wood.

ASSESSMENT OF CORRECTIVE MEASURES
FOR THE FLY ASH POND AND THE BOTTOM ASH POND
Coal Combustion Residuals Rule and Aquifer Protection Permit Compliance
Arizona Public Service Company
Cholla Power Plant
Navajo County, Arizona

Submitted to:
Arizona Public Service
400 North 5th St.
Phoenix, Arizona 85004

Prepared by:
Wood Environment & Infrastructure Solutions, Inc.
Phoenix, Arizona

Registered Professional Engineer (Civil)
Certificate No.
31672
N. CHRISMAN LAZARR
Date Signed 14June19
ARIZONA U.S.A.
Expires 09/30/2021

June 14, 2019

Project No. 14-2018-2040

TABLE OF CONTENTS

			Page
1.0	INTRODUCTION		1
	1.1	Site Background	1
		1.1.1 Facility and CCR Unit Descriptions	1
		1.1.2 Environmental Setting	2
	1.2	Basis for Corrective Measures Assessment	5
		1.2.1 Statistical Assessment of Collected CCR Monitoring System Data	5
		1.2.2 APP Alert Level Exceedances	6
2.0	NATURE AND EXTENT OF COCS		7
	2.1	Fly Ash Pond	7
		2.1.1 Characterization	7
		2.1.2 Remedial Efforts Conducted to Date	9
		2.1.3 Unit Closure Planning	10
	2.2	Bottom Ash Pond	10
		2.2.1 Characterization	10
		2.2.2 Remedial Efforts Conducted to Date	12
		2.2.3 Unit Closure Planning	13
3.0	CORRECTIVE MEASURES ASSESSMENT		14
	3.1	Fly Ash Pond	15
		3.1.1 Technology Screening	15
		3.1.2 Development and Evaluation of Alternatives	16
	3.2	Bottom Ash Pond	18
		3.2.1 Technology Screening	18
		3.2.2 Development and Evaluation of Alternatives	19
4.0	FUTURE WORK		21
	4.1	Pre-Design Studies	21
	4.2	Public Notice and Remedy Selection	21
5.0	REFERENCES		22

LIST OF TABLES

Table 1-1 Description of Coal Combustion Residual Units
Table 1-2 Summary of GWPSs and Appendix IV Constituent Statistical Analyses
Table 2-1 Water Quality Data Collected During Recent Groundwater Monitoring at the FAP
Table 2-2 Constituent of Concern Properties Impacting Mobility in Aquifer Environments
Table 2-3 Water Quality Data Collected During Recent Groundwater Monitoring at the BAP
Table 3-1 Corrective Measures Technology Screening for Releases from the FAP
Table 3-2 Evaluation of Corrective Measures for the FAP
Table 3-3 Corrective Measures Technology Screening for Releases from the BAP
Table 3-4 Evaluation of Corrective Measures for the BAP

LIST OF FIGURES

Figure 1-1 Site Location Map
Figure 1-2 CCR Units and Groundwater Monitoring System Summary
Figure 1-3 Land Ownership
Figure 2-1 Existing Infrastructure at the Fly Ash Pond
Figure 2-2 Fluoride Iso-Concentration Map for the Fly Ash Pond
Figure 2-3 Arsenic Iso-Concentration Map for the Fly Ash Pond
Figure 2-4 Cobalt Iso-Concentration Map for the Fly Ash Pond
Figure 2-5 Lithium Iso-Concentration Map for the Fly Ash Pond
Figure 2-6 Molybdenum Iso-Concentration Map for the Fly Ash Pond
Figure 2-7 Fly Ash Pond Cross-Section Map
Figure 2-8 Existing Infrastructure at the Bottom Ash Pond
Figure 2-9 Cobalt Iso-Concentration Map for the Bottom Ash Pond
Figure 2-10 Lithium Iso-Concentration Map for the Bottom Ash Pond
Figure 2-11 Bottom Ash Pond Cross-Section A-A’ Map
Figure 2-12 Bottom Ash Pond Cross-Section B-B’ Map
Figure 3-1 Fly Ash Pond Corrective Measures Alternative 1
Figure 3-2 Fly Ash Pond Corrective Measures Alternative 2
Figure 3-3 Fly Ash Pond Corrective Measures Alternative 3
Figure 3-4 Fly Ash Pond Corrective Measures Alternative 4
Figure 3-5 Bottom Ash Pond Corrective Measures Alternative 1
Figure 3-6 Bottom Ash Pond Corrective Measures Alternative 2

LIST OF APPENDICES

Appendix A Alternative Source Demonstration for Lithium at the Bottom Ash Pond
Appendix B Corrective Measures Assessment Groundwater Model Documentation

LIST OF ACRONYMS AND ABBREVIATIONS

§	Section
ASD	Alternative Source Demonstration
AMEC	AMEC Environment & Infrastructure, Inc.
Amec Foster Wheeler	Amec Foster Wheeler, Environment & Infrastructure, Inc.
amsl	above mean sea level
APP	Aquifer Protection Permit
APS	Arizona Public Service Company
AWQS	Aquifer Water Quality Standard
BAP	Bottom Ash Pond
BAM	Bottom Ash Monofill
BTV	background threshold value
CCR	coal combustion residuals
Cholla	Cholla Power Plant
CFR	Code of Federal Regulations
CM(s)	corrective measure(s)
COC(s)	constituent(s) of concern
CSM	conceptual site model
FAP	Fly Ash Pond
ft	foot, feet
GWPS(s)	Groundwater Protection Standard(s)
HDPE	high density polyethylene
I-40	Interstate 40
MCL	Maximum Contaminant Level
mg/L	milligrams per liter
POC	Point of Compliance
SEDI	Sedimentation Pond
SSI	statistically significant increase
SSL	statistically significant level
TDS	total dissolved solids
US EPA	United States Environmental Protection Agency
Wood	Wood Environment & Infrastructure Solutions, Inc.

1.0 INTRODUCTION

On behalf of Arizona Public Service Company (APS), Wood Environment & Infrastructure Solutions, Inc. (Wood) prepared this report documenting an Assessment of Corrective Measures (CMs) for two existing coal combustion residuals (CCR) units located at the Cholla Power Plant (Cholla) near Joseph City, Arizona (the Site).

The CM assessment documented herein was conducted in accordance with 40 Code of Federal Regulations (CFR) Part 257 (herein referred to as the CCR Rule; Federal Register, 2018) to support future selection of remedies for groundwater impacts. The CCR Rule became effective on October 19, 2015 and established standards for the disposal of CCR in landfills and surface impoundments at applicable sites. APS has conducted CCR Rule groundwater compliance activities at the Site and performed statistical assessments of collected groundwater data. Based on the results of these statistical evaluations, there is evidence to suggest that releases from the Site Fly Ash Pond (FAP) and Bottom Ash Pond (BAP) have impacted downgradient groundwater at concentrations that exceed applicable Groundwater Protection Standards (GWPSs) and require corrective action.

At present, discharging facilities at Cholla are also regulated under Arizona Aquifer Protection Permit (APP) regulations. Since June of 2017, fluoride concentrations monitored at an APP compliance well downgradient of the FAP have exceeded the permitted alert level for this constituent. It is the intent of this CM assessment to concurrently address the requirements of Site APP P-100568 by identifying the extent of fluoride impacts in the alluvial aquifer downgradient of the FAP and presenting an assessment of CMs to address fluoride releases from the FAP.

The remainder of this section (Section 1.0) provides a summary description of the power generating facility, Site CCR units, the facility's environmental setting, and groundwater compliance activities conducted at the Site to date which form the basis for this CM assessment. Section 2.0 identifies the nature and extent of the constituents of concern (COCs) by unit with documentation of unit-specific conditions affecting CM assessment. Section 3.0 defines the objective of CMs, screens applicable technologies, develops alternatives for evaluation and documents a CM assessment for each unit. Future requirements for remedy selection are listed in Section 4.0. Section 5.0 presents report references.

1.1 Site Background

1.1.1 <u>Facility and CCR Unit Descriptions</u>

Facility Description. Cholla is an operating power plant owned by APS and PacifiCorp. The plant burns coal in three electrical generating units (Units 1, 3, and 4) and has a net generating capacity of 767 megawatts. Unit 2 was retired in October of 2015.

Coal burned at the plant was previously sourced from the McKinley Mine in New Mexico. When the McKinley Mine closed in 2009, the source of coal switched to the Lee Ranch and El Segundo mines near Grants, New Mexico.

Coal combustion power generating operations at Cholla are scheduled to cease in 2025.

Facility Location. The plant and associated infrastructure are located on land owned/leased by APS adjacent to Interstate 40 (I-40) between the City of Winslow and the City of Holbrook in Navajo County, Arizona (Figure 1-1). The plant sits next to the Cholla Reservoir, a cooling pond and water storage reservoir that was originally constructed in the early 1900s by the Joseph City Irrigation Company (Shilling, 2005). Now used by APS for cooling water, Cholla Reservoir receives deliveries of groundwater pumped from the nearby Cholla Well Field extracting from the Coconino Sandstone Aquifer. The typical water surface elevation of Cholla Reservoir is 5,022 feet (ft) above mean sea level (amsl).

CCR Unit Descriptions. Plant infrastructure includes four single CCR units referred to as the FAP, BAP, Bottom Ash Monofill (BAM), and Sedimentation Pond (SEDI). All the CCR units except the SEDI are located north of I-40 (Figure 1-2). The SEDI was the first of the CCR Units placed into service in 1976. The FAP and BAP dams were completed in 1978, and the BAM came into operation in the late 1990s. Table 1-1 summarizes the location, function, operation, size/construction, and history of each unit. The boundaries of CCR units depicted in Figure 1-2 are based on available historical plans for the units. Figure 1-3 identifies the ownership of property in the vicinity of Site CCR units.

1.1.2 <u>Environmental Setting</u>

Unless otherwise noted, the following information is abstracted from Montgomery & Associates (2011), Montgomery & Associates (2017), and AMEC Environment & Infrastructure, Inc. (AMEC, 2012).

Climate. The plant is located in an arid climate within the Little Colorado River Basin. The area receives an average of 6 to 12 inches of precipitation annually. The evaporation rate exceeds the rate of precipitation by an order of magnitude.

Topography. Cholla is located at an elevation of approximately 5,025 ft amsl in the Colorado Plateau physiographic province of northeastern Arizona. This area is characterized by canyons, high elevations, and narrow, widely-spaced riverbeds. The topography of the plant area is characterized by rolling terrain, open vistas, and incised drainages/arroyos. In the vicinity of the plant, the ground surface gently slopes towards the Little Colorado River to the south at approximately 60 ft per mile; however, surface drainage immediately near Cholla Reservoir flows towards the reservoir. About two miles north and south of the plant, the ground surface rises out of the alluvial floodplain to an elevation of 5,100 to 5,200 ft amsl.

Surface Water Hydrology. The plant is located north of the Little Colorado River within the Middle Little Colorado watershed. The Little Colorado River is a meandering, intermittent stream with a large alluvial floodplain.

Two of the Site CCR units, the FAP and BAP, are located within ephemeral tributaries to the Little Colorado River (Figure 1-2). An unnamed wash system with a drainage basin of approximately 1,200 acres discharges into the FAP. The BAP is located within a tributary to Tanner Wash.

Site Geology. The Colorado Plateau, on which the plant is located, is typified by horizontal layered sequences of sedimentary rock, primarily sandstones, siltstones, and claystones. At the plant and nearby CCR units, the geologic units that are expected to influence groundwater flow and contribute to variations in naturally occurring constituent concentrations across the site are as follows (in descending order):

- **Little Colorado River and Tanner Wash Alluviums**: These quaternary surface alluviums overlie the bedrock formations in localized areas at Cholla and surrounding CCR units. The alluvium is unconsolidated, heterogeneous, and consists of clay, silt, sand, and gravel. In general, the Tanner Wash Alluvium is finer-grained than the Little Colorado River Alluvium. The alluvium ranges in thickness from non-existent to approximately 200 ft, and in general is thickest underneath the plant and Cholla Reservoir. A lower permeability layer of fine grained alluvial materials underlies the

Cholla Reservoir and limits leakage from the reservoir to the underlying alluvial aquifer. Around the CCR units, the alluvium ranges from approximately 50 ft thick in the vicinity of the FAP Dam to 100 ft thick in the vicinity of the BAP Dam.

- **Chinle Formation**: An outcropping of the Chinle Formation of Triassic age is present in the vicinity of the BAP. The Chinle is divided into the Shinarump and Petrified Forest Members. In this area, the Shinarump Member is present and mostly a yellowish-orange to yellowish-gray sandstone that is composed of very fine to very coarse quartz grains and rounded to well-rounded pebbles. The member is, for the most part, weakly cemented and forms slopes. Typically, the surface is soft, and covered with well-rounded pebbles of quartzite, jasper and chert.
- **Moenkopi Formation**: The Moenkopi Formation is the uppermost geologic unit beneath the plant and the CCR units and is present at land surface in areas where the alluvium is non-existent. The thickness of the Moenkopi Formation near the plant ranges from non-existent to over 300 feet thick; where it is sufficiently thick, the Moenkopi Formation acts as an aquitard between the shallow alluvial aquifer and the underlying Coconino Sandstone Aquifer. The Moenkopi Formation consists of three members, described below:
  - Holbrook Member: This member is composed of pale-red, thin to thick bedded sandstone. It is made up of medium to very fine poorly sorted sand and contains considerable silt. It is relatively permeable. In the area northwest of Tanner Wash near the BAP (which is the only region it is known to be present near the plant), the sandstone is overlain by about 30 ft of reddish-brown, thin-bedded mudstone and siltstone. This unit is generally a 40- to 50-ft thick member of the Moenkopi.
  - Moqui Member: This member is composed of pale-brown to reddish-brown gypsiferous mudstone and siltstone beds. It contains an abundance of gypsum nodules, stringers and layers. It contains thin bands composed of greenish-gray and dark yellow siltstone. The beds are lenticular and sharply defined channels are present. This unit is generally a 250- to 300-ft thick member of the Moenkopi although it is observed to be only 22 ft thick on the south side of the FAP at W-125.
  - Wupatki Member: This member consists of a lower sequence of pale-reddish-brown, thin-bedded siltstone with a few feet of yellowish-gray to almost white thin-bedded sandstone and mudstone at the base. An upper sequence consists of a grayish red to reddish-brown, very fine to fine-grained sandstone with minor amounts of silt. The sandstone in this unit can be in hydraulic connection with the underlying Coconino Sandstone. The Wupatki member is generally a 30- to 50-ft thick member of the Moenkopi.
- **Coconino Sandstone**: The Permian-age Coconino Sandstone is the principal lithologic unit of the C-aquifer, a regionally important aquifer for water supply. It is composed of very fine- to medium-grained, well-sorted, rounded to subangular quartz grains cemented commonly with silicious cement. The sandstone has variable permeability depending on the degree of fracturing and cementation. It is very pale orange to almost pure white in color. The unit is approximately 375 to 400 ft thick in the vicinity of the plant.
- **Schnebly Hill Formation**: The Schnebly Hill Formation is a very fine-grained, reddish sandstone that is about 300 to 350 ft thick near the plant. It is part of the C-aquifer, but its hydraulic conductivity is about 10 to 28 percent that of the Coconino Sandstone.
- **Supai Formation**: The Pennsylvanian to Lower Permian Supai Formation underlies the Coconino Sandstone. It has minimal impact on the surface operations of Cholla, other than containing an

approximately 600-ft thick deposit of halite and anhydrite in the Cholla well field area that impacts groundwater quality both regionally and in the vicinity of the plant.

Applicable Hydrostratigraphy. Two important hydrostratigraphic units are conceptualized beneath the plant and associated CCR units. These units form the basis for the hydrogeologic Conceptual Site Model (CSM) developed by Montgomery & Associates (2011 and 2017) for the purpose of evaluating point of compliance wells (POC) for Cholla's APP and the CCR Groundwater Monitoring System.

The first hydrogeologic unit, the Little Colorado River and Tanner Wash Alluvial Aquifers, is present under the plant area, Cholla Reservoir, and the Tanner Wash and Little Colorado River drainage channels. The alluvial aquifer in this area receives recharge from the Little Colorado River and any leakage through anthropogenic features such as the reservoir and the nearby Joseph City Canal. The alluvial aquifer is not used as a drinking water supply but does support a riparian habitat. Depth to water in the alluvial aquifers ranges from several feet to several tens of feet below land surface in the Cholla area, varying spatially based on proximity to recharge sources and topography and seasonally based on rainfall-runoff patterns. Where present, groundwater flows generally in the downstream direction of the drainages under which it is present, that is, from east to west in the Little Colorado River alluvium and from north to south in the Tanner Wash alluvium. Groundwater flow in the Little Colorado River alluvial aquifer is also influenced by deeper paleochannels that may not coincide with the present river channel.

The second hydrogeologic unit is the C-aquifer, which consists of the Coconino Sandstone and Schnebly Hill Formation in the vicinity of the plant. Groundwater in this aquifer is under confined conditions in areas north of the Little Colorado River where sufficiently thick layers of the Moenkopi Formation's Moqui member acts as a confining bed. Groundwater movement in the C-aquifer is generally to the north. However, the Cholla well field (southwest of the plant) has created a cone of depression that has made the groundwater flow in a westerly direction in that area. Near the FAP, the inferred flow of the groundwater in the C-aquifer is to the west or southwest, possibly due to the broad, northwest-trending anticline that extends from the vicinity of the FAP to near Joseph City.

The alluvial aquifer and the C-aquifer are generally separated by the Moenkopi Formation, a regional aquitard that creates a barrier between the two aquifers in the vicinity of Cholla. In areas where the C-aquifer in the Coconino Sandstone is confined (primarily north of the Little Colorado River), the Wupatki member of the Moenkopi has been observed to be water-bearing; however, the Moqui member, which can be 250 to 300 feet thick in the vicinity of the plant, limits hydraulic connection between the alluvial aquifer and the C-aquifer.

Ambient Groundwater Quality. Ambient groundwater quality has been characterized in several previous reports (Sergent, Hauskins, & Beckwith, 1973; Woodward-Clyde, 1991; Montgomery & Associates, 2011, 2017, and 2018; and AMEC, 2012). In general, early data from the Site suggest that background water quality in the Little Colorado River alluvium is variable and possibly fairly poor due to elevated total dissolved solids (TDS) concentrations (Sergent, Hauskins, & Beckwith, 1973; Montgomery & Associates, 2017). Near the BAP and the FAP, background water quality has naturally elevated concentrations of TDS and sulfate due to interaction with the Moqui member of the Moenkopi, which has gypsum stringers and an overall sulfate mineralogy (Montgomery & Associates, 2017; Woodward-Clyde, 1991). High nitrate concentrations observed in monitoring wells around the BAP are suspected to be naturally occurring (Woodward-Clyde, 1991). Background water quality in the alluvial aquifer improves near the Little Colorado River, as concentrations of TDS tend to decline.

Groundwater in the Wupatki member of the Moenkopi contains relatively high concentrations of TDS compared to what is found in the Coconino Sandstone in the same location. Background water quality in the Coconino Sandstone is variable. TDS concentrations can vary from less than 500 milligrams per liter (mg/L) in the area south of the Little Colorado River to over 60,000 mg/L in the area north of the Little Colorado River. The adverse impacts to groundwater quality are thought to be due to upward leakage of saline groundwater from the underlying Supai formation (Montgomery & Associates, 2017). In general, water quality in the Coconino Sandstone is better than that of groundwater found in the alluvium or the Moenkopi, and regionally the C-aquifer is a valuable drinking water resource.

1.2 Basis for Corrective Measures Assessment

As indicated earlier in this report, Cholla is currently regulated under both the Federal CCR Rule and Arizona's APP program. The following sections present the basis for the evaluation of CMs presented in this report which include both the statistical assessment activities conducted to comply with the CCR Rule and the results of groundwater monitoring required by the Site APP.

1.2.1 Statistical Assessment of Collected CCR Monitoring System Data

The groundwater monitoring and corrective action process defined in the CCR Rule includes a phased approach to groundwater monitoring for each CCR unit:

- Detection Monitoring: This groundwater monitoring phase focuses on a set of constituents (listed in Appendix III of the CCR Rule) that are relatively mobile components of CCR and therefore represent indicators of possible impacts from CCR in groundwater. If statistical significant increases (SSIs) of any of the Appendix III constituents relative to background conditions are detected in the downgradient waste boundary wells, and cannot be demonstrated to be associated with a source other than the CCR unit, then groundwater monitoring moves into assessment monitoring.
- Assessment Monitoring: This groundwater monitoring phase focuses on the constituents listed in Appendix IV of the CCR Rule. The Appendix IV constituents are generally less mobile and occur at lower concentrations in groundwater than the Appendix III constituents. Concentrations of Appendix IV constituents in downgradient wells are compared to GWPSs. The GWPSs, established for Appendix IV constituents only, are the higher of either the Federal Safe Drinking Water Act Maximum Contaminant Level (MCL), an alternative risk-based GWPS identified in the CCR Rule, or a statistically-driven background threshold value for each constituent.
- Groundwater Characterization and Corrective Action Assessment: If exceedances of the GWPSs are determined to be occurring in the downgradient boundary wells at statistically significant levels (SSLs) and no alternative sources for the exceedances can be demonstrated, then both additional groundwater characterization and assessment of corrective actions are initiated. Following assessment of corrective measures, a remedy (or set of remedial activities) is selected and implemented as the groundwater corrective action program for the CCR unit. According to the CCR Rule, groundwater corrective action will continue until compliance with the GWPSs has been attained in all impacted wells, and sustained for a period of three consecutive years

APS initiated CCR groundwater detection monitoring at Cholla in November 2015 and completed collection of at least eight initial rounds of monitoring at all wells in October 2017, in accordance with the CCR Rule. Statistical analysis of Appendix III constituent data collected during detection monitoring was completed in January 2018 and updated in May 2018. The analysis concluded that there is enough evidence to declare an SSI over background for one or more Appendix III constituents at the FAP, BAP and SEDI (Montgomery & Associates, 2018).

On the basis of this analysis, assessment monitoring was initiated at these CCR units and a statistical evaluation of Appendix IV constituent monitoring data was conducted. Table 1-2 summarizes GWPSs derived for each constituent by unit and identifies constituents and wells at which SSLs of the constituent over GWPSs have been reported. As indicated, there was sufficient evidence to declare GWPS exceedances for arsenic, cobalt fluoride, lithium, and molybdenum downgradient of the FAP (Wood, 2018a) and cobalt and lithium downgradient of the BAP (Wood, 2018b). No GWPS exceedances were declared for the SEDI (Wood, 2019a).

1.2.2 APP Alert Level Exceedances

The FAP has one alluvial POC well (W-126), a set of paired Moenkopi Wupatki/Coconino Sandstone POC wells (W-124 and W-125), and a Coconino Sandstone POC well (M-44D) that are monitored annually. W-126 is monitored for fluoride, nitrate, nitrite, pH, sulfate, TDS, boron, lead, cadmium, thallium, and total chromium. W-124, W-125, and M-44D are monitored for the same constituents at W-126 plus chloride. The results of monitoring show that average concentrations of monitored constituents in M-44D, W-124, and W-125 are less than respective alert levels. Average concentrations of monitored constituents in W-126 are less than respective alert levels with the exception of fluoride.

Concentrations of fluoride at W-126 have exceeded the permitted alert level of 3.2 mg/L since June of 2017, triggering monthly sampling of W-126 that continues to date. Some of the monthly samples have had fluoride concentrations above the Arizona Aquifer Water Quality Standard (AWQS) of 4.0 mg/L.

2.0 NATURE AND EXTENT OF COCS

This section presents the current understanding of site conditions relevant to an assessment of CMs for the FAP and BAP based on Site information available through April 2019. Unit-specific CSMs are presented to integrate unit construction/operation, hydrogeologic conditions, observed COC concentration distributions, and potential COC migration pathways. These summary CSMs were developed to assist in developing and evaluating CMs in Section 3.0.

2.1 Fly Ash Pond

Figure 2-1 shows relevant FAP infrastructure including the layout of the dam and locations of existing seepage intercept systems and groundwater monitoring wells completed in the alluvium, which is the uppermost aquifer underlying the FAP per the CCR groundwater monitoring system certification report (Montgomery & Associates, 2017).

Figures 2-2 through 2-6 present iso-concentration contour maps for fluoride, arsenic, cobalt, lithium, and molybdenum at the FAP, respectively, based on the results of monitoring well installation activities and groundwater sampling conducted from October 2018 through March 2019 during a *Hydrogeologic Investigation of the FAP and BAP* (Wood, 2019b). The extent of impact is defined by the respective COC GWPSs. Table 2-1 summarizes concentrations of COCs and select water quality parameters in samples collected from the FAP and downgradient groundwater monitoring wells during the Hydrogeologic Investigation and the first CCR assessment monitoring event of 2019.

Table 2-2 presents chemical properties impacting the mobility of Site COCs in aquifer environments.

2.1.1 <u>Characterization</u>

Key points of the summary CSM for the FAP are as follows:

- The FAP dam was constructed approximately 40 years ago on alluvial and Moenkopi Moqui geologic units within an unnamed wash system that previously discharged to the Little Colorado River alluvium.
- The FAP dam has a clay core and an underlying slurry cutoff wall that extends one foot into the Moenkopi Moqui or two feet into stiff clay along the centerline of the dam where the alluvium prior to dam construction was greater than 20 ft thick. Where the alluvium was less than 20 ft thick, no cutoff wall was constructed and the clay core was extended through the alluvium to the top of the Moenkopi Moqui bedrock. As a result, the slurry cutoff wall is only located in the middle portion of the dam and the extended clay core is located on the edges of the dam (Figure 2-1).
- The alluvium within the footprint of the FAP had minimal quantities of groundwater prior to the construction and operation of the FAP; furthermore, pre-construction boreholes advanced (in support of dam design) within the footprint of the FAP in the Moenkopi Moqui did not generally encounter groundwater prior to construction and operation of the FAP.
- Site investigations and evaluations to support design of the dam concluded that the alluvium has a relatively low permeability for alluvial materials due to the presence of silt and clay in the formation; the underlying Moenkopi Moqui is understood to have a low vertical permeability, but could possibly have a higher lateral secondary permeability through bedding planes, fractures, joint structures, and the presence of gypsum nodules, stringers and layers.

- Following dam construction, fourteen piezometers were drilled and screened in the Moenkopi Moqui downgradient of the dam to monitor dam stability. During drilling in 1979, none of the piezometers encountered groundwater. As of late 2018, all but two of the piezometers downgradient of the dam that are screened in the Moenkopi Moqui have measurable water levels. Piezometers screened downgradient of the FAP dam in the Moenkopi Moqui have approximately 30 to 50 feet of head and monitored levels appear to fluctuate with long-term water level trends in the FAP suggesting a hydraulic connection between the FAP and the Moenkopi Moqui in the vicinity of the dam.
- Cross-section A-A', through a portion of the FAP dam where the clay core extends to the Moenkopi Moqui (Figure 2-7), depicts the current inferred piezometric surface through the dam and relevant geologic units. Figure 2-7 also shows the relative thicknesses of geologic units in the vicinity of the dam. Downgradient of the dam and north of I-40, the depth of alluvium is thin, ranging from not present at the dam abutments to approximately 50 ft thick near the center of the dam. The thickness of the Moenkopi Moqui is less defined but is inferred to be approximately 20 to 45 ft thick in the vicinity of the dam based on the boring log for Coconino monitoring well W-125 (located near alluvial monitoring well W-123) and piezometer well logs, respectively.
- As depicted in Figure 2-1, the potentiometric surface for wells and piezometers screened in the alluvium and the Moenkopi Moqui indicate a significant drop in pressure head across the zone with the slurry cutoff wall, but higher heads at the edges of the dam where there is no cutoff wall. This observation suggests that seepage through or under the dam is more significant where the slurry cutoff wall is not present.
- Iso-concentration maps for FAP COCs fluoride, lithium, and molybdenum depict higher concentrations of these constituents in the alluvium downgradient of the dam where the cutoff wall is not present (Figures 2-2, 2-5, and 2-6). This observation suggests that the presence of the cutoff well mitigates seepage of COC mass from the FAP to the alluvial aquifer.
- Groundwater monitoring data indicate that significant attenuation in COC concentrations occurs between the FAP and downgradient unit boundary monitoring wells M-50A, M-51A, and W-123. Attenuation factors (the ratio of the concentration in the well to the concentration in the FAP) for fluoride and lithium (i.e., constituents that are less likely to participate in adsorption, precipitation or reaction attenuation mechanisms per Table 2-2) range from 0.03 to 0.17 based on recent data (Table 2-1). Groundwater quality observations in downgradient wells after an increase in FAP fluoride concentrations (resulting from the shutdown of the Cholla Plant Unit 2 in October 2015) suggest that corresponding increases in downgradient well fluoride concentrations were relatively immediate (within a year) and that concentrations quickly stabilized to current levels thereafter. These observations suggest that in the vicinity of the dam, migration of contaminants to unit boundary monitoring wells may be influenced by preferential flow paths through or under the dam.
- The distribution of fluoride, lithium and molybdenum exceeding respective GWPSs is similar but not the same. Fluoride concentrations that exceed the GWPS extend southwest from the dam to the west of the slurry cutoff wall (Figure 2-2) and appear to predominantly remain on APS property or I-40 right of way. Lithium concentrations that exceed the GWPS (Figure 2-5) are present across the entire extent of the alluvium downgradient of the dam and extend under I-40 right of way onto property owned by both APS and the Hunt Family. Molybdenum concentrations that exceed the GWPS (Figure 2-6) are predominantly confined to the region near and downgradient of the Geronimo seep which extends under I-40 right of way, APS property and property owned by the Hunt Family.

- Groundwater monitoring conducted after declaring SSLs of arsenic and cobalt over respective GWPSs indicates that the presence of these constituents in groundwater downgradient of the FAP is likely not associated with leakage of COC mass from the FAP. The distributions of arsenic and cobalt in the aquifer downgradient of the FAP (Figures 2-3 and 2-4) are not consistent with the distribution of other FAP COCs (i.e., fluoride, lithium, molybdenum) or boron, which has been used to indicate the presence of CCR at the Site. Arsenic is a naturally occurring constituent in soil and groundwater and observed variations could be associated with the heterogeneity of arsenic-containing minerals in a depositional environment (i.e., alluvial drainage system). Cobalt is not routinely present at concentrations exceeding the GWPS in downgradient monitoring wells and was likely identified as a COC based on a false positive SSL during the initial statistical analysis of Appendix IV data (Wood, 2018a). Section 4.1 presents planned activities supporting remedy selection; preparation of Alternative Source Demonstrations (ASDs) for these constituents is included.

2.1.2 Remedial Efforts Conducted to Date

Three seepage collection systems have been installed in the vicinity of the FAP to address observed seepage at ground surface (Figure 2-1). The seepage collection systems include the:

1. Geronimo Seepage Intercept System;
2. Hunt Seepage Intercept System; and
3. I-40 Seepage Intercept System.

Geronimo Seepage Intercept System. The Geronimo Seepage Intercept System was installed in 1993 in the vicinity of alluvial monitoring well W-123, which is screened from 14 to 29 ft bgs. The seepage intercept system consists of two shallow sumps approximately 10 ft deep and two pumping wells that are approximately 40 ft deep. The wells and the sumps are screened in the alluvium. In the past, flow from the Geronimo Seepage Intercept System was collected and pumped back to the FAP; however, collected seepage water is currently returned to the plant. The average pumping rate of the Geronimo Seepage Intercept System over the past five years ranges from near zero to 50 gallons per minute (gpm). The average pumping rate from the Geronimo Seepage Intercept System has declined concurrent with recent efforts to promote decreases in the water level elevation at the FAP (see Section 2.1.3).

Hunt Seepage Intercept System. The Hunt Seepage Intercept System has been in operation since at least 1995 and is located south of I-40 in the vicinity of alluvial monitoring well W-126, which is screened from 12 to 50 ft bgs. The seepage intercept system consists of a 461-ft long seepage collection trench that is less than 10 ft deep which is sloped to a dewatering sump at the western end of the trench. A 49-ft deep dewatering well (HSX-1) is also present south of the trench and northeast of W-126. The HSX-1 pump is set to pump when groundwater is between 23 and 43 ft bgs. The average pump rate of the Hunt Seepage Intercept System over the past five years ranges from zero to 15 gpm.

I-40 Seepage Intercept System. The I-40 Seepage Intercept System was installed in 1993 downgradient of the right abutment of the FAP. The seepage intercept system consists of approximately 200 ft of perforated high density polyethylene (HDPE) pipe buried close to 1 ft bgs, which connects to approximately 415 ft of unperforated HDPE pipe sloped to drain to a shallow, unlined evaporation pond (approximately 100-ft by 200-ft in area). According to Site operating records, no notable seepage flow has reported to the evaporation pond since monitoring of the I-40 Seepage Intercept System began.

2.1.3 Unit Closure Planning

As indicated in Section 1.1.1, coal combustion power generating operations at Cholla are scheduled to cease in 2025. APS has recently been limiting discharges to the FAP with water conservation measures to promote dewatering of the FAP in advance of unit closure. The water elevation has decreased from approximately 5098 to 5089 ft amsl since 2016.

The closure plan for the FAP includes closure of the unit by leaving the CCR in place, dewatering the liquid CCR present in the unit via evaporation/draining, regrading the area to prevent ponding of stormwater in the unit, placement of a final cover system after the unit is dewatered, and construction of perimeter drainage channels (AECOM, 2016a).

2.2 Bottom Ash Pond

Figure 2-8 shows relevant BAP infrastructure including the layout of the dam and locations of existing seepage intercept systems and groundwater monitoring wells completed in the Tanner Wash alluvium, which is the uppermost aquifer underlying the BAP per the CCR groundwater monitoring system certification report (Montgomery & Associates, 2017).

Figures 2-9 and 2-10 show current iso-concentration contour maps for cobalt and lithium, respectively, at the BAP, based on the results of groundwater sampling conducted from October 2018 through March 2019 during a *Hydrogeologic Investigation of the FAP and BAP* (Wood, 2019b). The extent of impact is defined by the respective COC GWPSs. Table 2-3 summarizes concentrations of COCs and select water quality parameters in samples collected from the BAP and downgradient groundwater monitoring wells during the Hydrogeologic Investigation and the first monitoring event of 2019.

2.2.1 Characterization

Key points of the summary CSM for the BAP are as follows:

- The BAP dam is comprised of southern and eastern dams operating as one dam system. The southern BAP dam was constructed on alluvial and Moenkopi Moqui geologic units within a tributary to Tanner Wash. The eastern BAP dam was constructed on alluvial, Moenkopi Holbrook, Moenkopi Moqui, and Chinle geologic units and generally is aligned parallel to flow in Tanner Wash. The dams have been used to impound bottom ash at the Site for approximately 40 years.
- Similar to the FAP, the southern BAP dam has a slurry cutoff wall in the region of the dam where the alluvium was greater than 20 feet thick prior to construction, and elsewhere in the southern and eastern dams, where the alluvium was less than 20 feet thick, the clay core extended through the alluvium to bedrock. As a result, the slurry cutoff wall was only constructed in the middle portion of the southern dam.
- Since the slurry cutoff wall was designed to provide dam stability and not prevent seepage under the dam, the slurry cutoff wall in the southern portion of the dam does not extend all the way through the alluvium to the Moenkopi Moqui bedrock. There is an approximately 10 to 20-ft thick layer of alluvium at the base of the cutoff wall above the Moqui. The base of the slurry cutoff wall is at an elevation of 4980 ft amsl.
- The presence of alluvium at the base of the cutoff slurry wall may explain the relationship between the water quality concentrations in the paired alluvial monitoring wells W-305 and W-306 (downgradient of the southern portion of the BAP dam). The screened intervals for W-305 (the

deeper well) and W-306 (the shallower well) range from approximately 4,944 to 4,964 ft amsl and 4,994 to 5,014 ft amsl, respectively. This relationship is shown on Cross-Section A-A' presented in Figure 2-11. The water elevations in the paired wells are similar, which suggests a hydraulic connection between the wells; however, the concentrations of water quality constituents vary. As indicated in Table 2-3, cobalt concentrations are higher in the deeper well (0.018 mg/L) than in the shallower well (less than 0.0020 mg/L) while lithium concentrations are higher in the shallower well (0.73 to 0.80 mg/L) than in the deeper well (0.21 to 0.22 mg/L).

- The alluvium in Tanner Wash and the wash beneath the southern dam appears to have a zone of coarser material at depth that includes clasts of petrified wood, likely eroded from the Chinle formation. It is likely that the various geologic units surrounding Tanner Wash contribute to natural variations in groundwater quality in the alluvium.
- Along the toe of the eastern dam, piezometers are screened in the Moenkopi Holbrook and Moenkopi Moqui formations and all have water elevations ranging between approximately 5,050 to 5,090 ft amsl. The Moenkopi Moqui is understood to have a low vertical permeability, but could possibly have a higher lateral secondary permeability through bedding planes, fractures, joint structures, and the presence of gypsum nodules, stringers, and layers. To the east of the eastern dam, the ground surface elevation declines and intersects the potentiometric surface produced by to the head in the BAP. Surface seeps have occurred where flow may be migrating through distinct beds in the Moqui that intersect ground surface. This relationship is depicted on Cross Section B-B' (Figure 2-12).
- In general, there are multiple pathways for seepage flow beyond the southern and eastern dams. The potentiometric surface and Cross Sections A-A' and B-B' (Figures 2-11 and 2-12, respectively) indicate hydraulic connection between the water in the BAP and the groundwater elevations in monitoring wells and piezometers screened in the alluvium, Moenkopi Holbrook, and Moenkopi Moqui. Water elevations in a majority of the piezometers have increased over the period of operation since their installation.
- Iso-concentration maps for BAP COC cobalt (Figure 2-9) suggest that this constituent is present in groundwater around the entire downgradient extent of the south and eastern dams at concentrations that exceed the GWPS (0.006 mg/L). Cobalt concentrations that exceed the GWPS extend onto adjacent properties owned by the US Forest Service and the Hansen Family. The highest concentrations are located in the vicinity of M-52A (screened from 20 to 70 ft bgs) and Tanner Wash well W-307 (screened from 40 to 60 ft bgs) at 0.036 mg/L and 0.076 mg/L, respectively. Cobalt concentrations were notably lower in samples collected from the water surface within the BAP (0.00099 mg/L). It is possible that water quality samples collected from the surface of the BAP are not representative of water throughout the BAP, and/or seepage from the BAP promotes mobilization of naturally occurring cobalt from aquifer material. Based on data collected from one well (W-301 at 0.017 mg/L), concentrations of cobalt in alluvial groundwater appear to exceed the GWPS a significant distance downgradient of the BAP, potentially to the vicinity of I-40. Groundwater monitoring downgradient of I-40 indicates that the plant area is not impacted by elevated concentrations of cobalt.
- Groundwater monitoring conducted after declaring SSLs of lithium over the GWPS indicates that the presence of this constituent in groundwater downgradient of the BAP is not associated with leakage of COC mass from the BAP. An ASD conducted for this constituent (see Appendix A) indicates that the distribution of lithium in the aquifer downgradient of the BAP (Figure 2-10) is not consistent with the distribution of boron, a CCR indicator constituent. Further, the absence of lithium in water samples collected from the BAP and the nature of variability in lithium

concentrations in Tanner Wash alluvium suggest that observed concentrations are associated with natural variation due to aquifer heterogeneity. On the basis of the ASD documented herein, lithium is declared not to be a COC at the BAP.

2.2.2 Remedial Efforts Conducted to Date

In the past, four seepage intercept systems and one seep monitoring location were installed in the vicinity of the BAP where seepage has been observed at ground surface (Figure 2-8). These intercept systems include the:

1. P-226 Seepage Intercept System,
2. Tanner Wash Seepage Intercept System,
3. Petroglyph Seepage Intercept System,
4. Toe Drain Seepage Intercept System, and
5. West Abutment Seep Monitoring Location.

The seepage intercept systems at P-226, Tanner Wash, and the Petroglyph Seep Areas are connected by piping, trenches, and electrical conduit to function as one system.

P-226 Seepage Intercept System. The P-226 Seepage Intercept System was installed in 1993 downgradient of the eastern dam of the BAP northwest of Tanner Wash, near piezometer P-226 and well W-314, which are screened from 18 to 48 ft bgs (in the alluvium and the Moenkopi Moqui) and 46 to 61 ft bgs (in the alluvium), respectively. The seepage intercept system consists of ten 5-inch diameter pumping wells spaced approximately 50 to 70 ft apart and installed to around 40 ft bgs in the alluvium. Pumps are only installed in eight of the wells and the pumps are set to operate when groundwater is between 21 and 35 ft bgs (set points vary by well). The average pumping rate of the P-226 Seepage Intercept System typically ranges from 10 to 25 gpm.

Tanner Wash Seepage Intercept System. The Tanner Wash Seepage Intercept System was installed in 1993 downgradient of the bend in the dam of the BAP northwest of Tanner Wash. The seepage intercept system consists of three 4- to 6-ft deep seepage intercept trenches with a total length of approximately 850 ft sloped to one 4-ft diameter sump installed to approximately 10.5 ft bgs. The pump in the sump is set to operate when the water level in the sump is between 6.5 to 7.5 ft bgs. The average pumping rate of the Tanner Wash Seepage Intercept System typically ranges from 2 to 13 gpm.

Petroglyph Seepage Intercept System. The Petroglyph Seepage Intercept System was installed in 1993 at the toe of the bend in the dam of the BAP. The seepage intercept system consists of two 4- to 6-ft deep seepage intercept trenches with a total length of approximately 250 ft sloped to one 4-ft diameter sump installed to approximately 10 ft bgs. The pump in the sump is set to operate when the water level in the sump is between 6 and 7 ft bgs. The average pumping rate of the Petroglyph Seepage Intercept System typically ranges from 4 to 12 gpm.

Toe Drain Seepage Intercept System. The Toe Drain Seepage Intercept System is downgradient of the center of the southern dam and in the vicinity of M-53A, which is screened from 10 to 35 ft bgs. The average pumping rate of the Toe Drain Seepage Intercept System typically ranges from 3 to 10 gpm.

West Abutment Seep Monitoring. Seepage at the western abutment of the southern dam is monitored using a weir. The average flow rate of the West Abutment Seep typically ranges from 1 to 4 gpm. After monitoring, seepage infiltrates back into the aquifer and is collected in the Toe Drain Seepage Intercept System.

2.2.3 Unit Closure Planning

The closure plan for the BAP includes closure of the unit by leaving the CCR in place, dewatering the liquid CCR present in the unit via evaporation/draining, regrading the area to prevent ponding of stormwater in the unit, placement of a final cover system after the unit is dewatered, and construction of perimeter drainage channels (AECOM, 2016b).

3.0 CORRECTIVE MEASURES ASSESSMENT

In accordance with 40 CFR Section (§)257.96 of the CCR Rule, assessment of CMs must be conducted after an Appendix IV constituent has been detected at an SSL exceeding a GWPS to prevent further releases, remediate any releases that have occurred, and restore affected areas to original conditions. The assessment must include an analysis of CM effectiveness in meeting all of the requirements and objectives of the remedy as described in §257.97 of the CCR Rule (Selection of Remedy). Remedies must:

1) Be protective of human health and the environment;
2) Attain the GWPS;
3) Control the sources(s) of releases so as to reduce or eliminate, to the maximum extent feasible, further releases of Appendix IV constituents into the environment;
4) Remove from the environment as much of the contaminated material that was released from the CCR unit as is feasible, taking into account factors such as avoiding inappropriate disturbance of sensitive ecosystems; and
5) Comply with standards for management of wastes as specified in §257.98(d) of the CCR Rule.

In consideration of these remedial objectives, this section screens applicable technologies for each unit, assembles retained technologies into developed alternatives, and then assesses the alternative CMs using the criteria defined in §257.96 of the CCR Rule (Assessment of Corrective Measures). The criteria include:

1) Performance, reliability, ease of implementation, and potential impacts of appropriate remedies, including safety impacts, cross-media impacts, and control of exposure to any residual contamination;
2) Time required to begin and complete the remedy; and
3) Institutional requirements, such as state or local permits or other requirements or public health requirements that may substantially affect the implementation of the remedy(s).

The technology screening process and CM assessment documented herein were informed by the development of a numerical contaminant flow and transport groundwater model for the Site which reflects the current understanding of the unit-specific CSMs summarized in Section 2.0. Appendix B documents the specifications for and use of the Cholla Power Plant Groundwater Model (the Groundwater Model) as part of this assessment, including the modeling platform, structure, parameters, conceptual water budget, calibration data, model run development, and model run results. The observed distribution of representative COCs in groundwater (fluoride at the FAP and cobalt at the BAP) and results from the *Hydrogeologic Investigation of the FAP and BAP* (Wood, 2019b) were used to calibrate the Groundwater Model to Site conditions prior to use as a tool in this CM assessment.

As identified in Section 2.0, APS has implemented existing CMs at both the FAP and BAP and developed closure plans for the units in accordance with §257.102(b) of the CCR Rule (Criteria for Conducting the Closure or Retrofit of CCR Units). These CMs are incorporated into the CM alternatives developed for the Site.

3.1 Fly Ash Pond

3.1.1 Technology Screening

Table 3-1 presents a description of the individual technologies considered applicable to the FAP as CMs based on the unit-specific CSM presented in Section 2.1. The benefits, constraints, risks, and an assessment of the relative time to benefit from implementation of the technology are also summarized for the individual technologies in Table 3-1.

Evaluation of benefits, constraints, risks, and the relative time to benefit was conducted using technical judgement and the following considerations:

- Benefits include a lowered risk to human health or environmental receptors; reduced concentrations, volumes, or overall quantities of COC mass in the aquifer; decreased liability and increased acceptance of the public; efficient or enhanced implementation leading to increases in technology effectiveness; and preservation of existing or future uses.
- Constraints include site factors that adversely impact the performance, reliability, or ease of implementation; or an extensive amount of predesign work that is required to implement the technology.
- Risks include adverse safety impacts or an increase in the potential of exposure to receptors of residual contamination.
- Relative time to benefit was assessed on a scale that identified technologies that have already been implemented as ‘fast’ and technologies that leave COCs in place to attenuate over time as ‘slow’.

The existing technologies implemented or currently identified for future implementation at the FAP were retained and include:

- Technology A – Operation of existing seepage collection systems near the I-40, Geronimo, and Hunt seeps to intercept seepage in areas where impacts at ground surface were previously observed;
- Technology B – Draining the FAP with closure of the CCR in place using engineering control measures to limit the introduction of stormwater into the unit, thereby controlling the ongoing source of seepage from the unit in the future; and
- Technology D – Ongoing natural attenuation of COCs.

These technologies are supplemented in Table 3-1 with various strategies to remove more of the potential source of groundwater impacts, capture impacted groundwater and remove COC mass thereby reducing risk and limiting the duration that remedies must be in place (i.e., the duration that COCs are present at concentrations exceeding GWPSs) At the FAP, these technologies include:

- Technology C - Excavation of the CCR contained in the FAP as a change to the current closure strategy;
- Technologies E and G - Capture of impacted groundwater directly downgradient of the FAP with new containment wells or a gravel filled seepage collection trench at potentially high contaminant flux locations;
- Technology F – Capture of impacted groundwater, south of I-40 in the downgradient alluvium; and

- Technology H – Installation of partial cutoff walls directly downgradient of the FAP to divert water to a centralized groundwater extraction system.

Removal of CCR as part of closure implementation would reduce the mass of COCs present at the Site and limit the potential for ongoing mobilization of COCs into groundwater. However, the duration required for impacts to be mitigated would not be appreciably shortened compared to CCR closure in place because the CCR would still require dewatering prior to excavation and the duration required to implement an excavation and disposal program would be extensive. The earliest date that discharges to the FAP could cease and draining/evaporation of free liquid in the ponds could begin is in three to four years when a new fly ash disposal facility could be designed, constructed, permitted, and placed in service. Excavation of CCR as part of closure would also have the following constraints and risks:

- Potential cross-media impacts during excavation, transport, and final placement at a suitable location;
- Logistical difficulties in locating and/or constructing a suitable facility for the excavated waste; and
- Likely concerns by the public regarding the high volume of traffic associated with transporting large quantities of waste in transportation corridors where the public could be exposed to the waste.

Given the potential benefit of this technology, removal of CCR as part of closure implementation is retained.

All identified groundwater containment technologies were retained except the cutoff wall with an associated groundwater extraction well system. Although this approach would likely be effective, the risk of potentially compromising the integrity of the thin Moenkopi Moqui when other retained technologies are likely to be equally effective is not warranted.

3.1.2 Development and Evaluation of Alternatives

Evaluation of CM alternatives included incorporating existing and planned technologies into CM Alternative 1 (i.e., operation of existing seepage collection systems, closure of the FAP including draining/evaporation of standing water either in place or by CCR removal, and natural attenuation of COCs in the impacted alluvial aquifer) and developing retained variations of the screened containment strategies presented in Table 3-1 into CM Alternatives 2 through 4 for comparison. Table 3-2 summarizes these CMs and presents the results of an assessment of these alternatives using the CCR Rule CM assessment criteria noted in the introduction to this section. Figures 3-1 through 3-4 visually depict the alternatives for further evaluation.

As indicated in Table 3-2, the estimated time to complete the remedy for CM Alternative 1 is longer than typical facility planning periods (i.e., 30 years). To estimate the required duration of CM Alternative 1, groundwater modeling was performed using fluoride at the FAP as it is the only constituent present at concentrations that exceed an Arizona AWQS, which is also the USEPA MCL and the GWPS for this constituent. The GWPSs for lithium and molybdenum are based on background threshold values (BTVs) and alternative risk-based GWPSs identified in the CCR Rule, respectively (Table 1-2). Although the exceedances of fluoride concentrations above the GWPS in groundwater downgradient of the FAP are relatively minor, the Groundwater Model predicts that fluoride concentrations will exceed the GWPS for 61 years. This extended duration is likely attributable to:

- Projected ongoing seepage from the FAP and associated alluvium through 2036 (based on Site dewatering projections and the elevation of the ground surface before FAP construction [i.e., 5,035 ft amsl]);
- Low permeability soils in the alluvium;
- Potential interactions between the alluvium and the Moenkopi Moqui that can to retard the migration of fluoride mass from regions where impacted groundwater has saturated the Moqui (i.e., around the FAP dam); and
- Limited inflow of non-impacted groundwater into the impacted aquifer in the region downgradient of the FAP.

The primary factors that distinguish alternatives with containment strategies (CM Alternatives 2, 3, and 4) include the footprint and location of the containment strategies, the quantity of water that will likely need to be extracted to contain impacted groundwater, and the estimated duration that these containment strategies will have to operate. The results from the groundwater modeling effort provide some insight into the potential advantages and constraints of the evaluated strategies:

- Locating a seepage interception system (either a containment well system or seepage collection trench) on APS property, downgradient of the dam and north of I-40, contributes to shorter remedial durations (CM Alternatives 2 and 4 have Groundwater Model predicted durations of 26 years and 22 years, respectively). In general, these durations are significantly impacted by how long ongoing seepage of impacted water from the FAP and associated alluvium will continue (17 years from present is predicted by the Groundwater Model).
- To contain COC impacted plumes, extraction from wells screened in the Moenkopi Moqui may be required. Figures 3-2 through 3-4 depict the number and locations of wells used in the Groundwater Model to contain the fluoride plume. These wells were sited iteratively and required screening of select wells in the Moenkopi Moqui (Layer 3 in the Groundwater Model; see Appendix B). Construction of the Groundwater Model relied on data collected from FAP dam piezometers that indicates the Moqui is locally saturated in the vicinity of the dam.
- Solely locating a containment well system south of I-40 (CM Alternative 3) will require a larger quantity of groundwater extraction to contain the plumes than a comparable system located north of I-40 due to the thicker alluvium and longer plume travel time to the containment system. Siting a containment well system south of I-40 also has more potential to adversely impact off-site property owners, as wells would likely be required off APS property.

The estimated durations of remedial implementation, volumes of extracted groundwater, and locations of containment infrastructure derived from the Groundwater Model are approximations of these parameters in a complex aquifer environment based on currently available information. The parameter values presented in this CM assessment should be considered for alternative evaluation purposes only.

Section 4.1 identifies planned CM predesign activities that will be conducted to refine the summary CSM for the FAP and inform remedy development and selection.

3.2 Bottom Ash Pond

3.2.1 Technology Screening

Table 3-3 presents a description of the individual technologies considered applicable to the BAP as CMs based on the unit-specific CSM presented in Section 2.2. Evaluation of benefits, constraints, risks, and the relative time to benefit from implementation of the technology was conducted in a manner similar to that described for the FAP in Section 3.1.1.

The existing technologies implemented or currently identified for future implementation at the BAP were retained and include:

- Technology A – Operation of existing seepage collection systems to the south and east of the dam to intercept seepage in areas where impacts at ground surface were previously observed;
- Technology B – Draining the BAP with closure of the CCR in place using engineering control measures to limit the introduction of stormwater into the unit, thereby controlling the ongoing source of seepage from the unit in the future; and
- Technology D – Ongoing natural attenuation of COCs.

These technologies are supplemented in Table 3-3 with various strategies to remove more of the potential source of groundwater impacts, capture impacted groundwater and remove COC mass thereby reducing risk and limiting the duration that remedies must be in place, and decrease the extent of hydraulic connection between water in the dam and the alluvium. At the BAP, these technologies include:

- Technology C - Excavation of the CCR contained in the BAP as a change to the current closure strategy;
- Technologies E, G and H - Capture of impacted groundwater directly downgradient of the BAP with new containment wells or collection trenches at potentially high contaminant flux locations; cut off walls could be used to enhance the effectiveness of these systems;
- Technology F – Capture of impacted groundwater in the downgradient alluvium of Tanner Wash; and
- Technology I – Permeation grouting on the south side of the dam in the alluvium at the base of the slurry cut off wall to target the gap of alluvium beneath the cut off wall.

The advantages and disadvantages of Removal of CCR as part of closure implementation would be the same as discussed in Section 3.1.1. Given the potential benefit of this technology, removal of CCR as part of closure implementation (Technology C) is retained.

Containment wells and/or collection trenches sited in close proximity to the dam with potential cutoff walls to increase the effectiveness of containment wells near the dam (Technologies E, G, and H) were retained. However, implementing these technologies along the entire length of the dam would likely be challenging given the difficult terrain and potential presence of uncharacterized discharges to the alluvium where seepage is not visible at the surface. These factors can limit the effectiveness of containment systems at the BAP.

Based on the extensive distribution of cobalt in groundwater downgradient of the BAP (Figure 2-9) and unreasonable volume of groundwater that would need to be extracted from a finite groundwater resource to contain very small quantities of cobalt mass (a constituent without an AWQS or MCL), containment wells located farther downgradient from the dam in the alluvium (Technology F) were not retained.

Given that cobalt concentrations appear to be elevated around the entire extent of the BAP and that the highest concentrations are associated with M-52A and W-307, and not W-305 which is sited directly downgradient of the alluvial gap at the base of the BAP dam cutoff slurry wall, permeation grouting of the alluvial gap (Technology I) is expected to have limited effectiveness in addressing the cobalt plume and was therefore not retained.

3.2.2 Development and Evaluation of Alternatives

Like the evaluation of CM alternatives for the FAP, evaluation of CM alternatives included incorporating existing and planned technologies into CM Alternative 1 (i.e., operation of existing seepage collection systems, closure of the BAP including draining/evaporation of standing water either in place or by CCR removal, and natural attenuation of cobalt in the impacted alluvial aquifer). CM Alternative 1 was assessed against a comparable alternative (CM Alternative 2) that is comprised of retained containment technologies in the vicinity of the BAP dam (i.e., new containment wells, collection trenches, and/or cutoff walls to enhance interception of seepage discharging into the alluvium). Table 3-4 summarizes these CMs and presents the results of an assessment of these alternatives using the CCR Rule CM assessment criteria. Figures 3-5 and 3-6 visually depict these alternatives for further comparison.

As indicated in Table 3-2, both CM Alternatives 1 and 2 are currently assessed as having limited effectiveness in intercepting seepage from the BAP prior to impacting the alluvial aquifer. This is due in part to a poor understanding of the mechanisms responsible for introducing cobalt into the alluvial aquifer to as well as incomplete characterization of where impacts are occurring. As indicated in the unit-specific CSM for the BAP, cobalt concentrations are not known to be elevated in the BAP and seepage investigation has only been conducted where surface seepage has been evident. Additional investigation is needed to better understand the nature of cobalt mass releases at the BAP and whether existing seepage collection systems can be enhanced and/or expanded to intercept seepage prior to discharge into the alluvium.

In addition to potential issues with efficacy, the duration that both CM Alternative 1 and 2 would need to remain in place is difficult to estimate at this time. The Groundwater Model predicts that cobalt will remain at concentrations that exceed the GWPS for more than 100 years which significantly exceeds the 30-year typical facility planning period. This extended duration is potentially attributable to:

- The thickness of the alluvium in Tanner Wash which has the capacity to store large volume of impacted groundwater, if contaminated.
- The significant head in the BAP relative to the ambient alluvial piezometric surface, which in the model, results in a reversal of flow direction in Tanner Wash towards the model boundary where boundary effects may be occurring.
- The unknown length of time required to dewater the BAP (bottom ash is anticipated to dewater quicker than fly ash but the duration has not been quantified). For the purpose of the model, the BAP was assumed to dewater at the same rate as the FAP.

The estimated durations of remedial implementation, volumes of extracted groundwater, and locations of containment infrastructure derived from the Groundwater Model are approximations of these parameters in a complex aquifer environment based on currently available information. The values presented in this CM assessment should be considered for alternative evaluation purposes only.

Section 4.1 identifies planned CM predesign activities that will be conducted to refine the summary CSM for the BAP and inform remedy development and selection.

4.0 FUTURE WORK

4.1 Pre-Design Studies

Additional site characterization is necessary prior to selection and design of FAP and BAP remedies. Currently planned activities include:

- *Moenkopi Moqui Investigation at the FAP*. At least one new well will be advanced on the south side of I-40 to investigate water quality in the Moqui downgradient of the FAP.
- *Aquifer Testing Downgradient of the FAP*. Aquifer testing will be conducted at various locations downgradient of the FAP to better understand aquifer properties in this region of the site.
- *Preparation of Alternative Source Demonstrations for Arsenic and Cobalt at the FAP*. ASDs for these constituents will be prepared to demonstrate that the source of GWPS exceedances in groundwater downgradient of the FAP is not the leakage of arsenic or cobalt mass from the FAP.
- *Stratified Sampling of Water in the BAP*. To assess spatial and depth-specific variations in cobalt concentrations in BAP water, a water sampling characterization program will be implemented.
- *Leaching Evaluation at the BAP*. Bottom ash as well as distinct geological units found at the BAP (i.e., the alluvium, the Chinle, the Moenkopi Holbrook, and the Moenkopi Moqui) will be sampled and evaluated for CCR Rule constituents and then subject to leach testing to evaluate the potential source of cobalt at the BAP.
- *Bottom Ash Pond Dewatering Projection*. A water balance will be developed to project pond dewatering at the BAP.
- *Seepage Intercept System Evaluation, Optimization, and Testing*. Existing systems at both the FAP and BAP will be evaluated and optimization strategies will be investigated. If feasible, testing will be conducted to better understand the influence of these systems in intercepting seepage discharges to the alluvium.

4.2 Public Notice and Remedy Selection

After placing this report documenting the CM assessment for the FAP and BAP in the facility's operating record in accordance with §257.96(d) of the CCR Rule, APS will select a remedy as soon as feasible. Assessment monitoring of groundwater at the FAP and BAP will continue throughout remedy selection and implementation.

As required by §257.96(e) of the CCR Rule, the results of this CM assessment will be made available to interested and affected parties through a public meeting at least 30 days prior to selecting remedy or remedies for the FAP and the BAP.

5.0 REFERENCES

AECOM, 2016a. Cholla Power Plant Closure Plan §257.102(b) – Fly Ash Pond. CH_ClosPlan_002_20161017. Certified August 30, 2016.

AECOM, 2016b. Cholla Power Plant Closure Plan §257.102(b) – Bottom Ash Pond. CH_ClosPlan_003_20161017. Certified August 30, 2016.

AMEC Earth & Infrastructure, Inc. (AMEC), 2012. Well Completion Report, Installation of Aquifer Protection Permit Monitor Wells, Arizona Public Service Company, Cholla Power Plant, Navajo County, Arizona. AMEC Job No. 17-2011-4054. May 7, 2012.

Federal Register, 2018. *40 Code of Federal Regulations Part 257 – Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals From Electric Utilities; Final Rule promulgated April 17, 2015 with Amendments to the National Minimum Criteria (Phase One, Part One) effective August 29, 2018*.

Montgomery & Associates, 2011. Arizona Public Service Cholla Power Plant Point of Compliance Evaluation. Prepared for APS. January 26, 2011.

Montgomery & Associates, 2017. *Cholla Power Plant Coal Combustion Residuals Program – Design, Installation, and Evaluation of Completeness of Groundwater Monitoring Networks*. Navajo County, Arizona. Document #CH_GW_SystemCert_020_20170919. September 19, 2017.

Montgomery & Associates, 2018. *Cholla Power Plant Coal Combustion Residuals Program – Statistical Analysis of Baseline Groundwater Monitoring Data, November 2015 through September 2017*. Navajo County, Arizona. January 12, 2018. Updated May 22, 2018.

Sergent, Hauskins & Beckwith, 1973. *Proposed Ash Disposal Areas Soil and Geologic Study Report. APS Cholla Power Plant, Near Joseph City, Arizona.* December 14, 1973.

Wood Environment & Infrastructure Solutions, Inc. (Wood), 2018a. *CCR Groundwater Assessment Monitoring Statistical Analysis and Results for the Fly Ash Pond*. Arizona Public Service Cholla Power Plant – Navajo County, Arizona. October 15, 2018.

Wood, 2018b. *CCR Groundwater Assessment Monitoring Statistical Analysis and Results for the Bottom Ash Pond*. Arizona Public Service Cholla Power Plant – Navajo County, Arizona. October 15, 2018.

Wood, 2019a. *CCR Groundwater Assessment Monitoring Statistical Analysis and Results for the Sedimentation Pond*. Arizona Public Service Cholla Power Plant – Navajo County, Arizona. January 14, 2019.

Wood, 2019b. *Hydrogeologic Investigation of the FAP and BAP*. Arizona Public Service Cholla Power Plant – Navajo County, Arizona. June 2019.

Woodward-Clyde Consultants, 1991. *Cholla Ash Ponds Groundwater Interpretative Report, Navajo County, Arizona.* Prepared for APS. June 30, 1991.

TABLES

Table 1-1
Description of Coal Combustion Residual Units

CCR Unit	Function	Operation	Size/Construction	History
Fly Ash Pond (FAP)	*Single CCR unit* - surface impoundment to store slurried fly ash from the plant.	Receives a slurry from the plant that contains primarily fly ash and flue gas emission control residuals but may also contain some bottom ash, boiler slag, boiler cleaning waste, oil/water separator solids, and storm water. Periodically receives solids from the SEDI.	- 430 acres in aerial extent. - Total storage capacity of about 18,000 acre-feet. - Normal operating pool elevation of 5,114 feet amsl.	- Constructed beginning in 1976 and placed into service in 1978. - Unlined; constructed on Moenkopi bedrock and a thin veneer of alluvial sediments. - The dam is constructed of earth fill with a central clay core that extends to bedrock where bedrock is shallow. In the central portion of the dam, where bedrock is deeper, a slurry cutoff wall extends one foot into bedrock or two feet into stiff clay.
Sedimentation Pond (SEDI)	*Single CCR unit* - collects water from drains around plant site, including storm water, process water, plant water, and slurry from plant leaks.	Collects discharge from on-site secondary wastewater treatment plant, effluent from the oil/water separator, vehicle wash water, plant wash water, and FGD wastes from scrubber or scrubber feed tank upsets. Water collected in the SEDI is pumped to Cholla's general water sump for recycling as process water.	- 1.3 acres in aerial extent. - Total storage capacity of 10.5 acre-feet. - Maximum pond depth of 10 feet. - the top of the pond side slope is at 5,019 feet amsl	- Placed into service in 1976. - Lined with a 2-foot-thick layer of compacted clay. - Constructed below grade.
Bottom Ash Pond (BAP)	*Single CCR unit* - surface impoundment to store slurried bottom ash from the plant.	Bottom ash is pumped to the BAP as a slurry. The bottom ash settles in the east and west upstream storage cells and the water is decanted to the reservoir and ultimately siphoned back to the plant for reuse. Slurry may also contain fly ash, boiler slag, flue gas emission control residuals, sedimentation pond effluent, cooling tower blowdown, oil/water separator effluent and solids, boiler cleaning waste, and storm water.	- 105 acres in aerial extent. - Total storage capacity of 2,300 acre-feet. - Normal operating pool elevation of 5,117.8 feet amsl.	- Constructed beginning in 1976 and placed into service in 1978. - Unlined; constructed on Moenkopi bedrock and Tanner Wash alluvium. - Consists of a reservoir directly behind the dam and two storage cells upstream of the reservoir. - The dam is constructed of earth fill with a central clay core that extends to bedrock where bedrock is shallow. Where bedrock is deeper, a slurry cutoff wall extends below the central clay core to provide stability to the dam.
Bottom Ash Monofill (BAM)	*Single CCR unit* - landfill for bottom ash solids excavated from the BAP.	Bottom ash that has been drained of water is excavated from the BAP and permanently stored in the BAM. Periodically receives solids from the SEDI.	- 41 acres in aerial extent.	- Placed into service in 1999.

Notes:

amsl - above mean sea level
BAP - Bottom Ash Pond
BAM - Bottom Ash Monofill
CCR - Coal combustion residuals
FAP - Fly Ash Pond
FGD - flue gas deulfurization
SEDI - Sedimentation Pond

Source:

GEI Consultants, Inc. 2009. *Final Coal Ash Impoundment Specific Site Assessment Report, Arizona Public Service, Cholla Power Plant.* Submitted to Lockheed-Martin Corporation. December 2009.

Table 1-2
Summary of GWPSs and Appendix IV Constituent Statistical Analyses

Constituent	BAP BTV [mg/L]	BAP GWPS [mg/L]	BAP Basis for GWPS	BAP Location of SSLs Over GWPS	BAP Range of Exceeding LCLs [mg/L]	FAP BTV [mg/L]	FAP GWPS [mg/L]	FAP Basis for GWPS	FAP Location of SSLs Over GWPS	FAP Range of Exceeding LCLs [mg/L]
Antimony	0.004	0.006	US EPA MCL	None	---	0.004	0.006	US EPA MCL	None	---
Arsenic	0.004	0.01	US EPA MCL	None	---	0.004	0.01	US EPA MCL	M-51A	0.012
Barium	0.05	2	US EPA MCL	None	---	0.05	2	US EPA MCL	None	---
Beryllium	0.001	0.004	US EPA MCL	None	---	0.001	0.004	US EPA MCL	None	---
Cadmium	0.0004	0.005	US EPA MCL	None	---	0.0004	0.005	US EPA MCL	None	---
Chromium	0.004	0.1	US EPA MCL	None	---	0.004	0.1	US EPA MCL	None	---
Cobalt	0.002	0.006	Alternative Risk-Based GWPS	M-52A, M-53A, W-305, and W-314	0.010-0.038	0.002	0.006	Alternative Risk-Based GWPS	M-51A	0.01*
Fluoride	0.8	4	US EPA MCL	None	---	0.8	4	US EPA MCL	M-51A	4.3
Lead	0.002	0.015	Alternative Risk-Based GWPS	None	---	0.002	0.015	Alternative Risk-Based GWPS	None	---
Lithium	0.31	0.31	BTV	W-306	0.52	0.31	0.31	BTV	M-50A, M-51A, and W-123	0.43 to 0.63
Mercury	0.0002	0.002	US EPA MCL	None	---	0.0002	0.002	US EPA MCL	None	---
Molybdenum	0.0061	0.1	Alternative Risk-Based GWPS	None	---	0.0061	0.1	Alternative Risk-Based GWPS	W-123	0.32
Selenium	0.002	0.05	US EPA MCL	None	---	0.002	0.05	US EPA MCL	None	---
Thallium	0.0014	0.002	US EPA MCL	None	---	0.0014	0.002	US EPA MCL	None	---
Combined Radium	1.6	5	US EPA MCL	None	---	1.6	5	US EPA MCL	None	---

Notes:

BAP - Bottom Ash Pond
BTV - Background Threshold Value
FAP - Fly Ash Pond
GWPS - Groundwater Protection Standard
LCL - Lower Confidence Limit
MCL - Maximum Contaminant Level
mg/L - milligrams per liter
SEDI - Sedimentation Pond
SSLs - statistically significant levels
US EPA - US Environmental Protection Agency

*The reporting limit for cobalt is in exceedance of the GWPS; it is possible this is a false positive SSL over the GWPS on account of the laboratory's inability to detect a concentration below the GWPS.

Table 2-1
Water Quality Data Collected During Recent Groundwater Monitoring at the FAP

				Analyte Concentration by Location and Date							
				FAP	FAP	M-50A	M-50A	M-51A	M-51A	MW-65A	MW-65A
Analyte	Units	GWPS	AWQS	3/30/19	4/29/19	10/24/18	2/13/19	10/24/18	2/13/19	12/5/18	2/14/19
Boron	mg/L	---	---	350	310	3.1	---	30	---	12	---
Calcium	mg/L	---	---	730	---	630	---	870	---	780	---
Chloride	mg/L	---	---	24000	24000	2200	---	5400	---	3900	---
pH	SU	---	---	6.7	7.1	7.4	---	7.3	---	7.3	---
Sulfate	mg/L	---	---	24000	25000	3100	---	2900	---	2700	---
Total Dissolved Solids	mg/L	---	---	74000	77000	8100	---	12000	---	9900	---
Antimony	mg/L	0.006	0.006	0.036	---	---	<0.0010	---	<0.0010	<0.0010	<0.0010
Arsenic	mg/L	0.01	0.05	**0.17**	---	0.0028	0.0028	**0.032**	**0.025**	0.0025	0.0017
Barium	mg/L	2	2	0.092	---	0.0092	0.0086	0.0074	0.0070	0.040	0.015
Beryllium	mg/L	0.004	0.004	0.0057	---	---	<0.0010	---	<0.0010	---	<0.0010
Cadmium	mg/L	0.005	0.005	<0.00040	<0.0010	<0.00010	<0.00010	0.00010	<0.00010	0.00013	<0.00010
Chromium	mg/L	0.1	0.1	0.0024	<0.020	0.0046	0.0014	0.021	0.013	0.0035	0.0028
Cobalt	mg/L	0.006	NS	0.0053	---	0.00063	0.00069	<0.0050	<0.0020	0.0047	0.0033
Fluoride	mg/L	4	4.0	**68**	**69**	2.3	2.2	**5.0/5.5**	**4.5**	1.9	1.7
Lead	mg/L	0.015	0.05	<0.0020	<0.0050	<0.00050	<0.00050	<0.00050	<0.00050	0.0010	<0.00050
Lithium	mg/L	0.31	NS	**4.1**	---	**0.43**	**0.46**	**0.46**	**0.49**	**0.54**	**0.58**
Mercury	mg/L	0.002	0.002	<0.00020	---	---	<0.00020	---	<0.00020	<0.00020	<0.00020
Molybdenum	mg/L	0.1	NS	**0.52**	---	0.0071	0.0070	0.092	0.082	0.059	0.059
Selenium	mg/L	0.05	0.05	0.034	---	0.0026	0.0027	<0.0050	<0.0020	0.0021	0.0022
Thallium	mg/L	0.002	0.002	<0.00040	<0.0010	---	<0.00010	---	0.00013	0.00011	<0.00010
Alkalinity as CaCO3	mg/L	---	---	36	---	---	---	---	---	160	---
Alkalinity, Phenolphthalein	mg/L	---	---	<6.0	---	---	---	---	---	<6.0	---
Bicarbonate Alkalinity as CaCO3	mg/L	---	---	36	---	---	---	---	---	160	---
Carbonate Alkalinity as CaCO3	mg/L	---	---	<6.0	---	---	---	---	---	<6.0	---
Hydroxide Alkalinity as CaCO3	mg/L	---	---	<6.0	---	---	---	---	---	<6.0	---
Magnesium	mg/L	---	---	4900	---	---	---	---	---	290	---
Potassium	mg/L	---	---	340	---	---	---	---	---	28	---
SiO2, Silica	mg/L	---	---	---	---	---	---	---	---	32	---
Sodium	mg/L	---	---	17000	---	---	---	---	---	2000	---

Notes:

Constituents of concern are highlighted in dark green; concentrations greater than the GWPS are bolded.

Acronymns:

AWQS = Aquifer Water Quality Standard
FAP = Fly Ash Pond
GWPS = Groundwater Protection Standard
mg/L = milligrams per liter
NS = no standard
SU = standard units

Table 2-1
Water Quality Data Collected During Recent Groundwater Monitoring at the FAP

				Analyte Concentration by Location and Date						
				MW-66A	MW-66A	MW-67A	MW-67A	W-123	W-123	W-126
Analyte	**Units**	**GWPS**	**AWQS**	**12/5/18**	**2/14/19**	**12/5/18**	**2/14/19**	**10/24/18**	**2/13/19**	**12/5/18**
Boron	mg/L	---	---	1.2	---	0.38	---	37	---	43
Calcium	mg/L	---	---	830	---	1500	---	850	---	760
Chloride	mg/L	---	---	4600	---	5000	---	6600	---	7400
pH	SU	---	---	8.1	---	6.9	---	7.7	---	7.4
Sulfate	mg/L	---	---	2900	---	1500	---	3600	---	4200
Total Dissolved Solids	mg/L	---	---	11000	---	9300	---	14000	---	17000
Antimony	mg/L	0.006	0.006	<0.0010	<0.0010	<0.0010	<0.0010		<0.0010	<0.0010
Arsenic	mg/L	0.01	0.05	0.0034	0.0021	**0.018**	**0.016**	0.0026	0.0024	0.0027
Barium	mg/L	2	2	0.095	0.016	0.058	0.022	0.0092	0.010	0.021
Beryllium	mg/L	0.004	0.004	---	<0.0010	---	<0.0010	---	<0.0010	---
Cadmium	mg/L	0.005	0.005	0.00029	0.00027	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Chromium	mg/L	0.1	0.1	0.0098	<0.0010	0.0082	0.0012	0.043	0.12	0.0026
Cobalt	mg/L	0.006	NS	0.0026	0.0013	0.0058	0.0037	0.0016	0.0018	0.0049
Fluoride	mg/L	4	4.0	0.93	1.1	1.0	<0.80	3.7/4.0	3.7	3.5
Lead	mg/L	0.015	0.05	0.0040	<0.00050	0.0019	<0.00050	<0.00050	<0.00050	0.00072
Lithium	mg/L	0.31	NS	**0.51**	**0.55**	<0.20	<0.20	**0.65**	**0.75**	**0.78**
Mercury	mg/L	0.002	0.002	<0.00020	<0.00020	<0.00020	<0.00020	---	<0.00020	<0.00020
Molybdenum	mg/L	0.1	NS	0.016	0.014	0.0061	0.0050	**0.37**	**0.37**	**0.20**
Selenium	mg/L	0.05	0.05	0.031	0.027	0.0011	0.00066	0.0059	0.0063	0.0015
Thallium	mg/L	0.002	0.002	0.00015	0.00012	<0.00010	<0.00010	---	<0.00010	0.00015
Alkalinity as CaCO3	mg/L	---	---	80	---	180	---	---	---	100
Alkalinity, Phenolphthalein	mg/L	---	---	<6.0	---	<6.0	---	---	---	<6.0
Bicarbonate Alkalinity as CaCO3	mg/L	---	---	80	---	180	---	---	---	100
Carbonate Alkalinity as CaCO3	mg/L	---	---	<6.0	---	<6.0	---	---	---	<6.0
Hydroxide Alkalinity as CaCO3	mg/L	---	---	<6.0	---	<6.0	---	---	---	<6.0
Magnesium	mg/L	---	---	280	---	270	---	---	---	470
Potassium	mg/L	---	---	11	---	12	---	---	---	91
SiO2, Silica	mg/L	---	---	55	---	41	---	---	---	24
Sodium	mg/L	---	---	2500	---	1400	---	---	---	4000

Notes:
Constituents of concern are highlighted in dark green; concentrations greater than the GWPS are bolded.

Acronymns:
AWQS = Aquifer Water Quality Standard
FAP = Fly Ash Pond
GWPS = Groundwater Protection Standard
mg/L = milligrams per liter
NS = no standard
SU = standard units

Table 2-2
Constituent of Concern Properties Impacting Mobility in Aquifer Environments

Constituent	General Behavior	pH and Redox Sensitivities	Adsorption Characteristics	Solubility Characteristics
Arsenic	Behaves as oxi-anions (arsenate and arsenite), not as a metallic cation	Redox sensitive – toxicity and mobility (retardation) depends on valence state	Adsorbs to iron (and manganese) oxide coatings on soils; adsorption is pH dependent since these oxides are soluble at low pH (less than 2 standard units) and reducing conditions Can be forced to desorb by competition for adsorption sites by other anions like phosphate or sulfate if concentrations are high enough	Elementary arsenic is fairly insoluble; arsenic compounds may readily dissolve
Cobalt	Cationic metal ion	More mobile at low pH and reducing conditions	Likely pH and adsorbent dependent	Forms numerous complexes that somewhat increase solubility (organic matter, chloride, etc.) Cobalt carbonate precipitation can limit solubility to low values
Fluoride	Anion	Not redox or pH sensitive	Not readily adsorbed to soils; little retardation	Soluble in water
Lithium	Cationic metal ion (+1 charge)	Not redox or pH sensitive	Not strongly adsorbed to soils	Generally quite soluble and mobile No major insoluble compounds
Molybdenum	Behaves as an oxi-anion (molybdate, etc.), not as a metallic cation	Dependent on redox conditions (mostly +4 and +6, but also +3)	Adsorbs to iron oxide coatings on soils	Can form low solubility metal molybdate compounds (e.g., iron and calcium)

Table 2-3
Water Quality Data Collected During Recent Groundwater Monitoring at the BAP

				Analyte Concentration by Location and Date							
				BAP	BAP	M-52A	M-52A	M-53A	M-53A	M-55A	M-55A
Analyte	**Units**	**GWPS**	**AWQS**	**3/30/19**	**4/29/19**	**12/8/18**	**2/15/19**	**12/7/18**	**2/15/19**	**12/8/18**	**2/15/19**
Boron	mg/L	---	---	4.8	---	4.3	---	3.4	---	0.43	---
Calcium	mg/L	---	---	550	---	920	---	620	---	700	---
Chloride	mg/L	---	---	2100	2100	4900	---	2300	---	4300	---
pH	SU	---	---	8.3	8.2	6.8	---	7.4	---	7.3	---
Sulfate	mg/L	---	---	3100	3100	2700	---	3000	---	3400	---
Total Dissolved Solids	mg/L	---	---	7700	8200	11000	---	7600	---	11000	---
Antimony	mg/L	0.006	0.006	0.0027	---	<0.0050	<0.0010	<0.0050	<0.0010	<0.0050	<0.0010
Arsenic	mg/L	0.01	0.05	0.017	---	0.0022	0.00077	<0.0020	0.00064	<0.0020	0.0033
Barium	mg/L	2	2	0.20	---	0.019	0.015	0.0085	0.013	0.014	0.014
Beryllium	mg/L	0.004	0.004	<0.0010	---	---	<0.0010	---	<0.0010	---	<0.0010
Cadmium	mg/L	0.005	0.005	0.00011	---	<0.0010	0.00027	0.0014	0.0011	<0.0010	<0.00010
Chromium	mg/L	0.1	0.1	0.0035	<0.010	0.043	0.037	<0.0050	0.0025	0.17	0.14
Cobalt	mg/L	0.006	NS	0.00099	---	**0.036**	**0.029**	**0.014**	**0.011**	<0.0020	0.00095
Fluoride	mg/L	4	4.0	3.7	3.7	1.0	0.93	2.3	1.2	<0.80	<0.80
Lead	mg/L	0.015	0.05	<0.00050	---	<0.0010	<0.00050	<0.0010	<0.00050	<0.0010	<0.00050
Lithium	mg/L	0.31	NS	<0.20	---	0.29	**0.32**	0.20	0.21	**0.39**	**0.43**
Mercury	mg/L	0.002	0.002	<0.00020	---	---	<0.00020	---	<0.00020	---	<0.00020
Molybdenum	mg/L	0.1	NS	0.027	---	0.031	0.020	0.042	0.0067	0.020	0.019
Selenium	mg/L	0.05	0.05	0.014	---	<0.0060	0.0015	<0.0060	0.00078	0.083	0.13
Thallium	mg/L	0.002	0.002	<0.00010	---	<0.0010	<0.00010	<0.0010	<0.00010	<0.0010	<0.00010
Alkalinity as CaCO3	mg/L	---	---	120	---	230	---	92	---	190	---
Alkalinity, Phenolphthalein	mg/L	---	---	<6.0	---	<6.0	---	<6.0	---	<6.0	---
Bicarbonate Alkalinity as CaCO3	mg/L	---	---	120	---	230	---	92	---	190	---
Carbonate Alkalinity as CaCO3	mg/L	---	---	<6.0	---	<6.0	---	<6.0	---	<6.0	---
Hydroxide Alkalinity as CaCO3	mg/L	---	---	<6.0	---	<6.0	---	<6.0	---	<6.0	---
Magnesium	mg/L	---	---	300	---	300	---	220	---	160	---
Potassium	mg/L	---	---	28	---	7.1	---	13	---	3.0	---
SiO2, Silica	mg/L	---	---	---	---	14	---	9.4	---	12	---
Sodium	mg/L	---	---	1500	---	2600	---	1600	---	2900	---

Notes:

Constituents of concern are highlighted in dark green; concentrations greater than the GWPS are bolded.

Acronymns:

AWQS = Aquifer Water Quality Standard
BAP = Bottom Ash Pond
GWPS = Groundwater Protection Standard
mg/L = milligrams per liter
NS = no standard
SU = standard units

Table 2-3
Water Quality Data Collected During Recent Groundwater Monitoring at the BAP

				Analyte Concentration by Location and Date							
				M-64A	W-301	W-301	W-302	W-302	W-304	W-304	W-305
Analyte	**Units**	**GWPS**	**AWQS**	**2/13/19**	**12/7/18**	**2/15/19**	**12/7/18**	**2/15/19**	**12/7/18**	**2/15/19**	**12/7/18**
Boron	mg/L	---	---	---	2.4	---	0.64	---	0.50	---	0.35
Calcium	mg/L	---	---	---	760	---	560	---	590	---	710
Chloride	mg/L	---	---	---	4000	---	2600	---	2900	---	2400
pH	SU	---	---	---	7.2	---	7.3	---	7.3	---	7.3
Sulfate	mg/L	---	---	---	3300	---	2400	---	2900	---	2300
Total Dissolved Solids	mg/L	---	---	---	10000	---	7200	---	8100	---	7000
Antimony	mg/L	0.006	0.006	<0.0010	<0.0050	<0.0010	<0.0050	<0.0010	<0.0050	<0.0010	<0.0050
Arsenic	mg/L	0.01	0.05	0.00089	<0.0020	0.0017	<0.0020	0.0043	<0.0020	0.0020	<0.0020
Barium	mg/L	2	2	0.012	0.013	0.0080	0.014	0.36	0.0083	0.011	0.012
Beryllium	mg/L	0.004	0.004	<0.0010	---	<0.0010	---	<0.0010	---	<0.0010	---
Cadmium	mg/L	0.005	0.005	<0.00010	<0.0010	0.00018	<0.0010	0.00089	<0.0010	<0.00010	<0.0010
Chromium	mg/L	0.1	0.1	<0.0010	<0.0050	<0.0010	<0.0050	0.020	<0.0050	<0.0010	<0.0050
Cobalt	mg/L	0.006	NS	<0.00050	**0.017**	**0.018**	0.0049	**0.022**	0.0034	0.0029	**0.018**
Fluoride	mg/L	4	4.0	<0.80	<0.80	<0.40	0.98	0.88	<0.80	<0.80	<0.80
Lead	mg/L	0.015	0.05	<0.00050	0.0012	<0.00050	<0.0010	0.028	<0.0010	<0.00050	0.0030
Lithium	mg/L	0.31	NS	0.29	**0.43**	**0.59**	**0.32**	**0.37**	**0.40**	**0.48**	0.21
Mercury	mg/L	0.002	0.002	<0.00020	---	<0.00020	---	0.00022	---	<0.00020	---
Molybdenum	mg/L	0.1	NS	0.0049	0.080	0.0046	0.068	0.0039	0.026	0.0017	0.021
Selenium	mg/L	0.05	0.05	0.00052	<0.0060	0.0084	<0.0060	0.0035	<0.0060	0.00059	<0.0060
Thallium	mg/L	0.002	0.002	<0.00010	<0.0010	<0.00010	<0.0010	0.00016	<0.0010	<0.00010	<0.0010
Alkalinity as CaCO3	mg/L	---	---	---	180	---	140	---	140	---	99
Alkalinity, Phenolphthalein	mg/L	---	---	---	<6.0	---	<6.0	---	<6.0	---	<6.0
Bicarbonate Alkalinity as CaCO3	mg/L	---	---	---	180	---	140	---	140	---	99
Carbonate Alkalinity as CaCO3	mg/L	---	---	---	<6.0	---	<6.0	---	<6.0	---	<6.0
Hydroxide Alkalinity as CaCO3	mg/L	---	---	---	<6.0	---	<6.0	---	<6.0	---	<6.0
Magnesium	mg/L	---	---	---	170	---	120	---	100	---	110
Potassium	mg/L	---	---	---	4.6	---	5.5	---	5.8	---	3.0
SiO2, Silica	mg/L	---	---	---	14	---	12	---	9.6	---	11
Sodium	mg/L	---	---	---	2600	---	1800	---	2100	---	1500

Notes:

Constituents of concern are highlighted in dark green; concentrations greater than the GWPS are bolded.

Acronymns:

AWQS = Aquifer Water Quality Standard
BAP = Bottom Ash Pond
GWPS = Groundwater Protection Standard
mg/L = milligrams per liter
NS = no standard
SU = standard units

Table 2-3
Water Quality Data Collected During Recent Groundwater Monitoring at the BAP

				Analyte Concentration by Location and Date							
				W-305	W-306	W-306	W-307	W-307	W-308	W-308	W-309
Analyte	**Units**	**GWPS**	**AWQS**	**2/15/19**	**12/7/18**	**2/15/19**	**12/8/18**	**2/15/19**	**12/8/18**	**2/15/19**	**12/8/18**
Boron	mg/L	---	---	---	1.1	---	2.4	---	0.45	---	0.42
Calcium	mg/L	---	---	---	410	---	790	---	730	---	280
Chloride	mg/L	---	---	---	1900	---	2700	---	2900	---	1300
pH	SU	---	---	---	7.9	---	7.2	---	7.1	---	8.1
Sulfate	mg/L	---	---	---	12000	---	2600	---	3000	---	2900
Total Dissolved Solids	mg/L	---	---	---	19000	---	7800	---	8300	---	6500
Antimony	mg/L	0.006	0.006	<0.0010	<0.0050	<0.0010	<0.0050	<0.0010	<0.0050	<0.0010	<0.0050
Arsenic	mg/L	0.01	0.05	0.00087	0.0041	0.0053	<0.0020	0.00088	0.0023	0.0019	0.0044
Barium	mg/L	2	2	0.011	0.010	0.011	0.012	0.012	0.0082	0.0066	0.011
Beryllium	mg/L	0.004	0.004	<0.0010	---	<0.0010	---	<0.0010	---	<0.0010	---
Cadmium	mg/L	0.005	0.005	<0.00010	<0.0010	<0.00010	<0.0010	0.00028	<0.0010	<0.00010	<0.0010
Chromium	mg/L	0.1	0.1	0.0017	<0.0050	<0.0010	<0.0050	<0.0010	<0.0050	<0.0010	<0.0050
Cobalt	mg/L	0.006	NS	**0.018**	<0.0020	0.00097	**0.076**	**0.073**	0.0033	0.00079	<0.0020
Fluoride	mg/L	4	4.0	<0.40	1.4	1.2	<0.80	<0.80	<0.80	<0.80	1.0
Lead	mg/L	0.015	0.05	0.0018	<0.0010	<0.00050	0.0020	0.00085	<0.0010	<0.00050	<0.0010
Lithium	mg/L	0.31	NS	0.22	**0.73**	**0.80**	0.24	0.26	**0.37**	**0.39**	<0.20
Mercury	mg/L	0.002	0.002	<0.00020	---	<0.00020	---	<0.00020	---	<0.00020	---
Molybdenum	mg/L	0.1	NS	0.020	0.028	0.031	0.0044	0.0045	0.032	0.0020	0.024
Selenium	mg/L	0.05	0.05	<0.00050	<0.0060	0.0021	<0.0060	0.00063	<0.0060	0.074	<0.0060
Thallium	mg/L	0.002	0.002	<0.00010	<0.0010	<0.00010	<0.0010	<0.00010	<0.0010	<0.00010	<0.0010
Alkalinity as CaCO3	mg/L	---	---	---	130	---	100	---	160	---	55
Alkalinity, Phenolphthalein	mg/L	---	---	---	<6.0	---	<6.0	---	<6.0	---	<6.0
Bicarbonate Alkalinity as CaCO3	mg/L	---	---	---	130	---	100	---	160	---	55
Carbonate Alkalinity as CaCO3	mg/L	---	---	---	<6.0	---	<6.0	---	<6.0	---	<6.0
Hydroxide Alkalinity as CaCO3	mg/L	---	---	---	<6.0	---	<6.0	---	<6.0	---	<6.0
Magnesium	mg/L	---	---	---	230	---	150	---	120	---	34
Potassium	mg/L	---	---	---	2.6	---	5.4	---	7.7	---	12
SiO2, Silica	mg/L	---	---	---	12	---	13	---	12	---	22
Sodium	mg/L	---	---	---	5700	---	1700	---	1900	---	1700

Notes:
Constituents of concern are highlighted in dark green; concentrations greater than the GWPS are bolded.

Acronymns:
AWQS = Aquifer Water Quality Standard
BAP = Bottom Ash Pond
GWPS = Groundwater Protection Standard
mg/L = milligrams per liter
NS = no standard
SU = standard units

Table 2-3
Water Quality Data Collected During Recent Groundwater Monitoring at the BAP

				Analyte Concentration by Location and Date			
				W-309	W-314	W-314	W-317
Analyte	**Units**	**GWPS**	**AWQS**	**2/15/19**	**12/8/18**	**2/15/19**	**3/30/19**
Boron	mg/L	---	---	---	1.1	---	0.20
Calcium	mg/L	---	---	---	800	---	320
Chloride	mg/L	---	---	---	2700	---	1400
pH	SU	---	---	---	7.3	---	7.5
Sulfate	mg/L	---	---	---	2100	---	670
Total Dissolved Solids	mg/L	---	---	---	7700	---	3300
Antimony	mg/L	0.006	0.006	<0.0010	<0.0050	<0.0010	<0.0010
Arsenic	mg/L	0.01	0.05	0.0047	<0.0020	0.0011	0.0036
Barium	mg/L	2	2	0.0083	0.013	0.011	0.039
Beryllium	mg/L	0.004	0.004	<0.0010	---	<0.0010	<0.0010
Cadmium	mg/L	0.005	0.005	<0.00010	<0.0010	0.00017	<0.00010
Chromium	mg/L	0.1	0.1	<0.0010	0.014	0.046	0.0035
Cobalt	mg/L	0.006	NS	<0.00050	**0.014**	**0.016**	0.00085
Fluoride	mg/L	4	4.0	1.1	0.89	0.82	<0.40
Lead	mg/L	0.015	0.05	<0.00050	<0.0010	<0.00050	<0.00050
Lithium	mg/L	0.31	NS	**0.35**	**0.32**	**0.34**	<0.20
Mercury	mg/L	0.002	0.002	<0.00020	---	<0.00020	<0.00020
Molybdenum	mg/L	0.1	NS	0.028	0.0087	0.012	0.064
Selenium	mg/L	0.05	0.05	0.19	<0.0060	<0.00050	<0.00050
Thallium	mg/L	0.002	0.002	<0.00010	<0.0010	<0.00010	<0.00010
Alkalinity as CaCO3	mg/L	---	---	---	94	---	190
Alkalinity, Phenolphthalein	mg/L	---	---	---	<6.0	---	<6.0
Bicarbonate Alkalinity as CaCO3	mg/L	---	---	---	94	---	190
Carbonate Alkalinity as CaCO3	mg/L	---	---	---	<6.0	---	<6.0
Hydroxide Alkalinity as CaCO3	mg/L	---	---	---	<6.0	---	<6.0
Magnesium	mg/L	---	---	---	160	---	110
Potassium	mg/L	---	---	---	1.8	---	7.1
SiO2, Silica	mg/L	---	---	---	8.9	---	
Sodium	mg/L	---	---	---	1500	---	650

Notes:

Constituents of concern are highlighted in dark green; concentrations greater than the GWPS are bolded.

Acronymns:

AWQS = Aquifer Water Quality Standard
BAP = Bottom Ash Pond
GWPS = Groundwater Protection Standard
mg/L = milligrams per liter
NS = no standard
SU = standard units

Table 3-1
Corrective Measures Technology Screening for Releases from the FAP

Technology	Description	Benefits	Constraints and Risks	Relative Time to Benefit	Retained?
(A) Operation of existing seepage collection systems	Existing well and collection systems attempt to intercept seepage in areas where impacts at ground surface were previously observed. After coal combustion power generation activites are shut down in 2025, collected seepage will be routed to a future evaporation pond.	(1) Targets known areas of surface seepage, theoretically controlling in part, the source of impacts to the alluvium.	(1) Existing systems are not deep and/or extensive enough to intercept the seepage responsible for currently observed impacts in the alluvium.	Fast	Yes
(B) Draining/evaporation of free liquid from the FAP and closure with CCR in place	Discharges to the FAP will be controlled through water conservation measures prior to the cessation of coal combusion power generation activities*; after these activites are shut down, free liquid will be allowed to evaporate and/or be actively drained from the FAP until a date when the FAP can be closed with CCR in place. Stormwater control measures would be implemented to prevent ponding behind the dam.	(1) Reduces head in the pond which will reduce the rate of seepage from the FAP. (2) Promotes FAP closure.	(1) Reducing/eliminating the head in the FAP will reduce seepage but will take time. (2) Although a low permeability cap will be installed on the FAP after it is dewatered and engineering control measures to divert stormwater away from the FAP will be put in place, if stormwater percolates through the drained FAP, impacted seepage from the FAP could be mobilized because the CCR remains in place. (3) Will not address existing impacts in groundwater.	Slow	Yes
(C) Draining/evaporation of free liquid from the FAP and closure of the pond through CCR removal	Discharges to the FAP will be controlled through water conservation measures prior to the cessation of coal combustion power generation activities*; after these activities are shut down, free liquid will be allowed to evaporate and/or be actively drained from the FAP until the CCR can be removed and placed in an appropriately lined facility.	(1) Reduces head in the pond which will reduce the rate of seepage from the FAP. (2) Promotes FAP closure. (3) Removes a potential ongoing source of contaminant mass from the Site.	(1) Removing the CCR in the FAP will take time to dewater and excavate. (2) Potential for cross media impacts during excavation, transport and final placement at new location. (3) Logistical difficulties in locating and/or constructing a suitable facility for the excavated waste. (4) Likely concerns from the public regarding the transport of and potential exposure to the waste in transportation corridors. (5) Will not address existing impacts in groundwater.	Slow	Yes

Table 3-1
Corrective Measures Technology Screening for Releases from the FAP

Technology	Description	Benefits	Constraints and Risks	Relative Time to Benefit	Retained?
(D) Monitored natural attenuation of COCs in the impacted alluvial aquifer	The COCs would be allowed to naturally attenuate via dilution, dispersion, and adsorption. Groundwater monitoring would continue as long as COC concentrations exceed GWPSs.	(1) No active mitigation would be required.	(1) The extent of COC plumes would continue to increase until the rate of attenuation exceeds the rate of migration; expansion of the plume could occur for some time before attenuating. (2) Additional monitoring wells would likely be required to monitor migration.	Slow	Yes
(E) Containment wells sited between the dam and I-40 in the vicinity of existing seepage collection systems.	A series of containment wells would target high contaminant flux locations at the right abutments and Geronimo Knob location. Wells would need to be completed deeper than existing collection systems, targeting the alluvium and distinct transmissive layers of the Moqui, up to 50 feet deep. Extracted water would be managed in the same manner as existing seepage collection systems.	(1) Wells could be installed incrementally so that spacing and depths could be evaluated and adjusted to promote effectiveness.	(1) Containment flows from individual wells could potentially be very low with only localized impacts. (2) The technology does not address the COC plume in the alluvium downgradient of the dam.	Fast	Yes
(F) Containment wells sited south of I-40 in downgradient alluvium	Containment wells would be located hydraulically downgradient in the alluvium across from the highway and sited to optimize the objectives of plume containment and treatment. Extracted water would be managed in the same manner as existing seepage collection systems.	(1) Could be more effective in containing a larger extent of the plume than containment wells located near the dam.	(1) Aquifer properties may require a series of wells to adequately contain and treat the plume. (2) Extraction systems would likely need to operate for long durations to clean up the COC plume. (3) Placement of the wells may be constrained by property ownership.	Moderate	Yes
(G) Gravel filled seepage collection trench (up to 50 ft deep)	A deep seepage collection system would be installed through the alluvium and into the Moqui. The trench would be backfilled with gravel and be a higher permeability than the adjacent units. Pumps would be installed in sumps located in the trench to pump seepage from the trench. Extracted water would be managed in the same manner as existing seepage collection systems.	(1) Could be very effective in intercepting seepage if adequate design information can be collected in advance of installation.	(1) A predesign investigation would need to be conducted. (2) The trench would likely need to extend into the Moqui and the length could be extensive; there is a risk that trenching into the Moqui could compromise vertical migration through the Moenkopi where the unit is thin. (3) The technology does not address the COC plume in the alluvium downgradient of the dam.	Moderate	Yes

Table 3-1
Corrective Measures Technology Screening for Releases from the FAP

Technology	Description	Benefits	Constraints and Risks	Relative Time to Benefit	Retained?
(H) Partial cutoff walls along the right and left portions of dam, with a groundwater extraction system near the center of the dam in the alluvium.	A cutoff slurry wall would be installed along the right and left side, along portions where the slurry cutoff wall beneath the dam was not installed. This would funnel flow to the center in alluvium where multiple wells would be installed to extract the groundwater from the subsurface. Extracted water would be managed in the same manner as existing seepage collection systems.	(1) The cutoff wall would increase the effectiveness of containment wells located in the alluvium.	(1) A predesign investigation would need to be conducted. (2) The trench would likely need to extend into the Moqui and the length could be extensive; there is a risk that trenching into the Moqui could compromise vertical migration through the Moenkopi where the unit is thin. (3) The technology may not address the COC plume in the alluvium downgradient of the dam, depending on where the cutoff wall is placed.	Moderate	No

Notes:

* Dewatering of the FAP for pond closure is not feasible prior to the cessation of coal combustion power generation activities in 2025 unless a new fly ash disposal facility is constructed. Siting, design and construction of a new facility would require three to four years to be operational. Since starting this work sooner than 2025 would have an immaterial impact on the time to achieve completion of the remedy, construction of a new fly ash pond is not considered a viable option.

FAP = Fly Ash Pond
COCs = Constituent of concerns (i.e., fluoride, lithium, and molybdenum)
GWPS = Groundwater Protection Standard

Table 3-2
Evaluation of Corrective Measures for the FAP

Corrective Measures	Performance and Reliability	Ease of Implementation	Potential Impacts[a]	Time to Begin Remedy	Time to Complete the Remedy	Institutional Requirements[b]
Alternative 1: (A) Operation of existing seepage collection systems (B/C) Draining/evaporation of free liquid from the FAP with closure either in place or by CCR removal (D) Natural attenuation of COCs in the impacted alluvial aquifer *As modeled: The October/December 2018 fluoride plume and hydraulic heads were evaluated in a transient, three-layer groundwater flow and transport model.*	Existing seepage collection systems do not prevent the discharge of all seepage from the FAP to the alluvium and thus may not effectively reduce the source and magnitude of risk until there is no free liquid in the FAP or the CCR has been removed from the FAP. If the CCR is removed after dewatering, the risk of future impacted seepage is lessened. However, the COCs will likely continue to be present at concentrations exceeding GWPSs in alluvial groundwater downgradient of the FAP for some time.	CMs for existing collection systems and wells are in place - long term-operation and management are required. Additional wells will likely be necessary to monitor impacts over time as the plume continues to migrate - these wells may not be located on APS property which would require coordination with neighboring property owners. A small amount of at least one of the COC plumes has already migrated offsite which could elicit concerns from the downgradient property owner. Removal of CCR as part of closure would be logistically intensive, requiring locating and/or constructing a suitable facility and arranging for transport of large quantities of waste between the Site and the facility, likely on public thoroughfares.	No human or ecological receptors are currently known to be impacted. If excavation of CCR is conducted, there would be a potential for cross media impacts during excavation (to air via dust and to surface water via runoff), transport (through spills, accidents, and/or transport vessel contamination), and final placement (if the receiving facility is not properly constructed or the integrity of the facility degrades over time).	Seepage collection systems are currently in place. Dewatering and pond closure will begin in 2025 (dewatering could take 10 or more years). Expansion of the monitoring system would be conducted as required.	*The groundwater model predicts fluoride will attenuate to concentrations less than the GWPS by 2080 (in 61 years or 44 years after removal of the source of seepage by draining and/or removing the CCR present in the FAP)*	Future wells would require ADWR permitting. If the CCR is removed, waste characterization/ management activities and permitting of the new facility where the excavated CCR is placed by ADEQ under the Aquifer Protection Permit program would be required.

Table 3-2
Evaluation of Corrective Measures for the FAP

Corrective Measures	Performance and Reliability	Ease of Implementation	Potential Impacts[(a)]	Time to Begin Remedy	Time to Complete the Remedy	Institutional Requirements[(b)]
Alternative 2: (A) Operation of existing seepage collection systems (B/C) Draining/evaporation of free liquid from the FAP with closure either in place or by CCR removal (D) Natural attenuation of COCs in the impacted alluvial aquifer (E/G) Containment wells/seepage collection trench sited north of I-40 *As modeled: 14 hypothetical pumping wells (in an evenly spaced line adjacent to the dam) extracting groundwater at a total rate of 335 gpm were evaluated using a transient, three-layer groundwater flow and transport model.*	New containment wells located north of I-40 that intercept seepage to the alluvium could reduce the source and magnitude of risk resulting from future FAP seepage. Alternatively, a seepage collection trench could be installed in the same location. COCs would continue to be present at concentrations exceeding GWPSs in alluvial groundwater downgradient of the FAP for some time.	The location, quantity and construction of new containment wells would likely be developed iteratively to promote effective seepage interception. Long term operation and management would be required. Downgradient impacts would be the same as Alternative 1.	Same as Alternative 1.	A new containment well installation program can begin within 3 months of remedy selection. Completion of constructible portions of the remedy could require 12 to 48 months.	Once new containment wells are in place - they would need to be operated for as long as adverse impacts from seepage occur (likely at least as long as there is standing water in the FAP). *The groundwater model predicts fluoride will exceed the GWPS until 2045 (for 26 years) with containment well operation.*	Same as Alternative 1.
Alternative 3: (A) Operation of existing seepage collection systems (B/C) Draining/evaporation of free liquid from the FAP with closure either in place or by CCR removal (D) Natural attenuation of COCs in the impacted alluvial aquifer (F) Containment wells sited on the south side of I-40 in the alluvium *As modeled: 15 hypothetical pumping wells (in an evenly spaced line along the southern edge of I-40) extracting groundwater at a total rate of 375 gpm were evaluated using a transient, three-layer groundwater flow and transport model.*	Downgradient containment wells could assist in containing the migration and extent of the COC plumes.	The location, quantity and design of new containment wells would likely be developed iteratively to promote effective seepage/COC plume interception. Long term operation and management would be required. Operation of containment wells on the southern side of I-40 could mitigate concerns that the plume may be migrating offsite.	Same as Alternative 1.	A new containment well installation program can begin within 3 months of remedy selection for wells that are located on APS property; initiation of an offsite well program could take 12 to 24 months and require another 12 to 36 months for construction completion.	Once new containment wells are in place - they would need to be operated for as long as adverse impacts from seepage occur (likely at least as long as there is standing water in the FAP). Downgradient containment wells would need to be operated until GWPSs are achieved or reasonably expected to be achieved based on a natural attenuation analysis. *The groundwater model predicts fluoride will exceed the GWPS until 2055 (for 36 years) with containment well operation.*	Same as Alternative 1.

Table 3-2
Evaluation of Corrective Measures for the FAP

Corrective Measures	Performance and Reliability	Ease of Implementation	Potential Impacts[a]	Time to Begin Remedy	Time to Complete the Remedy	Institutional Requirements[b]
Alternative 4: (A) Operation of existing seepage collection systems (B/C) Draining/evaporation of free liquid from the FAP with closure either in place or by CCR removal (D) Natural attenuation of COCs in in the impacted alluvial aquifer (E/G) Containment wells/seepage collection trench sited north of I-40 (F) Containment wells sited on the south side of I-40 in the alluvium *As modeled: 29 hypothetical pumping wells extracting groundwater at a total rate of 710 gpm were evaluated using a transient, three-layer groundwater flow and transport model.*	New containment wells or a seepage trench located north of I-40 that intercept seepage to the alluvium could reduce the source and magnitude of risk resulting from future FAP seepage. Downgradient containment wells could assist in containing the migration and extent of the COC plumes.	The location, quantity and design of new containment wells would likely be developed iteratively to promote effective seepage/COC plume interception. Long term operation and management would be required. Operation of containment wells on the southern side of I-40 could mitigate concerns that the plume may be migrating offsite.	Same as Alternative 1.	A new containment well installation program can begin within 3 months of remedy selection if wells are located on APS property; initiation of offsite well program could take 12 to 24 months and require another 12 to 48 months for construction completion.	Once new containment wells are in place - they would need to be operated for as long as adverse impacts from seepage occur (likely at least as long as there is free liquid in the FAP). Downgradient containment wells would need to be operated until GWPSs are achieved or reasonably expected to be achieved based on a natural attenuation analysis. *The groundwater model predicts fluoride will exceed the GWPS until 2041 (for 22 years with containment well operation).*	Same as Alternative 1.

Notes:
FAP = Fly Ash Pond
COCs = Constituents of concern (i.e., fluoride, lithium, and molybdenum)
GWPS(s) = Groundwater Protection Standard(s)

(a) Including safety impacts, cross-media impacts, and control of exposure to any residual contamination.
(b) Such as state or local permit requirements or other environmental or public health requirements that may substantially affect implementation of the remedy(s).

Table 3-3
Corrective Measure Technology Screening for Releases from the BAP

Technology	Description	Benefits	Constraints and Risks	Relative Time to Benefit	Retained?
(A) Operation of existing seepage collection systems	Existing well and trench-based collection systems intercept seepage to the south and east of the dam and discharge to the BAP. After coal combustion power generation activites are shut down in 2025, collected seepage will be routed to a future evaporation pond.	(1) Targets known areas of surface seepage, theoretically controlling in part, the source of impacts to the alluvium.	(1) Existing systems are not deep and/or extensive enough to intercept the seepage responsible for currently observed impacts in the alluvium.	Fast	Yes
(B) Draining/evaporation of free liquid from the BAP	Solids would continue to be dewatered and a portion of the clarified water in the BAP would continue to be piped to the plant for reuse until 2025; after the cessation of coal combustion power generation activities*, free liquid would either be drained from the BAP or allowed to evaporate.	(1) Reduces head in the pond which will reduce the rate of seepage from the BAP. (2) Promotes BAP closure.	(1) The volume of water to be drained is significant and could require an extensively sized evaporation pond if active dewatering is conducted. If evaporation is the only mechanism for removing water from the pond, the time to implement this measure would be longer.	Slow	Yes
(C) Draining/evaporation of free liquid from the BAP and closure of the pond through CCR removal	Solids would continue to be dewatered and a portion of the clarified water in the BAP would continue to be piped to the plant for reuse until 2025; after the cessation of coal combustion power generation activities*, free liquid will be allowed to evaporate and/or be actively drained from the BAP until the CCR can be removed and placed in an appropriately lined facility.	(1) Reduces head in the pond which will reduce the rate of seepage from the BAP. (2) Promotes BAP closure. (3) Removes a potential ongoing source of contaminant mass from the Site.	(1) Removing the CCR in the BAP will take time to dewater and excavate. (2) Potential for cross media impacts during excavation, transport and final placement at new location. (3) Logistical difficulties in locating and/or constructing a suitable facility for the excavated waste. (4) Likely concerns from the public regarding the transport of and potential exposure to the waste in transportation corridors. (5) Will not address existing impacts in groundwater.	Slow	Yes
(D) Natural attenuation of the COC in the impacted alluvial aquifer	The COC would be allowed to naturally attenuate via dilution, dispersion, and adsorption. Groundwater monitoring would continue as long as COC concentrations exceed the GWPS.	(1) No active mitigation would be required.	(1) The extent of the COC plume would continue to increase until the rate of attenuation exceeds the rate of migration; expansion of the plume could occur for some time before attenuating. (2) Additional monitoring wells would likely be required to monitor migration.	Slow	Yes

Table 3-3
Corrective Measure Technology Screening for Releases from the BAP

Technology	Description	Benefits	Constraints and Risks	Relative Time to Benefit	Retained?
(E) Containment wells sited adjacent to the south and east of the dam	A series of containment wells would target high contaminant flux locations close to the south and east of the dam. Wells would need to be completed deeper than existing collection systems, potentially targeting possibly distinct beds in the Moenkopi.	(1) Wells could be installed incrementally so that spacing and depths could be evaluated and adjusted to promote effectiveness. (2) A deep well sited near W-305 and W-306 may have significant impact in intercepting COC flux from the dam at depth.	(1) Containment flows from individual wells could potentially be very low with only localized impacts. (2) Targeting appropriate locations on the east side of the BAP could be difficult and may require a series of wells greater than 50 feet deep. (3) The technology does not address the COC plume in the alluvium downgradient of the dam.	Fast	Yes
(F) Containment wells sited further downgradient from the dam in alluvium	Containment wells would be located hydraulically downgradient in the Tanner Wash Alluvium and sited to optimize the objectives of plume containment and treatment.	(1) Could be more effective in containing a larger extent of the plume than containment wells located in shallow alluvium, near the dam.	(1) Wells would likely need to be located on non-APS property limiting ability to implement and access. (2) Extraction systems would likely need to extract significant quantities of water and operate for long durations to clean up the COC plume.	Moderate	No
(G) Collection trenches on east side of the dam	A deeper seepage collection system would be installed than currently exists. The current systems on the east side of the BAP are approximately 40 feet in depth or shallower and address visible seeps; there may be impacted seepage discharging deeper in the alluvium than the current systems can address.	(1) Could be very effective in intercepting seepage on the east side of the dam if adequate design information can be collected in advance of installation.	(1) A predesign investigation of the eastern dam area would need to be conducted. (2) The trench would likely need to extend into the Moqui and the length could be extensive. (3) The technology does not address the COC plume in the alluvium downgradient of the dam.	Moderate	Yes
(H) Cutoff wall along the east side of the dam with containment wells	A cutoff slurry wall would be installed along the east side of the dam to enhance the effectiveness of containment wells located between the dam and the cutoff wall.	(1) Would increase the effectiveness of containment wells located along the eastern side of the dam.	(1) The cutoff would likely need to extend into the Moqui and the length could be extensive. (2) The technology does not address the COC plume in the alluvium downgradient of the dam.	Moderate	Yes

Table 3-3
Corrective Measure Technology Screening for Releases from the BAP

Technology	Description	Benefits	Constraints and Risks	Relative Time to Benefit	Retained?
(I) Permeation grouting on the south side of the dam in the alluvium at the base of the slurry cutoff wall	Permeation grouting would target the gap of alluvium beneath the southern slurry cutoff wall with injected grout (the slurry cutoff wall placed during construction was not keyed into bedrock at the deepest portion of the alluvial channel).	(1) Could be very effective in reducing seepage from the southern side of the dam if successfully implemented.	(1) May be difficult to assess effectiveness and additional control along the southern side of the dam may still be required to address localized flux through the dam. (2) The technology does not address the COC plume in the alluvium downgradient of the dam.	Moderate	No

Notes:

* Dewatering of the BAP for pond closure is not feasible prior to the cessation of coal combustion power generation activities in 2025 unless a new bottom ash disposal facility is constructed. Siting, design and construction of a new facility would require three to four years to be operational. Since starting this work sooner than 2025 would have an immaterial impact on the time to achieve completion of the remedy, construction of a new bottom ash pond is not considered a viable option.

BAP = Bottom Ash Pond
COC = Constituent of concern (i.e., cobalt)
GWPS = Groundwater Protection Standard

Table 3-4
Evaluation of Corrective Measures for the BAP

Corrective Measures	Performance and Reliability	Ease of Implementation	Potential Impacts[(a)]	Time to Begin Remedy	Time to Complete the Remedy	Institutional Requirements[(b)]
Alternative 1: (A) Operation of existing seepage collection systems (B/C) Draining/evaporation of free liquid from the BAP and closure of the unit with CCR in place or by removal (D) Natural attenuation of COC in the impacted alluvial aquifer *As modeled: The December 2018 cobalt plume and hydraulic heads were evaluated in a transient, three-layer groundwater flow and transport model.*	Existing seepage collection systems do not prevent the discharge of all seepage from the BAP to the alluvium and thus may not effectively reduce the source and magnitude of risk until there is no free liquid in the BAP or the CCR has been removed from the BAP. If the CCR is removed after dewatering, the risk of future impacted seepage is lessened. However, the COC would continue to be present at concentrations exceeding GWPSs in alluvial groundwater downgradient of the BAP for some time.	CMs for existing collection systems and wells are in place - long term-operation and management would be required. Additional wells will likely be necessary to monitor impacts over time - these wells may not be located on APS property which would require coordination with neighboring property owners. The plume has already migrated offsite which could elicit concerns from downgradient property owners. Removal of CCR as part of unit closure would be logistically intensive, requiring locating and/or constructing a suitable facility and arranging for transport of large quantities of waste between the Site and the facility on transporation corridors.	No human or ecological receptors are currently known to be impacted. If excavation of CCR is conducted, there would be a potential for cross media impacts during excavation (to air via dust and surface water via runoff), transport (through spills and/or transport vessel contamination), and final placement (if the receiving facility is not properly constructed or the integrity of the facility degrades over time).	Seepage collection systems are currently in place. Dewatering and pond closure will begin in 2025 (dewatering could take years). Expansion of the monitoring system would be conducted as required.	Difficult to estimate. *The groundwater model predicts cobalt will exceed the GWPS for over 100 years with only natural attenuation to address residual COC mass in the system.*	Future wells would require ADWR permitting. If the CCR is removed, waste characterization and management activities would be required.
Alternative 2: (A) Operation of existing seepage collection systems (B/C) Draining/evaporation of free liquid from the BAP and closure of the unit with CCR in place or by removal (D) Natural attenuation of COC in the impacted alluvial aquifer (E/G/H) Containment wells or seepage trenches sited adjacent to the south and east of the dam with potential cut off walls *As modeled: 15 hypothetical pumping wells (in an evenly spaced line adjacent to the dam) extracting groundwater at a total rate of 375 gpm were evaluated using a transient, three-layer groundwater flow and transport model.*	New on-site containment wells or seepage collection trenches that intercept seepage to the alluvium could reduce the source and magnitude of risk resulting from future BAP seepage. However, the COC would continue to be present at concentrations exceeding GWPSs in alluvial groundwater downgradient of the BAP for some time.	The location, quantity and construction of new containment wells would likely be developed iteratively to promote effective seepage interception. Long term operation and management would be required. Offsite impacts would be the same as Alternative 1.	Same as Alternative 1.	A new containment well installation program can begin within 3 months of remedy selection if wells are located on APS property. Completion of constructible portions of the remedy could require 12 to 48 months.	Difficult to estimate. Once new containment wells are in place - they would need to be operated for as long as adverse impacts from seepage occur (likely at least as long as there is standing water in the BAP). *The groundwater model predicts cobalt will exceed the GWPS until 2126 (for 107 years) with containment pumping as described.*	Same as Alternative 1.

Notes:
BAP = Bottom Ash Pond
COC = Constituent of concern (i.e., cobalt)
GWPS = Groundwater Protection Standard

(a) Including safety impacts, cross-media impacts, and control of exposure to any residual contamination.
(b) Such as state or local permit requirements or other environmental or public health requirements that may substantially affect implementation of the remedy(s).

FIGURES

0 0.75 1.5 3 Miles

Job No.	14-2018-2040
PM:	NC
Date:	5/31/2019
Scale:	1" = 1.5 miles

N

The map shown here has been created with all due and reasonable care and is strictly for use with Wood Environment & Infastructure Solutions, Inc. Project Number 14-2018-2040. This map has not been certified by a licensed land surveyor, and any third party use of this map comes without warranties of any kind. Wood Environment & Infrastructure Solutions, Inc. assumes no liability, direct or indirect, whatsoever for any such third party or unintended use.

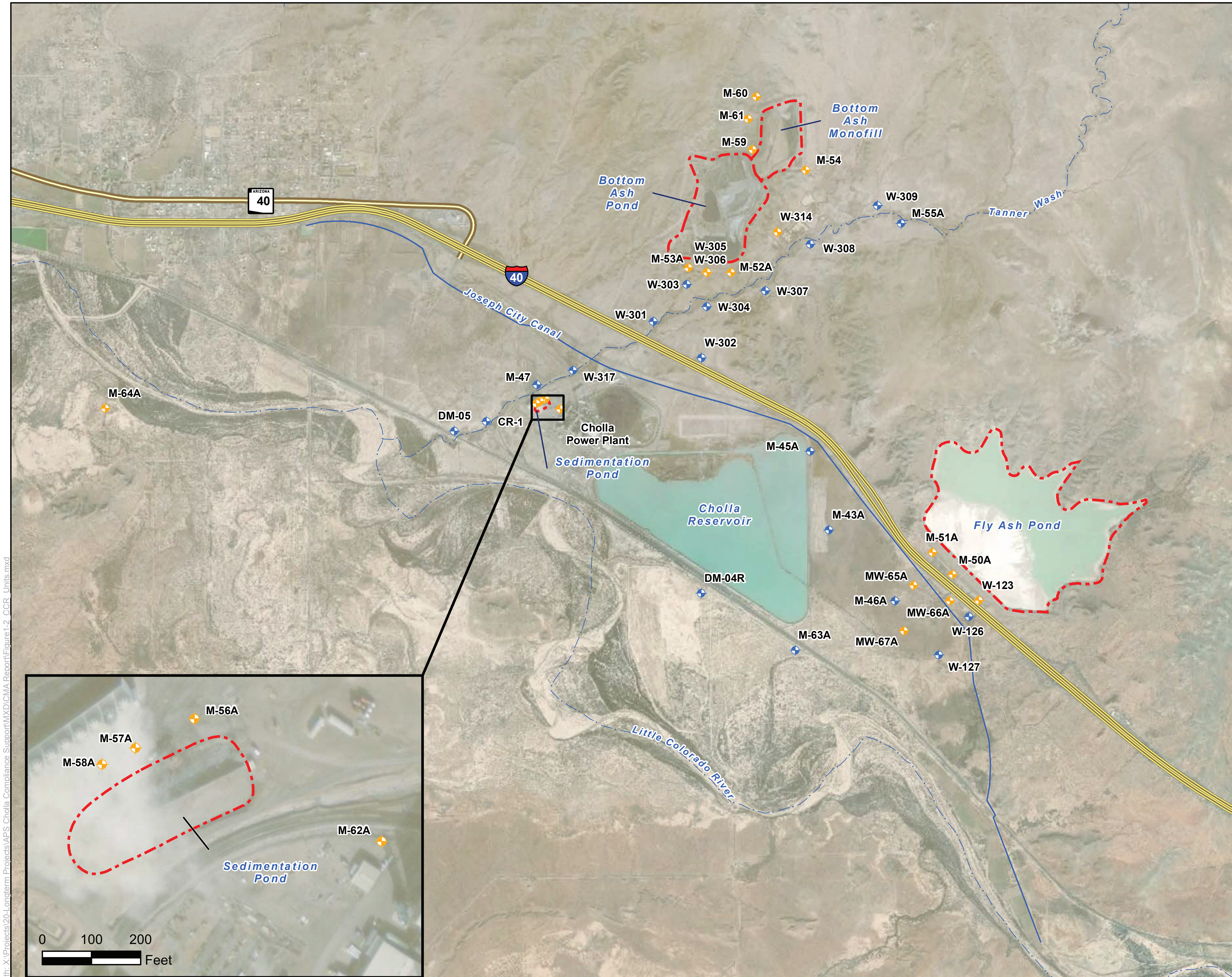
Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

Site Location Map

FIGURE
1-1

wood.

Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\CMA Report\Figure1-1_SiteLocationMap.mxd



Legend

- CCR Monitoring Well Location
- Supplementary Site Monitoring Well Location
- Ephemeral Surface Water Feature
- Canal
- Approximate Extent of CCR Unit

Notes:

CCR Coal Combustion Residuals

0 1,250 2,500
Feet

N

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

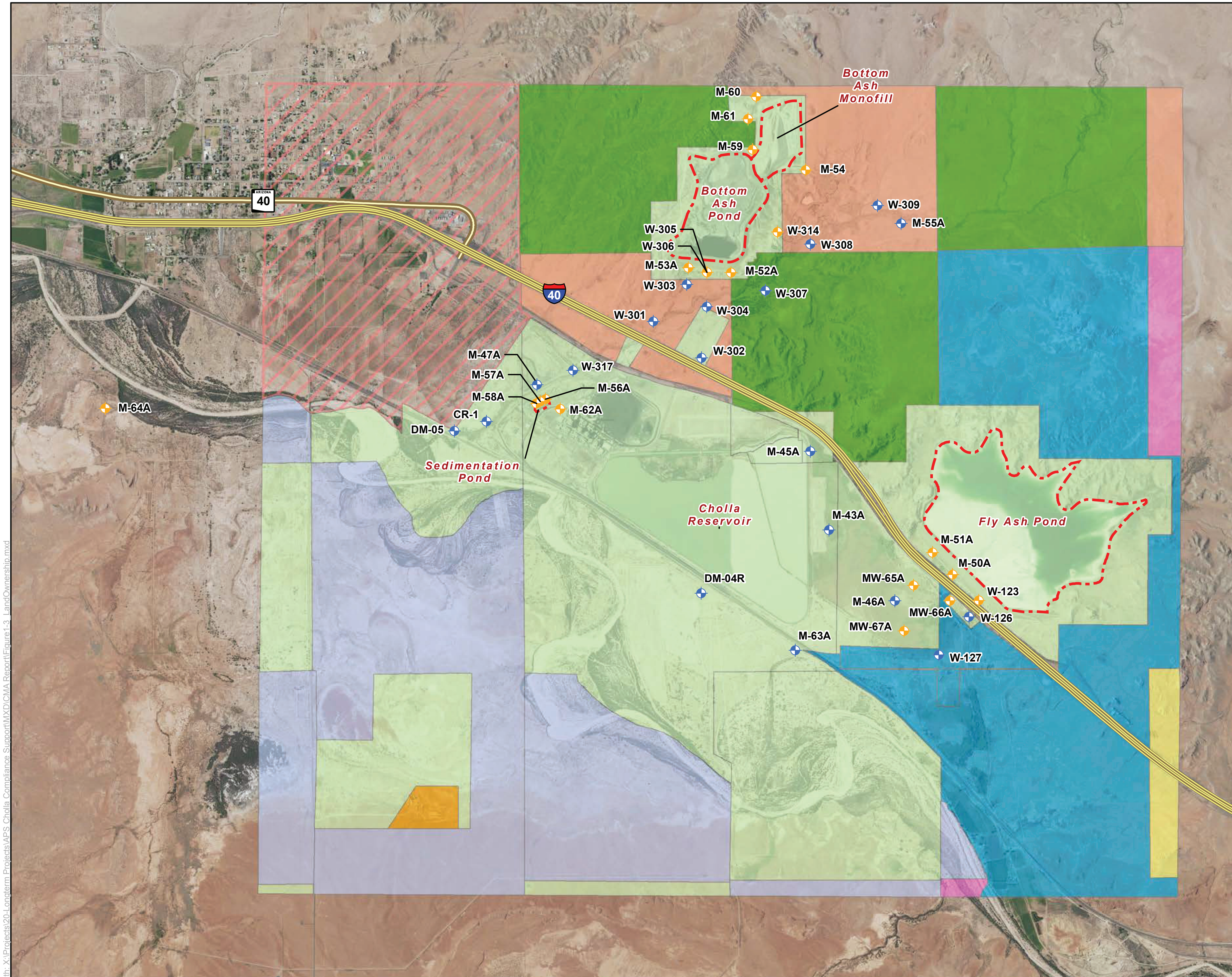
FIGURE 1-2

CCR Units and Monitoring System Summary

Job No.	1420182040
PM:	NCL
Date:	6/12/2019
Scale:	1"= 2500'

wood.

Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\CMA Report\Figure1-2_CCR_Units.mxd



Legend

- CCR Monitoring Well Location
- Supplementary Site Monitoring Well Location
- Approximate Extent of CCR Unit
- Hansen Family
- Hunt Family
- Arizona Public Service
- Arizona State Land Department
- Aztec
- DeSpain Ranch Trust Land
- Federal (BLM)
- US Forest Service
- Other Ownership

NOTES:
Parcel sizes and shapes are approximate.

Property Ownership Information Sources:
1. Navajo County Assessor Property Tax Map
2. Arizona State Land Department
Land Ownership shapefile

0 1,250 2,500
Feet

N

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

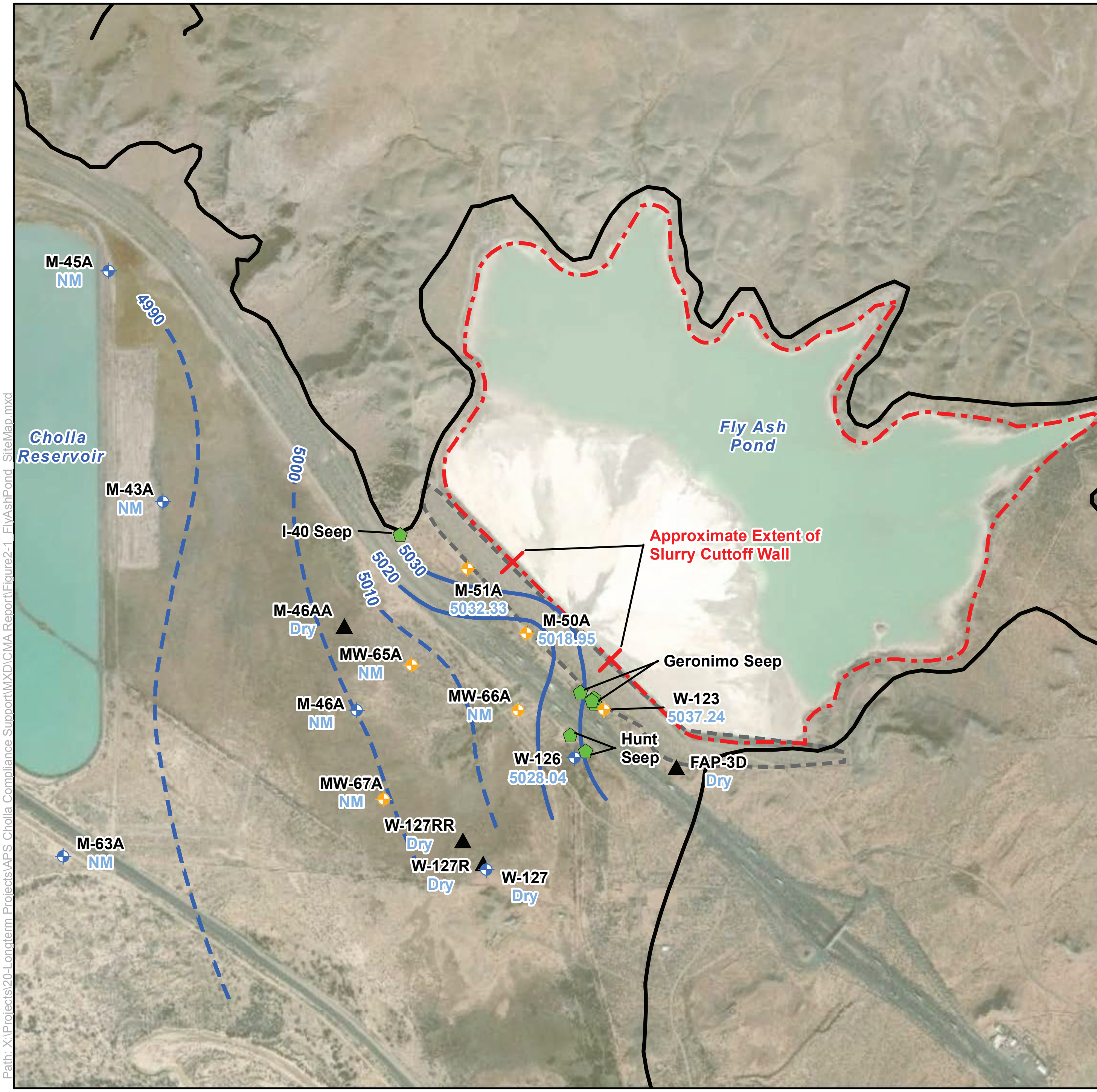
FIGURE
1-3

Land Ownership

Job No. 1420182040
PM: NCL
Date: 6/12/2019
Scale: 1"= 2500'

wood.

Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\CMA Report\Figure1-3_LandOwnership.mxd



State Overview

Legend

- CCR Monitoring Well Location
- Supplementary Site Monitoring Well Location
- Seep and Collection System Location
- Abandoned Boring
- Estimated Alluvial Extent
- Approximate Extent of CCR Unit
- Approximate Extent of Dam

Potentiometric Surface - October 2018

- (Dashed Where Inferred)

Notes:

W-123	Well Identification
5037.24	Groundwater elevation (ft amsl) measured in October 2018
NM	Not Measured
ft amsl	Feet above mean sea level

0 625 1,250
Feet

N

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

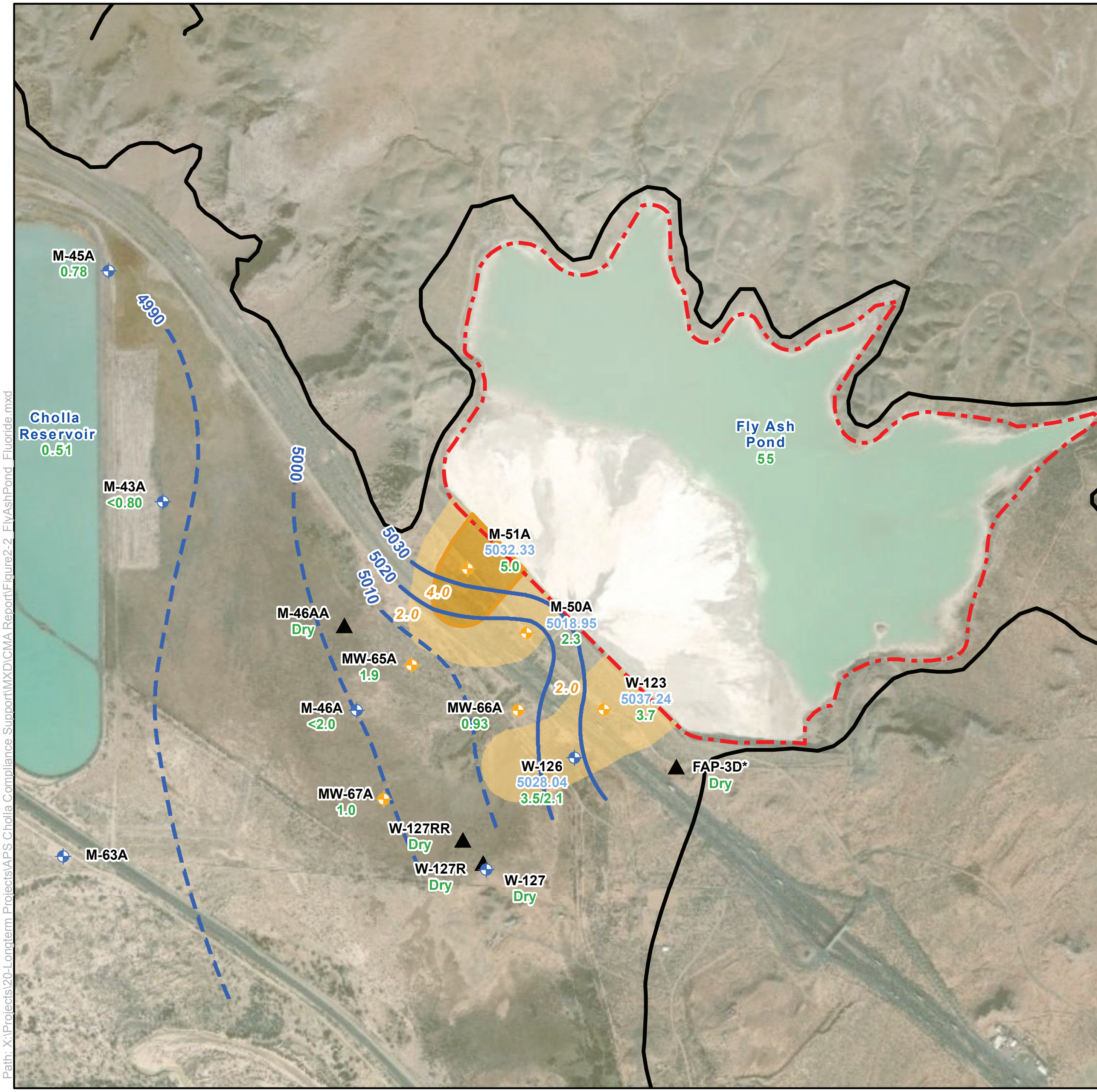
FIGURE
2-1

Existing Infrastructure at the Fly Ash Pond

Job No.	1420182040
PM:	NCL
Date:	6/12/2019
Scale:	1"= 1250'

wood.

Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\CMA Report\Figure2-1_FlyAshPond_SiteMap.mxd



State Overview

Legend

- CCR Monitoring Well Location
- Supplementary Site Monitoring Well Location
- Abandoned Boring
- Estimated Alluvial Extent
- Approximate Extent of CCR Unit

Potentiometric Surface - October 2018

- (Dashed Where Inferred)

Fluoride Concentration in Alluvial Aquifer (October-December 2018)

- 2 mg/L
- 4 mg/L
- GWPS (4 mg/L; Dashed Where Inferred)

Notes:

W-123	Well Identification
5037.24	Groundwater elevation (ft amsl) measured in October 2018
4.0	Fluoride concentration (mg/L)
*	Estimated location per Montgomery & Associates, (September 19, 2017)
ft amsl	Feet above mean sea level
mg/L	Milligrams per liter
GWPS	Groundwater Protection Standard

0 625 1,250 Feet

N

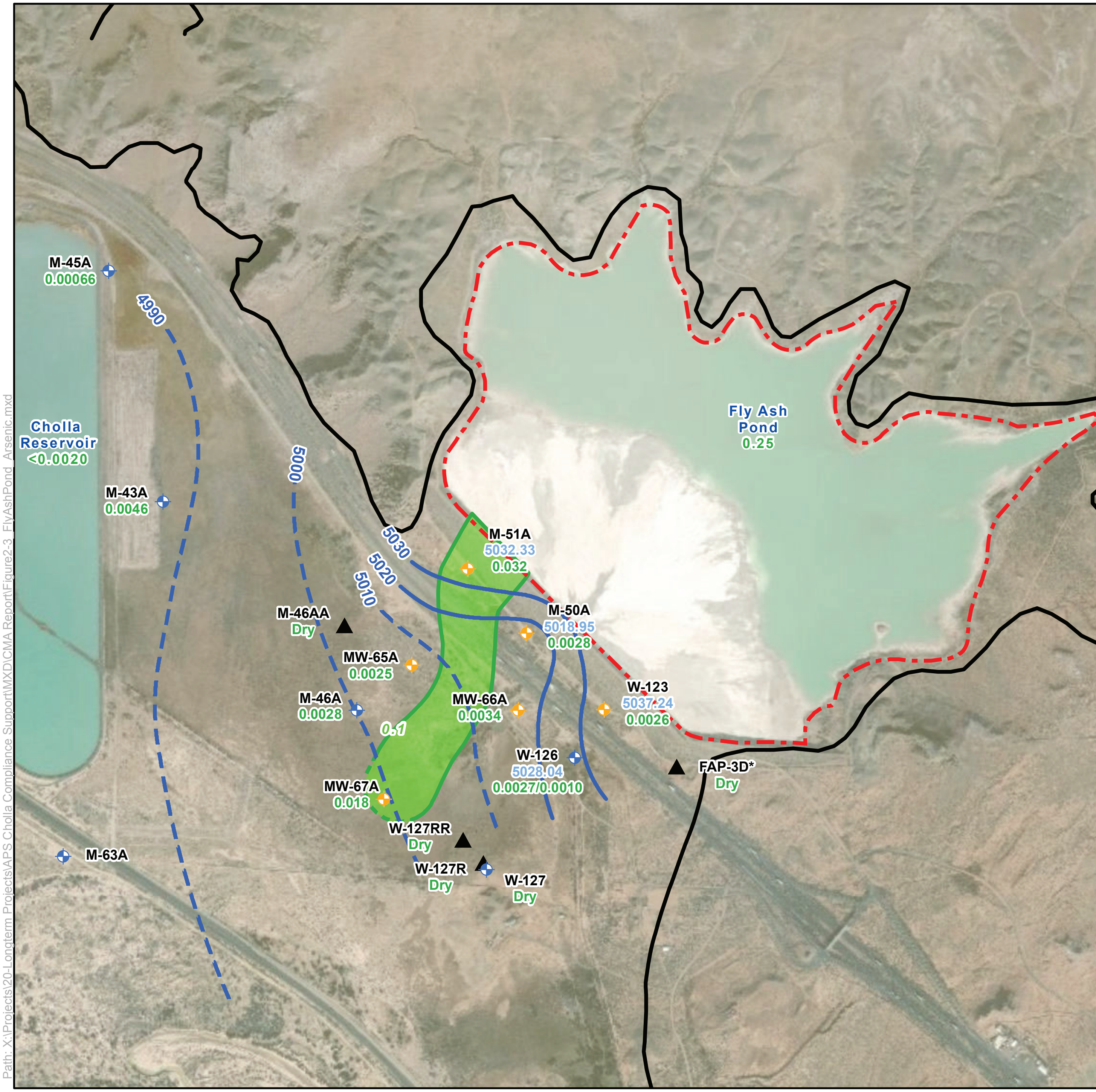
Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

FIGURE **2-2**

Fluoride Iso-Concentration Map for the Fly Ash Pond

Job No.	1420182040
PM:	NCL
Date:	5/31/2019
Scale:	1"= 1250'

Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\CMA Report\Figure2-2_FlyAshPond_Fluoride.mxd



State Overview

Legend

- CCR Monitoring Well Location
- Supplementary Site Monitoring Well Location
- Abandoned Boring
- Estimated Alluvial Extent
- Approximate Extent of CCR Unit

Potentiometric Surface - October 2018

- (Dashed Where Inferred)

Arsenic Concentration in Alluvial Aquifer (October-December 2018)

- >0.01 mg/L
- GWPS (0.01 mg/L; Dashed Where Inferred)

Notes:

W-123	Well Identification
5037.24	Groundwater elevation (ft amsl) measured in October 2018
0.0026	Arsenic concentration (mg/L)
*	Estimated location per Montgomery & Associates, (September 19, 2017)
ft amsl	Feet above mean sea level
mg/L	Milligrams per liter
GWPS	Groundwater Protection Standard

0 625 1,250 Feet

N

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

FIGURE **2-3**

Arsenic Iso-Concentration Map for the Fly Ash Pond

Job No.	1420182040
PM:	NCL
Date:	5/31/2019
Scale:	1"= 1250'

wood.

State Overview

Legend

- CCR Monitoring Well Location
- Supplementary Site Monitoring Well
- Abandoned Boring
- Estimated Alluvial
- Approximate Extent of CCR Unit

Potentiometric Surface - October

- (Dashed Where Inferred)

GWPS for Cobalt is 0.006 mg/L (no exceedences)

Notes:

W-123	Well Identification
5037.24	Groundwater elevation (ft amsl) measured in October 2018
0.0016	Cobalt concentration (mg/L)
*	Estimated location per Montgomery & Associates, (September 19, 2017)
ft amsl	Feet above mean sea level
mg/L	Milligrams per liter
GWPS	Groundwater Protection Standard

0 625 1,250 Feet

N

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

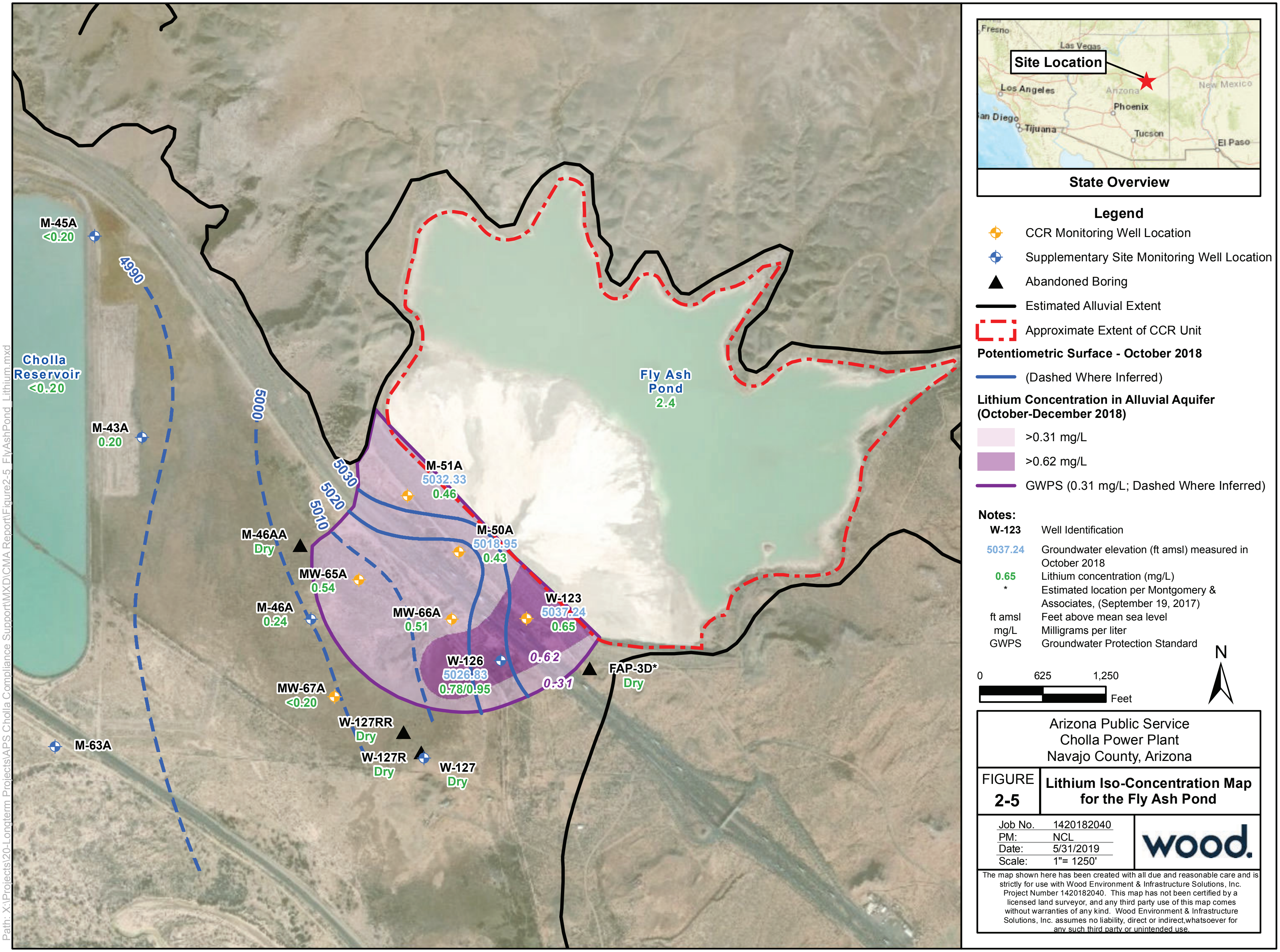
FIGURE 2-4

Cobalt Iso-Concentration Map for the Fly Ash Pond

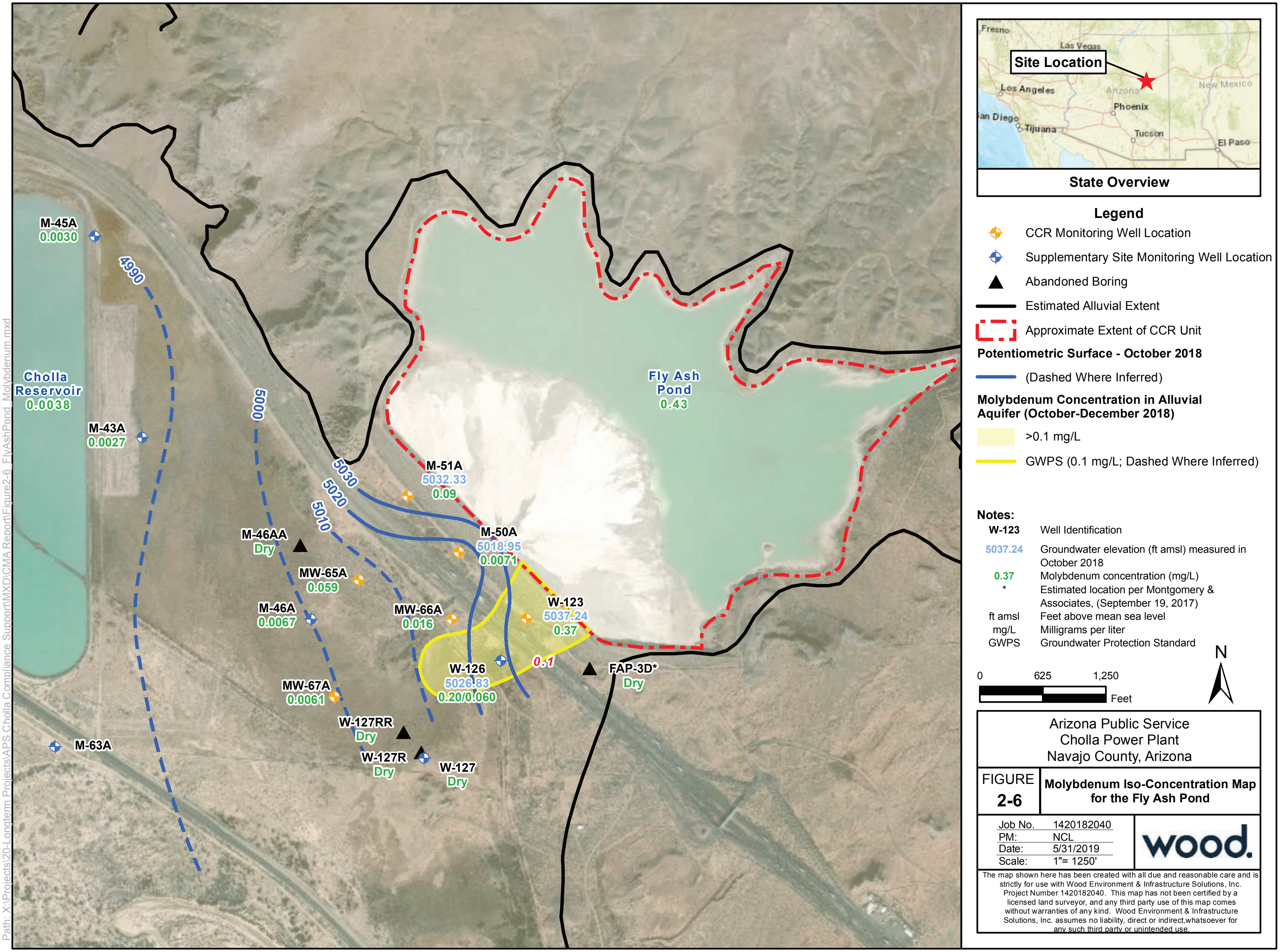
Job No. 1420182040
PM: NCL
Date: 5/31/2019
Scale: 1"= 1250'

wood.

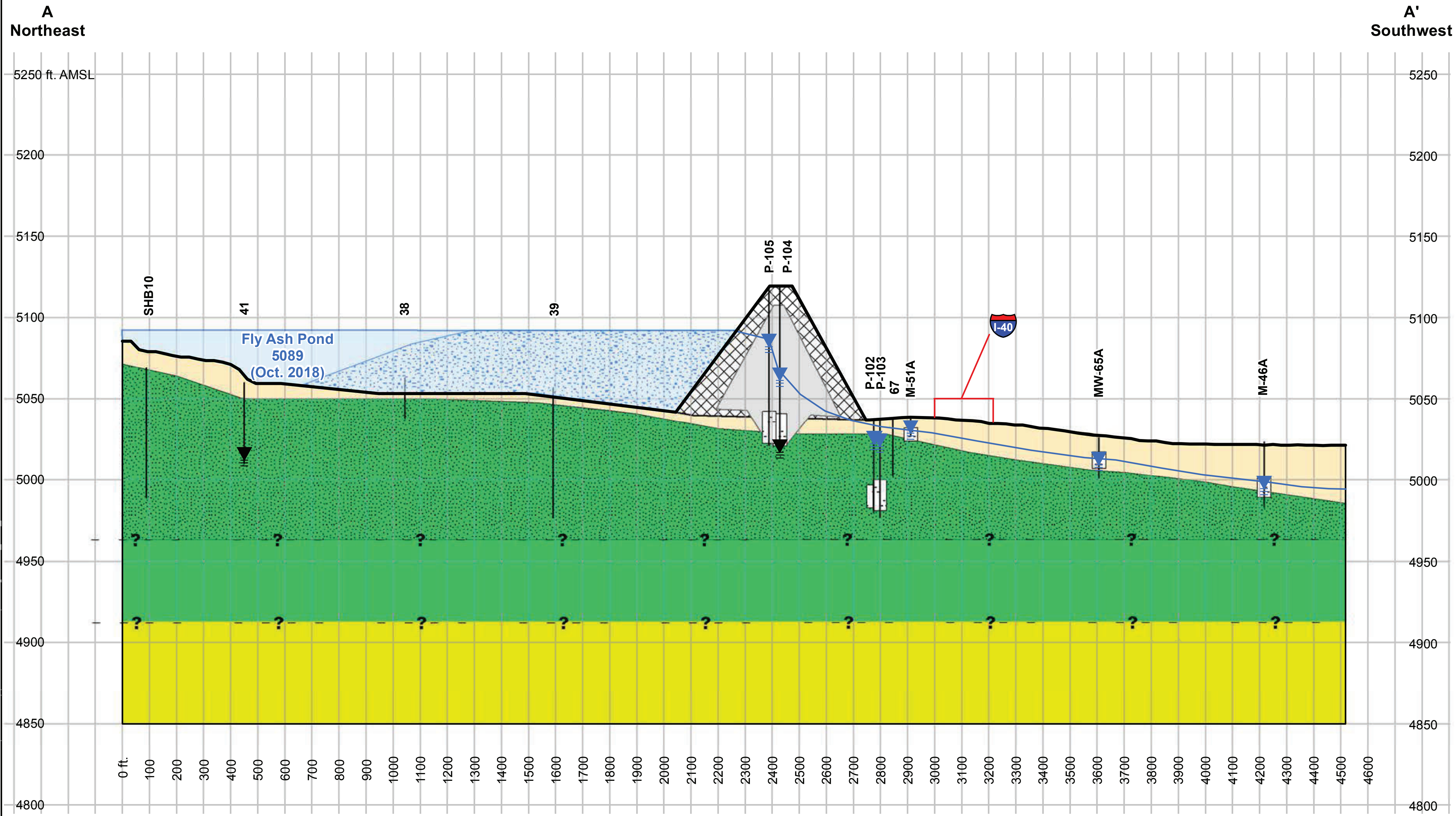
Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\CMA Report\Figure2-4_FlyAshPond_Cobalt.mxd

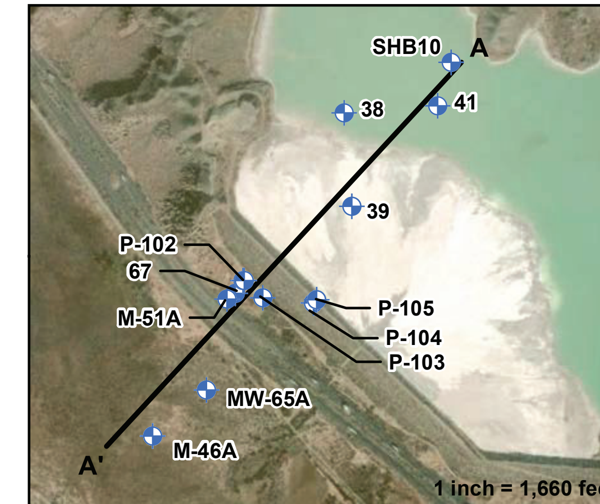


Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\CMA Report\Figure2-5_FlyAshPond_Lithium.mxd



Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\CMA Report\Figure2-6_FlyAshPond_Molybdenum.mxd





Area of Detail

Legend

- Depth to Water (Feb. 2019)
- Depth to Water During Drilling
- Surface Elevation
- Projected Boring Location and Length
- Piezometric Surface
- Approximate Contact
- Approximate Fly Ash Beach Limits
- Water Elevation at the Fly Ash Pond
- Screened Interval
- Dam Clay Core
- Dam Shell

Lithology

- Alluvium
- Moqui
- Wupatki
- Coconino

Notes:

-Vertical Exaggeration is 4 times the horizontal scale.
-Cross section search area is 900 feet to the northwest and the southeast.
-P-series wells were drilled and installed in 1979.
-SHB well was drilled in 1973.
-38, 39, and 41 wells were drilled in 1975.
-ft. AMSL = feet above mean sea level

0 215 430 Feet

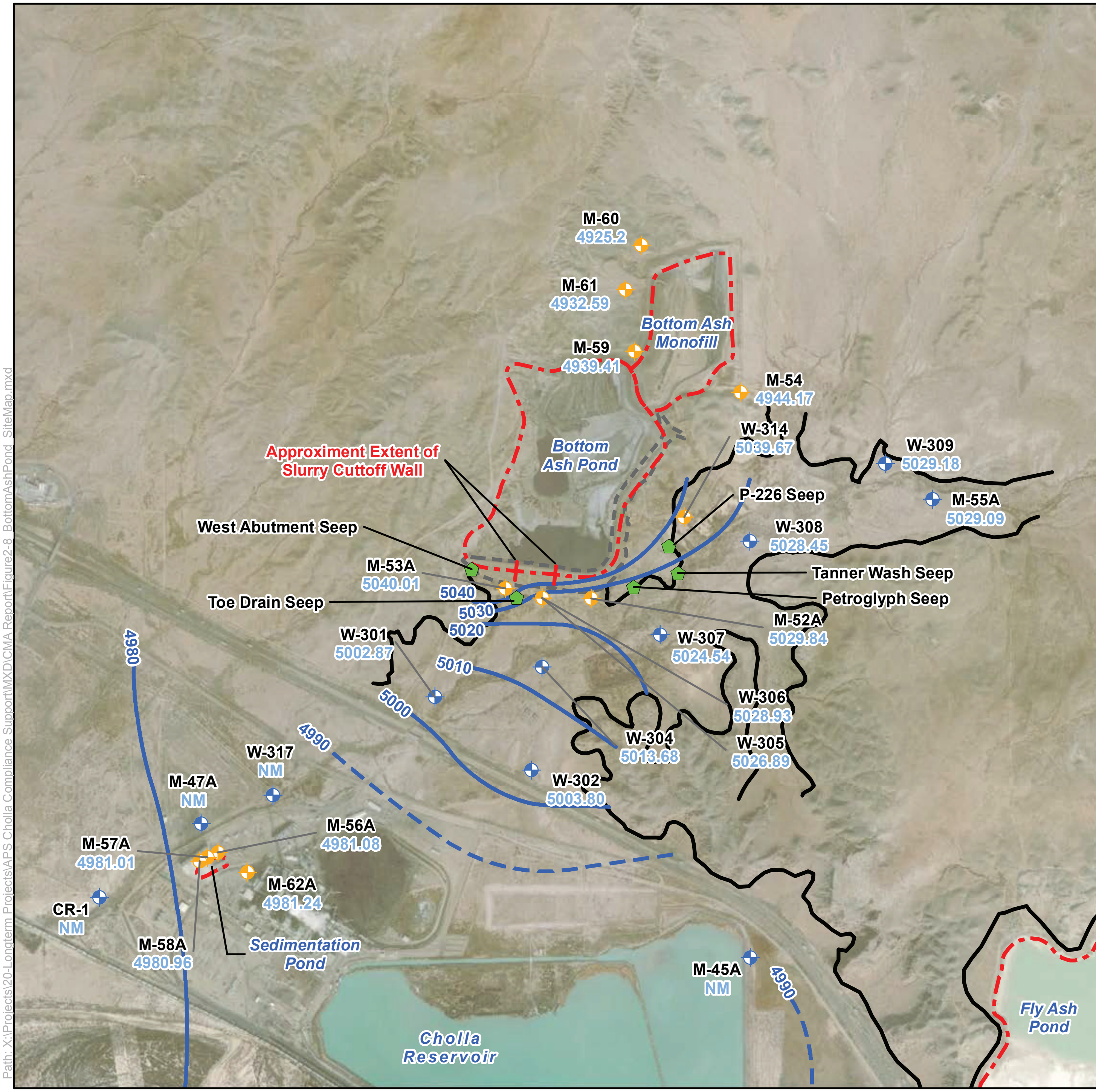
N

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

FIGURE **2-7**

Fly Ash Pond Cross-Section A - A'

Job No.	1420182040
PM:	NCL
Date:	6/4/2019
Scale:	1"= 430'



State Overview

Legend

- CCR Monitoring Well Location
- Supplementary Site Monitoring Well Location
- Seep and Inception System Location
- Estimated Alluvial Extent
- Approximate Extent of CCR Unit
- Approximate Extent of Dam

Potentiometric Surface - October 2018

- (Dashed Where Inferred)

Notes:

W-309	Well Identification
5029.18	Groundwater elevation (ft amsl) measured in October 2018
NM	Not Measured
ft amsl	Feet above mean sea level

0 915 1,830 Feet

N

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

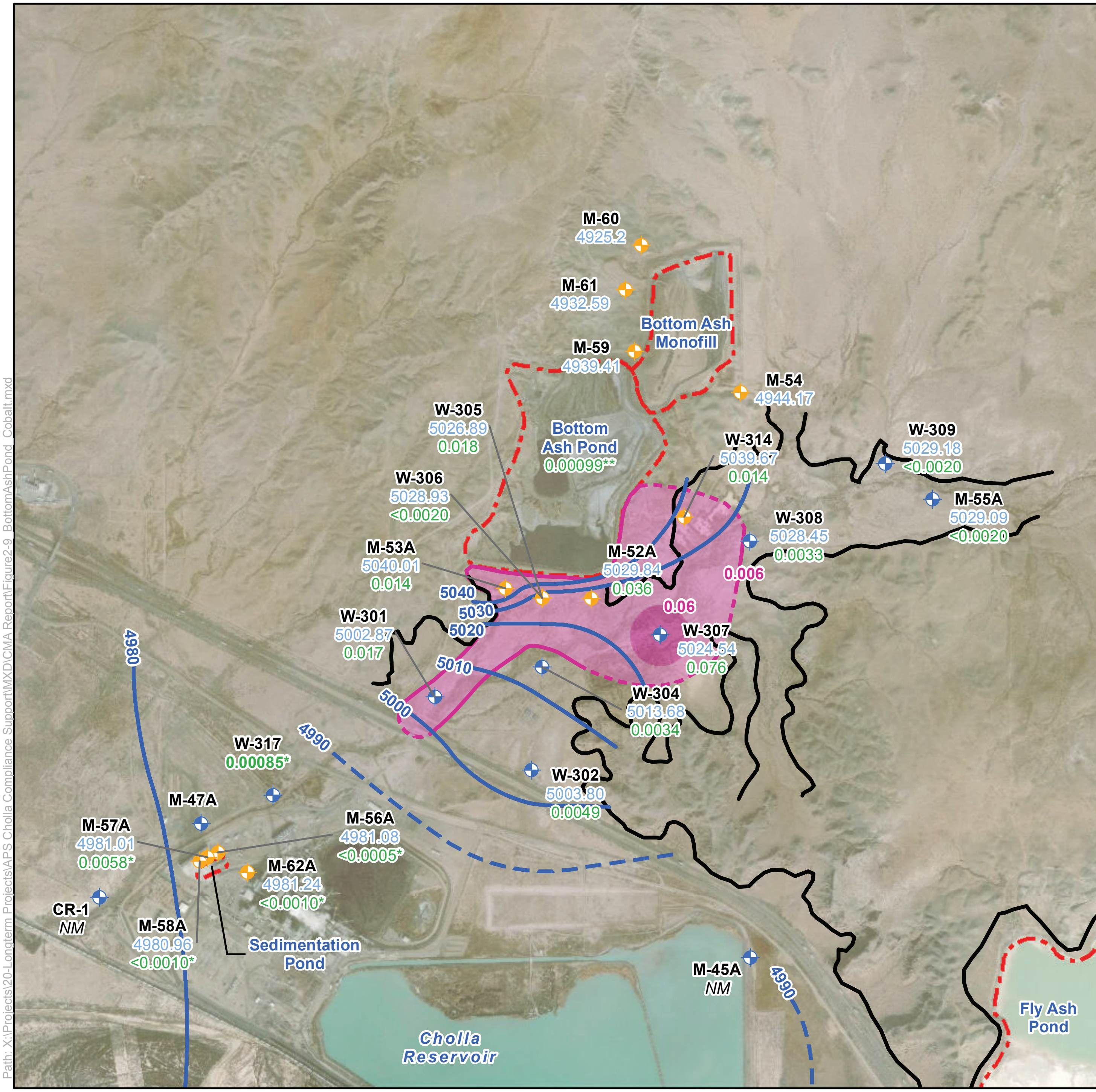
FIGURE 2-8

Existing Infrastructure at the Bottom Ash Pond

Job No.	1420182040
PM:	NCL
Date:	6/4/2019
Scale:	1"= 1,830'

wood.

Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\CMA Report\Figure2-8_BottomAshPond_SiteMap.mxd



State Overview

Legend

- CCR Monitoring Well Location
- Supplementary Site Monitoring Well Location
- Estimated Alluvial
- Approximate Extent of CCR Unit

Potentiometric Surface - October 2018

- (Dashed Where Inferred)

Cobalt Concentration in Alluvial Aquifer (December 2018)

- >0.06 mg/L
- >0.006 mg/L
- GWPS (0.006 mg/L; Dashed Where Inferred)

Notes:

W-309	Well Identification
5029.18	Groundwater elevation (ft amsl) measured in October 2018
<0.0020	Cobalt concentration (mg/L)
*	Sampled in May 2018
**	Sampled in March 2019
ft amsl	Feet above mean sea level
mg/L	Milligrams per liter
NM	Not Measured
GWPS	Groundwater Protection Standard

0 915 1,830 Feet

N

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

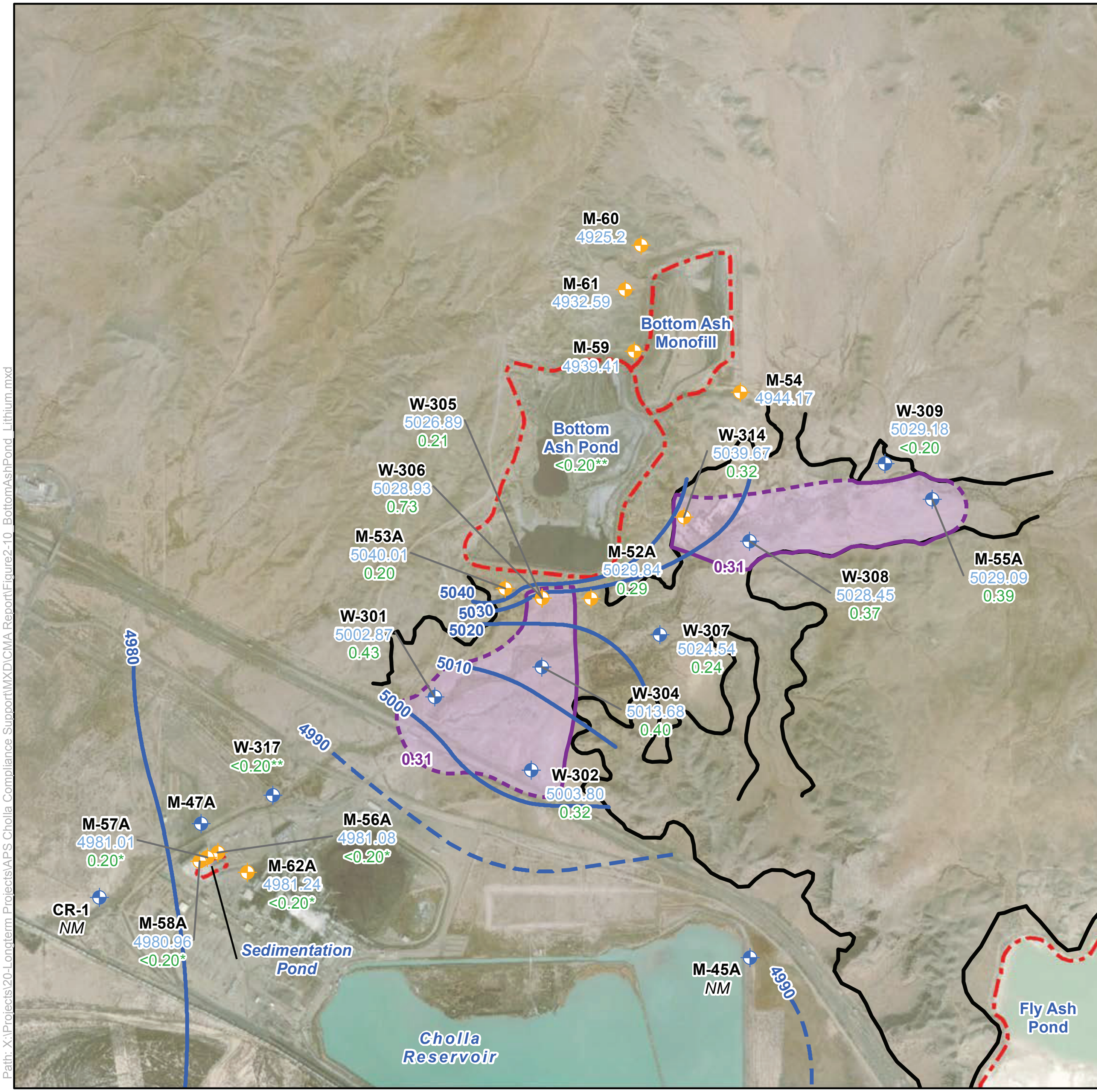
FIGURE 2-9

Cobalt Iso-Concentration Map for the Bottom Ash Pond

Job No.	1420182040
PM:	NCL
Date:	5/31/2019
Scale:	1"= 1,830'

wood.

Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\CMA Report\Figure2-9_BottomAshPond_Cobalt.mxd



Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\CMA Report\Figure2-10_BottomAshPond_Lithium.mxd

State Overview

Legend

- CCR Monitoring Well Location
- Supplementary Site Monitoring Well
- Estimated Alluvial
- Approximate Extent of CCR Unit

Potentiometric Surface - October 2018

- (Dashed Where Inferred)

Lithium Concentration in Alluvial Aquifer (December 2018)

- >0.31 mg/L
- GWPS (0.31 mg/L; Dashed Where Inferred)

Notes:

W-309	Well Identification
5029.18	Groundwater elevation (ft amsl) measured in October 2018
<0.20	Lithium concentration (mg/L)
*	Sampled in May 2018
**	Sampled in March 2019
ft amsl	Feet above mean sea level
mg/L	Milligrams per liter
NM	Not Measured
GWPS	Groundwater Protection Standard

0 915 1,830 Feet

N

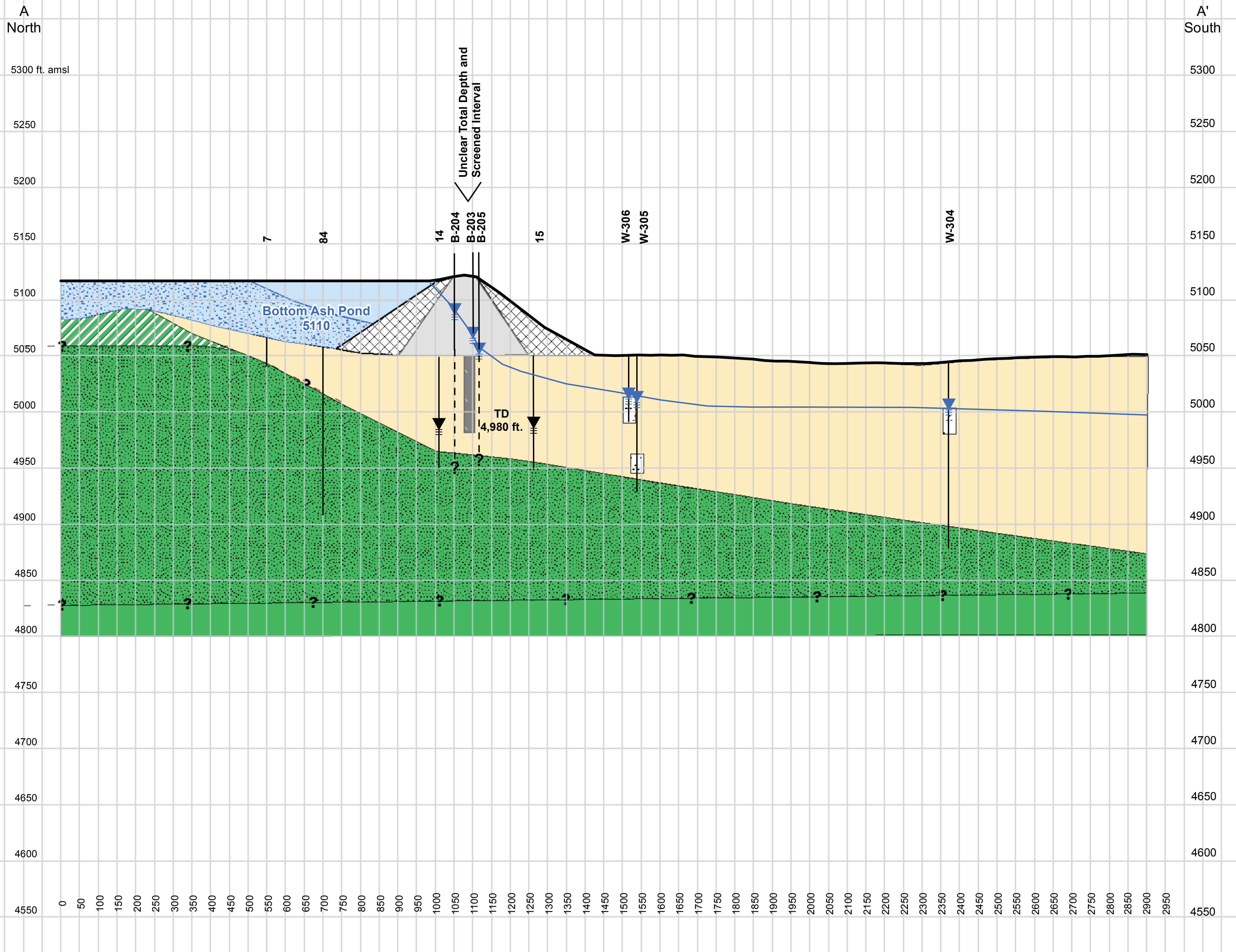
Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

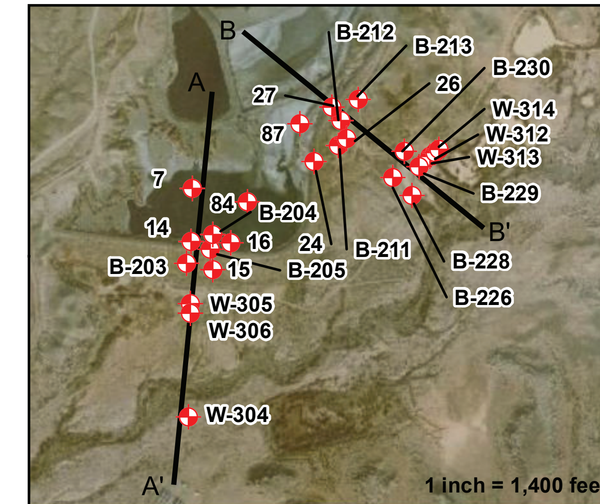
FIGURE 2-10

Lithium Iso-Concentration Map for the Bottom Ash Pond

Job No.	1420182040
PM:	NCL
Date:	6/5/2019
Scale:	1"= 1,830'

wood.





Area of Detail

Legend

- Depth to Water (Sep. 2018)
- Depth to Water During Drilling
- PiezometricSurf...
- Surface Elevation
- Projected Boring Location and Length
- Approximate Contact
- Screened Interval
- Dam Clay Core
- Dam Shell
- Slurry Cutoff Wall
- Bottom Ash Sediment
- Water Elevation at the Bottom Ash Pond

Lithology

- Alluvium
- Holbrook
- Moqui
- Wupatki

Notes:

-Vertical Exaggeration is 3 times the horizontal scale.
-EBASCO boreholes w ere drilled in 1975.
-B-203 Last depth to w ater measured in 2009.
-B-205 Last depth to w ater measured in 2011.

0 137.5 275 Feet

N

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

FIGURE 2-11	Bottom Ash Pond Cross-Section A - A'

Job No. 1420182040
PM: NCL
Date: 5/31/2019
Scale: 1"= 275'

wood.

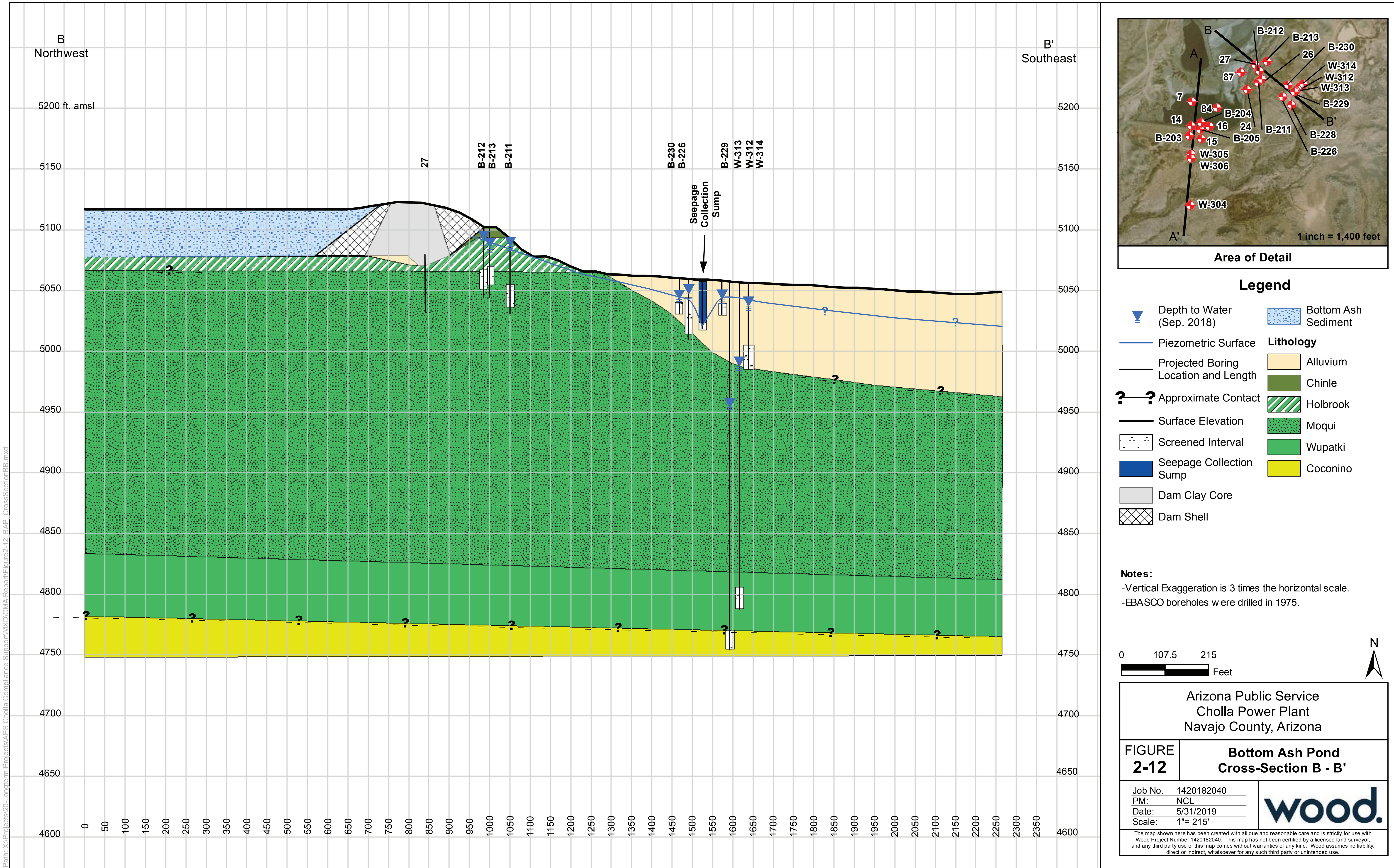
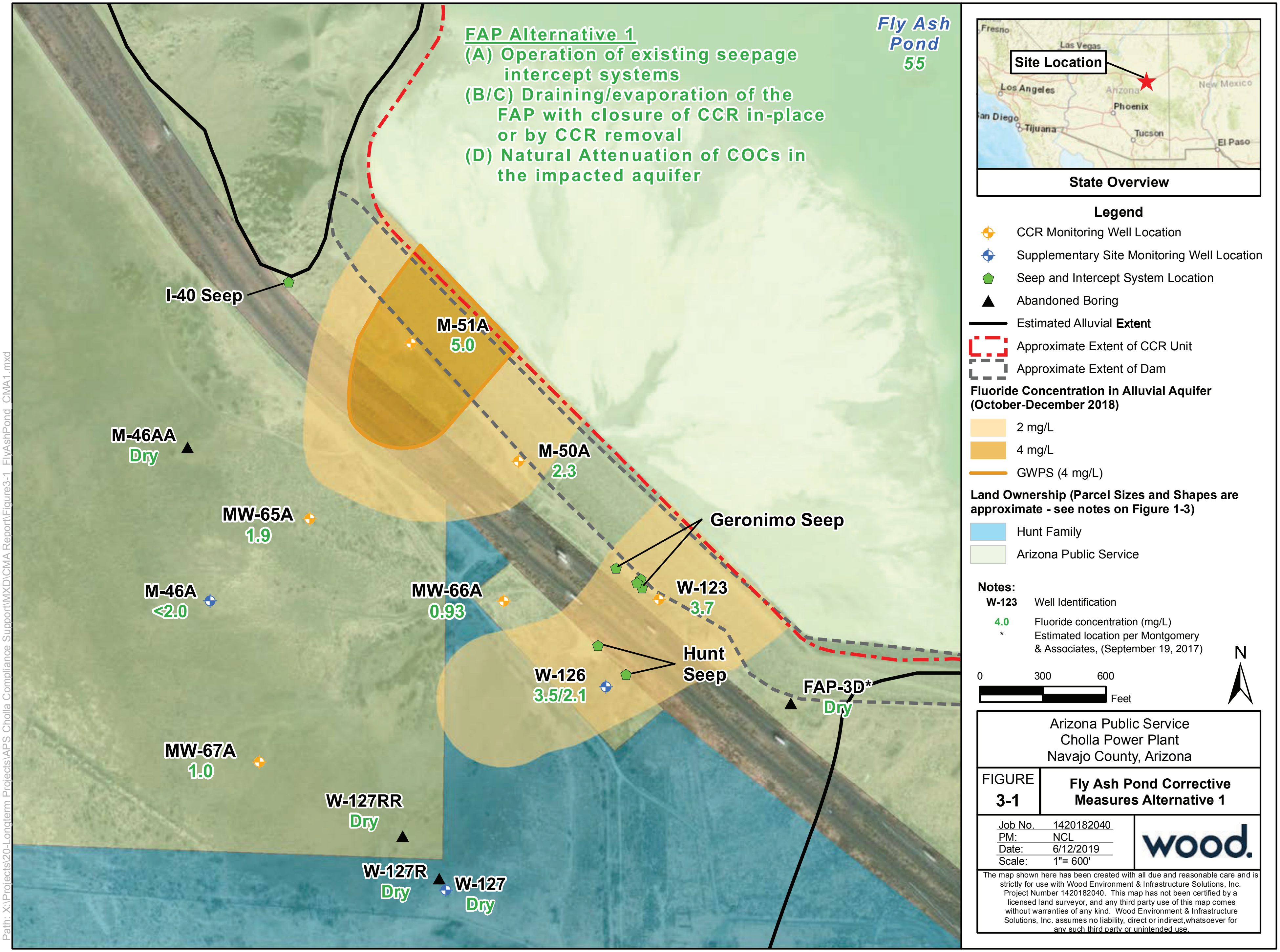
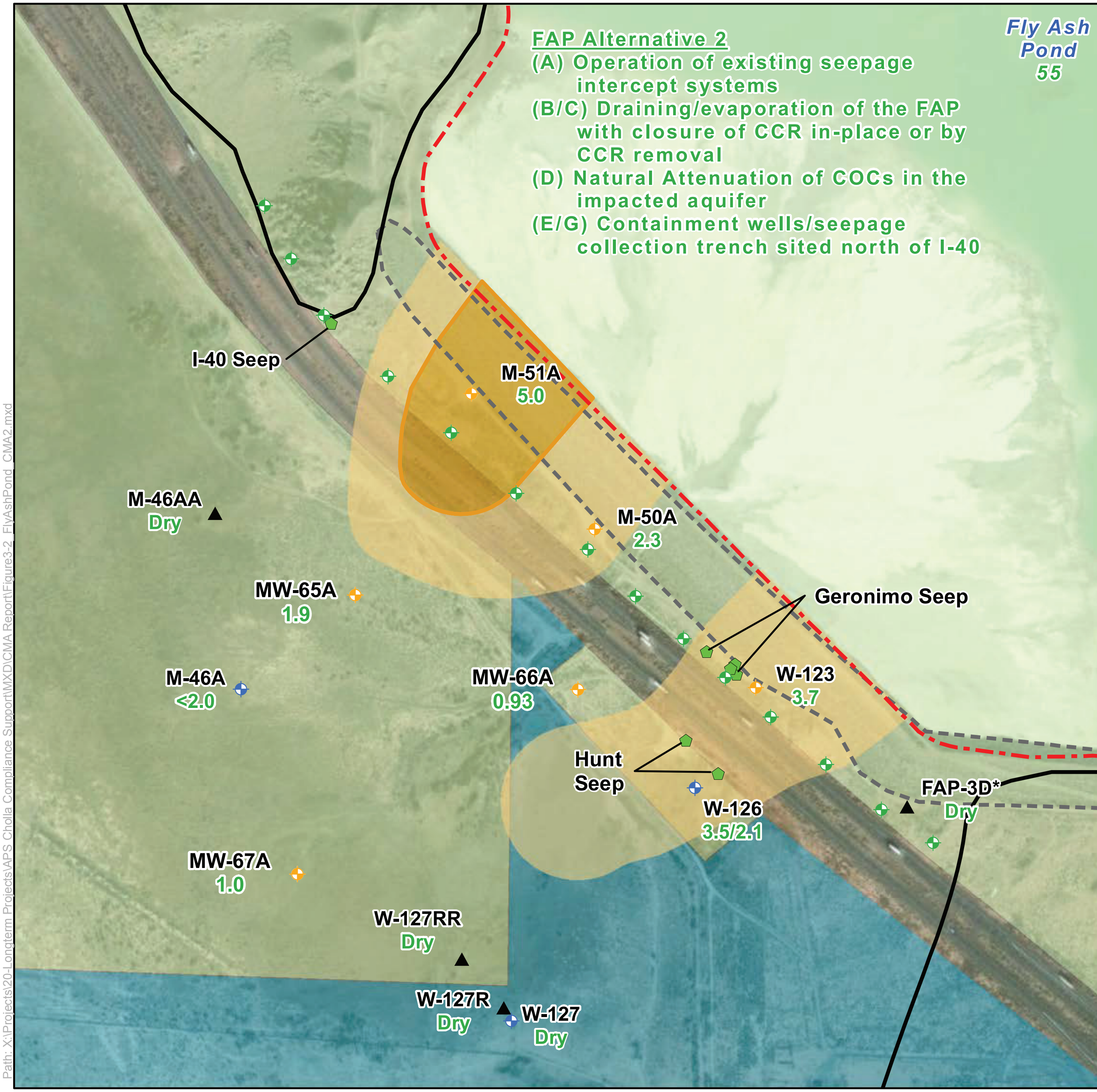


FIGURE 2-12 Bottom Ash Pond Cross-Section B - B'



Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\CMA Report\Figure3-1_FlyAshPond_CMA1.mxd



State Overview

Legend

- CCR Monitoring Well Location
- Supplementary Site Monitoring Well Location
- New Containment Wells
- Seep and Intercept System Location
- Abandoned Boring
- Estimated Alluvial Extent
- Approximate Extent of CCR Unit
- Approximate Extent of Dam

Fluoride Concentration in Alluvial Aquifer (October-December 2018)

- 2 mg/L
- 4 mg/L
- GWPS (4 mg/L)

Land Ownership (Parcel Sizes and Shapes are approximate - see notes on Figure 1-3)

- Hunt Family
- Arizona Public Service

Notes:

W-123 Well Identification

4.0 Fluoride concentration (mg/L)

* Estimated location per Montgomery & Associates, (September 19, 2017)

0 300 600 Feet

N

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

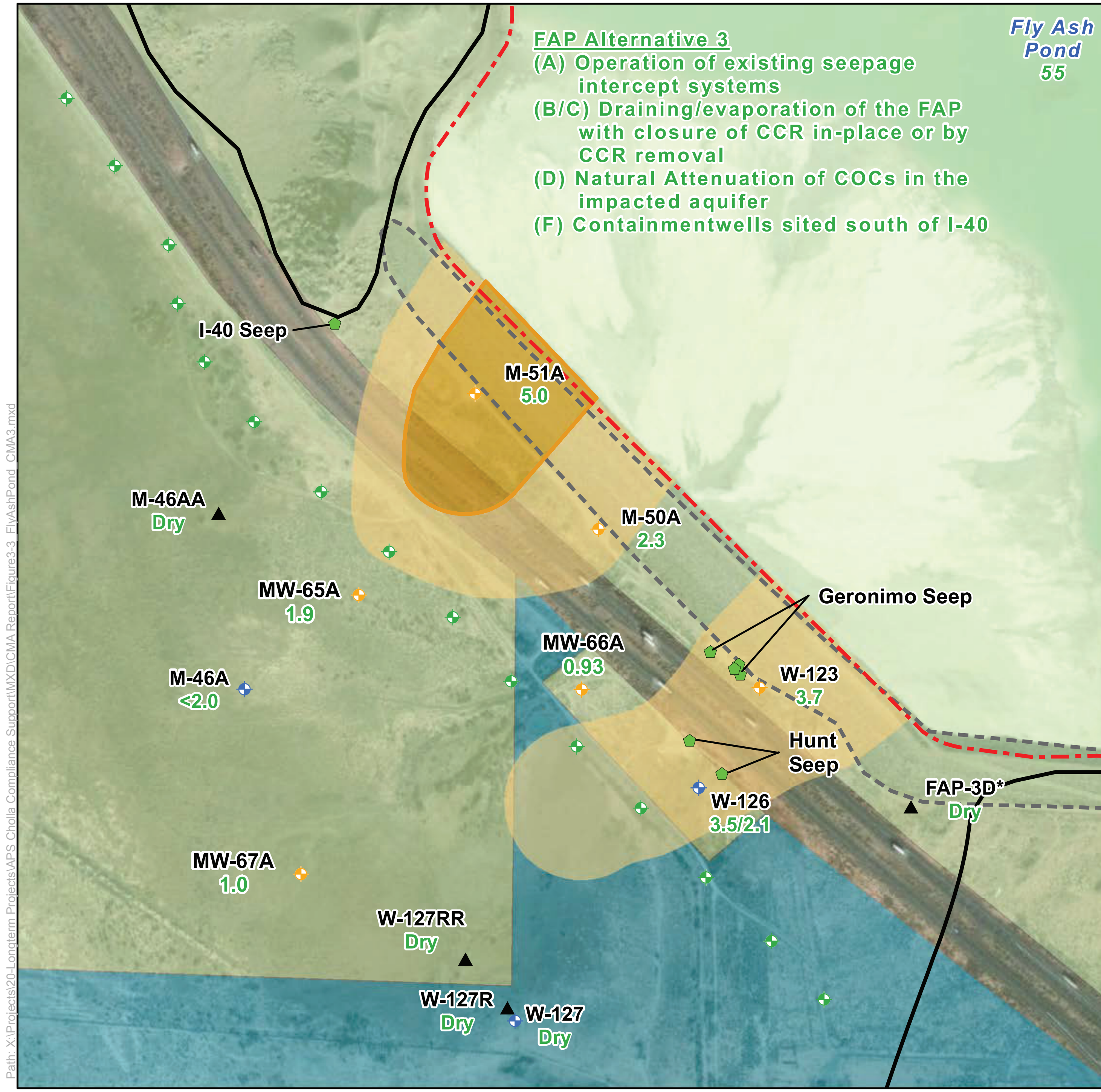
FIGURE **3-2**

Fly Ash Pond Corrective Measures Alternative 2

Job No.	1420182040
PM:	NCL
Date:	6/12/2019
Scale:	1"= 600'

wood.

Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\CMA Report\Figure3-2_FlyAshPond_CMA2.mxd



State Overview

Legend

- CCR Monitoring Well Location
- Supplementary Site Monitoring Well Location
- New Containment Wells
- Seep and Intercept System Location
- Abandoned Boring
- Estimated Alluvial Extent
- Approximate Extent of CCR Unit
- Approximate Extent of Dam

Fluoride Concentration in Alluvial Aquifer (October-December 2018)

- 2 mg/L
- 4 mg/L
- GWPS (4 mg/L)

Land Ownership (Parcel Sizes and Shapes are approximate - see notes on Figure 1-3)

- Hunt Family
- Arizona Public Service

Notes:

W-123 Well Identification

4.0 Fluoride concentration (mg/L)

* Estimated location per Montgomery & Associates, (September 19, 2017)

0 300 600 Feet

N

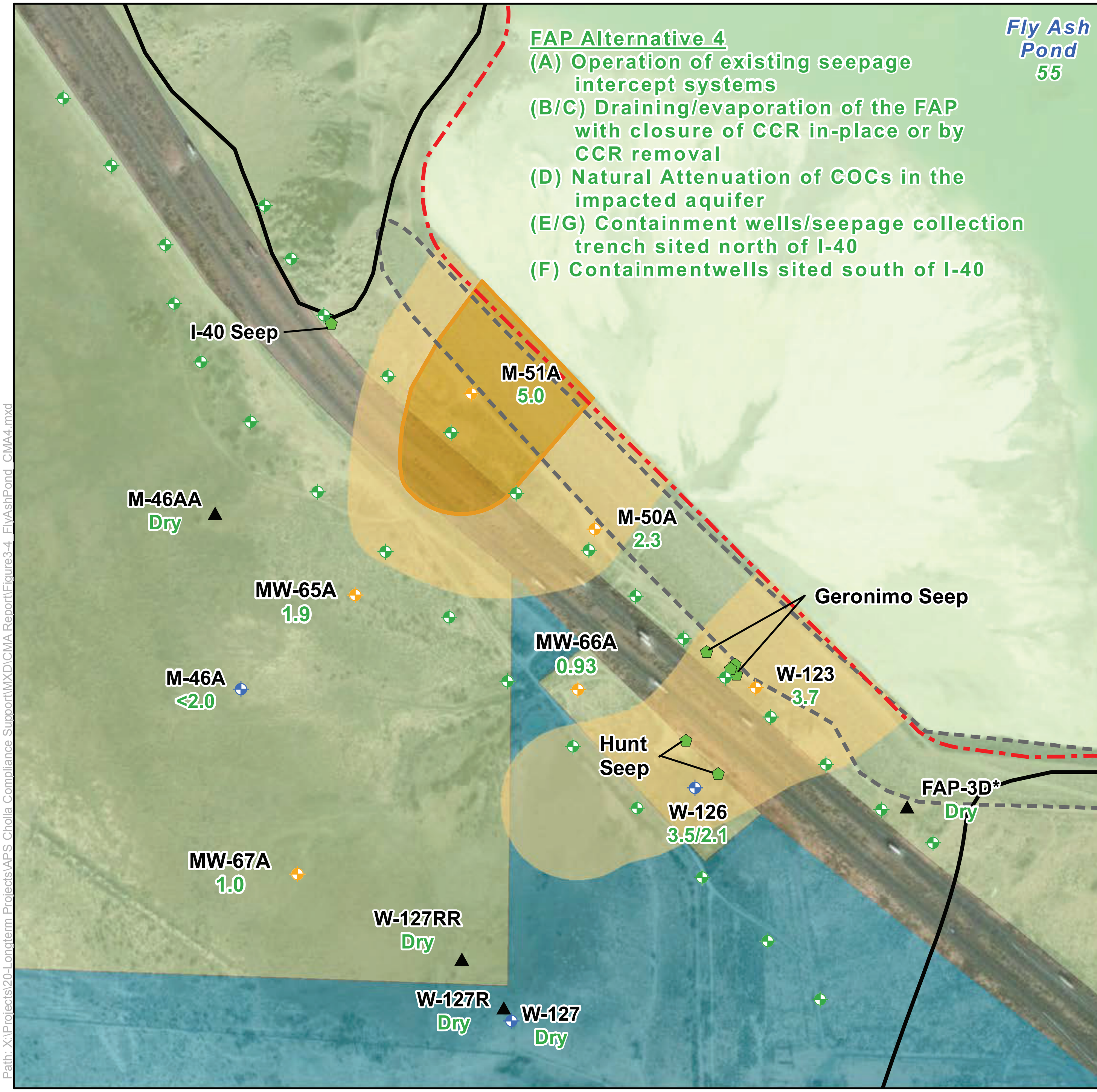
Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

FIGURE **3-3**

Fly Ash Pond Corrective Measures Alternative 3

Job No.	1420182040
PM:	NCL
Date:	6/12/2019
Scale:	1"= 600'

wood.



State Overview

Legend

- CCR Monitoring Well Location
- Supplementary Site Monitoring Well Location
- New Containment Wells
- Seep and Intercept System Location
- Abandoned Boring
- Estimated Alluvial Extent
- Approximate Extent of CCR Unit
- Approximate Extent of Dam

Fluoride Concentration in Alluvial Aquifer (October-December 2018)

- 2 mg/L
- 4 mg/L
- GWPS (4 mg/L)

Land Ownership (Parcel Sizes and Shapes are approximate - see notes on Figure 1-3)

- Hunt Family
- Arizona Public Service

Notes:

W-123 Well Identification

4.0 Fluoride concentration (mg/L)

* Estimated location per Montgomery & Associates, (September 19, 2017)

0 300 600 Feet

N

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

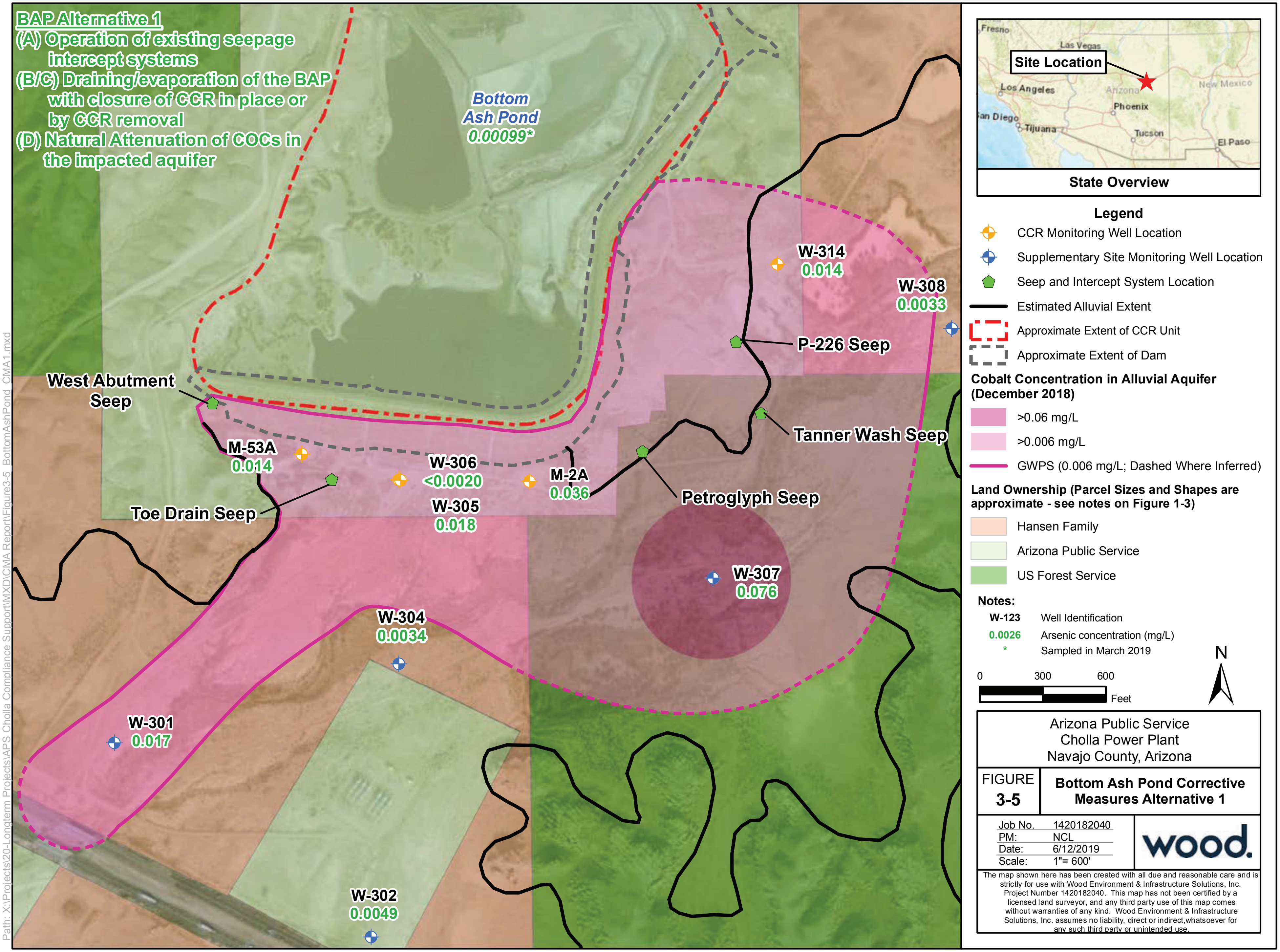
FIGURE 3-4

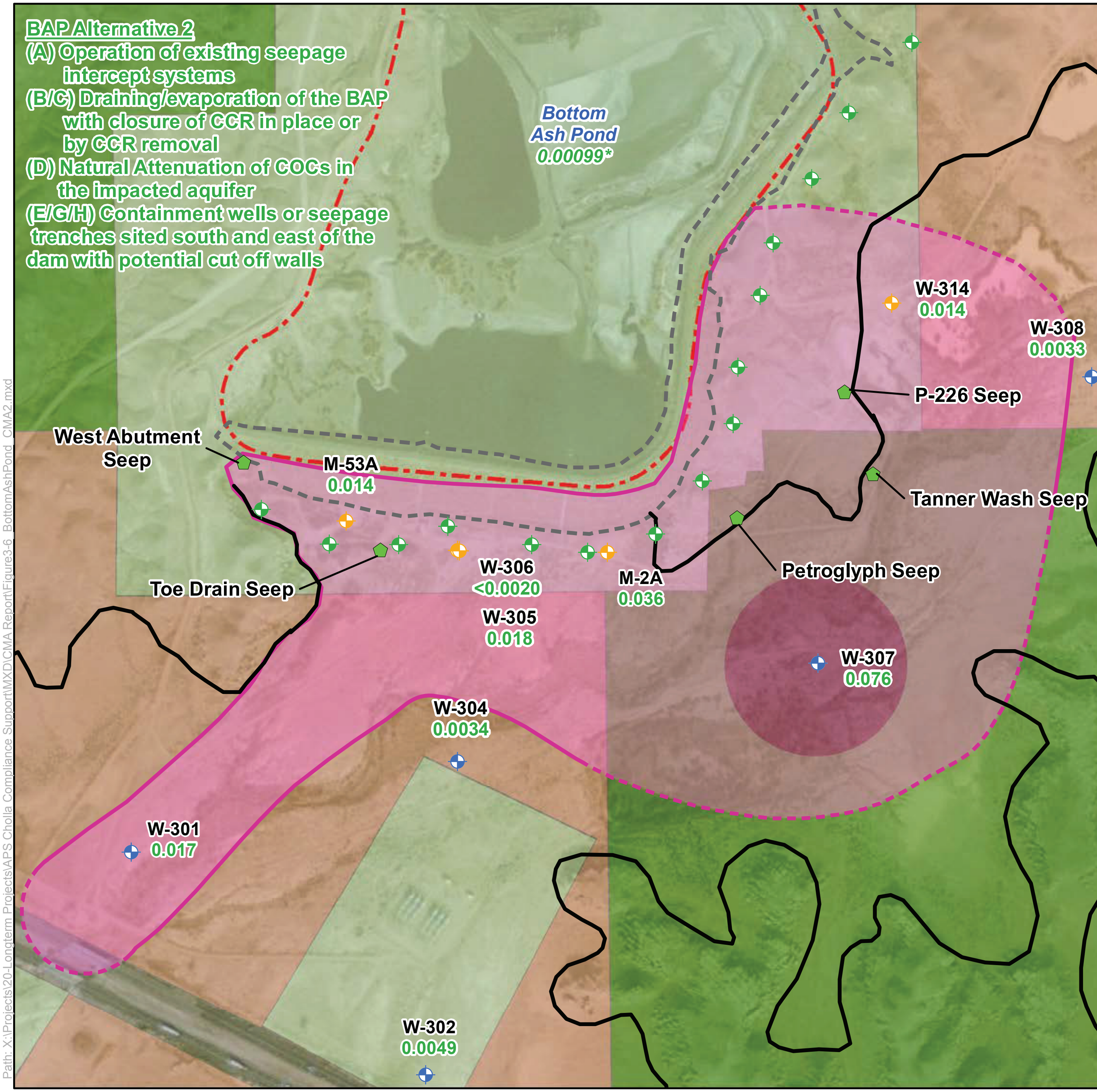
Fly Ash Pond Corrective Measures Alternative 4

Job No.	1420182040
PM:	NCL
Date:	6/12/2019
Scale:	1"= 600'

wood.

Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\CMA Report\Figure3-4_FlyAshPond_CMA4.mxd


BAP Alternative 1
(A) Operation of existing seepage intercept systems
(B/C) Draining/evaporation of the BAP with closure of CCR in place or by CCR removal
(D) Natural Attenuation of COCs in the impacted aquifer
Bottom Ash Pond
0.00099*
West Abutment Seep
M-53A
0.014
W-306
<0.0020
M-2A
0.036
W-305
0.018
Toe Drain Seep
Petroglyph Seep
Tanner Wash Seep
P-226 Seep
W-314
0.014
W-308
0.0033
W-307
0.076
W-304
0.0034
W-301
0.017
W-302
0.0049
Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\CMA Report\Figure3-5_BottomAshPond_CMA1.mxd
Site Location
Fresno
Las Vegas
Los Angeles
San Diego
Tijuana
Arizona
Phoenix
Tucson
New Mexico
El Paso
State Overview
Legend
CCR Monitoring Well Location
Supplementary Site Monitoring Well Location
Seep and Intercept System Location
Estimated Alluvial Extent
Approximate Extent of CCR Unit
Approximate Extent of Dam
Cobalt Concentration in Alluvial Aquifer (December 2018)
>0.06 mg/L
>0.006 mg/L
GWPS (0.006 mg/L; Dashed Where Inferred)
Land Ownership (Parcel Sizes and Shapes are approximate - see notes on Figure 1-3)
Hansen Family
Arizona Public Service
US Forest Service
Notes:
W-123 Well Identification
0.0026 Arsenic concentration (mg/L)
* Sampled in March 2019
N
0 300 600
Feet
Arizona Public Service
Cholla Power Plant
Navajo County, Arizona
FIGURE
3-5
Bottom Ash Pond Corrective Measures Alternative 1
Job No. 1420182040
PM: NCL
Date: 6/12/2019
Scale: 1"= 600'
wood.
The map shown here has been created with all due and reasonable care and is strictly for use with Wood Environment & Infrastructure Solutions, Inc. Project Number 1420182040. This map has not been certified by a licensed land surveyor, and any third party use of this map comes without warranties of any kind. Wood Environment & Infrastructure Solutions, Inc. assumes no liability, direct or indirect, whatsoever for any such third party or unintended use.



State Overview

Legend

- CCR Monitoring Well Location
- Supplementary Site Monitoring Well Location
- New Containment Wells
- Seep and Intercept System Location
- Estimated Alluvial Extent
- Approximate Extent of CCR Unit
- Approximate Extent of Dam

Cobalt Concentration in Alluvial Aquifer (December 2018)

- >0.06 mg/L
- >0.006 mg/L
- GWPS (0.006 mg/L; Dashed Where Inferred)

Land Ownership (Parcel Sizes and Shapes are approximate - see notes on Figure 1-3)

- Hansen Family
- Arizona Public Service
- US Forest Service

Notes:

W-123	Well Identification
0.0026	Arsenic concentration (mg/L)
*	Sampled in March 2019

0 300 600 Feet

N

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

FIGURE 3-6

Bottom Ash Pond Corrective Measures Alternative 2

Job No.	1420182040
PM:	NCL
Date:	6/14/2019
Scale:	1"= 600'

wood.

Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\CMA Report\Figure3-6_BottomAshPond_CMA2.mxd

APPENDIX A

ALTERNATIVE SOURCE DEMONSTRATION FOR LITHIUM AT THE BOTTOM ASH POND

Technical Memorandum

To:	Michele Robertson, RG Pamela Norris	**File No:**	14-2018-2040
From:	Emily LoDolce, PE	**Reviewed by:**	Natalie Chrisman Lazarr, PE Carla Landrum, PhD
Date:	June 6, 2019		

Subject: **ALTERNATIVE SOURCE DEMONSTRATION FOR LITHIUM AT THE BAP**
Arizona Public Service Cholla Power Plant – Navajo County, Arizona

1.0 INTRODUCTION

This technical memorandum (memo) documents an Alternative Source Demonstration (ASD) for lithium in groundwater downgradient of the Bottom Ash Pond (BAP), an existing coal combustion residuals (CCR) unit located at the Arizona Public Service Company (APS) Cholla Power Plant (Site) in Navajo County, Arizona. The memo is an appendix to a report documenting an *Assessment of Corrective Measures for the Fly Ash Pond and Bottom Ash Pond* (the Main Report) prepared by Wood Environment & Infrastructure Solutions, Inc. (Wood).

A full description of the Site location and background, CCR monitoring system, and historical operations is contained within the *2018 Annual Groundwater Monitoring and Corrective Action Report* (Wood, 2019). The BAP is one of four CCR units at the Site. It is a 2,300-acre-foot surface impoundment used to store slurried bottom ash generated at the plant. It was placed into service in 1978. The BAP dam was constructed of earth fill with a central clay core. The BAP is unlined and constructed on alluvium and underlying Moenkopi mudstone (considered an aquitard between the alluvial aquifer and the lower, confined Coconino Sandstone aquifer).

Statistical analyses of Appendix IV constituent data collected from downgradient BAP monitoring wells declare that lithium and cobalt concentrations exhibit exceedances of their respective Groundwater Protection Standards (GWPSs) at statistically significant levels (SSLs). Pursuant to 40 Code of Federal Regulations (CFR) Section (§)257.94(e)(2), the owner/operator is allowed to demonstrate that a source, other than the CCR unit, caused the apparent SSI within 90 days of the official SSI declaration. Potential sources include sampling and analysis errors, statistical method inadequacies and/or natural variation in groundwater quality. Each of these sources are explored within the scope of this memo.

The ASD documented herein only addresses lithium at the BAP and was prepared in association with an assessment of corrective measures; preparation of the ASD within 90 days of declaring an exceedance of the GWPS was not possible because analysis of recently available characterization information was necessary to support this ASD. Cobalt remains a constituent of concern at the BAP.

Wood's approach to conducting the ASD was to systematically review the potential alternative sources noted above to evaluate if any of these causes resulted in the apparent GWPS exceedances of lithium in groundwater downgradient of the BAP.

4600 East Washington Street, Suite 600
Phoenix, Arizona 85034-1917
Tel: (602) 733-6000
Fax: (602) 733-6100
www.woodplc.com

2.0 SAMPLING AND LABORATORY CAUSES

To assess potential sampling and laboratory causes, Wood reviewed sampling and analysis procedures as well as the results of laboratory data validation.

Based on a review of sampling procedures, Wood concluded that APS has conducted field sampling activities in accordance with the Groundwater Sampling and Analysis Plan (SAP) developed for the Site (Montgomery & Associates, 2015) to comply with the CCR Rule. On the basis that the SAP is sufficiently detailed and contains appropriate procedures for groundwater level measurement, groundwater sample collection, sample control, laboratory analysis, and data validation, no apparent sampling causes for lithium exceedances were noted.

Wood also reviewed laboratory data validation reports for the CCR groundwater monitoring program. Following receipt of final laboratory reports of analysis, APS contracted with Montgomery & Associates to evaluate the reports and associated sample data collected during detection and assessment monitoring for quality assurance purposes. The scope of the effort was a US Environmental Protection Agency Stage 2A validation. On the basis of Wood's review, there are no apparent issues with field forms or laboratory analyses that would explain the GWPS exceedances for lithium downgradient of the BAP.

3.0 ANTHROPOGENIC SOURCES

Wood reviewed surrounding property uses, historical property uses, and upgradient land uses to evaluate any potential anthropogenic sources for lithium exceedances. The surrounding land uses are undeveloped, rural land. On this basis, there is insufficient evidence to conclude that surrounding anthropogenic sources are the source to the GWPS exceedances for lithium downgradient of the BAP.

4.0 STATISTICAL EVALUATION CAUSE

A statistical evaluation cause refers to the possibility that the current statistical method is invalid for performing statistical comparisons, thereby resulting in a falsely declared GWPS exceedance for lithium. Currently, the Cholla BAP groundwater monitoring system is designed to perform interwell statistical comparisons. An interwell comparison is one where samples collected from two different geographic locations within the same water bearing unit are used to perform the statistical evaluation. One geographic location represents background, or baseline groundwater conditions we expect to see if the BAP is not impacting groundwater, and the other geographic location represents compliance monitoring wells downgradient of the BAP. Sample data collected from the two geographic locations are then statistically compared to assess site compliance. In general, interwell comparisons perform poorly in cases where an adequate and representative background location cannot be established for one or more sample constituents. Factors leading to inadequate or non-representative background can include, for example, spatial heterogeneity in groundwater conditions or discontinuous lithologies between background and compliance monitoring well locations. These inadequacies can cause an interwell statistical comparison to be meaningless and result in false positive or false negative statistical results.

The GWPS for lithium was developed using the data collected from the background monitoring well (M-64A) for the BAP, which was installed in February 2017. The baseline monitoring period for this well spans from February 2017 to September 2018 (for both Appendix III and Appendix IV constituents) plus two rounds of assessment monitoring (for Appendix IV constituents) in February 2018 and May 2018 (Wood, 2018a). The statistical evaluation of the lithium data in the background well resulted in a calculated background threshold value equal to 0.31 milligrams per liter (mg/L) and this value represents the GWPS for this constituent (Wood, 2018a). The statistical methods used to derive this value are detailed in the Statistical Data Analysis Work Plan for the Cholla Power Plant (Wood, 2018b). The background well exhibits lithium concentrations that range between 0.25 mg/L and 0.28 mg/L between February 2017 and May 2018.

The observed lithium concentrations in downgradient compliance wells, which were sampled over a relatively longer period, starting in November 2015 and ending in May 2018, vary by compliance well location and exhibit lithium concentrations ranging between less than 0.2 mg/L (non-detectable concentrations) to 0.78 mg/L. The range of lithium concentrations in the compliance wells are the same order of magnitude as concentrations observed in background.

Several factors can explain the discrepancy in the range of sample concentrations between background and compliance wells at the BAP. For example, previous work underscores that high sampling frequencies (e.g., bi-monthly in some cases) over a relatively shorter sampling period can be one source to the narrow range of lithium concentrations observed in the background well (Wood, 2018b). A high sampling frequency (e.g., less than quarterly) can bias the variability in sample concentrations because each sample is temporally correlated to the next, meaning the sample background data do not represent the true range of variability in background lithium concentrations. Furthermore, the lithium concentrations vary spatially between all monitoring well locations, suggesting that the groundwater system exhibits natural variation in lithium concentrations with respect to geographic location.

The natural variation argument that follows is rooted in the premise that spatial heterogeneity in lithium concentrations at the Site is not adequately represented by data collected from the background well and, as such, the underlying interwell assumptions for lithium are invalid. Therefore, the interwell statistical comparison method for lithium is unreliable in detecting leakage from the BAP. The following section presents statistical and non-statistical lines of evidence that support the conclusion that the lithium concentrations within the alluvial aquifer system beneath the BAP exhibit natural spatial variation and is the cause of the GWPS exceedance for lithium at the BAP.

5.0 NATURAL VARIATION CAUSE

Lithium is naturally present in soil and groundwater, particularly in arid environments, where it is associated with evaporites and precipitates (Cannon et al., 1975). To evaluate natural variation as the cause of the lithium exceedances, three different approaches to reviewing site data were applied. First, a statistical evaluation of lithium and select other constituents was performed to assess variability in observed concentrations. Second, the spatial distribution of lithium was compared to the spatial distribution of a constituent known to be associated with CCR in groundwater downgradient of the BAP (i.e., boron). Finally, the concentration of lithium measured from a surface water sample collected from the BAP was compared to the concentrations of lithium observed in CCR monitoring system groundwater monitoring wells.

5.1 Statistical Evaluation of Natural Variation

The objective of this statistical evaluation was to assess the variability in lithium concentrations, and other constituent concentrations, within the alluvial aquifer downgradient of the BAP. It is hypothesized that the GWPS exceedance declaration for lithium results from the intrinsic spatial variability of naturally-occurring lithium concentrations within the alluvial groundwater.

5.1.1 Data Inputs

Data from six groundwater monitoring wells (M-52A, M-53A, M-55A, W-305, W-306, and W-314) and one background well (M-64A) were used to complete this statistical evaluation. The sampling duration begins in the fourth quarter of 2015 and ends in the second quarter of 2019. The sampling duration is shorter, and the relative sample count is therefore lower, for M-64A because it was installed in 2017. The sampling frequency is inconsistent and ranges between monthly to quarterly.

This evaluation includes five constituents: lithium, cobalt, chloride, sulfate, and pH. Not all constituents were sampled concurrently between wells, which results in sampling gaps for this evaluation depending on the well and the constituent. Non-detect concentrations represent the corresponding reporting limit value.

5.1.2 Methods

The statistical methods employed to evaluate the variability in the data are a review of basic statistics, development of box and whisker plots, and a principal component analysis.

Basic Statistics - **Table 1** summarizes the basic statistics for each monitoring well and constituent. Basic statistics are useful for assessing sample counts and making relative comparisons between statistical measures, particularly the range in sample concentrations, the central tendencies (mean and median), and sample standard deviation. Constituents with a range and standard deviation close to zero are generally indicative of wells that sample a high frequency of non-detectable concentrations. Except for cobalt, the variability in the central tendencies between constituents and monitoring wells vary on the same order of magnitude.

Box and Whisker Plots - **Figures 1** through **5** illustrate the box and whisker plots for each constituent and well grouping. The box and whisker plots are useful for visually comparing the relative distribution of constituent concentrations between wells and provide a good indication of spatial heterogeneity in constituent concentrations between well locations. For each constituent, except for pH, the box plots generally position uniquely according to their central tendency (thick black line within the box) and the range of observed concentrations (area spanning between whiskers flanking the box) between wells. Unique position and lack of general overlap between box and whisker plots between different wells is an indication of spatial heterogeneity within the aquifer system.

The relative constituent concentrations for monitoring wells M-52A and W-306 are notable, particularly the inverse relationship between pH and chloride and cobalt for M-52A and a positive relationship between lithium and sulfate in W-306. These observations are congruent with lithium being associated with evaporates and precipitates and with increased cobalt solubility at lower pH values.

Principal Component Analysis – Principal component analysis (PCA) is a multivariate analysis that integrates all available data to simultaneously study correlations and associations between wells and their constituents (Everitt et al., 2011; James et al., 2013; Jolliffe, 2013). The correlations and associations can lend insight into the spatial heterogeneity of the alluvial aquifer system as it relates to broader geochemistry and other inferential aquifer characteristics that might impact constituent concentrations within the aquifer system (e.g., screened depths and lithologies, etc.).

Since the sample five constituents vary in their magnitude of concentration, the data were standardized prior to performing PCA to account for these differences.

Figures 6 and **7** present the results of the PCA. PCA plots, in general, illustrate how the sample data cluster. The color-coding is used to indicate which monitoring well the data are derived from. Wells that cluster together exhibit synergies in their underlying statistical variation, suggesting the groundwater observed by these wells derive from, or is influenced by the same in situ properties, mechanisms and/or processes. The vectors (arrows) represent each sample constituent. The constituent groupings and their vector magnitudes help explain the correlations between constituents and their overall importance. Using this information as a collective, it is possible to interpret the sources of statistical variation observed in the monitoring well clusters.

The baseline PCA scenario is shown in **Figure 6**, which includes all constituents and monitoring wells. In the baseline PCA scenario, lithium and sulfate strongly associate with sample data within W-306. Monitoring wells M-53A, M-55A, M-64A, and W-314 plot in gradient order along the same vector line (extrapolated) relative to their sulfate and lithium concentrations in comparison to W-306. It is notable that M-55A and M-64A (the background well) plot closest to W-306. Cobalt and chloride cluster together and are inversely related to pH. This inverse relationship indicates that higher cobalt and chloride concentrations associate with lower pH values and vice versa. Cobalt is known to become more mobile in the presence of lower pH values, which helps explain the inverse relationship observed between these two constituents. Data collected from M-52A dominates in explaining this relationship.

A second PCA scenario excludes W-306 to understand well clustering and constituent groupings in the absence of any masking effects produced by this well. **Figure 7** illustrates the results of this PCA scenario. Lithium and sulfate group together and plot closely to the M-55A and M-64A (background well) clusters. Lithium is known to associate with evaporites and precipitates and the occurrence of these constituents plotting closely to M-64A suggests naturally occurring lithium concentrations should be expected within the alluvial groundwater system. It is possible the lithium concentrations observed in W-306 are due to its proximity to a localized pocket of evaporites and precipitates within the aquifer system. Cobalt plots inversely to pH and associates most with data collected from M-52A. Groundwater monitoring data collected from W-314, M-53A, and W-305 associate with pH and inversely associate with cobalt, and to a degree, chloride. Notably, data collected from M-64A do not strongly associate with cobalt or pH in this scenario, suggesting the mechanism driving this described behavior for pH and cobalt might not be intrinsic to what is observed in background aquifer conditions.

5.2 Spatial Distribution

Boron is often used as a potential indicator for CCR because it is typically present in CCR unit leachate, it is non-reactive and mobile in common hydrogeologic environments, and it is not a common anthropogenic contaminant. Boron has been historically present in BAP downgradient monitoring wells at detectable concentrations, and the BAP is suspected to be the source of these concentrations. **Figure 8** shows the spatial distribution of boron concentrations measured in monitoring wells at the site in December 2018. The concentration of boron measured in the BAP in March 2019 was 4.8 mg/L, higher than the concentrations shown in downgradient wells. Wells with the highest concentrations of boron are closest to the BAP, and wells with the lowest concentrations of boron in groundwater tend to be more distant from the BAP.

Lithium is also non-reactive and mobile in common hydrogeologic environments. In contrast to the spatial distribution of boron, the spatial distribution of lithium concentrations measured in monitoring wells at the site in December 2018 (**Figure 9**) show no apparent correlation to proximity to the BAP. Concentrations of lithium in monitoring wells in the Tanner Wash alluvial aquifer (where the BAP is located) are all within the same order of magnitude, and ranged from less than 0.2 mg/L to 0.43 mg/L with the exception of the sample collected at W-306, which indicated a slightly higher concentration of 0.73 mg/L. The shading in **Figure 9** identifies areas of the alluvial aquifer where the concentration of lithium was above the GWPS of 0.31 mg/L. Notable wells with concentrations below the GWPS include monitoring wells M-53A and M-52A, both located adjacent to the south side of the BAP dam.

5.3 Concentrations in the BAP and Downgradient Aquifer

An exceedance of the GWPS is unlikely to be due to release from the facility if the concentration of the constituent in water collected from the CCR unit is not higher than the concentrations in downgradient wells. To evaluate this possibility, APS collected a water sample from the BAP on March 30, 2019 and sent it to TestAmerica Laboratories, Inc. (TestAmerica) located in Phoenix, Arizona, for analysis. TestAmerica is an Arizona Department of Health Services-licensed laboratory (AZ0728). The results of the analysis indicate that the lithium concentration in water collected from the BAP is less than the laboratory reporting limit of 0.20 mg/L, which is lower than the GWPS of 0.31 mg/L and lower than the concentration in many of the monitoring wells shown on **Figure 9**. This is a secondary line of evidence to suggest that the potential exceedance for lithium is not due to a release from the BAP. At this time there is only one water quality sample from the BAP with results for lithium. Including lithium in the list of analytes for future samples collected from the BAP would increase the sample size of representative data and potentially lend confidence to these results.

6.0 FINDINGS AND RECOMMENDATIONS

Natural variation in the aquifer is declared to be the cause of the GWPS exceedance for lithium at the BAP. The primary lines of evidence for this conclusion include:

- The multivariate statistical analysis of lithium and other compounds in the alluvial aquifer which points to the existence of spatial heterogeneity within the alluvial system; and
- The spatial distribution of lithium in the Tanner Wash alluvial aquifer is not consistent with a lithium source area located at the BAP.

Secondary lines of evidence include:

- The water quality sampling results that show concentrations of lithium in the BAP may be lower than lithium concentrations in the downgradient monitoring wells.

These lines of evidence support this ASD prepared in accordance with 40 CFR §257.95(g)(3)(ii) and support the position that the GWPS exceedance for lithium declared on November 14, 2018 was not due to a release from the BAP. Therefore, no further action (i.e., corrective measures analysis) is warranted for this constituent.

Wood recommends developing intrawell statistical comparisons for lithium and any other Appendix III and IV constituents that are determined to be influenced by aquifer heterogeneity at the BAP in the future. Intrawell comparisons are an industry accepted and recommended alternative to interwell comparisons (USEPA, 2009). Intrawell statistical comparisons are detailed in the USEPA Unified Guidance (2009) and in the Statistical Data Analysis Work Plan for the Cholla Power Plan (Wood, 2018b).

7.0 CERTIFICATION

By means of this certification, I certify that I have reviewed this ASD and find the information presented herein accurate and appropriate and meet the requirements of 40 CFR §257.95(g)(3)(ii).

Natalie Chrisman Lazarr
Printed Name of Registered Professional Engineer

Signature

31672	Arizona	14 June 2019
Registration No.	Registration State	Date

8.0 REFERENCES

Cannon, Helen L., Thelma F. Harms, and J.C. Hamilton, 1975. *Lithium in Unconsolidated Sediments and Plants of the Basin and Range Province, Southern California and Nevada*. Geological Survey Professional Paper 918, 1975.

Everitt, B. and T. Hothorn, 2011. *An Introduction to Applied Multivariate Analysis with R*. Springer Science+Business Media. pp 274.

Federal Register, 2018. *40 Code of Federal Regulations Part 257 – Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities; Final Rule promulgated April 17, 2015 with Amendments to the National Minimum Criteria (Phase One, Part One) effective August 29, 2018.*

James, G., D. Witten, T. Hastie and R. Tibshirani, 2013. *An Introduction to Statistical Learning with Applications in R*. Springer Science & Business Media. pp 426.

Jolliffe, I.T., 2013. *Principal Component Analysis*. Springer Science + Business Media. pp 271.

Montgomery & Associates, 2015. *Groundwater Sampling and Analysis Program, Cholla Power Plant, Joseph City, Arizona.* Prepared for APS. November 30, 2015.

Montgomery & Associates, 2018. *Cholla Power Plant Coal Combustion Residuals Program – Statistical Analysis of Baseline Groundwater Monitoring Data, November 2015 through September 2017. Navajo County, Arizona.* Prepared for APS. January 12, 2018.

Wood Environment & Infrastructure Solutions (Wood), 2018a. *Technical Memorandum, CCR Groundwater Assessment Monitoring Statistical Analysis and Results for the Bottom Ash Pond. Arizona Public Service Cholla Power Plant – Navajo County, Arizona.* October 15, 2018.

Wood Environment & Infrastructure Solutions (Wood), 2018b. Statistical Data Analysis Work Plan. Coal Combustion Residual Rule Groundwater Monitoring System Compliance. Cholla Power Plan, Joseph City, AZ. October, 15, 2018.

Wood, 2019. *Annual Groundwater Monitoring and Corrective Action Report for 2018. Coal Combustion Residual Rule Groundwater Monitoring System Compliance*. Prepared on behalf of Arizona Public Service. January 31, 2019.

TABLES

Table 1. Basic Statistics for Select Wells and Constituents

M-52A	Monitoring Well							
	Units	Sample Count	Mean	Standard Deviation	Median	Minimum	Maximum	Range
Lithium	mg/L	19	0.26	0.03	0.25	0.21	0.32	0.11
Cobalt	mg/L	19	0.05	0.01	0.05	0.03	0.07	0.04
Chloride	mg/L	17	4058.82	523.28	4000	3200	5100	1900
Sulfate	mg/L	17	2782.35	184.51	2700	2400	3100	700
pH	S.U.	16	7.06	0.19	7	6.8	7.5	0.7

M-53A	Monitoring Well							
	Units	Sample Count	Mean	Standard Deviation	Median	Minimum	Maximum	Range
Lithium	mg/L	19	0.2	0	0.2	0.2	0.21	0.01
Cobalt	mg/L	19	0.02	0	0.02	0.01	0.02	0.01
Chloride	mg/L	17	2435.29	136.66	2400	2200	2800	600
Sulfate	mg/L	17	2976.47	251.32	3000	2500	3400	900
pH	S.U.	16	7.5	0.09	7.5	7.4	7.7	0.3

M-55A	Monitoring Well							
	Units	Sample Count	Mean	Standard Deviation	Median	Minimum	Maximum	Range
Lithium	mg/L	16	0.36	0.03	0.36	0.31	0.43	0.12
Cobalt	mg/L	16	0.001	0.0009	0.0008	0.0005	0.004	0.035
Chloride	mg/L	14	3521.43	540.91	3650	2300	4300	2000
Sulfate	mg/L	14	3571.43	143.73	3500	3400	3800	400
pH	S.U.	13	7.42	0.13	7.4	7.3	7.7	0.4

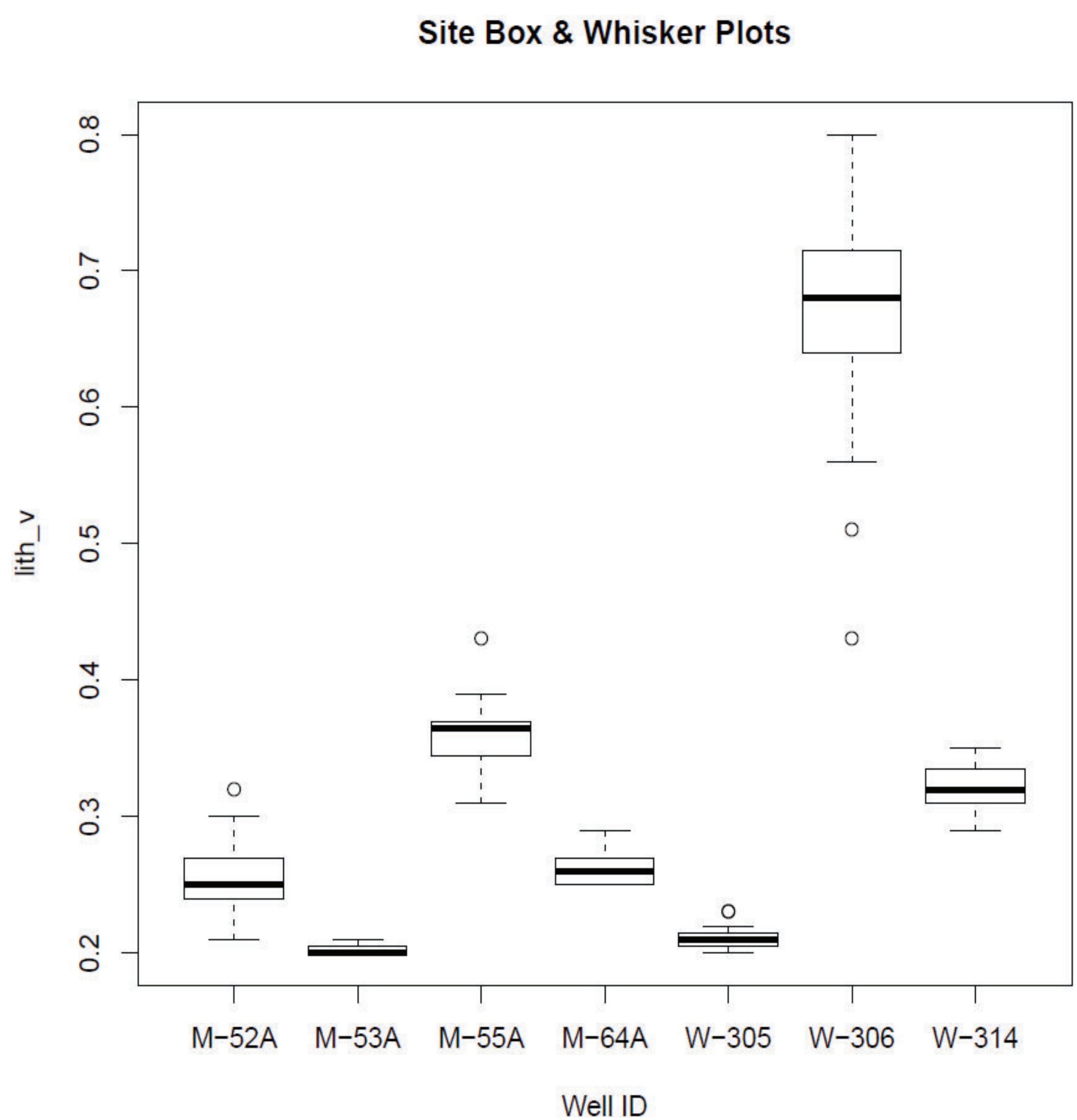
M-64A	Background Well							
	Units	Sample Count	Mean	Standard Deviation	Median	Minimum	Maximum	Range
Lithium	mg/L	13	0.26	0.01	0.26	0.25	0.29	0.04
Cobalt	mg/L	13	0.0008	0.0005	0.0006	0.0005	0.002	0.0015
Chloride	mg/L	11	4381.82	464.37	4400	3500	5100	1600
Sulfate	mg/L	11	4381.82	289.2	4400	3700	4800	1100
pH	S.U.	11	7.42	0.11	7.4	7.3	7.6	0.3

W-305	Monitoring Well							
	Units	Sample Count	Mean	Standard Deviation	Median	Minimum	Maximum	Range
Lithium	mg/L	19	0.21	0.01	0.21	0.2	0.23	0.03
Cobalt	mg/L	19	0.02	0	0.02	0.01	0.02	0.01
Chloride	mg/L	17	2352.94	162.47	2300	2100	2700	600
Sulfate	mg/L	17	2388.24	131.73	2400	2200	2800	600
pH	S.U.	16	7.41	0.16	7.4	7.05	7.7	0.65

W-306	Monitoring Well							
	Units	Sample Count	Mean	Standard Deviation	Median	Minimum	Maximum	Range
Lithium	mg/L	19	0.66	0.09	0.68	0.43	0.8	0.37
Cobalt	mg/L	19	0	0.01	0	0	0.03	0.03
Chloride	mg/L	17	1941.18	173.42	1900	1800	2400	600
Sulfate	mg/L	17	10982.35	2487.03	12000	3600	13000	9400
pH	S.U.	16	7.82	0.24	7.9	7.02	8.2	1.18

W-314	Monitoring Well							
	Units	Sample Count	Mean	Standard Deviation	Median	Minimum	Maximum	Range
Lithium	mg/L	19	0.32	0.02	0.32	0.29	0.35	0.06
Cobalt	mg/L	19	0.01	0	0.01	0.01	0.02	0.01
Chloride	mg/L	17	2776.47	125.15	2800	2600	3000	400
Sulfate	mg/L	17	2241.18	106.41	2200	2100	2500	400
pH	S.U.	16	7.44	0.13	7.4	7.3	7.7	0.4

FIGURES



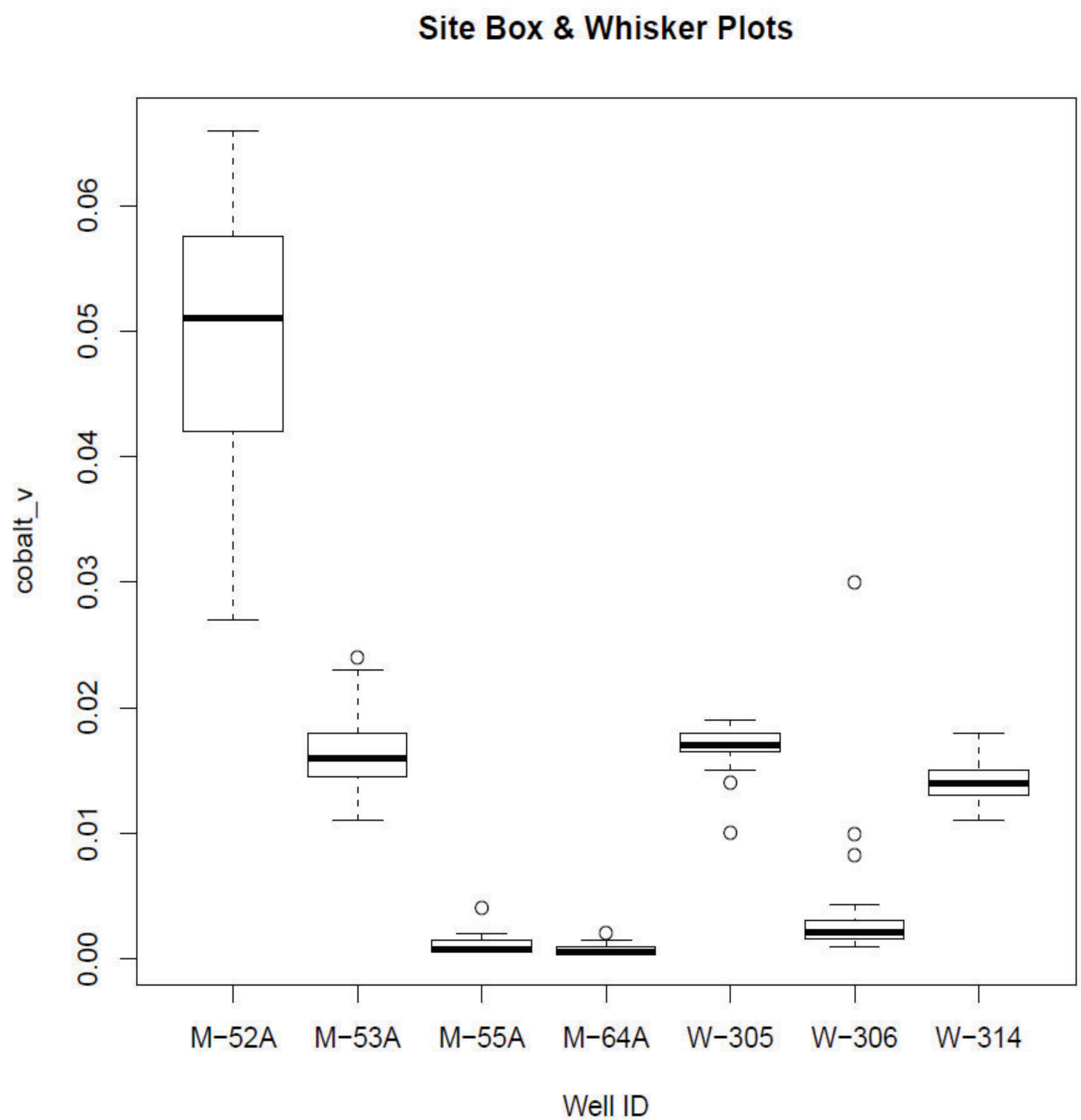
Job No.:	1420182040
PM:	NCL
Date:	6/3/2019
Scale:	As Shown

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

Box and Whisker Plots for Lithium

FIGURE
1

wood.



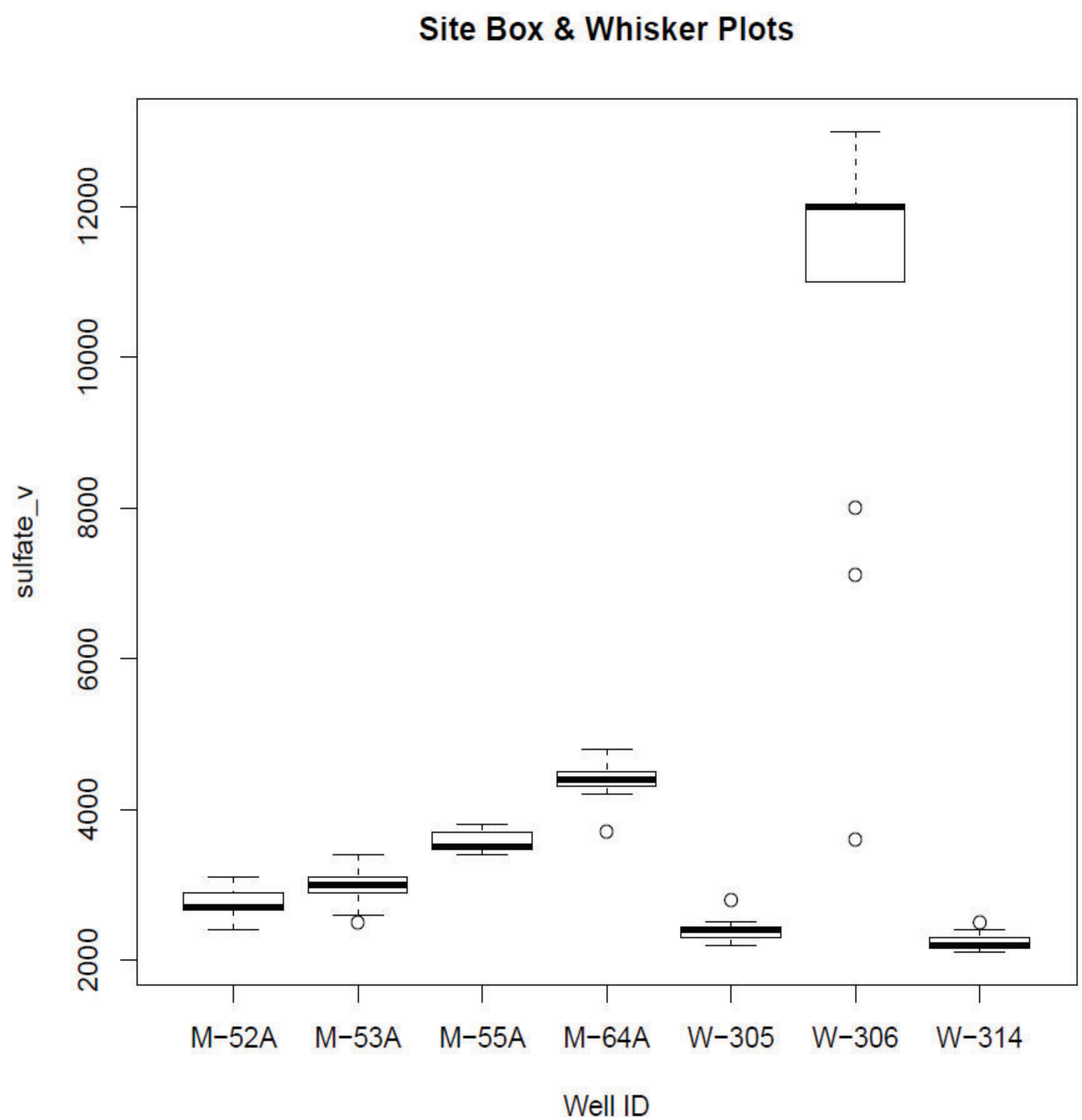
Job No.:	1420182040
PM:	NCL
Date:	6/3/2019
Scale:	As Shown

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

Box and Whisker Plots for Cobalt

FIGURE
2

wood.



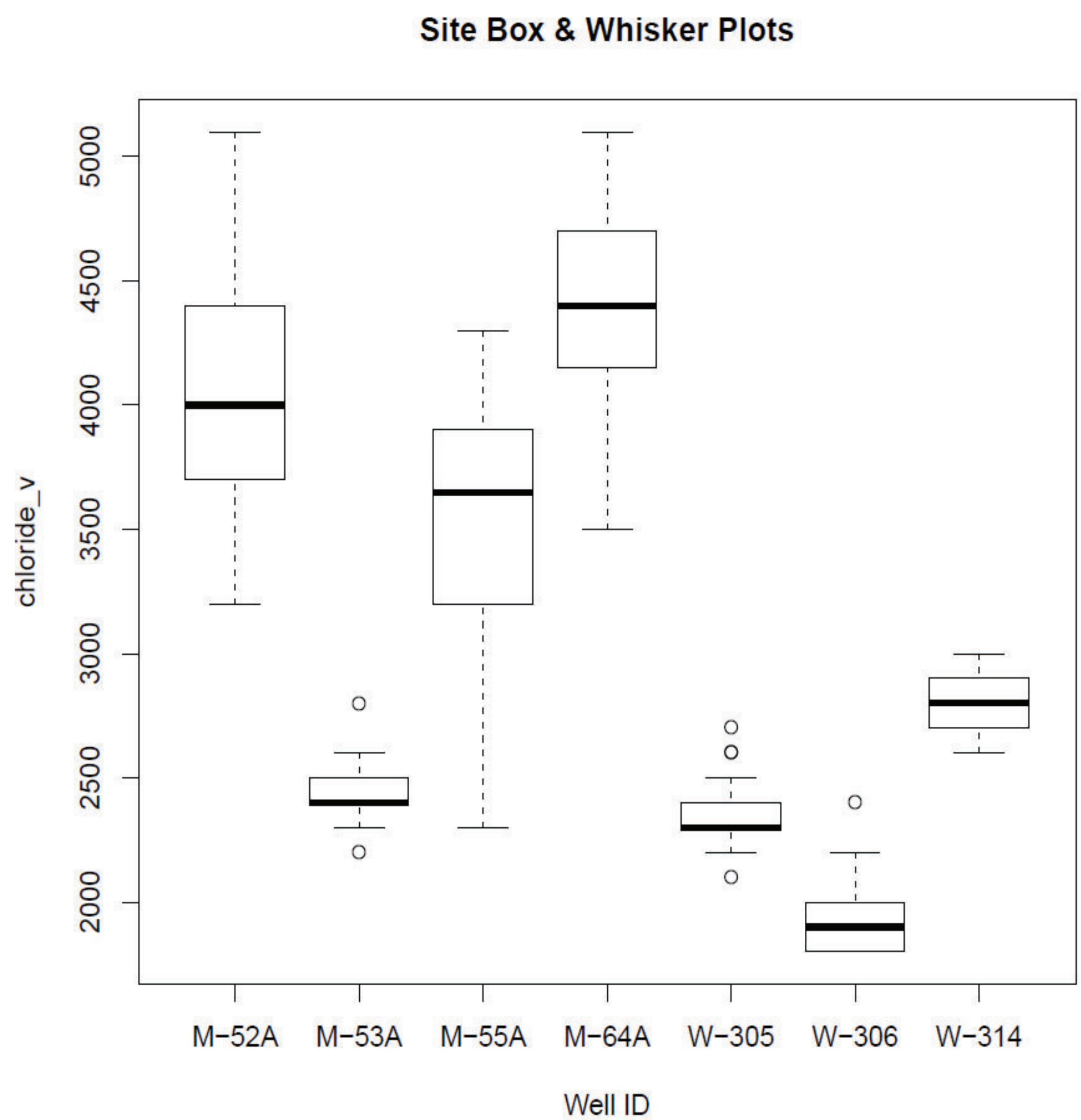
Job No.:	1420182040
PM:	NCL
Date:	6/3/2019
Scale:	As Shown

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

Box and Whisker Plots for Sulfate

FIGURE
3

wood.



Job No.:	1420182040
PM:	NCL
Date:	6/3/2019
Scale:	As Shown

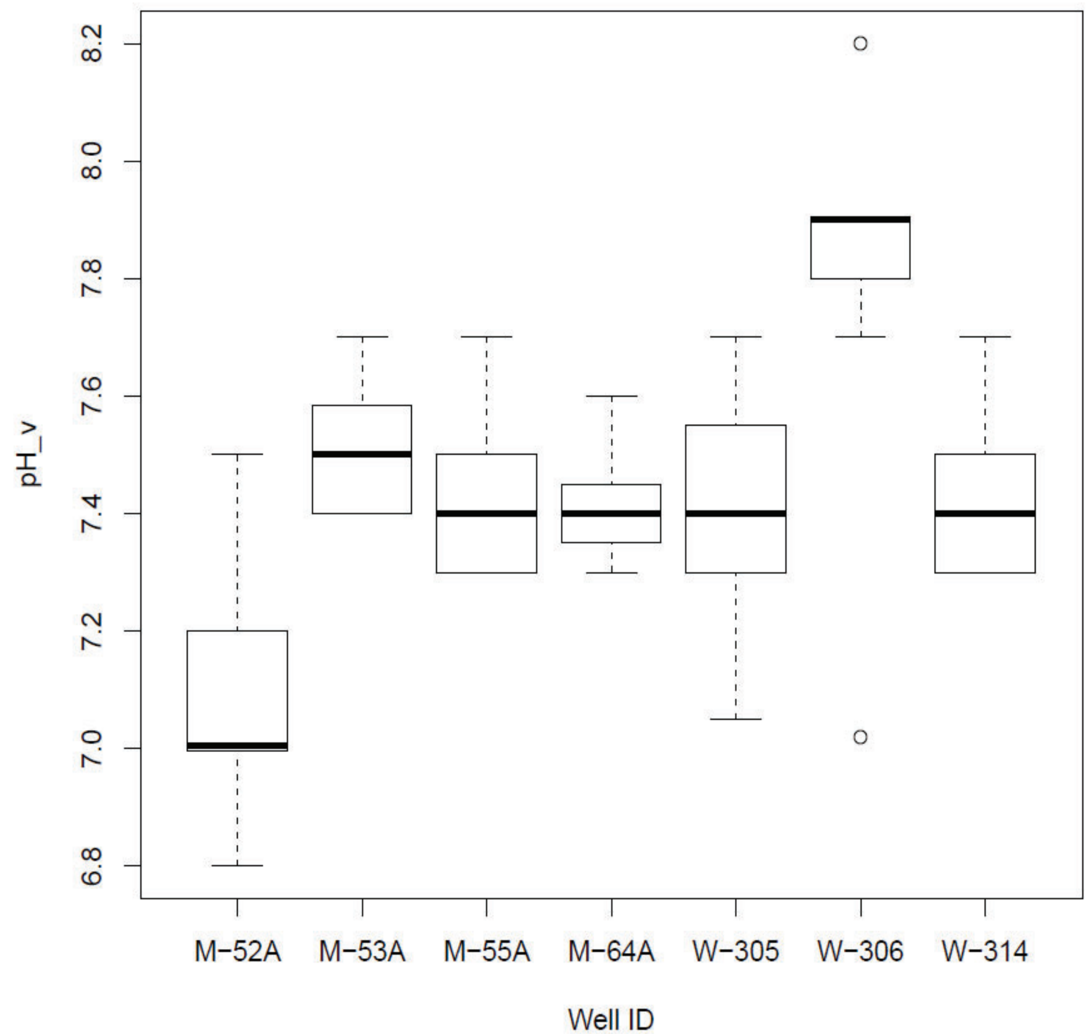
Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

Box and Whisker Plots for Chloride

FIGURE
4

wood.

Site Box & Whisker Plots



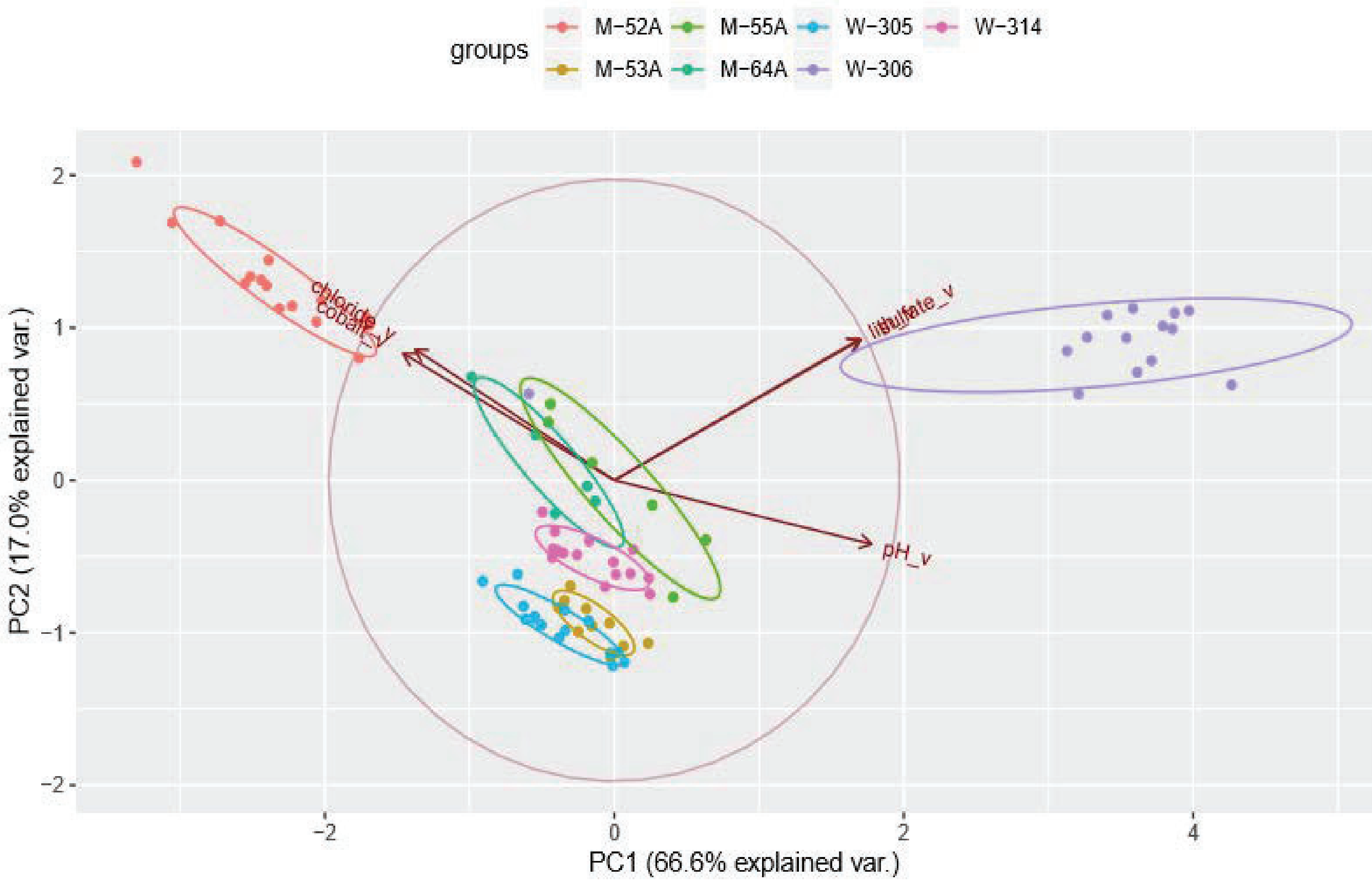
Job No.:	1420182040
PM:	NCL
Date:	6/3/2019
Scale:	As Shown

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

Box and Whisker Plots for pH

FIGURE
5

wood.



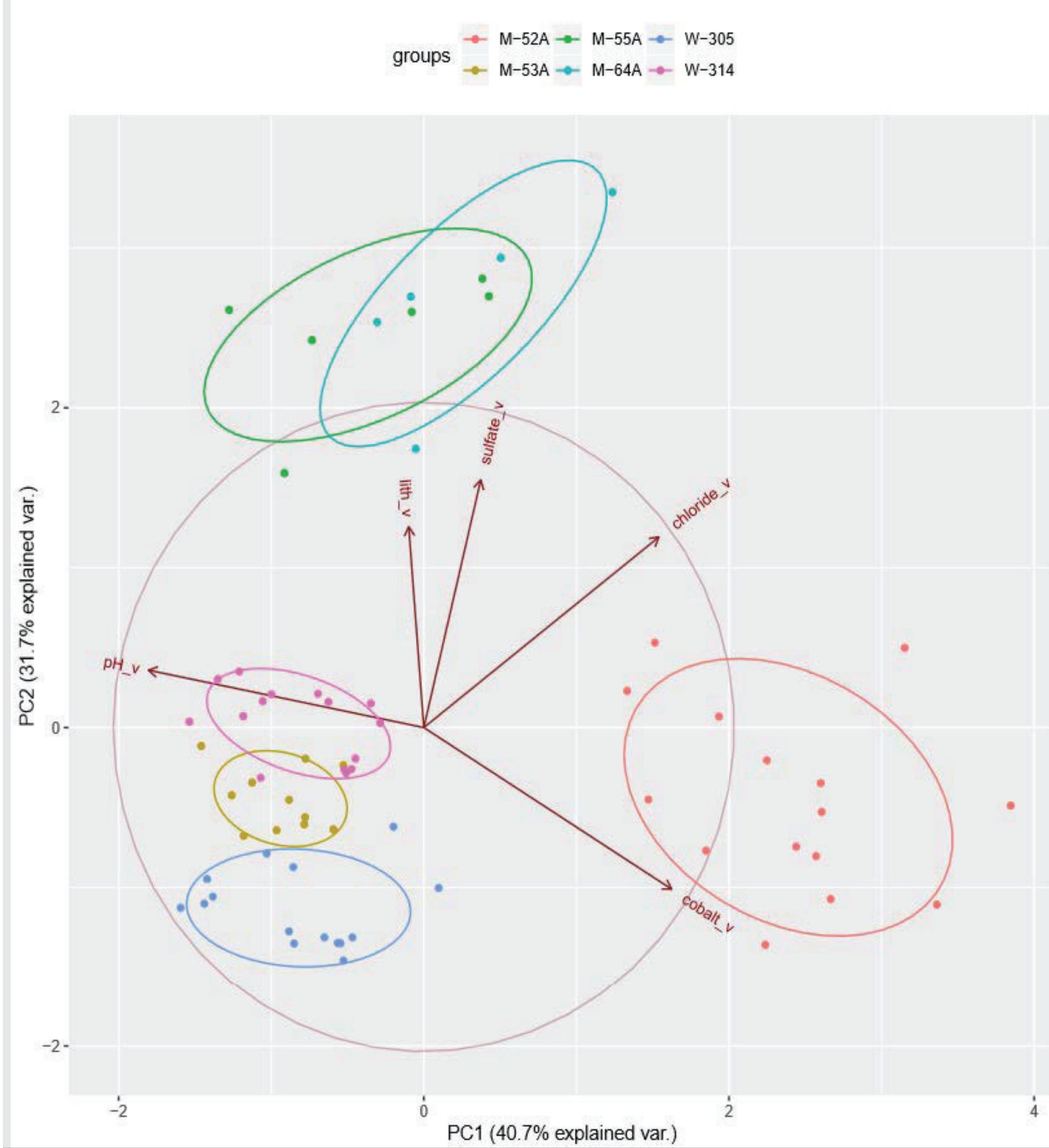
Job No.:	1420182040
PM:	NCL
Date:	6/3/2019
Scale:	As Shown

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

Plot for PCA Baseline Scenario

FIGURE
6

wood.



Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\CMA Report\Appendix\Figure7_PlotforPCABaselineScenario_ExcludingW306

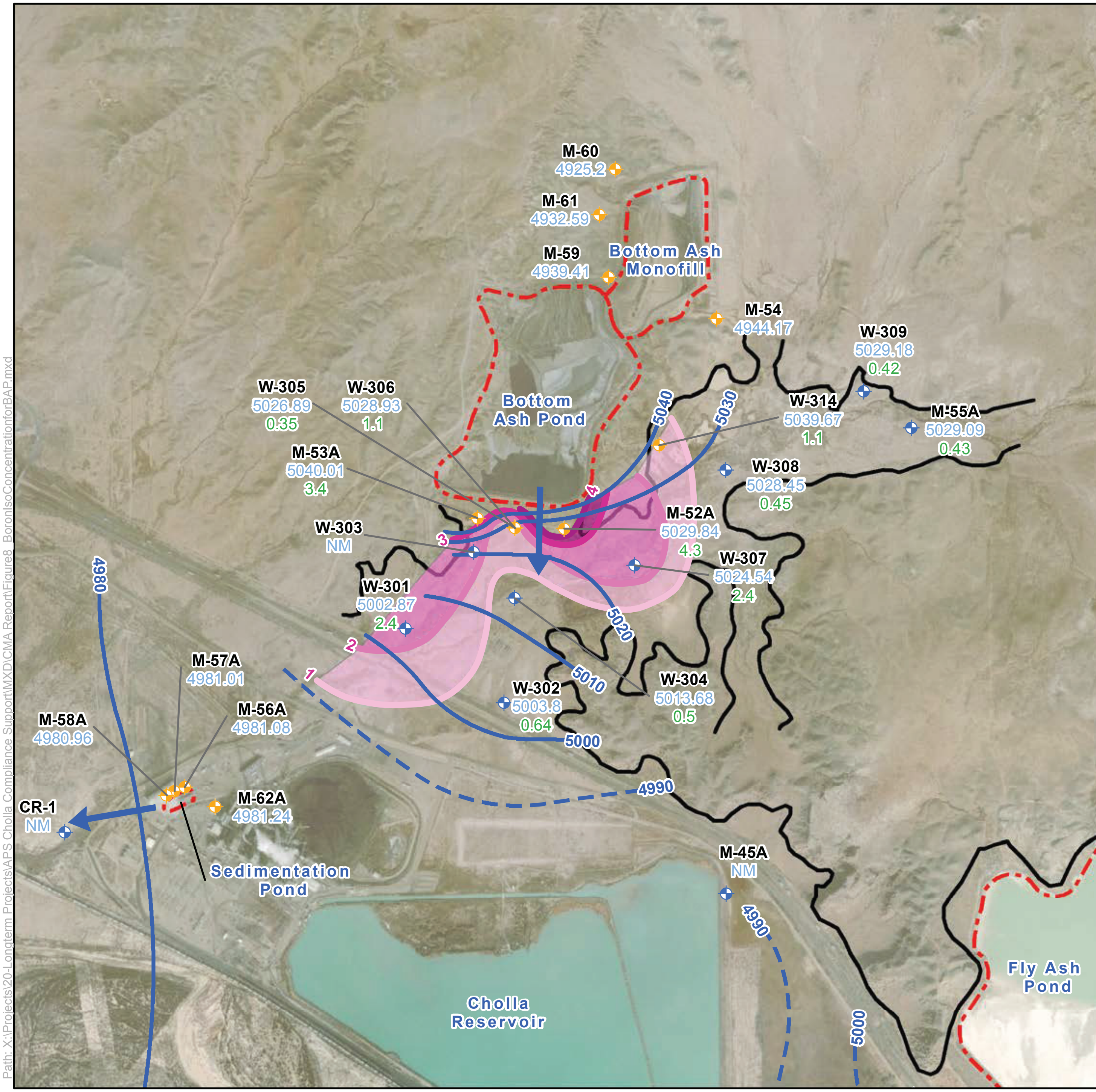
Job No.: 1420182040
PM: NCL
Date: 6/3/2019
Scale: As Shown

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

Plot for PCA Baseline Scenario Excluding W-306

FIGURE
7

wood.



State Overview

Legend

- CCR Monitoring Well Location
- Supplementary Site Monitoring Well Location
- Estimated Alluvial Extent
- Approximate Extent of CCR Unit

Potentiometric Surface - October 2018

- (Dashed Where Inferred)
- Groundwater Flow Direction

Boron Concentration in Alluvial Aquifer (December 2018)

- >1-2.0 mg/L
- >2-3.0 mg/L
- >3-4.0 mg/L

Notes:

W-308	Well Identification
5028.45	Groundwater elevation (ft amsl) measured in December 2018
0.45	Boron concentration (mg/L)
NM	Not Measured
ft amsl	Feet above mean sea level
mg/L	Milligrams per liter

N

0 900 1,800 Feet

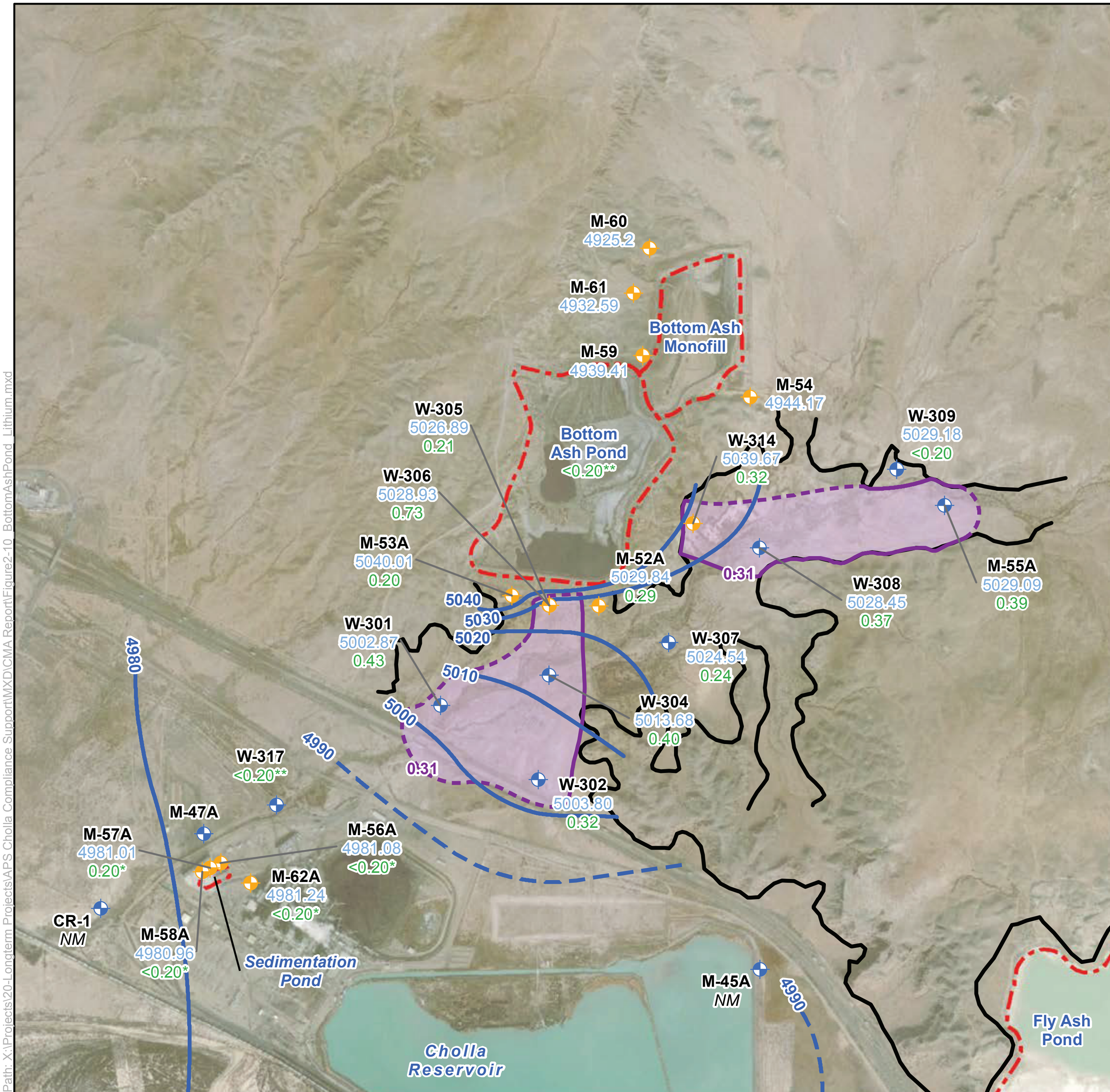
Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

FIGURE 8

Boron Iso-Concentration Map for the Bottom Ash Pond

Job No.	1420182040
PM:	NCL
Date:	6/4/2019
Scale:	1"= 1800'

wood.



State Overview

Legend

- CCR Monitoring Well Location
- Supplementary Site Monitoring Well
- Estimated Alluvial
- Approximate Extent of CCR Unit

Potentiometric Surface - October 2018

- (Dashed Where Inferred)

Lithium Concentration in Alluvial Aquifer (December 2018)

- >0.31 mg/L
- GWPS (0.31 mg/L; Dashed Where Inferred)

Notes:

W-309	Well Identification
5029.18	Groundwater elevation (ft amsl) measured in October 2018
<0.20	Lithium concentration (mg/L)
*	Sampled in May 2018
**	Sampled in March 2019
ft amsl	Feet above mean sea level
mg/L	Milligrams per liter
NM	Not Measured
GWPS	Groundwater Protection Standard

0 915 1,830 Feet

N

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

FIGURE 9

Lithium Iso-Concentration Map for the Bottom Ash Pond

Job No.	1420182040
PM:	NCL
Date:	6/5/2019
Scale:	1"= 1,830'

wood.

APPENDIX B

CORRECTIVE MEASURES ASSESSMENT GROUNDWATER MODEL DOCUMENTATION

Technical Memorandum

To:	Michele Robertson, RG Pamela Norris	**Project No:**	14-2018-2040
From:	Emily LoDolce, PE	**Reviewed by:**	Natalie Chrisman Lazarr, PE Chris Courtney, RG
Date:	June 14, 2019	**cc:**	File
Subject:	**CORRECTIVE MEASURES ASSESSMENT GROUNDWATER MODEL DOCUMENTATION Arizona Public Service Cholla Power Plant – Navajo County, Arizona**		

1.0 INTRODUCTION

This technical memorandum (memo) documents the development, calibration, and use of a three-dimensional (3-D) groundwater flow and transport model representing near surface hydrogeologic conditions at the Arizona Public Service (APS) Cholla Power Plant (the Site). The memo is an appendix to a report documenting an *Assessment of Corrective Measures for the Fly Ash Pond and Bottom Ash Pond* (the Main Report) prepared by Wood Environment & Infrastructure Solutions, Inc. (Wood).

The model was developed to serve as a scientific tool to evaluate potential corrective measures to address the elevated concentrations of Coal Combustion Residuals (CCR) Rule constituents observed in the alluvial aquifer downgradient of the Fly Ash Pond (FAP) and the Bottom Ash Pond (BAP). This memo presents the data and specifications for the Cholla Power Plant Groundwater Model (the model), including modeling platform, structure, parameters, conceptual water budget, and calibration data.

2.0 MODELING PLATFORM

Wood developed the model using MODFLOW 2005 (Harbaugh, 2005), a standard and widely-used USGS modeling code, with the PCG2 solver. Contaminant transport was simulated using MT3DMS (Zheng and Wang, 1999) with the finite difference solver, which has the advantage of being mass conservative. Groundwater Vistas Version 7.23 was used as a graphical user interface to facilitate modeling and visualization.

MODFLOW is a program that uses the finite difference method to solve a 3-D groundwater flow equation. The groundwater flow equation uses transmissivity (in unconfined aquifers, this is the product of hydraulic conductivity and saturated thickness), volumetric flux of water, and storage to solve for the change in head over time. MODFLOW solves the groundwater flow equation numerically by dividing the model domain into grid cells and calculating the head at the center of each cell. A complete discussion of the equations used in MODFLOW is available in the USGS open-file report 00-92, "MODFLOW-2000, the U.S. Geological Survey Modular Ground-Water Model – User Guide to Modularization Concepts and the Ground-Water Flow Process."

4600 East Washington Street, Suite 600
Phoenix, Arizona 85034
Tel (602) 733-6000
Fax (602) 733-6100
www.woodplc.com

MT3DMS is a program for simulating advection, dispersion/diffusion, and chemical reactions of contaminants in groundwater flow systems under general hydrogeologic conditions. The advection-dispersion equation uses porosity, dispersivity, and groundwater velocity to solve for the change in concentration over time. MT3DMS solves the advection-dispersion equation numerically using the groundwater flow field from the MODFLOW simulation and a finer discretization of time than what is used in the groundwater flow model to calculate the concentration in the center of each cell at each time step.

Groundwater Vistas (Environmental Simulations, Inc., 2017) is a proprietary graphical user interface that facilitates the modeling process by generating the input files required by MODFLOW 2005 and by displaying the modeling environment in a graphical manner. While this software is not required to run the model, the pre- and post-processing tools within this software package allow flow and transport models to be quickly constructed, run, and processed for evaluation. Additional tools for processing and visualizing model input and output data include Microsoft Excel and the ArcGIS (Version 10.3 [ESRI, 2014]) suite of programs, specifically ArcMap.

2.1 Modeling Approach

The approach to modeling the alluvial groundwater system at the Site was to first develop and calibrate a steady state groundwater flow model using groundwater elevations from Site monitoring wells and flow rates from Site seepage intercept systems as calibration data. The calibrated steady state flow model formed the basis for a transient model that was used to simulate groundwater flow and contaminant transport. The transient model was calibrated to observed concentrations of fluoride (at the FAP) and cobalt (at the BAP). Finally, the transient contaminant transport model was used to simulate the future impacts of alternative corrective measures at the Site.

2.2 Model Structure

To solve the groundwater flow equation, it is necessary to define the extent of the area of interest. This section discusses the geometry of the groundwater model, which can be thought of as a 3-D box that is cut out of the earth and isolated. The domain (edges of the box), cell size (partitions within the box), and layering (levels within the box) were developed by Wood in consultation with APS.

2.2.1 Model Domain

The model encompasses 10.9 square miles at the Cholla Power Plant in Navajo County, Arizona. General goals for model boundaries were to encompass the alluvial aquifer and to minimize the impact of model boundaries on the areas of potential corrective measures. Where feasible, this was done by extending the model to the geologic termination of the alluvium (as defined by AMEC Environment & Infrastructure, Inc. [AMEC], 2012 and Montgomery & Associates, 2017). Where no natural boundaries were present, the model domain is extended sufficiently beyond the area of interest to minimize boundary effects as described in Section 2.2.3. **Figure 1** presents an overview of the model domain, grid, and boundaries.

2.2.2 Grid Size, Orientation, and Layering

A grid cell size of 200 feet (ft) by 200 ft was used for the steady state groundwater flow model used to calibrate the flow field (except for the 100 ft by 200 ft cells in the vicinity of the FAP dam), and a grid cell size of 100 ft by 100 ft was used for the contaminant transport model. The grid is rotated 45.8 degrees from north to align with the primary direction of groundwater flow in the area of interest, i.e., the alluvium down-gradient of the FAP and the Tanner Wash alluvium cross- and down-gradient of the BAP (see **Figure 1** for groundwater flow direction arrows). The model consists of three layers with individual model cell thickness varying in accordance to local hydrogeologic stratification at a 200-ft scale.

Layer 1 is unconfined and represents the upper portion of the alluvium, which generally consists of fat clays with low permeability (Wood, 2019 [**Attachment A**]). Ground surface elevation (the top of Layer 1) was defined using 10-meter (m) Digital Elevation Model files (DEMs) from the USGS (USGS, 2013). These are raster files that are a product of satellite imagery, produced at a 10-m resolution which means the raster is pixilated in 10-m by 10-m pixels. Using a mapping and spatial analysis software program called ArcMap, Wood intersected the DEM with the model grid and calculated an average surface elevation for each 200 ft by 200 ft grid cell.

Layer 2 is variably confined and represents the lower portion of the alluvium and is unconfined where Layer 1 is dry and confined where Layer 1 is saturated. Layer 2 consists of a mixture of clays, sands, and gravels, and is generally more permeable than the upper alluvial material. The contact between Layer 1 and Layer 2 was based on boring logs from Site wells. Layer 2 is the primary groundwater bearing alluvial unit of interest at the Site.

Layer 3 represents the Moqui member of the Moenkopi Formation. It is modeled as a confined layer due to the presence of overlying Layers 1 and 2. As documented in the Main Report, the Moqui consists of gypsiferous mudstone and siltstone beds that are expected to have a low vertical permeability but have the potential to have higher lateral secondary permeability through bedding plans, fractures, and joint structures. Initially the groundwater model was conceptualized as representing only the alluvial aquifer. During model development, review of piezometer data near the FAP and the BAP suggested that the Moqui member of the Moenkopi Formation was not as impermeable as previously thought, especially in the vicinity of ponded surface water. Layer 3 was added to represent this relatively transmissive member in the model. The top of Layer 3 was derived using geologic contact elevation contours prepared by AMEC, 2012 and Montgomery & Associates, 2017. Wood used ArcMap to generate a surface raster from the geologic contact elevation contours, calculate an average contact elevation per grid cell, and assign that elevation to the model grid cell. The bottom of Layer 3 was set at 20 ft below the top of Layer 3 to provide sufficient grid cell thickness for the numerical solver.

2.2.3 Boundary Conditions

No-flow boundary cells are inactive cells in the model (i.e., the numerical solver does not solve for head in these cells) and are generally used to define the model domain. In general, no-flow cells correspond to areas in the model domain where the alluvial thickness is zero ft, as mapped by AMEC, 2012 and Montgomery & Associates, 2017.

Constant head boundary cells were used to represent the FAP, the BAP, the inflow from upper Tanner Wash north of the BAP, and inflow from the Little Colorado River alluvial channel. **Table 1** summarizes constant head values in the model.

Table 1. Constant Head Boundaries

Boundary	Constant Head (ft amsl)	Date of Measurement	Justification
Bottom Ash Pond (in Layer 1)	5,110.1	10/23/2018	Representative 2018 water level – closest in time to the measured water levels in the wells
Fly Ash Pond (in Layer 1)	5,088.8	10/23/2018	Representative 2018 water level – closest in time to the measured water levels in the wells
Upper Tanner Wash inflow (in Layers 2 and 3)	5,030.0	N/A	Adjusted during calibration
Inflow from Little Colorado River (LCR) alluvium at eastern boundary (in Layers 1, 2, and 3)	varies	2018	Based on potentiometric surface contour maps produced in 2018

Notes: ft amsl = feet above mean sea level

General head boundary (GHB) cells were used to define the downgradient boundary of the model, west of the power plant. One of the uncertainties in the conceptual model was the amount of underflow exiting the western border of the Site. The measured groundwater elevation in M-64A on October 22, 2018, i.e., 4,966.15 ft above mean sea level (amsl), was assigned to the GHB cells to allow groundwater to flow out of the model domain based on the calculated head difference between the model and the reference point of M-64A. The hydraulic conductivity of the GHB cells was adjusted during model calibration until modeled heads satisfactorily simulated observed heads in nearby monitoring wells.

Drain cells were used to represent seep intercept systems located near the FAP and the BAP. At the FAP, the Hunt A, Hunt B, and Geronimo seep intercept systems are represented. At the BAP, the West Abutment, Petroglyph, P-226, and Tanner Wash seep intercept systems are represented. **Table 2** summarizes drain cell values in the model.

Table 2. Drain Cell Parameters

Seep Intercept System Name	Drain Elevation (ft amsl)	Distance of Drain Elevation Below Top of Layer (ft)	Justification
Geronimo (in Layer 1)	5,037.5	36.43	Adjusted during calibration
Hunt A (in Layer 1)	5,002.0	36.92	Adjusted during calibration
Hunt B (in Layer 1)	5,000.3	38.74	Adjusted during calibration
West Abutment (in Layer 2)	5,042.0	26.60	Adjusted during calibration
Tanner Wash (in Layer 1)	4,983.0	66.33	Adjusted during calibration
Petroglyph (in Layer 2)	5,029.5	41.29	Adjusted during calibration
P-226 (in Layer 2)	5,027.9	34.84	Adjusted during calibration

Notes: ft amsl = feet above mean sea level

3.0 MODEL PARAMETERS

Model parameters used to describe the geology are hydraulic conductivity, specific yield (unconfined layers), porosity, and specific storage (confined layers). Parameter values used in this model were derived from the following sources:

- Soils lab testing of soil from the MW-67A boring (**Attachment B**)
- Literature values (Freeze and Cherry, 1979; Zheng and Bennet, 2002)
- Previous hydrogeologic investigations at the Site (Montgomery & Associates, 2017; AMEC, 2012; Sergent, Hauskins, & Beckwith [SHB], 1973)

Recharge, a common parameter in groundwater models, was not included in the Cholla groundwater model because the plant location is an arid, high-elevation plateau, and what little precipitation occurs is not expected to have a notable recharge effect on the groundwater. However, evapotranspiration was applied to the cells underlying the FAP and the BAP to improve the model calibration and, in the case of the transient fate and transport model, facilitate pond drainage during the modeled plant closure period.

3.1 Hydraulic Conductivity

Hydraulic conductivity is a measure of how freely groundwater can move through a geologic formation. The general distribution of hydraulic conductivity zones within the model was tied to geologic formations, and hydraulic conductivity values were adjusted during the calibration of the steady state model. The ratio of horizontal to vertical hydraulic conductivity was initialized at 10:1 but allowed to vary during calibration (see Section 4) if doing so resulted in a better match to observed heads and seep flux. **Table 3** summarizes the calibrated hydraulic conductivity values for each zone in the model and provides a comparison to literature or measured values.

Table 3. Range of Hydraulic Conductivity for Geologic Formations at the Site

Model Zone	Horizontal Hydraulic Conductivity (ft/day)	Vertical Hydraulic Conductivity (ft/day)	Vertical Anisotropy Ratio (Kv:Kh)	Geologic Unit Represented by this Zone	Comparable Site and/or Literature Value (ft/day) and Source
1	123.83	30.69	0.25	Alluvial material, primarily Layer 2, some Layer 1	0.032 to 7.2 (APS, 1984) 2.8e-3 to 28 (Freeze and Cherry, 1979)
2	0.19	0.99	5.21	Alluvial material near the FAP, Layer 1	0.032 to 7.2 (APS, 1984) 2.8e-3 to 28 (Freeze and Cherry, 1979)
3	0.047	0.27	5.74	Material underlying the FAP, Layers 1 and 3	Calibration parameter
4	8e-4	1e-4	0.13	Clay core earthen dam at FAP, Layers 1, 2, and 3	10e-4 (Woodward-Clyde, 1992)
5	8.01	0.66	0.08	Alluvial material, Layer 2	0.032 to 7.2 (APS, 1984) 2.8e-3 to 28 (Freeze and Cherry, 1979)
6	46.25	0.40	0.01	Alluvial material underlying the FAP, Layer 2 and limited Layer 3	0.032 to 7.2 (APS, 1984) 2.8e-3 to 28 (Freeze and Cherry, 1979)
7	245.74	0.017	7E-05	Alluvial material, Layer 2 and Layer 3 (paleo-channel near plant)	0.032 to 7.2 (APS, 1984) 2.8e-3 to 28 (Freeze and Cherry, 1979)
8	9e-6	8e-5	8.89	Clay core earthen dam at BAP, Layer 2	10e-4 (Woodward-Clyde, 1992)

Model Zone	Horizontal Hydraulic Conductivity (ft/day)	Vertical Hydraulic Conductivity (ft/day)	Vertical Anisotropy Ratio (Kv:Kh)	Geologic Unit Represented by this Zone	Comparable Site and/or Literature Value (ft/day) and Source
9	14.51	5.7e-3	4E-04	Moenkopi throughout the model domain including underlying the BAP, Layer 3	< 3e-4 to 4.5 (Woodward-Clyde, 1992) 3e-6 to 4e-3 (Domenico and Schwartz, 1990)
10	38.99	0.014	4E-04	Little Colorado River (LCR) alluvial material, Layer 1	0.032 to 7.2 (APS, 1984) 2.8e-3 to 28 (Freeze and Cherry, 1979)
11	4.7e-3	6.5e-3	1.38	Tanner Wash alluvial material, Layer 1	0.062 to 0.44 (Woodward-Clyde, 1992) 2.8e-3 to 28 (Freeze and Cherry, 1979)
12	1.98	1.29	0.65	Tanner Wash alluvial material, Layer 2	0.062 to 0.44 (Woodward-Clyde, 1992) 2.8e-3 to 28 (Freeze and Cherry, 1979)
13	54.66	0.12	2E-03	Material underlying the BAP, Layers 1 and 2	Calibration parameter
14	16.5	1.5	0.09	Tanner Wash Moenkopi, Layer 3	< 3e-4 to 4.5 (Woodward-Clyde, 1992) 3e-6 to 4e-3 (Domenico and Schwartz, 1990)

Notes: ft = feet; Kv = vertical hydraulic conductivity; Kh = horizontal hydraulic conductivity

In general, the hydraulic conductivities in the model were within the range of hydraulic conductivities measured at piezometers and boreholes at the Site, or if not, within the larger range of literature values for the given formation (clays, silts, and sands for the alluvium and siltstone for the Moenkopi Formation). Exceptions to this are the alluvial materials, which generally calibrated to a higher hydraulic conductivity than what was measured at the Site or presented in literature.

4.0 CALIBRATION

Model calibration is performed so that simulated hydraulic heads and fluxes satisfactorily approximate real-life observations. A model is considered calibrated when the difference between the observed and modeled heads and/or fluxes is sufficiently small. Calibration criteria for the model were decided with input from APS in advance of constructing the model and are as follows:

- Normalized root-mean-square-error (RMSE) < 10% (industry standard)
- $R^2 > 0.9$
- General direction of groundwater flow in the model matches observations
- General hydraulic gradient (change in head over distance) of groundwater in the model matches observations

The following subsections document the observation data (targets) and calibration statistics.

4.1 Head and Flux Targets

The data used for calibration are groundwater elevations measured at select Site monitoring wells and piezometers and flow rates measured at seepage intercept systems. The time period for head calibration data was between August 2018 and February 2019, as this represents one of the most complete recent datasets for groundwater elevations. For fluxes, the average flow rate in 2018 was used as the target flux. The model has head targets in all three layers based on well logs indicating the depth of the well and the formation in which it was completed. The drain target elevations were placed based on a combination of construction diagrams (if available) and calibration to the observed flow rate.

Table 4 summarizes the calibration targets and modeled residuals. **Figure 2** presents the locations of the calibration targets and the modeled groundwater elevation contours, and **Figure 3** is a graph of the observed versus modeled heads.

Table 4. Summary of Calibration Targets and Results

Well Name	Easting X (ft)	Northing Y (ft)	Layer	Date of Groundwater Measurement	Observed Head (ft amsl)	Computed Head (ft amsl)	Residual (ft)
W-305	662996.3	1437482	2	10/24/2018	5026.89	5032.00	-5.11
W-306	663002.9	1437479	2	10/24/2018	5028.93	5031.77	-2.84
W-307	664492.2	1437014	2	10/24/2018	5024.54	5025.78	-1.24
W-309	667339.2	1439182	2	10/24/2018	5029.18	5030.73	-1.55
W-308	665627.7	1438202	2	10/24/2018	5028.45	5030.56	-2.11
W-303	662488.4	1437178	1	8/7/2018	5021.76	5027.11	-5.35
W-304	662995.6	1436606	2	10/24/2018	5013.68	5014.98	-1.30
W-302	662863.3	1435304	1	10/24/2018	5003.8	4993.04	10.76
W-301	661640.4	1436230	2	10/24/2018	5002.87	4997.48	5.39
W-123	669917.0	1429138	2	8/6/2018	5037.02	5038.50	-1.48
W-126	669664.1	1428723	2	8/6/2018	5026.83	5017.06	9.77
CR-1	657397.9	1433689	1	8/7/2018	4979.51	4978.56	0.95
W-314	664796.7	1438508	2	8/7/2018	5039.44	5031.31	8.13
P-89	671429.6	1428488	3	8/24/2018	5057.66	5045.70	11.96
P-115	671188.6	1428639	3	8/24/2018	5031.82	5045.50	-13.68
P-113	670342.8	1428729	2	8/24/2018	5041.23	5042.05	-0.82
P-110	669907.5	1429674	2	8/24/2018	5087.21	5075.23	11.98
P-103	669028.6	1430008	3	8/24/2018	5017.6	5022.36	-4.76
P-102	668801.3	1430256	3	8/24/2018	5025.53	5027.05	-1.52
P-101	668536.0	1430581	3	8/24/2018	5049.53	5055.44	-5.91
P-100	668408.1	1431034	3	8/24/2018	5079.47	5073.80	5.67
DM-04R	662854.6	1429321	2	8/7/2018	4985.71	4988.04	-2.33
M-43A	666102.6	1430934	2	8/7/2018	4987.18	4990.05	-2.87
M-45A	665632.0	1432931	1	8/7/2018	4988.65	4991.90	-3.25
M-46A	667780.6	1429132	1	8/7/2018	4998.32	5003.18	-4.86
M-50A	669247.0	1429797	2	8/6/2018	5018.53	5024.47	-5.94
M-51A	668736.4	1430358	2	8/6/2018	5031.76	5032.05	-0.29
M-52A	663617.5	1437474	2	10/24/2018	5029.84	5030.04	-0.20
M-53A	662532.6	1437603	2	10/24/2018	5040.01	5040.81	-0.80
M-55A	667937.3	1438729	2	12/7/2018	5029.09	5030.49	-1.40
M-56A	658894.9	1434257	2	10/24/2018	4981.08	4980.68	0.40
M-57A	658761.9	1434200	2	10/24/2018	4981.01	4980.53	0.48

Well Name	Easting X (ft)	Northing Y (ft)	Layer	Date of Groundwater Measurement	Observed Head (ft amsl)	Computed Head (ft amsl)	Residual (ft)
M-58A	658666.7	1434151	2	10/24/2018	4980.96	4980.43	0.53
M-62A	659271.3	1434007	2	10/24/2018	4981.24	4981.31	-0.07
M-63A	665243.3	1427870	2	9/10/2018	4984.71	4990.72	-6.01
MW-65A	668253.2	1429524	2	2/14/2019	5013.21	5006.40	6.81
MW-66A	669177.2	1429131	2	2/14/2019	5004.47	5005.49	-1.02
MW-67A	668013.5	1428365	2	2/14/2019	4991.04	4998.95	-7.91

Notes: ft amsl = feet above mean sea level

In general, the lowest residuals (best match) were observed in wells near the plant area and the highest residuals (worst match) were observed in piezometers adjacent to or within the FAP dam. Near the plant, the change in head over distance (i.e., hydraulic gradient) is low and the geology is relatively homogeneous; therefore, the grid size was sufficient to allow the model to match observed heads with more precision. Near the FAP and the BAP, the hydraulic gradient is relatively steep, and the geology is more complex; therefore, the grid size may not be ideal to allow the model to match observed heads with more precision. Recommendations to further enhance calibration near the FAP and the BAP are provided in Section 8.

Table 5 summarizes the drain calibration targets and residuals. In general, the fluxes from the drain cells are a very good match to the observed fluxes. **Figure 4** is a graph of the observed versus modeled fluxes (drains).

Table 5. Flux Targets (Drain Cells)

Seepage Intercept System Name	Easting (ft) X	Northing (ft) Y	Layer	Observed Flux (gpm)	Computed Flux (gpm)	Residual (gpm)
Geronimo	669811.4	1429240	1	16.14	16.06	0.08
Hunt A	669539.6	1428985	2	3.12	3.01	0.11
Hunt B	669678.5	1428835	2	3.12	3.01	0.11
Tanner Wash	664718.9	1437800	1	5.01	4.56	0.45
Petroglyph	664155.3	1437617	2	7.93	7.75	0.18
West Abutment	662107.3	1437848	2	5.42	5.41	0.01
P-226	664471.6	1438348	2	9.74	9.73	0.01

Notes: ft = feet; gpm = gallons per minute

Steady state groundwater flow model calibration statistics are summarized in **Table 6**.

Table 6. Steady State Calibration Statistics

Statistic	Head Targets	Flux Targets
Residual Mean	-0.31	-34.98
Absolute Residual Mean	4.14	34.98
Residual Std. Deviation	5.57	33.96
Sum of Squares	1,181	16,638
RMS Error	5.58	48.75
Minimum Residual	-13.68	-86.11
Maximum Residual	11.98	-1.01

Statistic	Head Targets	Flux Targets
Number of Observations	38	7
Range in Observations	107.7	2508
Scaled Residual Standard Deviation	0.05	0.01
Scaled Absolute Residual Mean	0.04	0.01
Scaled RMS Error	5.18%	1.94%
Scaled Residual Mean	0.00	-0.01
R^2	0.96	1.00

The model has a normalized RMSE of 5.18% and 1.94% for the head and flux targets, respectively. The R^2 value for the head and flux targets is 0.96 (**Figure 3**) and 1.00 (**Figure 4**), respectively. The general direction of groundwater flow and the general hydraulic gradient in the model matches observations (**Figure 2**) with the exception of groundwater flow in upper Tanner Wash, as discussed in Section 4.2. The steady state flow model meets/surpasses the calibration criteria and as such is considered a suitable model for use as the basis of the transient transport simulations.

4.2 Modeled Water Budget

The modeled steady state groundwater budget (also called mass balance) is shown in **Table 7**:

Table 7. Steady State Groundwater Budget

Flux boundary	Inflow (cfd)	Outflow (cfd)
Storage	0	0
Constant Head	200,602	64,119
Little Colorado River alluvium	*79,538*	*0*
Tanner Wash alluvium	*0*	*64,119*
FAP	*96,764*	*0*
BAP	*24,300*	*0*
Wells	0	0
Drains	0	9,471
Evapotranspiration	0	55,397
GHBs	0	71,616
Total	200,602	200,603
Percent Discrepancy		0.00%

Notes: cfd = cubic feet per day

Water In:

The steady state groundwater budget indicates that water **enters** the model through the following cells:

- Constant head cells representing inflow from the Little Colorado (LCR) alluvium (79,538 cubic feet per day [cfd] / 0.92 cubic feet per second [cfs] / 413 gallons per minute [gpm])
- Constant head cells representing seepage from the FAP (96,764 cfd / 1.12 cfs / 503 gpm)
- Constant head cells representing seepage from the BAP (24,300 cfd / 0.28 cfs / 126 gpm)

Water Out:

Water **leaves** the model through the following cells:

- GHBs at the west edge of the model (71,616 cfd / 0.83 cfs / 372 gpm)

- Drain cells (9,471 cfd / 0.11 cfs / 49 gpm)
- Evapotranspiration (55,397 cfd / 0.64 cfs / 288 gpm)
- Constant head cells intended to represent inflow at the upper edge of Tanner Wash (64,119 cfd / 0.74 cfs / 333 gpm)

In general, the steady state groundwater budget appears to be a reasonable representation of the system. Water leaving the model at a boundary intended to simulate inflow (i.e., the Tanner Wash constant head cells) indicates that the model domain would benefit from being enlarged.

5.0 SENSITIVITY ANALYSIS AND PARTICLE TRACKING

As part of the calibration process, a sensitivity analysis was performed on hydraulic conductivity to assess which zones the model results were most sensitive to. To perform the analysis, horizontal hydraulic conductivity values in each zone were perturbed in increments of 0.1 from 0.5 to 1.5. The model was run and the sum of square residuals was recorded. This process was repeated for each increment and each zone individually. The results of the analysis are shown in graphical format in **Figure 5**. The lower the sum of square residuals, the better that version of the model fit to target values. The higher sum of square residuals, the worse that version of the model fit to target values. Ideally, the values centered around 1 will also be the lowest sum of square residuals. In instances where this is not the case, the modeler may choose to manually adjust that value to assess the change in calibration.

Based on the sensitivity analysis results shown in **Figure 5**, horizontal hydraulic conductivity (Kx = Ky) zones 5, 11, and 13 were adjusted during the calibration process. The other Kx = Ky zones were either already optimized at the current parameter value or changing the parameter resulted in a better overall model calibration but a worse calibration in key areas of the model (e.g. at the toes of dams or drain cells).

As a final exercise to understand the behavior of groundwater in the steady state model prior to converting to a transient model, a particle tracking exercise was conducted. Particles were added to cells adjacent to the constant head cells representing the FAP and the BAP with the intent of verifying that water is moving in the same direction in the model as it is observed to move at the Site. The particle tracking analysis showed that most of the particles exited the model through the GHB cells to the west, as is understood to occur in real life. A few particles exited to the model via the constant head boundary cells in upper Tanner Wash. This confirms what the mass balance shows as discussed in Section 4.2. For the purposes of understanding flow and transport at the FAP, this is likely not significant. ***At the BAP, the gradient reversal is worth noting in the interpretation of results.***

6.0 TRANSLATION TO TRANSIENT WITH CONTAMINANT TRANSPORT

The calibrated steady state model was modified to operate in transient mode to simulate the time-varying aspects of contaminant fate and transport. Developing the transient model involved assigning storage and transport parameters to the model, developing a pattern of stress periods, and performing limited calibration of modeled concentrations to observed concentrations. The stress periods for the transient model represent one-year or longer increments. Select boundary conditions and fluxes were allowed to vary based on stress period. The entire model grid was also re-discretized to 100 ft by 100 ft cells. This was done primarily to reduce the numerical error in the advection-dispersion equation software solver (MT3DMS with the GCG solver).

6.1 Storage and Transport Parameters

Specific storage, specific yield, and porosity are aquifer properties that, in the three-dimensional groundwater flow equation, are dependent on time and therefore not included in a steady-state calculation. These parameters were defined for the transient model. Porosity values were assigned based on a test conducted on a soil core from monitoring well MW-67A (Wood, 2019 and **Attachment B**) or based on literature values for the given geologic formation. **Table 8** summarizes the storage parameters in the transient model.

Table 8. Specific Storage, Specific Yield, and Porosity

Layer	Specific Storage (Ss)	Specific Yield (Sy)	Porosity (n)	Source
1	Not applicable	0.03	0.42	Sy from literature values (Zheng and Bennet, 2002) n from Wood soils lab results
2	0.005	0.03	0.42	Ss from literature values (Freeze and Cherry, 1979) Sy from literature values (Zheng and Bennet, 2002) n from Wood soils lab results
3	0.0005	Not applicable	0.21	Ss from literature values (Freeze and Cherry, 1979) n from literature value for siltstone (Zheng and Bennet, 2002)

Dispersivity is a contaminant transport parameter that allows for chemical dispersion between cells. It is not related to properties of the aquifer matrix or the contaminant; rather, it is adjusted during calibration within an upper and lower bound determined by model grid size. **Table 9** summarizes the dispersivity parameters in the transient model.

Table 9. Dispersivity

Layers	Longitudinal Dispersivity (ft)	Transverse Dispersivity (ft)	Transverse Vertical Dispersivity (ft)	Longitudinal Disperse Transmissivity (ft)
1 – 3	100	10	5	5

Notes: ft = feet

6.2 Initial Concentrations

Initial concentrations in the groundwater model were assigned as follows:

- **At the FAP:** Fluoride concentrations were identified as representative of contamination. Fluoride concentrations measured at the Site between October and December 2018 and shown in Figure 2-2 of the Main Report were processed in ArcGIS to create a raster that was then imported into all three layers of the groundwater model. The resulting distribution of concentration is shown in **Figure 6**.
- **At the BAP:** Cobalt concentrations were identified as representative of contamination. Cobalt concentrations measured at the Site in December 2018 and shown in Figure 2-4 of the Main Report were contoured and imported into all three layers of the groundwater model. The resulting distribution of concentration is shown in **Figure 7**.

6.3 Stress Periods

Stress periods are used to change a stress in the model (e.g. when pumping wells turn on or off, or when the water level in a specified head cell changes). The transient stress periods are presented in **Table 10**. The model uses an annual stress period pattern during the time when water levels in the FAP and BAP are declining. **Figure 8** presents an analysis conducted by AECOM to estimate evaporation rates in the FAP. This figure formed the basis of the water levels used for the FAP in the transient model. Water levels in the BAP are simulated to remain constant until 2025, at which time they decline at a rate of 4.5 ft per year (based on the rate in **Figure 8**). Both ponds are dewatered by the end of 2036.

Table 10. Transient Model Stress Periods

Stress Period (SP) Number	Length (days)	Time Steps	Representative Time Period	Alternative 1 (Natural Attenuation, FAP and BAP)	Alternatives 2 and 3 (FAP) and Alternative 2 (BAP)	Alternative 4 (FAP)
1	2,459	1	Steady state period representing conditions through Dec. 31, 2015	FAP WL = 5097 ft amsl BAP WL = 5110 ft amsl Drains (7) are operational	FAP WL = 5097 ft amsl BAP WL = 5110 ft amsl Drains (7) are operational	FAP WL = 5097 ft amsl BAP WL = 5110 ft amsl Drains (7) are operational
2	366	30	Jan. 1, 2016 to Dec. 31, 2016	No change from SP 1	No change from SP 1	No change from SP 1
3	365	30	Jan. 1, 2017 to Dec. 31, 2017	FAP WL = 5093.5 No change to BAP WL until SP 12	FAP WL = 5093.5 ft amsl No change to BAP WL until SP 12	FAP WL = 5093.5 ft amsl No change to BAP WL until SP 12
4	365	30	Jan. 1, 2018 to Dec. 31, 2018	FAP WL = 5090.5 ft amsl	FAP WL = 5090.5 ft amsl	FAP WL = 5090.5 ft amsl
5	365	30	Jan. 1, 2019 to Dec. 31, 2019	FAP WL = 5088 ft amsl	FAP WL = 5088 ft amsl	FAP WL = 5088 ft amsl
6	366	30	Jan. 1, 2020 to Dec. 31, 2020	FAP WL = 5086 ft amsl	FAP WL = 5086 ft amsl Extraction wells active	FAP WL = 5086 ft amsl Extraction wells active
7	365	30	Jan. 1, 2021 to Dec. 31, 2021	FAP WL = 5083.5 ft amsl	FAP WL = 5083.5 ft amsl	FAP WL = 5083.5 ft amsl
8	365	30	Jan. 1, 2022 to Dec. 31, 2022	FAP WL = 5082 ft amsl	FAP WL = 5082 ft amsl	FAP WL = 5082 ft amsl
9	365	30	Jan. 1, 2023 to Dec. 31, 2023	FAP WL = 5080.5 ft amsl	FAP WL = 5080.5 ft amsl	FAP WL = 5080.5 ft amsl
10	366	30	Jan. 1, 2024 to Dec. 31, 2024	FAP WL = 5079 ft amsl	FAP WL = 5079 ft amsl	FAP WL = 5079 ft amsl
11	365	30	Closure period - Jan. 1, 2025 to Dec. 31, 2025	FAP WL = 5077 ft amsl	FAP WL = 5077 ft amsl	FAP WL = 5077 ft amsl
12	2,922	60	8-yr closure period while FAP dewaters (evaporates) at a rate of 4.5 feet per year – Jan. 1, 2026 to Dec. 31, 2033	FAP WL = 5072.5 ft amsl BAP WL = 5105.5 ft amsl Drain cells remain active for the duration of the simulation	FAP WL = 5072.5 ft amsl BAP WL = 5105.5 ft amsl Drain cells remain active for the duration of the simulation	FAP WL = 5072.5 ft amsl BAP WL = 5105.5 ft amsl Drain cells remain active for the duration of the simulation
13	1,096	30	3-yr period during which the BAP continues to dewater (evaporate) – Jan. 1, 2034 to Dec. 31, 2036	FAP WL = 5035 ft amsl BAP WL = 5070 ft amsl	FAP WL = 5035 ft amsl BAP WL = 5070 ft amsl	FAP WL = 5035 ft amsl BAP WL = 5070 ft amsl
14	4,383	90	12-yr period during which both units are fully dewatered – Jan. 1, 2037 to Dec. 31, 2048	FAP GHB cells deactivated BAP GHB cells deactivated	FAP GHB cells deactivated BAP GHB cells deactivated	FAP GHB cells deactivated BAP GHB cells deactivated
15	36,889	300	100-yr attenuation period in MNA scenario during which both units are fully dewatered – Jan, 1, 2049 to Dec. 31, 2149	No change from SP 14	No change from SP 14 Note the model run time is shortened to end on Jan. 2, 2059	No change from SP 14 Note the model run time is shortened to end on Jan. 1, 2050

Notes: ft amsl = feet above mean sea level; GHB = general head boundary; SP = stress period; WL = water level; yr = year;

6.4 Concentration Calibration

The concentrations of fluoride and cobalt in the transient model were calibrated at select Site wells in order to initialize the model runs with values that were commensurate with Site observations. Dispersivity, porosity, and concentrations in the FAP and BAP were adjusted to achieve a reasonable match to Site data. **Figure 9** and **Figure 10** present graphs showing modeled versus observed concentrations at the FAP and BAP, respectively.

The concentration calibration was guided by a set of qualitative measures:

- Water quality observations from 1984 to 2015 indicate that fluoride concentrations in groundwater wells downgradient of the FAP were generally on the order of 2 to 3 mg/L and did not exceed 3.2 mg/L (the alert level for fluoride in the Cholla Aquifer Protection Permit [ADEQ, 2017]). The fluoride concentration measured in the FAP during that same time period was approximately 15 mg/L. This is evidence to suggest that dilution, attenuation, or immobilization of fluoride occurs as it moves from the FAP into the downgradient alluvial aquifer. In order to simulate this phenomenon in the groundwater model, the specified concentration in the constant head cells representing the FAP was adjusted during calibration until modeled concentrations at select wells approximated observed concentrations (**Figure 9**).
- Concentrations of fluoride in the groundwater downgradient of the FAP were observed to increase within a year of October 2015, which was when Unit 2 at the plant was removed from operation and the fluoride concentration in the water discharged to the FAP subsequently increased. Since then, concentrations have remained relatively stable at levels higher than pre-2015 but lower than observed concentrations in the FAP itself. Based on these data, fluoride concentrations are not anticipated to increase much beyond what is currently observed and were modeled as such.
- The period of record for collected CCR constituent data at the BAP is shorter than for the FAP. The same action of mixing or immobilization in the downgradient aquifer was therefore assumed for the BAP, and the specified concentration of cobalt in the constant head cells representing the BAP was adjusted during calibration until modeled concentrations at select wells approximated observed concentrations (**Figure 10**).

The following observations pertain to the concentration calibration:

- Simulated concentrations match observed concentrations within an order of magnitude and in many cases within 10% of the observation.
- The model appears to show more leakage on the east side of the FAP dam. This may explain why modeled concentrations in M-51A take longer to increase from pre-2015 to post-2015 levels than the rate of increase seen in the observed concentrations.
- The model shows detectable levels of fluoride at M-43A at times when the observed values are non-detectable, suggesting the lateral spread of fluoride in the model may be slightly overestimated.
- Preferential pathways between the BAP and Site monitoring wells may exist at the Site, whereas in the transport model contamination appears to be more uniformly distributed in the aquifer (see **Figure 10** showing simulated concentrations lower than observed concentrations at W-301, a monitoring well a couple thousand feet downgradient of the BAP, compared to simulated concentrations at M-53A, which is adjacent to the BAP).

- The flow model was well-calibrated, lending confidence to the simulated hydraulic conductivity and groundwater flow velocities. These two factors influence the contaminant transport results. Because the hydraulic conductivity is low and groundwater velocity is low, the result showing contamination lingering in the aquifer is not unexpected.
- Long-term concentrations of fluoride and cobalt in the model do not exceed anticipated levels based on the 30-year observation period from 1984 to 2015, and the layer thicknesses are based on Site-specific data (which suggests the overall volume of water in the model is realistic), suggesting that the appropriate amount of contaminant mass is simulated in the aquifer.

These factors support the use of the transient model for corrective measures evaluations.

7.0 CORRECTIVE MEASURES EVALUATION

This section summarizes the model runs used to evaluate potential groundwater corrective actions and their resultant effect on the groundwater resource. The general approach to evaluating the efficacy of the corrective action alternatives is to evaluate the differences between the active management alternatives and a natural attenuation alternative, which can be thought of as a "limited response action" look into the future. Potential corrective action goals for the Site include:

- Water removal at a rate that can be reasonably evaporated in an evaporation pond (generally less than 400 gpm); and
- Remediation of the aquifer to levels below the applicable Groundwater Protection Standards (GWPSs) within 30 years.

Alternatives addressing these goals were developed and compared to results from a natural attenuation alternative for both the FAP and the BAP. In the following section, the structure, details, and results of the FAP and BAP natural attenuation alternatives as well as several hypothetical active management alternatives are presented.

7.1 Alterative 1 – Natural Attenuation

FAP Alternative 1 and BAP Alternative 1 correspond to a transient model run representing the attenuation of fluoride and cobalt in the aquifer downgradient of the FAP and BAP, respectively. The model run is used to estimate when the concentrations will attenuate to less than the GWPSs under these future conditions:

- The seven seep intercept systems continue operating as they are currently operated;
- The surface elevation of the FAP declines as shown in **Figure 6** and goes dry in 2036;
- The surface elevation of the BAP remains at current levels until 2025, at which point it declines linearly until going dry in 2036, and;
- Evaporation cells continue to be active in the cells underlying the FAP and the BAP in order to remove excess water from the model.

In Alternative 1 the model was run for 135 years (from 2015 to 2150). **Figure 11** and **Figure 12** present the results of natural attenuation and the active management alternatives for the FAP and BAP, respectively. These figures show the maximum concentration anywhere in the downgradient aquifer at a given time in the model run. When the maximum concentration is less than the respective GWPS, the aquifer is considered remediated for the purposes of this analysis.

The model results for FAP Alternative 1 indicate that concentrations of fluoride in the aquifer will attenuate below the GWPS by early 2080, or 61 years from the present (**Figure 11**). This assumes the FAP goes dry in 2036, effectively removing the source of fluoride.

The model results for BAP Alternative 1 indicate that concentrations of cobalt above the GWPS will persist in the aquifer through the end of 2150. After the BAP goes dry in 2036, concentrations slowly attenuate and move with the direction of groundwater flow, which in the model is north towards the constant head cells representing Tanner Wash (see discussion in Sections 4.2 and 5.0) and south towards the plant. At the end of the model simulation, the concentrations of cobalt above the GWPS are located at the GHB cells representing underflow leaving the model domain, and close to where the Tanner Wash channel opens up into the LCR alluvium, where the alluvial material pinches out.

7.2 Alternative 2 – Containment Wells Adjacent to Dams

FAP and BAP Alternative 2 consists of:

- Operation of the existing seepage intercept systems;
- Draining/evaporating standing water from the FAP and BAP, and;
- The installation and operation of containment wells sited adjacent to the FAP and BAP dams.

One model run was developed for FAP Alternative 2 and a separate model run was developed for BAP Alternative 2. The locations of the containment wells for the FAP and BAP were developed iteratively and are shown in **Figure 13** and **Figure 14**, respectively. **Table 11** contains the cell locations and pumping rates for the wells for the FAP and BAP scenarios.

Table 11. FAP and BAP Alternative 2 Containment Well Locations

FAP Alternative 2 ***Number of wells: 14*** ***Total pumping rate: 335 gpm***				**BAP Alternative 2** ***Number of wells: 15*** ***Total pumping rate: 375 gpm***			
Layer	**Row**	**Column**	**Pumping Rate (gpm)**	**Layer**	**Row**	**Column**	**Pumping Rate (gpm)**
2-3	64	155	25	2-3	27	41	25
2-3	64	158	25	2-3	31	41	25
2-3	65	142	25	2-3	34	42	25
2-3	65	145	25	2-3	37	43	25
2-3	65	147	25	2-3	39	44	25
2-3	65	150	25	2-3	42	46	25
2-3	65	152	25	2-3	43	47	25
2-3	66	127	25	2-3	46	48	25
2-3	66	131	25	2-3	49	48	25
2-3	66	134	25	2-3	52	47	25
2-3	66	138	25	2-3	53	45	25
3	64	161	10	2-3	55	42	25
3	65	122	25	2-3	57	41	25
3	66	125	25	2-3	59	39	25
-	-	-	-	2-3	60	36	25

Notes: gpm = gallons per minute

The target location for the wells was identified as the area north of I-40 and south of the dam for the FAP. For the BAP, the target location for the wells was as close to the toe of the dam as possible. One difficulty in placing and operating the wells in the model was the low transmissivities in the vicinity of the FAP which leads to dewatering issues. Transmissivities are higher around the BAP; however, modeled wells in both areas still tended to dewater and turn off when pumping rates exceeded their dewatering threshold rates.

The model results for FAP Alternative 2 (**Figure 11**) indicate that concentrations of fluoride in the aquifer will attenuate below the GWPS by 2045, or 25 years from the start of pumping. This assumes the FAP goes dry in 2036, effectively removing the source of fluoride.

The model results for BAP Alternative 2 (**Figure 12**) indicate that concentrations of cobalt in the aquifer will attenuate below the GWPS by mid-2126, approximately 100 years from the start of pumping. A possible explanation for the excessive timeframe is the greater thickness of the Tanner Wash alluvium compared to the alluvium downgradient of the FAP. **Figure 15** highlights this difference, as shown at model row 67, which is the area where Tanner Wash opens up into the larger LCR alluvial plain and where I-40 crosses south of the FAP. The model cells in the area of Tanner Wash are at least twice as thick as the cells in the area of the FAP. This translates to a larger volume of available groundwater, a higher mass of chemicals in the aquifer, and more pumping required to contain the plume when compared to conditions at the FAP.

7.3 Alternative 3 – Containment Wells at the FAP South of I-40

FAP Alternative 3 consists of:

- Operation of the existing seepage intercept systems;
- Draining/evaporating standing water from the FAP, and;
- The installation and operation of containment wells sited downgradient of the FAP dams south of I-40.

The locations of the containment wells for Alternative 3 at the FAP were developed iteratively and are shown in **Figure 16**. **Table 12** contains the cell locations and pumping rates for the Alternative 3 wells.

The model results for FAP Alternative 3 (**Figure 11**) indicate that concentrations of fluoride in the aquifer will attenuate below the GWPS by early 2055, or 35 years from the start of pumping. This assumes the FAP goes dry in 2036, effectively removing the source of fluoride to the aquifer. Alternative 3 required one more well, and a higher pumping rate, in order to contain the plume. This suggests that siting containment wells further downgradient of the FAP is not advantageous as it results in a longer time to remediate below the GWPS.

Table 12. FAP Alternative 3 Containment Well Locations

FAP Alternative 3 Containment Well Locations *Number of Wells: 15* *Total Pumping Rate: 375 gpm*			
Layer	**Row**	**Column**	**Pumping Rate (gpm)**
2-3	68	121	25
2-3	70	123	25
2-3	71	125	25
2-3	71	128	25
2-3	71	133	25
2-3	71	136	25
2-3	71	140	25
2-3	71	144	25
2-3	71	147	25
2-3	71	151	25
2-3	71	155	25
2-3	71	159	25
2-3	71	162	25
3	66	114	25
3	67	117	25

Notes: gpm = gallons per minute

A model run simulating containment wells downgradient of the BAP dam, further south within Tanner Wash, was also developed under Alternative 3. However, after several iterations of well placement and pumping rates failed to produce the desired results within a reasonable amount of time and with feasible pumping rates, modeling this approach to corrective action at the BAP was abandoned.

7.4 Alternative 4 – Containment Wells at the FAP North and South of I-40

FAP Alternative 4 consists of:

- Operation of the existing seepage intercept systems;
- Draining/evaporating standing water from the FAP, and;
- The installation and operation of the containment wells sited adjacent to the FAP dam (from Alternative 2) and the wells downgradient of the FAP dams south of I-40 (from Alternative 3).

The objective of Alternative 4 was to evaluate whether substantial gains in time to remediate could be made by installing and operating containment wells on both sides of I-40. A similar model simulating containment wells adjacent to the BAP as well as further south within Tanner Wash was also developed but abandoned after it became apparent that the number of wells and pumping rates in the model were untenable.

One model run was developed for the FAP Alternative 4. The locations of the containment wells for Alternative 4 at the FAP are shown in **Figure 17**. **Table 13** contains the cell locations and pumping rates for the Alternative 4 wells.

Table 13. FAP Alternative 4 Containment Well Locations

FAP Alternative 4 Containment Well Locations *Number of Wells: 29* *Total Pumping Rate: 710 gpm*							
Layer	**Row**	**Column**	**Pumping Rate (gpm)**	**Layer**	**Row**	**Column**	**Pumping Rate (gpm)**
2-3	64	155	25	2-3	71	133	25
2-3	64	158	25	2-3	71	136	25
2-3	65	142	25	2-3	71	140	25
2-3	65	145	25	2-3	71	144	25
2-3	65	147	25	2-3	71	147	25
2-3	65	150	25	2-3	71	151	25
2-3	65	152	25	2-3	71	155	25
2-3	66	127	25	2-3	71	159	25
2-3	66	131	25	2-3	71	162	25
2-3	66	134	25	3	66	114	25
2-3	66	138	25	3	66	125	25
2-3	68	121	25	3	64	161	10
2-3	70	123	25	3	65	122	25
2-3	71	125	25	3	67	117	25
2-3	71	128	25	-	-	-	-

Notes: gpm = gallons per minute

The model results for FAP Alternative 4 (**Figure 11**) indicate that concentrations of fluoride in the aquifer will attenuate below the GWPS by mid-2041, or 21 years from the start of pumping. This assumes the FAP goes dry in 2036, effectively removing the source of fluoride to the aquifer. This alternative provides the relatively fastest time to remediate the aquifer of the four alternatives considered for the FAP, but at the expense of many more wells and a pumping rate that may not be feasible.

8.0 MODEL LIMITATIONS AND RECOMMENDATIONS FOR FUTURE IMPROVEMENT

The objective of the groundwater model was to provide a planning tool for better understanding the fate and transport of contamination in the aquifer at the FAP and BAP CCR units at the Cholla Power Plant specifically as it relates to future attenuation or remediation of constituents at the FAP and the BAP. The LCR alluvium, Tanner Wash alluvium, and the uppermost portion of the Moqui member of the Moenkopi Formation in the vicinity of the BAP and FAP is the area of interest and focus of the groundwater model, which is a simplification of the aquifer system at Cholla. Given the scale and complexity of the geology at the Site, there are uncertainties in the modeled hydrogeologic properties as well as assumptions related to operations of the BAP and FAP. The model in its present state is appropriate for estimating order-of-magnitude pumping rates and transport/remediation times. Several areas of refinement have been identified that could reduce model uncertainty for future use:

- **Grid cell discretization** – Discretizing the grid in the vicinity of the FAP and BAP dams would potentially allow the model to represent head changes at a smaller scale than it currently is able to, thus improving the calibration in these key areas.
- **Geologic heterogeneity** – The contact surfaces between the alluvium and the Moenkopi Formation were derived from previous investigations and applied to the model using spatial interpolation tools. Refinement to this contact surface using contact elevations from boring logs in key areas,

such as at piezometers in and around both the BAP and FAP dams, could improve the calibration in these locations.

- **Thickness of Layer 3** –Because the contact elevation between the Moqui and the underlying Wupatki has not been defined for the Site, a constant thickness (20 ft) for Layer 3 was applied and the hydraulic conductivity was calibrated to produce an acceptable match to observed heads in the steady state flow model. While this simplification has no impact on the groundwater flow, it has the potential to overestimate the amount of chemical mass in the aquifer because the model effectively treats Layer 3 as another alluvial layer. The relative thinness of Layer 3 is intended to mitigate this effect, but the model is likely conservative in its estimate of mass in the aquifer.
- **Draining of the BAP** – The BAP in the model is assumed to remain at its current elevation until 2025, after which it drains at a rate of 4.5 ft per year, based on a rate previously estimated for the FAP (**Figure 6**). The material in the BAP is coarser than the material in the FAP, and as such it would intuitively be expected to drain faster. It is recommended that a quantitative estimate of the evaporation/drainage rate at the BAP be developed, as this could result in the source of cobalt at the BAP deactivating in the model sooner than it does in the current simulation.
- **Upper Tanner Wash boundary** – The constant head cells representing Upper Tanner Wash allow water to exit the model rather than simulate natural recharge via underflow, as was intended. This suggests that the model domain would benefit from being enlarged to the point where the boundary condition is not interfering with Site features. This is not significant for simulations at the FAP but may have an impact on simulations at the BAP.

9.0 REFERENCES

Arizona Department of Environmental Quality (ADEQ), 2017. Aquifer Protection Permit No. P-100568, Place ID 447, LTF 65132. Arizona Public Service Cholla Power Plant. March 2, 2017.

Arizona Public Service (APS), 1984. Cholla Steam Electric Generating Station Aquifer Test Results. February 26 to March 2, 1984.

AMEC Environment & Infrastructure, Inc. (AMEC), 2012. *Well Completion Report, Installation of Aquifer Protection Permit Monitor Wells, Arizona Public Service Company, Cholla Power Plant, Navajo County, Arizona.* May 7, 2012.

Domenico, P.A. and F.W. Schwartz, 1990. Physical and Chemical Hydrogeology. John Wiley & Sons, New York.

Environmental Simulations, Inc. 2017. Guide to Using Groundwater Vistas, Version 7.

Environmental Systems Research Institute (ESRI), 2014. ArcGIS 10.3.1 for Desktop. Redlands, California.

Freeze, R. Allen and Cherry, John A. Groundwater. Prentice-Hall Inc. Englewood Cliffs, New Jersey. 1979.

Harbaugh, A.W., Langevin, C.D., Hughes, J.D., Niswonger, R.N., and Konikow, L. F., 2017, MODFLOW-2005 version 1.12.00, the U.S. Geological Survey modular groundwater model: U.S. Geological Survey Software Release, 03 February 2017, http://dx.doi.org/10.5066/F7RF5S7G.

Montgomery & Associates, 2017. *Cholla Power Plant Combustion Residuals Program – Design, Installation, and Evaluation of Completeness of Groundwater Monitoring Networks. Arizona Public Service, Navajo County, Arizona.* September 19, 2017.

Sergent, Hauskins, & Beckwith (SHB), 1973. Preliminary Soil and Geological Study Report on Ash Disposal Areas, APS Cholla Plant, near Joseph City, Arizona. December 14, 1973.

United States Geological Survey (USGS), 2013. USGS NED n35w111 1/3 arc-second 2013 1x1 degree ArcGrid raster digital data. Reston, VA. http://ned.usgs.gov.

Wood Environment & Infrastructure Solutions (Wood), 2019. Lithologic Logs for Boreholes MW-65, MW-66, and MW-67.

Woodward-Clyde Consultants (Woodward-Clyde), 1992. Evaluation of Hydrogeologic Conditions. Bottom Ash Pond, Cholla Steam Electric Station. May 22, 1992.

Zheng, Chunmiao and Bennet, Gordon. Applied Contaminant Transport Modeling, Second Edition. John Wiley and Sons, Inc. New York. 2002.

Zheng, Chunmiao, and Wang, P. Patrick. 1999. MT3DMS: A modular three-dimensional multispecies transport model for simulation of advection, dispersion, and chemical reactions of contaminants in groundwater systems; documentation and user's guide," Contract Report SERDP-99-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

FIGURES

Legend

- Grid (200 ft x 200 ft)
- CH in Layer 1
- Drain in Layer 1
- CH in Layer 2
- Drain in Layer 2
- CH in Layer 3
- GHB in Layers 1-3
- No-flow (all layers)
- Inferred Groundwater Flow Direction

Notes:
CH --- constant head
ft --- feet
GHB --- general head boundary

0 0.25 0.5 Miles

N

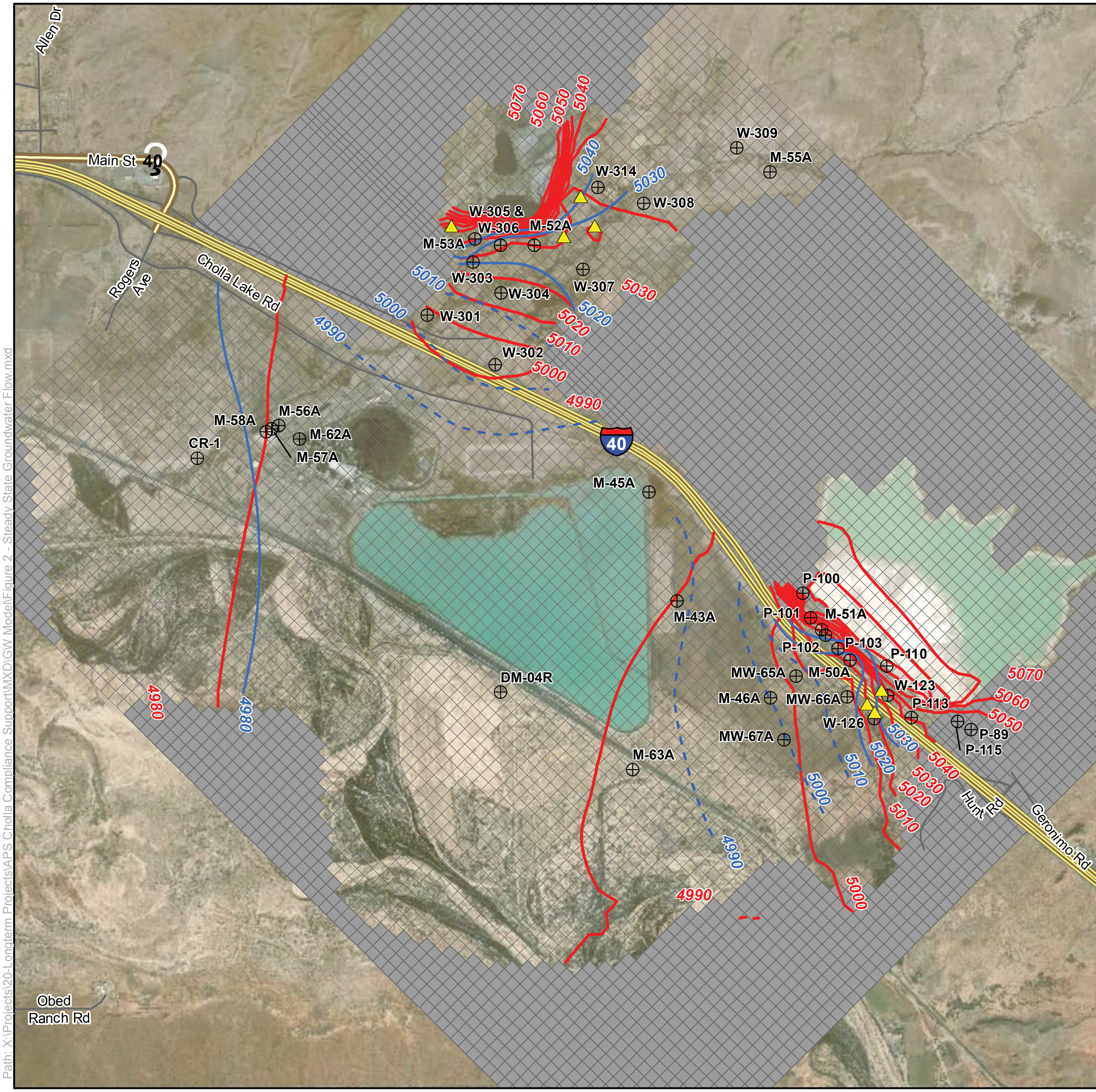
Groundwater Model Documentation
APS Cholla Power Plant, Navajo County, AZ

FIGURE 1

Model Domain, Grid, and Boundaries

Job No. 14-2018-2040
PM: NCL
Date: 6/4/2019
Scale: 1" = 0.5 miles

wood.



Legend

- Grid (200 ft x 200 ft)
- Noflow (all layers)
- Flux targets
- Head targets
- Modeled groundwater elevation contours (ft amsl)

Observed groundwater elevation contours (ft amsl)

- Inferred
- Known

0 0.25 0.5 Miles

N

Groundwater Model Documentation
APS Cholla Power Plant, Navajo County, AZ

FIGURE 2	Steady State Groundwater Flow

Job No.	14-2018-2040
PM:	NCL
Date:	6/1/2019
Scale:	1" = 0.5 miles

wood.

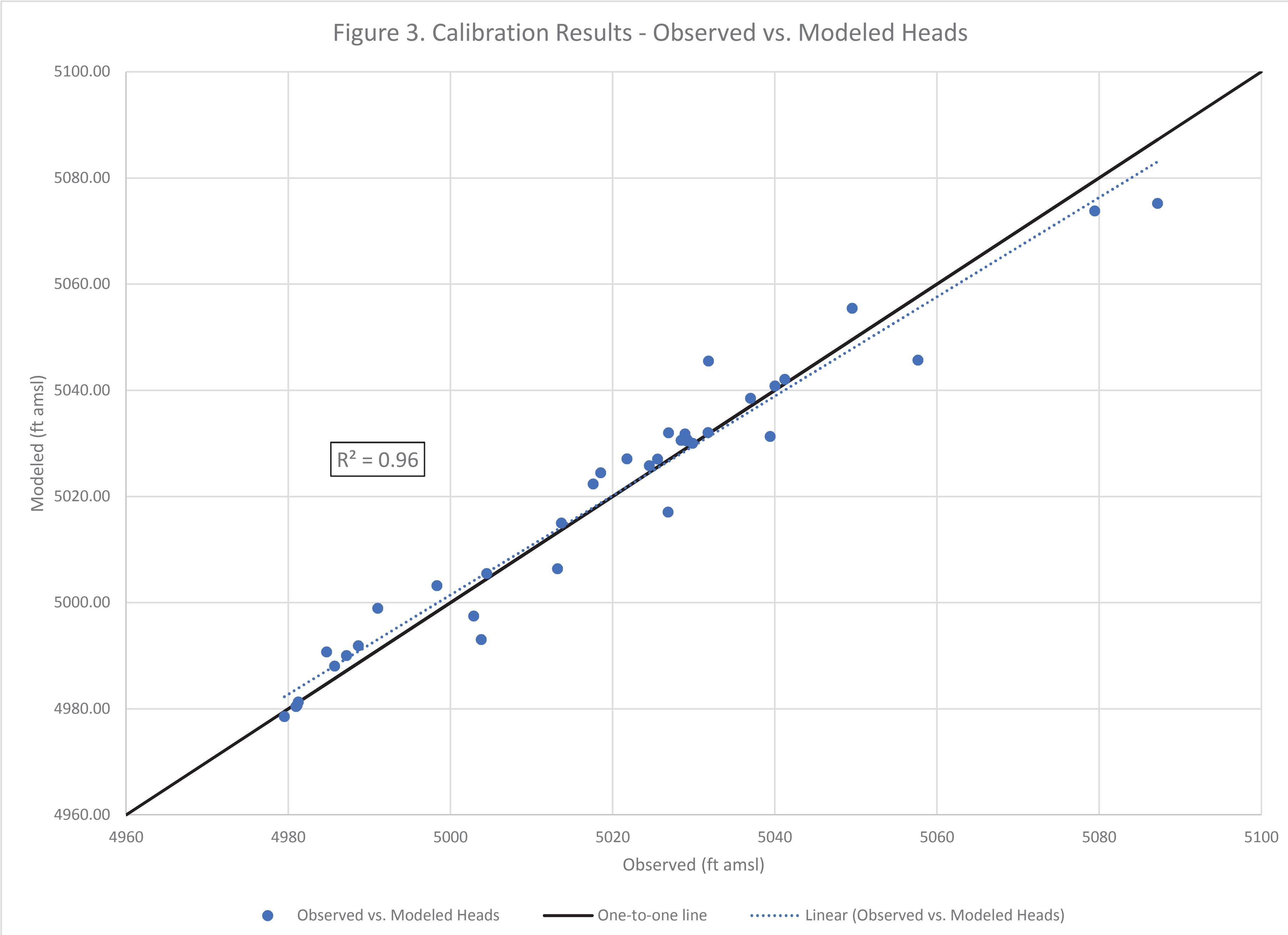


Figure 3. Calibration Results - Observed vs. Modeled Heads
5100.00
5080.00
5060.00
5040.00
5020.00
5000.00
4980.00
4960.00
Modeled (ft amsl)
R² = 0.96
4960
4980
5000
5020
5040
5060
5080
5100
Observed (ft amsl)
Observed vs. Modeled Heads
One-to-one line
Linear (Observed vs. Modeled Heads)

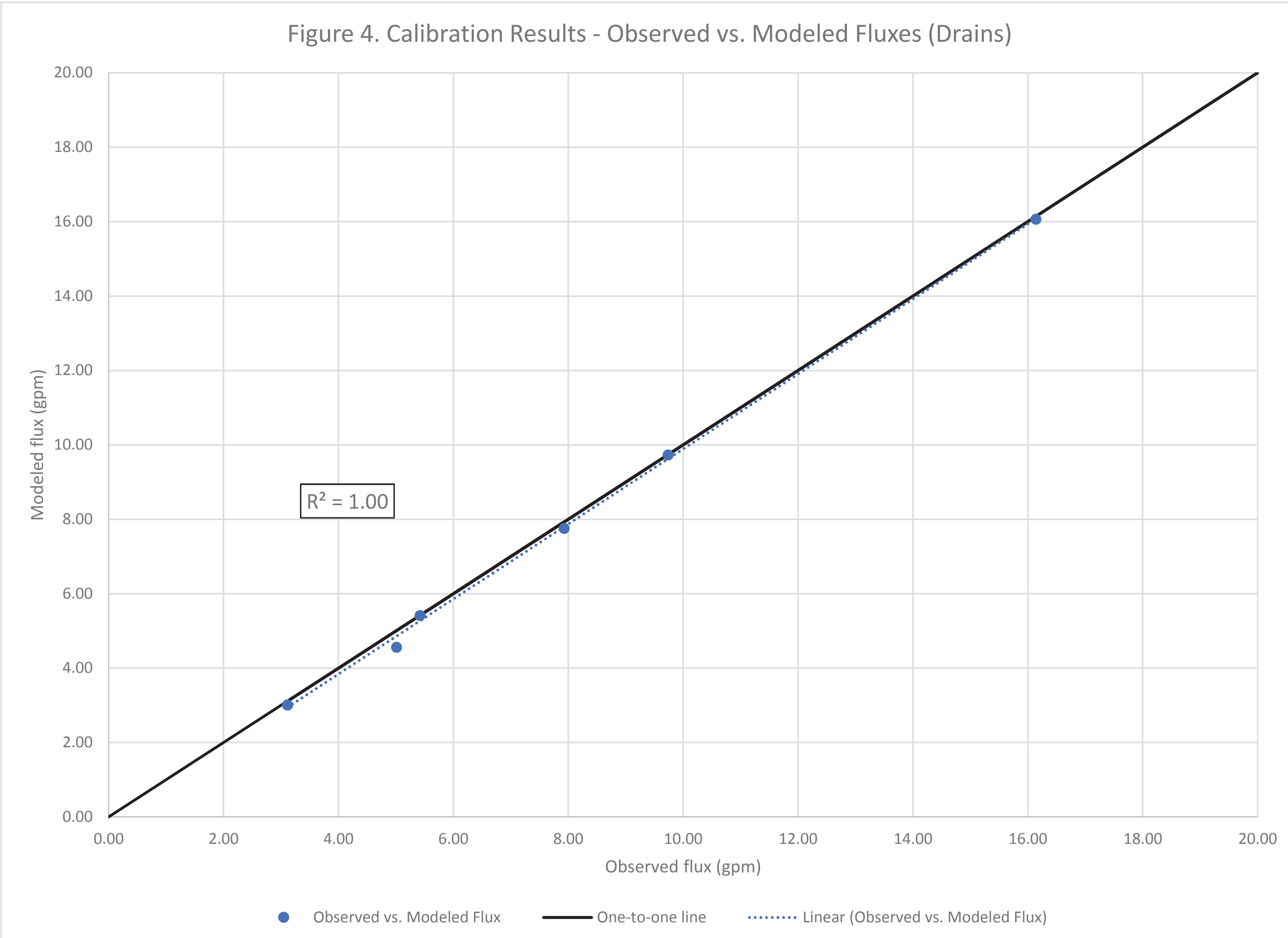


Figure 4. Calibration Results - Observed vs. Modeled Fluxes (Drains)
Modeled flux (gpm)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
R^2 = 1.00
Observed flux (gpm)
Observed vs. Modeled Flux
One-to-one line
Linear (Observed vs. Modeled Flux)

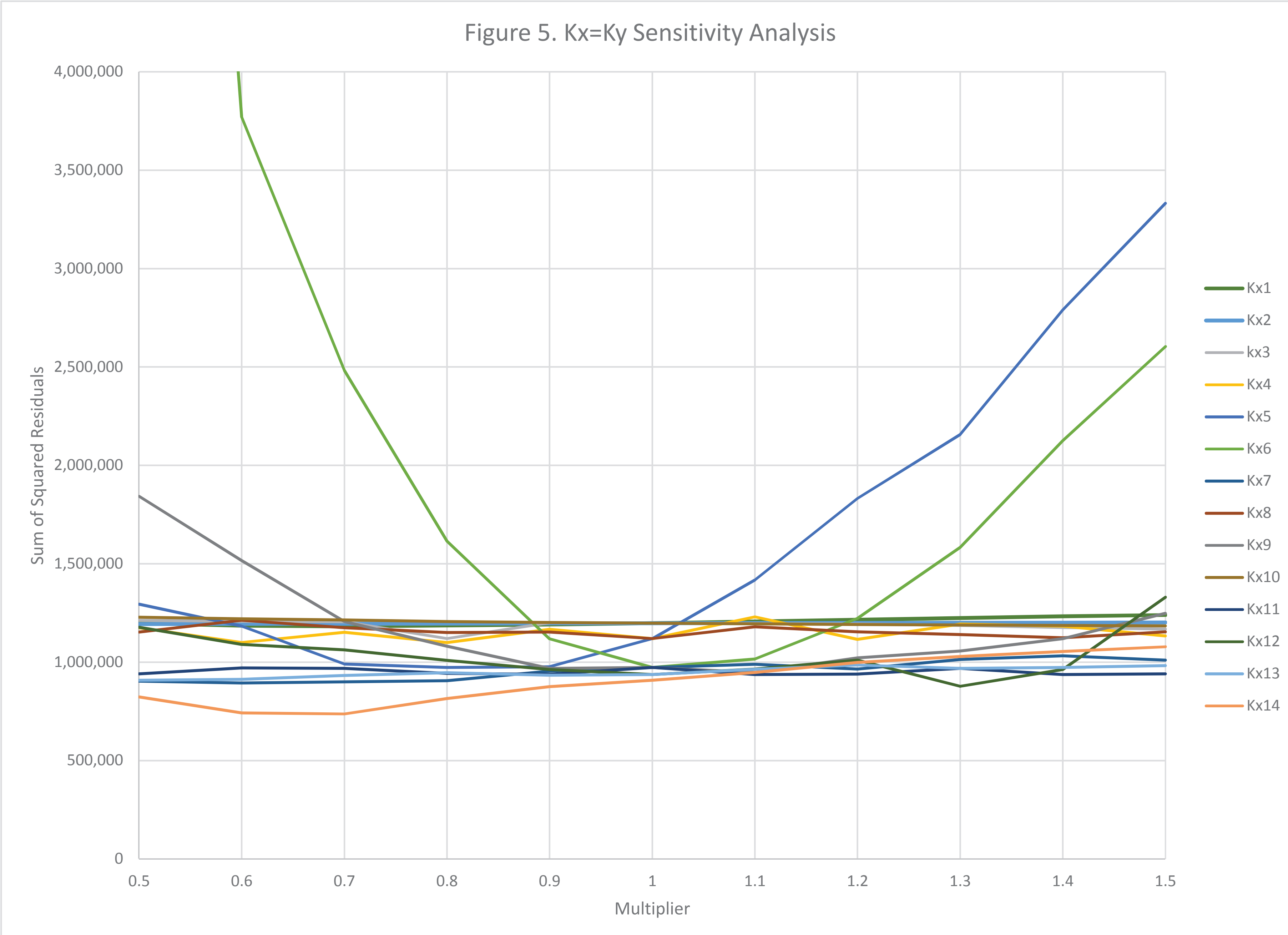
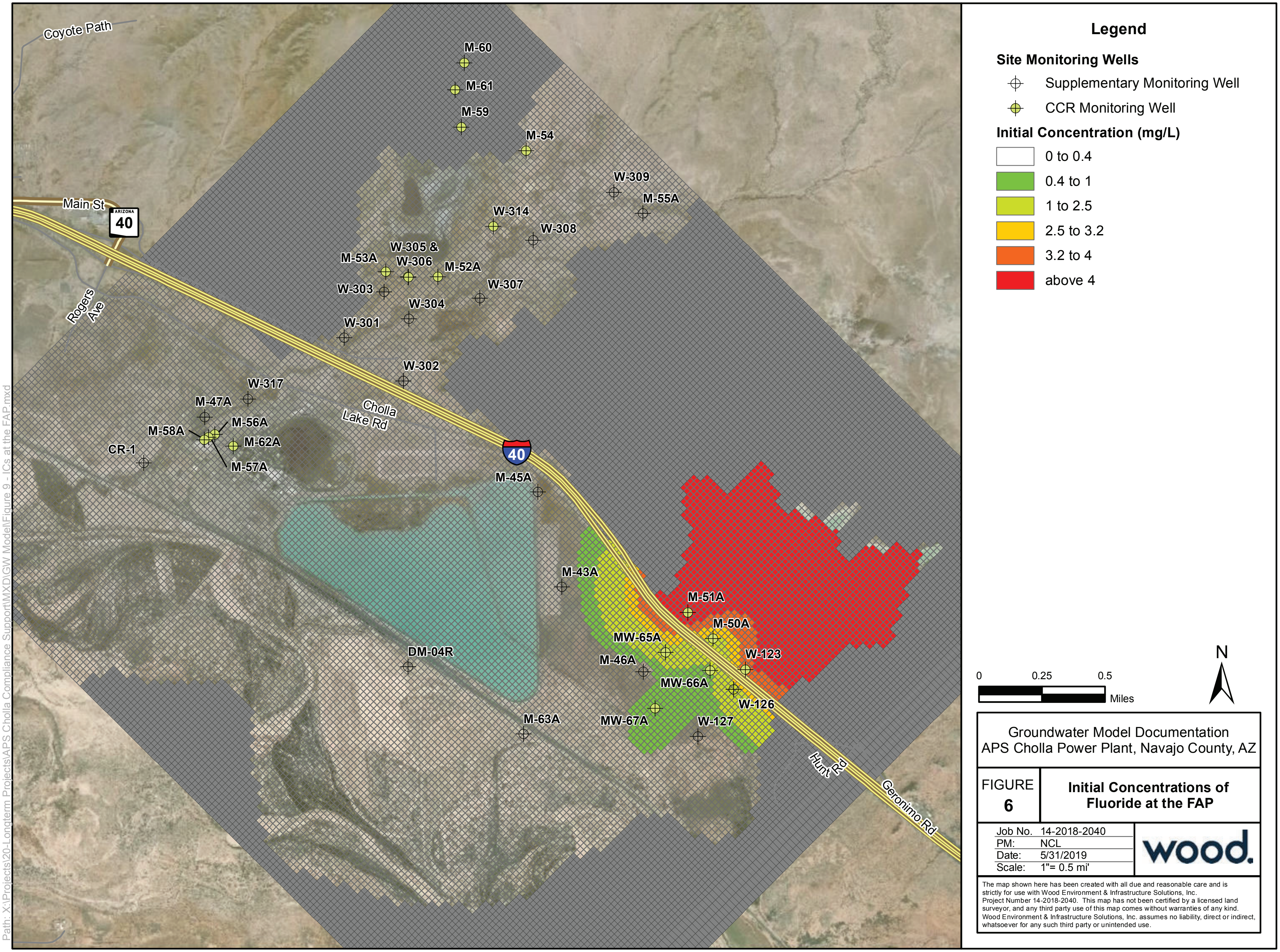


Figure 5. Kx=Ky Sensitivity Analysis
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
Sum of Squared Residuals
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
Multiplier
Kx1
Kx2
kx3
Kx4
Kx5
Kx6
Kx7
Kx8
Kx9
Kx10
Kx11
Kx12
Kx13
Kx14



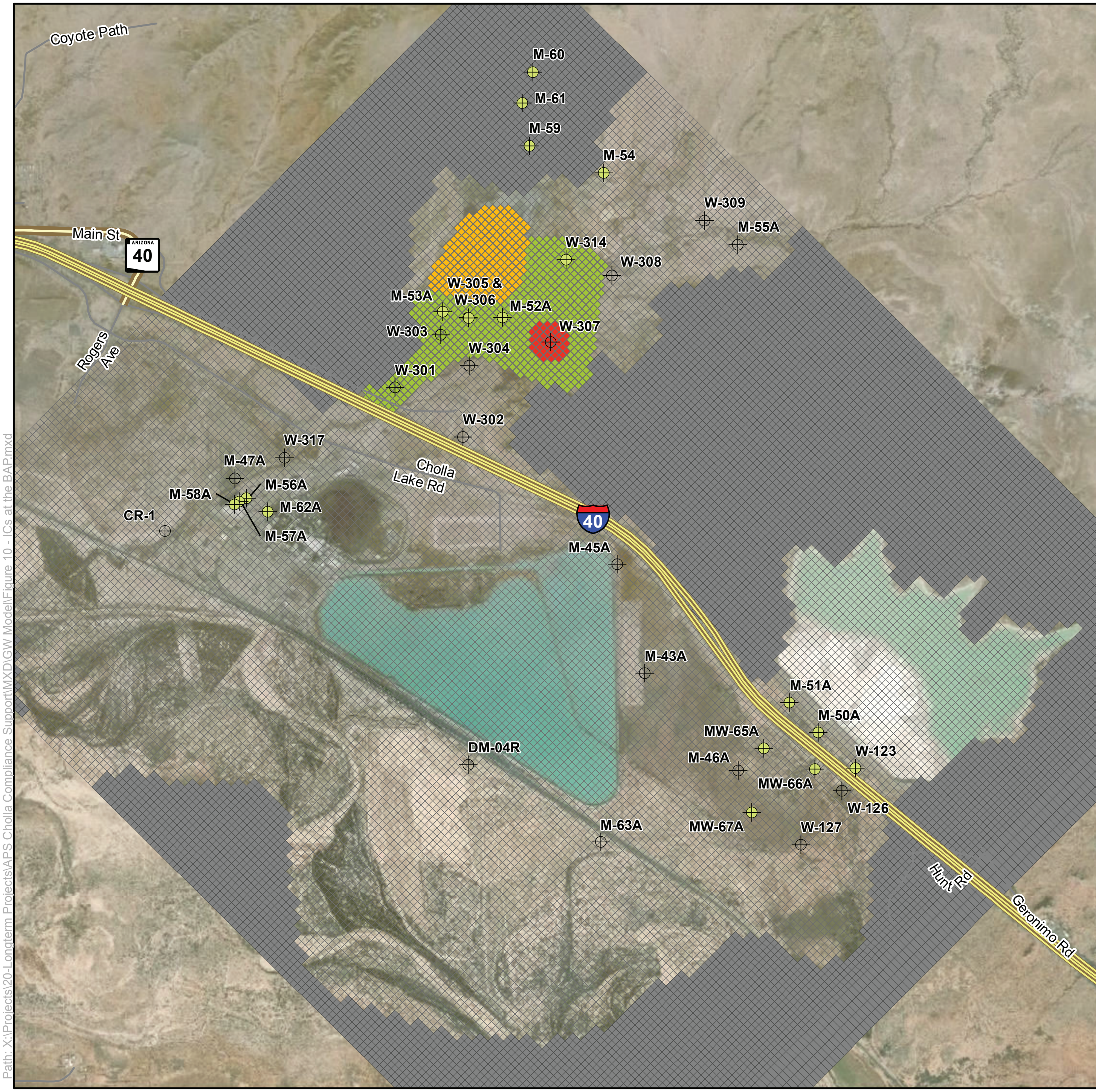
Groundwater Model Documentation
APS Cholla Power Plant, Navajo County, AZ

FIGURE 6

Initial Concentrations of Fluoride at the FAP

Job No.	14-2018-2040
PM:	NCL
Date:	5/31/2019
Scale:	1"= 0.5 mi'

wood.



Legend

Site Monitoring Wells

- Supplementary Monitoring Well
- CCR Monitoring Well

Initial Concentration (mg/L)

- 0 to 0.006
- 0.006 to 0.01
- 0.01 to 0.06
- above 0.06

0 0.25 0.5 Miles

N

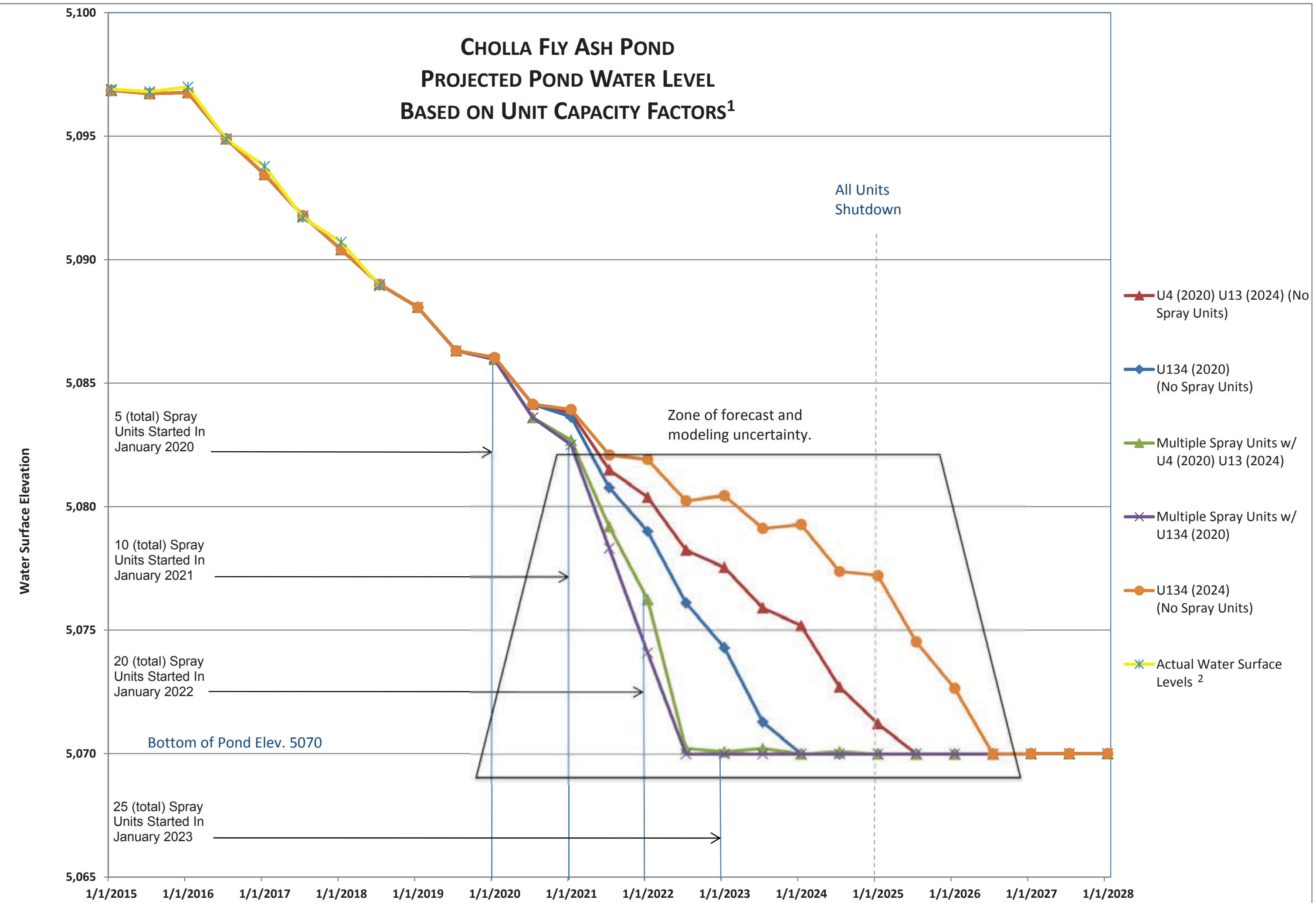
Groundwater Model Documentation
APS Cholla Power Plant, Navajo County, AZ

FIGURE 7

Initial Concentrations of Cobalt at the BAP

Job No.	14-2018-2040
PM:	NCL
Date:	5/31/2019
Scale:	1"= 0.5 mi'

Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\GW Model\Figure 10 - ICs at the BAP.mxd



Notes:

1. 09-14-2018 - Chart Revised from Summer Run Only to Using Capacity Factors (CF). CF Data Received in Emails Dated 09-12-2018 and 9-13-2018 for U4 and U1,3, Respectively.
2. 09-14-2018 - Actual Fly Ash Pond Water Surface Levels Added to Graph

AECOM

Job No.:	1420182040
PM:	NCL
Date:	6/3/2019
Scale:	As Shown

Arizona Public Service
Cholla Power Plant
Navajo County, Arizona

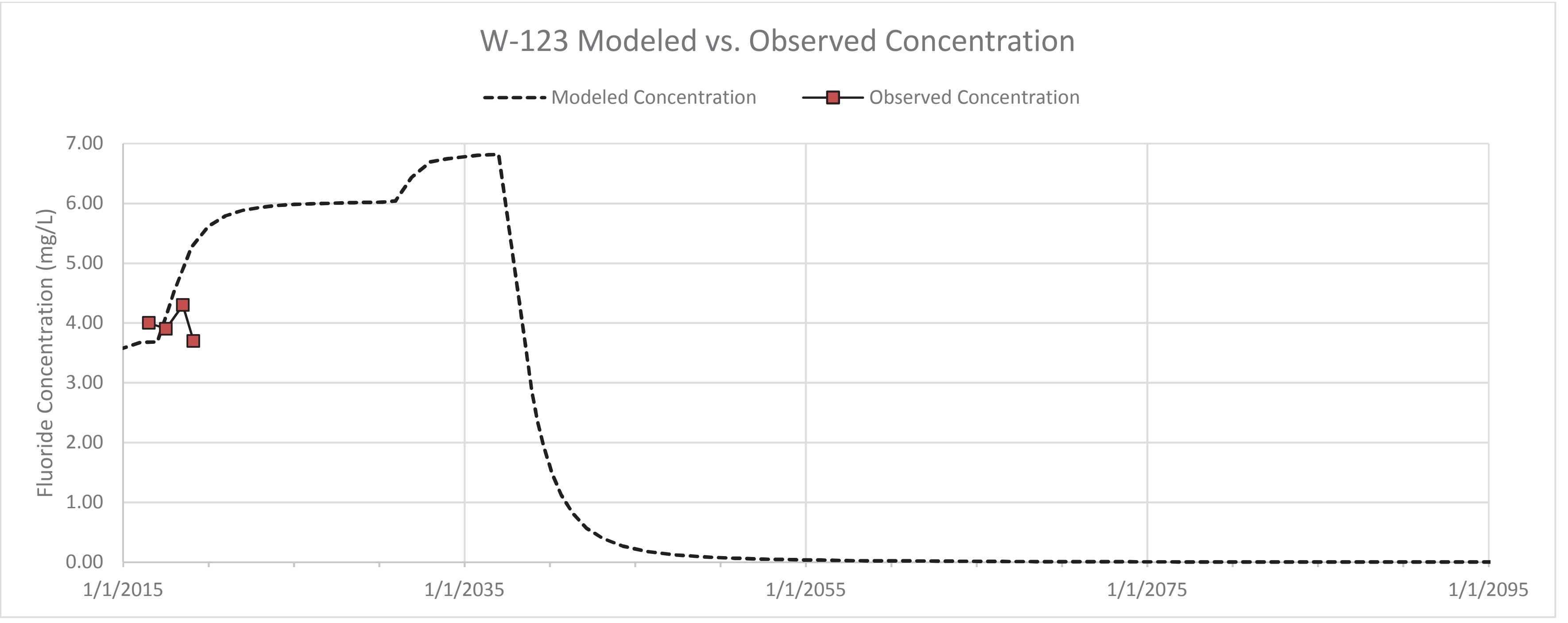
FAP Projected Pond Water Levels

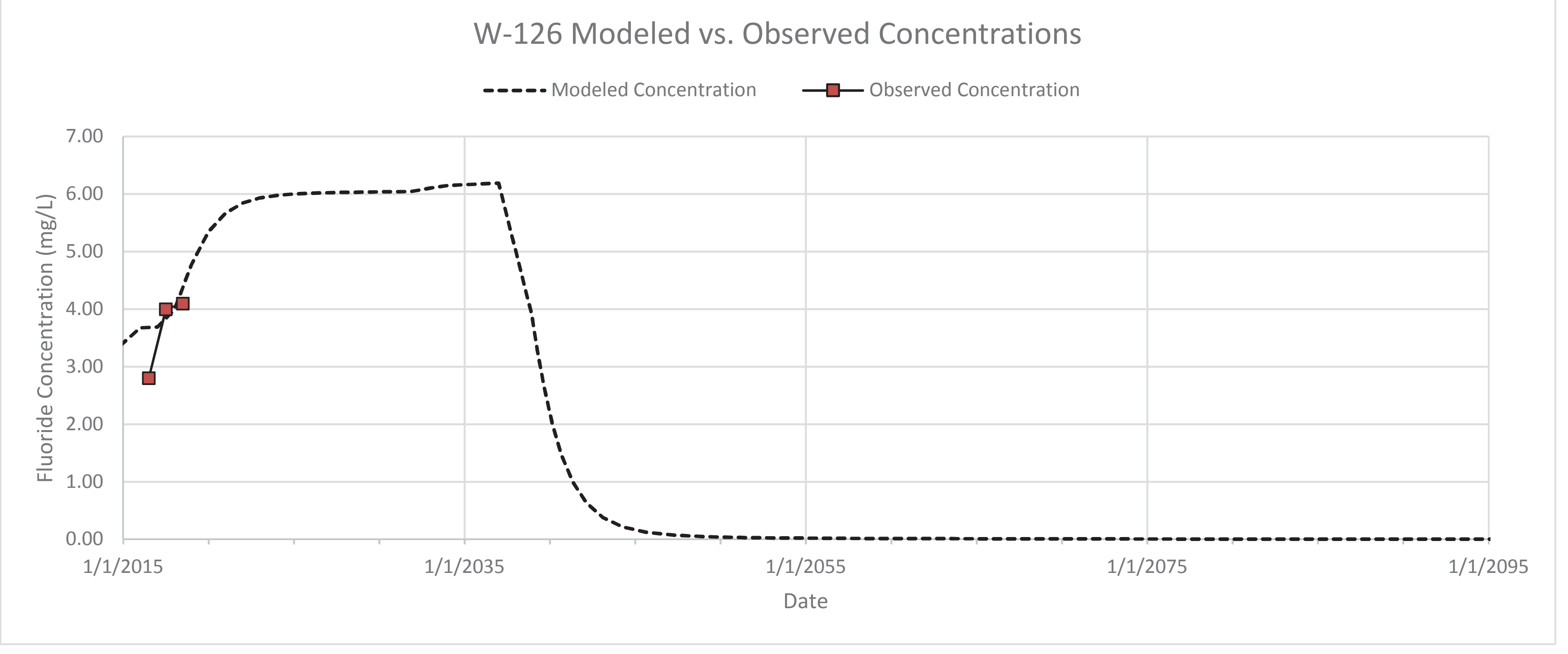
FIGURE
8

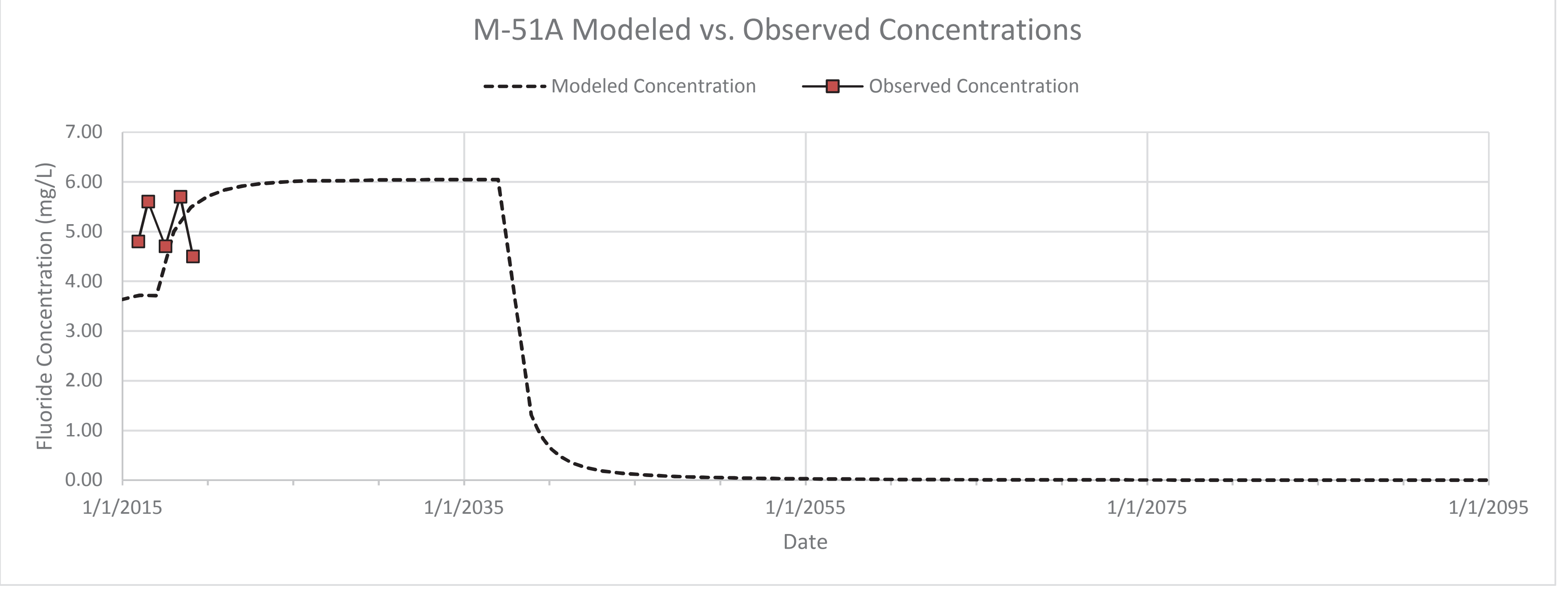
wood.

Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\CMA Report\Appendix\Figure8_FAPProjectedPondWaterLevels

Figure 9. Modeled vs. Observed Concentrations at Select FAP Wells







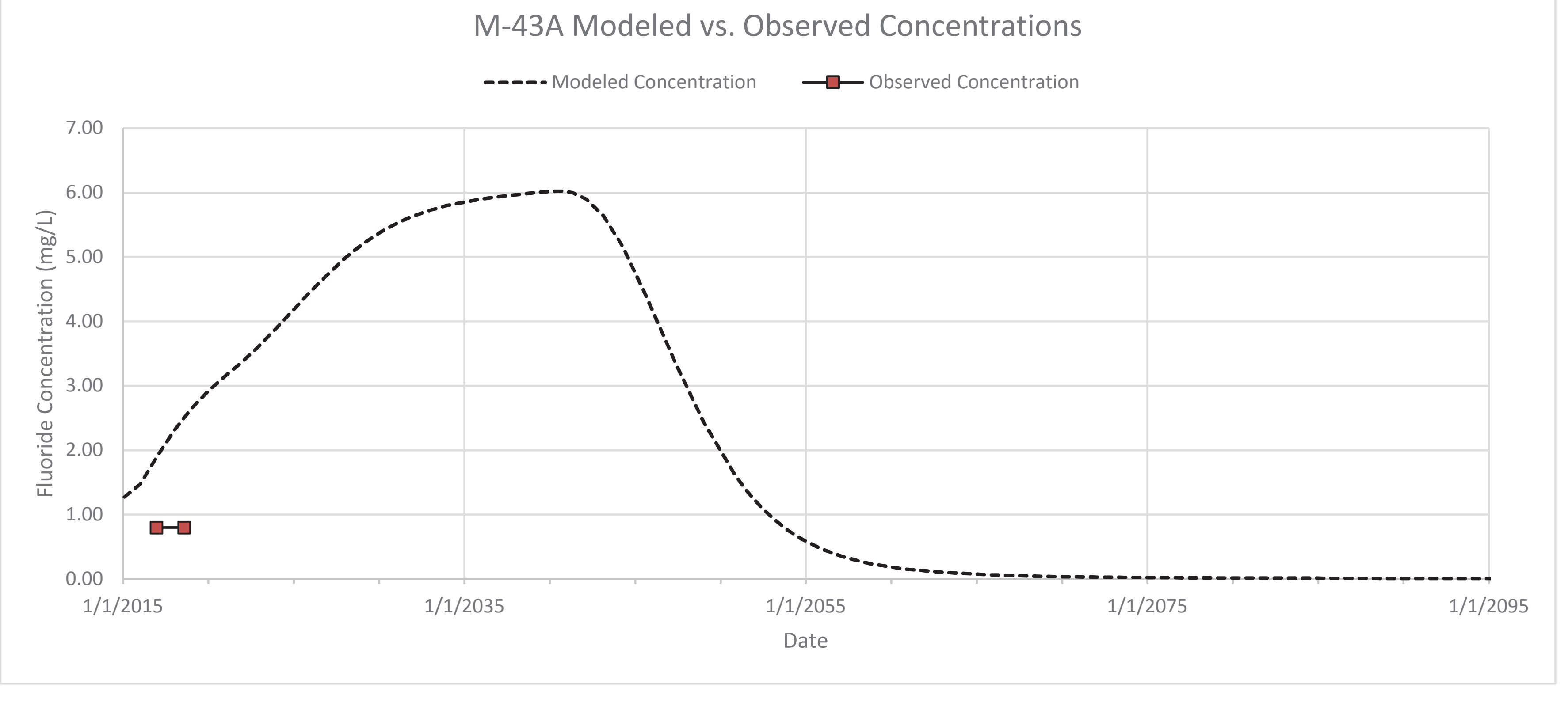
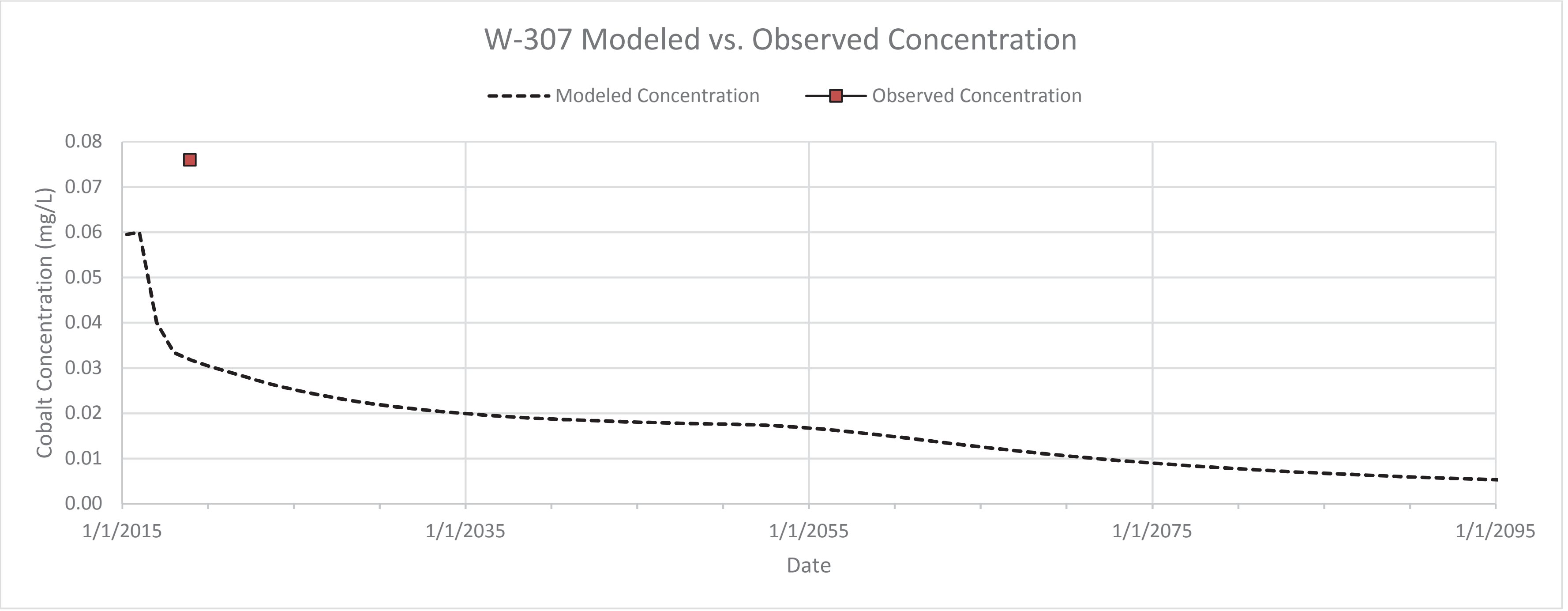
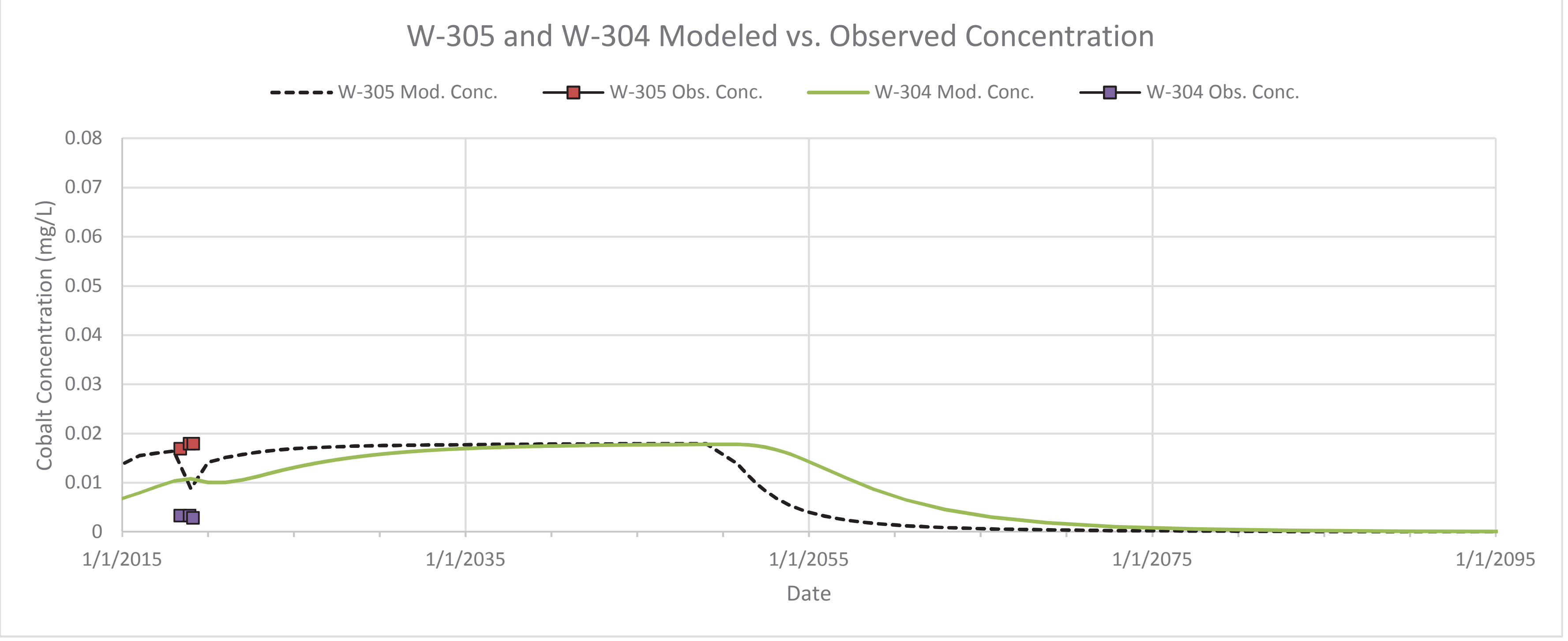
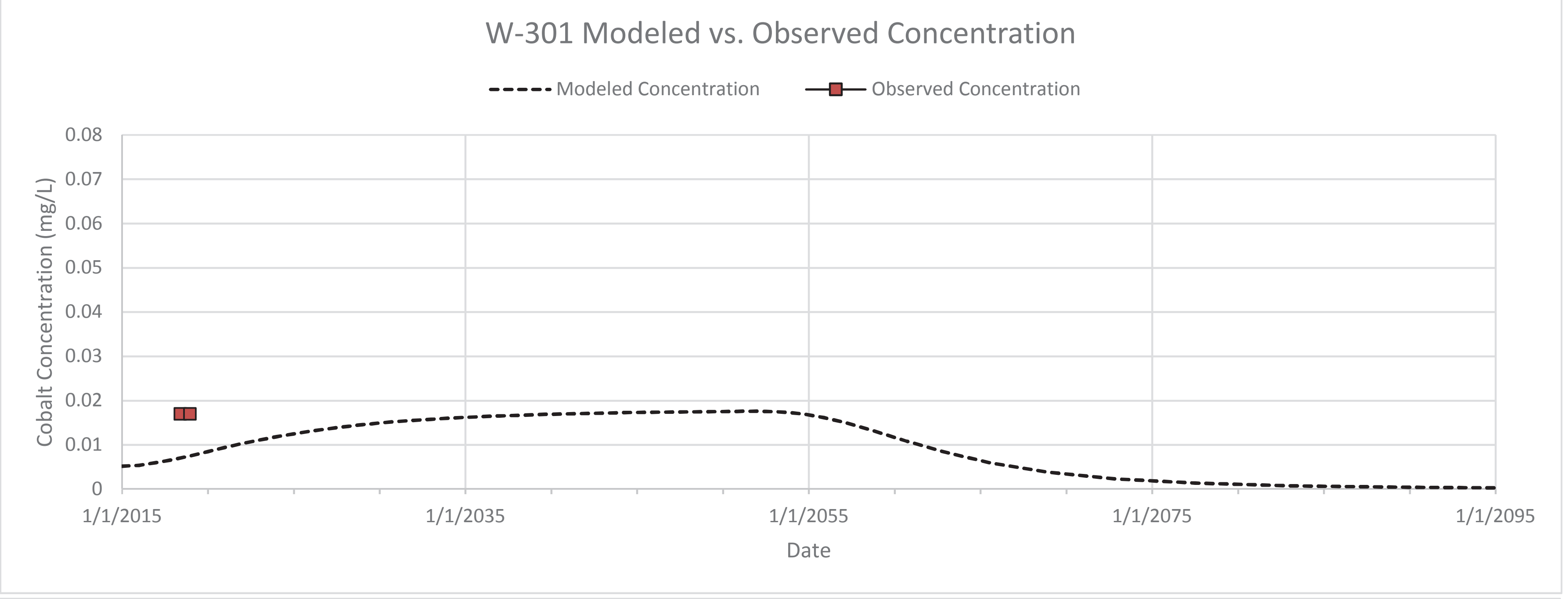
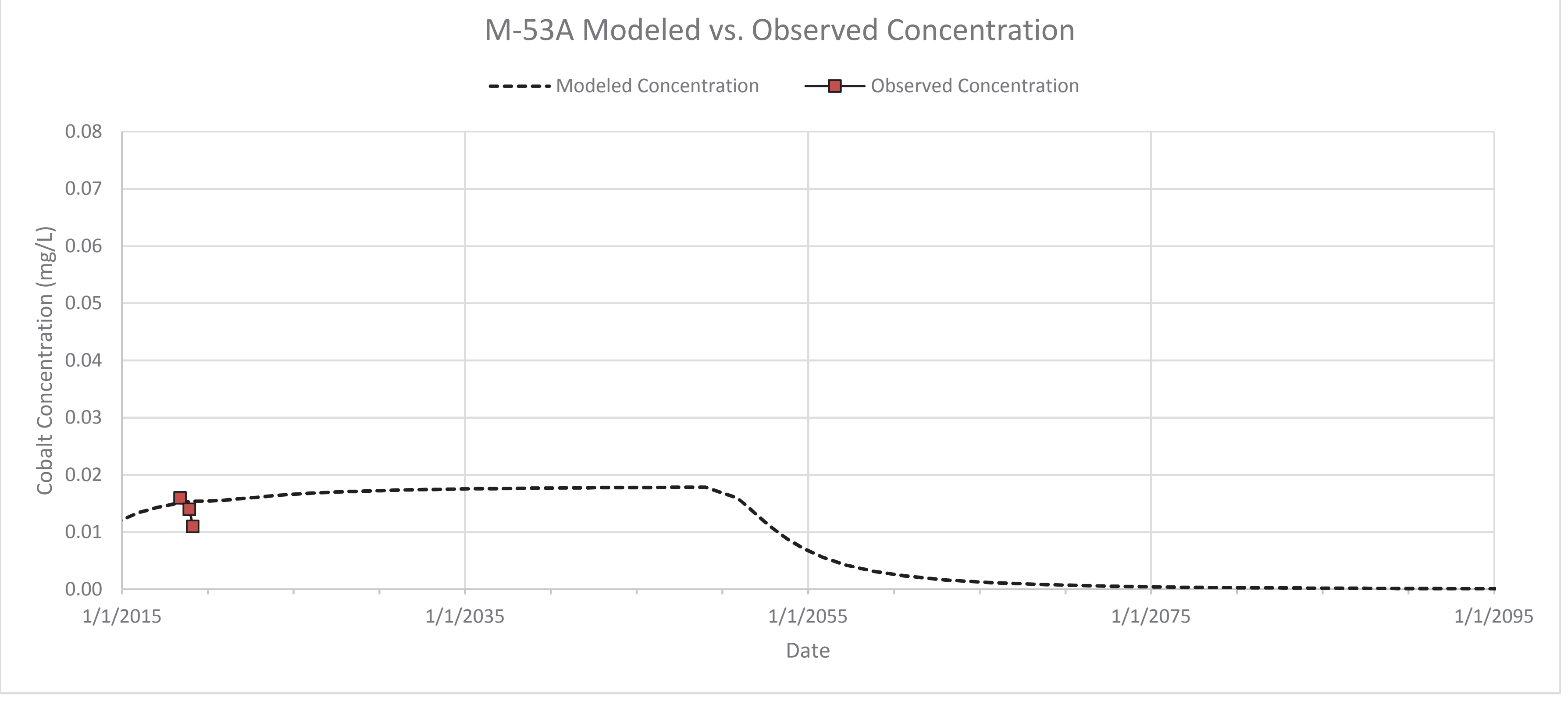


Figure 10. Modeled vs. Observed Concentrations at Select BAP Wells









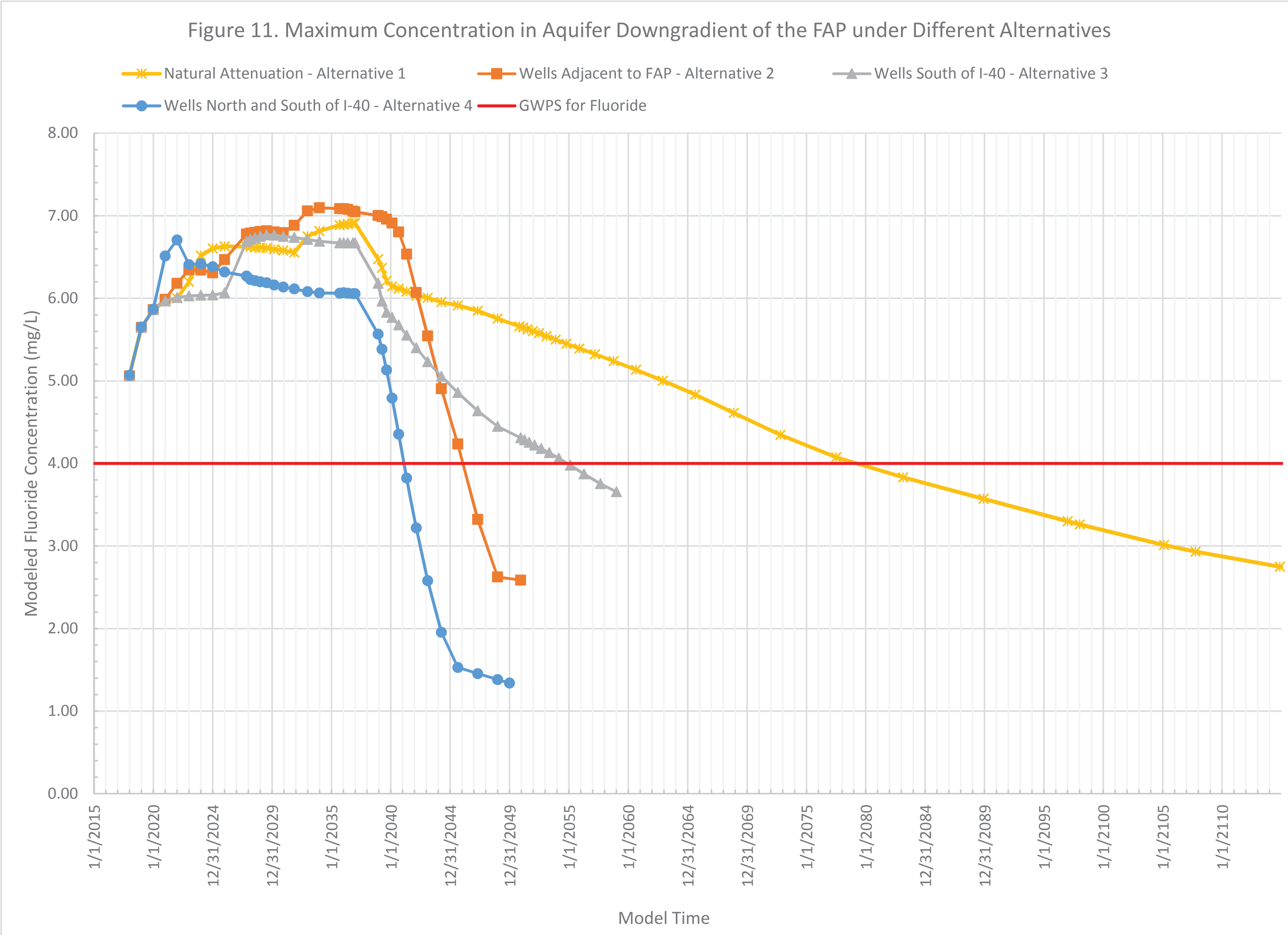


Figure 11. Maximum Concentration in Aquifer Downgradient of the FAP under Different Alternatives
Natural Attenuation - Alternative 1
Wells Adjacent to FAP - Alternative 2
Wells South of I-40 - Alternative 3
Wells North and South of I-40 - Alternative 4
GWPS for Fluoride
Modeled Fluoride Concentration (mg/L)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1/1/2015
1/1/2020
12/31/2024
12/31/2029
1/1/2035
1/1/2040
12/31/2044
12/31/2049
1/1/2055
1/1/2060
12/31/2064
12/31/2069
1/1/2075
1/1/2080
12/31/2084
12/31/2089
1/1/2095
1/1/2100
1/1/2105
1/1/2110
Model Time

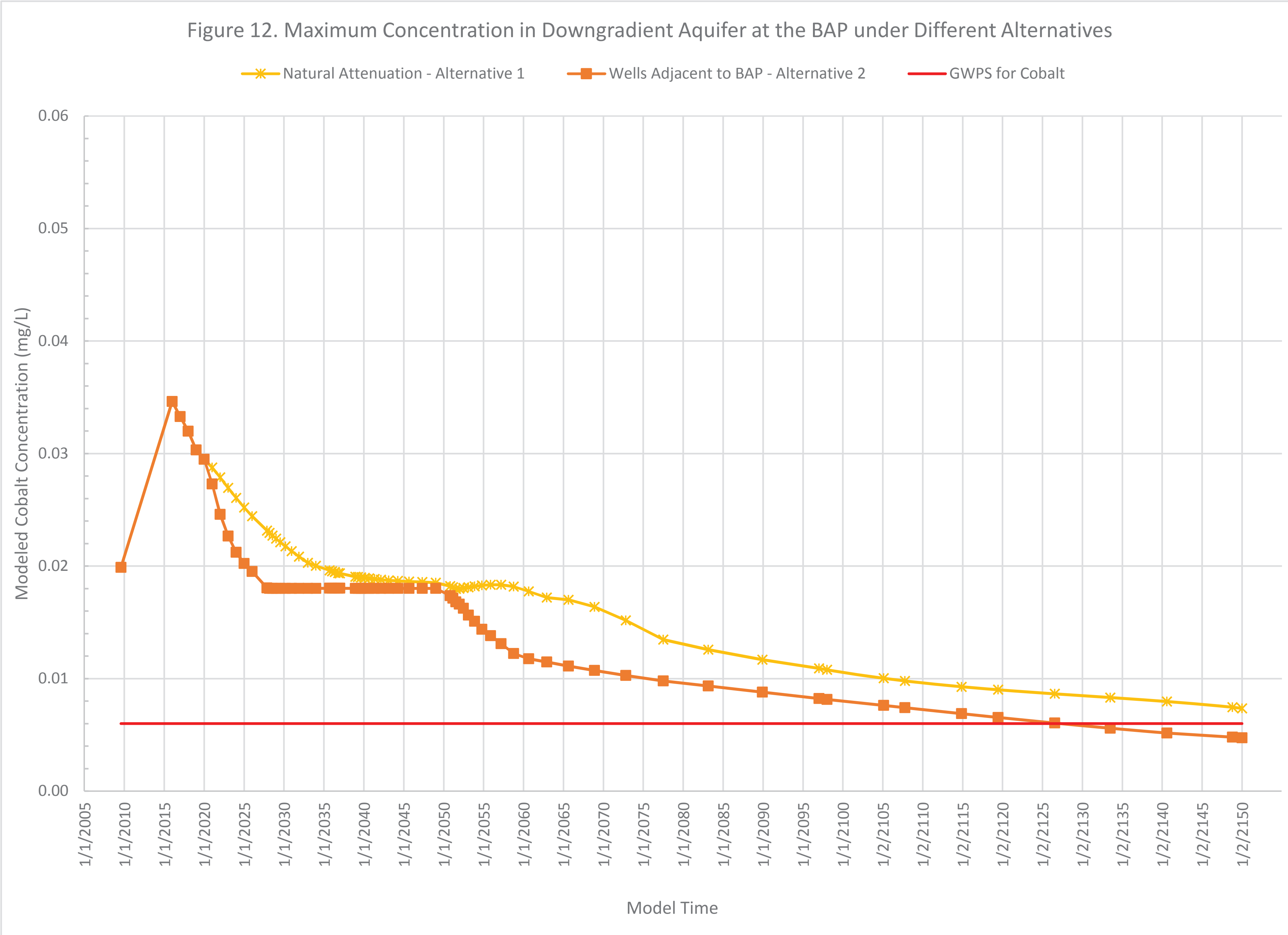


Figure 12. Maximum Concentration in Downgradient Aquifer at the BAP under Different Alternatives
Natural Attenuation - Alternative 1
Wells Adjacent to BAP - Alternative 2
GWPS for Cobalt
Modeled Cobalt Concentration (mg/L)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1/1/2005
1/1/2010
1/1/2015
1/1/2020
1/1/2025
1/1/2030
1/1/2035
1/1/2040
1/1/2045
1/1/2050
1/1/2055
1/1/2060
1/1/2065
1/1/2070
1/1/2075
1/1/2080
1/1/2085
1/1/2090
1/1/2095
1/1/2100
1/2/2105
1/2/2110
1/2/2115
1/2/2120
1/2/2125
1/2/2130
1/2/2135
1/2/2140
1/2/2145
1/2/2150
Model Time

Legend

Site Monitoring Wells

- Supplementary Monitoring Well
- CCR Monitoring Well

Modeled Wells

- Layers 2 and 3
- Layer 3
- Noflow cells

0 650 1,300
Feet

N

Groundwater Model Documentation
APS Cholla Power Plant, Navajo County, AZ

FIGURE 13	**FAP Alternative 2 Containment Well Placement**

Job No.	14-2018-2040
PM:	NCL
Date:	6/1/2019
Scale:	1"= 1300 ft

wood.

Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\GW Model\Figure 13 - Alt 2 at FAP.mxd

Legend

Site Monitoring Wells

- Supplementary Monitoring Well
- CCR Monitoring Well

Modeled Wells

- Layers 2 and 3
- Noflow cells

0 650 1,300
Feet

N

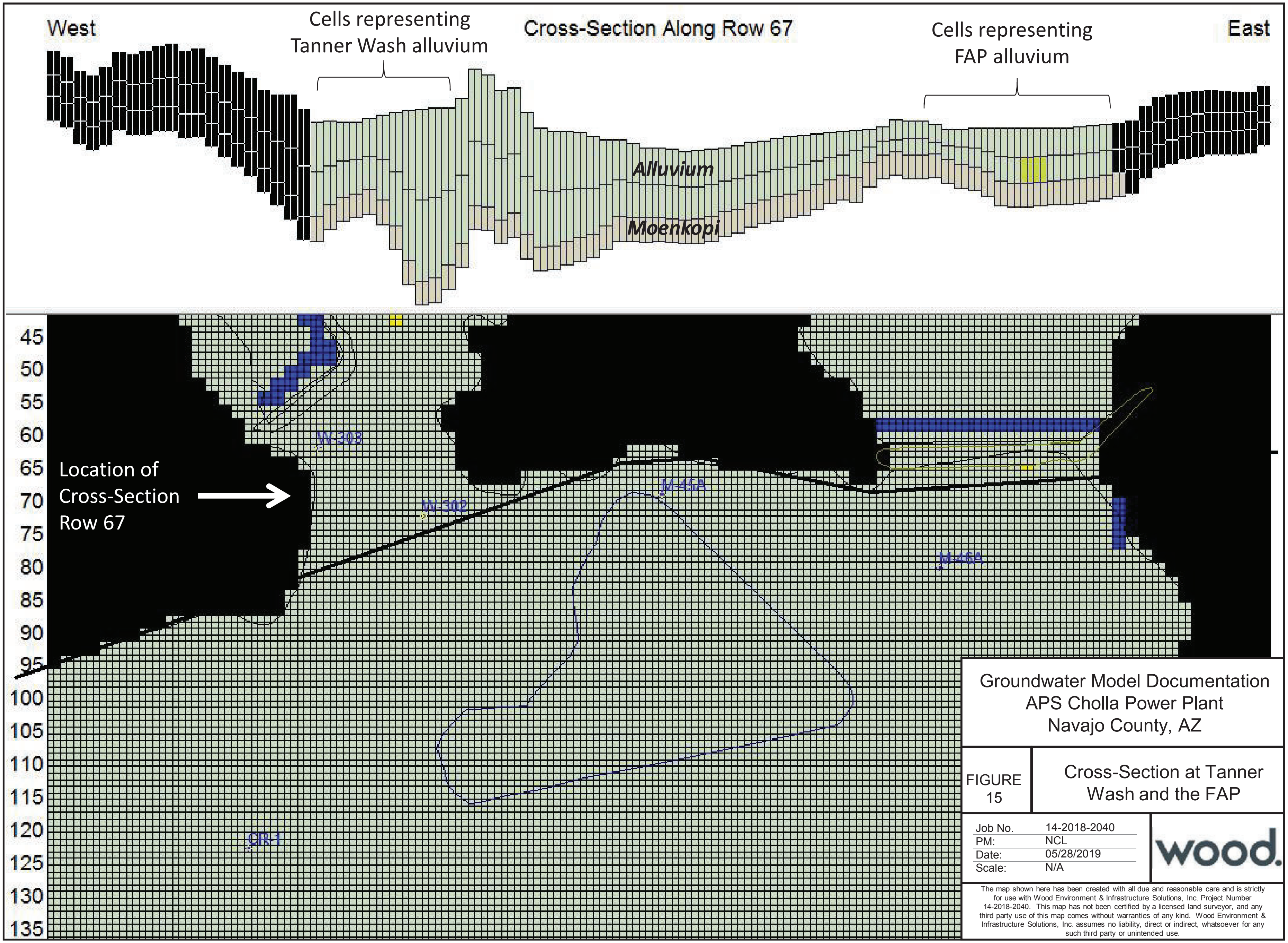
Groundwater Model Documentation
APS Cholla Power Plant, Navajo County, AZ

FIGURE 14

BAP Alternative 2
Containment Well Placement

Job No.	14-2018-2040
PM:	NCL
Date:	6/1/2019
Scale:	1"= 1300 ft

Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\GW Model\Figure 14 - Alt 2 at BAP.mxd



Groundwater Model Documentation
APS Cholla Power Plant
Navajo County, AZ

FIGURE 15

Cross-Section at Tanner Wash and the FAP

Job No.	14-2018-2040
PM:	NCL
Date:	05/28/2019
Scale:	N/A

wood.

Legend

Site Monitoring Wells

- Supplementary Monitoring Well
- CCR Monitoring Well

Modeled Wells

- Layers 2 and 3
- Layer 3
- Noflow cells

0 650 1,300
Feet

N

Groundwater Model Documentation
APS Cholla Power Plant, Navajo County, AZ

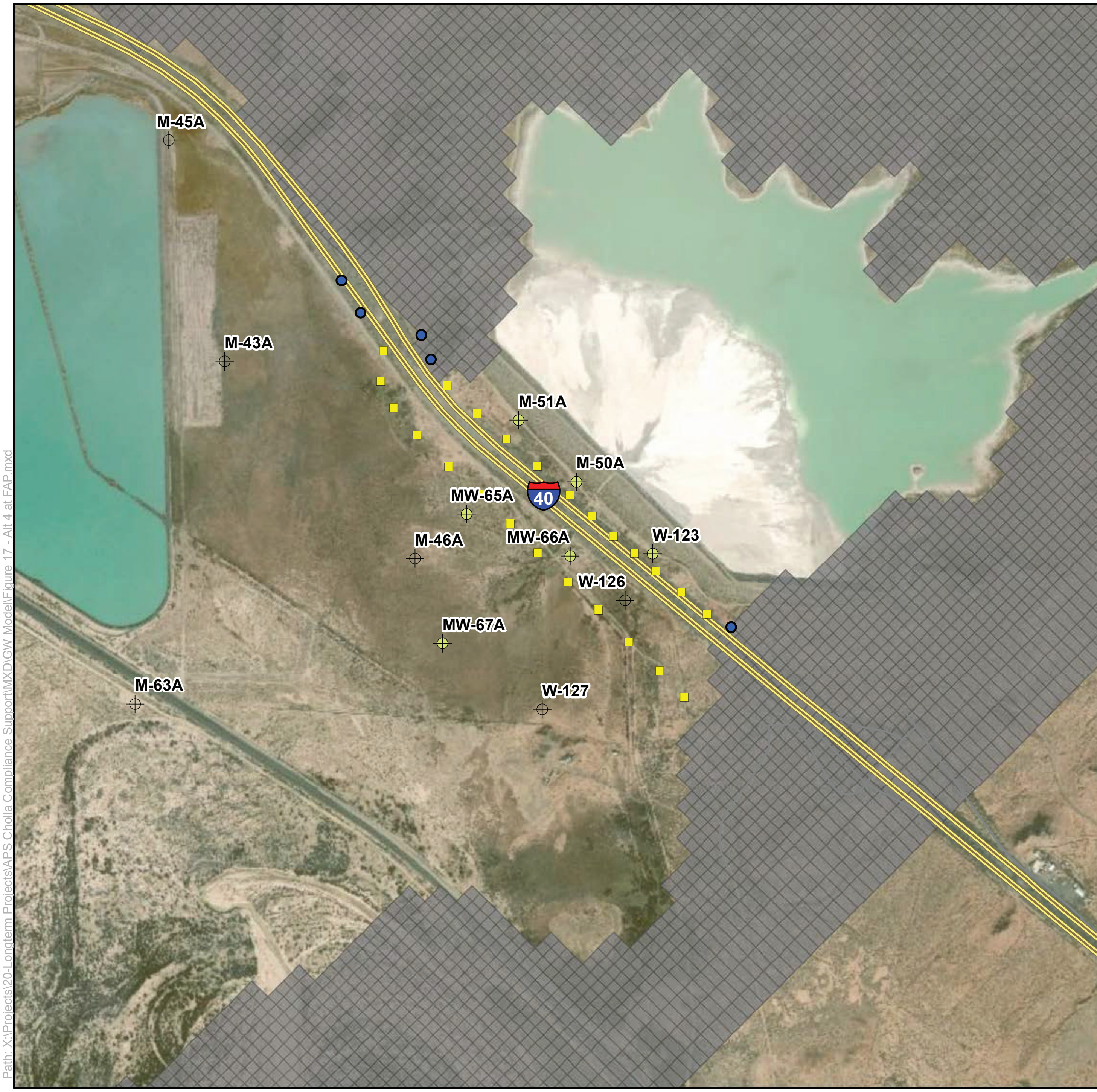
FIGURE 16

FAP Alternative 3
Containment Well Placement

Job No.	14-2018-2040
PM:	NCL
Date:	6/1/2019
Scale:	1"= 1300 ft

wood.

Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\GW Model\Figure 16 - Alt 3 at FAP.mxd



Legend

Site Monitoring Wells

- Supplementary Monitoring Well
- CCR Monitoring Well

Modeled Wells

- Layers 2 and 3
- Layer 3
- Noflow cells

0 650 1,300
Feet

N

Groundwater Model Documentation
APS Cholla Power Plant, Navajo County, AZ

FIGURE 17	**FAP Alternative 4 Containment Well Placement**

Job No.	14-2018-2040
PM:	NCL
Date:	6/1/2019
Scale:	1"= 1300 ft

wood.

Path: X:\Projects\20-Longterm Projects\APS Cholla Compliance Support\MXD\GW Model\Figure 17 - Alt 4 at FAP.mxd

ATTACHMENT A

BORING LOGS FOR MW-65A, MW-66A, AND MW-67A

wood.

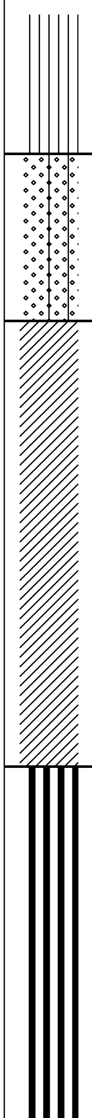
Environment & Infrastructure Solutions, Inc.
4600 East Washington Street, Suite 600
Phoenix, Arizona 85034

BORING LOG I.D.: MW-65A

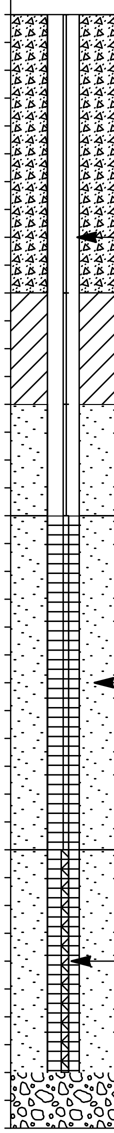
PROJECT:	APS Cholla Power Plant CCR Compliance	**PROJECT LOCATION:**	APS Cholla Power Plant
LOGGED BY:	Isaac Torres	**PROJECT FEATURE:**	Fly Ash Pond
DRILLER:	Darius Cervantez	**WOOD PROJECT #:**	14-2018-2040
DRILLER FIRM:	Boart Longyear	**ADWR REG. #:**	55-922299
RIG I.D.:	- - -	**COORDINATES:**	N1429526.69. E668254.52
RIG TYPE:	Rotosonic	**COORDINATE SYS:**	NAD83 (1982) Arizona State Plane
BORING TYPE:	- - - **BORING DIA.:** 8"	**SURFACE ELEV. (FT):**	5026.21
ORIENTATION:	90°	**MEAS. PT. ELEV. (FT):**	5027.86
HAMMER TYPE:	Not Applicable	**VERTICAL DATUM:**	NAVD88
HAMMER CALIBRATION-ENERGY TRANSFER RATIO:	N/A	**COMPLETION DATE:**	11-14-2018 **COMPLETION TIME:** 11:45
START DATE:	11-14-2018 **START TIME:** 11:15		

Elevation in Feet	Depth in Feet	Sample ID. or Date (Time)	PID Meter Reading (ppm)	Unified Soil Classification	VISUAL CLASSIFICATION (Color, Moist, % by wt., Plasticity, Dilatancy, Toughness, Dry Strength, Consistency)
2026.2	0			ML	**SANDY SILT,** 75% fines, 25% fine to coarse grained, subrounded sand, brown (7.5YR 4/3), nonlithified, granular to angular blocky soil structure, weakly effervescent, nonplastic, slightly moist, loose density, low dry strength, no stains, no odors note: at 2.5' coarse grained sand increases, gradational basal contact
		11-14-18 (11:15)		SW-SM	**WELL GRADED SAND WITH SILT & GRAVEL,** 65% fine to coarse grained, subrounded to subangular sand, 25% fine to coarse grained, subrounded to subangular gravel, 10% fines, brown (7.5YR 4/2), nonlithified, single grain soil structure, weakly effervescent, nonplastic, slightly moist, very loose density, no dry strength, no stains, no odors note: at 5.5' sharp basal contact
2021.2	5				
		11-14-18 (11:17)		CL	**SILTY CLAY,** 85% fines, 15% fine to coarse grained, subrounded to subangular sand, dark brown (7.5YR 3/3), predominate calcium carbonate filaments, weakly cemented, highly effervescent, thin laminae (<1 mm), nonplastic, slightly moist, very firm to hard, medium to high dry strength, friable, no stains, no odor note: at 10.5' coarse grained sand increase note: from 11' to 12.5' soil is moist, massive, and trace calcium carbonate nodules note: at 13' soil slightly moist, blocky soil, and calcium carbonate nodules increase; gradational basal contact at 13.5'
2016.2	10				
		11-14-18 (11:28)		MH	**SANDY ELASTIC SILT,** 60% fines, 40% fine to coarse grained, subrounded to subangular sand, dark reddish-brown (5YR 3/2), lenses with an increase of coarse grained sand (50%) starting at 15', nonlithified, effervescent, wet, low to medium plasticity, soft firmness, medium density, no stains, no odors note: at 14' calcium carbonate nodules abscent; note: at 16.5' lense of coarse grained sand (50%) note: at 17.5' lense of coarse grained sand (50%)
2011.2	15				
		11-14-18 (11:35)			
2006.2	20				

Graphical Log



WELL INFORMATION (Construction Details and/or Drilling Remarks)



- Steel casing stick up +2', minimum 8" clearance between top of steel casing and top of 4" PVC well casing
- 4000 PSI Concrete Mix from 0 to 5'
- 4" Nominal Diameter Schedule 80 PVC Blank Casing from +1' to 9'
- Bentonite Plug from 5' to 7'
- Filter Pack (8-12) from 7' to 19'
- 4" Nominal Diameter Schedule 80 PVC (0.020" Slot Screen) from 9' to 19'
- Dedicated submersible pump
- Pea Gravel from 19' to 20'

GROUNDWATER

	DEPTH(ft bgs)	HOUR	DATE
▽	13.7	11:55	11/14/18
▼	14.1	10:30	11/17/18

METHOD Not Applicable

(Continued Next Page)

wood.

Environment & Infrastructure Solutions, Inc.
4600 East Washington Street, Suite 600
Phoenix, Arizona 85034

BORING LOG I.D.: MW-65A

PROJECT:	APS Cholla Power Plant CCR Compliance	**PROJECT LOCATION:**	APS Cholla Power Plant
ADWR REG. #:	55-922299	**PROJECT FEATURE:**	Fly Ash Pond

Elevation in Feet	Depth in Feet	Graphical Log	Sample ID. or Date (Time)	PID Meter Reading (ppm)	Unified Soil Classification	VISUAL CLASSIFICATION (Color, Moist, % by wt., Plasticity, Dilatancy, Toughness, Dry Strength, Consistency)	Depth in Feet	WELL INFORMATION (Construction Details and/or Drilling Remarks)
2006.2	20				MH	note: at 20.5' olive brown staining near basal gradational contact **SANDY ELASTIC SILT,** continued	20	(Continued)
						Trmhm - Moqui Member of Moenkopi Formation (mid-unit), mudstone, 60% clay, 30% silt, 10% fine grained sand, dark reddish brown (5YR 3/4) with considerable olive brown staining (2.5Y 4/4), thin laminae (<0.5 mm), effervescent, wet, medium plasticity, medium stiff, ductile, no odors note: from 20.5' to 23' core sample is more compact in diameter note: from 22' to 23' gypsum nodules (<5 mm) present near sharp basal contact		Bentonite Chips from 20' to 25'
			11-14-18 (11:45)					
2001.2	25					**Trmhm - Moqui Member of Moenkopi Formation (mid-unit), silty mudstone,** 55% clay, 40% silt, 5% fine grained sand, dark reddish-brown (5YR 4/4), some filaments of gypsum (at about 23'), predominant lenses of gypsum (23.5' to 25'), thin laminae (<1 mm), weakly cemented, slightly moist, low to medium plasticity, hard, medium dry strength, friable, no odors	25	Total Depth = 25'
1996.2	30					Total Depth = 25'	30	
1991.2	35						35	
1986.2	40						40	
1981.2	45						45	

GROUNDWATER

	DEPTH(ft bgs)	HOUR	DATE
▽	13.7	11:55	11/14/18
▼	14.1	10:30	11/17/18
▼			
▼			

METHOD Not Applicable

wood.

Environment & Infrastructure Solutions, Inc.
4600 East Washington Street, Suite 600
Phoenix, Arizona 85034

BORING LOG I.D.: MW-66A

PROJECT:	APS Cholla Power Plant CCR Compliance	**PROJECT LOCATION:**	APS Cholla Power Plant
LOGGED BY:	Isaac Torres	**PROJECT FEATURE:**	Fly Ash Pond
DRILLER:	Darius Cervantez	**WOOD PROJECT #:**	14-2018-2040
DRILLER FIRM:	Boart Longyear	**ADWR REG. #:**	55-922300
RIG I.D.:	- - -	**COORDINATES:**	N1429134.06, E669178.50
RIG TYPE:	Rotosonic	**COORDINATE SYS:**	NAD83 (1982) Arizona State Plane
BORING TYPE:	- - - ; **BORING DIA.:** 8"	**SURFACE ELEV. (FT):**	5032.46
ORIENTATION:	90°	**MEAS. PT. ELEV. (FT):**	5033.35
HAMMER TYPE:	Not Applicable	**VERTICAL DATUM:**	NAVD88
HAMMER CALIBRATION-ENERGY TRANSFER RATIO:	N/A	**COMPLETION DATE:**	11-12-2018 ; **COMPLETION TIME:** 15:40
START DATE:	11-12-2018 ; **START TIME:** 09:35		

Elevation in Feet	Depth in Feet	Graphical Log	Sample ID. or Date (Time)	PID Meter Reading (ppm)	Unified Soil Classification	VISUAL CLASSIFICATION (Color, Moist, % by wt., Plasticity, Dilatancy, Toughness, Dry Strength, Consistency)	Depth in Feet	WELL INFORMATION (Construction Details and/or Drilling Remarks)
5032.5	0				ML	**SANDY SILT,** 80% fines, 15% fine to coarse grained, subrounded sand, 5% fine to coarse grained, subrounded to subangular gravel, brown (7.5 YR 4/3), nonlithified, granular to single grain soil structure, weakly effervescent, nonplastic, slightly moist, loose density, low dry strength, no stains, no odors note: at 2.5' sharp basal contact	0	Steel casing stick up +2', minimum 8" clearance between top of steel casing and top of 4" PVC well casing 4000 PSI Concrete Mix from 0 to 5'
					CL	**SILTY CLAY,** 90% fines, 10% fine to coarse grained, subrounded to subagular sand, dark brown (7.5YR 3/3), predominant calcium carbonate filaments, angular blocky soil structure, weakly cemented, highly effervescent, thin laminae (<1 mm), nonplastic, slightly moist, very firm to hard, low medium dry strength, friable, no stains, no odors		4" Nominal Diameter Schedule 80 PVC Blank Casing from +1' to 24'
5027.5	5		11-12-18 (09:35)				5	
5022.5	10		11-12-18 (09:45)			note: at 13' calcium carbonate filaments absent; gradational basal contact	10	Portland Neat Cement from 5' to 20'
					CL	**CLAY,** 90% to 95% fines, 5% to 10% fine to coarse grained, subrounded to subangular sand, dark reddish-brown (5YR 3/4), massive, effervescent, medium plasticity, moist, soft firmness, medium dry strength, ductile, no stains, no odors		
5017.5	15		11-12-18 (09:58)				15	
5012.5	20		11-12-18 (10:10)				20	

GROUNDWATER

	DEPTH(ft bgs)	HOUR	DATE
▽	31.9	15:50	11/12/18
▼	29.3	08:00	11/13/18
▼	28.9	07:35	11/14/18
▼	28.5	09:30	11/16/18

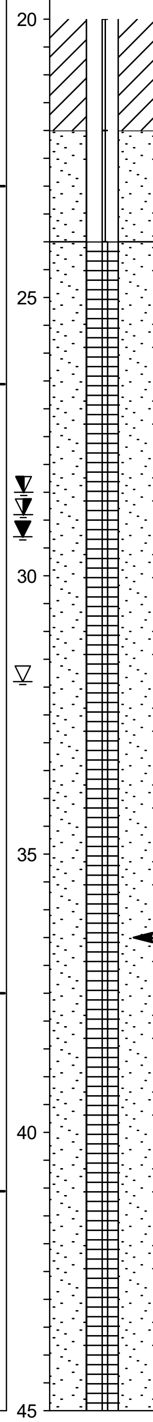
METHOD Not Applicable

(Continued Next Page)

PROJECT:	APS Cholla Power Plant CCR Compliance	**PROJECT LOCATION:**	APS Cholla Power Plant
ADWR REG. #:	55-922300	**PROJECT FEATURE:**	Fly Ash Pond

Elevation in Feet	Depth in Feet	Graphical Log	Sample ID. or Date (Time)	PID Meter Reading (ppm)	Unified Soil Classification	VISUAL CLASSIFICATION (Color, Moist, % by wt., Plasticity, Dilatancy, Toughness, Dry Strength, Consistency)
5012.5	20				CL	**CLAY,** continued note: at 23' sand decreases; gradational basal contact
5007.5	25		11-12-18 (10:35)		CL	**CLAY,** 98% fines, 2% fine to coarse grained, subrounded to subangular sand, dark brown (7.5YR 3/3), effervescent, medium to high plasticity, moist, soft to stiff firmness, medium dry strength, ductile, no stains, no odors note: at 25.5' sand slightly increases; gradational basal contact
5002.5	30		11-12-18 (12:20)		CL	**CLAY,** 95% fines, 5% fine to coarse grained, subrounded to subangular sand, dark reddish-brown (5YR 3/2), trace gypsum nodules (~3 mm) and occ filaments (~1 cm), effervescent, medium to high plasticity, moist, medium stiff to stiff firmness, medium dry strength, ductile, no stains, no odors note: at 32.5' gypsum filaments increase in length (~2.5 cm) note: at 33.0' clay decreases while silt increases
4997.5	35		11-12-18 (12:40)			note: at 37.5' bgs gypsum nodules decrease and no filaments, sand decreases, core sample more compact in diameter; gradational basal contact
					CL	**CLAY,** 98% fines, 2% fine to coarse grained, subrounded to subangular sand, dark reddish-brown (5YR 3/3), occasional gypsum nodules, massive, effervescent, high plasticity, moist, soft to medium stiff firmness, medium dry strength, ductile, no stains, no odors note: at about 40' sand decreases; sharp basal contact
4992.5	40		11-12-18 (13:06)		CL	**SILTY CLAY,** 95% to 98% fines, 2% to 5% fine to coarse grained, subrounded to subangular sand, dark-reddish brown (5YR 3/4), rare gypsum nodules, massive, effervescent, medium to high plasicity wet, soft to medium stiff firmness, medium dry strength, ductile, no stains, no odors note: at about 40' core samples more compact in diameter
4987.5	45					

WELL INFORMATION (Construction Details and/or Drilling Remarks)



(Continued)

Bentonite Plug from 20' to 22'

Filter Pack (8-12) from 22' to 49'

4" Nominal Diameter Schedule 80 PVC (0.020" Slot Screen) from 24' to 49'

GROUNDWATER

	DEPTH(ft bgs)	HOUR	DATE
▽	31.9	15:50	11/12/18
▼	29.3	08:00	11/13/18
▼	28.9	07:35	11/14/18
▼	28.5	09:30	11/16/18

METHOD Not Applicable

(Continued Next Page)

wood.

Environment & Infrastructure Solutions, Inc.
4600 East Washington Street, Suite 600
Phoenix, Arizona 85034

BORING LOG I.D.: MW-66A

PROJECT:	APS Cholla Power Plant CCR Compliance	**PROJECT LOCATION:**	APS Cholla Power Plant
ADWR REG. #:	55-922300	**PROJECT FEATURE:**	Fly Ash Pond

Elevation in Feet	Depth in Feet	Graphical Log	Sample ID. or Date (Time)	PID Meter Reading (ppm)	Unified Soil Classification	VISUAL CLASSIFICATION (Color, Moist, % by wt., Plasticity, Dilatancy, Toughness, Dry Strength, Consistency)	Depth in Feet	WELL INFORMATION (Construction Details and/or Drilling Remarks)
4987.5	45		11-12-18 (13:22)		CL	**SILTY CLAY,** continued note: at 47.5' trace gravels (<1 cm), sand increases; gradational basal contact	45	(Continued) Dedicated submersible pump
					CL	**GRAVELLY CLAY,** 75% fines, 20% fine to coarse grained, subrounded to subangular gravel, 5% fine to coarse grained, subrounded to subangular sand, dark-reddish brown (5YR 4/3), nonlithified, massive, slightly effervescent, low to medium plasticity, wet, soft firmness, low to medium dry strength, no odors note: at 52.5' core samples expanded back to normal, lenses of olive-brown staining, gradational basal contact		
4982.5	50						50	Pea Gravel from 49' to 51'
						Trmhm - Moqui Member of Moenkopi Formation (mid-unit), mudstone, 60% clay, 25% to 30% silt, 10% to 15% fine grained, subrounded to subangular sand, dark brown (7.5YR 3/3) with conssiderable lenses of olive brown staining (2.5Y 4/4), lithified, thin laminae (<0.5 mm), highly effervescent, slightly moist, medium to high plasticity, medium stiff, ductile, no odors. note: from 55' to 57' color dark reddish-brown (5YR 4/4), lithified samples in loose soil, trace gypsum nodules (mm), slightly moist, friable note: at 58' sharp basal contact with silty sandstone		
4977.5	55						55	Bentonite Chips from 51' to 60'
4972.5	60					Total Depth = 60'	60	Total Depth = 60'
4967.5	65						65	
4962.5	70						70	

GROUNDWATER

	DEPTH(ft bgs)	HOUR	DATE
▽	31.9	15:50	11/12/18
▼	29.3	08:00	11/13/18
▼	28.9	07:35	11/14/18
▼	28.5	09:30	11/16/18

METHOD Not Applicable

wood.

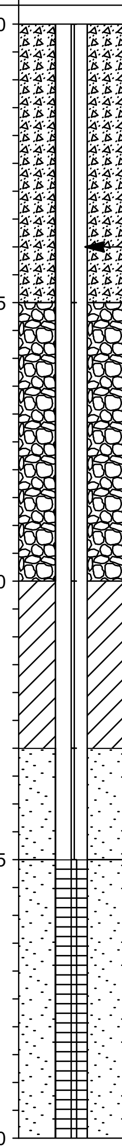
Environment & Infrastructure Solutions, Inc.
4600 East Washington Street, Suite 600
Phoenix, Arizona 85034

BORING LOG I.D.: MW-67A

PROJECT:	APS Cholla Power Plant CCR Compliance	**PROJECT LOCATION:**	APS Cholla Power Plant
LOGGED BY:	Isaac Torres	**PROJECT FEATURE:**	Fly Ash Pond
DRILLER:	Darius Cervantez	**WOOD PROJECT #:**	14-2018-2040
DRILLER FIRM:	Boart Longyear	**ADWR REG. #:**	55-922301
RIG I.D.:	- - -	**COORDINATES:**	N1428367.45, E668014.79
RIG TYPE:	Rotosonic	**COORDINATE SYS:**	NAD83 (1982) Arizona State Plane
BORING TYPE:	- - - **BORING DIA.:** 8"	**SURFACE ELEV. (FT):**	5024.05
ORIENTATION:	90°	**MEAS. PT. ELEV. (FT):**	5025.38
HAMMER TYPE:	Not Applicable	**VERTICAL DATUM:**	NAVD88
HAMMER CALIBRATION-ENERGY TRANSFER RATIO:	N/A	**COMPLETION DATE:**	11-15-2018 **COMPLETION TIME:** 10:20
START DATE:	11-14-2018 **START TIME:** 17:12		

Elevation in Feet	Depth in Feet	Graphical Log	Sample ID. or Date (Time)	PID Meter Reading (ppm)	Unified Soil Classification	VISUAL CLASSIFICATION (Color, Moist, % by wt., Plasticity, Dilatancy, Toughness, Dry Strength, Consistency)
5024.1	0				ML	**SANDY SILT,** 80% fines, 15% fine to coarse grained, subrounded sand, 5% fine to coarse grained, subrounded to subangular gravel, brown (7.5 YR 4/3), nonlithified, granular to single grain soil structure, weakly effervescent, nonplastic, slightly moist, loose density, low dry strength, no stains, no odors note: at 2.5' sharp basal contact
	2.5				CL	**SILTY CLAY,** 95% to 98% fines, 2% to 5% fine to coarse grained, subrounded to subangular sand, dark brown (7.5YR 3/3), considerable to predominate calcium carbonate lenses and filaments, weakly cemented, highly effervescent, thin laminae (<1 mm), low plasticity, slightly moist, hard firmness, medium dry strength, friable to ductile, no stains, no odors
5019.1	5		11-14-18 (17:12)			note: at 7.5' color slightly changes to dark brown (7.5YR 3/2) sand slightly increases (5%)
5014.1	10		11-14-18 (17:18)			note: at 10' moderate cementation and high dry strength, increased with depth
5009.1	15		11-14-18 (17:33)			note: at 17.5' calcium carbonate filaments decrease (occasional to trace), clay decreases while silt & sand increase; sharp basal contact
	17.5				ML	**SANDY SILT,** 85% to 90% fines, 10% to 15% fine to coarse grained, subrounded to subangular sand, dark reddish-brown (5YR 4/3), angular blocky soil structure, nonlithified, massive, moderately effervescent, low to medium
5004.1	20					

WELL INFORMATION (Construction Details and/or Drilling Remarks)



- Steel casing stick up +2', minimum 8" clearance between top of steel casing and top of 4" PVC well casing
- 4000 PSI Concrete Mix from 0 to 5'
- 4" Nominal Diameter Schedule 80 PVC Blank Casing from +<6" to 15'
- Portland Neat Cement from 5' to 10'
- Bentonite Plug from 10' to 13'
- Filter Pack (8-12) from 13' to 45'

GROUNDWATER

	DEPTH(ft bgs)	HOUR	DATE
▽	35.8	09:30	11/15/18
▼	34.4	09:40	11/15/18
▼	33.9	07:15	11/16/18
▼			

METHOD Not Applicable

(Continued Next Page)

Environment & Infrastructure Solutions, Inc.
4600 East Washington Street, Suite 600
Phoenix, Arizona 85034

BORING LOG I.D.: MW-67A

PROJECT:	APS Cholla Power Plant CCR Compliance	PROJECT LOCATION:	APS Cholla Power Plant
ADWR REG. #:	55-922301	PROJECT FEATURE:	Fly Ash Pond

Elevation in Feet	Depth in Feet	Sample ID. or Date (Time)	PID Meter Reading (ppm)	Unified Soil Classification	VISUAL CLASSIFICATION (Color, Moist, % by wt., Plasticity, Dilatancy, Toughness, Dry Strength, Consistency)	Depth in Feet	WELL INFORMATION (Construction Details and/or Drilling Remarks)
5004.1	20	11-15-18 (07:50)			plasticity, slightly moist, loose to medium density, medium to hard dry strength, friable, no stains, no odors note: at 22.5' calcium carbonate lenses to filaments absent; gradational basal contact	20	(Continued)
				CL	**CLAY,** 95% fines, 5% fine grained, subrounded to subangular sand, dark reddish-brown (5YR 3/2), weakly cemented, effervescent, low plasticity, slightly moist, very firm, high to very high dry strength, ductile, no stains, no odors note: at 26' sand & silt decrease while clay increases; gradational basal contact		
4999.1	25	11-15-18 (08:20)				25	
				CL	**CLAY,** 99% fines, fine grained, subrounded sand, dark brown (7.5YR 3/3), occasional gypsum nodules (<3 mm), massive, effervescent, medium to high plasticity, moist, stiff to very stiff firmness, medium dry strength, ductile, gray staining, no odors		4" Nominal Diameter Schedule 80 PVC (0.020" Slot Screen) from 15' to 45'
4994.1	30	11-15-18 (08:34)				30	
					note: at 35.0' gypsum nodules decrease (rare)		
4989.1	35	11-15-18 (08:53)			note: at 36.0' wet sandy elastic silt lense, ~1.5' (see MW-65A log for unit description) note: at 37.5' sharp basal contact	35	
				CL	**SILTY CLAY,** 99% fines, 1% fine grained, subrounded sand, dark reddish-brown (5YR 3/4), gypsum nodules absent, massive, effervescent, medium to high plasticity, moist to wet, stiff, medium to high dry strength, ductile, rare gray staining, no odors		
4984.1	40	11-15-18 (09:11)			note: from 40' to 43' core samples more compact in diameter note: at ~43' medium stiffness, sand increases, gravel present (0.5-7.5 cm), core sample diameter expanded, and gradational basal contact	40	
				CL	**GRAVELLY CLAY,** 70% fines, 20% fineto coarse grained, subrounded to subangular gravel, 10% fine to coarse grained, subrounded to subangular sand, dark reddish-brown (5YR 3/2),		Dedicated submersible pump
4979.1	45					45	

GROUNDWATER

	DEPTH(ft bgs)	HOUR	DATE
▽	35.8	09:30	11/15/18
▼	34.4	09:40	11/15/18
▼	33.9	07:15	11/16/18
▼			

METHOD Not Applicable

(Continued Next Page)

wood.

Environment & Infrastructure Solutions, Inc.
4600 East Washington Street, Suite 600
Phoenix, Arizona 85034

BORING LOG I.D.: MW-67A

PROJECT:	APS Cholla Power Plant CCR Compliance	**PROJECT LOCATION:**	APS Cholla Power Plant
ADWR REG. #:	55-922301	**PROJECT FEATURE:**	Fly Ash Pond

Elevation in Feet	Depth in Feet	Graphical Log	Sample ID. or Date (Time)	PID Meter Reading (ppm)	Unified Soil Classification	VISUAL CLASSIFICATION (Color, Moist, % by wt., Plasticity, Dilatancy, Toughness, Dry Strength, Consistency)	Depth in Feet	WELL INFORMATION (Construction Details and/or Drilling Remarks)
4979.1	45		11-15-18 (09:40)		CL	nonlithified, massive, effervescent, medium to high plasticity, wet, soft to very soft firmness, medium dry strength, no odors. note: at 45' wet sandy elastic silt lense, ~1.5' (see MW-65A log for unit descrip.) note: at 47' sharp basal contact with siltstone to mudstone	45	(Continued) Pea Gravel from 45' to 47.5' Bentonite Chips from 47.5' to 50'
						Trmhm - Moqui Member of Moenkopi Formation (mid-unit), SANDY SILT WITH SAND & Interbedded mudstone, 65% fines, 25% fine to coarse grained, subangular sand, dark reddish-brown (7.5YR 3/4) with rare olive brown staining (2.5Y 4/4), granular to rounded blocky soil structure, lithified mudstone samples, mudstone with thin laminae (<0.5mm), effervescent, slightly moist, medium plasticity, low to medium dry strength, friable, no odors		
4974.1	50		11-15-18 (10:00)			Total Depth = 50'	50	Total Depth = 50'
4969.1	55						55	
4964.1	60						60	
4959.1	65						65	
4954.1	70						70	

GROUNDWATER

	DEPTH(ft bgs)	HOUR	DATE
∇	35.8	09:30	11/15/18
▼	34.4	09:40	11/15/18
▼	33.9	07:15	11/16/18
▼			

METHOD Not Applicable

ATTACHMENT B

SOILS LAB RESULTS FOR CORE FROM MW-67A

wood.

PROJECT: Cholla APP & CCR Compliance Support
LOCATION: Joseph City, AZ
MATERIAL: Native Soil

JOB NO: 14-2018-2040.****.01
WORK ORDER NO: 1
DATE ASSIGNED: 11/19/18

DENSITY OF ROCK CORE USING VOLUMETRIC CALCULATIONS

LAB #	BORING	MOISTURE WET WT. (g)	MOISTURE DRY WT. (g)	MOISTURE CONTENT	DIA. (cm)	HGT. (cm)	WET WEIGHT & RINGS (g)	WEIGHT OF RINGS (g)	DRY DENSITY (pcf)	SPECIFIC GRAVITY	POROSITY
18-3840-02	MW 67A (11-11.5')	462.0	372.3	24.1%	4.9	13	602.2	138.5	94.4	2.738	0.45
18-3840-03	MW 67A (16-16.5')	558.0	427.9	30.4%	4.9	15	720.1	162.1	92.0	2.773	0.47
18-3840-04	MW 67A (21-21.5')	452.1	406.7	11.2%	4.9	14	615.5	147.0	99.8	2.741	0.42

Wood Environment & Infrastructure Solutions, Inc.
3630 E Wier Ave.
Phoenix, AZ 85040

REVIEWED BY ________________