L (Table 7), and consistent with the medium upstream monitoring locations for chloride (Table 2). The isolated elevated detection slightly above Hopi Tribe designated use for aquatic and wildlife habitat, and has not been repeated. Therefore, the Hopi Tribe designated use for aquatic and wildlife habitat use does not appear to be compromised due to the activities at the Kayenta Complex.

All reported concentrations of lead are at the MDL. Median downstream values (Table 7) are consistent with median upstream values (Table 2). Reported lead values are less than agricultural livestock water supply WQS, but greater than PBC (Hopi Tribe, 2008) and ScHC (NNEPA, 2007) WQS of 15 mg/L. The designated use for PBC and ScHC, which are the same by definition, do not appear to be compromised due to the activities at the Kayenta Complex; however, additional verification with a lower MDL may be necessary after consultation with the Hopi Tribe WRP and Navajo Nation WQP.

Hopi Tribe WRP established a total manganese standard of 10 mg/L for agricultural irrigation. The NNEPA has no manganese standards for the designated uses in the Moenkopi and Dinnebito CIAs. Reported manganese concentrations are variable in both upstream and downstream monitoring location for Moenkopi and Dinnebito CIAs. Dinnebito upstream median total manganese concentrations is 16 mg/L, and 12.9 mg/L for the downstream monitoring location. Moenkopi upstream median total manganese is 10 mg/L, and 7.96 for the downstream monitoring locations. The highest manganese detection (64 mg/L) occurred at monitoring location 26 in 1991, and reported concentrations have been below 20 mg/L from 1997 – present. Based on comparison of upstream and downstream monitoring locations, the Hopi Tribe designated use for agricultural livestock watering does not appear to be compromised due to the activities at the Kayenta Complex.

Upstream and downstream monitoring for dissolved mercury in both the Dinnebito and Moenkopi CIAs identified one detection at downstream monitoring location 25 (2.3 µg/L). All remaining mercury values are a result of a MDL between 0.1 – 0.2 µg/L. The Hopi Tribe WQS for $A\&W_e$ (chronic) is 0.01 µg/L. The designated uses do not appear to be compromised due to the activities at the Kayenta Complex; however, additional verification with a lower MDL may be necessary after consultation with the Hopi Tribe WRP and Navajo Nation WQP.

Molybdenum has a designated use WQS for agricultural water supply established by the Hopi Tribe WRP (10 µg/L) and NNEPA (1000 µg/L). All reported concentrations are a reflection of the MDL. When the MDL is less than 10 µg/L, no concentrations have been detected. Therefore, the agricultural water supply designated use does appear to be compromised from molybdenum concentrations due to the activities at the Kayenta Complex.

Selenium WQS are available for all designated uses in the Dinnebito and Moenkopi CIAs. Both the Hopi Tribe WRP and NNEPA established a WQS of 20 µg/L for agricultural irrigation water, and a WQS of 2 µg/L for $A\&W_e$ (chronic). All storm water quality samples collected at downstream monitoring locations were less than 20 µg/L. Lower detections are a result of the level of MDL being reported. The designated use for $A\&W_e$ (chronic) does not appear to be compromised due to the activities at the Kayenta Complex; however, additional verification with a lower MDL may be necessary after consultation with the Hopi Tribe WRP and Navajo Nation WQP.

Hopi Tribe WRP established a sulfate designated use standard for A&W$_e$ of 250 mg/L. This is the only designated use with a sulfate water quality standard applicable to the Moenkopi and Dinnebito CIAs. Results from upstream monitoring on Dinnebito Wash has a median sulfate concentration of 900 mg/L (Table 2), compared to a median downstream concentration of 660 mg/L (Table 7). Results from upstream monitoring on Moenkopi Wash has a median sulfate concentration of 150 mg/L (Table 2), compared to a median downstream concentration of 310 mg/L (Table 7). Although the downstream median sulfate concentration for the Moenkopi CIA is double the upstream median, downstream concentrations are within established sulfate variability, and no increasing trends were identified during review of the monitoring data. Therefore, the designated use for A&W$_e$ does not appear to be compromised due to the activities at the Kayenta Complex; however, OSMRE will notify Hopi Tribe WRP since detection is greater than 250 mg/L for 4 more consecutive samples.

TDS is very similar to sulfate for both designated uses and concentrations. A TDS WQS has been established by Hopi Tribe WRP for the designated use of A&W$_e$. This is the only designated use with a TDS water quality standard applicable to the Moenkopi and Dinnebito CIAs. Results from upstream monitoring on Dinnebito Wash have a median TDS concentration of 1444 mg/L, compared to a median downstream concentration of 1090 mg/L. Results from upstream monitoring on Moenkopi Wash have a median TDS concentration of 440 mg/L, compared to a median downstream concentration of 580 mg/L. Although the downstream median TDS are slightly higher than the upstream median, downstream concentrations are within established TDS variability, and no increasing trends are apparent in the downstream monitoring data (Figure 32). Therefore, the designated use for A&W$_e$ does not appear to be compromised due to the activities at the Kayenta Complex; however, OSMRE will notify Hopi Tribe WRP since detection is greater than 500 mg/L for 4 more consecutive samples at location 25.

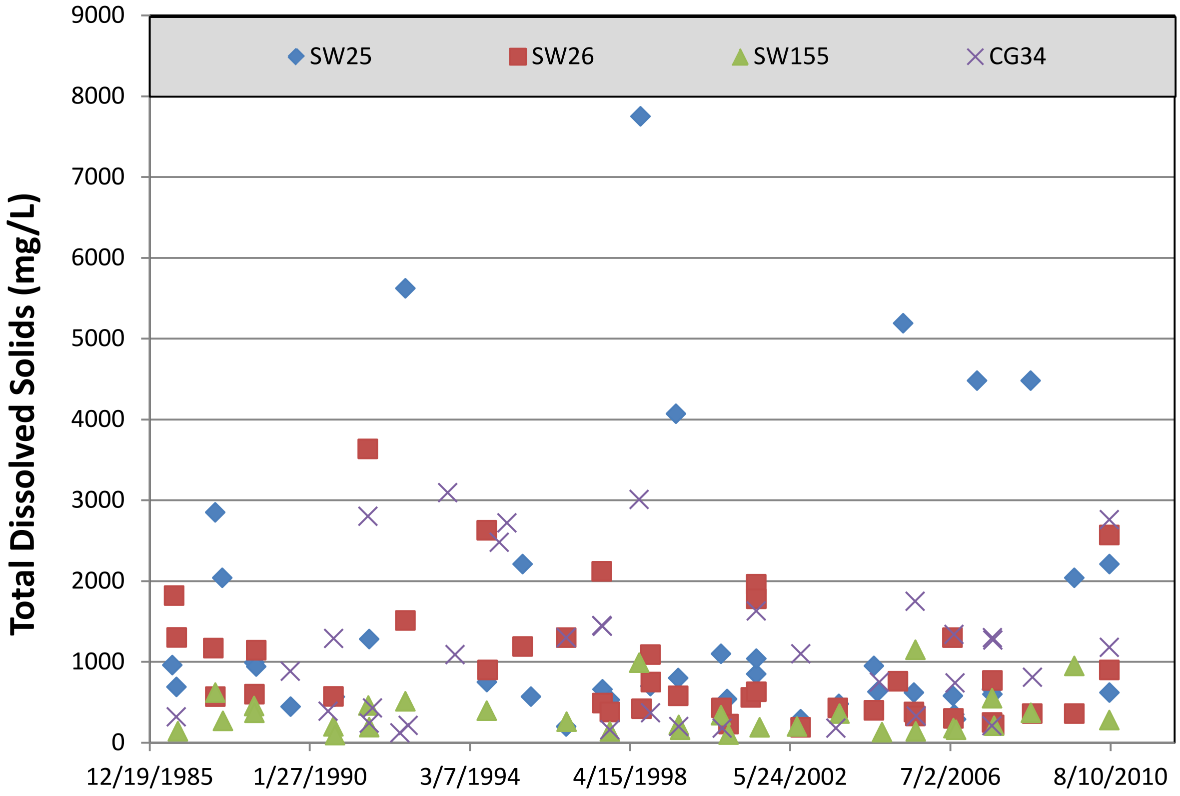


Figure 32. Downstream Surface Water TDS Concentrations, Kayenta Complex (1986 – 2010).

5.1.3.3 Surface Water Quality Material Damage Threshold and Limit

In summary, PWCC's hydrologic balance protection plan includes an approach to handle earth materials and surface water runoff in a manner that minimizes the formation of acidic or toxic drainage, and prevents additional contributions of suspended solids and other water pollutants from entering streamflow outside the permit area to the extent possible. As such, all areas disturbed by the mining operation drain to a series of sediment settling and containment ponds or dams which are designed to contain at least the 10-year, 24-hour runoff event plus an additional amount of sediment storage. Pond discharges from flow events exceeding the pond capacity are monitored for effluent compliance concentrations and reported in accordance with the requirements of NPDES permit number NN0022179.

The surface water monitoring program has provided sufficient information for OSMRE to make the impact assessment. After assessing the potential surface water quality impact of the mining operation on existing and foreseeable uses of Secondary Human Contact, Partial Body Contact, Agricultural Livestock Watering, Agricultural Water Supply, Aquatic and Wildlife Habitat (acute and chronic), and Fish Consumption water uses, OSMRE has determined that the operation has been designed to minimize surface water quality impacts within the permit area and prevent material damage outside the permit and adjacent area. OSMRE has developed a protocol to integrate Hopi Tribe WRP and NNEPA after review of monitoring data. OSMRE will work with the Hopi Tribe WRP and the NNEPA to evaluate potential mining impacts on established WQS.

5.2 Groundwater

The coal resources mined at the Kayenta Complex reside in the Wepo Formation of the Mesa Verde Group. The Mesa Verde Group consists of the overlying Yale Point Sandstone, the Wepo Formation, and the underlying Toreva Formation. Alluvial channels truncate the Yale Point Sandstone and Wepo Formations within the assessment area delineated in Section 2.2.1, limiting regional horizontal flow. OSMRE will evaluate the potential of the Kayenta Complex operation to result in contamination, diminution, or interruption of alluvial and Wepo Formation groundwater outside the permit area that may result in the inability to utilize water resources for existing and foreseeable livestock use.

Additionally, as discussed in Section 3.2, PWCC utilizes groundwater from water supply wells within the permit area. The wells predominantly withdraw groundwater from the N aquifer system, and a small portion is withdrawn from limited screened intervals of the overlying D aquifer system. The N aquifer is utilized regionally by Hopi and Navajo communities for domestic supply water, and the D aquifer is utilized in isolated areas where the water quantity and quality permits domestic and livestock water supply use. PWCC's past and present N aquifer use creates both water quantity and quality concerns that will be evaluated in this assessment.

5.2.1 Alluvium

OSMRE will evaluate whether the monitoring program has been appropriately designed to provide alluvial water quantity and quality information necessary to assess potential impacts in accordance with 30 CFR 780.21(g). OSMRE will also evaluate the potential impact of the Kayenta Complex on downstream uses outside the permit area related to alluvial water quantity and quality, and potential impact to the existing and foreseeable use of agricultural livestock watering.

5.2.1.1 Alluvial Quantity

The alluvial washes within the permit area are characterized as having large variations in both vertical saturated thickness and cross-sectional width based on seismic refraction studies and drill log information.

Variability of hydrologic characteristics was also confirmed through aquifer testing, where transmissivity results span three orders of magnitude (Figure 15). Additionally, the alluvial systems in the various washes are not continuous within the permit area. Some areas of the alluvium have up to 34-feet of saturated thickness, while other areas of the same wash may only have a thin veneer of unsaturated alluvium accumulated. However, OSMRE will evaluate the use potential based on water quantity and potential water quantity impact to the existing and foreseeable uses due to the Kayenta Complex.

5.2.1.1.1 Alluvial Quantity Monitoring Program

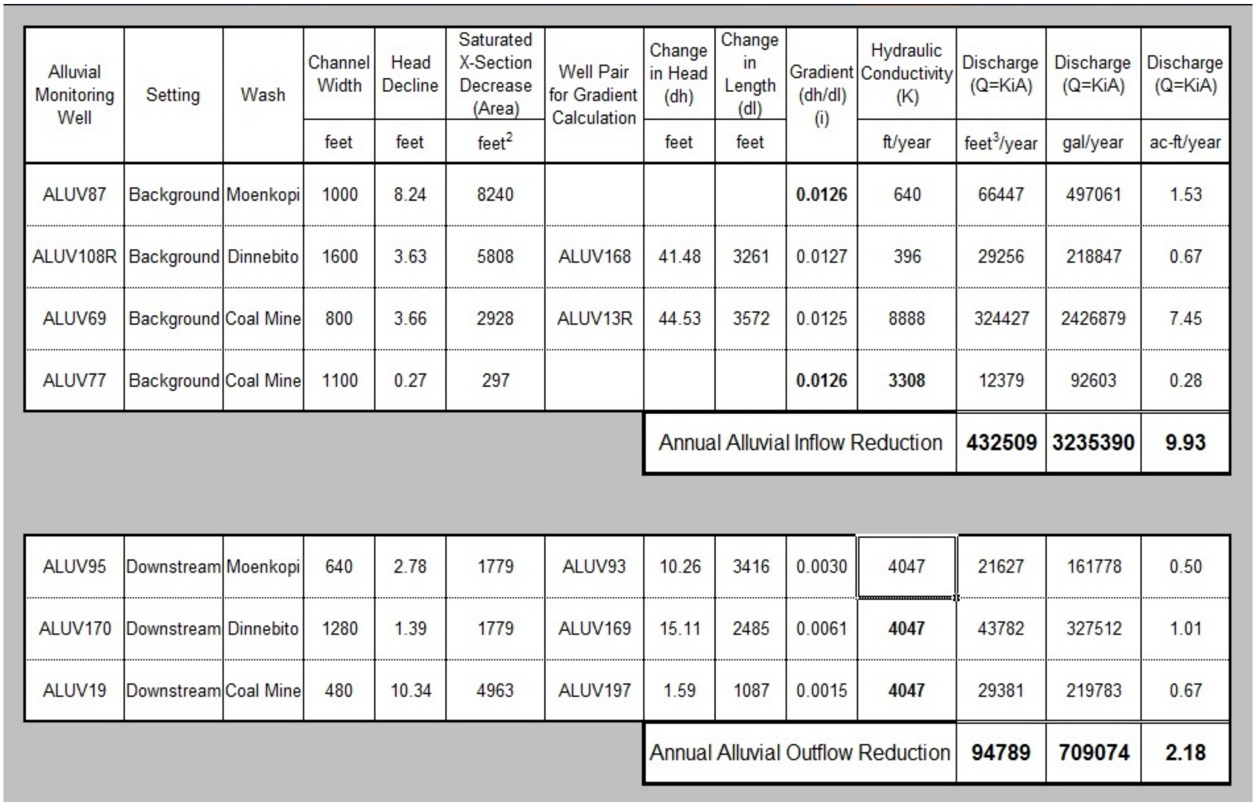
The monitoring program of the valley alluvium for water quantity was implemented to characterize background conditions, natural seasonal fluctuations, and identify the existing and foreseeable use potential of alluvial water. Specifically, mining related water quantity impact on the potential use of alluvial water for livestock watering has been identified as a concern for this evaluation.

The monitoring program identified that the groundwater quantity in the alluvial system is variable, and fluctuations in the background alluvial monitoring well data are predominantly related to precipitation and associated infiltration of surface water flow. Also, since precipitation is spatially variable, water level trends will generally mimic each other, but the amplitudes may vary depending on the spatial distribution of precipitation events and the amount of runoff generated as surface flow in the washes. The general trend measured in alluvial background monitoring locations 69, 77, 87, and 108R has been decreasing. The four background monitoring locations, coupled with multiple wells along the alluvial washes, provide good information for evaluating water quantity variations. Therefore, OSMRE finds that the existing alluvial monitoring program, which includes wells upgradient of mining activities, wells at the downgradient permit boundary of the primary washes, and wells along the primary washes, provide sufficient information for OSMRE's impact evaluation (Figure 13).

5.2.1.1.2 Alluvial Quantity Impact Potential to Designated and Foreseeable Uses

In order to quantify alluvium inflow reduction for comparison to outflow reduction, Darcy's Law was used. Darcy's Law relates outflow to hydraulic gradient, hydraulic conductivity of the porous medium, and a cross-sectional area. The calculations are detailed in Table 8. In 2002, the water levels declined from baseline in all background alluvial monitoring wells as follows: 77 (-0.27 feet), 108R (-3.63 feet), 69 (-3.66 feet), and 87 (-8.24 feet). Multiplying the channel width at each of the locations with the water level decline in saturated alluvium yields the cross-sectional area for background baseline evaluation. Next, water level pairs were identified for alluvial wells close to the background monitoring wells for hydraulic gradient calculations. Finally, hydraulic conductivity values were derived from pump test data performed on the specific background monitoring well. Since pump test data was not available for location 77, the average hydraulic conductivity value from 87, 108R, and 69, was used for quantity calculation at location 77. Additionally, no alluvial monitoring wells are in close proximity to locations 87 and 77; therefore, the average gradient from 108R and 69 was used for the gradient variable.

The inflow quantity reduction in the alluvium was most significant for the two background tributaries comprising Coal Mine Wash. By 2002, the alluvial inflow to the permit area via Coal Mine wash has decreased by approximately 7.73 ac-ft when compared with water level information from the early 1980's. Similarly, Dinnebito alluvium has a 0.67 ac-ft inflow decline in 2002 and Moenkopi a 1.53 ac-ft decline in 2002, when compared to water level information in the early 1980's. These background inflow volume declines were compared to the volumetric flow declines at the downgradient permit boundaries (Table 8).



Alluvial Monitoring Well	Setting	Wash	Channel Width	Head Decline	Saturated X-Section Decrease (Area)	Well Pair for Gradient Calculation	Change in Head (dh)	Change in Length (dl)	Gradient (dh/dl) (i)	Hydraulic Conductivity (K)	Discharge (Q=KiA)	Discharge (Q=KiA)	Discharge (Q=KiA)
			feet	feet	$feet^2$		feet	feet		ft/year	$feet^3$/year	gal/year	ac-ft/year
ALUV87	Background	Moenkopi	1000	8.24	8240				**0.0126**	640	66447	497061	1.53
ALUV108R	Background	Dinnebito	1600	3.63	5808	ALUV168	41.48	3261	0.0127	396	29256	218847	0.67
ALUV69	Background	Coal Mine	800	3.66	2928	ALUV13R	44.53	3572	0.0125	8888	324427	2426879	7.45
ALUV77	Background	Coal Mine	1100	0.27	297				**0.0126**	**3308**	12379	92603	0.28
							Annual Alluvial Inflow Reduction				**432509**	**3235390**	**9.93**
ALUV95	Downstream	Moenkopi	640	2.78	1779	ALUV93	10.26	3416	0.0030	4047	21627	161778	0.50
ALUV170	Downstream	Dinnebito	1280	1.39	1779	ALUV169	15.11	2485	0.0061	**4047**	43782	327512	1.01
ALUV19	Downstream	Coal Mine	480	10.34	4963	ALUV197	1.59	1087	0.0015	**4047**	29381	219783	0.67
							Annual Alluvial Outflow Reduction				**94789**	**709074**	**2.18**

Table 8: Alluvial Quantity Outflow Calculations for Primary Washes (2002).

Water level decreases of 0.27 feet to 8.24 feet have been measured at the background monitoring locations; therefore, decreases can be expected at the outflow areas since inflow to the alluvial aquifer system has decreased. Downgradient alluvial monitoring locations 19, 95 and 170 were used for comparison to the background information and assessment of potential mining related impact to existing and foreseeable livestock use. The water level declines at the three downgradient alluvial monitoring wells were as follows: 19 (-10.34 feet), 95 (-2.78 feet), and 170 (-1.39 feet). Using information of water level change, hydraulic conductivity, and hydraulic gradient, the total discharge reduction was determined and compared to the background reduction. Comparatively, Moenkopi Wash had a 1.53 ac-ft/yr inflow reduction at background location 87, and a 0.50 ac-ft/yr outflow reduction at downgradient location 95. Coal Mine Wash had a combined inflow reduction at background locations 69 and 77 of 7.73 ac-ft/yr, and a 0.67 ac-ft/yr reduction at downgradient location 19. Dinnebito Wash had an inflow reduction of 0.28 ac-ft/yr at background location 108R, and a 1.01 ac-ft/yr reduction at downgradient location 170.

Overall, alluvial quantity reductions have been measured in the background alluvial monitoring wells and downgradient alluvial monitoring wells adjacent to the permit boundary. Inflow quantity reductions are greater than outflow reductions. The discrepancy appears to be the result of retaining storm flow surface water in impoundments and baseflow discharge from the Wepo Formation. The impoundments allow storm flow water to be temporarily retained, and the retained water subsequently infiltrates through the bottom of the retaining structure and into the channel alluvium.

Historically, five locations within the permit and adjacent area were developed for alluvial water use. The locations are identified as 8A-PHS-10, 4M-190, and Sagebrush Well within the permit area, while Reed Well and Grapevine Well are located adjacent to the permit boundary on Moenkopi Wash (Figure 8). Additionally, two alluvial springs that discharged at a flow rate of 1-2 gpm were identified in the northwestern portion of the permit area. The two alluvial springs are identified as 8A-140 and 8M-141.

The water quantity of the alluvial system is largely related to the surface water flow and subsequent infiltration to the alluvium. As such, fluctuations in alluvial water levels and spring flow rates are typical. The fluctuations limit sustainable development of the alluvium. For instance, Sagebrush well is a cistern (artificial underground tank for storing liquid), located in the middle of the channel, and not utilized or maintained for several decades. Storm flow events occasionally overtop the cistern; therefore, the sediment rich storm flow water has induced the cistern to become filled with sediment. Similarly, location 8A-PHS-10 has not been operated for several decades and occasionally overtopped by storm flow events. Location 4M-190 has been cataloged as a historical use location, but any identifiable structure has either washed away during storm events, or buried by accumulated sediment, as there have been no visible observations of the location for several decades. Reed Well and Grapevine Well are also cistern-like structures, abandoned for several decades, and no longer operable.

5.2.1.1.3 Alluvial Quantity Material Damage Threshold and Limit

The available quantity of alluvial water stored in the alluvial system varies depending on location within the alluvial channel and quantity of water infiltrated in response to storm flow events. Additionally, developing alluvial water for agricultural livestock use is maintenance intensive due to the sediment transported during storm flow events, evidenced by the condition of the historical use locations. Although the reliability of using the alluvial system for agricultural livestock water supply development is low and maintenance prohibitive, surface water impoundment structures from the mining operations locally enhance alluvial water quantity, and the operations will not compromise foreseeable use of alluvial water quantity. Therefore, OSMRE will not establish a material damage criterion related to alluvial water quantity, but continued water alluvial water quality monitoring is necessary.

5.2.1.2 Alluvial Quality

Alluvial water quality of the primary drainages within the Kayenta Complex has been monitored for several decades, and data from the monitoring period 1986 – 2010 is evaluated in this assessment. The water quality information will be utilized to assess potential development of the alluvial water for livestock watering, and evaluate the potential impact of the mining operations on the foreseeable livestock watering use within the permit and adjacent area.

5.2.1.2.1 Alluvial Quality Monitoring Program

Similar to the monitoring program objectives presented previously, monitoring of the valley alluvium for water quality was implemented to characterize background conditions, natural seasonal variations, and identify the existing and foreseeable use potential of the alluvial water for livestock watering. Seasonal variations will not be evaluated separately, since seasonal variation is apparent but not statistically significant between monitoring locations.

Figure 13 illustrates that alluvial water quality information has been obtained at 80 locations within the permit area. There are currently 32 locations sampled as part of the active alluvial quality monitoring program. The remaining locations have been properly abandoned. The active locations are sampled either annually or semi-annually. Semi-annual monitoring is typically done at locations where geochemical trending of some water quality parameters has been observed. Eight locations are currently monitored semi-annually. Water quality samples are analyzed for a full suite of parameters consisting of parameters that have Arizona, Federal, or Navajo Nation livestock drinking water limits, all significant parameters necessary to perform QA/QC checks on laboratory data, and those parameters necessary to evaluate mining impacts (PWCC, v.11, ch.16, 2011).

The information obtained at the abandoned alluvial monitoring locations, coupled with ongoing monitoring of the existing locations, provide the necessary information to characterize background conditions, natural seasonal variations, and evaluate the water quality impact of the mining operations on the potential for watering livestock within the permit and adjacent area. Therefore, OSMRE finds that the alluvial monitoring is appropriately designed and implemented.

5.2.1.2.2 Alluvial Quality Impact Potential to Designated and Foreseeable Uses

Historical attempts have been made to develop alluvial water resources within in the permit and adjacent area. However, none of the locations have been utilized or maintained for several decades, and some of the locations have been either washed downstream during flood events or are filled with sediment. The lack of alluvial use locations within the permit and adjacent area is largely a function of the dynamic water quantity conditions in the channel alluvium, which is dependent on the duration and intensity of the surface water storm flow events. Another challenge pertinent to alluvial aquifer development is the fact that it is not continuously hydraulically connected through any significant geographic area. However, this evaluation will consider the potential to develop alluvial water within the permit and adjacent area to support livestock watering. HTWQS (Hopi Tribe, 2008) and NNSWQS (NNEPA, 2007) for agricultural livestock water supply will be used to support water quality evaluation of the alluvial aquifer.

Chemical parameters with an agricultural livestock water supply WQS, and major cations and anions are identified on Table 9. Downstream monitoring locations for the Moenkopi alluvial CIA identified one detection of cadmium above the agricultural livestock WQS (50 µg/L) at location 19. The elevated detection is a result of an elevated MDL in 1997, and subsequent concentrations have been less than the WQS the remainder of the monitoring period.

The Hopi Tribe WRP and NNEPA WQP established an agricultural livestock water supply WQS for lead at 100 µg/L. All reported concentrations are a result of the MDL. However, when the MDL is less than 100 µg/L, no positive concentrations above 100 µg/L have been identified.

Selenium concentrations measured at upstream and downstream alluvial monitoring locations are less than the agricultural livestock water supply WQS (50 µg/L), except for one detection (57 µg/L) at downstream monitoring location 172. The one selenium detection above 50 µg/L was followed by three samples that were less than 50 µg/L.

An agricultural livestock water supply WQS is not established for TDS. TDS is an aggregate indicator of the presence of a broad array of chemical constituents and provides a reasonable indication of the overall water quality. Elevated TDS concentrations typically correspond to elevated concentrations in one or more major cations or anions. Review of the upstream TDS data at location 87 indicates a significant increase from 2005 – 2010 (Figure 33). Monitoring location 87 is considered an upstream background location, and the cause for the significant increase is unknown. After the initial TDS increase at location 87 from 2005 – 2007, measured concentrations are returning to concentrations within the previously recorded range. The return to previously measured concentrations indicate the cause is likely not persistent, but the elevated concentrations will likely migrate through the Moenkopi alluvium within the permit area. Measured TDS concentrations in downstream Moenkopi alluvial monitoring well 95, indicate the poorer quality water has not reached downstream alluvial well 95 (Figure 34). Elevated TDS concentrations are expected to occur at location 95 in future sampling events. Overall, upstream and downstream monitoring of TDS indicates the range varies between 500 – 7000 mg/L. Continued monitoring at upstream and downstream monitoring locations continues to be necessary to assessment if elevated concentrations are the result of mining related impacts from the Kayenta Complex.

					Dinnebito Wash CIA				Moenkopi Wash CIA			
					Location 170				Locations 19, 95, and 172			
Chemical Parameter	Agricultural Livestock Watering WQS	WQS	Units	Type	# Samples	Low	Median	High	# Samples	Low	Median	High
Aluminum	HT	5	mg/L	Dissolved	n=55	0.03	0.2	0.2	n=133	0.03	0.05	0.5
Arsenic	HT and NN	200	µg/L	Dissolved	n=55	1	1	6	n=133	0.5	1	7
Bicarbonate	NNS	NNS	mg/L	Dissolved	n=55	605	803.5	903	n=138	61	372	891
Boron	NN	5000	µg/L	Dissolved	n=55	210	290	380	n=134	30	120	310
Calcium	NNS	NNS	mg/L	Dissolved	n=55	440	504	596	n=135	60.3	463	600
Cadmium	HT and NN	50	µg/L	Dissolved	n=55	3	20	30	n=135	3	5	80
Chloride	NNS	NNS	mg/L	Total	n=55	32	46	70	n=137	10	43.5	96
Chromium	HT and NN	1000	µg/L	Dissolved	n=55	10	50	50	n=133	5	10	80
Copper	HT and NN	500	µg/L	Dissolved	n=55	10	50	80	n=133	5	10	50
Lead	HT and NN	100	µg/L	Dissolved	n=55	20	200	200	n=133	1	20	200
Magnesium	NNS	NNS	mg/L	Dissolved	n=55	421	483	629	n=137	17	260	610
Mercury	HT	10	µg/L	Dissolved	n=55	0.1	0.2	0.3	n=135	0.1	0.2	1.3
Selenium	HT and NN	50	µg/L	Dissolved	n=55	1	2.5	12	n=135	1	5	57
Sodium	NNS	NNS	mg/L	Dissolved	n=55	505	635.5	1150	n=137	63.1	310.5	737
Sulfate	NNS	NNS	mg/L	Total	n=55	3300	3960	5800	n=137	90	2523.5	4200
TDS	NNS	NNS	mg/L	Total	n=55	5718	6424	9540	n=138	420	4054	7120
Vanadium	HT and NN	100	µg/L	Dissolved	n=55	5	30	50	n=133	5	10	50
Zinc	HT and NN	25	mg/L	Dissolved	n=55	0.01	0.05	0.1	n=133	0.01	0.02	5.81

NNS - No Numeric Standard
WQS - Water Quality Standard
mg/L - milligrams per liter
µg/L - micrograms per liter
NN - Navajo Nation
HT - Hopi Tribe
CIA - Cumulative Impact Area
T- Total

Table 9. Downstream Alluvial Water Quality Summary (1986 – 2010), Kayenta Complx.

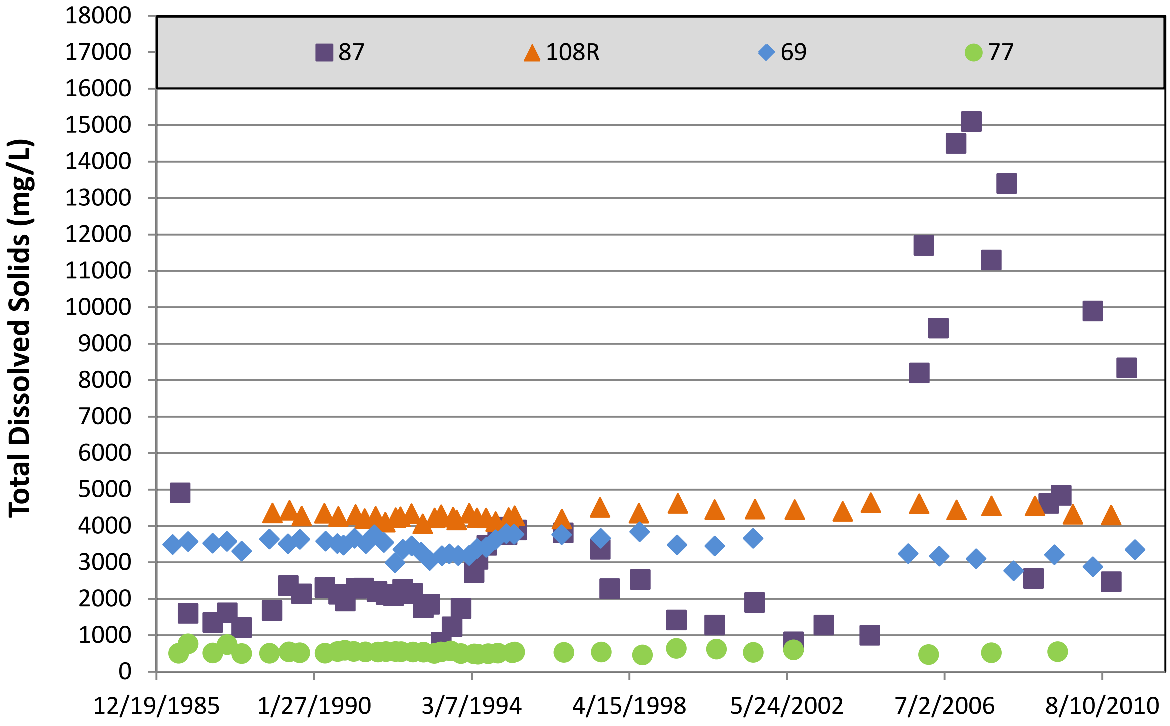


Figure 33. TDS Concentrations (1986 – 2010), Upstream Alluvial Monitoring Locations.

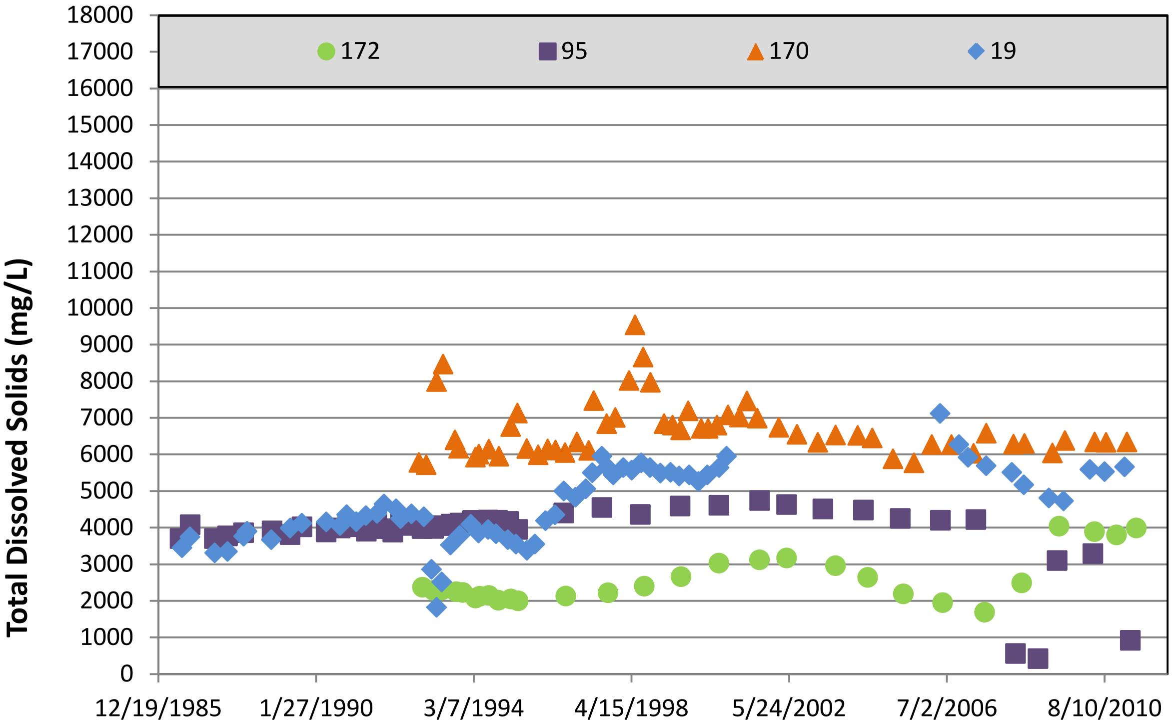


Figure 34. TDS Concentrations (1986 – 2010), Downstream Alluvial Monitoring Locations.

5.2.1.2.3 Alluvial Quality Material Damage Threshold and Limit

Overall, evaluation of alluvial water quality indicates that water quality is subject to some seasonal variability and a large amount of variability from location to location. Agricultural livestock watering use was considered for evaluation; however, historical alluvial use locations within the alluvial cumulative impact area have all been abandoned and no attempts to develop alluvial water have been initiated over the past 40 years within the CIA. Accessibility to potable public water standpipes and retention of surface water impoundments for livestock watering make development of the saturated alluvium for livestock watering a challenging and maintenance-intensive alternative. After comparison of upstream water quality with downstream water quality related to WQS and major cations and anions, there are no indications that the mining operation is compromising the agricultural livestock supply water outside the permit area. Alluvial water quality will continue to be monitored and evaluated against available livestock water quality standards. Similar to the surface water quality assessment protocol described in Section 5.1.3.2, if monitoring demonstrates that WQS have been exceeded for 4 out of 4 sampling events, OSMRE will the appropriate CWA authority, and evaluate if the exceedances are the result of a mining related impact.

5.2.2 Wepo Formation

The Wepo Formation lies within the late Cretaceous Mesa Verde Group. Due to the late Cretaceous depositional environment, the water bearing zones of the Mesa Verde Group are largely perched and intertongue with less permeable material. The Wepo Formation contains low yielding perched aquifers in some locations, and the permeable aquifer zones pinch out or are vertically displaced owing to some minor structure within the Kayenta Complex (PWCC, v.11, ch.18, 2011). The springs and seeps of the Mesa Verde Group identified by PWCC within the permit area emanate from contact zones between the bottom of permeable sandstones and the top of relatively impermeable shale layers exposed along the sides of washes, discharging into the alluvium (PWCC, v.9, ch.15, 2011).

The depositional environment during the late Cretaceous left a thick complex sequence of intertonguing siltstone, mudstone, sandstone, and coal beds (Figure 6). The Wepo Formation contains some discontinuous saturated zones, but attempts to utilize this water source have received limited success. The coal resources in the Wepo Formation of the Mesa Verde Group are being mined at the Kayenta Complex, and may intercept groundwater from the upper part of the Wepo Formation. Limited interception of the saturated Wepo has already occurred during the mining of coal resource areas N-11, J-1/N-6, N-14, J-16, J-19/J-20, and J-21. Since surface mining will potentially incept groundwater from the Wepo Formation, the hydrologic impacts in the Wepo Formation associated with mining were evaluated as part of the PHC determination (PWCC, v.11, ch.18, 2011). Similarly, OSMRE will evaluate the hydrologic consequences related to Wepo water quantity and quality, and assess the impact of the mining operations on the livestock water supply use of Wepo Formation water within the Wepo CIA.

5.2.2.1 Wepo Formation Quantity

PWCC experience of surface coal mining on Black Mesa has identified that “the permeable units within the Wepo Formation are perched aquifers in some locations, pinch out, or are vertically displaced owing to some minor structure within the Kayenta Complex” (PWCC, v.11, ch.18, 2011). Therefore, some conservative simplifying assumptions were necessary for impact evaluation of Wepo water quantity. The assumptions are conservative in that they overestimate the amount and areal extent of the Wepo water impacted. The overestimation of the annual water quantity withdraw allows for a protective delineation of a potential impact area for the Wepo Formation, and users of Wepo groundwater.

Assumptions of a continuous, confined, saturated Wepo Formation having a uniform thickness are significant simplifying assumptions for the purpose of hydrogeologic evaluation. Mining experience of the Wepo Formation, borehole data from geologic characterization of the coal resources throughout the Kayenta Complex, and aquifer testing of monitoring wells in the Wepo aquifer zones demonstrate the conservative nature of the above assumptions (PWCC, v.10, ch.15, 2011). Transmissivity values for the Wepo Formation, which reflect the ability of the aquifer to transmit water, can be found in Figure 18.

With respect to spoil material, which is predominantly composed of the Wepo Formation, these assumptions may not be as conservative. Where pit mining has occurred, replacing the original material of the Wepo Formation with spoil material, results in much higher porosity and permeability (PWCC, v.11, ch.18, 2011). This is due in part to the fact that the increase in surface area that occurs when the coal is mined from the Wepo Formation also results in increasing the total volume of the spoil material, changing the Wepo aquifer properties within the reclaimed areas of the Kayenta Complex.

5.2.2.1.1 Wepo Formation Quantity Monitoring Program

Forty-six Wepo monitoring locations have been installed within the Kayenta Complex to assess water quantity impacts to the Wepo Formation water bearing units. Twenty-five Wepo monitoring wells are currently retained for evaluating impacts to the Wepo Formation. Recognizing the discontinuity of the Wepo aquifer, PWCC typically installed a Wepo monitoring well upgradient and downgradient of active and future coal pit areas to assess immediate water quantity impacts related to mining (Figure 16).

The historical and existing Wepo Formation monitoring well network provides the appropriate information to assess water quantity impacts attributed to the mining operations on the Wepo Formation. Therefore, OSMRE finds that the monitoring program of the Wepo Formation has been appropriately designed and implemented to provide the necessary information for hydrologic impact assessment.

5.2.2.1.2 Wepo Formation Quantity Impact Potential

Historical and existing users of the Wepo Formation water were identified within the Wepo CIA delineated in Section 2.2.1. Utilizing USGS, BIA, and Tribal databases, and PWCC field investigations, six Wepo well locations have been identified within the CIA, and are denoted by the following well IDs on Figure 8: 8T-506, 8A-PHS-15, 4K-309, 4T-512, 4K-380, 4T-405. Well 8T-506 is completed in both the Wepo and underlying Toreva Formation. The available information for additional wells only includes the location coordinates and suspected aquifer zone being developed.

Nineteen Wepo aquifer springs and seeps have been identified within the Wepo water quantity impact area using USGS, BIA, Tribal databases, and PWCC field investigations. The 19 springs are denoted by the following IDs: DM-6, Hogan Gulch Spring, Goat Spring #2, 4M-190A, 4M-191, 2A-44, 8A-147, NSPG91, NSPG92, NSPG111, NSPG140, NSPG147, 8A-153, 8A-139, 8A-143, 8A-145, Pine Spring, Great Spring, and Sand Spring (Figure 8). Field investigation of the water resources within and immediately surrounding the Kayenta Complex indicates that many of these springs do not presently discharge, occur only as damp spots, or are indistinguishable in baseflow reaches (PWCC, v.11, ch.17, 2011). Therefore, only spring locations NSPG140, NSPG91, NSPG92, NSPG111, NSPG147, Sand Spring, Goat Spring #2, and Hogan Gulch Spring are monitored for evaluation of Wepo spring water quantity impacts. Discharge at these eight springs ranges from 0 - 4.2 gallons per minute, with NSPG92 having the highest recorded flow rate of the eight springs at 4.2 gallons per minute (PWCC, v.11, ch.18, 2011). Although use of Wepo Formation water is quite limited due to both the hydraulic and water quality characteristics of the aquifer, PWCC has minimized impacts to designated and foreseeable uses through water supply replacement within the Kayenta Complex. Given that the quantity of water available for use through this system is much greater than the original quantity that was used from the Wepo Foramtion, impacts to the designated uses have been minimized.

5.2.2.1.3 Wepo Formation Quantity Material Damage Criterion

OSMRE finds that the mining operations at the Kayenta Complex will not adversely impact existing or potential users of the Wepo Formation water outside the permit area due to the areal discontinuity of the saturated Wepo Formation. Additionally, eight Wepo springs are monitored within the Kayenta Complex and adjacent area. OSMRE has determined that the existing Wepo monitoring program is in compliance with 30 CFR 816.41, and PWCC shall continue the existing monitoring program for Wepo wells and Wepo springs. If the mining operation results in sustained spring flow depletion at these eight springs or well yield depletion at the eight wells, PWCC shall mitigate as required in 30 CFR 780.21. Therefore, OSMRE will not establish a material damage criterion specific to protection of Wepo water quantity.

5.2.2.2 Wepo Formation Quality

The removal of overburden and coal occurs in the Wepo Formation of the Mesa Verde Group at the Kayenta Complex. The Wepo Formation is incised by surface water drainages within the permit and adjacent area, making the saturated lithology within the Wepo Formation noncontiguous. However, these noncontiguous saturated sections of the Wepo Formation may be developed for water use. As presented previously, elevated TDS in the Wepo water limits development for domestic water supply within the permit area, but Wepo water may be utilized for livestock watering at some locations.

5.2.2.2.1 Wepo Formation Quality Monitoring Program

Mining areas that intercept a portion of saturated Wepo Formation act as ground water sinks, and the adjacent formation water will flow back toward the mined area in some locations and potentially saturate a portion of the backfill spoil material replaced in the coal resource areas. Due to the potential for backfill spoil material to re-saturate and cause water quality degradation, PWCC conducted several focused spoil water studies in coal resource areas N-7, N-2, N-14, and J-16, which intercepted Wepo Formation water. Eleven spoil wells were installed in the N-2 spoil; two in the N-7 spoil, six in N-14 spoil, and one well was completed in the J-16 spoil (Figure 16).

The historical and existing Wepo monitoring well network and focused spoil saturation studies provide the necessary information to assess water quality impacts attributed to the mining operations on the Wepo aquifer. Therefore, OSMRE finds that the hydrologic characterization and monitoring program of the Wepo aquifer system have been appropriately designed and implemented to provide the necessary information for hydrologic impact assessment.

5.2.2.2.2 Wepo Formation Quality Impact Potential

The concentrations of major cations and anions identified at background Wepo monitoring wells were compared to the median concentrations from spoil monitoring wells. Spoil water quality provides an indication of local water quality impacts of mining on Wepo Formation water. The major cation concentrations of sodium, calcium, and magnesium are illustrated on Figure 35. The major anion concentrations of chloride, bicarbonate, and sulfate are illustrated on Figure 36. Since TDS provides an indication of the overall water quality, Figure 37 illustrates background Wepo TDS concentrations compared to the median spoil TDS concentration.

Limited precipitation and associated infiltration to groundwater, and the discontinuous nature of water bearing zones in the Wepo Formation cause resaturation of the spoil material in the reclaimed mine pits to be slow. Many of the spoil wells that have been installed to monitor the potential effects of reclamation are still dry. Any impacts adjacent to the mine pits are minimized due to the shift of the hydraulic gradient towards the mine pits caused by this extremely slow rate of resaturation. This limits any effective transport of spoil water to adjacent areas of the Wepo aquifer.

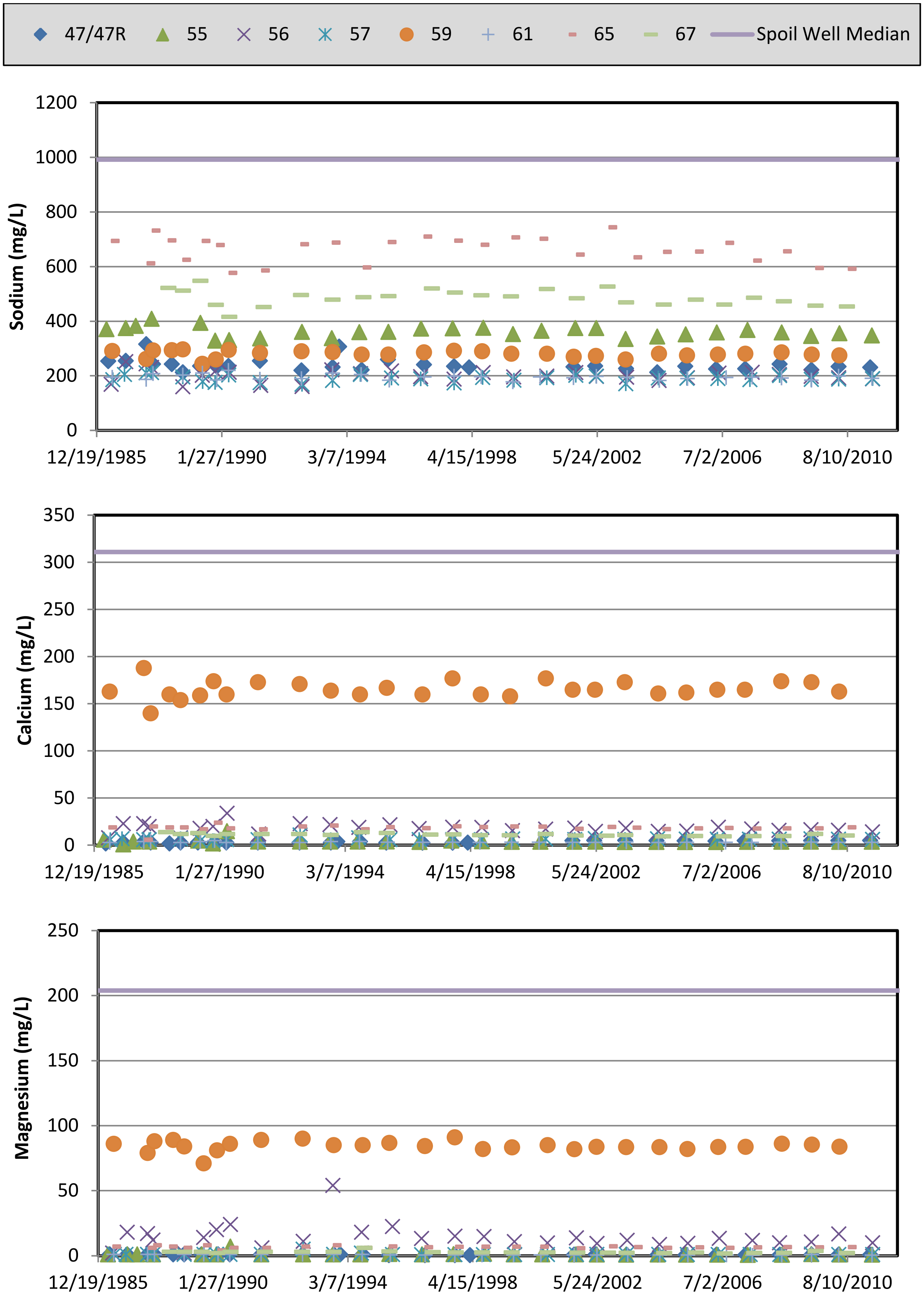


Figure 35. **Wepo Background Wells and Spoil Median Concentration for Major Cations.**

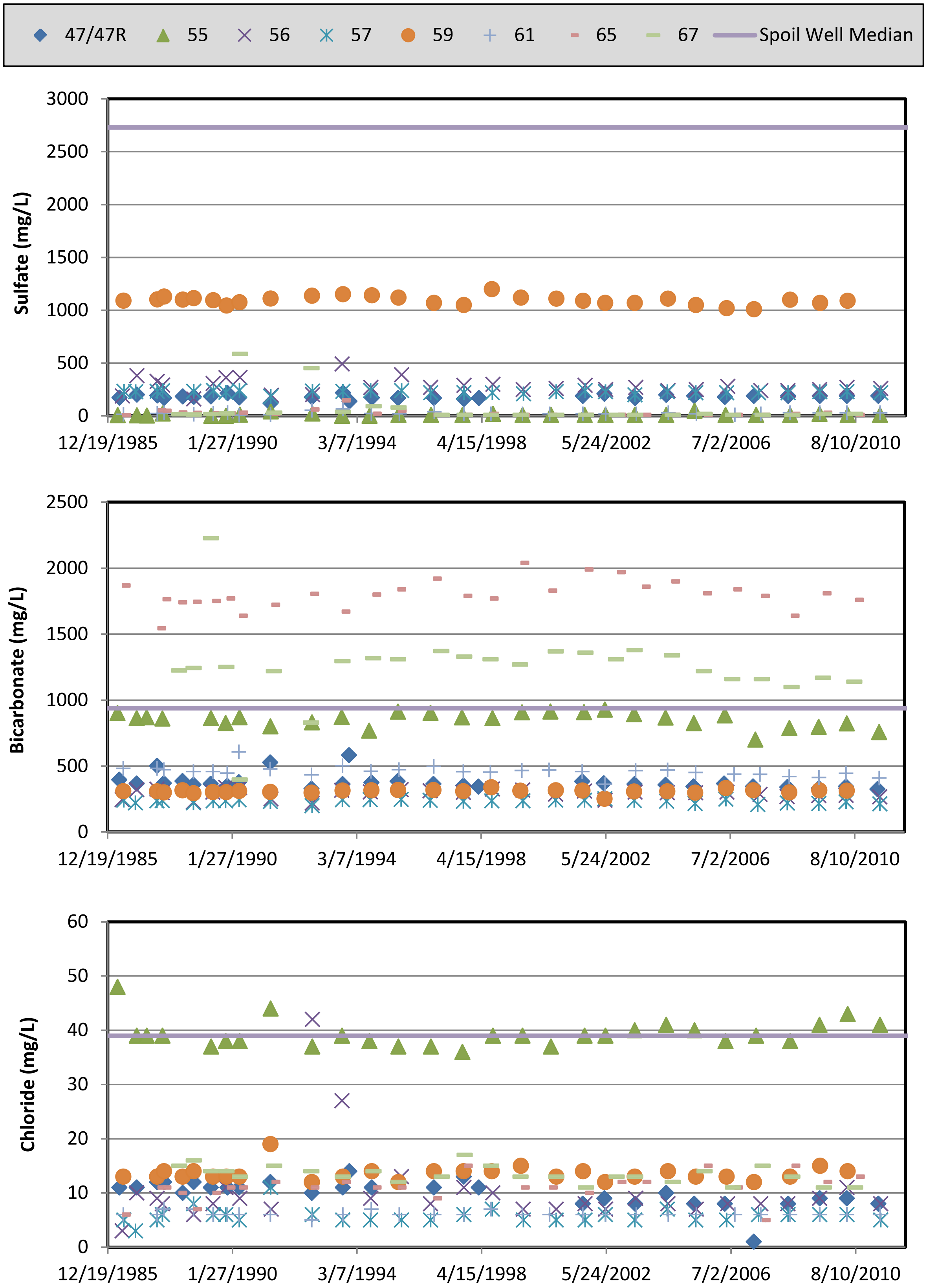


Figure 36. **Wepo Background Wells and Spoil Median Concentration for Major Anions.**

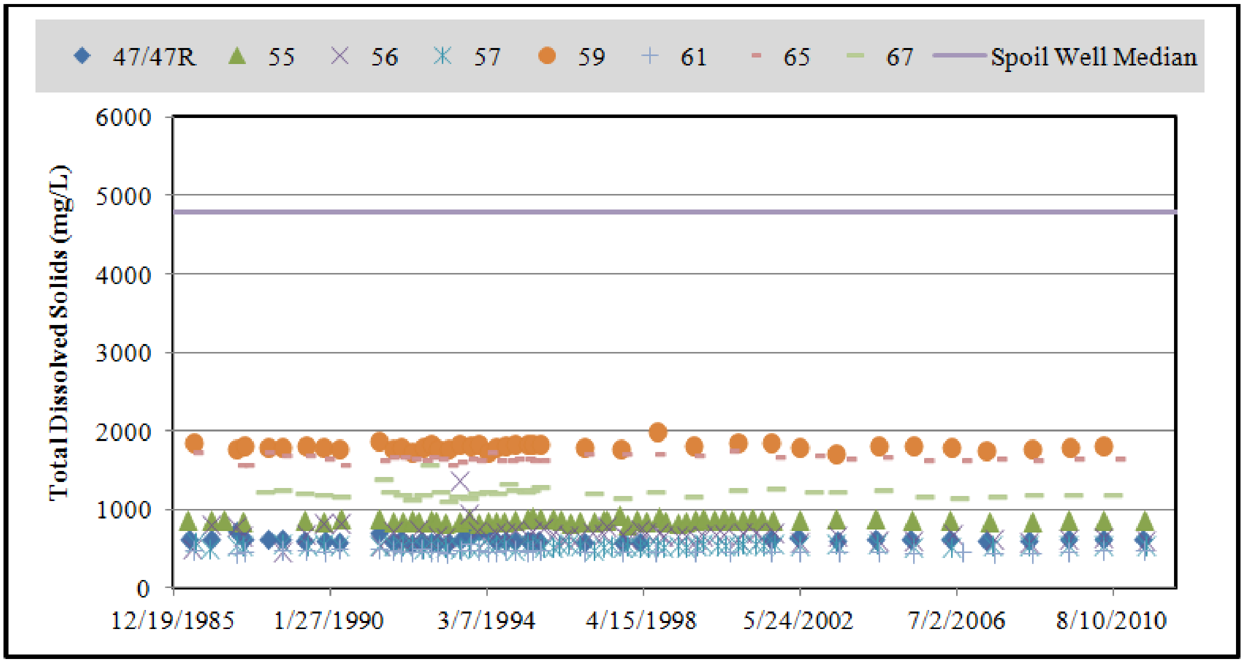


Figure 37. **Wepo Background Wells and Spoil Median Concentration for TDS**.

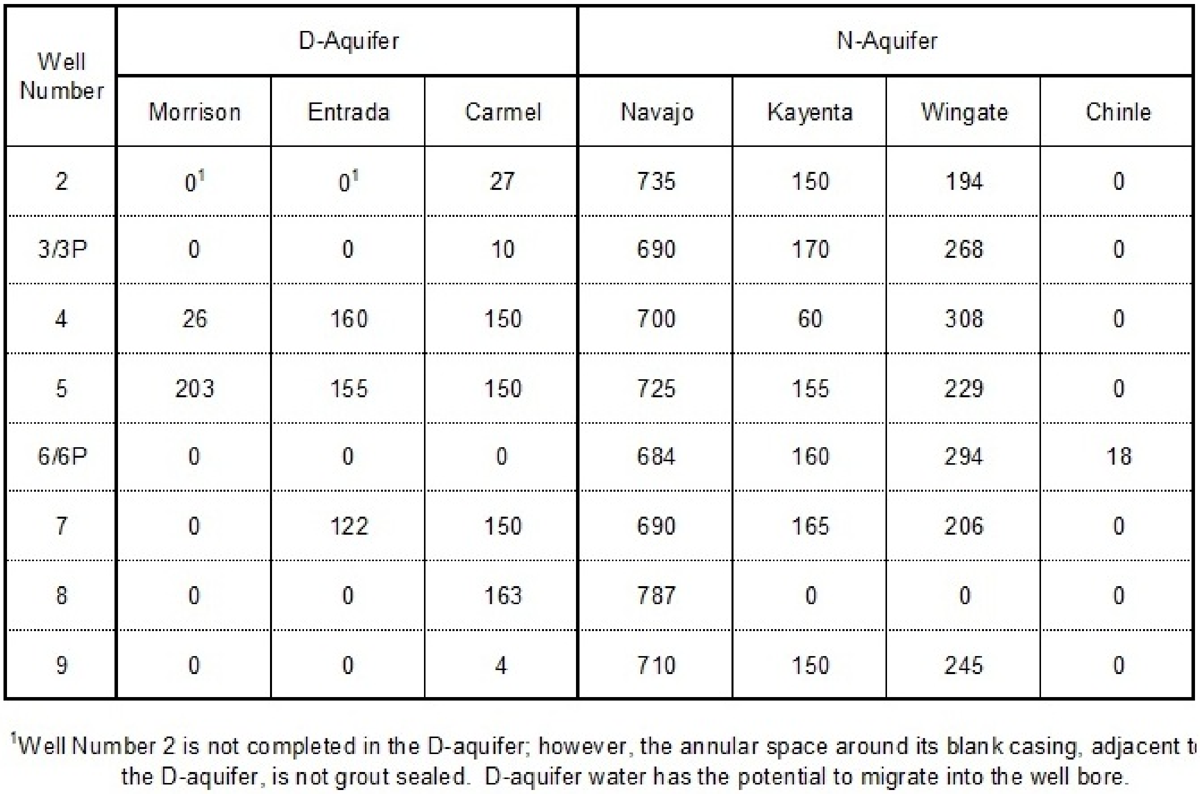
5.2.2.2.3 Wepo Formation Quality Material Damage Criterion

The impact of mining at the Kayenta Complex on Wepo Formation water quality outside of the permit area has been negligible with respect to livestock uses. Historically, there has been only isolated use of water from the Wepo Formation for livestock, and generally the water quality prevents it from being a widespread water source within the permit and adjacent area. Although spoil water could conceivably migrate into Wepo Formation along the periphery of backfilled mine pits, the hydraulic gradient is toward the spoil from the Wepo Formation. Combined with the low hydraulic conductivity and the discontinuous nature of Wepo Formation, there is no indication that water from the spoil is migrating or would migrate to any great extent into the Wepo Formation. Spoil water quality for major cations, anions, and TDS are elevated compared to background concentrations; however, the potential for degraded water quality migration outside the mine pit area is limited. If water quality migration outside the mine pit area occurred, the alluvial water quality monitoring program in the receiving alluvial channels will identify the migration of associated impacts. Therefore, OSMRE will not establish a material damage criterion specific to mining impacts on Wepo Formation water quality. OSMRE regularly evaluates quarterly monitoring data to ensure impacts to the Wepo Aquifer are minimized to the mine pit areas.

5.2.3 D aquifer

The D aquifer is confined above by the vertically thick and areally extensive Mancos Shale Formation. The D aquifer is confined below by the Carmel Formation in the northeastern area of Black Mesa, and the Carmel Formation becomes semi-confining toward the southwest edge of Black Mesa. Baseline conditions for the D aquifer system were established using water quality analysis (including isotope evaluation) and using groundwater modeling. The 3D Model (PWCC, 1999) was developed to evaluate the potential mining related impact on the D and N aquifers separated by the Carmel Siltstone Formation. However, it should be noted that substantially less historical and transient information exists for the D aquifer system compared to the N aquifer system. As such, the 3D Model (PWCC, 1999) did not undergo a transient calibration (i.e. simulating water levels changing over time) for the D aquifer system, as was performed for the N aquifer system, although a reasonable steady state (pre-significant pumping) water level map was achieved using the available D aquifer historical information (Figure 21).

PWCC operates water supply wells within the Kayenta Complex to support mining operations. The water supply wells are partially screened in some of the hydrologic units of the D aquifer (Table 10). Water supply wells NAV2, NAV3, NAV4, NAV5, NAV6, NAV7, and NAV8 are screened in portions of the Entrada sandstone (overlying the Carmel Formation), and NAV2 and NAV5 are also screened in portions of the Morrison Formation (overlying the Entrada Formation). Although these water supply wells are predominantly screened in the N aquifer, some water is derived from the overlying D aquifer. Since the D aquifer system water is partially or solely relied on at some communities for municipal water supply, agricultural use, and cultural use, the water quantity impacts associated with mine related drawdown are of concern and the subject of evaluation in this section.



Well Number	D-Aquifer			N-Aquifer			
	Morrison	Entrada	Carmel	Navajo	Kayenta	Wingate	Chinle
2	0[1]	0[1]	27	735	150	194	0
3/3P	0	0	10	690	170	268	0
4	26	160	150	700	60	308	0
5	203	155	150	725	155	229	0
6/6P	0	0	0	684	160	294	18
7	0	122	150	690	165	206	0
8	0	0	163	787	0	0	0
9	0	0	4	710	150	245	0

[1] Well Number 2 is not completed in the D-aquifer; however, the annular space around its blank casing, adjacent t the D-aquifer, is not grout sealed. D-aquifer water has the potential to migrate into the well bore.

Table 10: PWCC Pumping Wells Screened Aquifer Zone (feet) (PWCC, v.11, ch.15, 2011).

5.2.3.1 D aquifer Quantity

The D aquifer system is not extensively developed for water supply use. Wells that pump water from the D aquifer system are typically windmills, providing water for agricultural livestock water supply. PWCC withdraws D aquifer from wells partially screened in the D aquifer for industrial supply water. The communities of Chilchinbito, Kitsillie, and Kykotsmovi withdraw water from the D aquifer system for domestic water supply.

Two windmill wells are within 15-miles of the PWCC pumping center: identified as 4T-402 and 4K-387 (Figure 20). Windmill well 4T-402 withdraws water from the Dakota Sandstone Formation and is approximately 1-mile from the PWCC pumping center. Windmill well 4K-387 is screened in both the Cow Springs and Dakota Formations, and is approximately 15-miles from the PWCC pumping center. Maximum predicted drawdown attributed to PWCC pumping is greatest at well 4T-402, and is estimated at 50 feet of drawdown (PWCC, v.11, ch.18, 2011). The more distant windmill, 4K-387, is estimated to realize approximately 10-feet of drawdown related to PWCC pumping; however, the location is no longer available for use (PWCC, v.11, ch.18, 2011).

Figure 38 illustrates the D aquifer model simulated drawdown attributed to PWCC and community pumping from baseline condition to 2006 (PWCC, 1999). PWCC reduced wellfield pumping on December 31, 2005 by 70-percent compared to historical annual pumped quantities. Therefore, the illustrated drawdown centered on the Kayenta Complex represents a simulated maximum drawdown. The local D aquifer drawdown attributed to PWCC pumping is predicted to recover as the D aquifer system responds to the decreased PWCC pumping rate.

Water quantity concerns have been identified for domestic and agricultural water supply. The windmill in closest proximity to PWCC pumping has an available water column of approximately 550 feet, of which PWCC pumping may reduce by 50 feet. Windmill well 4K-387 is no longer operational. Therefore, OSMRE finds that PWCC impact on locations 4T-402 and 4K-387 will not adversely affect the existing or foreseeable use at these locations due to the limited amount of drawdown attributed to PWCC pumping.

5.2.3.1.1 D aquifer Quantity Material Damage Criterion

Simulated water level at windmill well 4T-402 will decrease by approximately 10-percent. Although an obstruction in the well prohibits water level confirmation, the operation of the windmill has not been compromised during the 40-plus year operation of the PWCC wellfield. Although a 10-percent reduction in water level elevation was simulated at location 4T-402, no additional operation cost has occurred since the location is wind powered. If the water availability is compromised, PWCC is responsible for water replacement in accordance with 30 CFR 816.41(h). Therefore, OSMRE will not establish a material damage criterion for the D aquifer quantity due to the absence of potential impact on domestic supply water, livestock supply water, or agricultural supply water.

5.2.3.2 D aquifer Quality Material Damage Criterion

Figure 22 illustrates difference in confined aquifer potentiometric surface between the D aquifer and N aquifer systems. Section 4.2.4.2 characterizes the overall D aquifer system quality as poor, compared to the N aquifer system. The natural hydrologic impact potential is for poorer quality D aquifer water to migrate downward to the N aquifer system (Truini and Longsworth, 2003). Therefore, since no hydrologic mechanism is present for PWCC operations to impact D aquifer quality OSMRE will not establish a material damage limit or monitoring criteria.

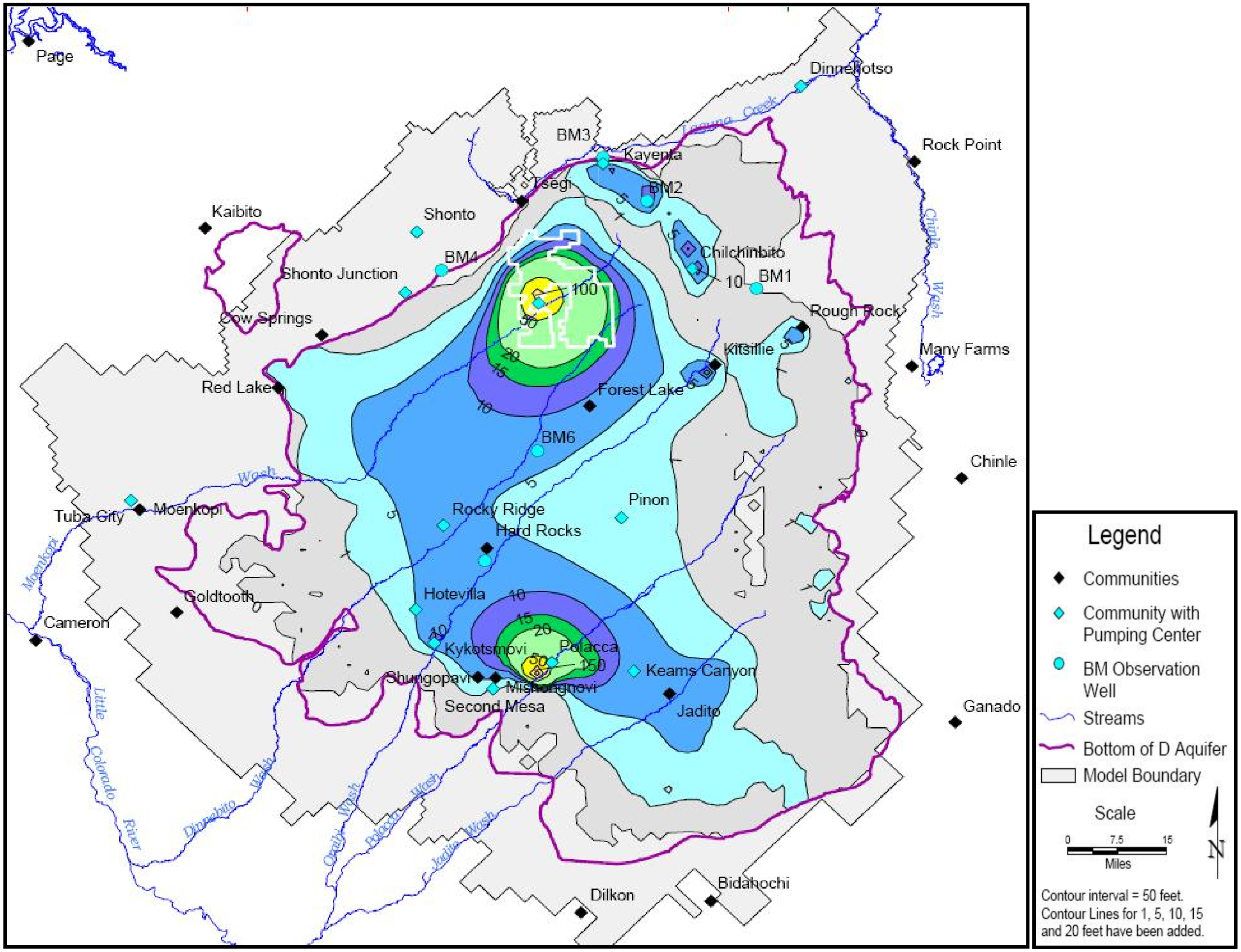


Figure 38: Groundwater Model Simulated D aquifer Drawdown in 2006 (PWCC, 1999).

5.2.4 N aquifer

PWCC pumping of the confined N aquifer prompted several concerns related to a reduction in the water pressure. The following groundwater concerns related to N aquifer pumping for coal mining operations will be evaluated for this CHIA:

- The potential impact of PWCC drawdown on community water supply wells.
- The potential impact on N aquifer baseflow to area washes.
- The potential impact on N aquifer spring discharge.
- The potential for land subsidence related to N aquifer drawdown.
- The potential for water quality degradation from the overlying D aquifer.

In order to assist in the evaluation of the concerns identified above, PWCC commissioned the development of a regional groundwater flow model for the D aquifer and N aquifer systems (3D Model), to be used for predicting and assessing potential mining related hydrologic impacts. The specific objectives of the 3D Model, were as follows (PWCC, 1999):

- Construct an accurate depiction of the geologic framework (lithology, structure, stratigraphy) that controls the flow of water in the D- and N aquifer formations within Black Mesa Basin;
- Study the components of recharge, leakage, ET, and discharge in order to refine values and understand their influence on the hydrologic system;
- Utilize both current and historical data on pumping rates and water levels to guide model design and calibration;
- Calibrate to both non-pumping and pumping conditions;
- Use a parameter-estimation approach to minimize bias;
- Simulate effects of future pumping on flow system; and
- Compare future pumping effects between USGS 2D and 3D models.

The 3D Model advances the previous USGS model (Brown and Eychaner, 1988) used in the 1989 Black Mesa CHIA for the following reasons:

- It has a finer grid spacing, which allows for a more accurate simulation of pumping effects near both the mine and adjacent communities.
- It incorporates more recent data on water levels and withdraws.
- It examined a longer historical data period (beginning in 1956 rather than 1965).
- It evaluated various pumping scenarios to predict water levels to the year 2054, rather than to 2014.
- It provides a more detailed characterization and analysis of system recharge.
- It evaluates geologic structure that influences groundwater flow.
- It provides better model boundaries and increases the model extent.
- It provides a more complex definition of the hydrologic system, using additional model layers to simulate the D aquifer system.

OSMRE has independently reviewed the 3D Model and determined that the model satisfies the intended objectives outlined above, and it is the most comprehensive groundwater assessment tool for predictive impact evaluations necessary to address concerns related to PWCC water supply pumping.

The 3D Model accounts for the 70-percent reduction in PWCC pumping, which after December 31, 2005, and makes predictions for the future potentiometric surface of the N aquifer based on variables such as different pumping scenarios, recharge rates, and evapotranspiration rates. The 3D model was validated against measured data in 2005 and 2010 to verify that model simulated water levels are consistent with measured trends.

5.2.4.1 N aquifer Quantity

Groundwater flows from areas of high groundwater hydraulic head to areas of lower groundwater hydraulic head. The areas of high groundwater head occur near the predominant recharge areas to the northwest and southeast of the Black Mesa basin (Figure 27). The aquifer naturally discharges as springs and baseflow to the northeast and southwest of the Black Mesa basin at areas of lower groundwater elevation. Prior to N aquifer pumping, the steady-state flow system pattern had a hydrologic groundwater divide oriented northwest to southeast, and passing near the southwest corner of the Kayenta Complex (Figure 27). A groundwater divide is a non-structural boundary from which groundwater moves away from the divide in both directions, and flow does not occur across the boundary. The steady-state flow system was developed from the evaluation of all available water levels in the Black Mesa basin.

After evaluating the quality of available water level information, 344 wells and springs were retained for the development of a steady-state potentiometric surface, and used as pre-pumping calibration targets (Figure 26). In a calibrated steady-state model, simulated water levels should not significantly differ from measured water levels. The difference between the simulated and measured water levels is considered the residual error, and represents the difference between model derived hydraulic head and field measured target values. The procedure for calibrated steady-state model development is explained in greater detail in the 3D Model report (PWCC, 1999). The procedure provided in the calibration report documentation and the residual water level error after calibration have been reviewed by OSMRE and determined acceptable.

Groundwater pumped from the confined area of the N aquifer is released from aquifer storage, making it vital to understand the concept of aquifer storage. The N aquifer is approximately 2500 feet below ground surface at the Kayenta Complex. Due to significant depth, the N aquifer matrix is under a tremendous amount of stress from the weight of the overlying rock and water. The pressure of the water and the structural skeleton of the aquifer material together support the downward stresses induced by the weight of the overlying material. The difference between the downward stress and the water pressure is called the effective stress, that part of the downward stress that is supported by the aquifer matrix (structural skeleton). The water and the aquifer matrix itself respond to the applied effective stress by expanding and contracting.

For instance, water fills the void spaces of the Wingate Sandstone, Moenave Formation, Kayenta Formation, and the Navajo Sandstone forming the N aquifer. When the N aquifer is pumped, water pressure decreases due to a reduction in interstitial pore water pressure caused by the pumping well. Therefore, the water pressure that was initially countering the downward stresses is reduced, and the stress load borne by the aquifer matrix increases. Since the net pressure is less (original water pressure minus pumping induced pressure decline) when pumping occurs, water levels decline when compared to the original steady state condition. This pumping induced water level change between pre- and post-pumping is known as drawdown; and its areal extent known as the cone of depression. However, it is important to note that the apparent expansion and contraction of the water in the aquifer and the aquifer matrix itself are characterized by the change in total hydraulic head in a well. The total hydraulic head is reflected in the static water level found in the well bore and respond to changes in the hydrostatic (water) pressure. The water levels in the confined N aquifer reflect the hydrostatic pressure regime in the aquifer and are an indication of the net stresses exerted on the N aquifer.

Specific storage is defined as the volume of water that a unit volume of aquifer takes into or releases from storage under a unit change in hydraulic head under saturated aquifer conditions (Freeze and Cherry, 1979). As the cone of depression grows, a larger area of aquifer material is available to contribute water to the pumping well. Therefore, drawdown near the pumping center will occur quickly at first, with drawdown exponentially slowing as a greater volume of aquifer material is influenced. In the confined area of the N aquifer system for the Black Mesa basin, PWCC and community pumping has occurred from 1968 to present. The most recent USGS N aquifer monitoring reports that the hydrographs for all but one of the dedicated Black Mesa (BM) observation wells have shown consistent water level declines in the confined area since 1972 (Macy and Brown, 2011). Due to the generally constant pumping volume from 1969-2005, the rate of static water level decline has slowed in recent years as the cone of depression has encompassed a larger contributing area. The increase in the volume of aquifer influenced by pumping has allowed more water to be released from storage, thus slowing the rate of growth of the cone of depression.

5.2.4.1.1 N aquifer Quantity Monitoring Program

As PWCC and community pumping has continued in the Black Mesa region since 1968, the flow system has changed, and the system is no longer in steady-state equilibrium as water continues to come from aquifer storage in the confined N aquifer attributed to the decrease in N aquifer water pressure from pumping. The changes are monitored by the USGS using an areally extensive monitoring network consisting of approximately 37 wells in the confined and unconfined portions of the N aquifer (Figure 39). Of the 37 wells, 6 are dedicated for the sole purpose of monitoring water level changes, and are not pumped for any beneficial use. Wells that are periodically pumped may give a false representation of the drawdown in the regional aquifer system since small cones of depression develop at the pumping wells. Therefore, in an effort to get the best annual representation the regional aquifer system using available wells, the USGS will only collect and report a water level measurement after the well remains idle for an appropriate period of time. The idle, non-pumping, period will vary from location to location depending on the magnitude of pumping stress at the various community wells or remote windmills. If the recent pumping occurred at the location at the time of data collection, a drawdown value will not be reported since it will give a false representation of the regional aquifer drawdown.

Six monitored wells in the USGS monitoring program are not pumped, and identified as BM-1 through BM-6 (Figure 39). The BM-well series were installed in the early 1970's, and have a nearly complete non-equilibrium water level record. Monitoring wells BM-2, BM-3, BM-4, BM-5, and BM-6 are equipped with automated continuous recording devices that record a water level measurement every 15-minutes, and the data is posted to a USGS website every 4-hours (USGS, 2011).

The BM-well series are primarily completed in the Navajo Sandstone, and were specifically located and installed for the purpose of evaluating drawdown related to pumping of the N aquifer. Since the BM-well series are not pumped for water supply purposes, the water levels represent true N aquifer system drawdown. Therefore, the quality of water level data in the BM-well series is extremely high for OSMRE's regulatory purposes. OSMRE finds that the N aquifer ground water quantity monitoring program is currently sufficient for OSMRE to make the required evaluation for material damage potential in this CHIA.

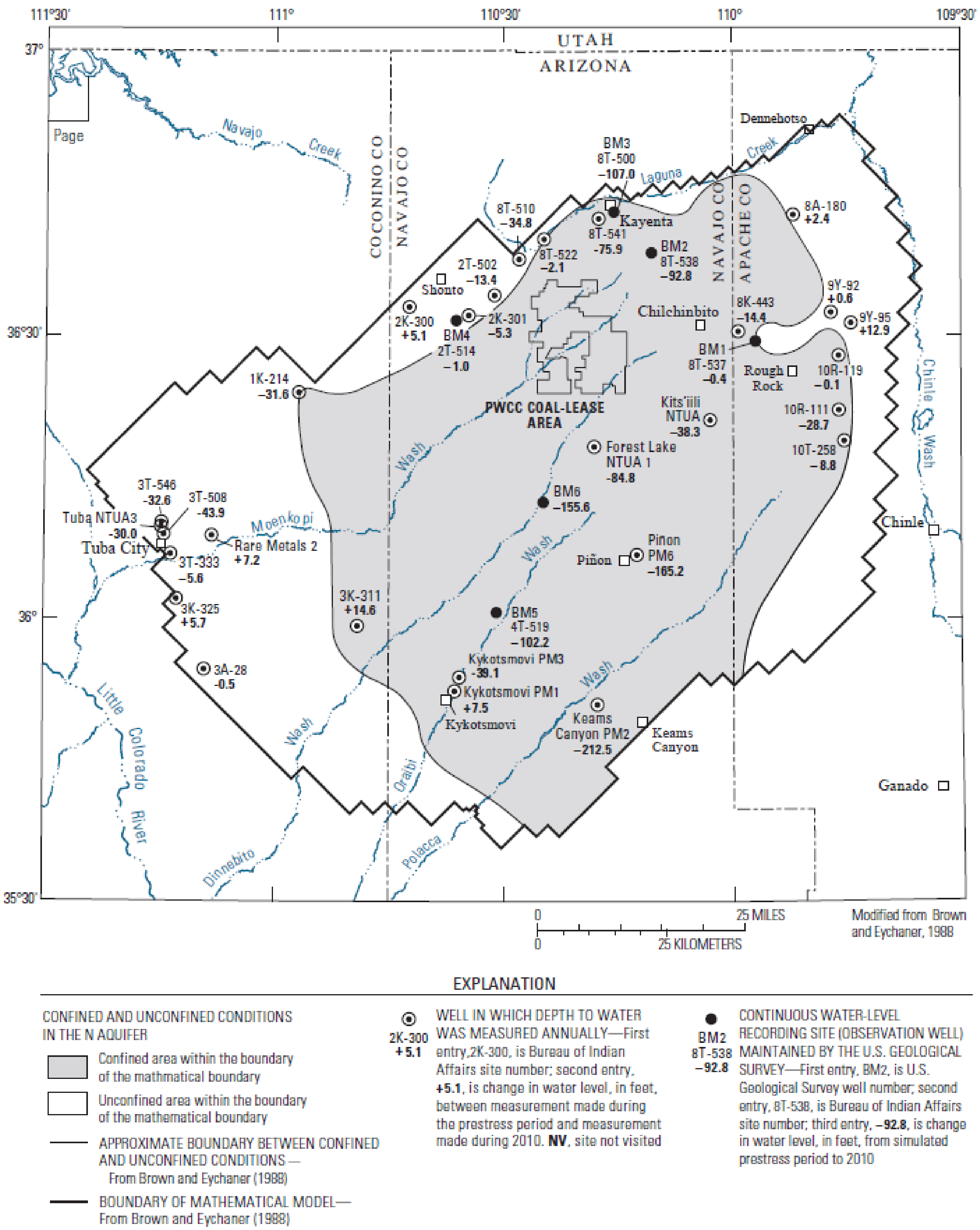


Figure 39: N aquifer water level changes from the pre-stress period to 2010 (Macy and Brown, 2011).

5.2.4.1.2 Transient Modeling

Changes in the regional groundwater system over time can be identified by using a numerical groundwater flow model to simulate known pumping rate stresses in the hydrologic system after calibration of steady-state conditions (i.e. baseline) and pumping conditions. Most notably, the extent and magnitude of N aquifer system drawdown can be reasonably simulated for the regional system. The simulation of changing drawdown over time is considered transient modeling. Similar to the steady-state simulation, the transient model simulates all the inflows and outflows to the hydrologic system through time, and uses various snapshots in time of the measured drawn down water levels as calibration targets.

A total of 47 wells were used for the transient non-equilibrium calibration targets. The high quality data and the spatial distribution of the BM-well series locations provided justification to weight the BM-well series data with a higher confidence compared to the other 41 transient calibration target locations. Specific information on the weighting factors for the drawdown residuals can be found in the 3D Model report (PWCC, 1999). Since the BM-well series have the most complete water level records, and were installed specifically for evaluating N aquifer drawdown, considerable effort was taken to numerically simulate the measured drawdown in the BM-wells while honoring the geologic model. After reviewing the calibrated transient model, OSMRE has determined that the calibrated model provides acceptable agreement with the measured water level changes. Figure 40 illustrates a comparison of measured water levels in the BM-6 with four calibrated 3D Model simulations for the dataset (through 1996) and more recently collected data (including the period after PWCC reduced their pumping at the end of 2005). It should be noted that OSMRE relies on the "High Evapotranspiration (ET), 100% Recharge" for predictive analysis, since that calibrated model most accurately matches measured water level conditions. The "High ET, 100% Recharge" is considered the base-case model. However, the results of all four calibrated model simulations are presented to illustrate the negligible to minor sensitivity to evapotranspiration and recharge.

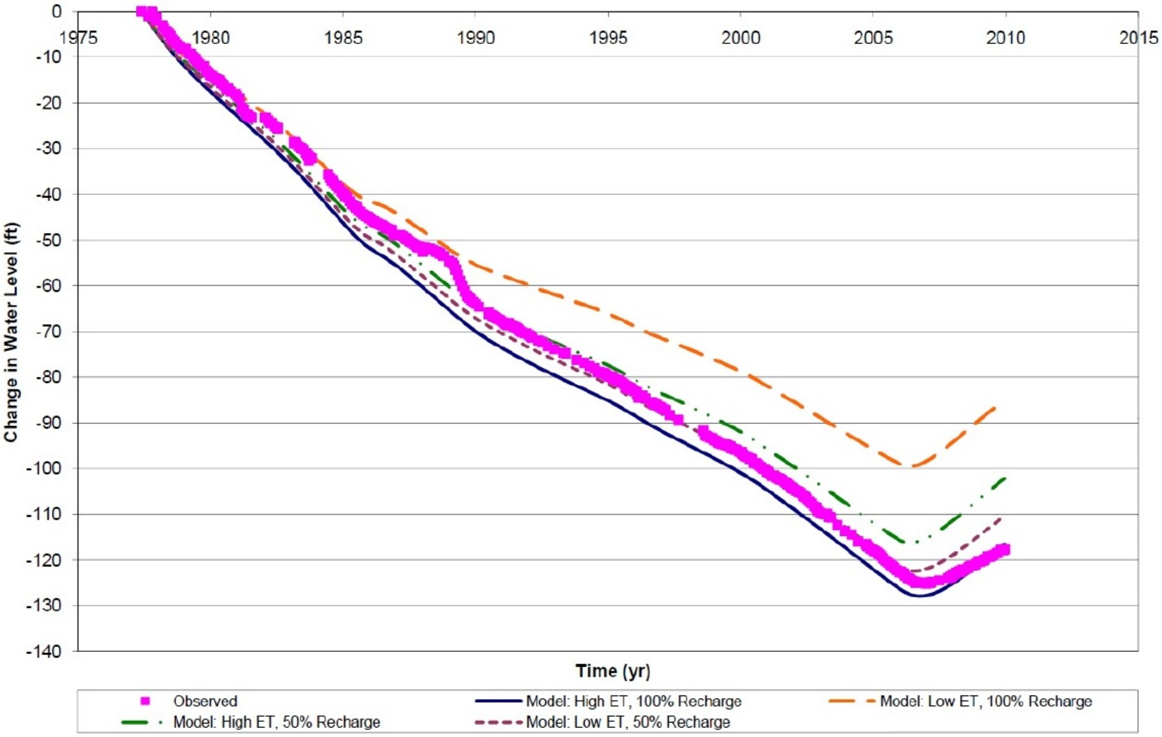


Figure 40: Simulated and Measured Drawdown at BM-6 (PWCC, v.11, ch.18, 2011).

In 2005, a supplemental report to the 3D Model further evaluated the sensitivity of model assumptions that may influence drawdown predictions, specifically N aquifer system thickness and aquifer structure. It also validated model predictions by comparing simulated and measured water levels for the BM wells through 2004 (PWCC, 2005). The model validation was completed again in 2010 using measured water level data through 2009, and results incorporated into the PWCC PHC (PWCC, v.11, ch.18, 2011). Aquifer thickness may influence transmissivity values, the amount of water held in storage, and ultimately water level measurements. The aquifer thickness in the confined area of the Navajo sandstone was divided by a factor of 2 to evaluate the sensitivity to aquifer thickness; however, hydraulic conductivity values had to be adjusted from the base case scenario (High ET, 100% Recharge) to adequately calibrate the new model to field measured water levels. The resultant calibrated model with reduced N aquifer system thickness provided similar agreement to the base-case 3D Model at the BM-series wells; however, simulated drawdown was lower at 5 of the 6 BM-wells compared to the base-case 3D Model. Therefore, although a calibrated model with thinner N aquifer system thickness is a reasonably good model of the N aquifer system, it is not as good at the base-case 3D Model.

The conceptual model for the base-case 3D Model also considered zones of lower hydraulic conductivity created by the deformation of rocks comprising the N aquifer along the Organ Rock and Comb Ridge monoclines north of the permit area. To test the sensitivity of the base-case model related to the effect of the lower hydraulic conductivity monocline zones, several additional calibrated models were developed. One additional calibrated model completely removed the monocline, and the other evaluated changes in hydraulic conductivity of the monocline zones related to measured water levels and drawdown. Removal of the low hydraulic conductivity monocline zones resulted in a calibrated model in good overall agreement between measured and simulated pre-pumping water levels, but the base-case 3D Model provides better overall agreement and is a better representation of the flow system and more accurately simulates the effects of PWCC pumping. Hydraulic conductivity of the monocline zones was also increased by two orders of magnitude using a separate calibrated model to evaluate if the increased hydraulic conductivity affects the predictions of PWCC pumping. The results indicate that the hydraulic conductivity can be increased in the monocline zones and yield similar simulated drawdown in the BM-wells compared to the base-case 3D Model (PWCC, 2005). However, increasing the hydraulic conductivity of the monocline may mask PWCC impacts from pumping near Kayenta and at the PWCC wellfield.

In summary, PWCC provided a numerical groundwater flow model of the Black Mesa basin for the D aquifer system and the N aquifer system; representing the D aquifer system as three hydrogeologic units, the N aquifer system as three hydrogeologic units, and separated by a low permeability confining unit. The model was successfully calibrated to simulate non-pumping equilibrium conditions (pre-1956), and then was successfully calibrated to simulate measured drawdown from 1956 through 1996. Once the transient groundwater model can adequately simulate drawdown when compared to measured drawdown while honoring the conceptual geologic model, the flow model is considered calibrated, and can be used for predictive simulations. Several sensitivity analyses verified that the base-case 3D Model most accurately simulates predictive drawdown effects from PWCC pumping while honoring the most reasonable conceptual geologic model.

The 3D Model, base-case scenario, will be used to evaluate concerns related to the PWCC pumping of the N aquifer. The N aquifer water quantity concerns to be evaluated for this CHIA are (1) impact to community N aquifer water supply wells, (2) impact to irrigation users in the Moenkopi area, (3) impact to N aquifer spring discharge, and (4) the potential for land subsidence.

5.2.4.1.3 N aquifer Impact Potential to Designated and Foreseeable Uses

Community Water Supply Wells

PWCC began pumping the N aquifer system to support mining operations at the Kayenta Complex in 1968 at 100 ac-ft/yr (Macy and Brown, 2011). By 1972, the annual pumping rate increased to 3,682 ac-ft. From 1972 through 2005, the average annual pumping rate was 3,983 ac-ft/yr, with the highest annual withdraw of 4,643 ac-ft occurring in 2002 (Macy and Brown, 2011). On January 1, 2006, the annual use of N aquifer decreased to an approximate rate of 1,400 ac-ft/yr.

Community pumping for municipal water supply also occurs in the confined N aquifer. In 1968, municipal community pumping in the confined N aquifer was 150 ac-ft (Macy and Brown, 2011). Municipal pumping rates steadily increased to 1,610 ac-ft of annual withdraw in the confined N aquifer in 2000, and averaged 1,409 ac-ft from 1998 - 2007 (Macy and Brown, 2011).

As described previously, groundwater pumping reduces pore water pressure. Since the net pressure is less (original water pressure minus pumping induced pressure decline) when pumping occurs, water levels have declined when compared to the original steady state condition. This pumping induced water level change between pre- and post-pumping is known as drawdown; and the areal extent of which is known as the cone of depression. It is the cone of depression in the confined N aquifer, represented by changes in pore water pressure, which has been raised as a concern by area residents. However, the saturated thickness of the confined N aquifer has remained unchanged, and the water resource remains available for the existing and foreseeable demands for municipal supply water.

As water is released from confined storage and the cone of depression grows, a larger area of aquifer material is available to contribute water to the pumping well. Therefore, drawdown near the pumping center will occur quickly at first, with drawdown exponentially slowing as a greater volume of aquifer material is influenced. Figure 41 illustrates the extent and magnitude of drawdown created by PWCC pumping from 1969 to 2005. Although the saturated thickness in the confined N aquifer has not changed, the drawdown contours represent a reduction in water pressure. Since are 70-percent reduction in PWCC pumping began on January 1, 2006, Figure 41 illustrates the approximate magnitude and extent of PWCC pumping influence on the N aquifer. USGS monitoring of the BM-well series, provides field measured confirmation for the simulated drawdown. The BM-well series had the following drawdown on December 31, 2005: BM-2 (85-feet), BM-3 (100-feet), BM-4 (0-feet), BM-5 (90-feet), and BM-6 (155-feet). Similar to measuring drawdown in the confined N aquifer, water level increases are expected in response to the reduced pumping rate at the PWCC wellfield. Since the drawdown measured at the BM-wells is a combination of both PWCC pumping and community pumping, complete recovery is not expected due to continued community and PWCC pumping.

PWCC wellfield pumping does not preclude the ability to develop the water resource for municipal water supply. However, the lowering of the potentiometric surface causes an increase in electrical power costs to lift the water to surface. The PWCC 3D Model provides the ability to separate the drawdown associated the municipal pumping and PWCC. Table 11 provides a snapshot of drawdown attributable to PWCC pumping at calendar year 1970, 1980, 1990, 2000, 2005, and 2010 for community water supply wells in the confined N aquifer. Table 12 provides a snapshot of annual pumping volume for community wells in the same calendar years.

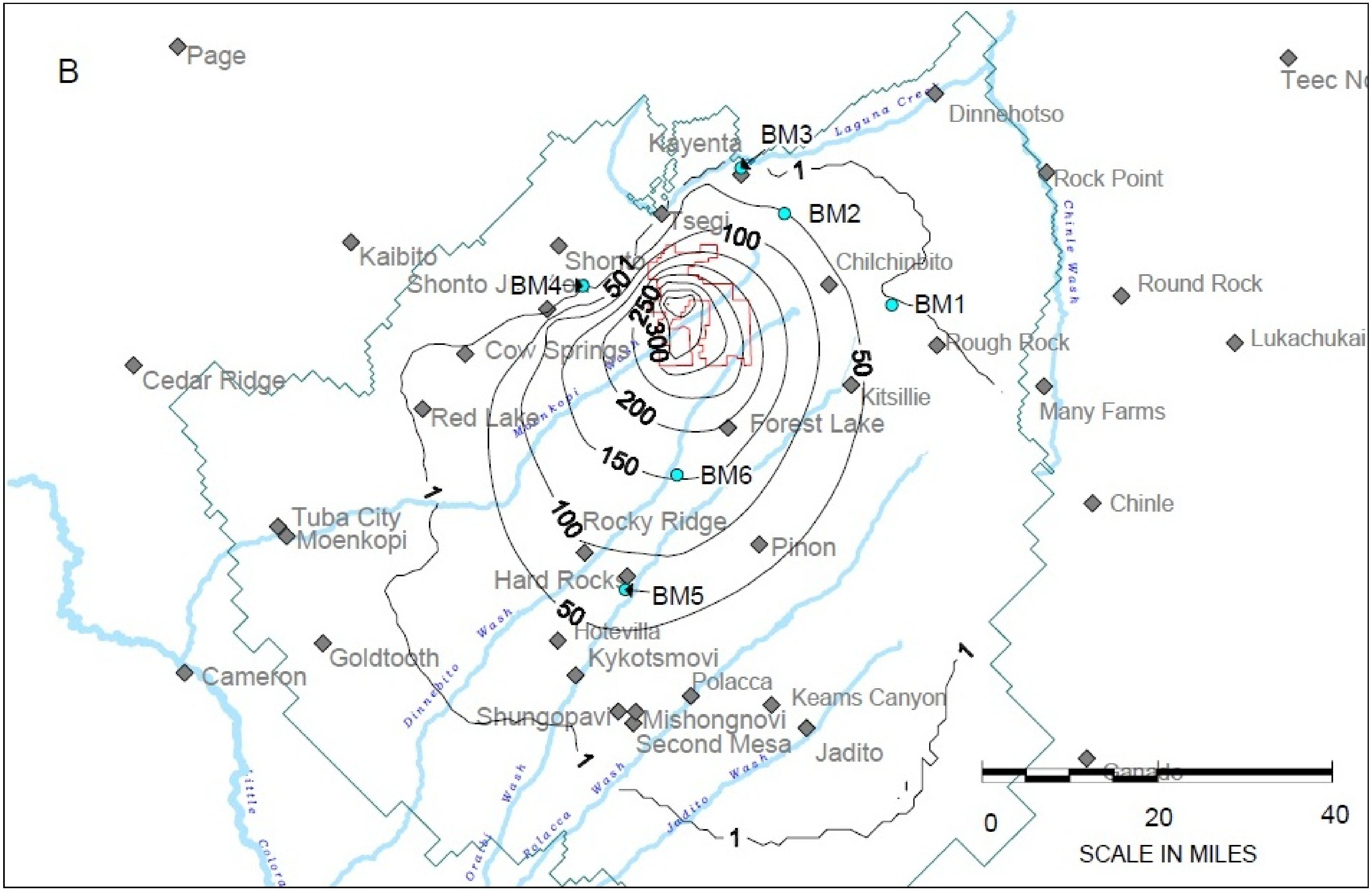
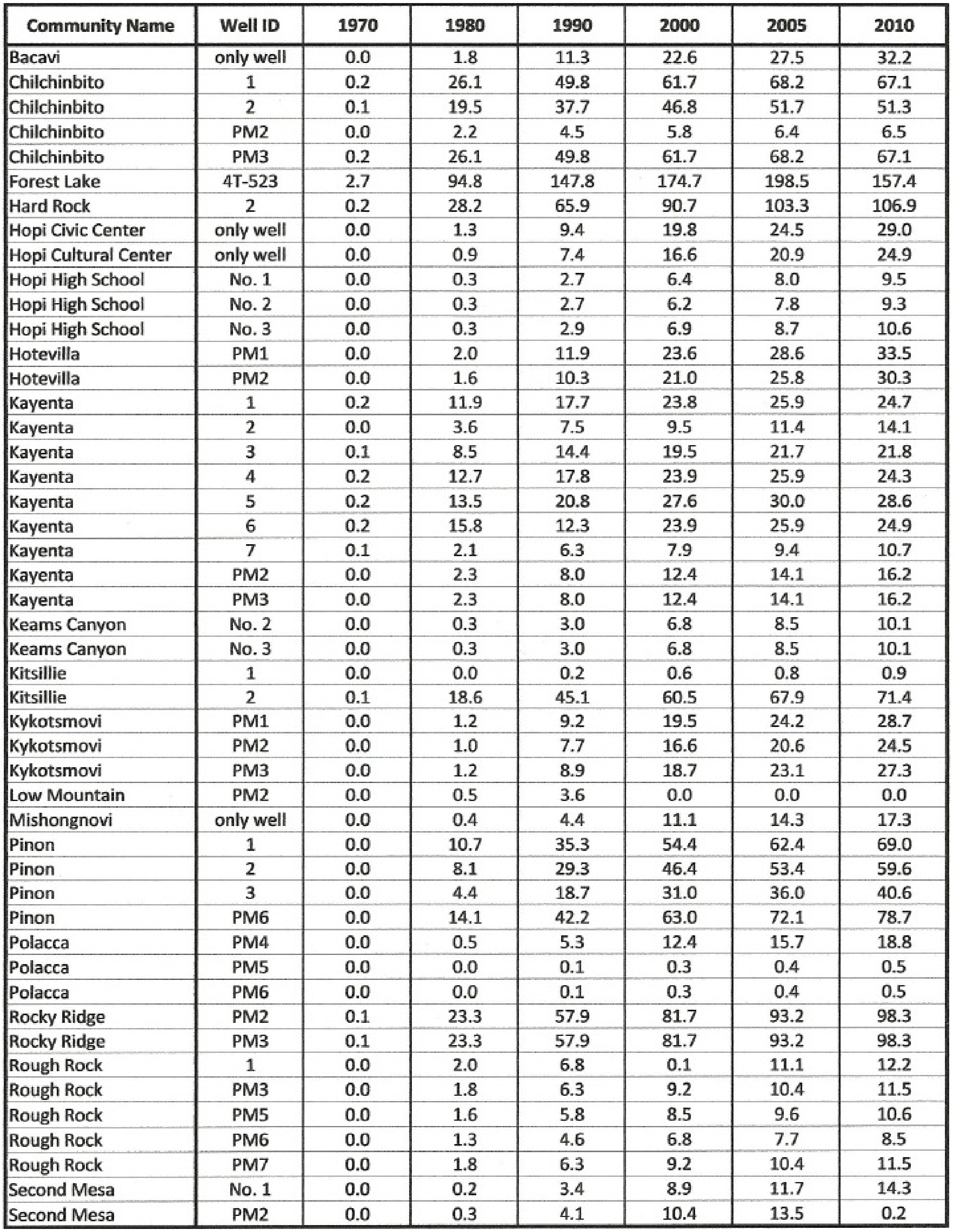
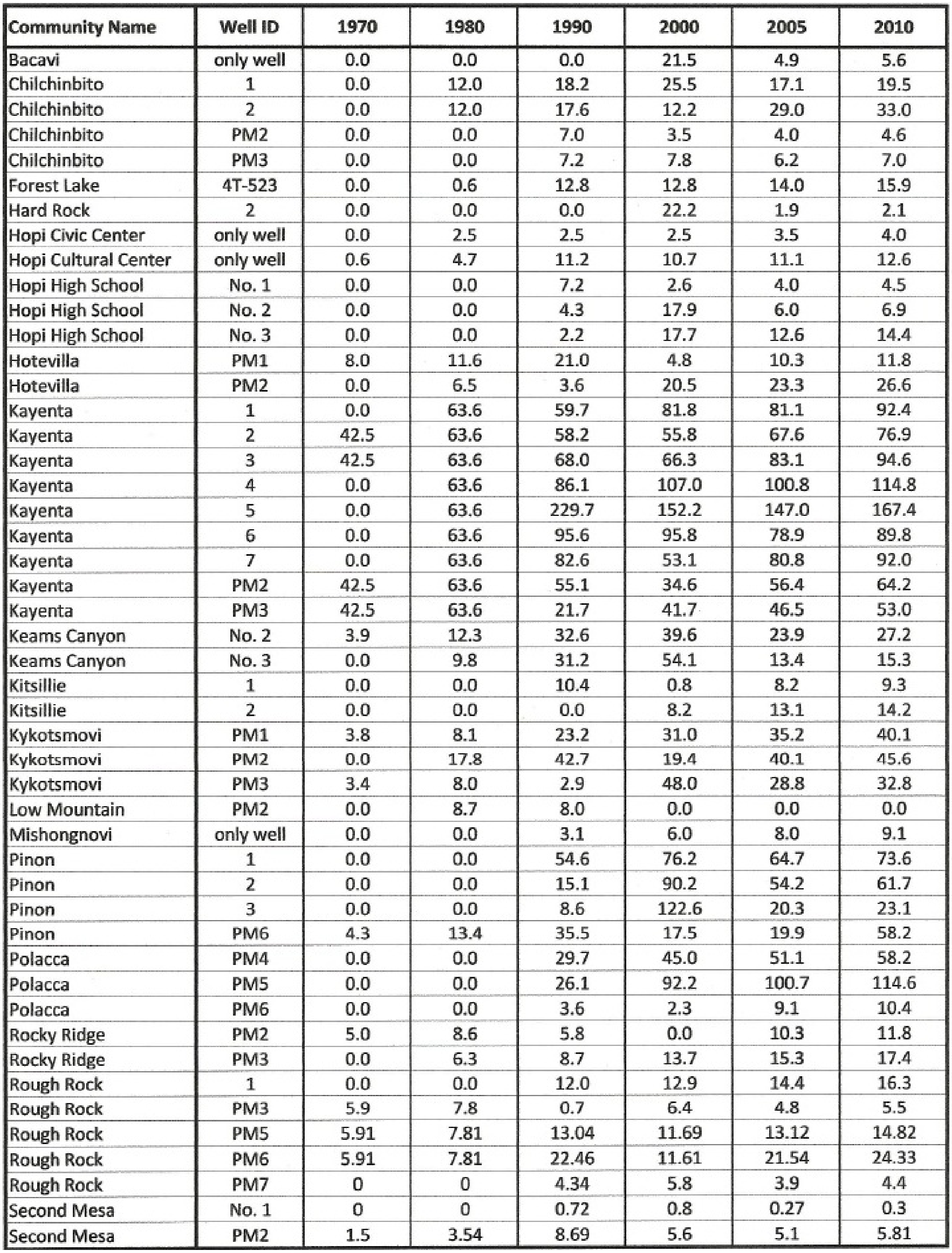


Figure 41: Simulated Drawdown in the N aquifer in 2005; Only PWCC Pumping (PWCC, v.11, ch.18, 2011).



Community Name	Well ID	1970	1980	1990	2000	2005	2010
Bacavi	only well	0.0	1.8	11.3	22.6	27.5	32.2
Chilchinbito	1	0.2	26.1	49.8	61.7	68.2	67.1
Chilchinbito	2	0.1	19.5	37.7	46.8	51.7	51.3
Chilchinbito	PM2	0.0	2.2	4.5	5.8	6.4	6.5
Chilchinbito	PM3	0.2	26.1	49.8	61.7	68.2	67.1
Forest Lake	4T-523	2.7	94.8	147.8	174.7	198.5	157.4
Hard Rock	2	0.2	28.2	65.9	90.7	103.3	106.9
Hopi Civic Center	only well	0.0	1.3	9.4	19.8	24.5	29.0
Hopi Cultural Center	only well	0.0	0.9	7.4	16.6	20.9	24.9
Hopi High School	No. 1	0.0	0.3	2.7	6.4	8.0	9.5
Hopi High School	No. 2	0.0	0.3	2.7	6.2	7.8	9.3
Hopi High School	No. 3	0.0	0.3	2.9	6.9	8.7	10.6
Hotevilla	PM1	0.0	2.0	11.9	23.6	28.6	33.5
Hotevilla	PM2	0.0	1.6	10.3	21.0	25.8	30.3
Kayenta	1	0.2	11.9	17.7	23.8	25.9	24.7
Kayenta	2	0.0	3.6	7.5	9.5	11.4	14.1
Kayenta	3	0.1	8.5	14.4	19.5	21.7	21.8
Kayenta	4	0.2	12.7	17.8	23.9	25.9	24.3
Kayenta	5	0.2	13.5	20.8	27.6	30.0	28.6
Kayenta	6	0.2	15.8	12.3	23.9	25.9	24.9
Kayenta	7	0.1	2.1	6.3	7.9	9.4	10.7
Kayenta	PM2	0.0	2.3	8.0	12.4	14.1	16.2
Kayenta	PM3	0.0	2.3	8.0	12.4	14.1	16.2
Keams Canyon	No. 2	0.0	0.3	3.0	6.8	8.5	10.1
Keams Canyon	No. 3	0.0	0.3	3.0	6.8	8.5	10.1
Kitsillie	1	0.0	0.0	0.2	0.6	0.8	0.9
Kitsillie	2	0.1	18.6	45.1	60.5	67.9	71.4
Kykotsmovi	PM1	0.0	1.2	9.2	19.5	24.2	28.7
Kykotsmovi	PM2	0.0	1.0	7.7	16.6	20.6	24.5
Kykotsmovi	PM3	0.0	1.2	8.9	18.7	23.1	27.3
Low Mountain	PM2	0.0	0.5	3.6	0.0	0.0	0.0
Mishongnovi	only well	0.0	0.4	4.4	11.1	14.3	17.3
Pinon	1	0.0	10.7	35.3	54.4	62.4	69.0
Pinon	2	0.0	8.1	29.3	46.4	53.4	59.6
Pinon	3	0.0	4.4	18.7	31.0	36.0	40.6
Pinon	PM6	0.0	14.1	42.2	63.0	72.1	78.7
Polacca	PM4	0.0	0.5	5.3	12.4	15.7	18.8
Polacca	PM5	0.0	0.0	0.1	0.3	0.4	0.5
Polacca	PM6	0.0	0.0	0.1	0.3	0.4	0.5
Rocky Ridge	PM2	0.1	23.3	57.9	81.7	93.2	98.3
Rocky Ridge	PM3	0.1	23.3	57.9	81.7	93.2	98.3
Rough Rock	1	0.0	2.0	6.8	0.1	11.1	12.2
Rough Rock	PM3	0.0	1.8	6.3	9.2	10.4	11.5
Rough Rock	PM5	0.0	1.6	5.8	8.5	9.6	10.6
Rough Rock	PM6	0.0	1.3	4.6	6.8	7.7	8.5
Rough Rock	PM7	0.0	1.8	6.3	9.2	10.4	11.5
Second Mesa	No. 1	0.0	0.2	3.4	8.9	11.7	14.3
Second Mesa	PM2	0.0	0.3	4.1	10.4	13.5	0.2

Table 11. PWCC Portion of Total Simulated Drawdown (feet) (PWCC, v.11, ch.18, 2011).



Community Name	Well ID	1970	1980	1990	2000	2005	2010
Bacavi	only well	0.0	0.0	0.0	21.5	4.9	5.6
Chilchinbito	1	0.0	12.0	18.2	25.5	17.1	19.5
Chilchinbito	2	0.0	12.0	17.6	12.2	29.0	33.0
Chilchinbito	PM2	0.0	0.0	7.0	3.5	4.0	4.6
Chilchinbito	PM3	0.0	0.0	7.2	7.8	6.2	7.0
Forest Lake	4T-523	0.0	0.6	12.8	12.8	14.0	15.9
Hard Rock	2	0.0	0.0	0.0	22.2	1.9	2.1
Hopi Civic Center	only well	0.0	2.5	2.5	2.5	3.5	4.0
Hopi Cultural Center	only well	0.6	4.7	11.2	10.7	11.1	12.6
Hopi High School	No. 1	0.0	0.0	7.2	2.6	4.0	4.5
Hopi High School	No. 2	0.0	0.0	4.3	17.9	6.0	6.9
Hopi High School	No. 3	0.0	0.0	2.2	17.7	12.6	14.4
Hotevilla	PM1	8.0	11.6	21.0	4.8	10.3	11.8
Hotevilla	PM2	0.0	6.5	3.6	20.5	23.3	26.6
Kayenta	1	0.0	63.6	59.7	81.8	81.1	92.4
Kayenta	2	42.5	63.6	58.2	55.8	67.6	76.9
Kayenta	3	42.5	63.6	68.0	66.3	83.1	94.6
Kayenta	4	0.0	63.6	86.1	107.0	100.8	114.8
Kayenta	5	0.0	63.6	229.7	152.2	147.0	167.4
Kayenta	6	0.0	63.6	95.6	95.8	78.9	89.8
Kayenta	7	0.0	63.6	82.6	53.1	80.8	92.0
Kayenta	PM2	42.5	63.6	55.1	34.6	56.4	64.2
Kayenta	PM3	42.5	63.6	21.7	41.7	46.5	53.0
Keams Canyon	No. 2	3.9	12.3	32.6	39.6	23.9	27.2
Keams Canyon	No. 3	0.0	9.8	31.2	54.1	13.4	15.3
Kitsillie	1	0.0	0.0	10.4	0.8	8.2	9.3
Kitsillie	2	0.0	0.0	0.0	8.2	13.1	14.2
Kykotsmovi	PM1	3.8	8.1	23.2	31.0	35.2	40.1
Kykotsmovi	PM2	0.0	17.8	42.7	19.4	40.1	45.6
Kykotsmovi	PM3	3.4	8.0	2.9	48.0	28.8	32.8
Low Mountain	PM2	0.0	8.7	8.0	0.0	0.0	0.0
Mishongnovi	only well	0.0	0.0	3.1	6.0	8.0	9.1
Pinon	1	0.0	0.0	54.6	76.2	64.7	73.6
Pinon	2	0.0	0.0	15.1	90.2	54.2	61.7
Pinon	3	0.0	0.0	8.6	122.6	20.3	23.1
Pinon	PM6	4.3	13.4	35.5	17.5	19.9	58.2
Polacca	PM4	0.0	0.0	29.7	45.0	51.1	58.2
Polacca	PM5	0.0	0.0	26.1	92.2	100.7	114.6
Polacca	PM6	0.0	0.0	3.6	2.3	9.1	10.4
Rocky Ridge	PM2	5.0	8.6	5.8	0.0	10.3	11.8
Rocky Ridge	PM3	0.0	6.3	8.7	13.7	15.3	17.4
Rough Rock	1	0.0	0.0	12.0	12.9	14.4	16.3
Rough Rock	PM3	5.9	7.8	0.7	6.4	4.8	5.5
Rough Rock	PM5	5.91	7.81	13.04	11.69	13.12	14.82
Rough Rock	PM6	5.91	7.81	22.46	11.61	21.54	24.33
Rough Rock	PM7	0	0	4.34	5.8	3.9	4.4
Second Mesa	No. 1	0	0	0.72	0.8	0.27	0.3
Second Mesa	PM2	1.5	3.54	8.69	5.6	5.1	5.81

Table 12. Annual Pumping at Community Supply Wells (ac-ft) (PWCC, v.11, ch.18, 2011).

Using an assumed power cost value of $0.074 Kw/hr, annual pumped volume, and drawdown attributable to PWCC pumping, the increase in cost to operate a well in the confined N aquifer can be calculated using the following equation (Campbell and Lehr, 1974):

$$Cost / Hour = \frac{(pumping\,rate\ (gpm))\,x\,(Lift + friction\ (ft))\ x\ (0.746)\,x\,(power\ (K/kW - hr))}{(3960)\ x\ (pump\,efficiency)\ x\ (motor\,efficiency)}$$

Where:

Friction = 0
Pump Efficiency = 0.75 (75%)
Motor Efficiency = 0.90 (90%)
Power Costs = $0.074 per kW-hr

There is a cost for lifting the water, and a separate cost associated with the pressure loss caused by friction in the pump column. The following discussion only addresses the cost for lifting the water, as that cost is a function of the depth to water, and thus the drawdown caused by pumping at the Kayenta Complex. The term “friction” in the above equation is set to zero, so that the calculated cost only reflects the cost to lift the water. Using the above equation and assumptions, coupled with the annual pumping rate and drawdown information, an assessment of PWCC impacts on municipal well locations can be completed. Consistent with the Kayenta Mine EA (OSMRE, 2011c), percent increase in pumping costs attributable to PWCC pumping will be used for impact assessment criteria. Percent increase in pumping cost at community supply wells attributable to N aquifer pumping at the Kayenta Complex are provided in Table 13. The impacts are considered moderate if there is a 26 – 50 percent increase in pumping costs. Therefore, OSMRE will establish the material damage threshold as a 26-percent increase in pumping cost. The impacts are considered major if increases in pumping costs are greater than 50-percent, and considered the material damage limit.

Forest Lake is the closest community in the confined N aquifer relative the PWCC pumping center. In 2005, drawdown attributable to PWCC pumping was 198.5 feet (Table 11). In 2010, the drawdown at Forest Lake attributable to PWCC pumping is 157.4 feet. The water level rise reflects the influence of PWCC’s 70-percent reduction in N aquifer pumping at the end of 2005. Percent increase in pumping costs at Forest Lake attributable to PWCC is 18.1% in 2005, and 14.4% in 2010.

Pinon is the community in the confined N aquifer with the high annual volume of pumping. Review of Pinon well PM6 indicates drawdown attributable to PWCC pumping in 2005 of 72.1 feet, and 78.7 feet in 2010 (Table 11). Water level recovery at Pinon well PM6 due to reduced PWCC pumping is simulated to begin in 2011, and is delayed compared to Forest Lake due to proximity to the PWCC pumping center (PWCC, v.11, ch.18, 2011). Percent increase in pumping costs at Pinon PM6 attributable to PWCC pumping is 9.7% in 2005, and 10.6% in 2010.

Similar to the community of Pinon, the community of Rocky Ridge is about the same distance from the PWCC pumping center, and the maximum drawdown attributed to PWCC pumping occurs in 2010. Simulated drawdown attributable to PWCC pumping at Rocky Ridge well PM2 is 93.2 feet in 2005, and 98.3 feet in 2010 (Table 11). Percent increase in pumping costs at Rocky Ridge well PM6 is 20.0% in 2005, and 21.1% in 2010 (Table 13). Rocky Ridge represents the location with highest percent increase attributable to PWCC pumping, and is below the material damage threshold of 26%.

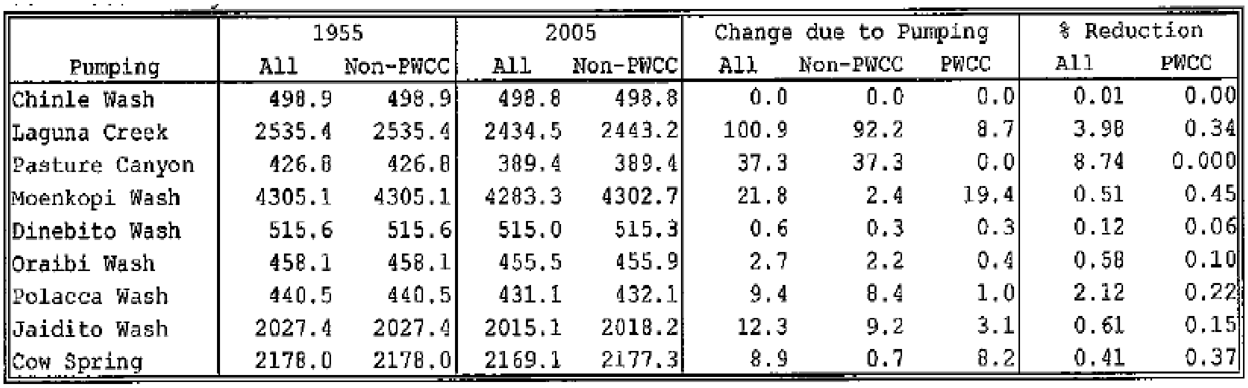
Community Name	Well ID	1970	1980	1990	2000	2005	2010
Bacavi	only well	0.0	0.2	1.2	2.5	3.0	3.6
Chilchinbito	1	0.0	5.7	10.9	13.5	14.9	14.6
Chilchinbito	2	0.0	7.1	13.7	17.1	18.8	18.7
Chilchinbito	PM2	0.0	0.6	1.1	1.4	1.6	1.6
Chilchinbito	PM3	0.0	6.5	12.3	15.2	16.8	16.6
Forest Lake	4T-523	0.2	8.6	13.5	15.9	18.1	14.4
Hard Rock	2	0.0	4.6	10.7	14.7	16.7	17.3
Hopi Civic Center	only well	0.0	0.3	2.5	5.2	6.4	7.5
Hopi Cultural Center	only well	0.0	0.1	0.9	1.9	2.4	2.9
Hopi High School	No. 1	0.0	0.1	0.6	1.4	1.7	2.0
Hopi High School	No. 2	0.0	0.1	0.6	1.5	1.8	2.2
Hopi High School	No. 3	0.0	0.1	0.7	1.7	2.1	2.6
Hotevilla	PM1	0.0	0.2	1.3	2.5	3.0	3.5
Hotevilla	PM2	0.0	0.2	1.1	2.2	2.8	3.2
Kayenta	1	0.1	5.9	8.7	11.7	12.7	12.1
Kayenta	2	0.0	0.7	1.6	2.0	2.4	2.9
Kayenta	3	0.1	4.9	8.4	11.4	12.6	12.7
Kayenta	4	0.1	6.2	8.6	11.6	12.5	11.8
Kayenta	5	0.1	6.0	9.2	12.3	13.3	12.7
Kayenta	6	0.1	10.0	7.8	15.1	16.4	15.7
Kayenta	7	0.0	1.2	3.5	4.4	5.3	5.9
Kayenta	PM2	0.0	1.0	3.5	5.4	6.1	7.1
Kayenta	PM3	0.0	1.0	3.5	5.4	6.1	7.1
Keams Canyon	No. 2	0.0	0.1	1.0	2.3	2.9	3.4
Keams Canyon	No. 3	0.0	0.1	1.0	2.3	2.9	3.4
Kitsillie	1	0.0	0.0	0.0	0.0	0.1	0.1
Kitsillie	2	0.0	1.4	3.5	4.7	5.2	5.5
Kykotsmovi	PM1	0.0	0.6	4.2	8.8	11.0	13.1
Kykotsmovi	PM2	0.0	0.5	3.5	7.5	9.4	11.1
Kykotsmovi	PM3	0.0	0.6	4.2	8.9	11.0	13.0
Low Mountain	PM2	0.0	0.1	0.7	0.0	0.0	0.0
Mishongnovi	only well	0.0	0.0	0.6	1.4	1.8	2.2
Pinon	1	0.0	1.4	4.7	7.3	8.4	9.3
Pinon	2	0.0	1.1	3.9	6.2	7.2	8.0
Pinon	3	0.0	0.6	2.5	4.2	4.8	5.5
Pinon	PM6	0.0	1.9	5.7	8.5	9.7	10.6
Polacca	PM4	0.0	0.3	3.1	7.3	9.2	11.0
Polacca	PM5	0.0	0.0	0.1	0.2	0.2	0.3
Polacca	PM6	0.0	0.0	0.1	0.2	0.2	0.3
Rocky Ridge	PM2	0.0	5.0	12.4	17.5	20.0	21.1
Rocky Ridge	PM3	0.0	5.0	12.4	17.5	20.0	21.1
Rough Rock	1	0.0	0.3	1.0	0.0	1.6	1.7
Rough Rock	PM3	0.0	0.3	0.9	1.3	1.5	1.6
Rough Rock	PM5	0.0	0.5	1.9	2.8	3.2	3.5
Rough Rock	PM6	0.0	0.2	0.6	1.0	1.1	1.2
Rough Rock	PM7	0.0	0.3	0.9	1.3	1.4	1.6
Second Mesa	No. 1	0.0	0.1	1.2	3.2	4.2	5.1
Second Mesa	PM2	0.0	0.1	1.1	2.8	3.6	0.0

Table 13. Percent Lift Cost Increase Attributable to PWCC Pumping at Community Wells.

N aquifer Baseflow

Baseflow represents groundwater discharge to surface water that has seeped into a stream bed. Baseflow occurs in unconfined conditions, and the discharge rate is dependent on the water table elevation height in relation to surface water elevation in the receiving streambed. The N aquifer water level elevations adjacent to the various washes where the exposed N aquifer is unconfined are typically higher than the surface water elevations in the various washes, allowing for baseflow discharge to occur. In the N aquifer CIA, baseflow from the N aquifer occurs at Chinle Wash, Laguna Creek, Pasture Canyon, Moenkopi Wash, Dinnebito Wash, Oraibi Wash, Polacca Wash, Jadito Wash, and Cow Springs; there are areas where surface stream activity has eroded through the overlying geologic units, exposing the N aquifer in the various washes.

Using the 3D Model, impacts to baseflow discharge at the above listed washes can be assessed. Table 14 presents the discharge reductions from pre-pumping conditions in 1955. The discharge reductions to the washes attributed to PWCC pumping, community pumping, and all pumping are presented for the year 2005. Washes projected to have the highest reduction in baseflow in 2005 due to N aquifer pumping include Laguna Creek, Pasture Canyon, and Polacca Wash. However, the flow reduction for the three washes with highest simulated reduction in baseflow is largely attributed to community N aquifer pumping, not PWCC pumping. Currently, PWCC pumping has not caused more than 0.5% reduction in baseflow to any of the washes receiving discharge from the N aquifer.



	1955		2005		Change due to Pumping			% Reduction	
Pumping	All	Non-PWCC	All	Non-PWCC	All	Non-PWCC	PWCC	All	PWCC
Chinle Wash	498.9	498.9	498.8	498.8	0.0	0.0	0.0	0.01	0.00
Laguna Creek	2535.4	2535.4	2434.5	2443.2	100.9	92.2	8.7	3.98	0.34
Pasture Canyon	426.8	426.8	389.4	389.4	37.3	37.3	0.0	8.74	0.000
Moenkopi Wash	4305.1	4305.1	4283.3	4302.7	21.8	2.4	19.4	0.51	0.45
Dinebito Wash	515.6	515.6	515.0	515.3	0.6	0.3	0.3	0.12	0.06
Oraibi Wash	458.1	458.1	455.5	455.9	2.7	2.2	0.4	0.58	0.10
Polacca Wash	440.5	440.5	431.1	432.1	9.4	8.4	1.0	2.12	0.22
Jaidito Wash	2027.4	2027.4	2015.1	2018.2	12.3	9.2	3.1	0.61	0.15
Cow Spring	2178.0	2178.0	2169.1	2177.3	8.9	0.7	8.2	0.41	0.37

Note: All Discharge Rates in acre-feet per yer.

Table 14: Effects of Pumping on Simulated Discharge to Streams: 1955–2005 (PWCC, v.11, ch.18, 2011)

Moenkopi Wash is the only wash potentially impacted by PWCC pumping in the Black Mesa area that relies on N aquifer baseflow water for a designated use. Hopi and Navajo farmers in the Moenkopi area may pump water from Moenkopi Wash alluvium to irrigate crops. Since baseflow provides a constant source of water to saturate the alluvium, reduction in Moenkopi baseflow attributed to PWCC pumping is a concern. However, as presented in Table 14, Moenkopi baseflow reductions attributed to PWCC pumping do not exceed 1% of the total baseflow.

Consistent with the Kayenta Mine EA (OSMRE, 2011c), simulated percent reduction in baseflow discharge attributable to PWCC pumping will be used for impact assessment criteria. The impacts are considered moderate if there is a 21 to 30-percent simulated reduction in groundwater discharge. Therefore, OSMRE will establish the material damage threshold as a 21-percent simulated reduction in groundwater discharge. The impacts are considered major if simulated reduction in groundwater discharge is greater than 30-percent. The 30-percent reduction will be considered the material damage limit.

N aquifer Spring Discharge

The N aquifer system is regionally continuous throughout the groundwater CIA in the Black Mesa Basin. The N aquifer system is hydraulically confined in the interior of the Black Mesa Basin and becomes unconfined around the basin where the hydrologic formations are exposed at the surface. Similar to baseflow, the discharge rate is dependent on the water table elevation height in relation to surface water elevation in the receiving channel. The N aquifer water level elevations where the exposed N aquifer is unconfined are typically higher than the elevations of the adjacent downcut channels and formation outcrop areas, allowing for spring discharge to occur and formation water to seep at the formation outcrop areas.

Springs and seeps may emanate from the N aquifer formations along the confined—unconfined boundary. The Hopi communites at the southern extent of Black Mesa were largely settled due to their proximity to springs and seeps. However, due to its stratigraphic position above the N aquifer system, springs and seeps from the D aquifer system discharge near the Hopi communites, and the N aquifer system discharges as baseflow approximately 5-10 miles south of the Hopi communites where the washes downcut through the N aquifer formations. Springs and seeps also emanate on the western edge of Black Mesa at and near the communities of Moenkopi and Tuba City. Area residents are concerned about four specific springs and seeps in the Moenkopi and Tuba City area related to PWCC pumping, although it is acknowledged that more than four springs exist in this area. The four springs are known as Pasture Canyon Spring, Kerley Valley Spring, Red Point Outcrop Spring, and the Moenkopi School Spring. The subject of this impact assessment is whether PWCC pumping at Kayenta Complex will significantly and measurably impact spring discharge and the associated cultural and irrigation water uses.

Figure 41 illustrates the cone of depression for PWCC pumping at Kayenta Complex from 1956 through 2005. Figure 41 illustrates that the effects of PWCC pumping do not propagate out to the unconfined N aquifer in the Tuba City and Moenkopi area. Although beyond the scope of this assessment, it appears that local pumping in this area will impact spring flow and baseflow based on the proximity of springs to the local pumping areas. In 2009, Tuba City pumped 962.3 ac-ft, and Moenkopi pumped 79.6 ac-ft from the unconfined N aquifer (Figure 10). The lack of potential impact in the Tuba City area from PWCC pumping is due to differences in the type of aquifer system at the PWCC pumping center compared to the Tuba City pumping center. Both the Tuba City and PWCC pumping centers withdraw water from the N aquifer; however, the N aquifer is unconfined at Tuba City and confined at the PWCC wellfield.

Pumped water comes from aquifer storage. In a confined setting, aquifer storage is small (0.005 – 0.00005) compared to larger values (0.01 – 0.30) in an unconfined setting (Freeze and Cherry, 1979). Since the values are small in a confined setting, a larger area is influenced (represented as drawdown or changes in pressure head) to accommodate the water withdraw demand. Although the pressure head component of water level elevation changes, the saturated thickness remains unchanged in a confined aquifer. In an unconfined setting, the saturated thickness of the aquifer changes in response to pumping; therefore, the values of water coming from storage are much higher. As modeled and measured, PWCC effects of pumping the confined area of the N aquifer propagate out to the confined-unconfined boundary, where the hydrologic characteristics change. The fact that the hydrologic characteristic change from confined to unconfined is why measurable effects of PWCC pumping stop outward propagation near this boundary. Conversely, the hydrologic characteristics of pumping an unconfined system at Tuba City is why the effects of drawdown do not propagate very far from Tuba City even though a significant volume of water is withdrawn annually.

Even though the effects of Tuba City pumping do not extend very far from the Tuba City pumping, the N aquifer springs of concern are in close proximity to the Tuba City pumping, causing the spring flows in the area to potentially be impacted. For instance, the 3D Model predicts zero reduction in flow to Pasture

Canyon attributed to PWCC pumping, yet approximately a 9% reduction in Pasture Canyon discharge in 2005 attributed to local pumping (Table 14).

Due to the current N aquifer water withdraws at Tuba City, and the Village of Moenkopi to a lesser extent, which are near the N aquifer springs of concern, reductions in flow discharge are likely to occur if current community pumping trends continue. However, PWCC pumping of the N aquifer will not have impact on N aquifer springs of concern for religious and irrigation use in the area. Burro Spring is the only location on the confined—unconfined boundary with a historical monitoring record. Burro Spring discharge is statistically variable from year to year, but consistently flowing at less than a gallon a minute. Community pumping of the N aquifer near Burro Spring puts the sustainability of Burro Spring flow at risk. No additional N aquifer springs have been identified for monitoring as part of the USGS cooperative effort concerning the monitoring of N aquifer hydrologic resources. Additionally, a new delineation of the confined N aquifer extent has not been proposed during the USGS Cooperators annual meetings. The Black Mesa water resource monitoring program was established in 1971 by the USGS in cooperation with the Arizona Department of Water Resources. In 1983, the BIA entered into the cooperative effort. Overall, the persistence of this low flow spring at the confined—unconfined N aquifer boundary provides support that water quantity impacts have been minimized in this sensitive area.

Land Subsidence

There are three mechanisms that contribute to the compressibility of a porous medium. Compressibility can be achieved by: (1) compression of water, (2) compression of individual sand grains, and (3) by rearrangement of sand grains into a more closely packed configuration (Freeze and Cherry, 1979). The compressibility of individual well-sorted quartz sand grains is considered negligible, but the rearrangement of sand grains can often be the cause of land subsidence from pumping. Pore water pressure typically supports the packing arrangement of the aquifer material in unconsolidated basin fills. Therefore, when pore water pressure decreases in unconsolidated basin fills, the packing arrangement may change to a more closely packed arrangement. The closer arrangement may result in a decrease in aquifer thickness, which translates to the surface as a depression, or subsidence.

When the N aquifer is pumped, the pore water pressure decreases, and water comes from aquifer storage. Theoretically, the opportunity exists for the N aquifer sand grains to rearrange and cause subsidence. However, rearrangement of the aquifer material from pumping typically occurs in younger poorly sorted unconsolidated basin deposits; but the N aquifer is an old consolidated well sorted sandstone deposit. The N aquifer sediments are more than 135 million years old, and are buried deep enough that the majority of compaction and rearrangement has already occurred. Because the rocks in the Black Mesa area are presently being eroded, the rocks in the N aquifer have been subjected to greater stresses in the geologic past than they are currently. GeoTrans (1993) used eleven thin sections of rock sampled from the Navajo Sandstone to evaluate grain size, mineral content and cementation. The results of the evaluation identified that the high overburden pressure over the extensive period of time caused the quartz grains to weld together, confirming that subsequent rearrangement of the aquifer material would be minimal, if any. Additionally, the quartz sand grains comprising the Navajo Sandstone were concave/convex, which supports the concept that rearrangement of the aquifer material has already been realized from the high overburden pressure over the significant period of time due to the concave/convex deformation observed in the quartz grains.

PWCC also evaluated the results of triaxial compression tests on Navajo Sandstone samples taken at outcrops in the unconfined portion of the N aquifer. Pressures ranging between 400 psi and 2,000 psi were applied during testing, with the highest pressures being equivalent to the effective stress on the Navajo Sandstone in the center of the Black Mesa Basin. Compressibility determined from the results of the applied pressures during laboratory testing ranged from 2.78×10^{-7} ft^2/lb to 3.04×10^{-8} ft^2/lb, which results in the potential aquifer thickness reduction ranging from 1.93 feet to 17.44 feet in the center of the basin where impacts would be most realized (GeoTrans, 1993). The results of the testing are conservatively biased toward greater compressibility for the following reasons:

(1) The samples were taken from unconfined outcrops where Navajo Sandstone compaction and stress release has partially occurred.
(2) The outcrop samples encountered some degree of weathering and loss of cementation.
(3) The compression test samples were oriented to apply the maximum loading parallel to the bedding planes, where the actual stress on the aquifer material is nearly perpendicular to the bedding plane. A sample loaded perpendicular to the bedding is expected to be stiffer, resulting in less compression than those loaded parallel to the bedding planes.

The compaction results derived from laboratory testing identified that the potential for measurable surface subsidence to occur as a result of PWCC wellfield pumping, is unrealistic. The conservative bias of the laboratory tests suggest that using samples from the confined area, and stressing the samples perpendicular to the bedding plane would result in less than 17-feet of reduction in N aquifer thickness. Additionally, a 17-foot reduction in N aquifer thickness would not likely translate through 2000-feet of overlying sediments to result in a 17-foot reduction in land surface. Rather, the overlying sediments would likely experience minute deformation to compensate for the change in thickness, resulting in immeasurable surface elevation change. PWCC also conducted video surveys of several Black Mesa mine water supply wells, the most recent occurring in September 2004 on well NAV5. No evidence of casing distress was noted in any of the surveyed well as might be expected if significant compression of the Navajo Sandstone or overlying units has occurred.

However, on February 13, 2003 and May 1, 2003 representatives from OSMRE, Navajo Nation Minerals Dept, Navajo Nation Water Resources Dept, USGS, PWCC, and Black Mesa residents investigated a report of land subsidence south of the lease boundary (OSMRE, 2004). Land subsidence features in the form of sinkholes, cracks, and slumps were reported near Forest Lake, about seven miles south of the Kayenta Complex. After investigation, the representatives identified that all of the subsidence features of concern were either in or adjacent to unconsolidated alluvial valley deposits. Several years of severe drought prior to the year 2003 produced desiccation cracks in the near surface, fine-grained, unconsolidated alluvial sediments. During periods of short and intense rainfall, surface runoff piped through the cracks. The piped water enlarged the cracks in the unconsolidated alluvium until the surface was undermined, forming near surface cavities that collapsed and became small sinkholes, and eventually larger slump areas within the alluvium.

PWCC has provided documentation to suggest that structural collapse of the N aquifer is unlikely. Additionally, field investigations have not revealed documented evidence to indicate the structural collapse of the N aquifer. Therefore, OSMRE finds that material damage to the structural stability of the N aquifer has not occurred, and the potential to cause material damage to existing and foreseeable uses is not supported by the available data and observations, and a material damage criterion is not warranted.

5.2.4.1.4 N aquifer Quantity Material Damage Threshold and Limit

In summary, PWCC pumping of the confined N aquifer system has reduced the water pressure within the N aquifer system. The reduction in water pressure does not limit the ability of the communities to utilize the N aquifer water resource for existing and foreseeable domestic water supply. However, a regional N aquifer monitoring network with reliance on the BM-wells, and a local water level monitoring at the PWCC wellfield will continue to be monitored to verify impact predictions in the base-case 3D Model, and validate simulated predictions against measured data. OSMRE will protect the N aquifer water resource by establishing material damage criteria with a threshold of a 26-percent increase in pumping costs attributable to PWCC pumping, and a material damage limit of greater than a 50-percent increase in pumping costs.

Additionally, N aquifer baseflow will be assessed with the calibrated and validated 3D Model. Confirmation of simulated baseflow discharge to Moenkopi Wash using area specific monitoring near the primary discharge location was contemplated; however, cultural sensitivities and concerns of environmental surface impacts restricted the feasibility to implement confirmation monitoring. Therefore, based on the small simulated reduction in baseflow and cultural sensitivity to the specific baseflow discharge area, it is appropriate to rely on numerical simulation for impact assessment related to baseflow discharge. OSMRE will protect the N aquifer baseflow by establishing a material damage threshold of 21-percent reduction in simulated baseflow, and a material damage limit of greater than 30 percent reduction in simulated baseflow.

OSMRE finds that PWCC has adequately demonstrated the lack of measurable impact to N aquifer spring flow for the N aquifer springs of concern attributed to PWCC pumping. One low-flow spring, Burro Spring, exists at the confined—unconfined boundary, and will continue to be monitored for persistence. Therefore, OSMRE will not establish a material damage criterion for potential impacts to the reduction of N aquifer spring discharge. Regional N aquifer monitoring with reliance on the BM-wells, and a local water level monitoring at the PWCC wellfield will continue to be evaluated to verify impact predictions in the base-case 3D Model.

5.2.4.2 Navajo Aquifer Quality

Groundwater flows from areas of high hydraulic head potential to areas of low hydraulic head potential, and generally follows the flow path of least resistance. The total hydraulic head potential is reflected in the static water level measured in the wellbore. The water levels in the confined N aquifer reflect the hydrostatic pressure regime in the aquifer and are an indication of the net stresses exerted on the N aquifer.

The D aquifer system water predominantly flows horizontally due to the Carmel Formation aquitard separating the D aquifer and N aquifer systems. However, D aquifer water levels typically have a higher groundwater levels compared to N aquifer water levels, which means that there is a downward component of groundwater flow (Figure 22). Water level drawdown from pumping of the N aquifer system creates a greater difference between D aquifer and N aquifer water levels; therefore, the downward movement of water increases as drawdown increases. The rate at which water moves is determined by the vertical permeability of the Carmel Formation, its thickness, and the difference in water levels between the D and N aquifers.

The N aquifer is characterized as having a good water quality compared to the overlying D aquifer (Truini and Macy, 2006). In general, N aquifer water meets water quality standards for domestic supply established by NNEPA and HTWRP, while D aquifer water is not as good and typically does not meet domestic supply water quality standards. Therefore, a hydrologic impact concern related to N aquifer pumping is an increase in the leakage rate of poorer quality D aquifer water to the N aquifer, significantly degrading N aquifer water quality.

The USGS evaluated the hydrogeology of Black Mesa using geochemical and isotopic analysis, concluding that “the similarity of ground-water ages in the D aquifer to ages in the N aquifer suggests that leakage has been occurring for thousands of years” (Truini and Longsworth, 2003). The USGS evaluation also concluded that leakage is most likely to occur in the southern part of Black Mesa based on the geologic and hydrologic environment in that area (Truini and Longsworth, 2003). In the northern part of Black Mesa, isotopic analysis revealed significant statistical differences between the D aquifer and N aquifer water (Truini and Longsworth, 2003). The statistical difference in the northern area suggests that the leakage potential under natural pre-pumping conditions was not as great compared to the southern area. However, the pumping and associated drawdown created by PWCC has increased the potential leakage in the northern area compared to equilibrium steady-state conditions.

The evaluation by the USGS indicates that the rate of leakage of water from the D aquifer to the N aquifer in the northern area under pre-pumping conditions was small. Otherwise, the water in the N aquifer would have been impacted by the D aquifer water because the leakage has been occurring for thousands of years. If the natural leakage rate was low, a significant increase in leakage rate (for example, a 100-percent increase or doubling the leakage rate) would have immeasurable effect on the quality of water in the N aquifer. Conversely, if the rate of pre-pumping leakage was higher, the impact on the water quality could be appreciable with a smaller percentage increase in leakage rate. Thus, monitoring water quality is a better approach to measuring impact than estimating percentage increases in the leakage rate.

5.2.4.2.1 N aquifer Quality Monitoring Program

Since PWCC pumping increases the pre-mining leakage potential between the D aquifer and N aquifer, the degradation of N aquifer quality due to mine related pumping remains a hydrologic concern. The USGS predicted that any increase in leakage from the D aquifer would first appear as increased total TDS (Eychaner, 1983). The USGS (Eychaner, 1983) also identified increased chloride and sulfate concentrations as important indicators of increased D aquifer leakage. Therefore, the USGS and PWCC have compiled and evaluated TDS, chloride, and sulfate concentrations in N aquifer wells since the early 1980’s. To date, “the USGS Black Mesa monitoring program has not detected any significant changes in the major-ion water chemistry of the N aquifer that are related to induced leakage” (Thomas, 2002) (Truini and Longsworth, 2003).

OSMRE has been evaluating N aquifer production well water quality for more than three decades for trends in TDS, sulfate, and chloride in addition to many other water quality parameters. No significant increasing or decreasing trends in concentrations of TDS, sulfate, or chloride have been observed at any PWCC production well. Figures 42, 43, and 44 illustrate concentrations at PWCC N aquifer wells for the last 15 years for TDS, sulfate, and chloride, respectively.

All samples from PWCC pumping wells at the Kayenta Complex have maintained a TDS concentration of less than 350 mg/L over the last 15 years. Additionally, all samples from PWCC pumping wells typically have maintained a chloride concentration less than 10 mg/L over the last 15 years. NAV8 has maintained sulfate concentrations of approximately 120 mg/L, compared to all other NAV wells with sulfate concentrations typically less than 30 mg/L over the last 15 years.

Slight variations in water quality between the various production wells are a result of the screened interval. For instance, as presented in Table 10, NAV8 is the only well not drilled past the Navajo Sandstone into the underlying Kayenta Formation and Wingate Sandstone. Therefore, NAV8 has consistently elevated TDS and sulfate concentrations when compared to the other NAV water supply wells. However, the use potential for the Navajo aquifer remains unchanged at all production wells and is suitable for domestic and livestock uses.

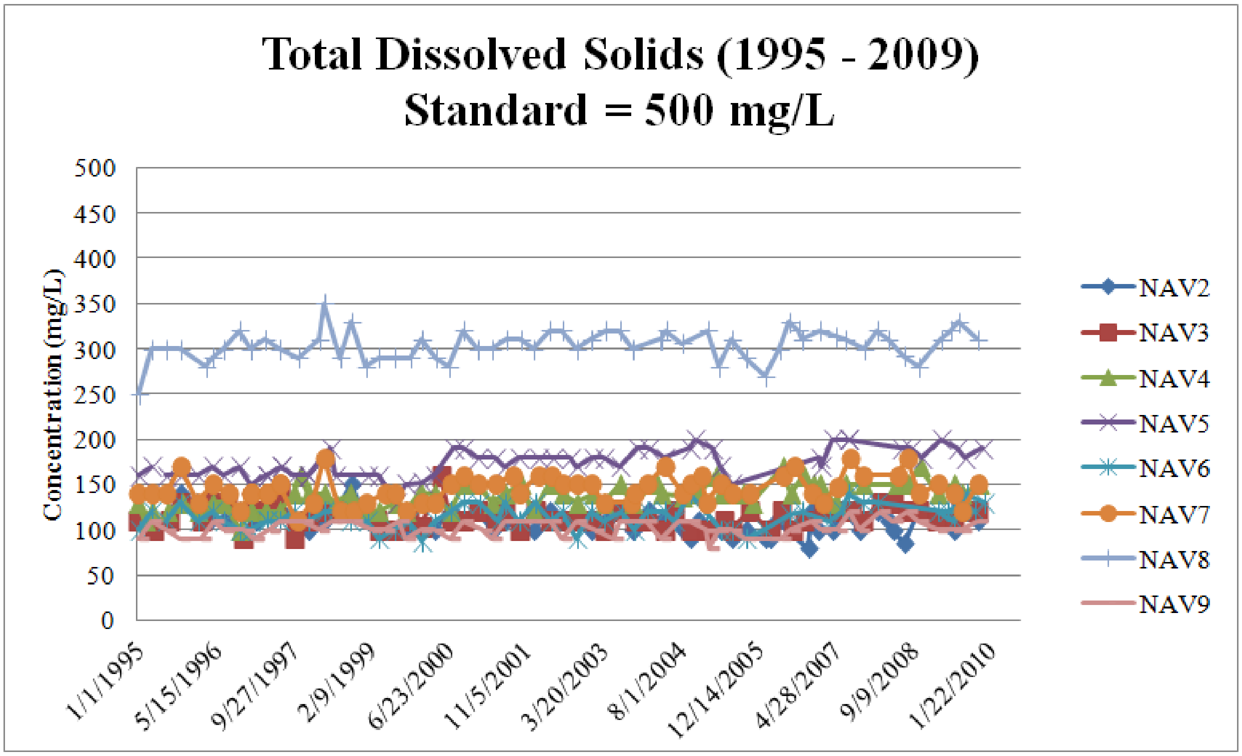


Figure 42: TDS Concentrations in PWCC Pumping Wells (1995 – 2009).

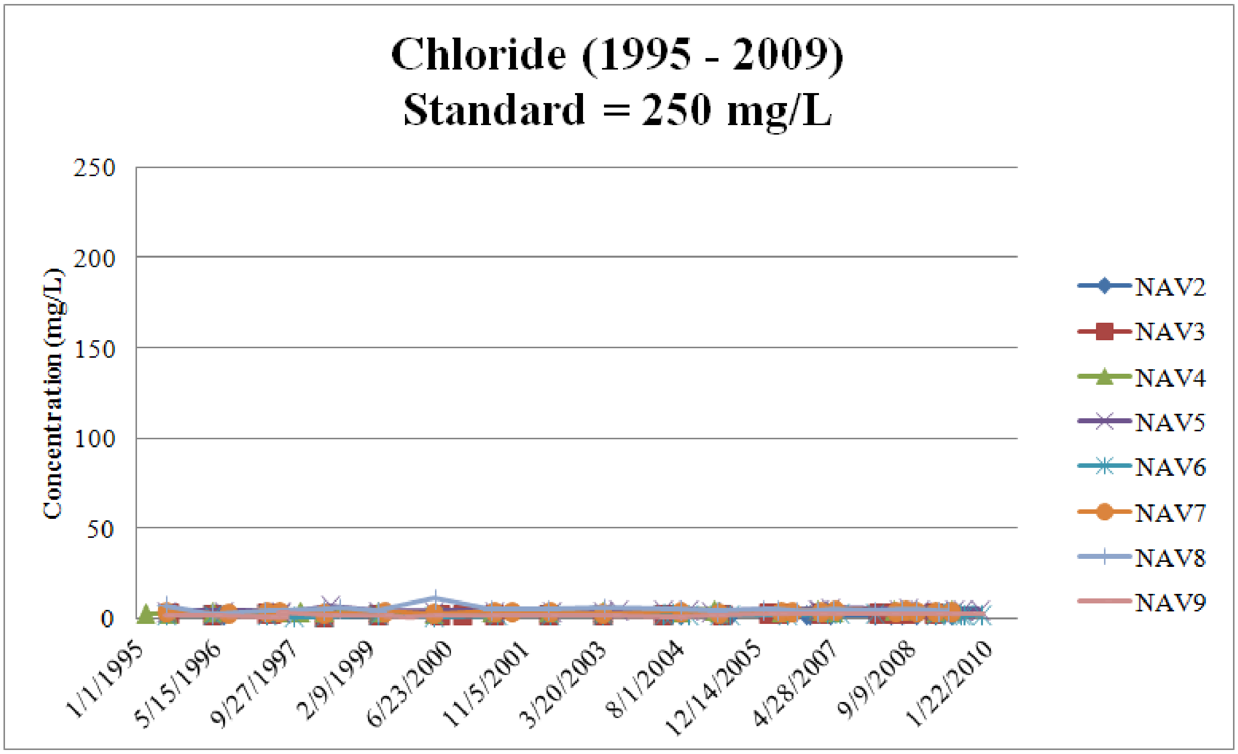


Figure 43: Chloride Concentrations in PWCC Pumping Wells (1995 – 2009).

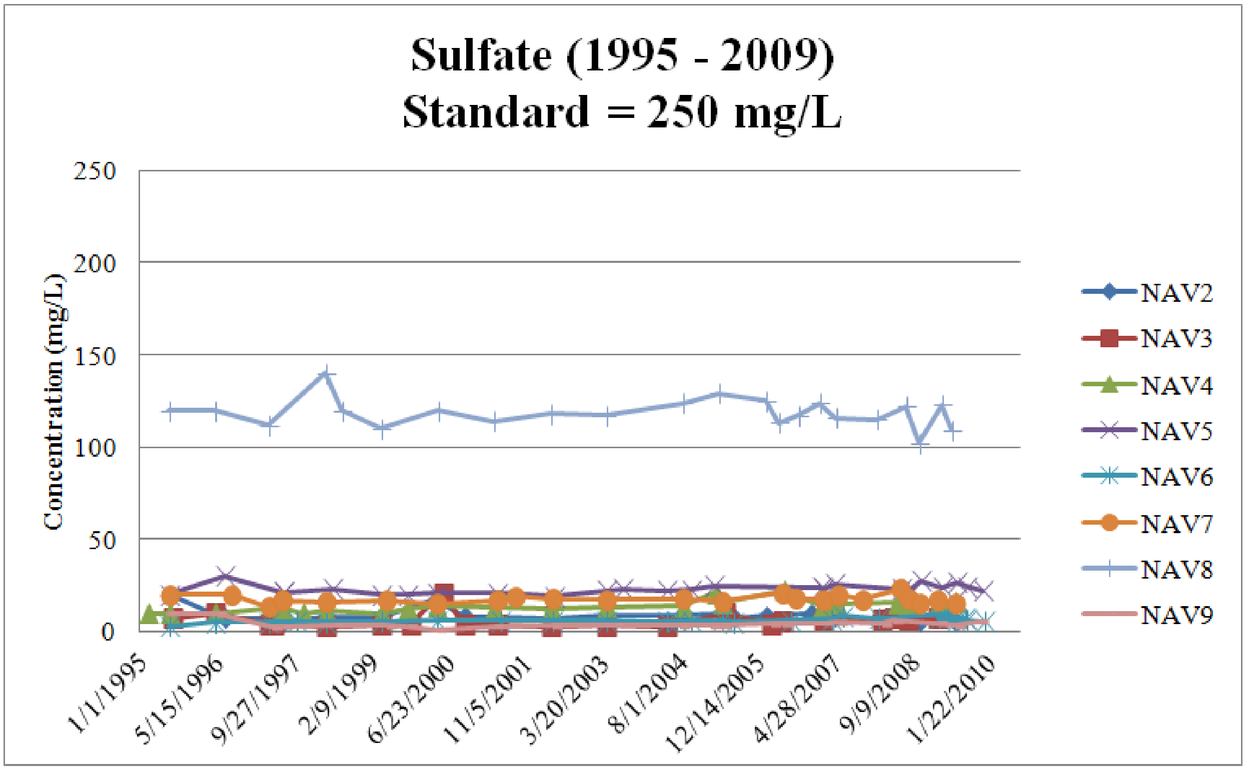


Figure 44: Sulfate Concentrations in PWCC Pumping Wells (1995 – 2009).

5.2.4.2.2 N aquifer Quality Impact Potential to Designated and Foreseeable Uses

Mine related pumping has not degraded the N aquifer water quality, and significant degradation causing material damage to the existing and foreseeable uses is unlikely to propagate outside the areal extent of the permit boundary. Water quality of the PWCC wellfield will continue to be assessed on a quarterly basis to ensure that the N aquifer continues to meet drinking water quality standards for TDS, sulfate, and chloride as established indictor water quality parameters.

5.2.4.2.3 N aquifer Quality Material Damage Threshold and Limit

OSMRE will assess N aquifer water quality impacts based on water quality at the PWCC wellfield, since highest N aquifer water quality impact potential is in the vicinity of the wellfield based on drawdown. OSMRE will continue to evaluate TDS, chloride, and sulfate water quality concentrations against the standards for domestic water supply. A material damage threshold of four consecutive exceedances will be established. A level of material damage will be considered a PWCC NAV well no longer meeting the TDS, chloride, and sulfate domestic water supply use standards. To date, PWCC pumping of the N aquifer has not caused material damage to the quality of N aquifer. PWCC's operation of the Kayenta Complex has been designed to prevent material damage to the quality of the N aquifer. However, water quality of the PWCC wellfield will continue to be assessed on a quarterly basis to ensure that the N aquifer continues to meet applicable water quality standards.