# 4 BASELINE HYDROLOGIC CONDITIONS

The issuance SMCRA established that surface coal mining operations are to be conducted as to protect the environment, and to assure that a balance between the protection of the environment and the production of coal as a source of energy is maintained (SMCRA, Section 102(d) and (f), 1977). Therefore, as presented in OSMRE's guidance document for the preparation of PHC's and CHIA's, the goals in establishment of baseline hydrologic conditions are to characterize the local hydrology, understand the regional hydrologic balance, and identify any water resource or water use that could be affected by the mining operation (OSMRE, 2002). The guidance document is consistent with 30 CFR 780.21. However, mining operations at the Kayenta Complex commenced prior to the issuance of SMCRA, making quantification of baseline conditions for impact assessment uncertain for some hydrologic resources due to the absence of pre-mining information since it was not required prior to 1977.

In compliance with the issuance of SMCRA, PWCC initiated an extensive hydrologic monitoring program documenting the interaction between the surface water system and alluvial and Wepo groundwater systems within the permit area. Additionally, the USGS began regional monitoring assistance in the mid 1970's. The continued monitoring conducted by the USGS in the Black Mesa area is designed to track the effects of industrial and municipal pumpage on ground water levels, stream and spring discharge, and ground water chemistry (Macy and Unema, 2014).

Although the majority of hydrologic information was collected after mining operations began at the Kayenta Mine Complex, the data collected from the mid 1970's to present provide insight on water quality and quantity. The groundwater models that have been developed also greatly assist with assessing hydrologic conditions and changes within the CIAs.

## 4.1 Surface Water

The drainages in the surface water CIAs are considered ephemeral and intermittent based on OSMRE definitions at 30 CFR 701.5. An ephemeral stream is when a stream flows only in direct response to precipitation in the immediate watershed or in response to the melting of a cover of snow and ice, and which has a channel bottom that is always above the local water table. An intermittent stream is considered a stream, or reach of a stream, that is below the water table for a least some part of the year, and obtains its flow from both surface runoff and groundwater discharge. PWCC refers to reaches of channels whose channel beds are located periodically below the local water table as wet reaches (PWCC, v.9, ch.15, 2016). OSMRE further defines intermittent at 30 CFR 701.5 as a stream, or reach of stream, that drains a watershed of a least one square mile.

### 4.1.1 Surface Water Regulatory Requirements

*Water Quality*

Surface water runoff from areas disturbed by mining operations is required to be managed in a manner that prevents additional contribution of suspended solids to stream flow outside the permit area to the extent possible with the best technology currently available, and otherwise prevents surface water pollution (30 CFR 816.41(d)). PWCC complies with 30 CFR 816.41(d) by designing, constructing, and maintaining siltation structures, impoundments, and diversions. Additionally, PWCC complies with 30 CFR 816.41(d) by monitoring in-stream surface water quality according to the approved monitoring plan in the PAP. The Moenkopi surface water CIA includes 253 $mi^2$ of the 2,635 $mi^2$ Moenkopi Wash (HUC 15020018), and the Dinnebito surface water CIA includes 51 $mi^2$ of the 743 $mi^2$ Dinnebito Wash (HUC

15020017). However, all water in the Moenkopi and Dinnebito surface water CIA's does not pass through siltation structures or impoundments due to the absence of mining disturbance in some areas, or compliance as a NPDES western alkaline outfall.

PWCC is required to submit a quarterly report to the USEPA regarding NPDES Permit #NN0022179. The NPDES reports document the water quality and quantity of discharge to the washes when high runoff events exceed the storage capacity design of the structure and surface water discharge to the wash occurs. Additionally, PWCC may dewater ponds in order to ensure sufficient design capacity by either transferring water to nearby ponds with available capacity, or by discharging water into the downstream wash in accordance with the NPDES permit.

*Water Quantity*

PWCC is required to reclaim lands disturbed by mining so the lands may be returned to the appropriate land management agency in a condition compatible with and capable of supporting the approved post-mining land uses. The approved Kayenta Mine Complex post-mining land uses are livestock grazing and wildlife habitat, which are consistent with the pre-mining land uses. As such, PWCC "has designed its reclamation efforts to return mined lands to the land use of livestock grazing and wildlife habitat" (PWCC, v.8, ch.14, 2016). In order to support the livestock grazing and wildlife habitat post-mining land uses, and after consultation with the Navajo Nation, Hopi Tribe, and the Bureau of Indian Affairs (BIA), PWCC proposed the construction and retention of 51 permanent surface water structures to ensure an adequate distribution of post-mining water resources in order to promote a greater viability of post-mining land use success. The reclamation plan has been previously agreed to by the BIA and the Hopi Tribe and Navajo Nation. By the year 2019, there will be 50 permanent impoundments, 115 temporary impoundments, and 101 reclaimed impoundments (BOR, 2016).

The retention of surface water impounded by temporary and permanent impoundments was contested by the Hopi Tribe in 1991, and presented before Administrative Law Judge (ALJ) John R. Rampton, Jr. (Rampton, 1991). ALJ Rampton's decision concluded that trust responsibilities are owed equally to both the Hopi Tribe and the Navajo Nation, who dispute each other's water rights claims. ALJ John H. Kelly reaffirmed ALJ Rampton's decision on June 5, 1992 (Kelly, 1992). To date, these water rights claims have not been adjudicated. Therefore, OSMRE cannot determine which tribe holds adjudicated water rights that require protection until the water claims are adjudicated.

While OSMRE does not have the authority to make determinations of possible violations of adjudicated water rights between the Hopi Tribe and Navajo Nation, OSMRE evaluates surface water quantity related to existing and foreseeable downstream uses and the impact of the mining and reclamation operations on the hydrologic balance.

### 4.1.2 Surface Water Baseline Quantity

Precipitation that does not infiltrate into the subsurface, or return to the atmosphere by evapotranspiration, flows in the washes as surface water. The nature of the surface water flow depends on the type of precipitation and behavior of the storm. "Forty-six percent of the annual precipitation is received in the months of July, August and September, and sixty-four percent is received in the period April through September" (PWCC, v.8, ch.11, 2016). The majority of surface runoff results from precipitation from April through September. A much smaller amount of runoff occurs in other months, such as snowmelt derived runoff in February and March.

The average channel gradient in the permit area is approximately 1%, which induces high velocities during runoff events (PWCC, v.9, ch.15, 2016). The high velocity is reflected in most hydrographs by a short time to peak and a quick reduction in flow after the storm ends. Velocities measured by PWCC personnel using current meters commonly exceed 5 feet per second (ft/sec) and have been as high as 10 ft/sec or greater during large flow events. PWCC monitoring also indicates that it is not uncommon to have a time to peak of two to three minutes at the various monitoring stations (PWCC, v.9, ch.15, 2016). Multiple peak hydrographs are a characteristic observed during monitoring of the Black Mesa hydrology. The multiple peaks are likely the result of the localized nature, movement, and varying intensity of the thunderstorms that cause runoff. PWCC observations indicate that a thunderstorm cell might produce intense rain in a small upper tributary, move to other tributaries within the same watershed, and may change intensity as the thunderstorm cell migrates over the area, producing multiple runoff surges at downstream monitoring stations (PWCC, v.9, ch.15, 2016).

Stream monitoring sites were established to characterize the surface water regime related to surface water quantity (Figure 11). Above-mining and below-mining monitoring sites were selected on the primary drainages in the CIA: Yellow Water Wash, Coal Mine Wash, Moenkopi Wash, Red Peak Valley Wash, and Dinnebito Wash. The flow monitoring provides information on the hydrograph characteristics representing a range of drainage areas, watershed shapes, slopes, channel densities, and vegetative characteristics. Once the flow hydrographs are characterized for the snowmelt, convective and frontal storm events, the information provides reasonable flow volume estimates from the peak flow measurements. The flow quantity estimates are based on a strong correlation identified during regression analysis between peak flow and flow volume for the various type of flow event (PWCC, v.9, ch.15, 2016).

PWCC demonstrated through the use of upstream and downstream flow hydrographs for a storm event occurring entirely in the watershed above the upstream site that the upstream hydrographs only provide information on the channel transmission losses and the dampening effects these losses will have on the shapes and peaks of the downstream hydrographs (PWCC, 2001). Therefore, in 2002, OSMRE approved the reduction of continuous flow monitoring at upstream monitoring locations since PWCC demonstrated characterization of the surface water quantity and quality regime and the potential for surface water impacts. Additionally, no significant mining-related disturbance is present upgradient of the Kayenta Mine Complex and the distinct geographic edge of Black Mesa.

PWCC currently monitors surface water at downstream monitoring locations 155 (Red Peak Valley Wash), 25 (Coal Mine Wash), 26 (Moenkopi Wash), and 34 (Dinnebito Wash). Locations 155, 26, and 25 collect continuous flow stage levels during storm flow events using ultrasonic gages mounted to a platform over the wash at established channel control sections. Location 34 is a crest gage (CG) used to measure peak flow, and the peak measurement can be applied to the appropriate hydrograph type to approximate the total discharge event. In 2010, PWCC installed monitoring location 34 near CG34, which has the same continuous monitoring design capabilities as locations 25, 26, and 155. These gaging locations provide useful surface water quantity information during the evaluation of potential impact to the hydrologic balance outside the permit area.

Monitoring locations 25, 26, and 155 measure surface water runoff that does not pass through PWCC dams, ponds, or impoundments; with the exception of overflow quantities that periodically occur due to discharges from sediment control structures and are reported as part of compliance with the NPDES permit. During the NN0022179 permit term (2005-2009), discharges from precipitation events ranged from 0 ac-ft in 2009 to 57.81 ac-ft in 2007, averaging 21.28 ac-ft per year over the 5-year period. Combined measured surface flow at monitoring locations 25, 26, and 155 varies annually for the period 1987-2008. Total combined runoff for these three locations was a low (124.1 ac-ft) in 1991, and a maximum (4,105.8 ac-ft) in 2006; averaging 1,488.5 ac-ft from 1987-2008 (PWCC, v.11, ch.18, Table 15, 2016). Based on the combined drainage area for the three locations (253 $mi^2$), less the total PWCC impounded area during each calendar year, an average annual runoff of 0.15-inches was calculated for the Moenkopi surface water CIA (PWCC, v.11, ch.18, Table 15, 2016).

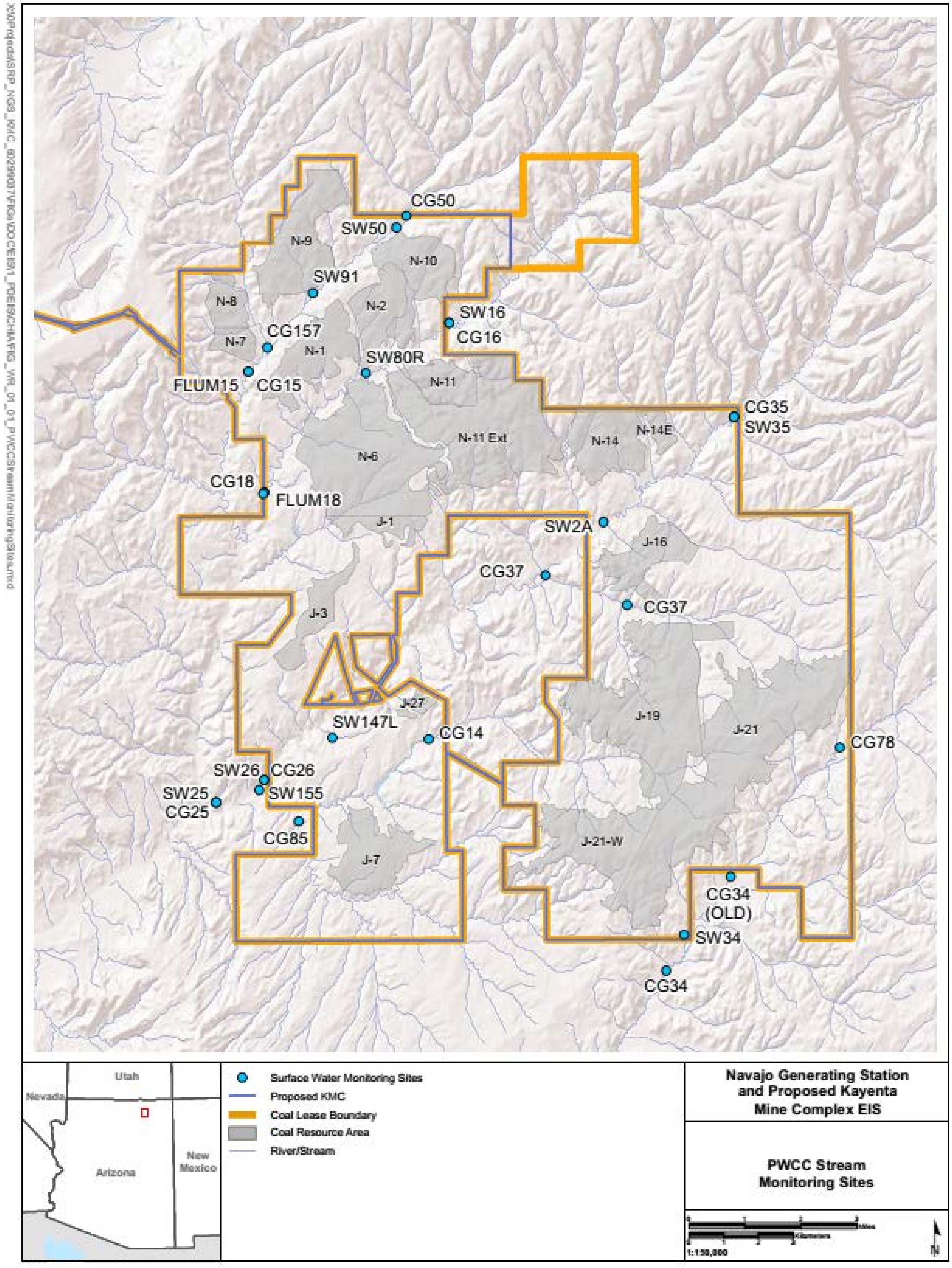



**Figure 11: PWCC Surface Water Monitoring Locations (BOR, 2016, Figure WR-1.1)**

### 4.1.3 Surface Water Baseline Quality

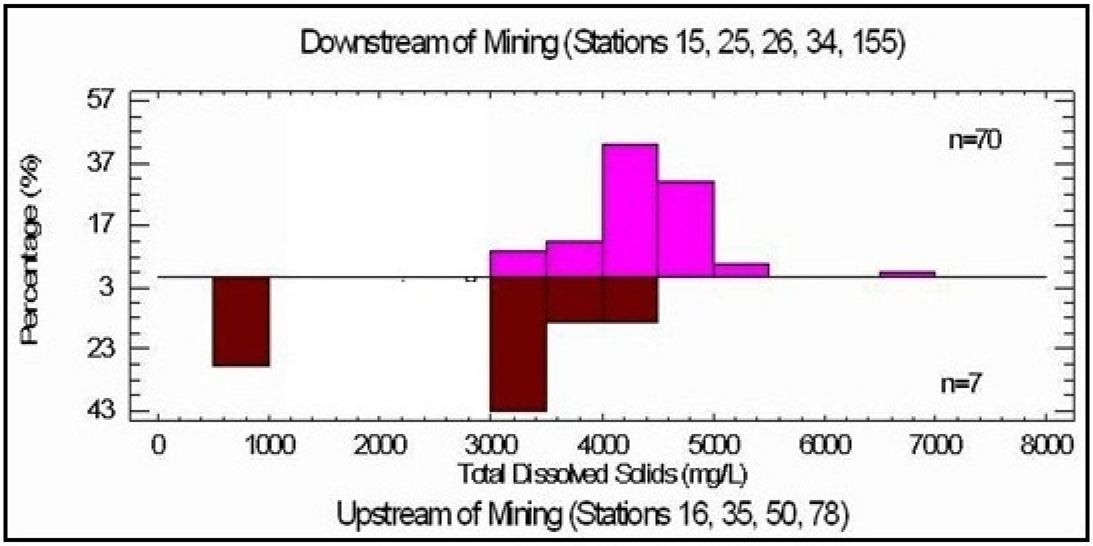
Surface water quality varies based on the type of runoff: storm water runoff, snowmelt runoff, or baseflow runoff (PWCC, v.9, ch.15, 2016). Data collected from surface water monitoring locations from September 1980 to June 1985 indicates that the dominant dissolved ions are calcium, magnesium, sometimes sodium, bicarbonate and sulfate (PWCC, v.9, ch.15, 2016). Dominant water types are calcium-magnesium sulfate and calcium-magnesium bicarbonate (PWCC, v.9, ch.15, 2016). Surface water flows in the Dinnebito Wash and Moenkopi Wash CIAs primarily originate from storm water runoff, and resulting flows can be classified as flash floods of varying magnitude (PWCC, v.9, ch.15, 2016). Storm water runoff in the CIAs can entrain the channel wash sediment. The amount of entrained sediment can be expressed as total suspended solids (TSS). The PWCC monitoring program established that as the flow discharge increases, TSS concentrations will increase (PWCC, v.9, ch.15, 2016). A maximum TSS concentration of 994,000 milligrams per liter (mg/L) was recorded during the 1980 to 1985 monitoring period (PWCC, v.9, ch.15, 2016).

The USGS collected surface water quality samples in December 1973 and then quarterly through the second half of 1975 in Moenkopi Wash approximately one mile downstream of the permit boundary (retired Station No. 09401240). Samples collected at retired USGS station 09401240 had mean sulfate concentrations of 1,600 mg/L and total dissolved solids (TDS) concentrations of 2,691 mg/L. The USGS also periodically collected water quality samples throughout the mid 1970's in Moenkopi Wash, Yellow Water Canyon Wash, and Coal Mine Wash within and adjacent to the Kayenta Complex.

TDS a valuable indicator of water quality conditions in surface water flow, and represents a broad measure of the overall quality of surface water. Figure 12 compares baseflow and storm flow TDS values between stations located upstream and downstream of mining activity. The data indicate that upstream baseflow TDS is consistent with downstream baseflow TDS concentrations. However, the Wepo Formation outcrops, and sub-crops in the alluvium, across the permit area; trending northwest to southeast. Therefore, baseflow is more prevalent on the downstream channels, and downstream water quality is influenced by the quality of water discharging from the Wepo Formation. Storm flow TDS is consistent when comparing upstream and downstream locations. Concentrations of TDS and other constituents are greater at downstream sampling locations compared to upstream sampling locations, likely attributed to the overlying Yale Point Sandstone. The Wepo Formation is present adjacent to the stream channels, but approximately 80% of the surface area between the eastern Kayenta Mine Complex boundary and the rim of the mesa has been mapped as Yale Point sandstone (Repenning and Page, 1956). The Yale Point does not contribute as much of a dissolved load to the surface water compared to the Wepo. Within the Kayenta Mine Complex, the land surface is dominated by the Wepo Formation at surface, and the Yale Point is present only in the northeastern extension of the permit area. Therefore, within the permit area, runoff has a higher dissolved load, and the Wepo-influenced water recharges the alluvium in stream channels with higher TDS water. A review of sulfate data indicates that the distribution relationship is consistent with the TDS baseflow – stormflow relationship.

Table 2 provides summary information for upstream surface water monitoring locations for the Dinnebito Wash and Moenkopi Wash CIAs of the Kayenta Complex. Surface water monitoring location 78 represents upstream water quality for the Dinnebito Wash CIA. Surface water monitoring locations 16, 35, and 50 represent the upstream water quality for the Moenkopi Wash CIA. Storm flow water quality data collected between 1986 and 2010 is presented relative to the most protective WQS considering HTWQS (Hopi Tribe, 2011) and NNSWQS (NNEPA, 2009).

**Baseflow TDS**




**Stormflow TDS**

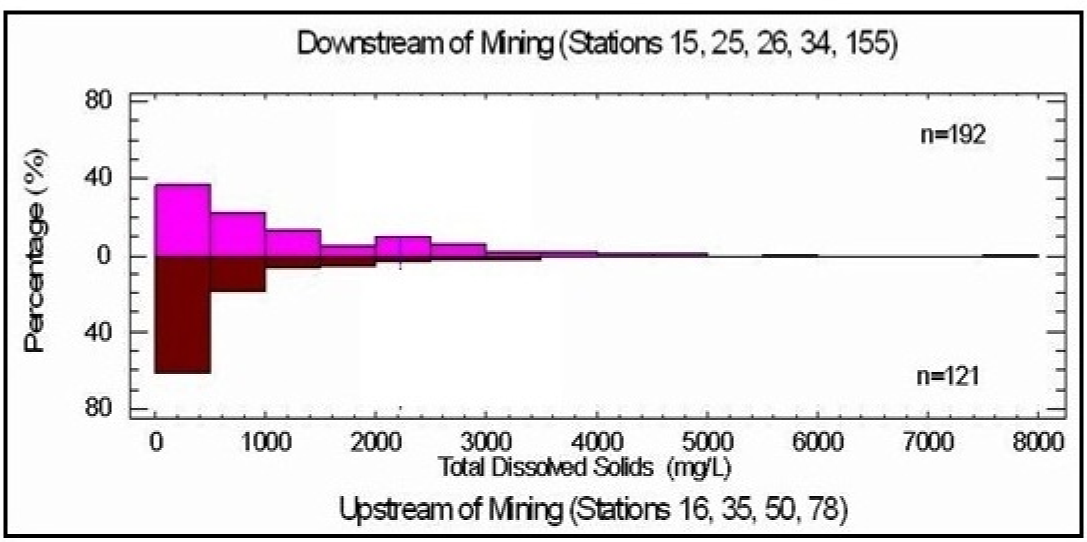



**Figure 12: Comparison of Upstream and Downstream TDS Surface Water Quality Data for Baseflow and Stormwater flow (1986-2004).**

| | | | | | Dinnebito Wash CIA Location 78 Storm Water Samples | | | | Moenkopi Wash CIA Locations 16, 35, and 50 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 | 0.1 | 0.5 | n=45 | 0.05 | 0.5 | 1.1 |
| Antimony | Aquatic (NN) | 88 | μg/L | Dissolved | n=15 | 1 | 200 | 485 | n=38 | 1 | 200 | 860 |
| Arsenic | Aquatic (HT) | 230 | μg/L | Dissolved | n=20 | 1 | 20 | 30 | n=45 | 1 | 20 | 30 |
| Barium | Secondary Contact (NN) | 98000 (T) | μg/L | Dissolved | n=17 | 90 | 195 | 500 | n=44 | 20 | 250 | 1500 |
| Bicarbonate | NNS | NNS | mg/L | Dissolved | n=34 | 39 | 95 | 390 | n=86 | 26.8 | 94 | 1022 |
| Boron | Agricultural (NN) | 1000 (T) | μg/L | Dissolved | n=35 | 20 | 100 | 500 | n=87 | 10 | 10 | 10 |
| Calcium | NNS | NNS | mg/L | Dissolved | n=35 | 32 | 173 | 570 | n=88 | 14 | 60 | 580 |
| Cadmium | Fish Consumption (NN) | 8 (T) | μg/L | Dissolved | n=18 | 3 | 5 | 20 | n=42 | 10 | 100 | 504 |
| Chloride | Aquatic (HT) | 230 (T) | mg/L | Total | n=34 | 1 | 17.9 | 282 | n=88 | 2 | 5 | 15 |
| Chromium | Agricultural (HT)(NN) | 1000 (T) | μg/L | Dissolved | n=18 | 10 | 20 | 50 | n=41 | 1 | 7 | 69 |
| Copper | Agricultural (NN) | 200 | μg/L | Dissolved | n=20 | 10 | 10 | 30 | n=45 | 10 | 20 | 50 |
| Fluoride | Secondary Contact (NN) | 56 (T) | mg/L | Total | n=34 | 0.1 | 0.5 | 1.9 | n=88 | 0.1 | 0.3 | 0.8 |
| Iron | NNS | NNS | mg/L | Total | n=27 | 1.57 | 444.5 | 3871.0 | n=76 | 7.75 | 352 | 4125 |
| Lead | Secondary Contact (NN) | 15 (T) | μg/L | Dissolved | n=18 | 20 | 20 | 540 | n=41 | 20 | 20 | 280 |
| Magnesium | NNS | NNS | mg/L | Dissolved | n=35 | 7 | 78.7 | 1300 | n=88 | 2.7 | 13 | 247 |
| Manganese | Agricultural (HT) | 10 (T) | mg/L | Total | n=28 | 0.12 | 16 | 84 | n=76 | 0.2 | 10 | 79 |
| Mercury | Aquatic (HT) | 0.01 | μg/L | Dissolved | n=18 | 0.1 | 1 | 2.0 | n=42 | 0.1 | 1 | 20 |
| Molybdenum | Agricultural (HT) | 0.01 | μg/L | Dissolved | n=15 | 1 | 200 | 500 | n=40 | 1 | 200 | 500 |
| Nickel | Fish Consumption (NN) | 4600 (T) | μg/L | Dissolved | n=15 | 20 | 20 | 300 | n=40 | 10 | 50 | 300 |
| Nitrate as N | Secondary Contact (NN) | 1493 (T) | mg/L | Total | n=33 | 0.0 | 0.96 | 82.9 | n=88 | 0.01 | 0.9 | 7.5 |
| Nitrite as N | Secondary Contact (NN) | 93.3 (T) | mg/L | Total | n=33 | 0.00 | 0.05 | 0.9 | n=88 | 0.00 | 0.04 | 1 |
| NO3+NO2 | Livestock Watering (NN) | 132 | mg/L | Total | n=33 | 0.24 | 1.29 | 83 | n=70 | 0.02 | 0.99 | 8.5 |
| pH | All Uses | < 9.0 | s.u. | Total | n=33 | 6.2 | 7.3 | 8.0 | n=88 | 6.8 | 7.4 | 8.2 |
| Selenium | Aquatic (HT) | 2 (T) | μg/L | Dissolved | n=20 | 1 | 5 | 50 | n=46 | 1 | 10 | 50 |
| Silver | Secondary Contact (NN) | 4670 (T) | μg/L | Dissolved | n=15 | 10 | 20 | 30 | n=40 | 5 | 20 | 40 |
| Sodium | NNS | NNS | mg/L | Dissolved | n=35 | 7.2 | 87 | 1740 | n=88 | 1 | 4 | 108 |
| Sulfate | Aquatic (HT) | 250 (T) | mg/L | Total | n=34 | 48 | 900 | 9096 | n=88 | 10 | 150 | 3060 |
| TDS | Aquatic (HT) | 500 | mg/L | Total | n=34 | 170 | 1444 | 13250 | n=88 | 72 | 440 | 6620 |
| Vanadium | Agricultural (HT)(NN) | 100 (T) | μg/L | Dissolved | n=20 | 5 | 20 | 500 | n=45 | 5 | 100 | 1000 |
| Zinc | Agricultural (HT)(NN) | 10 (T) | mg/L | Dissolved | n=20 | 0.01 | 0.02 | 0.10 | n=45 | 0.01 | 0.02 | 0.5 |

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 2. Storm water sample ranges for upstream locations, Kayenta Mine Complex (1986-2010).

## 4.2 Groundwater

The proposed mining effect on groundwater quantity and quality is a hydrologic impact consideration related to the Kayenta Mine Complex. The coal resource areas mined at the Kayenta Complex are in the Wepo Formation of the Mesa Verde Group, and the alluvial channels are locally connected to the formations of the Mesa Verde Group. PWCC utilizes groundwater from water supply wells within the Kayenta Mine Complex, withdrawing groundwater from the N aquifer. The N aquifer is utilized regionally by Hopi and Navajo communities for domestic supply water, the overlying D aquifer is utilized in isolated areas where the water quantity and quality supports domestic or livestock water supply use. A third regional aquifer system, C aquifer, exists below the N aquifer and is confined from the N aquifer by siltstone, mudstone, and claystone comprising the Chinle Formation.

### 4.2.1 Groundwater Regulatory Requirements

30 CFR 816.41(h) states that a water supply of an owner of interest used for domestic, agricultural, industrial, or for other legitimate use that is adversely impacted by contamination, diminution, or interruption proximately resulting from surface mining activities shall be replaced. PWCC use of water for mining operations is authorized based on previous and current permit agreements. The coal leases from the Navajo Nation and Hopi Tribe state that Peabody may "develop and utilize water obtained from wells located on the leased premises for use in its mining operations including the transportation by slurry pipeline of coal mined from the leased premises…" (Stetson, 1966). PWCC commits to proper protection and maintenance of the production wells in accordance with the leases. PWCC will seal and properly abandon all monitoring wells in the alluvial and Wepo aquifers and remove the surface installations and instrumentation, unless the Tribes request retention of specific wells in the groundwater monitoring program.

### 4.2.2 Alluvium

Geomorphic mapping of the alluvium and colluvium along the principal washes and tributaries in the permit and adjacent area in 1980 identified that Dinnebito, Reed Valley, lower Coal Mine, and lower Moenkopi (2-mile segment downstream from permit boundary) washes have the largest amount of alluvium and saturated material (PWCC, v.11, ch.17, 2016). During 1980, PWCC conducted studies to determine the presence of alluvial valley floors. The studies concluded that the potential for agricultural practices in alluvial areas on and adjacent to the Kayenta Mine Complex is limited, and alluvial valley floors do not exist on or immediately adjacent to the Kayenta Mine Complex (PWCC, v.11, ch.17, 2016). The headwater reaches of all washes, and side tributaries, contain little to no alluvial water. PWCC has installed approximately one hundred wells, and replacement wells when necessary to characterize and monitor the hydrogeologic conditions of the alluvium (Figure 13). Seismic refraction surveys were completed to evaluate alluvium thickness and saturation (Figure 14). This section will assess baseline water quantity and agricultural livestock use quality with information from the alluvial monitoring well program on the primary washes and tributaries within the surface water CIAs. The surface water CIAs will be used for evaluation of the alluvium due to the shallow and variable alluvial thickness and high infiltration rates in the channel alluvium, which provide a mechanism for the surface water system and alluvial groundwater system to interact with each other.

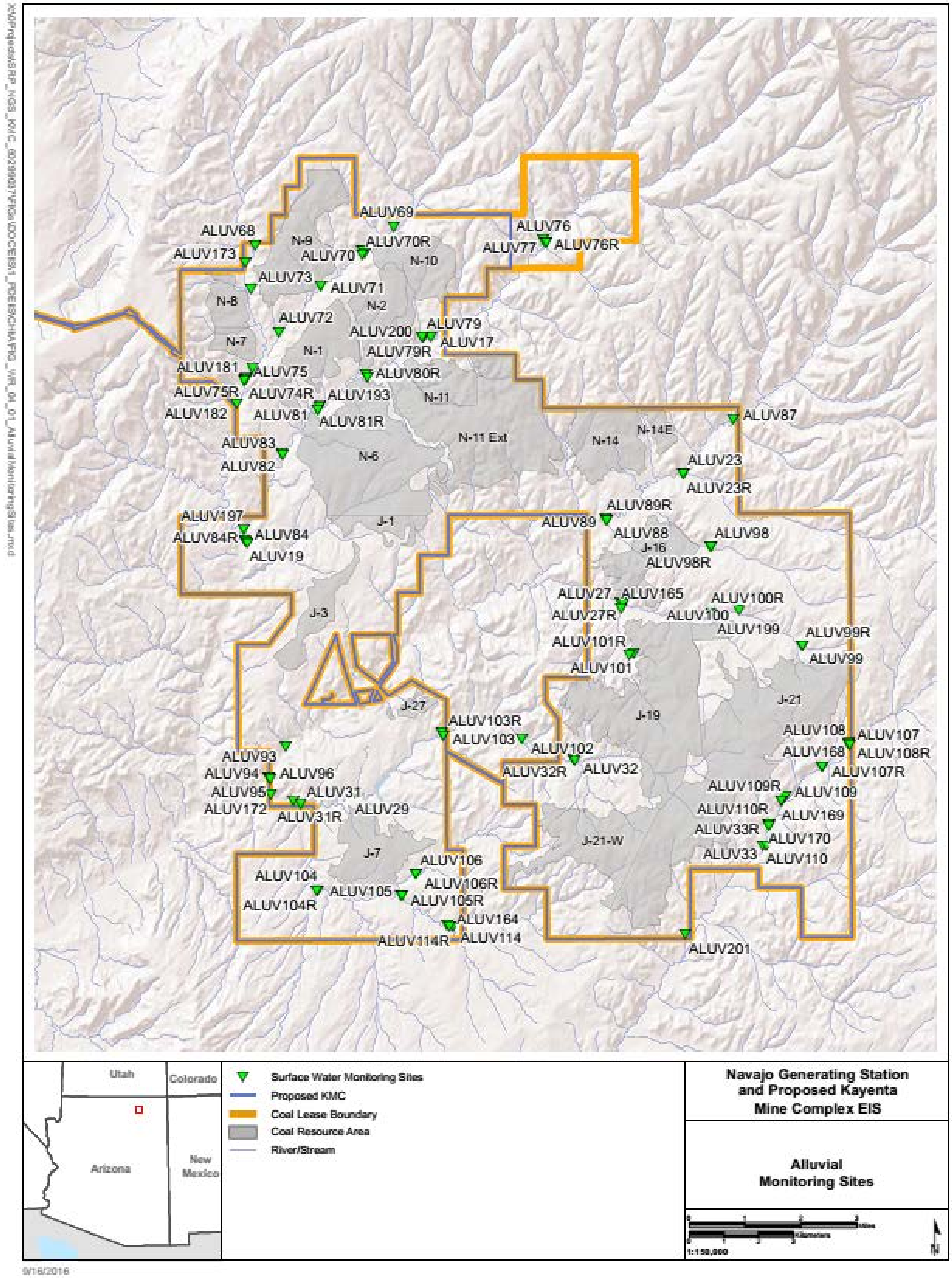



**Figure 13: PWCC Alluvial Water Monitoring Locations (BOR, 2016, Figure WR-4.1)**

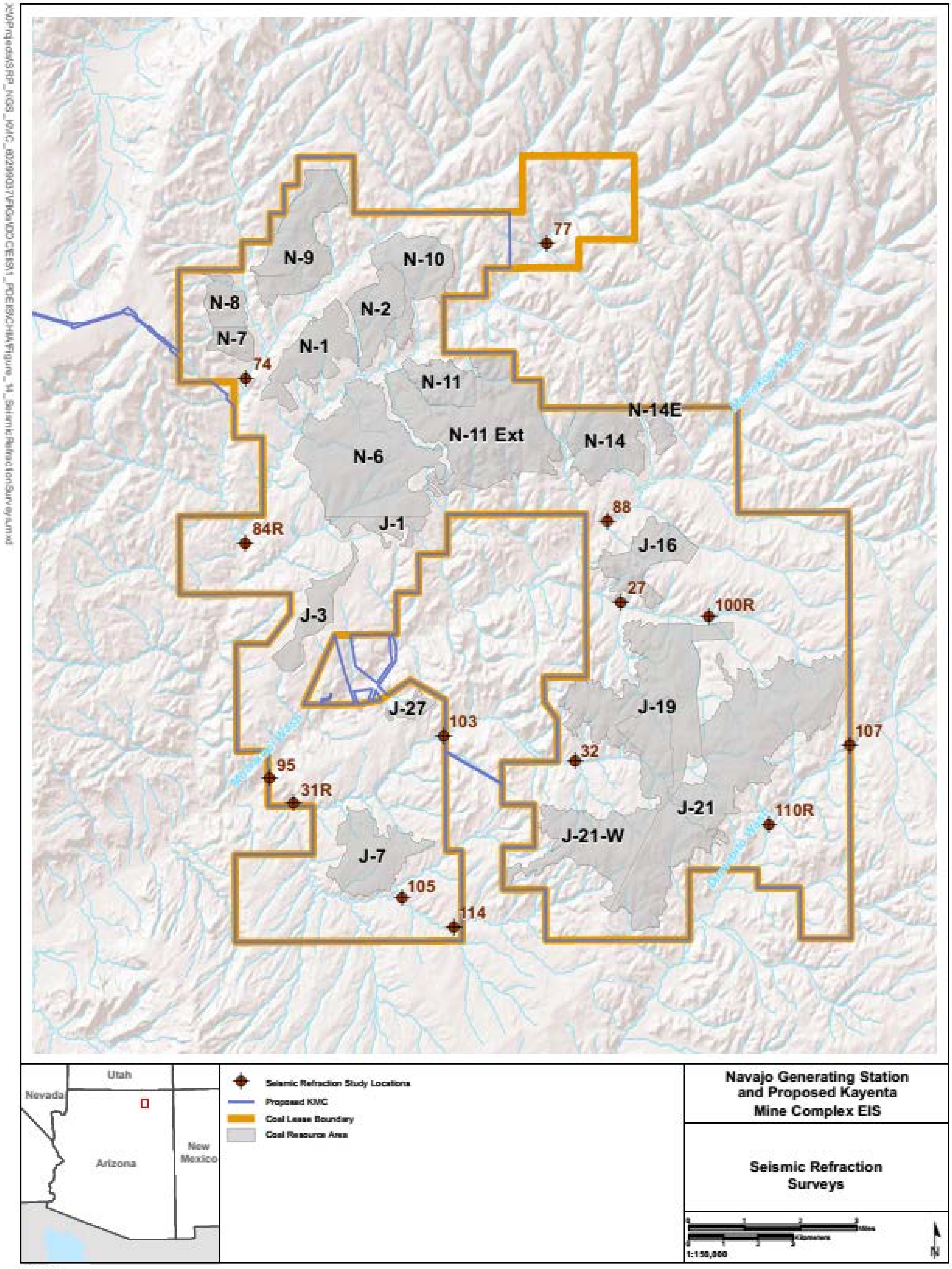



**Figure 14: Seismic Refraction Evaluation Locations for Alluvium, Kayenta Mine Complex.**

#### 4.2.2.1 Alluvial Baseline Quantity

Saturated thicknesses and saturated cross-sectional areas were estimated for the primary washes within the permit area using borehole lithology, groundwater monitoring wells, and the geophysical technique of seismic refraction. The major washes investigated include Reed Valley Wash, Red Peak Valley Wash, Yellow Water Canyon Wash, Coal Mine Wash, Yucca Flat Wash, Moenkopi Wash, and Dinnebito Wash.

Seismic evaluation at locations within the Kayenta Mine Complex and at select adjacent areas resulted in average saturated thicknesses from 3 feet to 34 feet, while saturated cross-sectional areas ranged from 900 square feet to 40,000 square feet (Figure 14). Thinnest saturated areas in the permit area were present at Upper Red Peak Valley Wash, Upper Yellow Water Canyon Wash and Upper Yucca Flat Wash, while greatest saturated thicknesses were found at Lower Yellow Water Canyon Wash, Lower Coal Mine Wash, Lower and Upper Dinnebito Wash, and Middle Reed Valley Wash. Greatest saturated cross-sectional areas were found along Dinnebito, Lower Moenkopi and Coal Mine Washes (PWCC, v.9, ch.15, 2016).

Groundwater gradients were also evaluated on both micro-scale (180-foot length) and macro-scale (lengths of several thousand feet) along the alluvial channels using seismic refraction and water levels in the alluvial ground water monitoring wells. Gradients on a macro-scale ranged from 0.007-0.025 feet/feet, and 0.002-0.028 feet/feet on a micro-scale (PWCC, v.9, ch.15, 2016).

Additionally, a review of borehole lithology identified that the alluvium consists of poorly sorted sediments ranging from clays to cobbles. The alluvium varies in width and depth within the same wash and compared to other washes. The variation is a result of previous channel scour and associated sediment deposition. Subsequent events of channel scour and sediment deposition further add to the heterogeneity and anisotropy of the alluvial system. The variations in alluvial material influence the hydraulic conductivity of the saturated material throughout the various washes, and ultimately the transmissivity which is the product of hydraulic conductivity and saturated thickness. “The ability of an aquifer to transmit water is described by its hydraulic conductivity. The hydraulic conductivity is integrated in the vertical dimension to give an average transmission characteristic known as transmissivity, or hydraulic conductivity times the aquifer’s saturated thickness” (Anderson and Woessner, 1992).

Transmissivity for the alluvial washes was evaluated in the permit area at 19 locations using time-distance drawdown aquifer tests in pits excavated into the alluvium or slug injection tests in the alluvial well bores (Figure 15). Time-drawdown pit tests were performed when meaningful drawdown responses could not be obtained in the alluvial wells prior to depleting all the water from the well bores. Therefore, where alluvial water levels were shallow and hydraulic conductivity high, pit pumping tests were performed. Transmissivity values from pit pumping tests near alluvial wells 74, 84, 88, and 95 ranged from 1870-5100 gallon per day per foot (gpd/ft), and transmissivity values derived from slug injection tests ranged from 21-1517 gpd/ft (PWCC, v.9, ch.15, 2016). The heterogeneity of the channel alluvium identified during review of the borehole lithology is evident in the transmissivity results for the various washes, which typically vary an order of magnitude within the same wash.

The alluvium is recharged from infiltration of surface water runoff from direct precipitation, and from groundwater emanating from saturated areas of the Mesa Verde Group in communication with the valley alluvium. The alluvial channels have not downcut to elevations in the permit area where the channels truncate the Toreva Formation of the Mesa Verde Group. Therefore, the groundwater portion of recharge is predominantly derived from saturated areas of the Wepo Formation of the Mesa Verde Group truncated by alluvial channels, and minor contribution from the Yale Point Sandstone Formation of the Mesa Verde Group in the northern and northeastern areas of Black Mesa above the permit area (PWCC, v.9, ch.15, 2016). Recharge to the alluvium from the truncated saturated areas of the Wepo Formation account for the maintenance of alluvial water levels during extended dry periods.

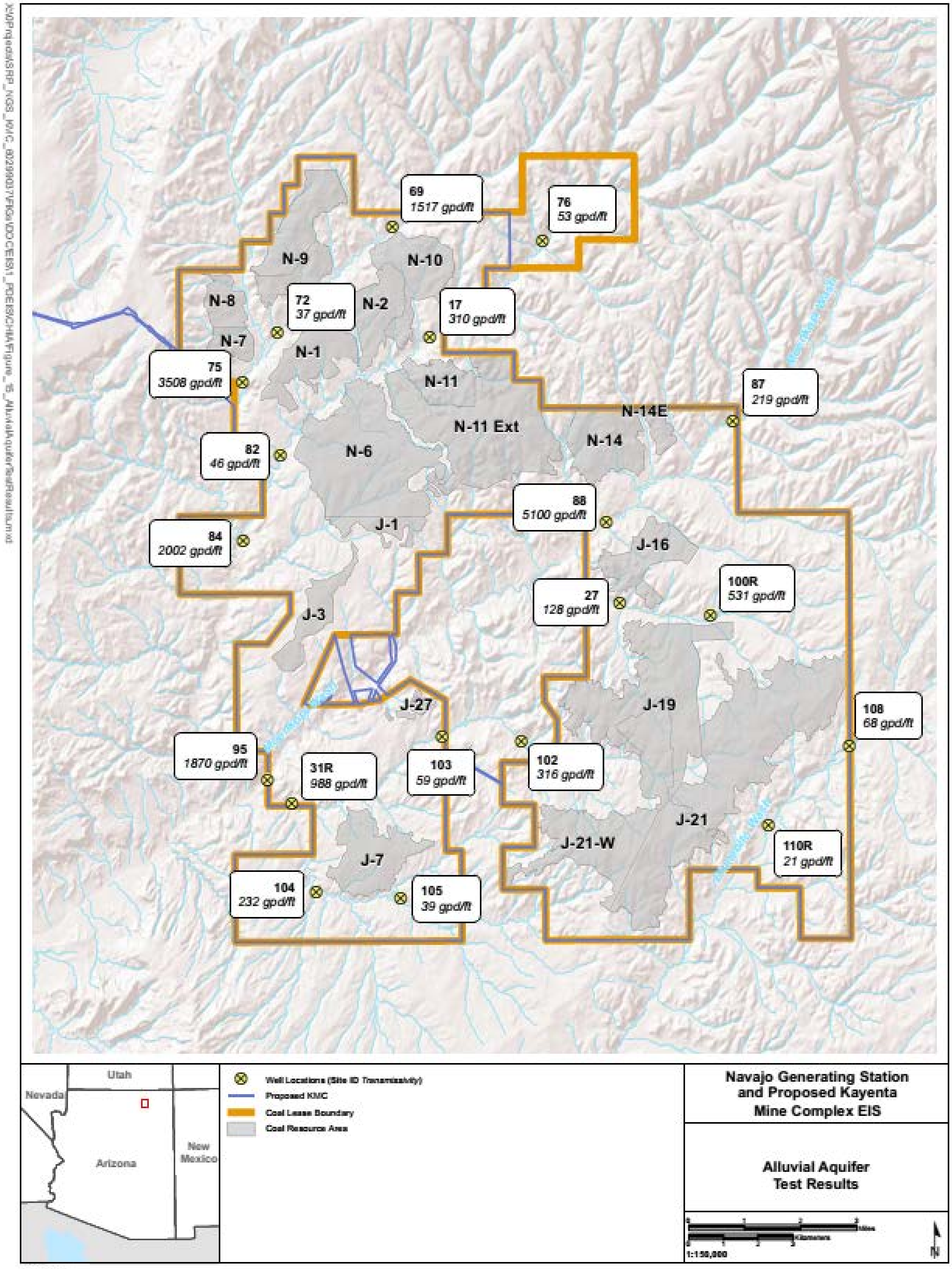



**Figure 15: Alluvial Aquifer Test Results, Kayenta Mine Complex.**

Seismic refraction surveying noted the occurrence of water level gradients from the Wepo Formation to the alluvium at alluvial monitoring locations 31R, 77, 100R, 103, 107, and 110R (PWCC, v.9, ch.15, 2016). Typically, alluvial monitoring well hydrographs show gradual water level declines in the spring and late fall, and water level rises during the summer monsoon period and during wet winters in response to the infiltration of surface water runoff.

Alluvial groundwater flow rates are driven by local hydrologic gradients, which vary depending on magnitude, frequency, and duration of the surface runoff and subsequent infiltration rates. Alluvial water discharge to the atmosphere by transpiration of phreatophytes along the alluvial channels is a factor at localized areas. Water level fluctuations during the spring and summer months have been observed at alluvial monitoring wells 33R, 83, 84, and 95 near tamarisk phreatophytes (PWCC, v.11, ch.18, 2016).

#### 4.2.2.2 Alluvial Baseline Quality

Water quality of the alluvial drainages was evaluated for agricultural livestock watering use with the alluvial monitoring well network (Figure 13). Table 3 presents water quality summary statistics for upstream alluvial monitoring wells for the Dinnebito Wash CIA and Moenkopi Wash CIA related to Agricultural Livestock Watering WQS.

The nature of recharge to the alluvium varies depending on the season of the year. The majority of alluvial recharge occurs during the monsoon season of July, August, and September when surface water flow events infiltrate into the channel alluvium. Recharge to the alluvium also occurs as a result of surface water runoff generated from snowmelt events typically occurring in February and March. When surface water runoff is not recharging the alluvium from downward infiltration of surface water, the dominant recharge process occurs from horizontal flow of the Wepo Formation discharging into the adjacent alluvium, typically during April and May. Therefore, the nature of recharge may potentially have seasonal influence on alluvial water quality.

In order to assess the potential seasonal influence on alluvial water quality within the primary alluvial washes, statistical analysis of sulfate was evaluated for time periods when the alluvium is recharged by storm water flow, snow melt runoff, or contribution from the Wepo Formation. The first part of the analysis evaluated the entire group of sulfate concentrations within each major wash broken down by dominant recharge mechanism, determined by sample collection date, and compared recharge mechanisms. The second part of the analysis evaluated the differences in sulfate concentrations between the monitoring locations within each wash after grouping the data by recharge mechanism, and compared location differences. Parametric and non-parametric statistical methods were applied to evaluate the statistical significance of the means and medians of the data grouped by recharge mechanism. Normality of the data distribution was also considered. If the data were normally distributed, then ANOVA, Cochran, Barlett, Hartley, and Levene analyses were considered. If the data were not normally distributed, then the Kruskal-Wallis method was considered.

The results indicate that differences in alluvial water quality based on comparing recharge mechanism are not statistically significant at the 95% confidence interval for the four primary alluvial drainages (PWCC, v.11, ch.18, 2016). However, statistical differences are apparent when comparing concentrations in alluvial wells from different locations within the same alluvial drainage. Location based statistical differences are also apparent in all sampled alluvial drainages when comparing the different recharge mechanisms. The local seasonal influences of the different recharge mechanisms may effect on the water quality variability at any location, but not significantly compared to the water quality variability from location to location. Therefore, OSMRE evaluated upstream alluvial monitoring wells and downstream alluvial monitoring wells for comparison. If impacts are identified at downstream alluvial monitoring locations, evaluation of specific stream reaches may be necessary.

| | | | | | Dinnebito Wash CIA<br>Location 108R | | | | Moenkopi Wash CIA<br>Locations 69, 77, and 87 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemical Parameter | Agricultural Livestock Watering WQS | WQS | Units | Type | # Samples | Low | Median | High | # Samples | Low | Median | High |
| Aluminum | HT | 5 | mg/L | Dissolved | n=37 | 0.03 | 0.05 | 0.5 | n=129 | 0.03 | 0.05 | 2 |
| Arsenic | HT and NN | 200 | μg/L | Dissolved | n=37 | 0.5 | 1 | 32 | n=99 | 0.5 | 1 | 20 |
| Bicarbonate | NNS | NNS | mg/L | Dissolved | n=36 | 242 | 305 | 354 | n=132 | 193 | 338 | 827 |
| Boron | NN | 5000 | μg/L | Dissolved | n=37 | 10 | 100 | 160 | n=129 | 20 | 110 | 500 |
| Calcium | NNS | NNS | mg/L | Dissolved | n=37 | 479 | 561 | 666 | n=132 | 106 | 214 | 604 |
| Cadmium | HT and NN | 50 | μg/L | Dissolved | n=37 | 3 | 5 | 50 | n=132 | 3 | 5 | 300 |
| Chloride | NNS | NNS | mg/L | Total | n=37 | 30 | 59 | 77 | n=129 | 3 | 26 | 230 |
| Chromium | HT and NN | 1000 | μg/L | Dissolved | n=37 | 10 | 10 | 90 | n=129 | 5 | 10 | 500 |
| Copper | HT and NN | 500 | μg/L | Dissolved | n=37 | 10 | 10 | 60 | n=129 | 5 | 10 | 500 |
| Lead | HT and NN | 100 | μg/L | Dissolved | n=37 | 20 | 20 | 200 | n=129 | 1 | 20 | 400 |
| Magnesium | NNS | NNS | mg/L | Dissolved | n=37 | 201 | 242 | 289 | n=132 | 21 | 205 | 1470 |
| Mercury | HT | 10 | μg/L | Dissolved | n=37 | 0.1 | 0.2 | 0.5 | n=132 | 0.1 | 0.2 | 1 |
| Selenium | HT and NN | 50 | μg/L | Dissolved | n=37 | 1 | 1 | 10 | n=132 | 1 | 2 | 10 |
| Sodium | NNS | NNS | mg/L | Dissolved | n=37 | 260 | 314 | 401 | n=132 | 78 | 165 | 1570 |
| Sulfate | NNS | NNS | mg/L | Total | n=37 | 2390 | 2774 | 3005 | n=132 | 175 | 1470 | 9410 |
| TDS | NNS | NNS | mg/L | Total | n=37 | 4058 | 4311 | 4640 | n=132 | 460 | 2312 | 15100 |
| Vanadium | HT and NN | 100 | μg/L | Dissolved | n=37 | 5 | 10 | 50 | n=129 | 5 | 10 | 500 |
| Zinc | HT and NN | 25 | mg/L | Dissolved | n=37 | 0.01 | 0.01 | 0.12 | n=129 | 0.01 | 0.01 | 0.5 |

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 3. Alluvial water quality sample ranges for upstream locations, Kayenta Mine Complex (1986-2010).

Seasonal water quality was documented using TDS in the alluvial wells to evaluate the water quality variability in the PHC demonstration (PWCC, v.11, ch.18, 2016). Data were grouped into dominant recharge mechanisms based on seasonal recharge characteristics to the alluvium: snowmelt recharge, Wepo recharge, and rainfall recharge. TDS concentrations are typically lower in alluvial wells during rainfall recharge as the infiltrated rain water has a diluting effect on alluvial water quality. When Wepo recharge is dominant during the dry period, Wepo Formation water having typically elevated TDS concentrations is the major recharge source water. The elevated TDS concentrations are reflected in the alluvial monitoring wells. Similarly, elevated TDS concentrations are observed in alluvial monitoring wells during the snowmelt period. Higher TDS concentrations during the snowmelt period in the alluvial wells may be attributed to a combination of the increased residence time for snowmelt to interact with mineral facies, or recharge from the Wepo still acting as the dominant recharge mechanism. Therefore, seasonality of the recharge water adds to the variability in the data, but the water quality variability between monitoring locations is most significant for impact evaluation regardless of recharge mechanism.

Due to the statistical variability in between locations, trend analysis was performed at each location. A time series plot of each parameter of interest was developed and fit with a least squares trend line best fitting the data for trend analysis. The slope of the trend line was determined to have a positive or negative trend, and whether the slope of the trend was statistically different from zero at the 95% confidence interval (PWCC, v.11, ch.18, 2016). The trends identified will be further discussed in the impact evaluation in Chapter 5. However, the trends for the monitoring well furthest upstream of all mining impacts in the sampled drainages will be discussed.

Monitoring well 69 is located in Yellow Water Canyon Wash, and upstream of all mining activities. Negative trends for sulfate, calcium, sodium, and magnesium, and positive trends in bicarbonate and TDS were identified at location 69 based on the period of record; however, no trend has a slope significantly different than zero. Monitoring well 77 is located in Coal Mine Wash, upgradient of all mining activities. Negative trends for sulfate, calcium, sodium, magnesium, and TDS were identified at location 77; however, none of the negative slopes are significantly different than zero. Location 77 does have a positive trend for bicarbonate that is significantly different than zero. Monitoring well 87 is located on Moenkopi Wash upstream of all mining activities and has a negative sulfate trend slope not significantly different than zero, a negative trend for calcium, sodium, magnesium, TDS, and a positive trend slope for bicarbonate. Monitoring location 108R located in Moenkopi Wash upstream of all mining activities has mixed trend slope results for the primary parameters of interest. Sulfate and calcium trends are not significantly different than zero at location 108R. Positive trends for sodium, bicarbonate, and TDS, and a negative trend for magnesium are apparent at location 108R for the period of record. Overall, the upstream background locations typically have a signature of elevated sulfate concentrations, with the exception of the upper reach of Coal Mine Wash, and the upstream water quality is not changing appreciably.

### 4.2.3 Wepo Formation

The Mesa Verde Group is the uppermost lithology on Black Mesa and includes in the Yale Point Sandstone, Wepo Formation, and Toreva Formation. The Wepo Formation consists of the coal mined at the Kayenta Mine Complex, and the mining operations may intercept local areas of groundwater from the Wepo Formation. This section characterizes the nature of water quantity and quality for the Wepo Formation within Wepo Formation CIA delineated in Section 2.2.1 using information collected at PWCC Wepo sampling locations (Figure 16).

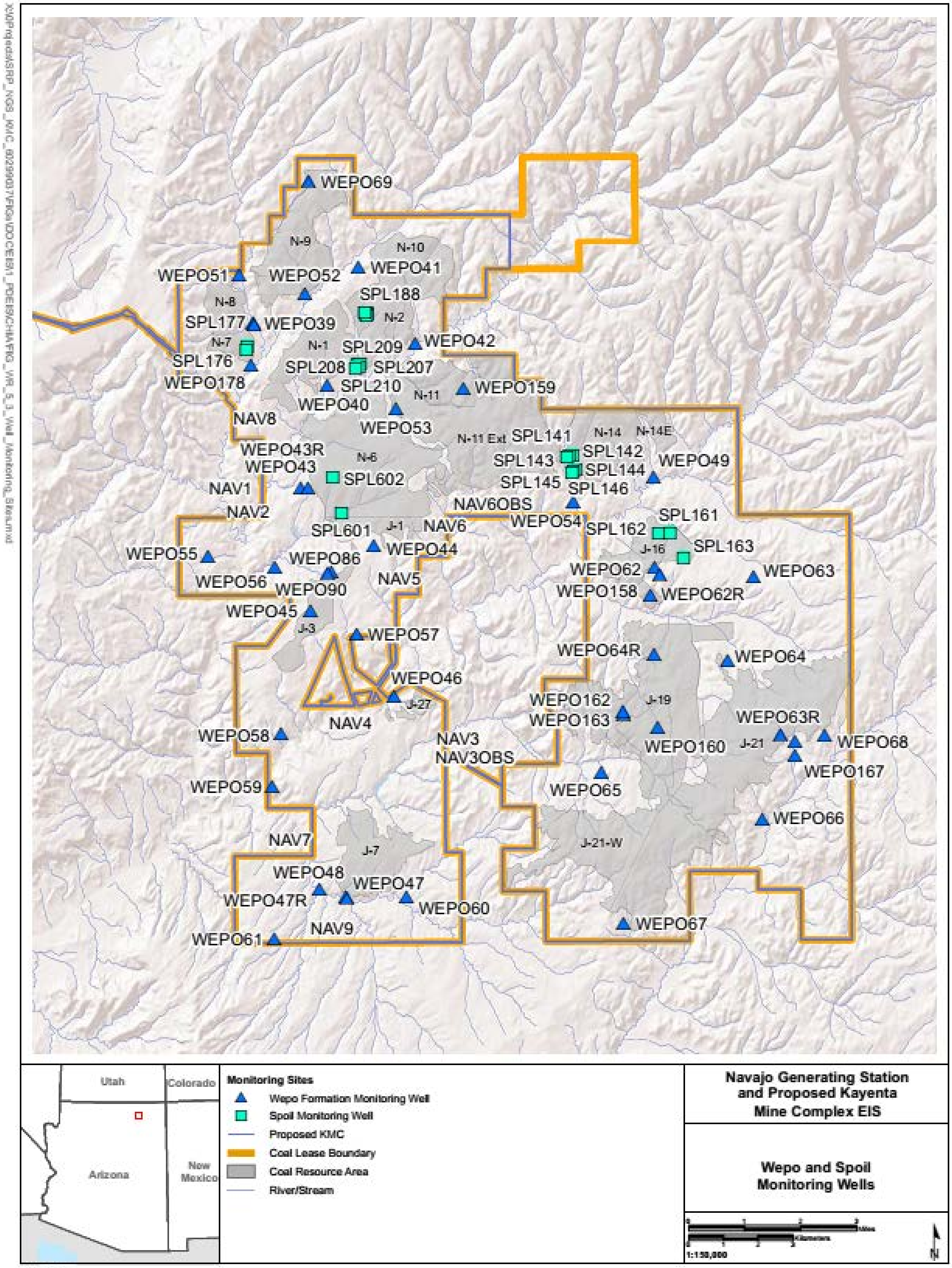



**Figure 16: Wepo and Spoil Monitoring Wells, Kayenta Mine Complex (BOR, 2016, Figure WR-5.3)**

#### 4.2.3.1 Wepo Formation Baseline Quantity

Wepo Formation monitoring wells were primarily located downgradient of existing and potential surface mine areas. Additional Wepo Formation wells were installed upgradient from mine areas, within reclaimed mine pits, and in areas where mining is not anticipated to occur to provide further characterization of the Wepo aquifer and use potential. Well logs indicate the Wepo Formation is highly heterogeneous throughout the CIA delineated in Section 2.2.1 (Figure 8). The Wepo Formation contains low yielding perched aquifers that pinch out or are vertically displaced by minor structural deformation identified within the Kayenta Mine Complex (PWCC, v.11, ch.18, 2016). Figure 17 illustrates the coal bed sequence in the previously mined N-6 resource area. The coal deposits are typically five to fifteen feet thick and separated by interburden deposits. Some minor geologic structural deformation has been identified in the permit area identified by small stratigraphic offsets in the Wepo Formation.

**Figure 17: Wepo Formation in N-6 with minor offset (photos by OSMRE, 5-25-2005).**

The primary alluvial drainages (Yellow Water Canyon Wash, Coal Mine Wash, Moenkopi Wash, and Dinnebito Wash) and associated tributaries truncate the Wepo Formation in areas within the CIA. Throughout the permit area, the Wepo Formation receives direct recharge from surface precipitation since it is exposed at the surface (Repenning and Page, 1956). Infiltrated precipitation source water flows towards areas of lower elevation until the water discharges to the surface as surface flow, or the alluvial drainages as baseflow. Therefore, the groundwater flow paths for water in the Wepo Formation are typically oriented towards the primary alluvial drainages and towards the mine pits when Wepo Formation water is intercepted (Figure 8). Since the flow paths are oriented toward the alluvial drainages, the groundwater contours generally mimic the surface topography.

The surface topography is highest to the northeast of the permit area and lowest to the southwest. Since the water level contours generally mimic the surface topography, regional Wepo Formation groundwater flow is toward the southwest and locally toward the alluvial drainages. Therefore, groundwater impact to the Wepo Formation will not extend significantly north of the mined coal resource areas based on groundwater flow direction. The eastern boundary of the CIA is defined by coal resource area J-21 and Dinnebito Wash. Similar to the northern coal resource areas, potential groundwater impacts will not propagate in the opposite direction of the flow path near J-21, which defines part of the eastern CIA boundary. Dinnebito Wash provides a hydrologic boundary to Wepo groundwater impacts. Dinnebito Wash has incised the Wepo Formation, allowing Wepo Formation water to discharge to the wash. The discharged water to Dinnebito Wash is monitored as part of the alluvial monitoring program. The southern CIA boundary crosses two surface water drainages: Moenkopi Wash and Dinnebito Wash. Therefore, some Wepo Formation water discharges to Dinnebito Wash and some discharges to Moenkopi Wash. The southern boundary was delineated to mimic surface topography divides. The western boundary of the CIA was delineated considering Yellow Water Canyon Wash and Coal Mine Wash as hydrologic boundaries. Downcutting of surface water in Yellow Water Canyon Wash and Coal Mine Wash have incised the Wepo Formation and allows discharge of Wepo water to these two washes.

Twenty-two Wepo wells were tested to characterize the water production potential of the Wepo Formation within the CIA. The Wepo Formation transmissivity values in the CIA, which relate the water production potential, vary four orders magnitude; from 0.1 gpd/ft at well 62, to 666 gpd/ft at well 51 (Figure 18). The median transmissivity is 40 gpd/ft, and mean transmissivity 121 gpd/ft.

Where the Wepo Formation is in hydrologic communication with the alluvium, the Wepo may receive recharge from surface water that has infiltrated into the alluvium. When the alluvium is saturated during surface flow events, the hydraulic gradient may temporarily reverse until the surface flow event and water in alluvial bank storage dissipates. Temporary and localized influence of the surface water and alluvial groundwater on the Wepo monitoring system has been observed shortly after surface flow events in several Wepo monitoring wells in close proximity to the alluvium (PWCC, v.9, ch.15, 2016).

#### 4.2.3.2 Wepo Baseline Quality

Table 4 presents water quality summary statistics for parameters with an Agricultural Livestock Watering WQS, and major cations and anions, for the wells screened in the Wepo Formation within the Kayenta Mine Complex. The major cations and anions include TDS, sulfate, magnesium, calcium, bicarbonate, sodium, and chloride. The following Wepo wells are considered background wells due to significant distance from area disturbed by mining: 54, 55, 56, 57, 58, 59, 61, 65, and 67. Additional monitored Wepo wells may also be representative of background conditions based on the water quality results from the monitoring period, but OSMRE has identified the above listed wells as representative of background for this assessment.

The TDS concentrations in the selected background Wepo Formation wells range from 446 mg/L at well 61 to 2,000 mg/L at well 59. The median TDS concentration for all of the background Wepo Formation wells is 779 mg/L. Sulfate concentrations in background Wepo Formation wells range from 2 mg/L at well 55 to 1,200 mg/L at well 59. The median sulfate concentration for all background Wepo wells is 121 mg/L. Magnesium concentrations in background Wepo Formation wells range from 0.3 mg/L to 91 mg/L with a median concentration of 2.1 mg/L. Calcium concentrations in background Wepo Formation wells range from 1 mg/L to 188 mg/L with a median concentration of 9.8 mg/L. Sodium concentrations range from 160 mg/L to 744 mg/L with a median concentration of 270 mg/L. Chloride concentrations range from 3 mg/L to 48 mg/L in background Wepo Formation wells with a median concentration of 11 mg/L.

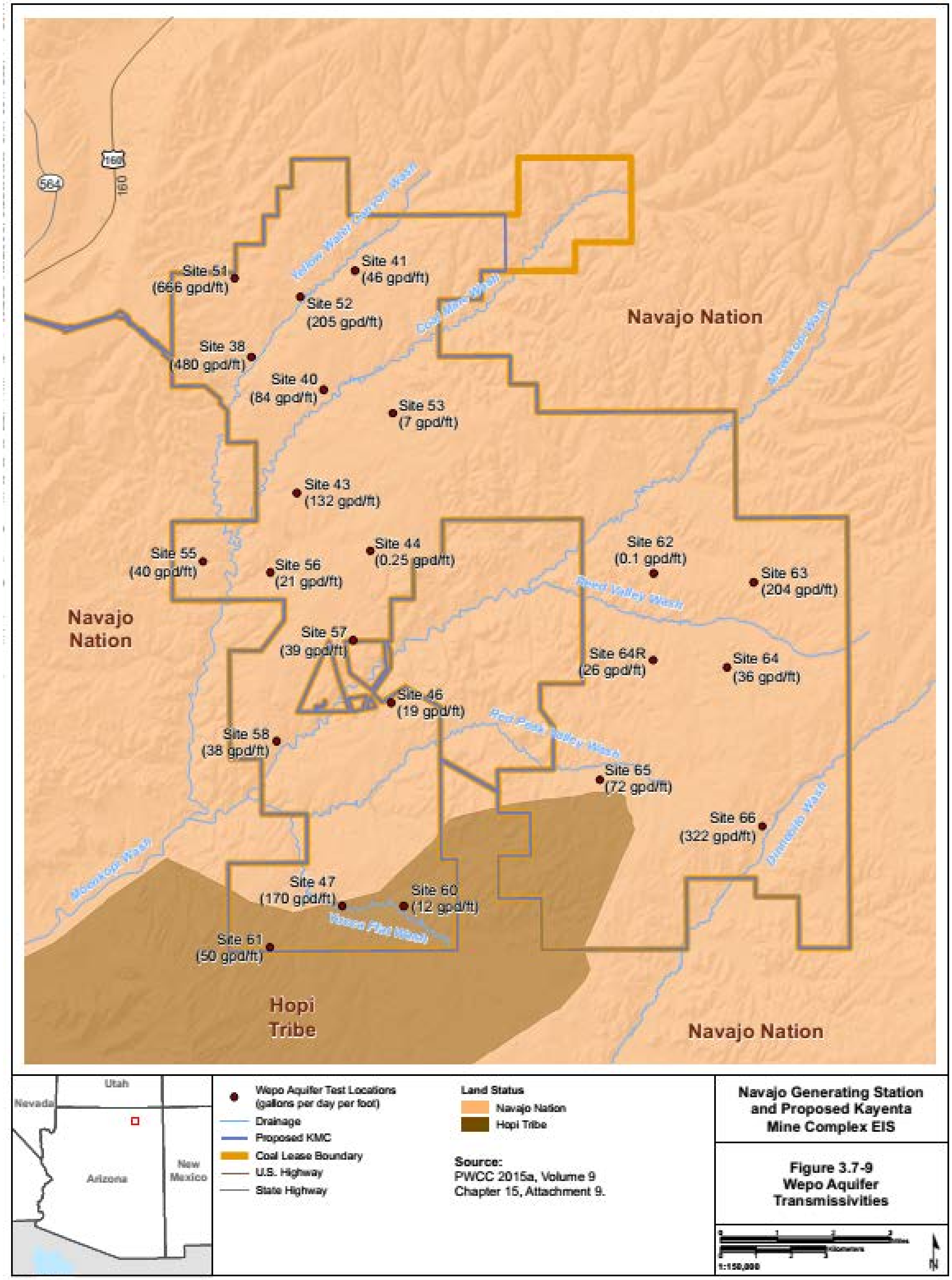



**Figure 18: Wepo Aquifer Transmissivities, Kayenta Mine Complex (BOR, 2016, Figure 3.7-9).**

| Chemical Parameter | Agricultural Livestock Watering WQS | WQS | Units | Type | Background Wepo Wells Locations 47, 55, 56, 57, 59, 61, 65, 67 | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | # Samples | Low | Median | High |
| Aluminum | HT | 5 | mg/L | Dissolved | n=212 | 0.03 | 0.05 | 1.69 |
| Arsenic | HT and NN | 200 | µg/L | Dissolved | n=212 | 0.1 | 1 | 20 |
| Bicarbonate | NNS | NNS | mg/L | Dissolved | n=212 | 200 | 434 | 2228 |
| Boron | NN | 5000 | µg/L | Dissolved | n=212 | 20 | 200 | 1200 |
| Calcium | NNS | NNS | mg/L | Dissolved | n=212 | 1 | 9.8 | 188 |
| Cadmium | HT and NN | 50 | µg/L | Dissolved | n=212 | 3 | 5 | 20 |
| Chloride | NNS | NNS | mg/L | Total | n=212 | 3 | 11 | 48 |
| Chromium | HT and NN | 1000 | µg/L | Dissolved | n=212 | 5 | 10 | 30 |
| Copper | HT and NN | 500 | µg/L | Dissolved | n=212 | 5 | 10 | 50 |
| Lead | HT and NN | 100 | µg/L | Dissolved | n=212 | 1 | 40 | 200 |
| Magnesium | NNS | NNS | mg/L | Dissolved | n=212 | 0.3 | 2.1 | 91 |
| Mercury | HT | 10 | µg/L | Dissolved | n=212 | 0.1 | 0.2 | 1 |
| Selenium | HT and NN | 50 | µg/L | Dissolved | n=212 | 1 | 1 | 11 |
| Sodium | NNS | NNS | mg/L | Dissolved | n=212 | 160 | 270 | 744 |
| Sulfate | NNS | NNS | mg/L | Total | n=212 | 2 | 121 | 1200 |
| TDS | NNS | NNS | mg/L | Total | n=369 | 446 | 779 | 2000 |
| Vanadium | HT and NN | 100 | µg/L | Dissolved | n=212 | 5 | 5 | 500 |
| Zinc | HT and NN | 25 | mg/L | Dissolved | n=212 | 0.005 | 0.01 | 0.08 |

NNS - No Numeric Standard
WQS - Water Quality Standard
CIA - Cumulative Impact Area

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

NN - Navajo Nation
HT - Hopi Tribe

Table 4. Wepo Formation water quality sample ranges for background locations, Kayenta Mine Complex (1986-2010).

### 4.2.4 D Aquifer

The D aquifer is regionally extensive throughout the Black Mesa area (Figure 19), and limited water is currently withdrawn from the D aquifer system by communities and windmills. Historically, the PWCC wellfield withdrew limited D aquifer water from PWCC NAV wells with screened portions of D aquifer. However, from 2014 - 2016 wells with screened interval into the D aquifer were either cased off or properly abandoned after Tribal approval. Currently, no PWCC pumping wells are open to the D aquifer.

The D aquifer is composed, in order of oldest to youngest, of the Entrada Sandstone of the Summerville Formation, the Cow Springs Sandstone, the sandstone members of the Morrison Formation and the Dakota Sandstone. The Entrada Sandstone consists of three members, represented by two facies: a clean sandstone facies in the upper and lower members, and a silty facies in the middle member. The Summerville Formation is comprised of an upper sandy facies and a lower silty facies. The thickness of the Summerville Formation is variable where tongues of the Cow Springs Sandstone constitute part of the formation. The Cow Springs sandstone deposits are extensive, ranging from 230 feet to 449 feet in the southwest portion of the CIA. The tongues of the Cow Springs sandstone also intertongue extensively with members of the Morrison Formation. In the northeast part of the CIA, the Cow Springs sandstone is hydraulically connected with the Recapture and Salt Wash Members of the Morrison Formation. In the southwestern CIA area, the Cow Springs is hydraulically connected to the Entrada Sandstone and Dakota Formation, as the Morrison is absent in this area. The Dakota sandstone ranges in thickness from 40 feet to 150 feet, regionally thinning to the south and southwest on Black Mesa. Additional detail of the D aquifer lithology can be found in the documentation for the regional three-dimensional numerical model of the Black Mesa Basin (3D Model) (PWCC, 1999).

The D aquifer system is a complex hydraulic interconnection of several formations and members. However, an evaluation of D aquifer water level and water chemistry data indicates that the Mancos shale confining unit above, and the Carmel Formation below, allows these interconnected formations to behave as a regional aquifer system.

#### 4.2.4.1 D aquifer Baseline Quantity

Water quantity for the D aquifer system is based on the hydraulic properties of the formations comprising the system. Hydraulic properties of horizontal and vertical hydraulic conductivity, saturated thickness, flow gradients, and aquifer storage of the D aquifer formations assist in the evaluation of water quantity. Stetson (1966) installed a test well in the permit area as part of a wellfield development feasibility study for the Kayenta Mine Complex. Isolating and stressing the saturated 1,050 feet of Entrada, Morrison, and Dakota Formations comprising the D aquifer system at this location for 700 minutes, at a rate of 23 gallons per minute, produced 59 feet of drawdown in the pumping well (Stetson, 1966). Using the Theis recovery test for hydraulic property analysis, a transmissivity of 440 gallons/day/foot (hydraulic conductivity of 0.056 ft/day) was calculated based on the natural rate of recovery (Stetson, 1966).

Similar horizontal conductivity values as Stetson (1966) were developed for formations comprising the D aquifer system through steady state calibration of the 3D Model (PWCC, 1999). Steady state calibration involves adjusting hydraulic conductivity and storage values until model simulated D aquifer water levels generally agree with regional measured water level elevations in D aquifer wells prior to significant pumping. For the 3D Model, steady state conditions occurred prior to 1956; however, hydraulic head measurements up through the end of 1969 were included as calibration targets for equilibrium conditions to increase the areal coverage due to the limited measurements made prior to 1956. Community pumping effects were localized at Kayenta, Kykotsmovi, Rocky Ridge, and Rough Rock prior to 1969, and significant pumping at the PWCC wellfield did not begin until 1970 (Macy and Unema, 2014); therefore, the inclusion of hydraulic head water levels from 1956-1969 for equilibrium conditions is appropriate.

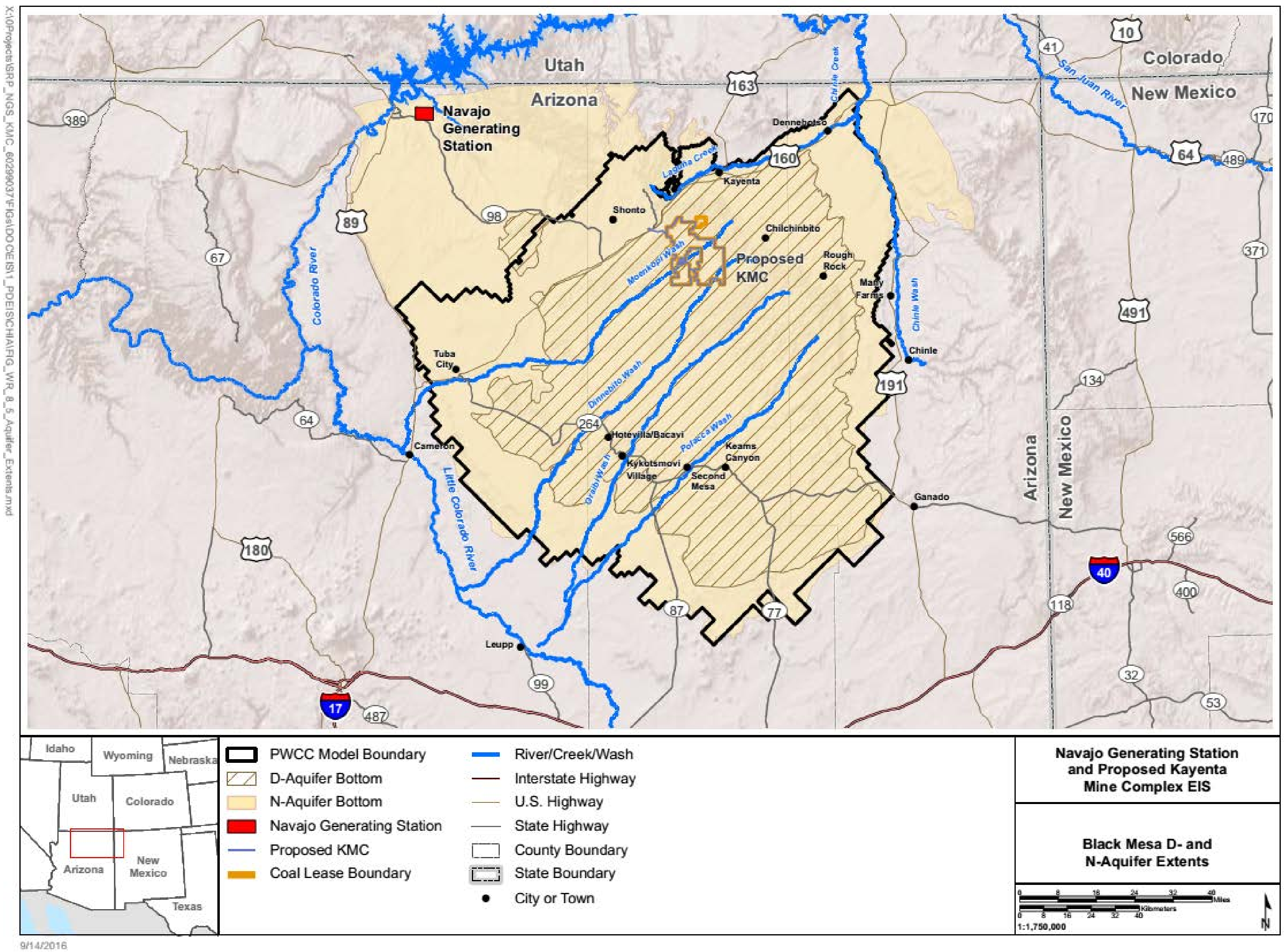



**Figure 19: Black Mesa D and N Aquifer Extents (BOR, 2016, Figure WR-8.5).**

After review of well log information, water level measurements, water chemistry, geologic structure information, and spring elevations, water level data from wells and springs were used as D aquifer steady state calibration targets for the 3D Model pre-pumping simulation (Figure 20). The resultant steady state potentiometric surface map for the D aquifer is illustrated as Figure 21. The D aquifer system is recharged from direct precipitation on ephemeral streams in areas where D aquifer formations are exposed at the surface or covered by permeable veneer of unconsolidated sediments. Steady state (pre-significant pumping) D aquifer flow occurred from the recharge area in the southeast and east predominantly toward the west and southwest and through the center of the basin. Steady state D aquifer discharge occurred northeast to Laguna Creek and along downcut washes intercepting the D aquifer formations near the southern Hopi communities.

#### 4.2.4.2 Dakota Aquifer Baseline Quality

As water recharging the D aquifer flows toward the discharge areas, water-rock reactions dissolve formation constituents changing the groundwater chemistry along the flow path. Thin section analysis of rocks comprising the D aquifer reveal the persistence of alkali and plagioclase feldspars, clays, iron oxides, chert, and calcium-carbonate cement (GeoTrans Inc., 1993). The dissolution of feldspar contributes calcium, sodium, potassium, aluminum, and silicon into solution along the flow path. Then, the exchange of calcium and sodium ions in the clays and lignite found in the Dakota Sandstone contribute to the formation of sodium bicarbonate type water along the flow path (Truini and Longsworth, 2003). Additionally, the dissolution of sulfate from gypsum and lignite stringers contributes to increases in sulfate along the D aquifer flow paths. The overall quality of the D aquifer tends to have higher dissolved concentrations of boron, chloride, sodium, and sulfate compared to N aquifer water, resulting in elevated TDS concentrations (Truini and Longsworth, 2003). Elevated ion concentrations and TDS often limit the use and development of the D aquifer in the region.

Groundwater will flow from areas of high potential energy to areas of lower potential energy, and follow the path of least resistance. Since the D aquifer is confined above by the Mancos Shale, and below by the Carmel Formation having a low hydraulic conductivity compared to the formations comprising the D aquifer, flow is generally horizontal from east to west along the D aquifer flow paths. However, measured water levels defining the D aquifer potentiometric surface are typically higher than measured water levels of the underlying N aquifer potentiomentric surface in the area of the confined D aquifer. Figure 22 illustrates the hydraulic head differences between the D and N aquifers. Therefore, a vertical flow potential exists for poorer quality D aquifer water to flow through the Carmel Formation to the underlying N aquifer.

The baseline vertical flow potential from the D aquifer to the N aquifer was investigated by the USGS using geochemical and isotopic analysis (Truini and Longsworth, 2003). The findings indicate that vertical flow leakage from the D aquifer to the N aquifer has been occurring for thousands of years, and has a higher likelihood of occurring in the southern part of Black Mesa (Truini and Longsworth, 2003). Truini and Macy (2006) related the thickness and lithology of the Carmel Formation to groundwater leakage in the southern part of Black Mesa using borehole-geophysical data and lithologic descriptions from drill logs. Figure 23 illustrates the approximate area where groundwater leakage likely occurs.

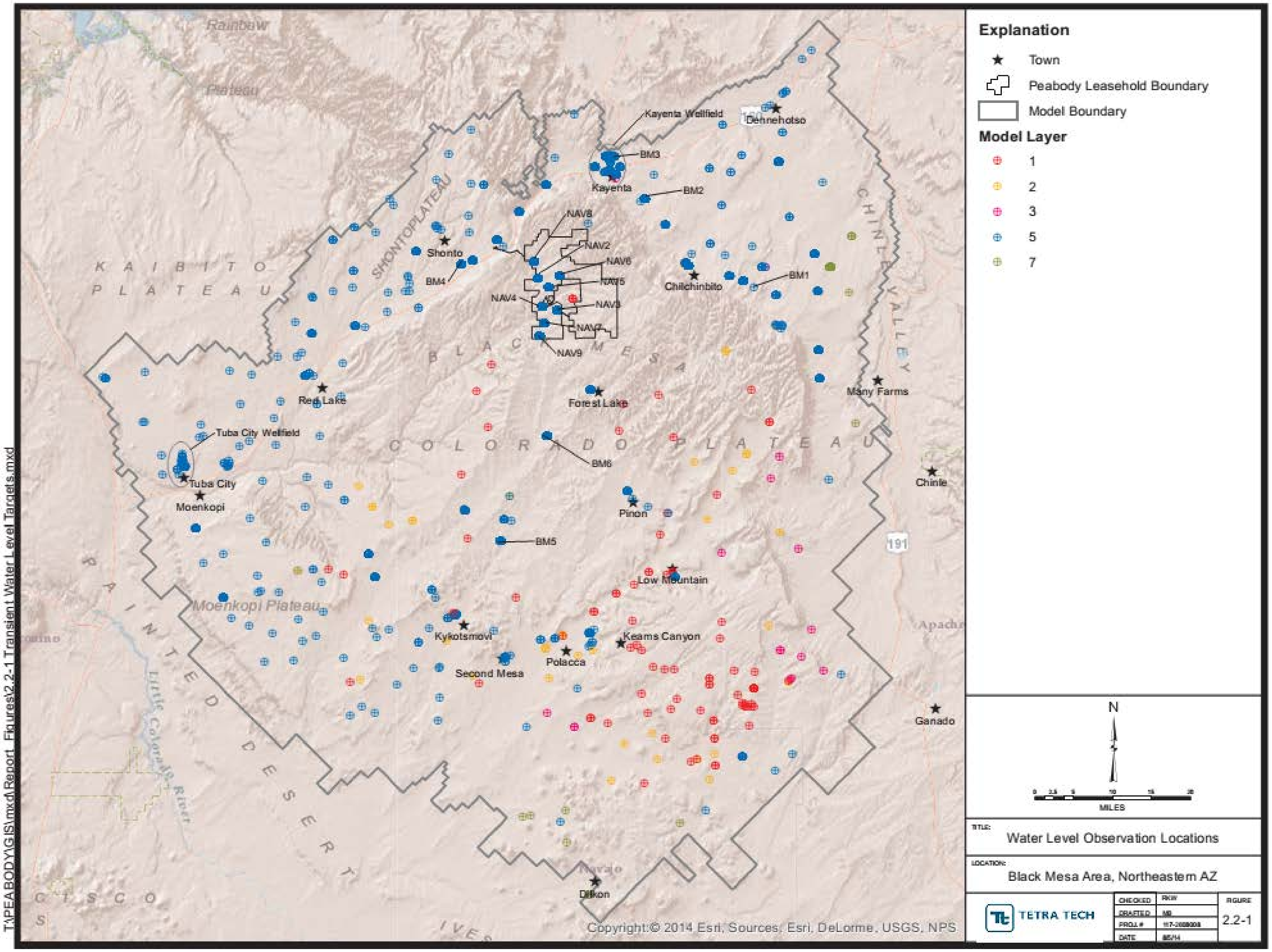



**Figure 20: D aquifer (Layer 3) and N aquifer (Layer 5) Steady State Target Water Level Locations, Black Mesa, Arizona (PWCC, 2016).**

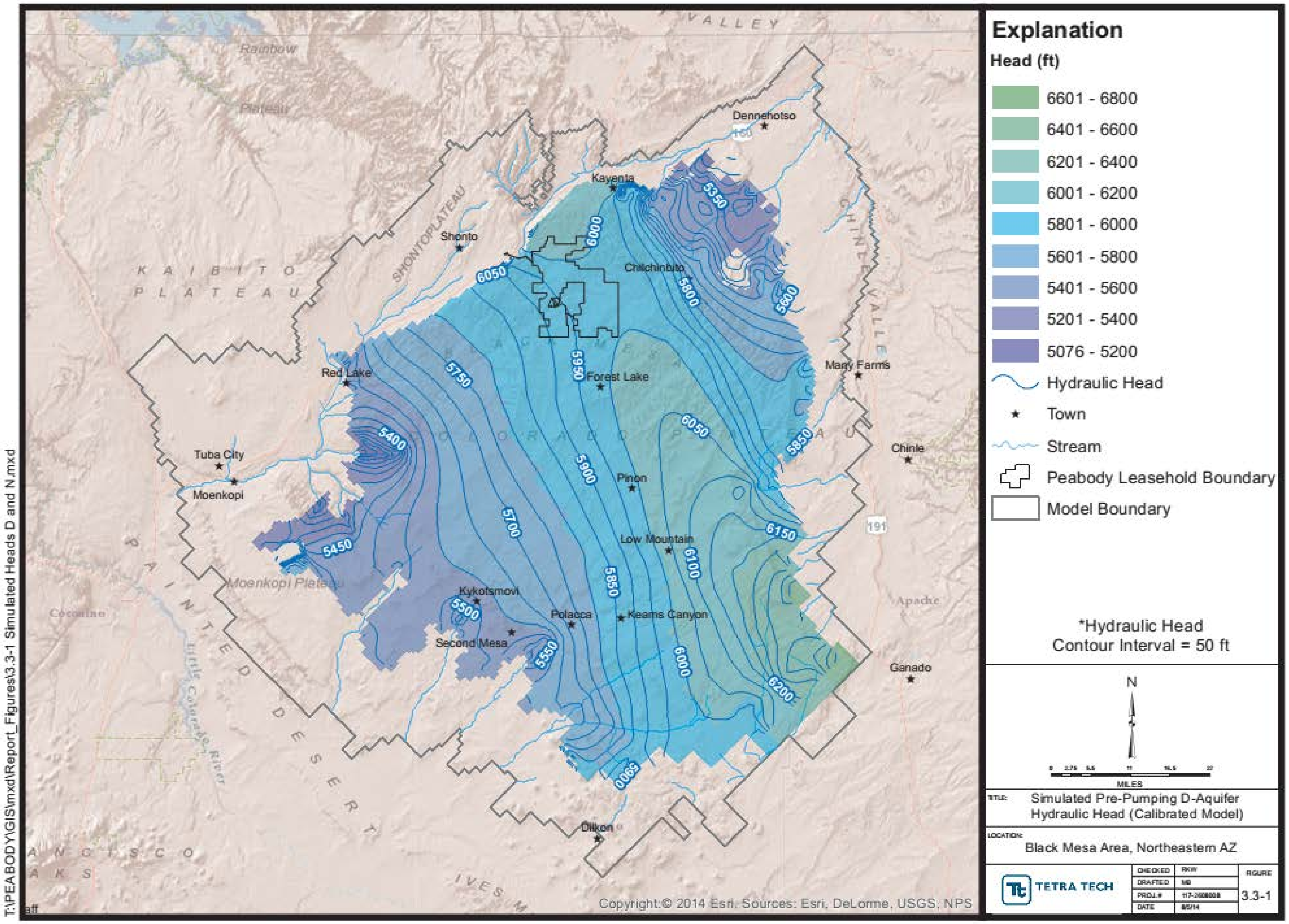



**Figure 21: D aquifer Steady State Potentiometric Surface, Black Mesa, Arizona (PWCC, 2016).**

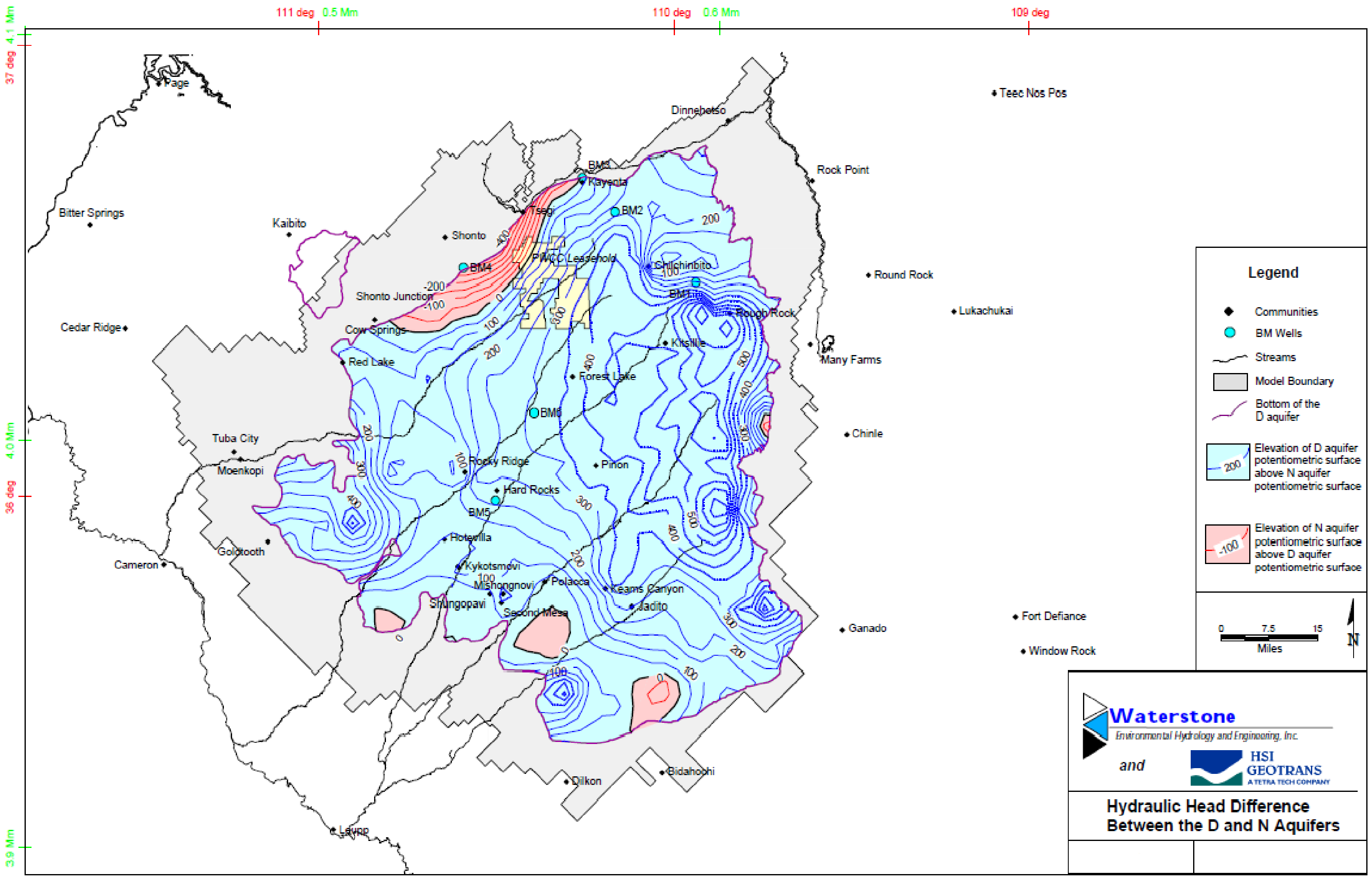



**Figure 22: Hydraulic Head Difference Between the D and N Aquifers, Black Mesa, Arizona (PWCC, 1999).**

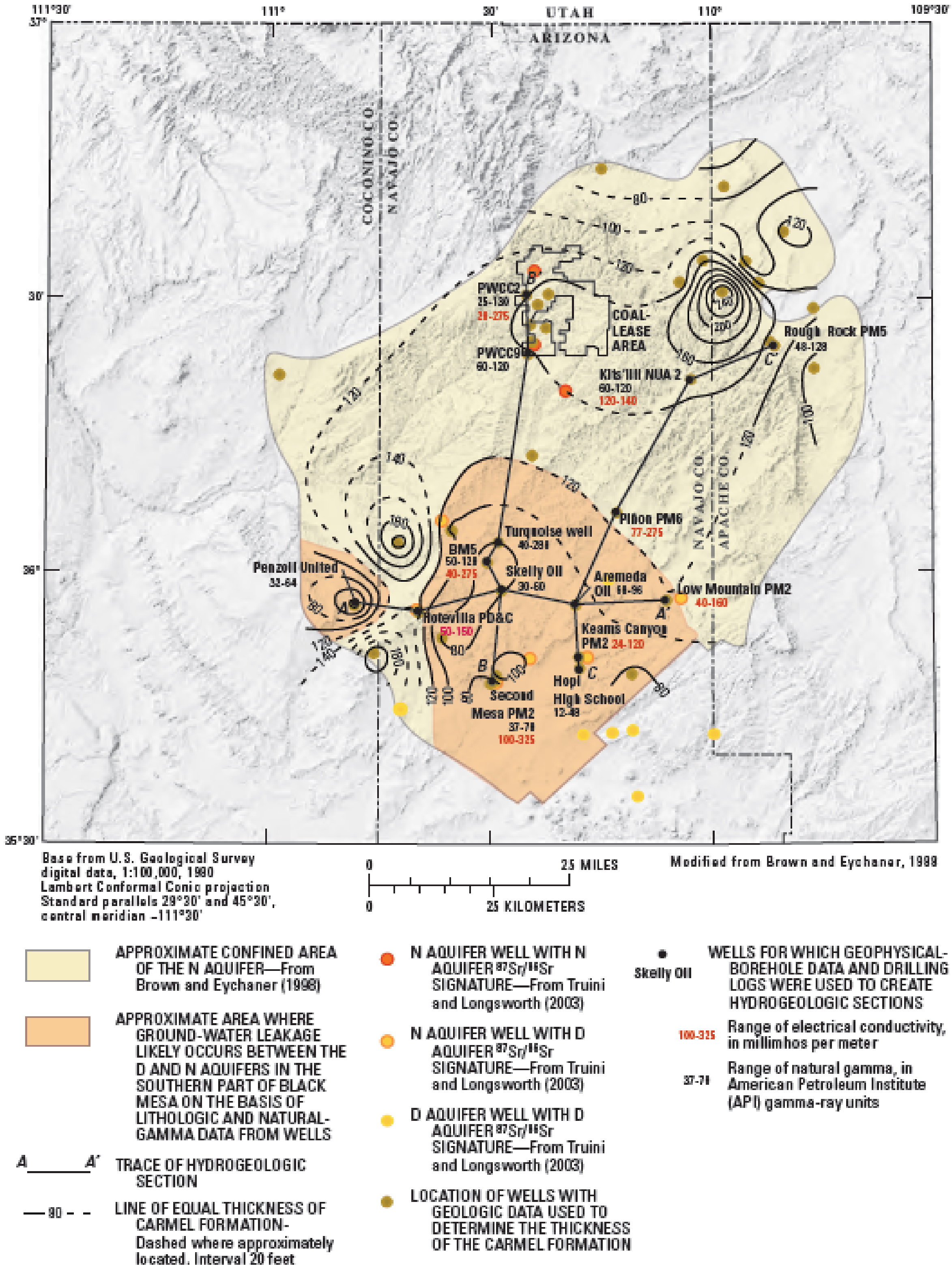



**Figure 23: Approximate area where groundwater leakage likely occurs between the D and N aquifers in the southern part of Black Mesa (Truini and Macy, 2006).**

### 4.2.5 N Aquifer

The N aquifer is known for its well sorted massive sandstone matrix, high water production potential, and drinking quality water. The N aquifer is comprised of (in ascending stratigraphic order) the Wingate Sandstone, Moenave Formation, Kayenta Formation, and the Navajo Sandstone. The combination of these hydrologically connected formations range in thickness from less than 100 feet around the perimeter of Black Mesa to approximately 1700 feet in the center of the Black Mesa Basin. In the center of the groundwater CIA, the stratigraphy of the N aquifer dips steeply into a synclinal basin, facilitating confined aquifer conditions (Figure 24). The N aquifer is separated from the C aquifer below by the low permeability Chinle Formation and is effectively confined from the D aquifer above by the Carmel Formation over much of the Black Mesa area (Figure 23). The Carmel Formation is discontinuous in some areas, and leakage between the D and N aquifers likely occurs in these discontinuous areas via vertically oriented fractures (PWCC, 1999).

#### 4.2.5.1 N Aquifer Baseline Quantity

N aquifer is recharged by rainfall infiltrating on exposed formations of the N aquifer system around the perimeter of Black Mesa (Figure 25), and leakage from the overlying D aquifer. Before extensive pumping of the N aquifer, the hydrologic system was approximately in equilibrium, or steady state. A system is in equilibrium when the inflow equals the outflow, and aquifer storage remains constant. Prior to significant pumping in 1970, aquifer storage was essentially constant; therefore, the volume of water infiltrating into the N aquifer system as recharge equaled the volume discharged as springs and baseflow into washes.

After review of well log information, water level measurements, water chemistry, geologic structure information (Figure 26), and spring elevations (Figure 26), water level data spring locations were used as N aquifer steady state calibration targets for the 3D Model pre-pumping simulation (Figure 20). The resultant steady state potentiometric surface map for the N aquifer is illustrated as Figure 27. N aquifer recharge occurs in areas to the north and northwest near Tsegi and Shonto on exposed outcrop areas east of Black Mesa. N aquifer flow during steady state conditions was predominantly towards the southwest and northeast from a ground water divide through the center of the basin; discharging to Laguna Creek to the northwest and along downcut washes intercepting the N aquifer formations to the southwest.

#### 4.2.5.2 N Aquifer Baseline Quality

Since 1971, the USGS has worked in partnership with PWCC, BIA, and the Hopi Tribe and Navajo Nation to perform monitoring of wells, springs, and stream flows outside the permit area. The primary N aquifer water types are calcium bicarbonate and sodium bicarbonate. Calcium bicarbonate water is generally found in the recharge areas of the N aquifer, and sodium bicarbonate water in the confined area of the N aquifer. Figure 28 illustrates the N aquifer water type collected annually by the USGS as part of the ongoing regional monitoring program (Macy and Unema, 2014). The N aquifer water quality for USGS monitored wells typically meet water quality standards for domestic water supply, except for locations on the eastern edge of the mesa where TDS and sodium concentrations are elevated.

The USGS evaluated the geochemistry of Black Mesa using geochemical and isotopic analysis (Truini and Longsworth, 2003). The USGS evaluation identifies that downward 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.

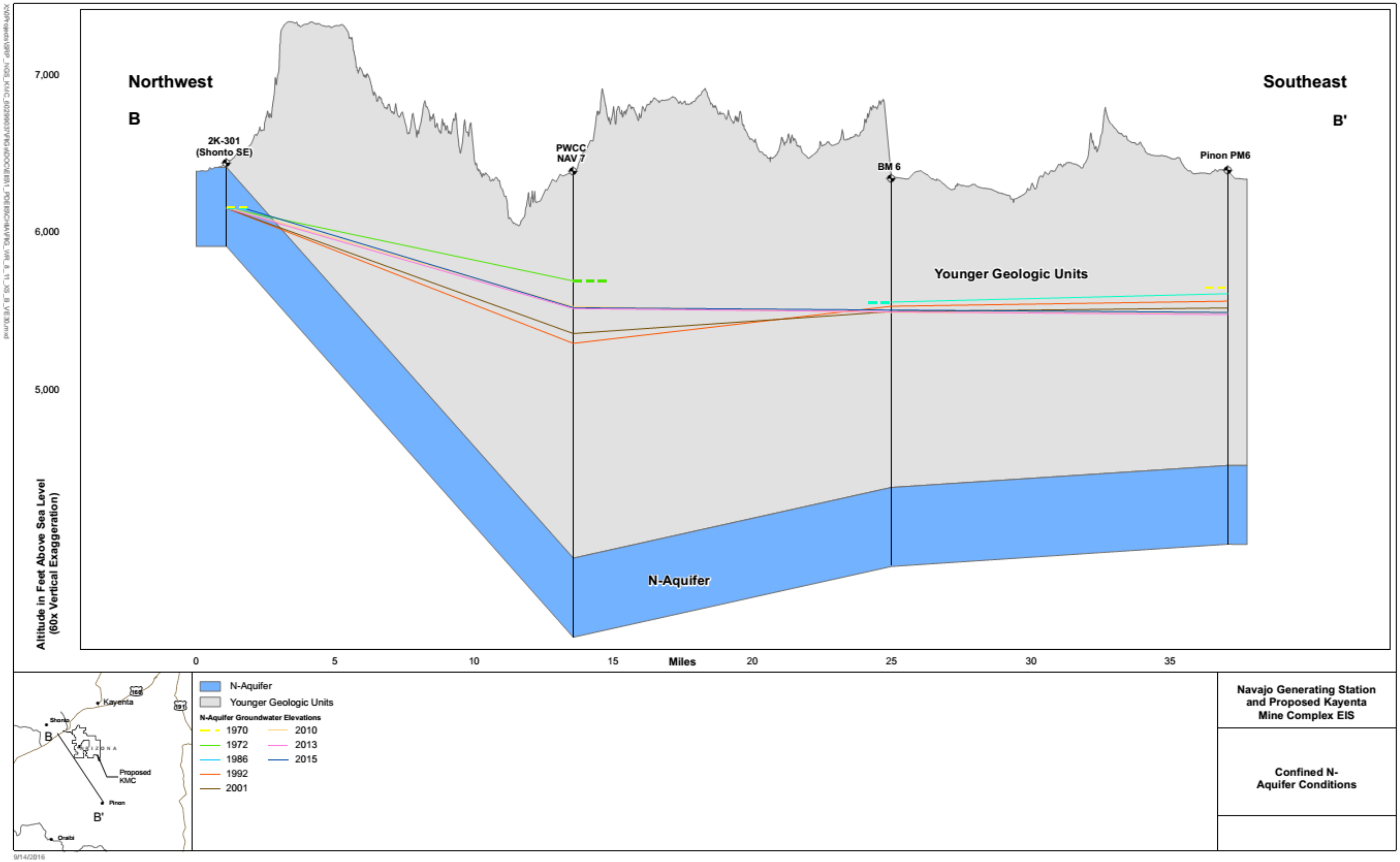



**Figure 24: Confined N Aquifer Conditions, Black Mesa, Arizona (BOR, 2016, Figure WR-8.11).**

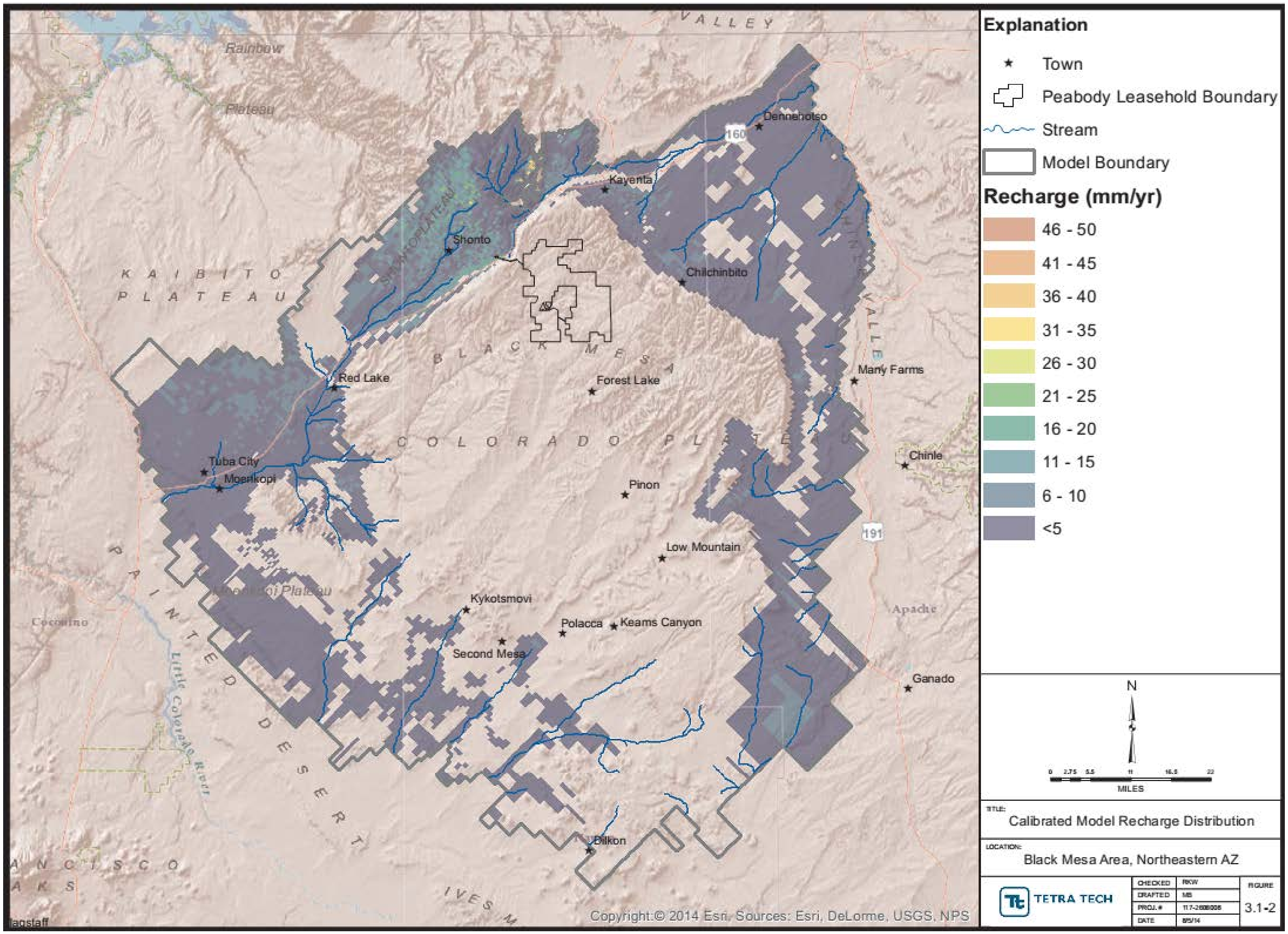



**Figure 25: Average Annual Groundwater Recharge, Black Mesa, Arizona (PWCC, v.11. ch.18, 2016).**

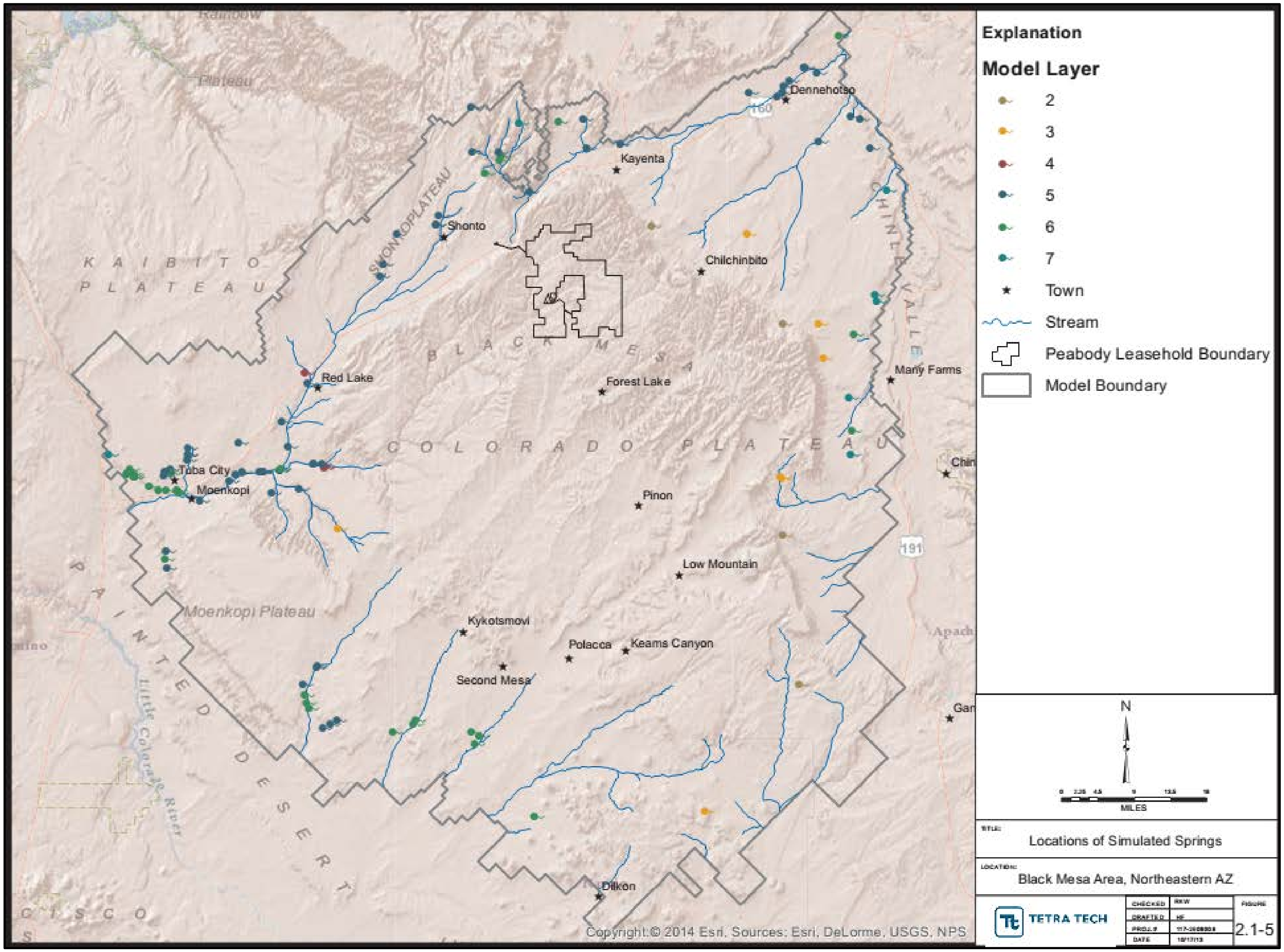



**Figure 26: D aquifer (Layer 3) and N aquifer (Layer 5) Simulated Spring Locations, Black Mesa, Arizona (PWCC, v.11. ch.18, 2016).**

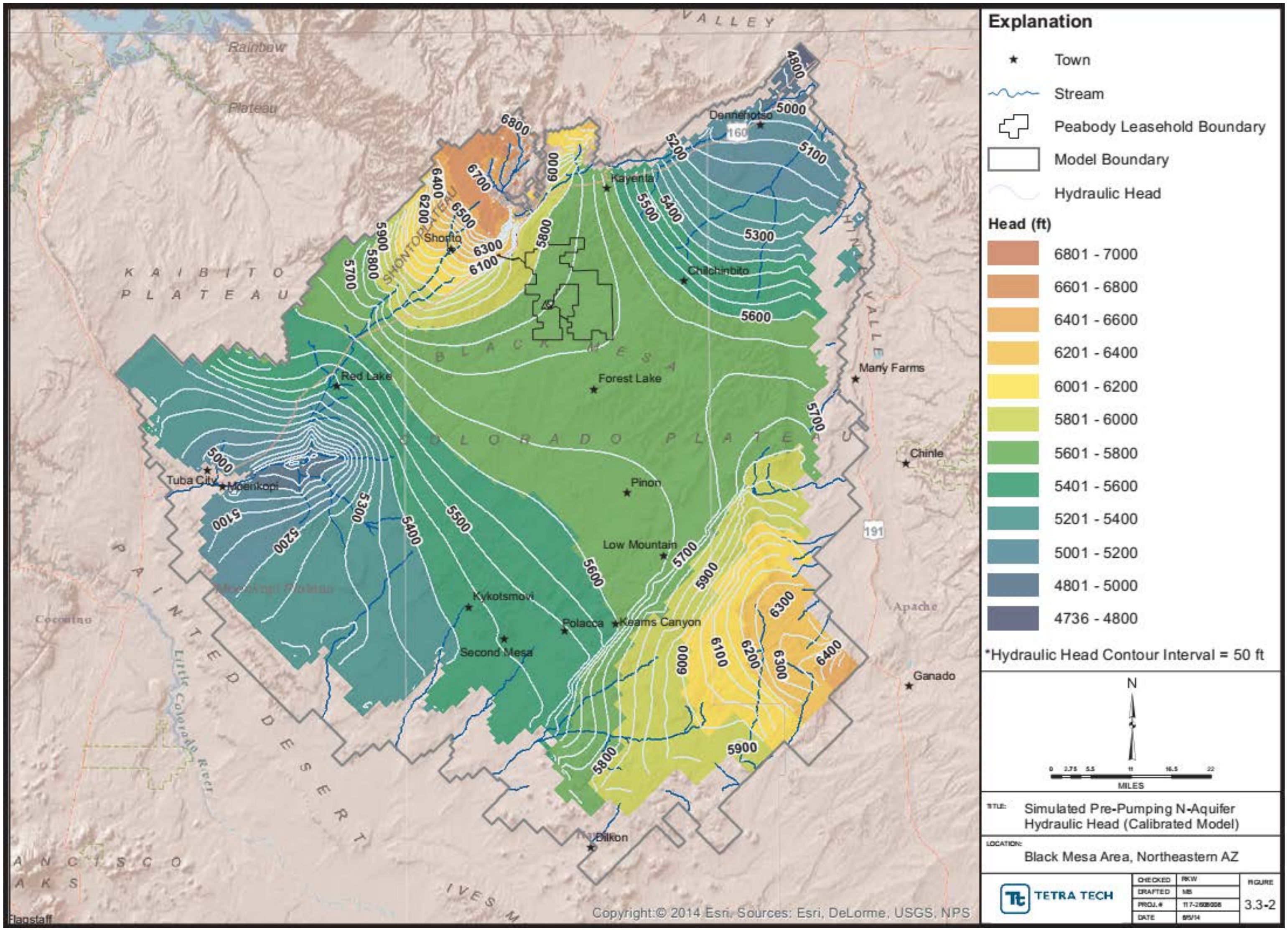



**Figure 27: N aquifer Steady State Potentiometric Surface, Black Mesa, Arizona (PWCC, v.11. ch.18, 2016).**

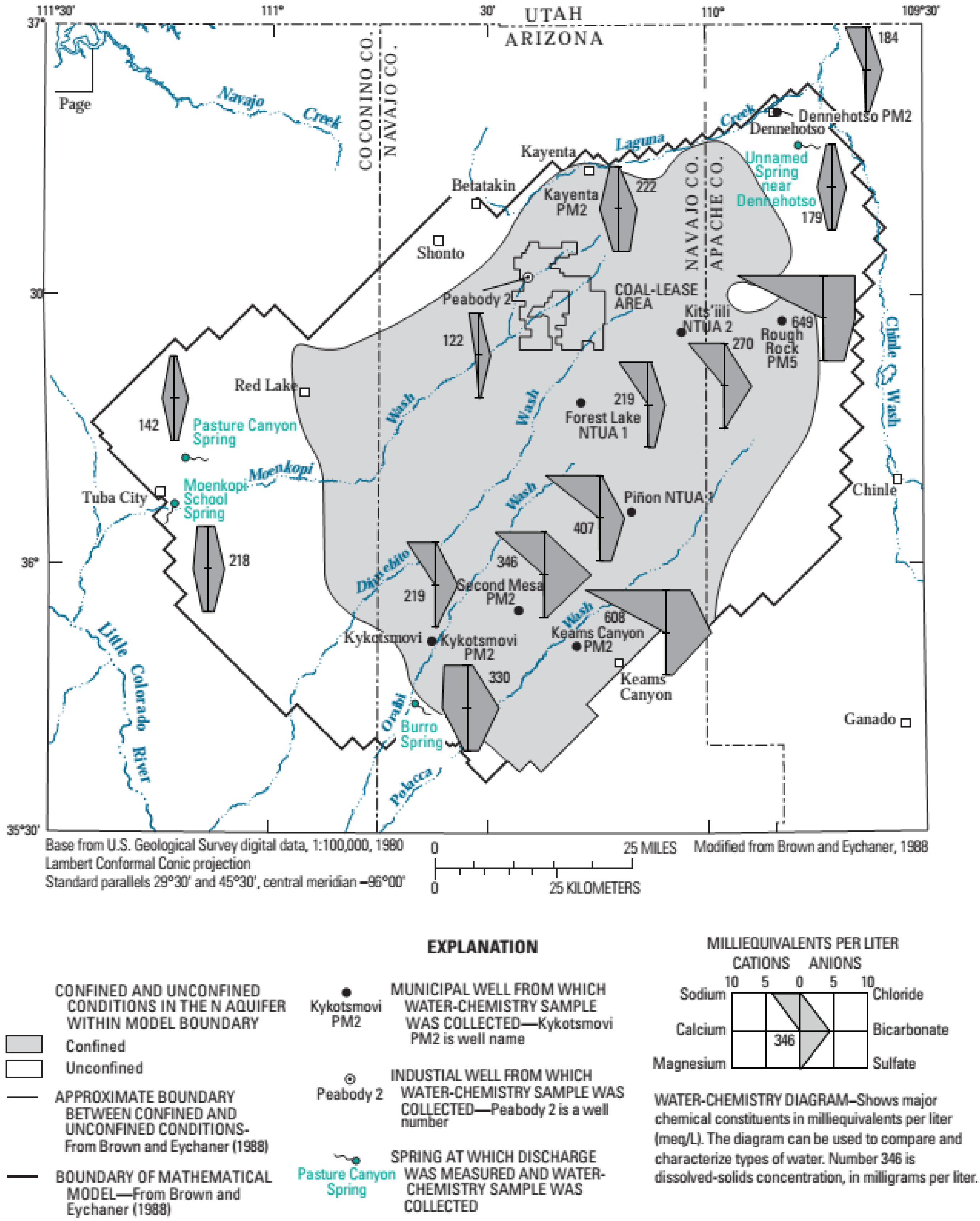



**Figure 28: N aquifer Water Quality Type, 2012 Results (Macy and Unema, 2014).**

In 2006, the USGS applied the results of the geochemical and isotope analysis to a study that evaluated the Carmel Formation, which confines the N aquifer and separates the overlying poorer quality D aquifer water from the better quality N aquifer. The results indicate that thickness and lithology of the Carmel Formation are factors influencing groundwater leakage between the D aquifer and N aquifer. Areas where the Carmel Formation is 120 feet thick or less coincide with areas where $^{87}Sr/^{86}Sr$ isotope analysis indicate that overlying D aquifer water has historically mixed with underlying N aquifer water under natural conditions (Truini and Macy, 2006). In the vicinity of the PWCC wellfield, the Carmel Formation has a thickness greater than 120 feet.