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Prepared by
Ramboll Environ
Emeryville, California

Date
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ATHENS ROAD WELL FIELD CAPTURE EVALUATION AND MATRIX DIFFUSION STUDY WORK PLAN

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RAMBOLL ENVIRON

Athens Road Well Field
Capture Evaluation and Matrix Diffusion Study Work Plan

Nevada Environmental Response Trust Site
(Former Tronox LLC Site)
Henderson, Nevada

Nevada Environmental Response Trust (NERT) Representative Certification
I certify that this document and all attachments submitted to the Division were prepared at the request of, or under the direction or supervision of NERT. Based on my own involvement and/or my inquiry of the person or persons who manage the system(s) or those directly responsible for gathering the information or preparing the document, or the immediate supervisor of such person(s), the information submitted and provided herein is, to the best of my knowledge and belief, true, accurate, and complete in all material respects.

Office of the Nevada Environmental Response Trust

not individually, but solely as Pres. Trust

Signature: Jay A Steinberg, __________, not individually, but solely in his representative capacity as President of the Nevada Environmental Response Trust Trustee

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Responsible Certified Environmental Manager (CEM) for this project

I hereby certify that I am responsible for the services described in this document and for the preparation of this document. The services described in this document have been provided in a manner consistent with the current standards of the profession and, to the best of my knowledge, comply with all applicable federal, state and local statutes, regulations and ordinances.

September 22, 2017

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ACRONYMS AND ABBREVIATIONS

AMEW	Auto Mall Extraction Well
AMPAC	American Pacific Corporation
APEW	Athens Pen Extraction Well
AREW	Athens Road Extraction Well
AWF	Athens Road Well Field
bgs	Below ground surface
BMI	Black Mountain Industrial
Br-	Bromide ion
CEM	Certified Environmental Manager
COH	City of Henderson
COPCs	Chemicals of potential concern
EC	Electrical conductivity
ENVIRON	ENVIRON International Corporation
FGD	Field Guidance Document
FS	Feasibility Study
GEI	GEI Consultants, Inc.
gpm	Gallons per minute
GWETS	Groundwater extraction and treatment system
GWTS	Groundwater treatment system
IWF	Interceptor Well Field
lbs/day	pounds per day
mg/L	milligrams per liter
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NDEP	Nevada Division of Environmental Protection
NERT	Nevada Environmental Response Trust
OSSM	Olin/Stauffer/Syngenta/Montrose
PEPCON	Pacific Engineering and Production Company
Ramboll Environ	Ramboll Environ US Corporation
RI	Remedial Investigation
SAP	Sampling and Analysis Plan
SWF	Seep Well Field

TDS	Total dissolved solids
Tetra Tech	Tetra Tech, Inc.
TIMET	Titanium Metals Corporation
Tronox	Tronox LLC
Trust	Nevada Environmental Response Trust
UMCf	Upper Muddy Creek Formation
UMCf-cg1	Upper Muddy Creek Formation (first coarse-grained facies)
UMCf-fg1	Upper Muddy Creek Formation (first fine-grained facies)
USEPA	United States Environmental Protection Agency
WRF	Water Reclamation Facility
xMCf	Transitional Muddy Creek Formation

1. INTRODUCTION

On behalf of the Nevada Environmental Response Trust (the Trust), Ramboll Environ US Corporation (Ramboll Environ) has prepared this work plan for the Athens Road Well Field (AWF) capture evaluation and matrix diffusion study for the Nevada Environmental Response Trust Site (the NERT Site), located in Clark County, Nevada.

In comments on the 2015 and 2016 Annual Remedial Performance Reports, the Nevada Division of Environmental Protection (NDEP) noted recent increasing perchlorate concentrations in wells located downgradient of the AWF and suggested that capture at the AWF be further evaluated (NDEP 2015, 2016). This work plan describes investigations to address the issues raised by NDEP, as well as to provide information to refine the conceptual site model in the vicinity of the AWF in support of the Remedial Investigation (RI) and Feasibility Study (FS).

As discussed in the Phase 1 Remedial Investigation Data Evaluation Technical Memorandum (Ramboll Environ 2016c), perchlorate present in the UMCf is likely migrating upwards into the alluvium as a result of back diffusion and upward flow caused by a natural upward vertical gradient. This is suspected to be the primary reason for the persistently elevated concentrations of perchlorate in several monitoring wells located directly downgradient of the AWF. The objectives of the tasks described in this work plan are (1) to confirm that matrix diffusion can explain the persistent perchlorate concentrations downgradient of the AWF, and (2) to confirm that there are no gaps in capture at the AWF that would allow significant migration of perchlorate to downgradient areas.

Section 2 of this work plan provides a summary of the background of the NERT Site, and Section 3 provides a review of existing data relevant to the evaluation of the AWF. Section 4 describes the proposed scope of work, which includes a tracer study to evaluate capture at the AWF and a matrix diffusion study to quantify the effects of matrix diffusion on perchlorate concentrations measured in the alluvium downgradient of the AWF. Section 5 describes the reporting and anticipated schedule for the scope of work. References are provided in Section 6.

2. STUDY AREA BACKGROUND

The NERT Site is located within the Las Vegas Valley in the southern region of Clark County, Nevada. Las Vegas Valley is encompassed by a set of mountain ranges, including the Spring Mountains to the west, the Sheep Range and Las Vegas Range to the north, the Frenchman Mountains and Sunrise Mountains to the east, and the River Mountains and McCullough Mountains to the south (Figure 1). The most significant stream in the valley is the Las Vegas Wash, which flows generally from west to east before discharging into Lake Mead. The climate in the area varies from semi-arid in the mountains to arid in the lowlands. Rainfall averages about 5 inches per year and occurs in storms of high intensity and short duration that often lead to floods. Potential evaporation in the area is significant and can be higher than 80 inches per year in the lower portion of the valley (UNLV 2003).

2.1 Geology and Hydrogeology

The valley floor consists of fluvial, paludal (swamp), playa, and lacustrine deposits surrounded by more steeply sloping alluvial fan aprons derived from erosion of the surrounding mountains. Generally, the deposits grade finer with increasing distance from their source and with decreasing elevation. The uppermost unit is composed of Quaternary alluvial deposits that slope north toward Las Vegas Wash. The alluvium consists of a reddish-brown heterogeneous mixture of well-graded sand and gravel with lesser amounts of silt, clay, and caliche. A major feature of the alluvial deposits is the stream-deposited sands and gravels that were laid down within paleochannels eroded into the surface of the underlying Upper Muddy Creek Formation (UMCf) during infrequent flood runoff periods.

The Pleistocene age UMCf consists of valley-fill deposits that are coarse-grained near mountain fronts and become progressively finer-grained toward the center of the valley. In some locations, the Transitional Muddy Creek Formation (xMCf) is encountered at the base of the alluvium. The xMCf consists of reworked sediments derived from the UMCf. Beneath the NERT Site, the UMCf is composed of at least two thicker units of fine-grained sediments of clay and silt (the first and second fine-grained facies) interbedded with at least two thinner units of coarse-grained sediments of sand, silt, and gravel (the first and second coarse-grained facies). Except for the southernmost 1,000 feet adjacent to Lake Mead Parkway, the first fine-grained facies (UMCf-fg1) separates the first coarse-grained facies (UMCf-cg1) from the overlying alluvium at the NERT Site. Within the southern 1,000 feet of the NERT Site, the UMCf-fg1 pinches out along a roughly west-northwesterly trending line. South of this line, the UMCf-cg1 directly underlies the alluvium.

Groundwater flows north and discharges into Las Vegas Wash, and then exits Las Vegas Basin and flows into Lake Mead. This generally uniform flow pattern may be modified locally by paleochannels cut into the underlying UMCf, areas of localized recharge from artificial ponds and trenches, and groundwater extraction from remediation system well fields.

2.2 Remediation Activities

The NERT Site comprises approximately 346 acres within the Black Mountain Industrial (BMI) Complex in Henderson, Nevada. Former industrial and waste management activities at the NERT Site have resulted in contamination of soil and groundwater with perchlorate and other chemicals. At the NERT Site, remedial activities to address off-site perchlorate impacts have been underway since approximately 1997. The perchlorate groundwater plume has migrated from the NERT Site to the Las Vegas Wash and, eventually, into the Colorado River. Off-site pump-and-treat remedial systems in operation since 1998 have reduced perchlorate discharges to the Las Vegas Wash. A detailed description of remediation activities conducted at the NERT Site is described in the Phase 5 Modeling Report (Ramboll Environ 2016b), with a summary presented below.

2.2.1 NERT Well Fields

The NERT Groundwater Extraction and Treatment System (GWETS) consists of three well fields shown on Figure 2.

Interceptor Well Field
Installation of the Interceptor Well Field (IWF), processing equipment, and a recharge trench was completed in 1987 to remediate chromium impacts to the alluvium. The recharge trenches were operational at the IWF from 1994 to 2010. A barrier wall was emplaced at the IWF in 2001 (Ramboll Environ 2016c). The locations of IWF pumping wells, barrier wall, and the recharge trenches are shown on Figure 2.

Athens Road Well Field
The Athens Road Well Field (AWF) was initially designed to intercept perchlorate in groundwater downgradient of the IWF and the NERT Site (Figure 2). The AWF is approximately 8,200 ft north (downgradient) of the barrier wall and the IWF. The AWF was constructed as a series of 14 groundwater extraction wells screened in the alluvium that span approximately 1,200 ft across two alluvial paleochannels located on either side of an UMCf ridge. The AWF was completed in March 2002 and continuous pumping began in mid-October of that year (Ramboll Environ 2016a). Groundwater levels at the AWF are currently much lower than they were in 2002 before pumping began, and the alluvium overlying the UMCf ridge has been partially dewatered.

Seep Well Field
The Seep Well Field (SWF) and the seep capture sump[1], located approximately 4,500 ft north (downgradient) of the AWF near the Las Vegas Wash, were installed in response to the discovery of perchlorate-impacted groundwater migrating (via an intermittent surface seep) to Las Vegas Wash. The SWF and sump are shown on Figure 2. Presently, the SWF consists of 10 extraction wells—two of which (PC-99R2 and PC-99R3) are connected and operate as one combined well. The wells comprising the SWF are screened across the full thickness of the alluvium and across the deepest portion of an alluvial channel (Ramboll Environ 2016a).

2.2.2 OSSM Well Field

Since December 1983, Olin Chlor Alkali Products, Stauffer Management Company, LLC/Syngenta Crop Protection, LLC, and Montrose Chemical Corporation of California (collectively referred to herein as OSSM) have been operating the Groundwater Treatment System (GWTS) at the OSSM site. As shown on Figure 2, the GWTS consists of recharge trenches and series of extraction wells. The treatment system uses air stripping and liquid-phase activated carbon treatment to remove organic compounds.

[1] The seep capture sump was reportedly last operated in April 2007 and was decommissioned (pump removed and piping blocked) shortly thereafter. Currently only the seep sump remains.

2.2.3 AMPAC Well Fields

The former Pacific Engineering and Production Company (PEPCON) facility, which operated from approximately 1958 until 1988, manufactured ammonium perchlorate and related propulsion systems. Groundwater remediation of the perchlorate plume originating from the former PEPCON site is currently being conducted by Endeavor, LLC. Remediation was previously conducted by American Pacific Corporation (AMPAC). The initial remediation system was an in-situ bioremediation treatment system that operated from 2006 to 2012 (AMPAC 2012). This system comprised an array of nine extraction wells (6 AREWs [Athens Road Extraction Wells] and 3 APEWs [Athens Pen Extraction Wells]), a water handling and conditioning plant, and a re-injection area. In 2012, the in-situ system was replaced with an ex-situ groundwater treatment system and five new extraction wells, referred to as the Auto Mall Extraction Wells (AMEWs), were installed to extract perchlorate contaminated groundwater from near the former PEPCON site source area. The 14 extraction wells (AMEWs, AREWs, and APEWs) and former injection wells are shown on Figure 2.

2.2.4 TIMET Well Field

To address groundwater impacts from volatile organic compounds, a barrier/slurry wall was constructed along the Titanium Metals Corporation (TIMET) northern site boundary in 2013. Beginning in 2014, extraction and treatment of groundwater began from a line of 19 extraction wells screened in the alluvium and extending approximately 3 to 5 ft into the UMCf (GEI 2014). The wells are generally located 150 to 160 ft apart and approximately 100 ft upgradient of their slurry wall (Figure 2). Groundwater is treated by air stripping and discharged into injection trenches located just north of the slurry wall.

3. ATHENS ROAD WELL FIELD

As described above, the AWF was constructed as a series of 14 groundwater extraction wells screened in the alluvium at six paired well locations (ART-1/1A, ART-2/2A, ART-3/3A, ART-4/4A, ART-7A/7B, ART-8/8A) and two individual well locations (ART-9, PC-150) that span approximately 1,200 ft across two alluvial paleochannels located on either side of an UMCf ridge. The six well pairs act as "buddy" wells, with one well pumping while the adjacent well is used to measure water levels and monitor the effect of pumping on the water table (Figure 3). A summary of the operation of the AWF since pumping began in 2002 is provided in this section.

3.1 Pumping Rates

Figure 4a shows the annual average pumping rates measured in individual extraction wells at the AWF from 2002 to 2017. The averages for 2017 include data from January through July. Over this period, pumping in wells ART-8 and ART-9 (located on the western and eastern side of the UMCf ridge at the AWF) significantly increased. This increase in pumping is reflected in the combined pumping rates of wells located on the eastern and western side of the UMCf ridge (Figure 4b). The total average AWF pumping increased from 130 gallons per minute (gpm) in 2002 to 405 gpm in 2017.

3.2 Groundwater Elevations and Perchlorate Concentrations

Historical groundwater level trends for monitoring and extraction wells at and downgradient of the AWF are shown on Figures 5a through 5d.

3.2.1 AWF Extraction and Monitoring Wells

Groundwater elevations and perchlorate concentration in the AWF extraction wells are shown on Figure 5a. In general, the groundwater elevations fluctuate in response to changes in extraction rates. The average perchlorate concentrations in the AWF's eight pumping wells have significantly decreased since 2002. More recently, concentrations in individual wells have fluctuated between sampling events. Perchlorate concentrations are significantly lower in extraction well ART-1, but concentrations have been increasing since 2012. As described in section 2.2.3, there is a separate perchlorate plume (the AMPAC plume) that originates at the former PEPCON plant. The AMPAC plume is commingling with the NERT plume at the western end of the AWF. The increasing trend of perchlorate in ART-1 is most likely the result of the AMPAC plume being drawn into the AWF in response to pumping.

As shown on Figure 5b, the monitoring wells located close to the AWF also show decreasing perchlorate concentration trends, except for wells PC-142 and PC-122 that are located on the edges of the well field and are likely outside of the capture zone of the AWF.

3.2.2 Athens Road Piezometer Well Line

Approximately 250 feet north of the AWF, eight wells comprise the Athens Road Piezometer or "ARP" well line. Groundwater elevations and perchlorate concentrations in the western side of the "ARP" well line (represented by ARP-1, ARP-2A, ARP-3A, and MW-K4) and the eastern side of the well line (represented by ARP-4A, ARP-5A, ARP-6B, and ARP-7) are shown on Figure 5c. With the exception of wells MW-K4 and ARP-6B, concentration trends in the ARP well line appear relatively stable. Concentrations in well

MW-K4 initially declined with the onset of AWF operation in 2002 and dropped further when ART-9 began pumping in September 2006. Perchlorate concentrations in MW-K4 generally declined between January 2010 (300 mg/L) and December 2011 (150 mg/L), but rebounded during 2012, once again reaching 300 mg/L. These increases and decreases in perchlorate concentration in MW-K4 do not appear related to changes in water elevation.

Analysis first presented in Appendix E of the 2011-2012 Annual Performance Report indicated that there could be a gap in the capture zone that may be responsible, in whole or in part, for the elevated concentrations in MW-K4 (ENVIRON 2012). This finding prompted activation of upgradient extraction well PC-150, which occurred in November 2014. Perchlorate concentrations in MW-K4 have generally decreased since pumping at PC-150 commenced. No significant changes in perchlorate concentrations were observed downgradient of well ART-7B, which was activated in October 2014. The well ARP-6B exhibited a slightly increasing trend of perchlorate concentrations until fourth quarter 2015. By January 2016, concentrations in ARP-6B had returned to levels consistent with historical trends.

The potential effects of matrix diffusion on the concentrations in wells MW-K4 and ARP-6B will be investigated in the proposed matrix diffusion study described in Section 4.

3.2.3 Water Reclamation Facility Well Line

Near the City of Henderson (COH) Wastewater Reclamation Facility (WRF), there is a line of monitoring wells referred to as the COH WRF well line (wells PC-103, PC-98R, MW-K5, PC-53, PC-1, PC-2, and PC-4), located approximately 2,200 ft north (downgradient) of the AWF. Figure 5d presents historical water elevations and perchlorate concentrations at the COH WRF well line. As shown in the figure, current perchlorate concentrations at the COH WRF well line are generally below concentrations measured in the same wells in May 2002.

More recent perchlorate concentrations at wells PC-53, PC-1, PC-2, and PC-4 have been relatively stable, while concentrations at PC-103 have been gradually increasing since 2006 and concentrations at MW-K5 and PC-98R have been increasing since 2009. The gradually increasing concentrations in wells located in the western portion of the COH WRF well line is currently unknown, but could be related to migration of the AMPAC plume or changes in the operation of the wastewater ponds at the Henderson Birding Viewing Preserve located just to the north.

Concentrations in the COH WRF wells from December 2015 through April 2016 were temporarily influenced by the Groundwater Bioremediation Treatability Study. The study area for the bioremediation treatability study is located just upgradient of the COH WRF wells, as shown on Figure 3. Emulsified oil substrate followed by chase water was injected into three injection wells in December 2015 and March 2016 (Tetra Tech 2016). Perchlorate concentrations were monitored in the downgradient wells to determine whether in-situ bioremediation could be an effective means of treating perchlorate in groundwater.

3.3 Mass Removal and Capture

Figure 6 shows the monthly perchlorate mass removal, monthly pumping rates, and average perchlorate concentrations at the AWF since pumping began. The average perchlorate mass removed from the AWF is approximately 620 lbs/day. Figure 6 shows that the combined pumping at the AWF has increased from 250 gpm in July 2004 to approximately 458 gpm in July 2017. There has also been a decrease in the average perchlorate concentration in AWF extraction wells from approximately 390 mg/L in 2002 to approximately 83 mg/L in July 2017.

Based on pumping rates from second quarter 2017, the simulated capture zone for the AWF in the Shallow Water Bearing Zone using the steady-state version of the Phase 5 Groundwater Model is shown on Figure 7. The perchlorate mass flux within the AWF capture zone along a transect upgradient of the AWF is estimated to be 421 lbs/day based on the 2016 perchlorate isoconcentration map, with any perchlorate not captured at the AWF captured further downgradient by the SWF. The model generated capture zone does not include the entire UMCf ridge located in the center of the AWF. The mass flux moving through the UMCf ridge area is estimated to be 2 lbs/day, which is less than 0.5% of the mass flux captured at the AWF. The mass flux moving through the UMCf ridge area is relatively minor for two reasons: (1) The mass of perchlorate within the area is limited; and (2) The alluvium is desaturated in this area, so that perchlorate transport occurs mainly within the UMCf, where transport will be much slower than within the alluvium due its much lower hydraulic conductivity. The water levels near the UMCf ridge measured in second quarter 2016 are shown on the geologic cross-section through the AWF presented in Figure 8. Water levels measured in 2017 are similar.

Along the ARP well line downgradient of the AWF, perchlorate concentrations in monitoring wells located downgradient of the gap in capture have been persistently elevated. For example, wells MW-K4 and ART-6B had perchlorate concentrations in 2016 of 30 mg/L and 34 mg/L, which were generally higher than other wells in the ARP well line. Historical concentrations at the ARP well line are shown on Figure 5c, and perchlorate concentrations from second quarter 2016 are shown on Figure 7. At these locations, perchlorate present in the UMCf is likely migrating upwards into the alluvium as a result of back diffusion and upward flow resulting from the natural upward vertical gradient. Vertical transport from the UMCf to the alluvium is considered the primary explanation for the persistence of perchlorate concentrations at MW-K4 and ARP-6B. However, since MW-K4 and ARP-6B are located directly downgradient of the UMCf ridge, it is possible that the minor mass flux through the UMCf ridge area is at least partially responsible for the persistently elevated perchlorate concentrations. The proposed scope of work described in the next section is designed to evaluate the effects of vertical transport from the UMCf and loss of capture at the AWF on concentrations in MW-K4 and ARP-6B.

4. PROPOSED SCOPE OF WORK

The objective of the proposed scope of work is to investigate potential causes of persistently elevated perchlorate concentrations downgradient of the AWF. The potential causes that have been identified are (1) back diffusion from the UMCf, (2) incomplete capture of the NERT plume at the AWF, and (3) contribution from the AMPAC plume. In order to investigate the first two potential causes, the proposed evaluation will focus on wells MW-K4 and ARP-6B located just downgradient of the AWF within the main paleochannels that are unlikely to be significantly influenced by the AMPAC plume. The contribution from the AMPAC plume is not evaluated in this work plan.

The main tasks are:

- To conduct tracer tests at the AWF to confirm capture near the UCMf ridge.
- To conduct field and laboratory testing to quantify the effects of back diffusion on alluvium perchlorate concentrations downgradient of AWF.

A description of each of these tasks is described in the following sections.

4.1 Tracer Tests

Tracer tests are proposed at two locations at the AWF to confirm that the perchlorate present in the alluvium upgradient of the UMCf ridge is being captured by the AWF. Additionally, the tracer tests will help quantify transport parameters that can be used to support the evaluation and design of in situ remediation systems. The only previous multi-well tracer tests at the NERT Site were conducted in 2000 by Kerr-McGee. Tracer testing was used for determining groundwater velocities at three locations between the Pittman Lateral and the Seep Well Field using deionized water and bromide as tracers (Errol Montgomery 2000).

4.1.1 Well Installation

Two new shallow wells (TRA-1 and TRA-2) will be installed approximately 60 and 50 feet upgradient of the AWF (see Figure 9). The tracer injection wells are located at the edge of the saturated alluvium adjacent to the UMCf ridge. If there is a gap in capture, it is expected to be located at this location.

The boreholes will be drilled using a sonic drilling technique. The borings will be advanced to 10 feet below the UMCf contact. All wells will be constructed of four-inch diameter Schedule 40 PVC casing, with a screened interval across the saturated thickness of the alluvium. To avoid potential damage to utilities, aboveground and underground utilities that could potentially be affected by the drilling of the wells will be identified prior to initiating any intrusive activities. Activities associated with subsurface clearance will follow procedures outlined in Field Guidance Document (FGD) 003 (ENVIRON 2014). Well drilling and completion will follow procedures outlined in FGD 003 and FGD 007 (ENVIRON 2014). Wastes derived from the drilling process will be handled in accordance with FGD 001 (ENVIRON 2014).

Soils from the borings will be sampled every foot below the water table down to 10 feet below the UMCf contact, and samples will be analyzed for perchlorate, chlorate, chromium, hexavalent chromium, and TDS. Laboratory analysis of the samples will be conducted using the methods listed in Table 1. Soil and groundwater sampling activities will the follow the Field Sampling and Analysis Plan (ENVIRON 2014).

Following well installation and construction, the new monitoring wells will be developed following FGD 008 (ENVIRON 2014a). Water quality parameters, flow rate, and water level information will be recorded during development. As specified in FGD 007 (ENVIRON 2014a), well locations and elevations will be surveyed by a Nevada-licensed surveyor and tied to an established state or county benchmark. Horizontal coordinates will be surveyed to a horizontal accuracy of at least 0.1 foot and referenced to the Nevada Coordinate System of 1983 (NAD83). The vertical elevations survey will be accurate to 0.01 foot relative to mean sea level datum (NAVD88).

4.1.2 Tracer Testing

Bromide ion (Br-) was selected as the tracer because it is non-toxic, low-cost, easily detected in the field, biologically stable, non-reactive and been used extensively in groundwater and surface water applications. A significant advantage of using bromide as a tracer is that concentrations can be determined in the field using a bromide-specific electrode, which allows concentration measurements to be made at very frequent time intervals and provides more accurate information about tracer arrival time and recovered mass. If during initial testing interference from the presence of other dissolved ions in groundwater significantly degrades the accuracy of the bromide probe, an alternative tracer such as a fluorescent dye will be used instead of bromide. Determination of the amount of tracer to inject will be based on natural background concentrations, the detection limit for the tracer, and the dilution expected. Background concentrations of bromide ranged from non-detect to 12 mg/L in recent samples from the nearby study area (Tetra Tech 2016).

Two parallel tracer tests (one at each new well location) will be performed. During the tests, bromide will be monitored in existing wells located downgradient of TRA-1 (PC-150, PC-144 and MW-K4) and downgradient of TRA-2 (ART-6, ART-9, PC-136, PC-145 and ARP-6B). The monitoring network (shown in Figure 9) includes monitoring wells located along the estimated flow path of groundwater downgradient of the tracer injection wells. In each monitoring location, bromide-specific probes and associated data loggers will be placed in the monitoring wells so that near continuous monitoring can be conducted. Grab groundwater samples for laboratory analysis of bromide will be collected from each well prior to the start of the test and weekly during the test. The laboratory samples will be used to confirm the results of the bromide probes. Based on the estimated groundwater velocity, if the tracer is not captured by the extraction wells, it would be detected in wells MW-K4 and ARP-6B after about 5 days of injection with the peak occurring after about 10 days. Monitoring will continue for up to 12 weeks following the tracer injection.

The tracer breakthrough curves from each monitoring point will be evaluated to estimate the effectiveness of capture around the UMCf ridge. The presence of the tracer in downgradient monitoring wells would indicate a lack of capture. Conversely, a high mass recovery rate in the extraction wells would indicate a high degree of capture.

4.1.3 Permitting

The tracer test will require an Underground Injection Control (UIC) permit since it involves injection of a chemical tracer into the subsurface via injection wells. NDEP administers the Nevada UIC program and regulates injection wells under the authority of the Nevada Revised Statutes (NRS) 445A.300 - 445A.730 and the Nevada Administrative

Code (NAC) NAC 445A.810 - 445A.925, inclusive. Based on communication with NDEP Bureau of Water pollution Control, approval for the injection of tracer can be sought through the existing UIC permit (UIC Permit UNEV94218), which provides for the operation of two on-site recharge trenches downgradient of the barrier wall (currently idle), by submitting UIC Form U240: UIC Requests for Chemical Use and an accompanying letter with supplemental information (purpose of injection, locations, description of monitoring, etc.).

The tracer test will also require a NAC 534.441 Monitor Well Drilling Waiver and a NAC 534.320 Notice of Intent Card to install monitoring wells. As required, the monitoring wells will be drilled by a licensed well driller pursuant to Nevada Revised Statutes 534.160 and will be constructed pursuant to NAC Chapter 534 – Underground Water and Wells.

4.2 Matrix Diffusion Study

A matrix diffusion study will be performed to quantify the effect of back diffusion from the UMCf to the alluvium on the concentrations of perchlorate measured in alluvium monitoring wells MW-K4 and ARP-6B. Historically, when site discharges containing high concentrations of perchlorate were migrating downgradient in the alluvium, vertical transport from the alluvium to the UMCf would have occurred creating a significant mass of perchlorate in the uppermost reaches of the UMCf. As perchlorate concentrations in the overlying alluvium decreased with the onset of pumping activities and natural flushing, perchlorate mass that accumulated in the UMCf would migrate upward from the UMCf into the alluvium via back diffusion and upward groundwater flow. In order to quantify matrix diffusion effects, the characteristics of both the alluvium and UMCf must will be investigated. The components of the matrix diffusion study will include the following elements:

- Measurement of the vertical hydraulic gradient between the alluvium and the UMCf using clusters of piezometers at different depths.
- Determination of the perchlorate concentration gradient via developing vertical concentration profiles from soil and groundwater sampling.
- Measurement of the groundwater velocity in the alluvium using borehole dilution tests.
- Measurement of the hydraulic conductivity of the alluvium and UMCf using slug tests.
- Field determination of diffusion parameters in the UMCf using borehole dilution tests and confirmed using laboratory diffusion tests.
- Laboratory testing of soil physical properties will be used to confirm field tests. For example, hydraulic conductivities from slug tests will be confirmed using laboratory testing on soil cores.

The data from the matrix diffusion study will be interpreted using a simple model of flow and transport. The components of the study are described in more detail below.

4.2.1 Soil Boring and Piezometer Installation

To determine the perchlorate concentration gradient that would drive matrix diffusion, detailed soil concentration profiles will be constructed. Two soil borings will be drilled downgradient of MW-K4 and ARP-6B through the alluvium-UMCf contact which is anticipated to be encountered at a depth of approximately 45 ft below ground surface (bgs). The borings will be drilled to a total depth of 65 feet below ground surface (bgs), and will penetrate approximately 20 ft into the UMCf. The approximate locations of proposed soil borings (PZ-1 and PZ-2) are shown on Figure 9. Within each soil boring, soil samples will be collected with a 1 foot spacing beginning 3 ft above the alluvium-UMCf contact to 17 ft below the contact (20 soil samples in total). Soil samples will be analyzed for the parameters listed in Table 1. Soil retrieved using continuous core sampling equipment will be logged. Only relatively undisturbed samples will be selected for physical testing, which will include dry bulk density, specific gravity, grain density, total porosity, effective porosity, hydraulic conductivity, USCS soil classification, and grain size distribution.

After the soil borings are completed, permanent clustered piezometers will be constructed in order to accurately measure vertical hydraulic gradients. Each clustered piezometer location will have three closely-spaced piezometers: shallow (PZ-1S, PZ-2S), middle (PZ-1M, PZ-2M), and deep (PZ-1D, PZ-2D). The deep piezometers will be installed to a depth of approximately 65 feet below ground surface (bgs), which corresponds to 20 feet below the base of the alluvium. The middle wells will be installed to approximately 10 feet below the base of the alluvium, and the shallow wells will be installed to the base of the alluvium. Each individual well will be screened at the bottom with a 1-foot screen.

To avoid potential damage to utilities, aboveground and underground utilities that could potentially be affected by the drilling of the wells will be identified prior to initiating any intrusive activities. Activities associated with subsurface clearance will follow procedures outlined in Field Guidance Document (FGD) 003 (ENVIRON 2014). The boreholes will be drilled using a sonic drilling technique. A sonic drilling rig will be utilized to advance the borehole to approximately 65 feet bgs. Well drilling and completion will follow procedures outlined in FGD 003 and FGD 007 (ENVIRON 2014). Wastes derived from the drilling process will be handled in accordance with FGD 001 (ENVIRON 2014).

As specified in FGD 007 (ENVIRON 2014), well locations and elevations will be surveyed by a Nevada-licensed surveyor and tied to an established state or county benchmark. Horizontal coordinates will be surveyed to a horizontal accuracy of at least 0.1 foot and referenced to the Nevada Coordinate System of 1983 (NAD83). The vertical elevations survey will be accurate to 0.01 foot relative to mean sea level datum (NAVD88). Following well installation and construction, the new monitoring wells will be developed following FGD 008 (ENVIRON 2014). Water quality parameters, flow rate, and water level information will be recorded during development.

Groundwater samples from the proposed piezometers will be collected and analyzed for chlorate, chromium, hexavalent chromium, perchlorate, and TDS (six groundwater samples in total from PZ-1 and PZ-2 clusters, three samples at each piezometer cluster). The specific analytical testing methods are summarized in Table 1. In addition, to gain a better understanding of groundwater geochemistry and how geochemical conditions affect the fate and transport of chemicals of concern groundwater samples from the proposed piezometers will be analyzed for standard geochemical parameters. The geochemical parameters, which are summarized in Table 1, include dissolved major and minor ions and redox sensitive parameters. The data quality of the major ion results will be checked by performing an anion-cation balance, comparing measured and calculated TDS, and comparing measured TDS to the electrical conductivity (EC) ratio.

Soil and groundwater sampling activities will generally follow the Field Sampling and Analysis Plan (ENVIRON 2014).

4.2.2 Slug Testing and Borehole Dilution Testing

Slug testing will be performed in each of the six piezometers to obtain hydraulic conductivity measurements. Prior to conducting each slug test, the water level in the piezometer will be measured manually with an electronic water level probe to determine the static groundwater level. An electronic pressure transducer with data logger will then be suspended in the well, and water levels will be monitored until static conditions are reestablished. A failing-head slug test will then be performed by quickly lowering a weighted and sealed PVC pipe into the piezometer (slug), securing it in place above the transducer while recording the changes in water levels with the transducer. Once water levels return to static conditions, a rising-head slug test will be performed by quickly removing the slug and recording the changes in water levels with the transducer. Barometric pressure changes during the testing will be monitored and recorded using a pressure transducer placed above the water table in a nearby monitoring well. AQTESOLV (Duffield 2007) will be used for slug test analysis in order to estimate hydraulic conductivities.

Borehole dilution testing will be performed in the shallow (above the contact in Qal) and middle piezometers (10 ft bellow the contact in UMCf) to obtain information regarding horizontal groundwater flow velocity. The borehole dilution tests will be conducted by quickly releasing a tracer into the well and continuously monitoring the concentration within the same well. Due to high TDS in the area (8,300 mg/L and 6,900 mg/L measured in August 2016 at MW-K4 and ARP-6B, respectively), distilled water will be used as the tracer and monitoring will be conducted using an electrical conductivity meter with associated data logger placed in the well. All wells selected for testing will be sampled and analyzed for TDS in the laboratory to determine baseline concentrations.

A borehole dilution test in an alluvium well was recently performed by Tetra Tech as part of the In Situ Bioremediation Treatability Study using a similar approach. The test was concluded in 5 hours after reaching the baseline concentration. It is anticipated that the proposed borehole dilution testing in the shallow (alluvium) piezometers will take a similar amount of time. Based on preliminary calculations, borehole dilution testing in the UMCf piezometers will take approximately 5 and 31 days to reach 50% and 90% of the baseline TDS concentrations, respectively. Monitoring would be conducted until the concentrations have returned to near (~90%) baseline concentrations.

The tracer will be injected after several days of hydraulic head monitoring in order to avoid possible hydraulic fluctuation and ensure that the test is conducted in a stable and steady-state flow regime. Injection should not last more than a few minutes (2-5 minutes in the alluvium and 10-20 minutes in UMCf-fg), so that it can be considered an instantaneous injection in comparison to the length of the monitoring period. During the entire duration of the test, the water within the injection borehole will be frequently mixed (to avoid density effects) using circulation pumps located within the well. To verify the results of the conductivity probes, groundwater samples will be collected for laboratory analysis of TDS on the following schedule: hourly for the first 8 hours after the injection (day 1), twice a day for the following week (days 2-7), and once a week for the following 3 weeks (days 8-31).

The data from the borehole dilution test will be analyzed using the models STANMOD (Šimůnek et al. 2008) and MIN3P (Mayer et al. 2014) in order to estimate groundwater flow velocities. For the dilution test in the UMCf piezometers, diffusion from the UMCf may significantly affect tracer concentration and will be assessed during the analysis of the results. If diffusion is significant, the tests performed in the UMCf can also be used to quantify diffusion parameters (Bernstein et al. 2007), which will provide a confirmation of laboratory diffusion testing.

4.2.3 Laboratory Testing of Diffusion Coefficient

Two soil samples from the UMCf at each location (PZ-1 and PZ-2) will be collected and used for laboratory diffusion experiments (4 samples in total). The through-diffusion cell test method will be used to estimate the effective diffusion coefficient of soil samples. In this method, a sample is positioned between two solution reservoirs of equal hydraulic head. A concentration gradient is established across the soil sample by the addition of a tracer to one of the reservoirs. Following the initial breakthrough of tracer, the amount of tracer diffusing through the sample into the elution reservoir will eventually reach a steady-state. Once the system has reached a steady state, the flux of tracer across the sample will be measured and the effective diffusion coefficient of the tracer in the soil sample can be estimated.

The laboratory diffusion studies will be performed in Dr. Jacimaria Batista’s laboratory at the University of Nevada, Las Vegas. The results of the diffusion tests will be analyzed using MIN3P in order to estimate effective diffusion coefficients.

4.3 Data Analysis

The tracer test results will be analyzed to determine whether there is any indication that groundwater flowing near the UMCf ridge is not being completely captured by the AWF extraction wells. Soil samples collected from the injection well locations will be evaluated to determine the vertical distribution of perchlorate.

From the matrix diffusion test locations, the following analyses will be conducted on the data collected:

- Determine hydraulic conductivity from slug tests results.
- Estimate groundwater velocities from the borehole dilution test results.
- Evaluate vertical hydraulic gradients from water levels in the piezometers and vertical distribution of perchlorate from the soil samples.
- Evaluate effective diffusion coefficients from the laboratory diffusion study and the borehole dilution tests from the UMCf.
- Summarize soil physical properties in different geologic units from laboratory testing data.

The results from the investigations described above will be incorporated into a simple focused model of flow and transport in order to understand the relative effects of matrix diffusion, upward groundwater flow, and loss of capture at the AWF on the alluvium concentrations at wells MW-K4 and ARP-6B. The modeling will be conducted with the

MIN3P code, with the model input parameters defined by the results of the field and laboratory investigations.

4.4 Reporting

Monthly status updates will be provided to the Trust, NDEP, and US EPA summarizing the progress of this task. At the conclusion of the work, the results will be integrated into the OU-1/OU-2 RI Report. This will include:

- Analytical results summary of soil and groundwater samples collected during field activities;
- Results of the slug tests, borehole dilution tests, and diffusion tests along with a description of how the data were analyzed;
- Results of the tracer test and matrix diffusion study along with a description of how the data were analyzed; and
- Quantitative assessment of the relative effects of matrix diffusion and loss of capture at the AWF on the persistent perchlorate concentrations at MW-K4 and ARP-6B.

5. SCHEDULE

The field investigations described in Section 4 will be conducted after the approval of this work plan by NDEP. It is anticipated that the field implementation of the tracer test and matrix diffusion study can begin within 30 days following NDEP approval of the work plan and authorization of a scope of work and budget for the study implementation, providing all access agreements, as appropriate, have been secured.

The following schedule is subject to change, but is based on Ramboll Environ's experience on this and similar projects. However, the actual scheduling of the study implementation will be based on direction to Ramboll Environ from the Trust. The anticipated schedule has been divided into five phases, to be conducted sequentially except for Phases 3a and 3b that can be conducted in parallel.

Phases	Time Required
Phase 1. Permitting and Pre-Mobilization Tasks	**2 to 4 weeks**
Phase 2. Mobilization, Soil Boring and Well Installation	**3 to 4 weeks**
Phase 3a. Slug, Tracer, and Borehole Dilution Testing	**8 to 10 weeks**
Phase 3b. Laboratory Analytical and Diffusion Testing	**6 to 8 weeks**
Phase 4. Data Analysis	**8 weeks**
Phase 5. Data Integration in the RI Report	**4 weeks**

The schedule is illustrated on Figure 10.

6. REFERENCES

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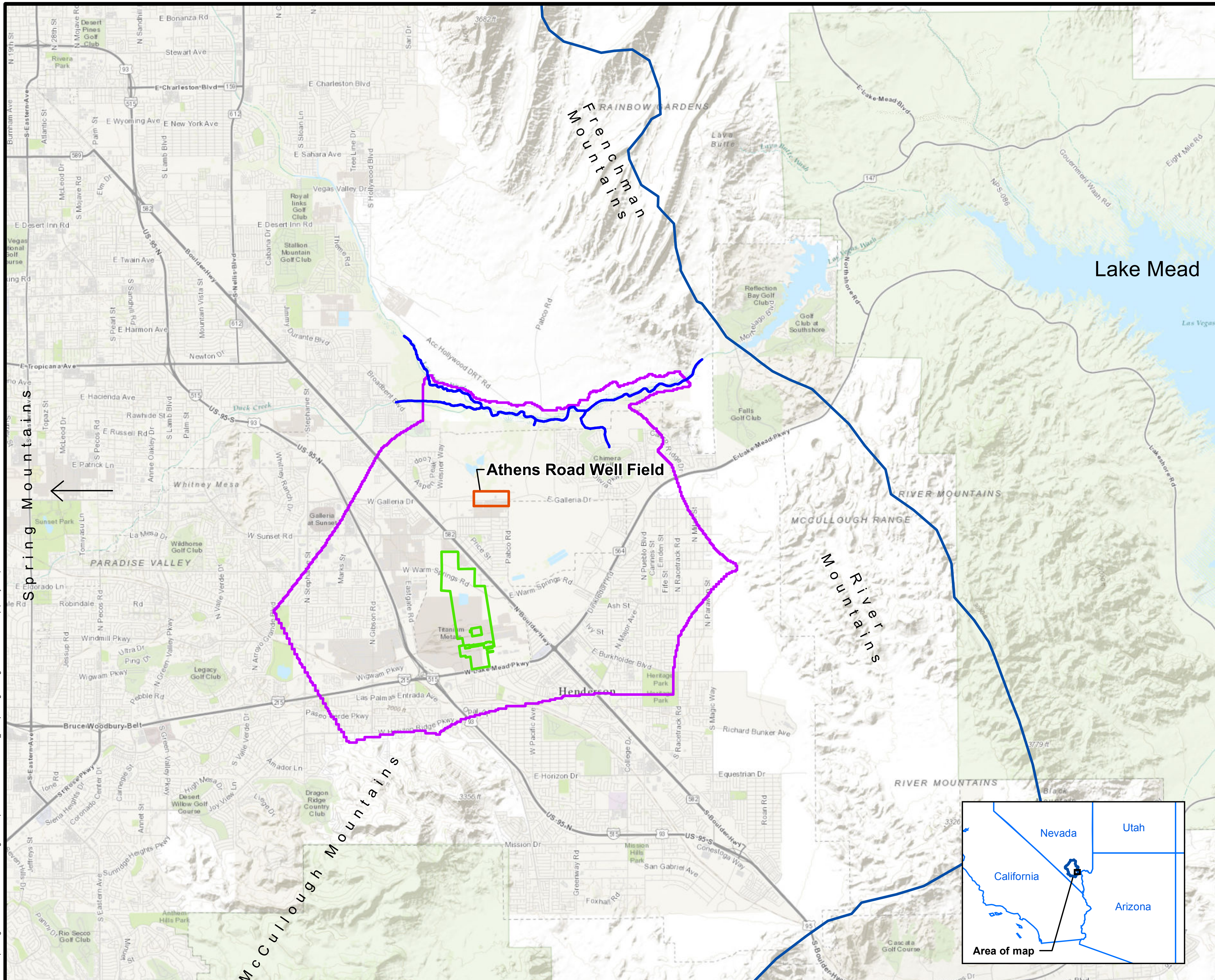
FIGURES



Path: \\Wcevfps1\eng\LePetomane\NERT\Modeling\AWF Capture Evaluation-L12\AWF_Workplan\Figures\Figure 1 - Location Map (Study Area).mxd

EXPLANATION

- Las Vegas Wash
- NERT Property Boundary
- Las Vegas Valley Hydrologic Basin
- Phase 5 Model Extent

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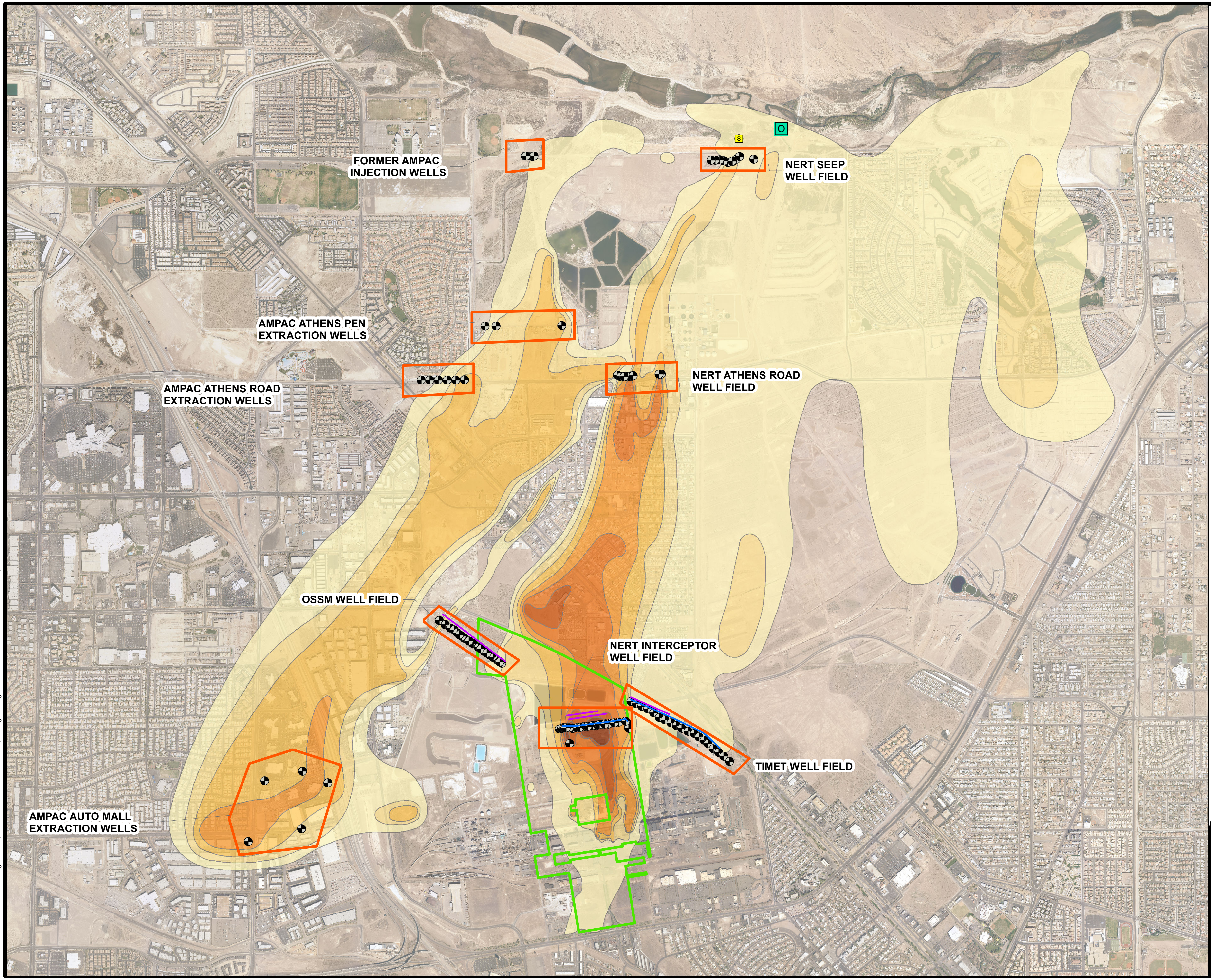
STUDY AREA LOCATION MAP

Nevada Environmental Response Trust Site
Henderson, Nevada

Date: 8/18/2017	Contract Number: 21-41400C		Figure 1
Drafter: AS	Approved:	Revised:	



EXPLANATION

- S Surface Flow Capture Sump (Not operational since 2007)
- Recharge Trench
- Slurry / Barrier Wall
- Pumping Well
- O NERT / AMPAC / TIMET / COH Outfall Location
- NERT Property Boundary

Perchlorate Iso-concentration (2016)

- 1-10
- 10-25
- 25-100
- 100-250
- 250-500
- 500-1,000
- >1,000 mg/L

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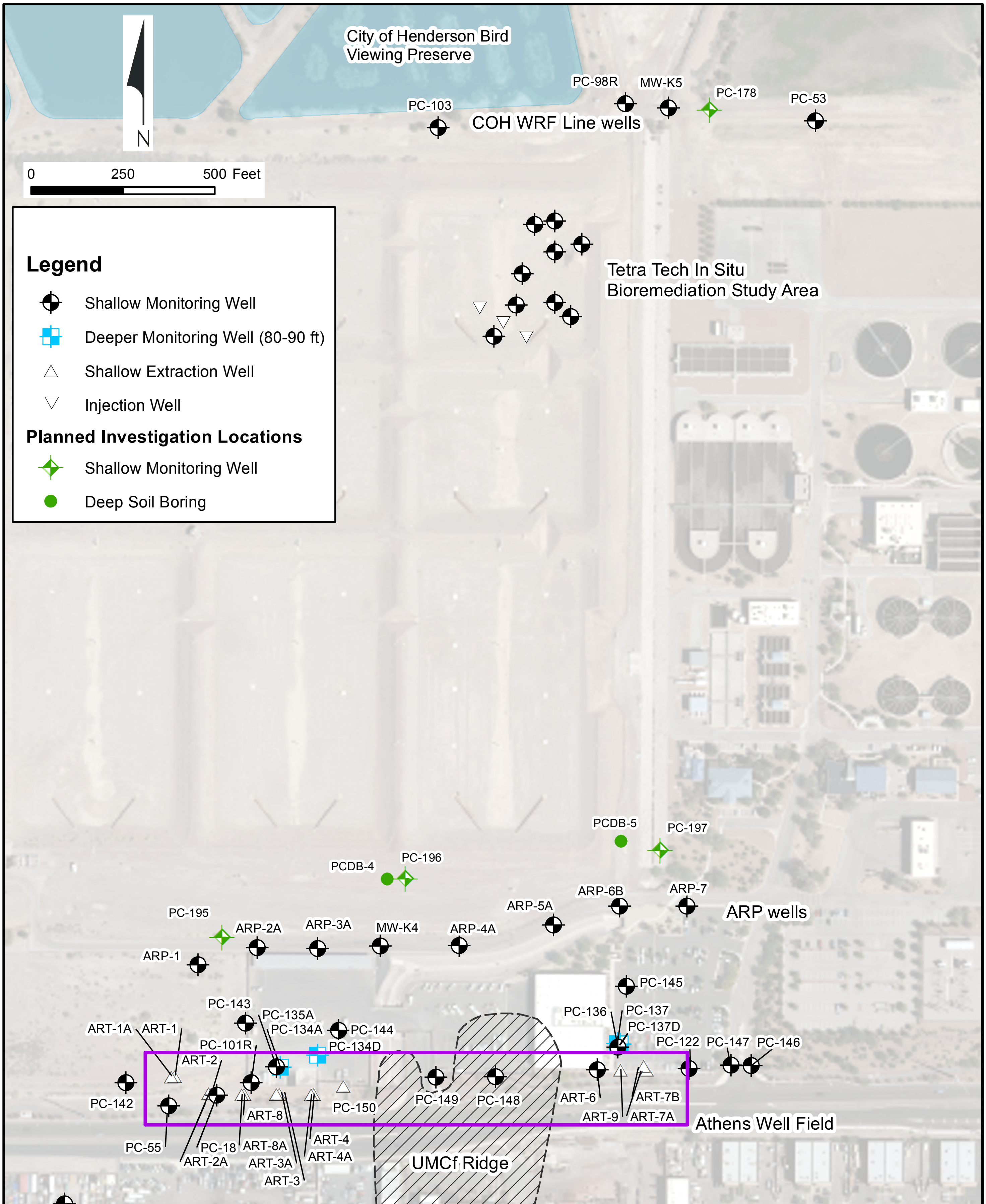
REMEDIATION SYSTEMS
Nevada Environmental Response Trust Site
Henderson, Nevada

Date:	Contract Number:		Figure
9/21/2017	21-41400C		2
Drafter: AS	Approved:	Revised:	

Path: H:\LePetomane\NERT\Modeling\AWF Capture Evaluation-L12\AWF_Workplan\Figures\Figure 2 - Well Field Location (with Plume Map).mxd



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Athens Road Well Field Location Map

Nevada Environmental Response Trust Site
Henderson, Nevada

Figure **3**

Drafter: JL | Date: 8/24/2017 | Contract Number: 21-41400C | Approved: | Revised: PR

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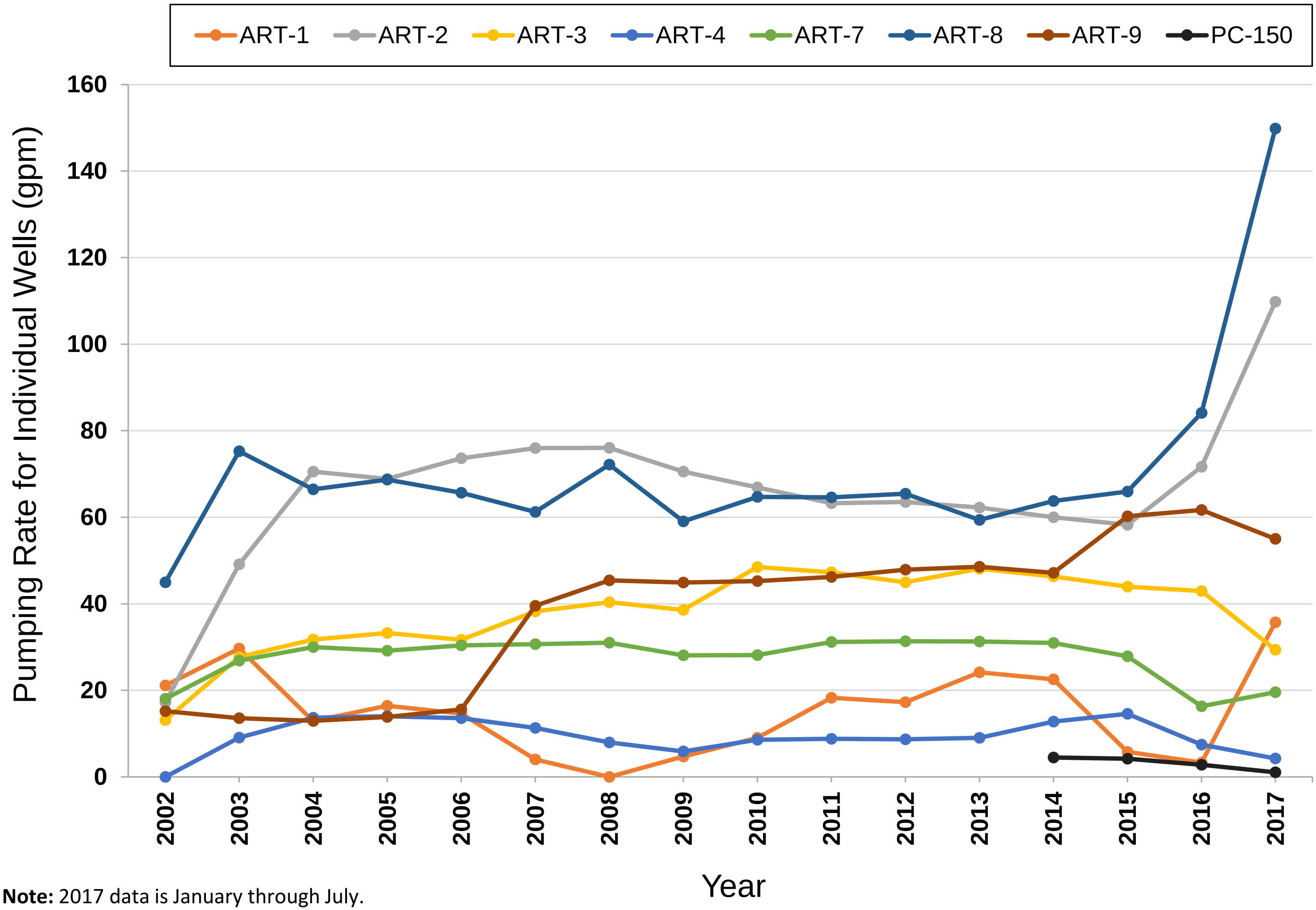

Note: 2017 data is January through July.

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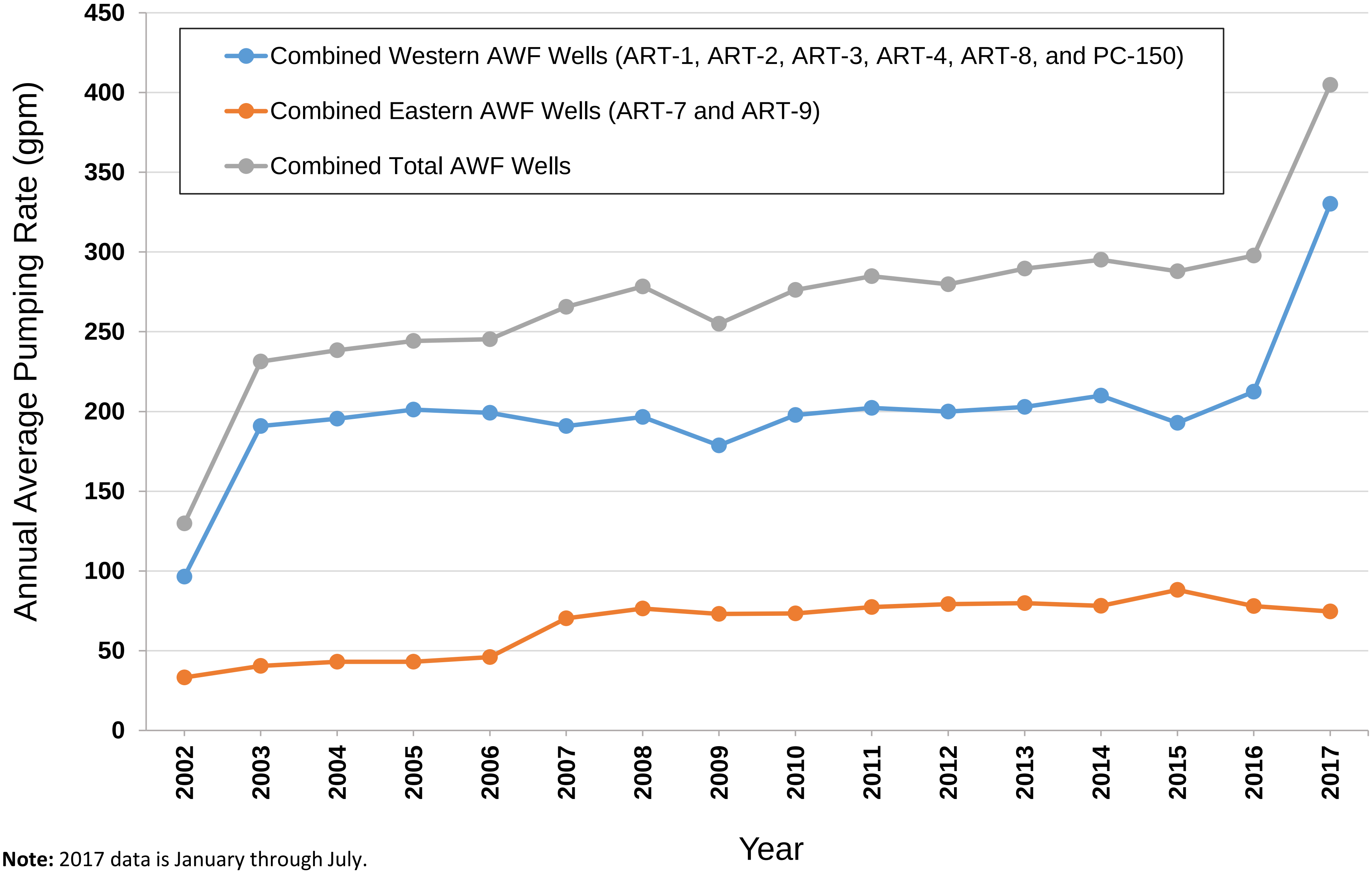
DRAFTED BY: JSM | 7/26/2017

Annual Average Pumping Rates at the Athens Road Well Field

Nevada Environmental Response Trust Site
Henderson, Nevada

Figure 4a

PROJECT: 21-41400C



Note: 2017 data is January through July.

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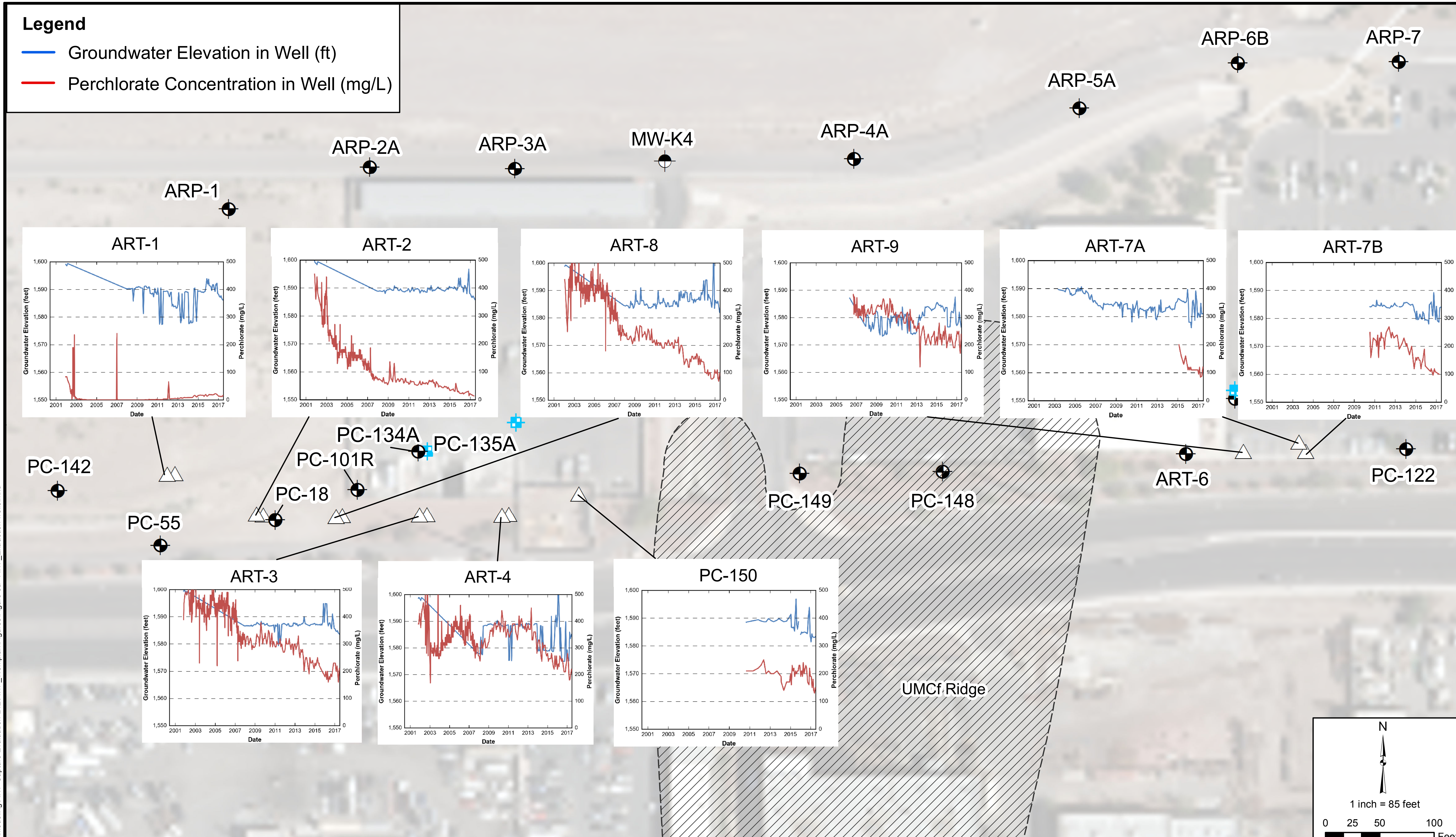
DRAFTED BY: JSM | 7/26/2017

Combined Pumping Rates for the Eastern and Western Portions of the Athens Road Well Field

Nevada Environmental Response Trust Site
Henderson, Nevada

Figure 4b

PROJECT: 21-41400C



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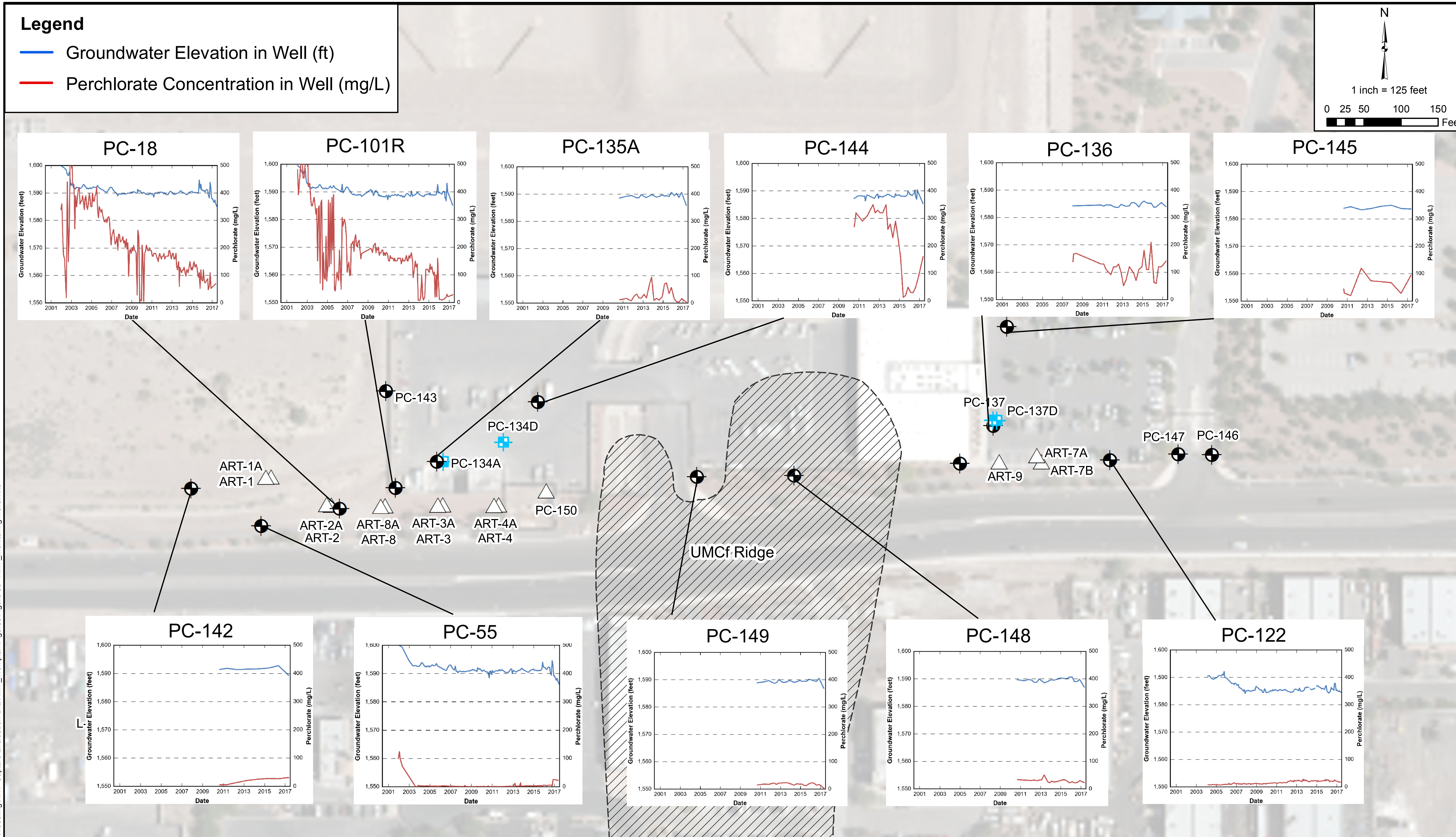
Perchlorate Concentrations and Groundwater Elevations for Pumping Wells at the Athens Road Well Field
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
5a

Drafter: AS | Date: 9/18/2017 | Contract Number: 21-41400C | Approved by: AS | Revised: AS

Path: H:\LePetomane\NERT\Modeling\AWF Capture Evaluation-L12\AWF_Workplan\Figures\Figure 5a - AWF_Extraction wells.mxd



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Perchlorate Concentrations and Groundwater Elevations for Monitoring Wells at the Athens Road Well Field

Nevada Environmental Response Trust Site

Henderson, Nevada

Figure **5b**

Drafter: AS | Date: 9/14/2017 | Contract Number: 21-41400C | Approved by: AS | Revised: AS

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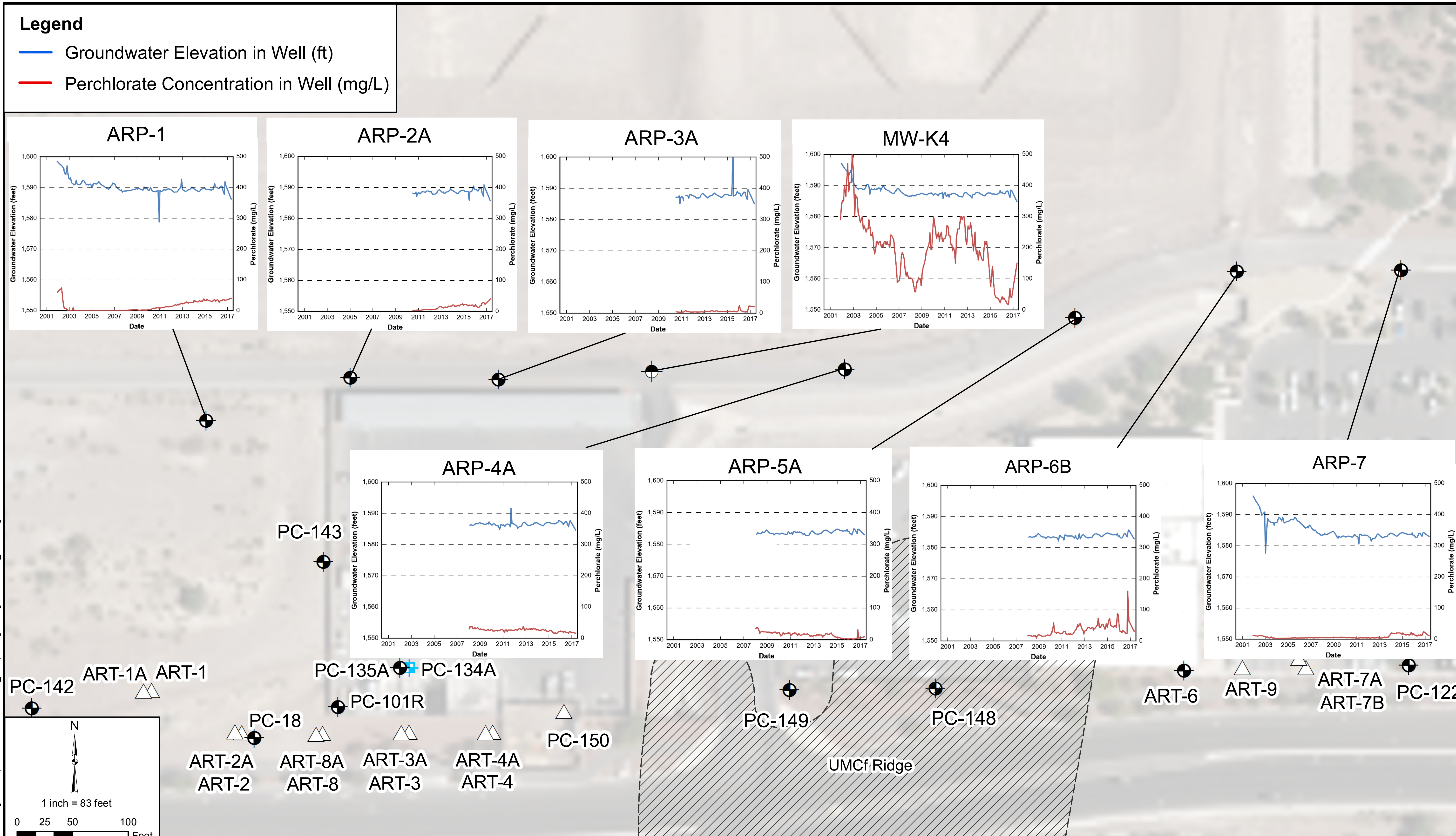

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Perchlorate Concentrations and Groundwater Elevations at the "ARP" Well Line

Nevada Environmental Response Trust Site
Henderson, Nevada

Figure **5c**

Drafter: AS | Date: 9/14/2017 | Contract Number: 21-41400C | Approved by: AS | Revised: AS

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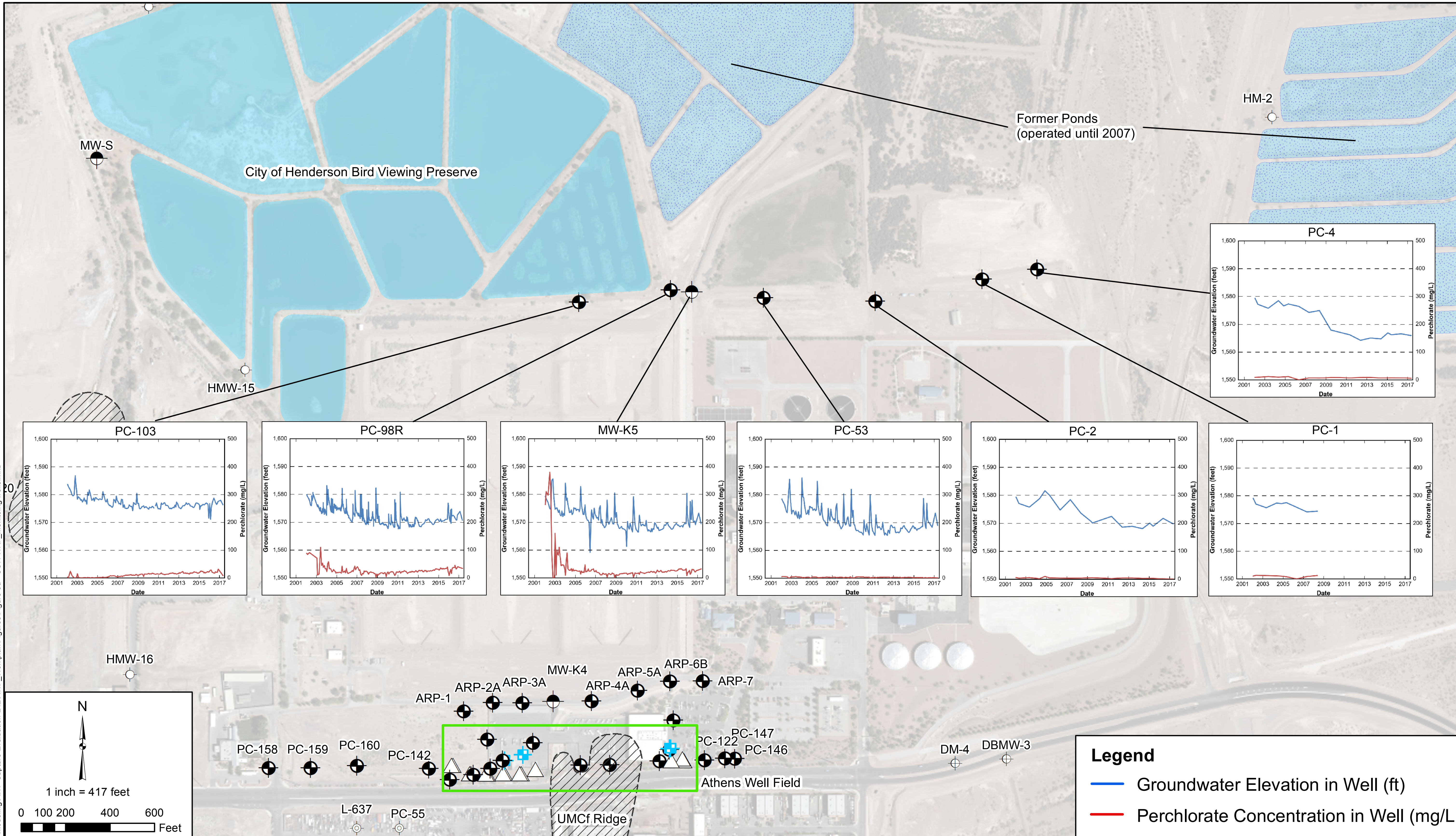

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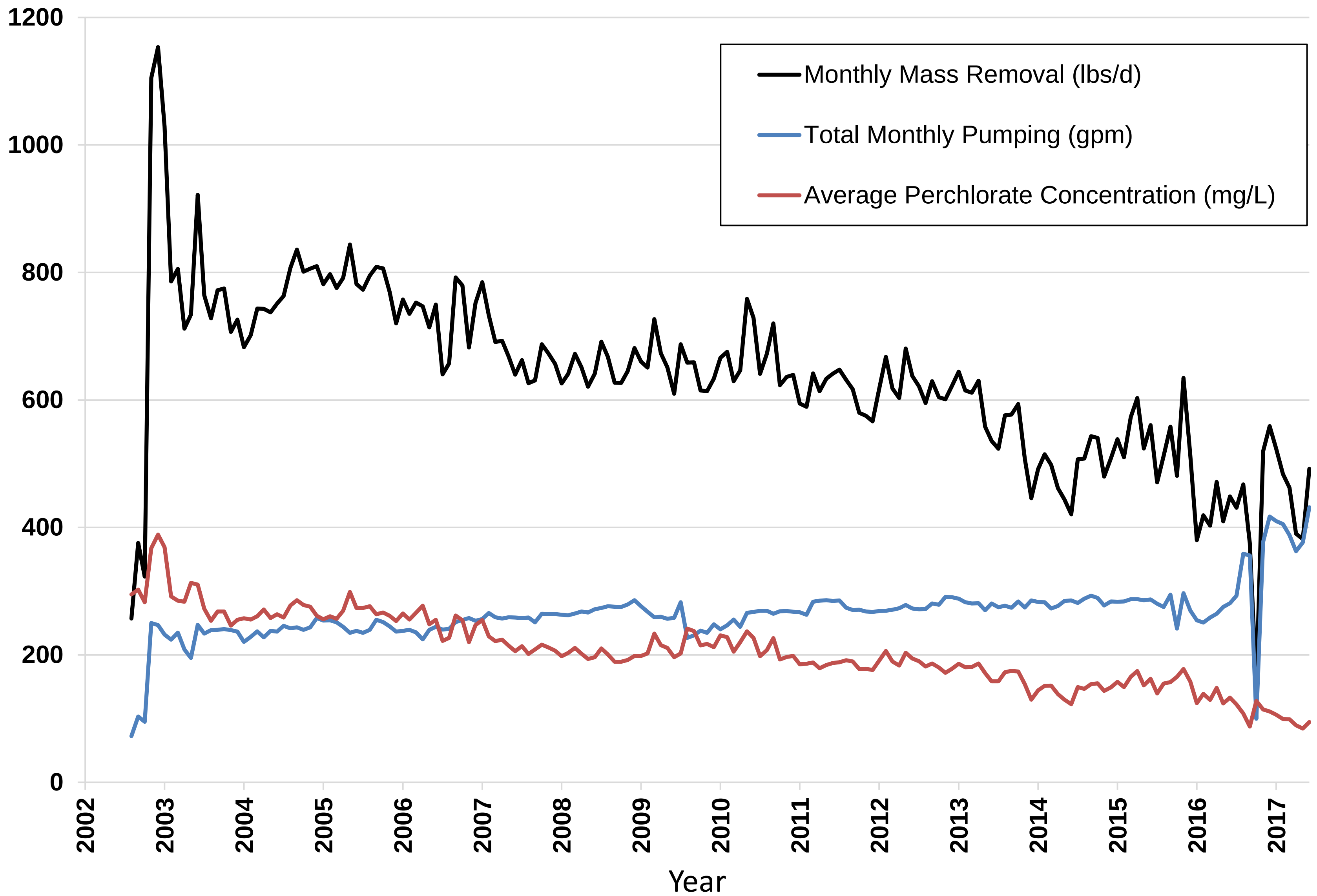
Perchlorate Concentrations and Groundwater Elevations at the COH WRF Well Line

Nevada Environmental Response Trust Site
Henderson, Nevada

Figure **5d**

Drafter: JL | Date: 9/14/2017 | Contract Number: 21-41400C | Approved by: AS | Revised: AS



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Perchlorate Mass Removal at the Athens Road Well Field

Nevada Environmental Response Trust Site
Henderson, Nevada

Figure 6

DRAFTED BY: JSM | 7/26/2017

PROJECT: 21-41400C

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Estimated Capture Zone of the Athens Road Well Field

Nevada Environmental Response Trust Site

Henderson, Nevada

Figure **7**

Drafter: AS | Date: 9/19/2017 | Contract Number: 21-41400C | Approved by: AS | Revised: AS

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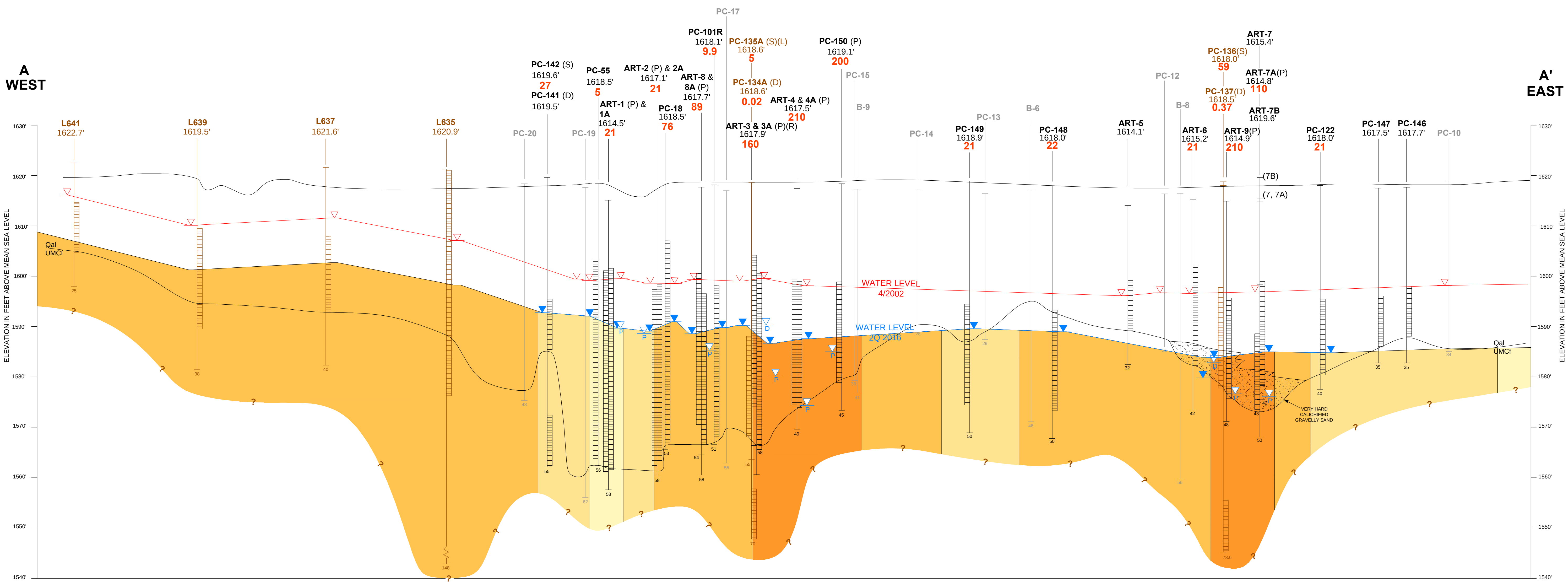
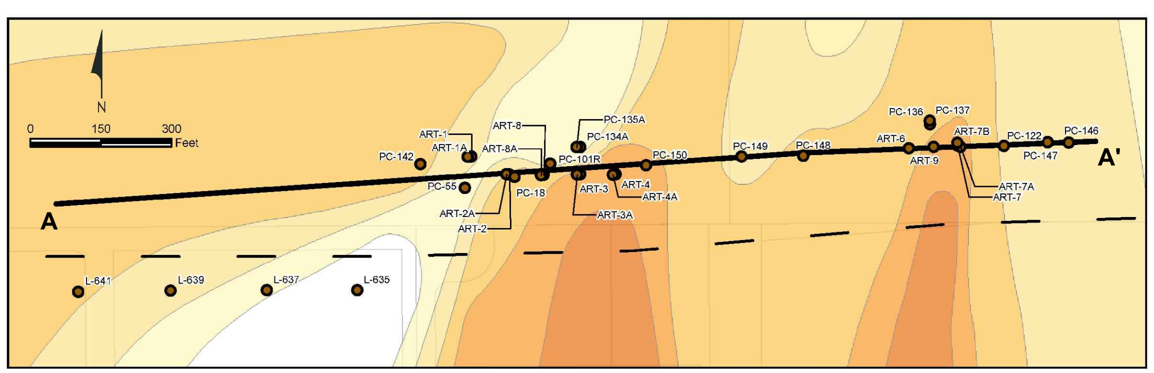


CROSS-SECTION LOCATION



NOTES:
1) The shallow, middle, and deep screened interval designations are used to distinguish well screens in this cross section and do not refer to NDEP's definition of the water bearing zones (WBZs).
2) Total depth labeled is rounded to the nearest foot.
3) Water levels from pumping, middle, and deep wells are not used for interpolating.

LEGEND

UMCf - UPPER MUDDY CREEK FORMATION
Qal - ALLUVIUM
(P) - PUMPING
J - ESTIMATED CONCENTRATION
940 - PERCHLORATE CONCENTRATION, MAY 2016 (mg/L)

VERTICAL SCALE IN FEET: 0', 10', 20'
HORIZONTAL SCALE IN FEET: 0', 80', 160'

PLUGGED AND ABANDONED 1750.0' — 57
PROJECTED 1750.0' — 57
1750.0' TOP OF CASING ELEVATION
SCREENED INTERVAL
(S) SHALLOW
(M) MIDDLE
(D) DEEP
(R) RIGHT
(L) LEFT
BLANK CASING
QAL-UMCf CONTACT
57 BOREHOLE DEPTH (FT BGS)

STATIC WATER LEVEL PRIOR TO INITIAL PUMPING, APRIL 2002
GROUNDWATER LEVELS MEASURED, MAY 2016
P WATER LEVEL FROM PUMPING WELL, MAY 2016
D WATER LEVEL FROM DEEP WELL, MAY 2016
M WATER LEVEL FROM MIDDLE WELL, MAY 2016

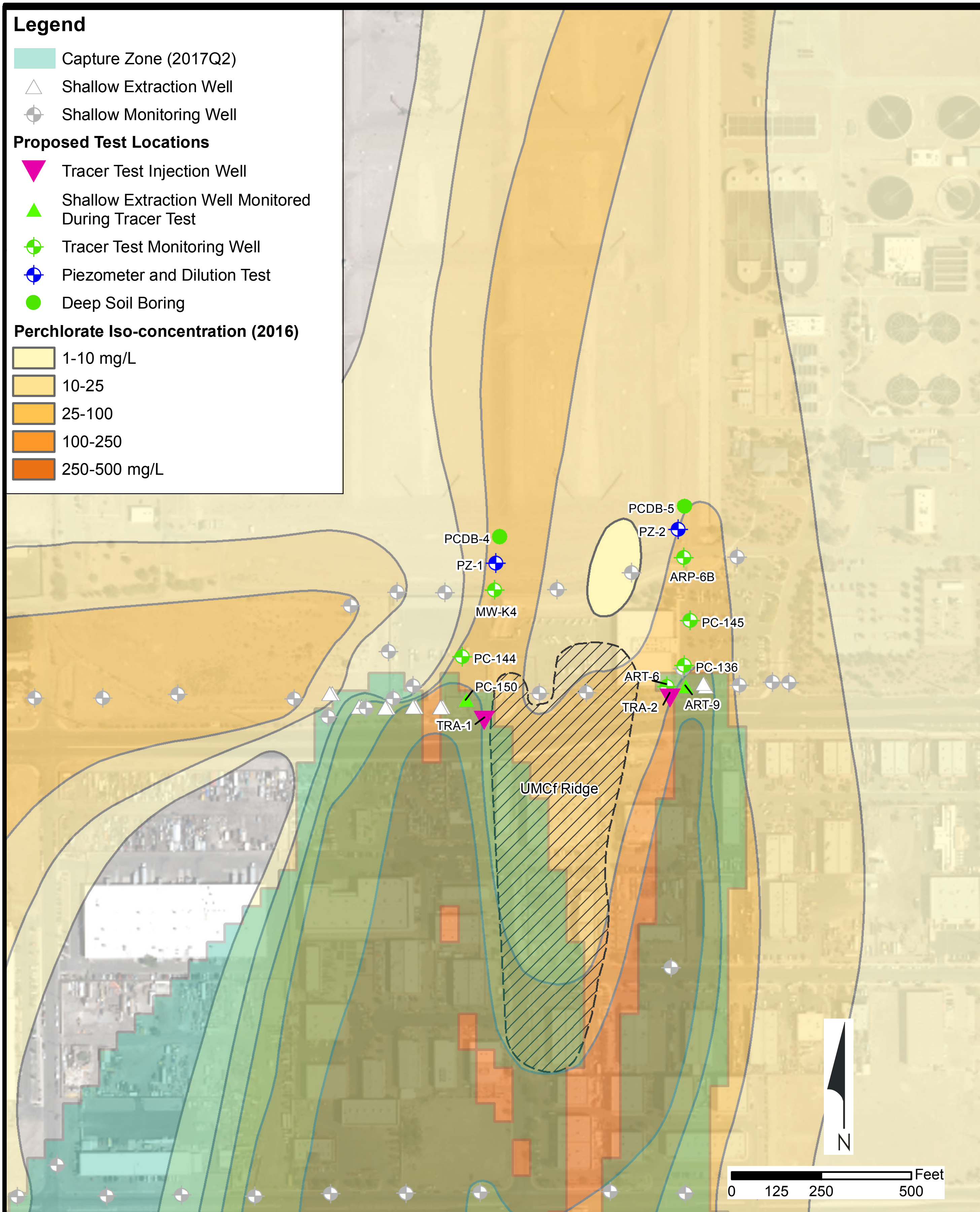
PERCHLORATE CONCENTRATIONS
<1 mg/L
1-10
10-25
25-100
100-250

RAMBOLL ENVIRON

Drafter: RS Date: 7/25/17 Contract Number: 21-41400C L12
Approved: Revised:

West-East Hydrogeologic Cross-Section A - A'
Athens Road Well Field, Second Quarter 2016
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
8



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Proposed Tracer Test and Matrix Diffusion Study Locations

Nevada Environmental Response Trust Site
Henderson, Nevada

Figure 9

Drafter: JL | Date: 9/19/2017 | Contract Number: 21-41400C | Approved: | Revised:

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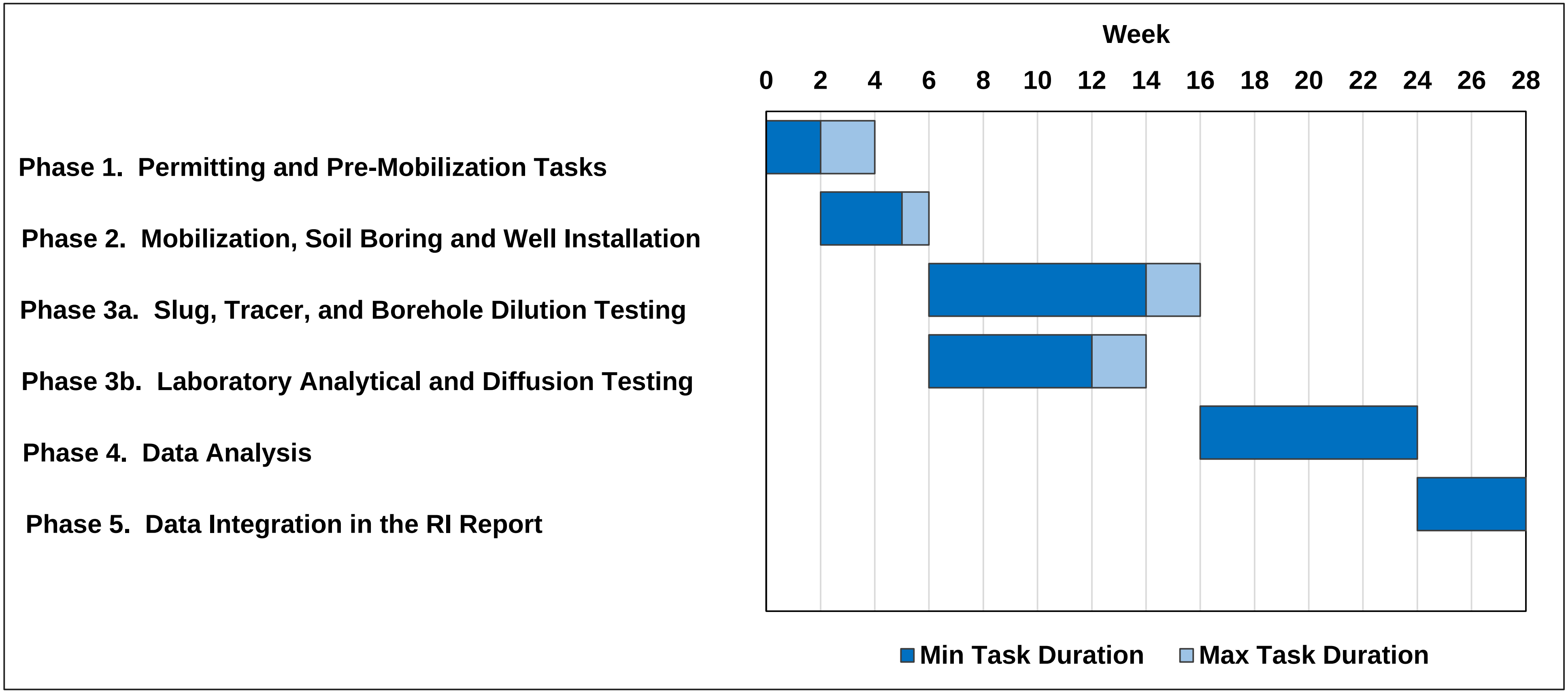

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DRAFTED BY: PR | 8/22/2017

Proposed Schedule for the Athens Road Well Field Capture Evaluation

Nevada Environmental Response Trust Site
Henderson, Nevada

Figure 10

PROJECT: 21-41400C

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TABLES

TABLE 1: PHYSICAL AND CHEMICAL PARAMETERS AND ANALYTICAL METHODS

Athens Well Field Capture Evaluation And Matrix Diffusion Study Work Plan

Nevada Environmental Response Trust Site Henderson, Nevada

Parameter	Method	Matrix
Physical Properties		
Grain Size Analysis	ASTM D422/4464	Soil
Atterberg Limits	ASTM D4318	Soil
Grain Size Distribution: Sieve Method	ASTM D422	Soil
Moisture Content	ASTM D2216	Soil
Bulk density-dry	ASTM D2937	Soil
Specific Gravity	ASTM D854	Soil
Grain Density	API RP40	Soil
Total Porosity	API RP40	Soil
Effective Porosity	Mod. ASTM D425	Soil
Hydraulic Conductivity	ASTM D5084/API RP40/EPA 9100	Soil
USCS Soil Classification	ASTM D2487	Soil
Chemical Properties		
pH	EPA 9045	Soil
Total Dissolved Solids (TDS)	SM2540 C (TBD)	Soil
Total Organic Carbon	Walkley-Black	Soil
Fraction Organic Carbon	Walkley-Black	Soil
NO3	EPA 300	Soil
Chlorate	EPA 300.1B	Soil
Perchlorate (IC)	EPA 314	Soil
Chromium, Hexavalent (IC)	EPA 7199	Soil
Ba, B, Cd, Co, Cu, Fe, Pb, Mg, Mn, Mo, Ni, P, Ag, Sr, W, V, Zr	EPA 6010B	Soil
Mercury (CVAA)	EPA 7471A	Soil
Volatile Organic Compounds	EPA 8260B	Soil
pH	EPA 9040C	Water
Total Dissolved Solids (TDS)	SM2540 C	Water
Conductivity, Specific Conductance	EPA 2510B	Water
Alkalinity all forms as ionic species	EPA 2320B	Water
Chlorate	EPA 300.1B	Water
Perchlorate (IC)	EPA 314	Water
Br, Cl, SO4	EPA 300	Water
NO3, NO2, OPO4	EPA 300	Water
Phosphorus, Total	EPA 365.3	Water
Sulfide, Acid soluble and Insoluble (Titrimetric)	EPA 9034	Water
Cyanide, Total	EPA 4500	Water
Organic Carbon, Dissolved (DOC)	SM5310	Water
Chromium, Hexavalent (Ion Chromatography)	EPA 218.6	Water
Al, B, Ca, Cr, Fe, Pb, Mg, Mn, K, Na, Sr, V, Zr	EPA 200.7	Water
As only	EPA 200.8	Water