APPENDIX B
AWF CAPTURE ZONE AND MATRIX DIFFUSION EVALUATION

APPENDIX B: ATHENS ROAD WELL FIELD CAPTURE EVALUATION AND MATRIX DIFFUSION STUDY

CONTENTS

TABLES

FIGURES

ATTACHMENTS

B.1 INTRODUCTION

This appendix describes the results of the Athens Road Well Field Capture Evaluation and Matrix Diffusion Study (the "Study"), in support of the Remedial Investigation (RI) being performed for the Nevada Environmental Response Trust (NERT or the "Trust") Site located in Clark County, Nevada (the "Site"). This work was conducted to address comments on the NERT 2015 and 2016 Annual Remedial Performance Reports from the Nevada Division of Environmental Protection (NDEP), which noted increasing perchlorate concentrations in shallow wells located downgradient of the Athens Road Well Field (AWF) and suggested that capture at the AWF be further evaluated (NDEP 2015, 2016). The Study was performed consistent with the Athens Road Well Field Capture Evaluation and Matrix Diffusion Study Work Plan ("Work Plan"; Ramboll Environ 2017), dated September 22, 2017, and approved by NDEP on October 3, 2017. The general location of the AWF is shown in Figure B-1.

As discussed in the Conceptual Site Model (CSM) section of the RI Report for OU-1 and OU-2, perchlorate present in the underlying, fine-grained Upper Muddy Creek Formation (UMCf) throughout the NERT RI Study Area is migrating upwards into the shallower alluvium as a result of back diffusion and upward flow caused by a natural upward vertical gradient. At the time of the NDEP comments, this was suspected to be the primary reason for the persistently elevated concentrations of perchlorate in several monitoring wells located directly downgradient of the AWF. However, as described in the Work Plan, other potential causes include incomplete capture of the NERT plume at the AWF and contribution from the perchlorate plume originating from the former AMPAC/PEPCON site. Additional details about the plume from the former AMPAC/PEPCON site are provided in Section 9.5.1 of the RI Report for OU-1 and OU-2. The purpose of the Study was to evaluate capture at the AWF and the effect of matrix diffusion, but not the contribution from the AMPAC plume.

Consistent with the Work Plan, a tracer test was conducted to verify that the NERT perchlorate plume is being captured by the AWF. The following tasks were performed as part of the tracer testing:

- Installation of two shallow wells to use for tracer injection located on the eastern and western sides of an UMCf ridge upgradient of the AWF;
- Background sampling of tracer monitoring points to characterize background fluorescence;
- Tracer dye injection and monitoring in 14 monitoring wells for 16 weeks; and
- Analysis of tracer test findings to evaluate whether the AWF is capturing the NERT perchlorate plume.

In this appendix, the term matrix diffusion is used to refer to the upward migration of perchlorate (or other chemicals of potential concern) from the fine-grained UMCf into the alluvium by both diffusion and advection. To investigate the effect of matrix diffusion on concentrations of perchlorate in monitoring wells downgradient of the AWF, the following tasks were performed:

- Installation and soil sampling of four borings (two upgradient and two downgradient of the AWF) to provide a detailed, vertical soil concentration profile. This was used to characterize perchlorate mass storage in the UMCf and to estimate the concentration gradient that drives back diffusion;

- Installation of clusters of three piezometers at different depths at two locations downgradient of the AWF. Continuous hydraulic head monitoring in the clusters was conducted using transducers to quantify the vertical hydraulic gradient between the alluvium and UMCf. This data was used to evaluate the upward migration of perchlorate from the UMCf to the alluvium due to advection;
- Borehole dilution and slug testing was conducted at two locations downgradient of the AWF to quantify groundwater flow velocity and hydraulic conductivity;
- Laboratory testing of soil samples from the UMCf to measure the field diffusion coefficient. This was combined with the concentration gradient to quantify the upward migration of perchlorate from diffusion; and
- Analysis of matrix diffusion study findings to quantify the effect of matrix diffusion on perchlorate concentrations downgradient of the AWF.

The appendix is organized as follows. Section 2 provides a summary of the operations and monitoring of the AWF. Section 3 describes the tracer test study conducted to evaluate capture at the AWF. Section 4 describes the matrix diffusion study conducted to quantify the effects of matrix diffusion. Section 5 summarizes the findings from the tracer test and matrix diffusion study. References are provided in Section 6.

B.2 ATHENS ROAD WELL FIELD

This section provides background information about the operation and performance monitoring of the AWF that is helpful for understanding the capture evaluation described in Section 3 and the matrix diffusion evaluation described in Section 4. A general summary of the NERT Groundwater Extraction and Treatment System (GWETS) is provided in the RI Report for OU-1 and OU-2 in Section 3.3.4. Details of the GWETS operation are provided on an ongoing basis in the NERT Annual and Semi-Annual Remedial Performance Reports for Chromium and Perchlorate (e.g., Ramboll 2019b).

B.2.1 AWF Pumping Rates

The location of the AWF in relation to the commingled AMPAC and NERT perchlorate plumes is shown in Figure B-2. The AMPAC plume is located to the north (downgradient) of the former AMPAC/PEPCON site shown on Figure B-2 and to the west of the NERT plume. The AWF began operating in 2002. The 14 groundwater extraction wells of the AWF are 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 feet (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 B-3).

Figure B-4 shows the annual average pumping rates measured in individual extraction wells at the AWF from 2002 to 2020. The averages were calculated over the reporting period used in the Annual Performance Reports (July through June) (e.g., Ramboll 2019b; Ramboll 2021). As shown in Figure B-4, pumping in wells ART-2 and ART-8 significantly increased in recent years. The total average AWF pumping increased from 130 gallons per minute (gpm) in 2002 to 464.1 gpm in 2019 when the Study was carried out (Ramboll 2019b).

B.2.2 Groundwater Elevations and Perchlorate Concentrations

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

B.2.2.1 AWF Extraction and Monitoring Wells

Groundwater elevations and perchlorate concentrations in the AWF extraction wells are shown on Figure B-5a. In general, the groundwater elevations fluctuate in response to changes in extraction rates. With the exception of ART-1, the average perchlorate concentrations in the AWF's eight pumping wells have significantly decreased since 2002. Perchlorate concentrations are significantly lower in extraction well ART-1 than in the other extraction wells; however, concentrations in ART-1 have been slowly increasing since 2012. As described in Section 9.5.1 of the main RI Report, there is a separate perchlorate plume (the AMPAC plume) that originates at the former AMPAC/PEPCON plant. The AMPAC plume is commingling with the NERT plume at the western end of the AWF. The increasing trend of perchlorate concentrations in ART-1 is most likely the result of the AMPAC plume being drawn into the AWF in response to pumping. AMPAC acknowledges that a portion of their perchlorate plume is captured by the NERT GWETS (Geosyntec 2017).

As shown on Figure B-5b, the monitoring wells located close to the AWF also show decreasing perchlorate concentration trends, except for wells PC-142 and PC-122 (where concentrations are slightly increasing over time); these two wells are located on the edges of the well field and are likely outside of the capture zone of the AWF.

B.2.2.2 Athens Road Piezometer Well Line

Approximately 250 ft 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 B-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 effects of matrix diffusion on the concentrations in wells MW-K4 and ARP-6B will be discussed in the matrix diffusion study described in Section B-4.

B.2.3 AWF Mass Removal and Capture Zone

The average perchlorate mass removed from the AWF from October 2002 to June 2019 is approximately 615 lbs/day. Combined pumping at the AWF in June 2019 was approximately 413 gpm. There has also been a decrease in the average perchlorate concentration in AWF extraction wells from approximately 298 mg/l in May 2005 to approximately 74 mg/l in June 2019 (Ramboll 2019b). Average monthly mass removal in AWF extraction system is shown in Figure B-6.

Based on pumping rates from second quarter 2019, the simulated capture zone for the AWF in the Shallow Water Bearing Zone using the steady-state version of the Phase 6 Groundwater Model is shown on Figure B-7 (Ramboll 2019a). Although 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 relatively minor for two reasons: the mass of perchlorate within the area is limited; and 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 2019 are shown on the geologic cross-section through the AWF presented in Figure B-8.

B.3 TRACER TESTING

Dye tracer tests were conducted at two locations to the east and to the west of the UMCf ridge to confirm that the perchlorate in the alluvium is being adequately captured by the AWF extraction system. The dye tracer test was designed and implemented by Ramboll in conjunction with Ozark Underground Laboratory (OUL) of Protem, Missouri.

B.3.1 Dye Tracer Injection Wells

Two new shallow injection wells, TRA-1 and TRA-2, were installed on the eastern and western sides of the UMCf ridge upgradient of the AWF extraction wells, as shown on Figure B-7. The figure also shows the simulated capture zone of the AWF, which indicates a gap in capture immediately to the east of the UMCf ridge. The injection wells were located as close as possible (given access constraints) to the inside edges of the paleochannels where potential gaps in capture were most likely to occur. The wells were screened at the base of the alluvium. Well construction details are provided in Table B-1.

B.3.1.1 Injection Well Installation

Prior to drilling activities at each location, preliminary utility clearance was initiated by establishing dig tickets through the Underground Service Alert (USA) North One-Call System (#811). As necessary, Ramboll personnel worked directly with private and municipal utility location personnel to establish the estimated location of subsurface utilities relative to planned drilling locations. Direct utility clearance was conducted using third-party utility location services (i.e., ground penetrating radar [GPR] and electrical line locating), combined with direct underground clearance via either hand auger clearance to 5 ft below ground surface (bgs), or air vacuum (air knife) clearance to 10 to 15 ft bgs.

Drilling was conducted in accordance with procedures outlined in the Field Sampling Plan (FSP; ENVRION 2014), as described below. Drilling for the AWF Capture Evaluation dye tracer well installation was conducted by Cascade Drilling, LP (Cascade), under the oversight of Ramboll personnel. The tracer injection wells were completed using rotary sonic drilling methods. Well installation involved using a 6-inch diameter core barrel to retrieve undisturbed subsurface soil samples and an 8-inch diameter conductor casing to maintain the integrity of the borehole as it was advanced to the planned total depth. Soil cuttings and logged soil core, or investigative derived waste, were transported to the NERT site and stored in lined and covered bulk storage containers, termed roll-off containers.

During well installation, soil sampling was conducted at 1-ft intervals beginning at approximately 1 ft below the water table and continuing until approximately 10 ft below the alluvium-UMCf contact. Soil cores were collected in 2.5-ft long soil core plastic sleeves by the driller. The plastic sleeves were then cut by Ramboll personnel and the soil core was split to expose the inner portions of the core, not in contact with the inside of the core barrels. Soil samples were then collected from the inner portions of the core, placed directly into laboratory-provided sampling jars, placed on ice, and shipped out to the laboratory each day. Samples were analyzed for perchlorate, chlorate, and nitrate. Soil cores were logged by a Ramboll geologist using the Unified Soil Classification System (USCS), and all boring logs were reviewed by a senior geologist for quality control (QC) purposes.

The injection wells were installed in accordance with procedures outlined in the FSP, as described herein. Each injection well boring was advanced to 10 ft below the alluvium-UMCf contact and then backfilled to the desired depth for well placement. The borings were backfilled using bentonite chips topped with 1 to 2 ft of filter pack sand. Once the appropriate depth was achieved, drilling personnel who were handling well materials donned clean gloves to ensure that contaminants were not introduced into the borehole during installation. Well screen and blank (riser) casing were carefully lowered into the ground section-by-section (well string) through the conductor casing. Each section of the well (either 5-ft or 10-ft sections) was constructed of flush-threaded, water-tight joints that were fully tightened to ensure well integrity. The well string was then centered and suspended in the borehole to ensure that the well was sufficiently plumb and straight.

Well screen filter pack sand was gently poured into the annulus while using a weighted tape to measure progress and the top of the filter pack sand was extended to 2 ft above the top of the well screen. A bentonite chip seal (well seal) was then installed above the well screen, again using the weighted tape to monitor progress. The well seals were extended to 5 ft above the sand filter pack and were hydrated with clean water as necessary. The remainder of the borehole annulus above the well seal was then backfilled using neat cement grout. During construction of the sand filter pack and bentonite seal, the conductor casing was slowly removed to ensure the integrity of the borehole while preventing the sand and bentonite from bridging.

The wells were constructed using a factory-sealed, commercially-available well screen and blank casing. Each well was constructed with a 4-inch diameter Schedule 40 polyvinyl chloride (PVC), using a 0.02-inch slotted screen with #3 size filter pack sand. The introduction wells are both located in high traffic areas, so the surface completions installed consisted of flush-with-grade traffic-rated vaults. Both wells were capped with water-tight locking caps. Boring logs and well construction logs are provided in Attachment B-1.

B.3.1.2 Injection Well Development

Following well installation, the wells were then developed. Well development was conducted by Cascade, using specifically designed development equipment (i.e., development rig) under the supervision of Ramboll personnel. The general methodology for conducting well development is described below.

Prior to beginning well development, as-built well construction logs were obtained to provide general well information such as total depth, well screen interval, well diameter, and anticipated depth to water. The initial depth to water was then measured using an electronic water level indicator with an accuracy of ±0.01 ft. Well construction and water level information were entered onto a well development logging form and the well casing volume and the expected total well purging volume were calculated.

Well development began no sooner than 48 hours after installation. Well development was initiated by using surge block and bailing techniques to agitate the well screen to remove fine- and coarse-grained material from the filter pack. A surge block consists of a 4.5 ft long, 1.5 in diameter rubber plunger attached to PVC rods. The stainless-steel bailers used to purge the suspended material from the well are 10 ft long and 3.5 inches in diameter and are equipped with a check ball valve. Surging/bailing cycles were conducted until sand and sediments within the well were visibly reduced. The wells were then pumped using a PVC Typhoon submersible pump until well development was completed. Well construction details are presented in Table B-1.

During well development, frequent monitoring of pH, specific conductivity, temperature, and turbidity (water quality parameters) was conducted to determine when natural conditions were obtained, which indicates that the well was sufficiently developed. Drawdown and relative recovery were monitored throughout the development process and documented on the well development form (Attachment B-2). Well development continued until at least 10 casing volumes had been removed. To determine the level of development of a well, the criteria includes the production of relatively clear water (goal of less than 5 nephelometric turbidity units), as well as stabilized water quality parameters within 10 percent between well volumes. Purge water produced during the well development process was containerized and transported to the NERT site and discharged directly to the GW-11 Pond in coordination with Envirogen.

B.3.2 Tracer Dyes and Required Regulatory Permitting

The fluorescent dyes selected as tracers were fluorescein and rhodamine WT. Each of these fluorescent dyes have been used extensively in groundwater and surface water tracer applications. The dyes are safe, non-toxic, and can be measured over a concentration range that spans up to six orders of magnitude, resulting in the ability to detect a very small fraction of the introduced concentration. Prior to implementation, UIC Form U240 (Chemical Use Request) was required by the NDEP Bureau of Water Pollution Control – Underground Injection Control Program, as the Study involved introduction of a chemical dye tracer into groundwater 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. For purposes of remediation, it is typical that for any short-term field tests (less than six months), a Class V General Short-Term Remediation UIC permit is required. However, the introduction of dye tracers was not intended for remediation purposes and therefore a formal UIC Permit was not required.

Based on communication with the NDEP Bureau of Water Pollution Control, the necessary documents to receive regulatory approval for dye tracer testing include the UIC Form *U240:*

Chemical Use Request, in addition to an accompanying letter with supplemental information (purpose of dye tracer introduction, dye introduction locations, post-dye introduction monitoring locations, description of monitoring [background and post-dye introduction], etc.). U240 Forms were submitted for each dye tracer (fluorescein and rhodamine WT) to the NDEP Bureau of Water Pollution Control for approval on November 14, 2018, and were approved on November 26, 2018. The approved U240 forms and safety data sheets for each dye tracer are included in Attachment B-3.

Notification to NDEP of a dye tracer injection outside of the formal form submittal process was required because the AWF extraction system is an active part of the NERT GWETS, which operates under NPDES Permit NV0023060. A formal notification email was submitted from the Trust to NDEP on December 3, 2018. The notification email to NDEP is included in Attachment B-4.

B.3.3 Background Fluorescence Sampling

To determine background fluorescence prior to commencement of the dye tracer tests, all wells that were selected as tracer injection wells or monitoring wells were sampled and tested twice. The locations of tracer injection and monitoring wells are shown in Figure B-7. Sampling for background fluorescence was conducted using the same methods as monitoring for downgradient dye tracer detections. Ozark Underground Laboratory (OUL) tracer test standard procedures and criteria description is provided in Attachment B-5.

Background sampling was conducted for 2 weeks prior to dye tracer introduction in order to characterize any background fluorescence that could interfere with the dye tracer tests. Activated charcoal packets were deployed in the middle of the saturated screened interval of each monitoring well using string, plastic twist wire ties, and a weighted plastic bailer. The activated charcoal packets were retrieved and replaced once per week for two weeks. A grab groundwater sample was also collected with each activated charcoal sample, except for well PC-150, which only allowed for an activated charcoal sampler to be deployed due to extraction system plumbing. Once samples were collected, they were packaged and shipped on ice to OUL.

Table B-2 includes the date ranges, locations, and groundwater elevations for the locations where background sampling was conducted. No background samples showed evidence of fluorescent dye tracers. The analytical laboratory reports from Ozark are provided in Attachment B-6.

B.3.4 Tracer Test Dye Injection

The fluorescein dye tracer was delivered in powder form and had to be mixed prior to introduction into the well. On December 3, 2018, approximately five gallons of water was mixed with the powder fluorescein to create the tracer dye liquid. The fluorescein powder is very fine, so during the mixing process all efforts were made to prevent any spillage or cross-contamination. Mixing of the tracer dye took place at the NERT property and any equipment used was either cleaned with bleach or discarded. Conversely, the rhodamine WT tracer dye was delivered in liquid form and did not need preparation for introduction into the well.

During the background sampling, injection well TRA-1 had approximately 0.78 ft of water in the well, which was an indicator that there could be a possibility that the entire screen interval would not be saturated. To assist in the tracer dye testing, TRA-1 was hydrated one day before dye introduction (December 3, 2018). Well TRA-1 was hydrated by adding approximately 100 gallons of water (water was acquired from a non-potable fire hydrant located on the NERT property). The well was hydrated at a rate of approximately 2 gallons per minute. Depth to water was constantly monitored to prevent over filling the well into the well vault.

On December 4, 2018, dye tracers were introduced by Ramboll at injection wells TRA-1 and TRA-2, upgradient of the AWF extraction well system. The dye tracer introduction consisted of the placement of four pounds of fluorescein dye tracer (mixed with five gallons of water) into the western injection well (TRA-1) and 16 pounds of rhodamine WT dye tracer (approximately 1.7 gallons) into the eastern injection well (TRA-2). The dye tracer introductions were conducted using a different dye tracer in each well so that origin of the dye tracer could be distinguished in the dye monitoring conducted at the downgradient wells. During tracer dye introduction, all precautions were taken to prevent spillage on the ground surface or cross-contamination of wells. Each tracer dye was gravity-fed into the well by Ramboll at a rate of approximately 3-gallons per minute. Introduction of each tracer dye was immediately followed by a minimum of five well volumes of chase water for flushing. TRA-2 received approximately 30 gallons of chase water, and TRA-1 received approximately 100 gallons of chase water (the increased amount here was to ensure flushing of the dye tracer due to the limited saturation of the well screen/filter pack).

B.3.5 Tracer Test Groundwater Monitoring

Following the dye tracer introduction, monitoring took place in approximately 14 existing monitoring wells on the downgradient (north) side of the AWF extraction system, as shown in Figure B-7. These monitoring wells were chosen for their likelihood of having dye tracer detections should the AWF extraction system capture zone be insufficient. Tracer test monitoring was conducted for a period of 16 weeks.

Tracer monitoring was conducted by collecting grab samples of groundwater for analysis, in addition to analyzing activated carbon samplers. Grab groundwater samples provided a measure of dye tracer concentrations at fixed times for a given sampling location. The activated carbon samplers absorb the dye tracer continuously, which accumulates over time, and therefore the activated carbon samplers are the best indication of the timing for a dye tracer arrival at a given sampling location. Activated carbon samplers were deployed in each downgradient monitoring well either prior to, or shortly after, the dye tracer introduction in the upgradient wells. Tracer sampling was conducted twice a week for the first two weeks following dye introduction and then once a week for the next 12 weeks. Tracer sampling involved the retrieval of the activated carbon samplers, collection of grab groundwater samples at each location, and the deployment of new activated carbon samplers.

Both the activated carbon samplers and the grab groundwater samples were packaged and shipped to OUL for analysis. The procedures for the use of the activated carbon samplers, as well as the OUL lab reports for all samples collected, are included in Attachment B-5 and B-6, respectively. Grab groundwater samples were only analyzed if a dye tracer was detected during the analysis of the associated activated carbon sampler. Table B-3a and B-3b present a summary of the tracer test monitoring data.

B.3.6 Tracer Test Findings

Figure B-9 presents the results of the tracer test study, showing location where tracers were detected in downgradient monitoring wells in the study area. Summaries of detected analytical results from the carbon samplers and grab samples are provided in Tables B-3a and B-3b, respectively.

Fluorescein dye tracer was introduced into well TRA-1. Analytical results associated with 16 weeks of tracer sampling of the downgradient wells showed detectable levels of Fluorescein dye in AWF extraction well PC-150, but in none of downgradient monitoring wells (See Figure B-9). Fluorescein dye tracer detections in extraction well PC-150 were expected, as this is the AWF extraction well that is closest to TRA-1. Thus, there is no evidence of a gap in the AWF capture zone to the west of the UMCf ridge.

Rhodamine WT dye tracer was introduced into well TRA-2. Analytical results associated with 16 weeks of tracer sampling of the downgradient wells showed detectable levels of the Rhodamine WT dye in AWF extraction well ART-9 and two nearby monitoring wells (ART-6 and PC-136), as shown in Figure B-9. The maximum detection of the Rhodamine WT dye tracer from carbon samplers in extraction well ART-9 was 654,000 parts per billion (ppb), while the maximum detections were much smaller in monitoring wells ART-6 (35.3 ppb) and PC-136 (43.1 ppb). Rhodamine WT was also detected at very low levels in isolated activated carbon samplers at ART-7A (1.31 ppb) and PC-148 (3.02 ppb). Since these detections were not confirmed by the corresponding grab samples, the detections may not be valid. There were no detections in the monitoring wells located further downgradient. The tracer detections in extraction well ART-9 were expected, as this is the AWF extraction well that is closest to TRA-2. Monitoring wells ART-6 and PC-136 are located very close to extraction well ART-9, and as a result are likely within the capture zone of ART-9. Thus, given that no tracer was detected in the monitoring wells located further downgradient, the low detections of tracer in ART-6 and PC-136 are not considered to be an indication of loss of capture. Overall, there is no evidence of a material gap in the AWF capture zone to the east of the UMCf ridge. Therefore, the tracer test results indicate that the AWF is effective in preventing the migration of perchlorate past the AWF.

B.4 MATRIX DIFFUSION STUDY

The matrix diffusion study was designed to evaluate whether upward migration of perchlorate from the UMCf to the alluvium is a significant cause of the elevated concentrations observed downgradient of the AWF (e.g., in wells MW-K4 and ARP-6B). Upward migration occurs by both advection (due to the hydraulic gradient) and diffusion (due to the concentration gradient). Conceptually, the total upward migration of perchlorate from the UMCf would then mix with groundwater flowing horizontally within the alluvium. Perchlorate in the UMCf would act as a continual source of contamination to shallow groundwater. In order to evaluate the effect of matrix diffusion on concentrations in the alluvium in the area of the AWF, data was collected to characterize the following: 1) upward migration of perchlorate from the UMCf due to advection, 2) upward migration of perchlorate from the UMCf due to diffusion, and 3) horizontal flow of groundwater in the alluvium.

The components of the study are described in more detail below.

B.4.1 Soil Boring and Piezometer Installation

Soil borings were drilled at the matrix diffusion test locations PZ-1 and PZ-2, located downgradient of the existing alluvium wells MW-K4 and ARP-6B that have persistently elevated perchlorate concentrations as shown on Figure B-5c. The locations of PZ-1 and PZ-2 are shown on Figure B-7. The PZ-1 and PZ-2 borings were drilled to total depths of 55 and 76 ft bgs, respectively.

To determine the perchlorate concentration gradient that would drive matrix diffusion, detailed soil concentration profiles were obtained. Within each soil boring, soil samples were collected with a 1 ft spacing, beginning 3 ft above the alluvium-UMCf contact to 17 ft below the contact. Twenty soil samples were collected in total, with analytical results shown in Table B-4. Perchlorate and chlorate soil concentration profiles at each location (TRA-1, TRA-2, PZ-1, and PZ-2) are presented Figure B-10 and Figure B-11. In general, the vertical profiles show a peak concentration at or very close to the alluvium-UMCf contact (encountered at approximately 33 ft bgs in PZ-1D and 45 ft bgs in PZ-2D). These vertical concentration profiles are consistent with previous studies (Ball et al. 1997; Liu and Ball 2002; and Chapman and Parker 2005) of matrix diffusion from fine grain to coarse grain formations. This indicates that diffusion is occurring from the contact upwards into the alluvium.

Soil retrieved using continuous core sampling equipment was logged. Only relatively undisturbed samples were selected for physical testing of the following parameters: dry bulk density, specific gravity, grain density, total porosity, effective porosity, hydraulic conductivity, USCS soil classification, and grain size distribution. The results of physical testing conducted by CoreLab are presented in Attachment B-7. Soil sampling activities generally followed the Field Sampling and Analysis Plan (ENVIRON 2014).

At each location (PZ-1 and PZ-2), a piezometer cluster was constructed in order to accurately measure vertical hydraulic gradients. Piezometers at three depths were installed: a shallow piezometer at the base of the alluvium (PZ-1S, PZ-2S), a middle piezometer approximately 10 ft below the alluvium-UMCf contact (PZ-1M, PZ-2M), and a deep piezometer approximately 20 ft below the alluvium-UMCf contact (PZ-1D, PZ-2D). Each piezometer has a short 1 ft screen to accurately measure hydraulic head at each depth. Well construction details are provided in Table B-1.

To measure hydraulic gradients, transducers were placed at the base of each piezometer. Pressure transducers stayed in the piezometers for one month (from August 18 to September 19, 2018). Figures B-12 and B-13 present transducer readings at each piezometer cluster for the duration of the test. Piezometers at both locations were relatively stable at the start of data collection until early September 2018, when hydraulic heads started increasing until they were approximately 1 ft higher at the end of data collection. Vertical gradients between the piezometers in each cluster are presented in Figures B-14 and B-15. At each location, vertical gradients were calculated between deep, middle, and shallow transducers. The vertical gradients also began changing in early September 2018. At PZ-1, the average vertical gradient changed from 0.083 ft/ft at the beginning of data collection to 0.07 at the end of data collection. At PZ-2, the average vertical gradient decreased from 0.065 ft/ft to 0.05 ft/ft, then increased back to 0.065 ft/ft at the end of data collection. A summary of the vertical gradient measurements is presented in Table B-5.

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

B.4.2 Slug Testing

Slug testing was planned for six locations (PZ-1S, PZ-1D, PZ-2S, PZ-2D, TRA-1, and TRA-2). However, due to insufficient water, slug testing could not be completed at PZ-1S or TRA-1.

B.4.2.1 Slug Testing Procedures

Slug tests were conducted by quickly lowering (falling head test) or raising (rising head test) a weighted slug with an approximate displacement factor of one gallon into the well, resulting in an instantaneous change in water level. At PZ-2S, both falling head and rising head tests were conducted with two different slugs with different displacements as a quality control measure. The slugs used included a 3.1-ft long by 3-inch diameter slug and 4.0-ft long by 1.5-inch diameter slug (used for the quality control test). The slugs were raised and lowered using a custom well sampling reel equipped with a stainless-steel cable that allowed for rapidly raising and lowering the slug once it was positioned in the well. Slug testing was performed in accordance with American Society for Testing and Materials (ASTM) Standard D4044-96 (ASTM 2008).

Prior to conducting each slug test, the water level in the well was measured manually with an electronic water level probe, with an accuracy of ±0.01 ft, to determine the static groundwater level. An In-Situ Level TROLL 700 pressure transducer with integral datalogger was then suspended in the well, at either a minimum of 10 ft below the measured static groundwater level, or no deeper than approximately 1 ft from the bottom of the well. The pressure transducer was securely deployed by a vented direct-read cable, allowing for the real-time observation/monitoring of data. Water levels were then monitored electronically for approximately 10 minutes to one hour prior to the commencement of testing to ensure that static water level conditions had been established.

A falling-head test was then conducted by lowering the weighted slug into the well smoothly, securing it in place above the transducer, and electronically recording the rate of water level decrease. Once groundwater returned to approximately the initial static conditions, a rising-head test was conducted by removing the slug and allowing the water level to again recover to static conditions while electronically recording the rate of water level recovery. In general, each test (either rising-head or falling-head) was run until the water level reached close-to-full recovery (less than 0.01 ft water level change in 10 minutes), before initiating the next test in the sequence. For a series of tests, the next test in a sequence was not initiated unless the prior test had achieved 95% recovery.

To prevent cross-contamination, the well slugs, transducers, water level indicators, direct-read transducer cables, and other downhole equipment were decontaminated prior to and between uses by washing with a Liquinox/water solution, followed by rinses with distilled water. For the most part, slug testing did not generate wastewater that had to be managed and disposed of. Minor volumes of water that were used to decontaminate equipment was retained in buckets and disposed of into the GW-11 holding pond for processing through the GWETS, as necessary. At the end of each test, the pressure transducer was removed from the well and the water level displacement data was downloaded to a laptop computer.

B.4.2.2 Slug Test Analysis

The data were interpreted using AQTESOLV for Windows (Duffield 2014) with the Zlotnik-Goss-Duffield model (Zlotnik et al. 2010). A summary of slug tests results is presented in Table B-6. The average hydraulic conductivity of the alluvium at well PZ-2S based on the slug tests was 353 ft/day. The average hydraulic conductivity of the UMCf at wells PZ-1D and PZ-2D based on the slug tests was 0.36 ft/day. Thus, the hydraulic conductivity of the alluvium is approximately four orders of magnitude higher than the UMCf. Detailed slug test analysis results are presented in Attachment B-8.

B.4.3 Single Borehole Dilution Testing

Single borehole dilution tests were conducted in August and September 2018. A borehole dilution test is simple hydrogeological technique that is used to estimate horizontal flow velocity in the aquifer surrounding a well. The dilution test is conducted by either introducing a conservative tracer into a well and monitoring its decreasing concentration over time, or by introducing deionized water and then measuring the increase in the natural aquifer specific conductivity over time. For this study, deionized water with very low specific conductivity was introduced to the well's screened interval. Background specific conductivity in the NERT RI Study Area is typically high (3,000–4,000 uS/cm) due to high levels of total dissolved solids (TDS); therefore, deionized water with two to three orders of magnitude lower specific conductivity (1-50 uS/cm) was used for this test. The tests were conducted in the PZ-1D and PZ-2D piezometers which are screened in the UMCf.

B.4.3.1 Borehole Dilution Testing Procedures

During the test, specific conductivity was monitored using multiple water quality and pressure transducers (In-Situ Aqua TROLL 200) attached to the exterior of the deployment device. The sensor for PZ-1D and PZ-2D was deployed at the center of the one-foot screened interval and was not attached to the deployment device. The reason for not attaching the sensor to the deployment device was that the sensor was left in place for an extended period to monitor the specific conductivity over time in support of the project objectives.

The deionized water was delivered into the well through a custom-built deployment device. The deployment device consisted of a 2-inch well casing with a 20-ft screened interval and a flat PVC end cap. Within the 2-inch well casing, a 1¼-inch well casing was inserted into an end cap that was permanently secured to the flat well end cap. The connection between the 1¼-inch well casing and the end cap was water tight and designed in such a way that the inner well casing could be removed easily from the well, releasing the deionized water and leaving the 2-inch well casing in place with the sensors.

Prior to installing the deployment device, depth to water was measured using an electronic water level meter with an accuracy of ±0.01 ft. With the depth to water documented and the sensors attached to the 2-inch well casing, the deployment device was then constructed in 10-ft sections while lowering the device into the well until it came to rest on the bottom of the test well. Depth to water was then measured again to see if the deployment device caused the water level to change. If a change in water level was observed, the depth to water was monitored until stabilization was reached. Once stabilization was reached, the data logs were started on the sensors and the approximate volume (in gallons) of deionized water required for the test was calculated.

The deionized water was then measured out to match the volume of water in the well and was poured into the inner 1¼-inch well casing. The purpose behind matching the well volume with the dilution testing liquid was to minimize the potential risk of negatively influencing the aquifer when the dilution testing liquid was released into the well, which maximizes the chance of observing the natural groundwater flow in the aquifer. While the deionized water was being added to the inner well casing of the deployment device, the specific conductivity and water level were monitored using the various sensors mounted to the deployment device to demonstrate that the inner well casing was water tight and no deionized water had escaped the inner casing prior to beginning the test.

The test was initiated by breaking the inner well casing end cap seal and removing the inner well casing from the well. This allowed the deionized water to be released into the test well and mix with groundwater. Specific conductivity was then monitored, primarily from the bottom sensor. Once specific conductivity returned to near the original starting value, the test was considered completed and data logging was ceased. With the testing complete, the deployment device was removed from the well, decontaminated, and data was downloaded from the sensors.

B.4.3.2 Borehole Dilution Test Analysis Method

The analysis of borehole dilution tests is described in Halevy et al. (1966), Hall et al. (1991), and Hall (1993). The change in log tracer concentration over time within the wellbore is linearly related to the flow velocity within the well, V_w, as follows:

$$V_w = \frac{d(\ln C)/dt}{-A/V} \qquad (1)$$

where C is the tracer concentration, A is the cross-sectional area within the well screen, and V is the well volume over the measurement section. As shown by Halevy et al. (1966), the cross-sectional area within the well screen in Equation (1) is adjusted to account for the in-well tracer-measurement system (downhole probe, cables), as follows:

$$V_w = -\frac{d(\ln C)/dt}{\left[2r_w/\pi\left(r_w^2 - r_t^2\right)\right]} \qquad (2)$$

where r_w is the radius of well screen, and r_t is the equivalent radius of the tracer-measurement system (assumed to be 0.625 inches for all tests).

V_w is related to actual groundwater velocity within the aquifer (V_a) by the following relationship:

$$V_w = V_a . n_e . \alpha \qquad (3)$$

where n_e is the effective porosity, and α is the groundwater-flow-distortion factor with a common range of 0.5 to 4. The distortion factor accounts for perturbations in the flow field caused by the contrast between the hydraulic properties of the well and the surrounding undisturbed aquifer. The following equation (Halevy et al. 1966; Drost et al. 1968) is used to estimate α:

$$\alpha = \frac{4}{1+\left(\frac{r_1}{r_2}\right)^2+\left(\frac{k_2}{k_1}\right)\left[1-\left(\frac{r_1}{r_2}\right)^2\right]} \tag{4}$$

where:

r_1 = the inner well casing radius,

r_2 = the combined radius of the well casing and filter pack,

k_1 = the combined hydraulic conductivity of the well screen and filter pack, and

k_2 = the hydraulic conductivity of the undisturbed formation.

For the analysis of borehole dilution tests conducted as part of the study, the combined hydraulic conductivity of the filter pack and well screen were assumed to be 150 ft/day. The hydraulic conductivity of the undisturbed formation was estimated from slug tests performed at each of the wells (see Section 5.2).

B.4.3.3 Borehole Dilution Test Results

On October 19, 2018, after 36 days, sensors were recovered from the boreholes and recorded data retrieved. Electrical resistivity data from PZ-1D and PZ-2D for the test duration are presented in Figures B-16 and B-17, respectively. The results are presented in terms of electrical resistivity as it is more intuitively corresponds with concentration. Due to its high TDS, the background electrical resistivity of groundwater is lower than deionized water. As expected, after releasing the DI water in the borehole, the electrical resistivity increases initially and then starts to return to the background value as the tracer is flushed out with groundwater. Some irregularity at the beginning of the test is expected before the resistivity stabilizes due to mixing.

In PZ-1D, it took 62 minutes for the resistivity to reach its peak of 362.3 ohm-centimeters (ohm-cm). After that a steady drop of resistivity was observed. After 100 hours (approximately 4 days), the resistivity stabilized at the background value of 357.2 ohm-cm. For the analysis, the first 10 hours of data was used to calculate velocity at PZ-1D (Figure B-16).

In PZ-2D, after initial increase of resistivity from the background value (281 ohm-cm) to its peak at 324.6 ohm-cm in 8 minutes, resistivity drops to 297.2 ohm-cm and stays almost unchanged for the entire monitoring period and never returns to the background value (Figure B-17). The initial increase of resistivity and its dramatic drops in 12 minutes is more likely the result of tracer and groundwater mixing at the borehole rather than groundwater transport, especially considering the low hydraulic conductivity measured by the slug test of 0.31 ft/day. The unchanging resistivity at PZ-2D over most of the monitoring period indicates that there is almost no horizontal flow of groundwater at this location, making it impossible analyze the data further.

Using the analysis method described in the previous section, the specific conductivity data record for PZ-1D was analyzed to estimate average groundwater velocity. Figure B-18 shows the test analysis results. A summary of parameters used for the analysis and the resulting estimates of average groundwater flow velocity are presented in Table B-7. An effective porosity of 5.71% was used based on physical testing results within the screened interval, presented in Attachment B-7. The resulting estimate of groundwater flow velocity at PZ-1D is 2.14E-4 ft/day.

B.4.4 Laboratory Diffusion Cell Testing

Two series of soil samples from the UMCf at each location (PZ-1 and PZ-2) were collected and used for laboratory diffusion experiments. The through-diffusion cell test method was used to estimate the effective diffusion coefficient for ions in the soil samples. In this method, a sample was positioned between two solution reservoirs of equal hydraulic head (for diffusion only scenarios). A concentration gradient was 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 eventually reaches steady state. Once the system has reached a steady state, the flux of tracer across the sample is measured and the effective diffusion coefficient of the tracer is estimated. This site-specific effective diffusion coefficient is necessary to calculate a site-specific estimate of diffusion from the UMCf.

B.4.4.1 Diffusion Cell Testing Procedures

The laboratory diffusion studies were performed in Dr. Jacimaria Batista's laboratory at the University of Nevada, Las Vegas (UNLV). UNLV was instructed by Ramboll to follow Nuclear Waste Management Organization of Canada laboratory protocol to build and conduct the diffusion tests (Vilks and Miller 2007). A copy of the protocol is presented in Attachment B-9.

UNLV completed its own soil physical testing for the samples that they used for cell diffusion tests from PZ-1M and PZ-2M, with the results summarized in Table B-8. Soil concentrations measured by UNLV of sulfate, chloride, perchlorate, chlorate, and nitrate are shown in Table B-9. UNLV groundwater analytical results are provided in Table B-10.

As listed in Table B-11, a total of 8 tests (4 diffusion tests and 4 diffusion-advection tests) were completed. Because of the relatively low concentrations of perchlorate and chlorate in the samples, sulfate was used as a surrogate for perchlorate and chlorate in the calculation of diffusion coefficients. Four diffusion tests and one diffusion-advection test were modelled. The other three diffusion-advections tests were excluded from the analysis because the results were anomalous. Diffusion and diffusion-advection cell test results are summarized in Table B-12a and Table B-12b, respectively. Additional details of the UNLV laboratory studies are presented in Attachment B-10.

B.4.4.2 Diffusion Cell Data Analysis

The one-dimensional analytical solution of instantaneous mass input was used to model the data generated by experiments. Concentration change over time at each point is:

$$C(x,t) = \frac{M_0}{n_e A} X_l(x,t) \qquad (5)$$

where:

$$X_l = \frac{1}{\sqrt{4\pi D_x}} e^{-\frac{(x-V_x t)}{4D_x t}} \qquad (6)$$

C is the concentration $[M/L^3]$, M_0 is mass [M], x is distance [L], t is time [T], n_e is effective porosity [-], A is cross section area $[L^2]$, D_x is hydrodynamic dispersion coefficient $[L^2/T]$ and V_x is groundwater velocity. Hydrodynamic dispersion is the sum of effective diffusion and dispersion coefficients (if advection is occurring). The effective diffusion coefficient is the pore (or free) diffusion coefficient multiplied by tortuosity (τ). Tortuosity is a dimensionless factor which accounts for tortuous diffusion path of molecules in a porous media. Tortuosity was estimated using Archie's model: $\tau = \sqrt[3]{n_e}$. The one-dimensional analytical solution does not take into account mixing within the chambers.

The fit between the analytical model and the observations is presented in Figures B-19 and B-20 for laboratory tests conducted from soil and groundwater collected from PZ-1M and PZ-2M, respectively. A summary of diffusion and advection cell results is shown in Table B-13. In general, there was an acceptable match between model results and observations. Only one of the diffusion-advection tests gave reasonable results (second advection test at PZ-2M-56ft); the first advection test at PZ-2M-56ft produced results that did not match the model and so were not reported.

Since we are not considering the effect of electrostatic interaction of ions in the solution on effective diffusion (known as multicomponent diffusion), the effective diffusion coefficient of other ions in solution can be calculated simply by multiplying the pore diffusion coefficient of each ion by the average tortuosity coefficient (tortuosity coefficient is equal for all ions in this case). By doing so, we obtain the average effective diffusion coefficients for perchlorate of 9.31-10 m^2/s and 8.70E-10 m^2/s for PZ-1 and PZ-2, respectively.

B.4.5 Matrix Diffusion Study Results

The matrix diffusion study was designed to evaluate whether upward migration of perchlorate from the UMCf to the alluvium is a significant cause of the elevated concentrations observed downgradient of the AWF (e.g., in wells MW-K4 and ARP-6B). The study confirmed that upward migration is occurring by both advection (due to the hydraulic gradient) and diffusion (due to the concentration gradient). The total upward mass flux from the UMCf mixes with groundwater flowing horizontally within the alluvium. Based on the results of the matrix diffusion testing at PZ-1 and PZ-2, potential perchlorate concentrations in the alluvium from upward migration were estimated at each location. These estimated concentrations were then compared to actual alluvium concentrations measured at MW-K4 (near PZ-1) and ARP-6B (near PZ-2).

B.4.5.1 Upward Migration at PZ-1

The total upward perchlorate mass flux from the UMCf to the alluvium is the sum of the advective and diffusive fluxes. The advective flux F_{adv} in $[ML^{-2}T^{-1}]$ is calculated as the product of the vertical specific discharge of groundwater and the perchlorate concentration at the alluvium-UMCf contact:

$$q_z = K_z \cdot i_v \qquad (7)$$

$$F_{adv} = q_z \cdot C_w \qquad (8)$$

where q_z is vertical specific discharge in [LT^{-1}], K_z is vertical hydraulic conductivity in [LT^{-1}], i_v is the vertical gradient [-], and C_w is the perchlorate concentration at the alluvium-UMCf contact in [ML^{-3}].

The diffusive mass flux F_{diff} is:

$$F_{diff} = D_{eff} \cdot \frac{C_{w2}-C_{w1}}{Z_2-Z_1} \qquad (9)$$

where D_{eff} is effective diffusion coefficient in [L^2T^{-1}], and C_{w2} and C_{w1} are concentrations in the UMCf and alluvium in [ML^{-3}] measured at depths Z_2 and Z_1 in [L], respectively. The total mass flux is:

$$F_{Total} = F_{adv} + F_{diff} \qquad (10)$$

Table B-14 shows that the total upward mass flux based on the measurements at PZ-1 is 71 mg/ft^3-d.

In order to estimate the resulting alluvium concentration, we assume that this mass flux occurs at the same rate between the AWF and PZ-1 (a distance of 330 ft) and that it is diluted by mixing with the horizontal flow of groundwater in the alluvium downgradient of the AWF. The horizontal groundwater flux in the alluvium per unit width is calculated using Darcy's law. The concentration in the alluvium is:

$$C = F_{total} \cdot L / K_x \cdot i_h \cdot b \qquad (12)$$

Where L is the distance between the AWF and PZ-1 [L], K_x is alluvium horizontal hydraulic conductivity in [LT^{-1}], i_h is horizontal gradient, and b is the alluvium mixing zone thickness [L]. The mixing zone thickness was assumed to be 10 ft near PZ-1.

As shown on Table B-14, the estimated concentration in the alluvium resulting from the total estimated upward mass flux calculated at PZ-1 is 23 mg/L. This is the same order of magnitude as the average perchlorate concentration measured from April 2018 to June 2019 at nearby alluvium well MW-K4 of 40 mg/l (Ramboll 2019). Thus, this evaluation indicates that upward migration from the UMCf could be a cause of persistent concentrations of perchlorate measured in the alluvium at MW-K4.

B.4.5.2 Upward Migration at PZ-2

Using the same approach, the matrix diffusion evaluation at PZ-2 is shown in Table B-15. The alluvium mixing zone thickness was assumed to be 5 ft since the paleochannel is not as deep at this location. The concentration in the alluvium resulting from the total upward mass flux at PZ-2 is estimated to be 30 mg/L. This is the same order of magnitude as the average perchlorate concentration measured from April 2018 to June 2019 at nearby alluvium well ARP-6B of 23 mg/l (Ramboll 2019b). Thus, this evaluation indicates that upward migration from the UMCf could be a cause of persistent concentrations of perchlorate measured in the alluvium at ARP-6B.

B.4.5.3 Matrix Diffusion Findings

The results of matrix diffusion study indicate that total vertical perchlorate mass flux (the sum of advective and diffusive flux) from the UMCf to the alluvium is a significant component of the long-term observed elevated perchlorate concentrations in wells downgradient of the AWF. The estimated effect of matrix diffusion is subject to uncertainty. As a result, while this study confirmed that vertical perchlorate mass flux is significant, it does not rule out the possibility that other contributors, such as the AMPAC plume, could be impacting the concentrations observed in groundwater downgradient of the AWF.

B.5 SUMMARY OF FINDINGS

The Athens Road Well Field Capture Evaluation and Matrix Diffusion Study was conducted to address comments on the 2015 and 2016 Annual Remedial Performance Reports for Chromium and Perchlorate from NDEP, which noted increasing perchlorate concentrations in shallow wells located downgradient of the AWF and suggested that capture at the AWF be further evaluated (NDEP 2015, 2016). Possible causes of elevated perchlorate concentrations in downgradient wells identified in the Work Plan include lack of complete capture of the perchlorate plume by the AWF, matrix diffusion from the UMCf to the alluvium, and in the case of the west side of the UMCf ridge, contribution from the AMPAC plume.

As part of the Study, potential gaps in the capture of the perchlorate plume by the AWF extraction wells were evaluated using a tracer test. The effect of matrix diffusion was evaluated at two locations located downgradient of the AWF using a combination of field and laboratory investigations. Consistent with the scope of the Work Plan, contaminant contribution from the AMPAC plume was not evaluated as part of the Study.

A summary of findings is as follows:

- The tracer test showed no evidence of a material gap in the AWF capture zone either to the west or the east of the UMCf ridge.
- Soil sampling at PZ-1, PZ-2, TRA-1, and TRA-2 indicated that perchlorate impacts extend at least 10 ft into the UMCf. Strong upward vertical hydraulic gradients were measured at PZ-1 and PZ-2.
- Slug testing indicated that the hydraulic conductivity of the alluvium is approximately four orders of magnitude higher than that of the UMCf. Borehole dilution testing indicated very slow groundwater velocities in the UMCf.
- The laboratory study conducted by UNLV indicated that the average effective diffusion coefficient for perchlorate is between 8.7E-10 m^2/s and 9.3E-10 m^2/s.
- The matrix diffusion study indicated that total vertical perchlorate mass flux (from both advection and diffusion) from the UMCf to the alluvium is a significant, on-going source to shallow groundwater that is likely occurring throughout the RI Study Area where perchlorate concentrations are elevated in the UMCf. The impact of this on-going source is discussed in Section 9 of the RI Report for OU-1 and OU-2.
- The estimated magnitude of the vertical mass flux near the AWF from the matrix diffusion study is sufficient to explain the observed elevated perchlorate concentrations in wells downgradient of the AWF. However, the study does not rule out a contribution from other sources, including a contribution from the AMPAC plume.

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TABLES

TABLE B-1. WELL CONSTRUCTION DETAILS
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

Well ID	Screened Unit	Date Installed	Ground Surface Elevation (ft msl)	TOC (ft msl)	Borehole Diameter (in)	Borehole Depth (ft bgs)	Filter Pack Interval (ft bgs)	Screen Interval (ft bgs)	Well Casing Material
PZ-1S	Alluvium	7/12/2018	1612.93	1615.42	8	55	33.5 - 35	34 - 35	4" PVC
PZ-1M	UMCf	7/11/2018	1612.87	1615.44	8	49	41 - 45	43 - 44	4" PVC
PZ-1D	UMCf	7/10/2018	1613.37	1615.36	8	55	51 - 55	53 - 54	4" PVC
PZ-2S	Alluvium	7/24/2018	1615.57	1615.14	8	55	44.5 - 46	45 - 46	4" PVC
PZ-2M	UMCf	7/23/2018	1615.66	1615.2	8	65	54.5 - 56	55 - 56	4" PVC
PZ-2D	UMCf	7/13/2018	1615.41	1614.96	8	76	74.5 - 76	75 - 76	4" PVC
TRA-1	Alluvium	7/19/2018	1618.96	1618.58	8	40	17 - 30	19 - 29	4" PVC
TRA-2	Alluvium	7/20/2018	1617.85	1617.49	8	50	25 - 38	27 - 37	4" PVC

Notes:

ft = feet in = inches
ft msl = feet above mean sea level
ft bgs = feet below ground surface
UMCf = Upper Muddy Creek Formation
PVC = Polyvinyl chloride. Unless indicated otherwise, schedule 40 PVC well casing was installed.
TOC = Top of casing

TABLE B-2. TRACER TEST BACKGROUND SAMPLING

AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

Well ID	Sampler Deployment Dates	Sampler Retrieval Dates	Water Level Depth (ft bTOC)	Groundwater Level Elevation (ft amsl)
ARP-4A	October 30 & November 6, 2018	November 6 & November 13, 2018	NA*	--
ARP-5A	October 30 & November 6, 2018	November 6 & November 13, 2018	32.95	1583.28
ARP-6B	October 5 & October 12, 2018	October 12 & October 19, 2018	31.79	1583.73
ART-6	October 5 & October 12, 2018	October 12 & October 19, 2018	34.37	1581.08
ART-7A	October 30 & November 6, 2018	November 6 & November 13, 2018	34.1	1580.74
ART-9	October 30 & November 6, 2018	November 6 & November 13, 2018	33.2	1581.81
MW-K4	October 5 & October 12, 2018	October 12 & October 19, 2018	30.74	1584.13
PC-136	October 5 & October 12, 2018	October 12 & October 19, 2018	33.53	1584.84
PC-144	October 5 & October 12, 2018	October 12 & October 19, 2018	34.64	1584.12
PC-145	October 5 & October 12, 2018	October 12 & October 19, 2018	33.47	1584.52
PC-148	October 30 & November 6, 2018	November 6 & November 13, 2018	32.3	1585.83
PC-149	October 30 & November 6, 2018	November 6 & November 13, 2018	33.6	1585.48
PC-150	October 30 & November 6, 2018	November 6 & November 13, 2018	NA*	--
TRA-1	October 5 & October 12, 2018	October 12 & October 19, 2018	28.2	1590.38
TRA-2	October 5 & October 12, 2018	October 12 & October 19, 2018	31.25	1586.24

Notes:

ft amsl = feet above mean sea level

ft bTOC = feet below top of casing

NA - Not applicable

-- = Not Available

* ARP-4A was almost dry; sampler was placed at bottom of well. At PC-150, water level meter did not fit due to extraction system header on the well casing.

TABLE B-3a. TRACER TEST RESULTS - CARBON SAMPLES
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

Well ID	Date/Time		Fluorescein		Rhodamine WT		OUL Number
	Placed	Collected	Peak λ (nm)	Conc. (ppb)	Peak λ (nm)	Conc. (ppb)	
ART-6	12/21/18 8:48	12/29/18 7:02	ND	<0.025	568	49	D4145
ART-6	12/29/18 7:04	1/4/19 15:56	ND	<0.025	568.2	35.3	D4177
ART-6	1/4/19 16:00	1/11/19 12:50	ND	<0.025	567.8	14.9	D4308
ART-6 (FD)	1/4/19 16:01	1/11/19 12:51	ND	<0.025	568	17.9	D4309
ART-6	1/11/19 12:54	1/18/19 14:48	ND	<0.025	567.2	1.17	D4434
ART-6	2/1/19 13:03	2/7/19 0:00	ND	<0.025	569	3.12	D4755
ART-6	2/7/19 14:54	2/14/19 15:02	ND	<0.025	570.6 *	0.762*	D4823
ART-6	2/22/19 12:44	3/1/19 14:24	ND	<0.025	568.2 *	0.761*	D5170
ART-7A	12/10/18 10:32	12/13/18 14:51	ND	<0.025	566.4	1.31	D3898
ART-7A	1/4/19 16:20	1/11/19 13:20	ND	<0.025	ND	<0.02	D4311
ART-9	11/6/18 10:40	12/5/18 15:44	ND	<0.025	568.3	88.3	D3726
ART-9	12/5/18 15:47	12/10/18 10:14	ND	<0.025	569.8	33.5	D3817
ART-9	12/10/18 10:19	12/13/18 14:32	ND	<0.025	566.7	206,000	D3897
ART-9	12/13/18 14:45	12/17/18 10:09	ND	<0.025	566.6	567,000	D3996
ART-9	12/17/18 10:11	12/21/18 8:52	ND	<0.025	566.7	257,000	D4062
ART-9	12/21/18 8:56	12/29/18 7:11	ND	<0.025	566.8	191,000	D4146
ART-9	12/29/18 7:16	1/4/19 16:08	ND	<0.025	566.6	654,000	D4178
ART-9	1/4/19 16:11	1/11/19 13:03	ND	<0.025	566.6	32,200	D4310
ART-9	1/11/19 13:07	1/18/19 14:58	ND	<0.025	566.5	46,400	D4435
ART-9	1/18/19 15:00	1/25/19 14:44	ND	<0.025	566.5	12,300	D4589
ART-9	1/25/19 14:47	2/1/19 13:10	ND	<0.025	566.5	49,400	D4656
ART-9	2/1/19 13:14	2/7/19 0:00	ND	<0.025	567	51,300	D4756
ART-9	2/7/19 15:06	2/14/19 15:14	ND	<0.025	566.5	6,770	D4824
ART-9	2/14/19 15:18	2/22/19 12:53	ND	<0.025	566.6	4,830	D4943
ART-9	2/22/19 12:56	3/1/19 14:35	ND	<0.025	566.6	8,040	D5171
PC-136	12/21/18 8:39	12/28/18 17:01	ND	<0.025	569	2.55	D4144
PC-136	12/28/18 17:05	1/4/19 15:47	ND	<0.025	568.2	5.64	D4176
PC-136	1/4/19 15:51	1/11/19 12:40	ND	<0.025	567.4	13.4	D4307
PC-136	1/11/19 12:43	1/18/19 14:41	ND	<0.025	567.8	5.99	D4433
PC-136	1/18/19 14:43	1/25/19 14:19	ND	<0.025	567.6	22	D4587
PC-136	1/25/19 14:22	2/1/19 12:49	ND	<0.025	567.2	29.6	D4654
PC-136	2/1/19 12:53	2/7/19 0:00	ND	<0.025	567	29.3	D4754
PC-136	2/7/19 14:43	2/14/19 14:54	ND	<0.025	567.1	43.1	D4822
PC-136	2/22/19 12:35	3/1/19 14:10	ND	<0.025	567.2	37.3	D5169
PC-148	12/29/18 7:34	1/4/19 16:38	ND	<0.025	568.4	3.02	D4179
PC-150	11/6/18 9:30	12/5/18 16:21	514.8	0.353	ND	<0.17	D3730
PC-150	12/10/18 11:13	12/13/18 15:23	513.4 *	0.561*	ND	<0.17	D3902

Notes:

Only detected results are shown.

Conc. = Concentration
(FD) = Field Duplicate
ND = Not Detected
nm = nanometers

ppb = parts per billion
OUL = Ozark Underground Laboratory
WT = Water Tracing
λ = wavelength

* Flourescent dye peak associated with this sample did not meet all criteria for a positive dye result.

TABLE B-3b. TRACER TEST RESULTS - GRAB SAMPLES
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

Well ID	Date/Time Collected	Fluorescein		Rhodamine WT		OUL Number
		Peak λ (nm)	Conc. (ppb)	Peak λ (nm)	Conc. (ppb)	
ART-6	12/29/18 7:02	ND	<0.002	573.7	1.4	D4154
ART-6	1/4/19 15:56	ND	<0.002	574.2	0.874	D4243
ART-6	1/11/19 12:50	ND	<0.002	573.4	0.095	D4334
ART-6 (FD)	1/11/19 12:51	ND	<0.002	576.4	0.045	D4335
ART-6	1/18/19 14:48	ND	<0.002	ND	<0.02	D4457
ART-6	2/7/19 0:00	ND	<0.002	ND	<0.02	D4785
ART-7A	12/13/18 14:51	ND	<0.002	ND	<0.02	D4245
ART-7A	1/4/19 15:56	ND	<0.002	ND	<0.02	D4010
ART-9	12/10/18 10:14	ND	<0.002	573.8	490	D3904
ART-9	12/13/18 14:32	ND	<0.002	573.8	500	D4009
ART-9	12/17/18 10:09	ND	<0.002	573.9	1,540	D4046
ART-9	12/21/18 8:52	ND	<0.002	573.8	1,340	D4101
ART-9	12/29/18 7:11	ND	<0.002	573.9	153	D4155
ART-9	1/4/19 16:08	ND	<0.002	573.7	162	D4244
ART-9	1/11/19 13:03	ND	<0.002	573.8	43.6	D4336
ART-9	1/25/19 14:44	ND	<0.002	573.2	7.8	D4610
ART-9	2/1/19 13:10	ND	<0.002	573.8	22.7	D4687
ART-9	2/7/19 0:00	ND	<0.002	573.2	36	D4786
ART-9	2/14/19 15:14	ND	<0.002	573.8	19.9	D4834
ART-9	2/22/19 12:53	ND	<0.002	573.2	14	D5155
ART-9	3/1/19 14:35	ND	<0.002	573.6	15	D5224
PC-136	12/28/18 17:01	ND	<0.002	572.8	0.21	D4153
PC-136	1/4/19 15:47	ND	<0.002	574.8	0.46	D4242
PC-136	1/11/19 12:40	ND	<0.002	574.2	0.60	D4333
PC-136	1/18/19 14:41	ND	<0.002	572.8	0.39	D4456
PC-136	1/25/19 14:19	ND	<0.002	572.8	1.56	D4609
PC-136	2/1/19 12:49	ND	<0.002	573.2	1.22	D4686
PC-136	2/7/19 0:00	ND	<0.002	573.2	1.81	D4784
PC-136	2/14/19 14:54	ND	<0.002	572.8	1.41	D4833
PC-136	3/1/19 14:10	ND	<0.002	572.2	1.52	D5223
PC-148	1/4/19 16:38	ND	<0.002	ND	<0.02	D4246

Notes:
Only detected results are shown.
Conc. = Concentration
(FD) = Field Duplicate
ND = Not Detected
nm = nanometers
ppb = parts per billion
OUL = Ozark Underground Laboratory
WT = Water Tracing
λ = wavelength

TABLE B-4. SOIL CONCENTRATION VERTICAL PROFILE
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

Well	Sample Date	Depth Interval (ft bgs)	Concentration (mg/kg)			Sample Type
			Chlorate	Nitrate [a]	Perchlorate	
TRA-1	7/19/18	20 - 20.5	<0.02	--	<0.0095	N
		21 - 21.5	<0.02	--	<0.0095	N
		22 - 22.5	<0.02	--	<0.0095	N
		23 - 23.5	<0.02	--	<0.0095	N
		24 - 24.5	<0.02	--	<0.0095	N
		25 - 25.5	<0.02	--	<0.0095	N
		26 - 26.5	0.85	--	2.5	FD
		26 - 26.5	0.86	--	2.3	N
		27 - 27.5	32	--	22	N
		28 - 28.5	69	--	55	N
		29 - 29.5	70.0	--	43	N
		30 - 30.5	55	--	44	N
		31 - 31.5	44	--	33	N
		32 - 32.5	43	--	33	FD
		32 - 32.5	44	--	31	N
		33 - 33.5	42	--	26	N
		34 - 34.5	44	--	30	N
		35 - 35.5	37	--	28	N
		36 - 36.5	33	--	26	N
		37 - 37.5	15	--	16	N
		38 - 38.5	1.4	--	2.9	N
		39 - 39.5	0.46	--	5.6	N
TRA-2	7/20/18	29 - 29.5	21	--	14	N
		30 - 30.5	26	--	19	N
		31 - 31.5	36	--	20	N
		31 - 31.5	35	--	21	FD
		32 - 32.5	27	--	19	N
		33 - 33.5	49	--	26	N
		34 - 34.5	25	--	16	N
		35 - 35.5	25	--	17	FD
		35 - 35.5	26	--	16	N
		36 - 36.5	44	--	20	N
		37 - 37.5	100	--	63	N
		38 - 38.5	86	--	53	N
		39 - 39.5	110	--	62.0	N
		40 - 40.5	110	--	55	N
		41 - 41.5	77	--	43	N
		42 - 42.5	65	--	31	N
		43 - 43.5	60	--	28	N
		44 - 44.5	52	--	22	N
		45 - 45.5	52	--	18	N
		46 - 46.5	14	--	5.5	N
		47 - 47.5	8.8	--	4.1	N
		48 - 48.5	6.2	--	2.6	N

TABLE B-4. SOIL CONCENTRATION VERTICAL PROFILE
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

Well	Sample Date	Depth Interval (ft bgs)	Concentration (mg/kg)			Sample Type
			Chlorate	Nitrate [a]	Perchlorate	
PZ-1D	7/10/18	30 - 30.5	6.0	7.9	3.6	N
		30 - 30.5	5.9	7.0	3.6	FD
		31 - 31.5	5.7	7.2	3.6	N
		32 - 32.5	6.7	7.0	5.6	N
		33 - 33.5	28	29	33	N
		34 - 34.5	25	10	20	N
		35 - 35.5	28	8.9	32	N
		36 - 36.5	26	8.2	27	N
		37 - 37.5	18	5.7	20	N
		38 - 38.5	10	5.2	15	N
		39 - 39.5	8.0	<3.5	13	N
		40 - 40.5	5.8	<3.5	11	N
		41 - 41.5	4.7	<3.5	9.9	N
		42 - 42.5	2.3	<3.5	5.3	N
		43 - 43.5	0.42	<3.5	2.9	N
		44 - 44.5	0.19	<3.5	1.2	N
		45 - 45.5	0.17	<3.5	0.97	N
		46 - 46.5	0.24	<3.5	<0.0095	N
		47 - 47.5	0.16	<3.5	<0.0095	N
		48 - 48.5	<0.05	<3.5	<0.0095	N
		49 - 49.5	<0.05	<3.5	<0.0095	N
		49 - 49.5	<0.05	<3.5	<0.0095	FD
PZ-2D	7/13/18	42 - 42.5	28	12	9.1	N
		42 - 42.5	28	18	11	FD
		43 - 43.5	33	15	9	N
		44 - 44.5	58	19	12	N
		45 - 45.5	77	28	17	N
		46 - 46.5	69	31	11	N
		47 - 47.5	64	27	9.5	N
		48 - 48.5	57	22	7.2	N
		49 - 49.5	37	20	6.4	N
		50 - 50.5	24	12	4.1	N
		51 - 51.5	18	8.6	2.8	N
		52 - 52.5	13	7.0	2.3	N
		53 - 53.5	11	6.5	2.0	N
		54 - 54.5	6.5	6.1	1.4	N
		55 - 55.5	4.8	<3.5	0.89	N
		56 - 56.5	0.17	<3.5	0.018	N
		57 - 57.5	<0.02	<3.5	<0.0095	N
		58 - 58.5	<0.02	<3.5	<0.0095	N
		59 - 59.5	<0.02	<3.5	<0.0095	N
		60 - 60.5	<0.02	<3.5	<0.0095	N
		61 - 61.5	<0.02	<3.5	<0.0095	N
		62 - 62.5	<0.02	<3.5	<0.0095	N
		62 - 62.5	<0.02	<3.5	<0.0095	FD

Notes:

ft bgs = feet below ground surface	N = Normal
mg/kg = milligrams per kilogram	FD = Field Duplicate
-- = Not Available	[a] Nitrate is measured as NO_3^-.

TABLE B-5. SUMMARY OF VERTICAL GRADIENT MEASUREMENTS
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

Well ID	Range of Depth to Water [a] (ft)	Time Range [a]	Average Depth to Water (ft)	Screen Interval (ft bgs)	Midpoint of Screen Interval (ft bgs)	Vertical Gradient (ft/ft)		
						D to M	M to S	D to S
PZ-1								
PZ-1S	32.74 - 32.78	8/20/2018 - 8/31/2018	32.76	34 - 35	34.5	-0.10	-0.06	-0.08
PZ-1M	32.16 - 32.22	8/20/2018 - 8/31/2018	32.19	43 - 44	43.5			
PZ-1D	31.14 - 31.20	8/20/2018 - 8/31/2018	31.17	53 - 54	53.5			
PZ-2								
PZ-2S	32.92 - 32.98	8/23/2018 - 8/31/2018	32.95	45 - 46	45.5	-0.09	-0.02	-0.07
PZ-2M	32.76 - 32.82	8/23/2018 - 8/31/2018	32.8	55 - 56	55.5			
PZ-2D	30.90 - 30.94	8/23/2018 - 8/31/2018	30.92	75 - 76	75.5			

Notes:

ft = feet

ft bgs = feet below ground surface

D = Deep

M = Middle

S = Shallow

[a] Over stable portion of data

TABLE B-6. SUMMARY OF SLUG TEST RESULTS
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

Well ID	Screened Geologic Unit	Test Date [a]	Slug Size	Test Type	Predicted H_0 (ft)	Modeled H_0 (ft)	Analysis Method	K (ft/d)	K_{avg} (ft/d)
PZ-1D	UMCf	10/4/2018	3.1 ft x 3 in	FH	1.74	1.413	ZGD	0.4067	0.36
PZ-2D	UMCf	10/4/2018	3.1 ft x 3 in	FH	1.73	1.202	ZGD	0.3064	
PZ-2S	Alluvium	8/16/2018	3.1 ft x 3 in	FH	1.74	1.855	ZGD	330.9	353
PZ-2S	Alluvium	8/16/2018	4 ft x 1.5 in	FH	0.58	0.5669	ZGD	335.9	
PZ-2S	Alluvium	8/16/2018	3.1 ft x 3 in	FH	1.74	1.524	ZGD	338.7	
PZ-2S	Alluvium	8/16/2018	4 ft x 1.5 in	FH	0.46	0.5098	ZGD	356.7	
PZ-2S	Alluvium	8/16/2018	3.1 ft x 3 in	RH	1.74	1.278	ZGD	325.4	
PZ-2S	Alluvium	8/16/2018	4 ft x 1.5 in	RH	0.32	0.4902	ZGD	405.0	
PZ-2S	Alluvium	8/16/2018	3.1 ft x 3 in	RH	1.74	1.511	ZGD	326.2	
PZ-2S	Alluvium	8/16/2018	4 ft x 1.5 in	RH	0.31	0.4573	ZGD	407.5	
TRA-2	Alluvium	8/16/2018	3.1 ft x 3 in	FH	1.416	1.342	ZGD	430.3	430

Notes:

ft = feet in = inch

ft/d = feet per day

K = hydraulic conductivity

K_{avg} = average hydraulic conductivity

H_0 = Initial water-level displacement

FH = Falling Head

RH = Rising Head

ZGD = Zlotnick, Goss, and Duffield (2010)

[a] Test start date shown for tests conducted over multiple days

TABLE B-7. SUMMARY OF BOREHOLE DILUTION RESULTS
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

Well ID	Hydraulic Conductivity, K (ft/d)	Groundwater Flow Distortion Factor, α	Effective Porosity, n_e	Flow Velocity in the Well, V_w (ft/d)	Groundwater Velocity, V_a (ft/d)
PZ-1D	0.41	3.19	0.0571	3.91E-05	2.14E-04

Notes:

ft/d = feet per day

K = hydraulic conductivity

$V_w = V_a * n_e * \alpha$

V_a = actual groundwater velocity

n_e = effective porosity

α = groundwater flow distortion factor

TABLE B-8. PHYSICAL SOIL PROPERTIES OF DIFFUSION SAMPLES
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

Soil Physical Property	Sample			Unit
	PZ-1M (46.5’)	PZ-2M (55.5’)	PZ-2M (66.0’)	
Moisture Content	93.07	34.90	58.65	%
Specific Gravity	2.729	2.770	2.745	g/cm^3
Porosity	72.25	48.64	61.99	%
Degree of Saturation	97.58	103.42	99.19	--
Wet Bulk Density	91.25	119.76	103.28	lb/ft^3
Dry Bulk Density	47.26	88.77	65.10	lb/ft^3

Notes:

g/cm^3 = grams per cubic centimeter

lb/ft^3 = pounds per cubic foot

(46.5')= sample depth in feet below ground surface

-- = unitless

TABLE B-9. INITIAL SOIL CONCENTRATION IN DIFFUSION CELLS
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

Boring ID / Depth (ft bgs)	Soil Concentration				
	Chlorate (µg/g of wet soil)	Chloride (mg/g of wet soil)	Nitrate as N (mg/g of wet soil)	Perchlorate (µg/g of wet soil)	Sulfate (mg/g of wet soil)
PZ-1M/ 46.5’	0.07	0.23	0.0009	0.57	0.40
PZ - 2M/ 55.5’	11.71	0.26	0.0018	5.54	0.46
PZ - 2M/ 56’	5.87	0.16	0.0060	0.67	0.53
PZ - 2M/ 65’	3.14	0.12	0.0012	2.02	0.44
PZ - 2M/ 66.5’	0.64	0.14	0.0010	0.63	0.86

Notes:

ft bgs = feet below ground surface

mg/g = milligram per gram

µg/g = microgram per gram

TABLE B-10. DIFFUSION AND ADVECTION CELL INFLUENT WATER CONCENTRATION
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

Test	Water Source	Dilution Factor	Water Concentration					
			Chlorate (µg/L)	Chloride (mg/L)	Nitrate as N (mg/L)	Nitrate as NO_3^- (mg/L)	Perchlorate (µg/L)	Sulfate (mg/L)
Raw	PZ-1M	Raw	340	410	0.15	0.67	380	840
Raw	PZ-2M	Raw	14,000	490	1.6	6.9	3,100	1,200
Diffusion Test 1	PZ-1M	10	52	44	< 0.11	< 0.5	< 100	88
	PZ-2M	1,000	15	0.6	< 0.11	< 0.5	< 100	1.3
Diffusion Test 2	PZ-1M	1,000	< 100	0.75	< 0.11	< 0.5	< 100	1.9
	PZ-2M	1,000	26	1.3	< 0.11	< 0.5	< 100	4.4
Advection Test	PZ-1M	2	170	220	0.098	0.43	170	440
Advection Test 1	PZ-2M	10	1,400	45	0.16	0.7	330	110
Advection Test 2	PZ-2M	10	1,400	49	0.12	0.55	300	120
Advection Test 3	PZ-2M	10	1,500	50	0.19	0.83	330	120

Notes:

mg/L = milligrams per liter

µg/L = micrograms per liter

TABLE B-11. DIFFUSION AND ADVECTION CELL TEST DATES
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

Test	Location	Start Date	Duration	Sample Used
Diffusion Test 1	PZ-1M	12/6/2018	132 Days	PZ-1M-46.5'
	PZ-2M		132 Days	PZ-2M-56.5'
Diffusion Test 2	PZ-1M	3/4/2019	16 Days	PZ-1M-46.5'
	PZ-2M		16 Days	PZ-2M-56.5'
Advection Test 1	PZ-1M	2/16/2019	33 Days	PZ-1M-46.5'
Advection Test 1	PZ-2M	2/9/2019	73 Hours	PZ-2M-56'
Advection Test 2	PZ-2M	3/19/2019	16 Days	PZ-2M-56'
Advection Test 3	PZ-2M	3/25/2019	37 Hours	PZ-2M-56'

TABLE B-12a. DIFFUSION CELL ANALYTICAL RESULS
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

Test	Accumulated Time (days)	Sample Concentration												Note
		Chlorate (µg/L)		Chloride (mg/L)		Nitrate as N (mg/L)		Nitrate as NO_3^- (mg/L)		Perchlorate (µg/L)		Sulfate (mg/L)		
		PZ-1M	PZ-2M	PZ-1M	PZ-2M	PZ-1M	PZ-2M	PZ-1M	PZ-2M	PZ-1M	PZ-2M	PZ-1M	PZ-2M	
1st Diffusion Test	-	52	15	44	0.6	< 0.11	< 0.11	< 0.5	< 0.5	< 100	< 100	88	1.3	[A]
	0.1	100	630	73	26	< 0.11	< 2.2	< 0.5	< 10	< 100	110	150	73	--
	5	< 100	< 2	64	22	< 0.11	< 2.2	< 0.5	< 10	< 100	< 100	140	81	--
	7	< 100	< 2	61	20	< 0.11	< 2.2	< 0.5	< 10	< 100	< 100	130	72	--
	13	< 100	< 2	58	20	< 0.11	< 2.2	< 0.5	< 10	< 100	< 100	120	67	--
	20	< 100	< 2	49	17	< 0.11	< 2.2	< 0.5	< 10	< 100	< 100	100	58	--
	32	< 100	< 100	44	12	< 0.11	< 0.11	< 0.5	< 0.5	< 100	< 100	94	45	--
	43	< 0.054	< 100	41	11	< 0.11	< 0.11	< 0.5	< 0.5	< 100	< 100	85	41	--
	63	< 100	< 100	41	8.6	< 0.11	< 0.11	< 0.5	< 0.5	< 100	< 100	85	33	--
	70	< 100	< 100	41	10	< 0.11	0.097	< 0.5	0.43	< 100	< 100	85	32	--
	77	< 100	< 100	44	8.7	< 0.11	< 0.11	< 0.5	<0.5	< 100	< 100	85	29	--
	84	< 100	< 22	42	8.5	< 0.11	< 0.11	< 0.5	<0.5	< 100	< 100	83	27	--
	95	< 100	< 100	42	8	< 0.11	< 0.11	< 0.5	<0.5	< 100	< 100	77	24	--
	103	< 100	< 100	44	7.9	< 0.11	< 0.11	< 0.5	<0.5	< 100	< 100	75	23	--
	109	< 100	< 100	44	7.6	< 0.11	< 0.11	< 0.5	<0.5	< 100	< 100	71	21	--
	116	< 100	< 100	42	6.4	< 0.11	< 0.11	< 0.5	<0.5	< 100	< 100	63	20	--
	123	< 100	< 100	89	7.3	< 0.11	< 0.11	< 0.5	<0.5	< 100	< 100	110	20	--
	132	< 100	< 100	43	6.3	-	< 0.11	-	<0.5	< 100	< 100	42	18	--
	140	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	--
	147	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	--
2nd Diffusion Test	0.5	13	200	6.1	7.4	<0.11	<0.11	<0.5	<0.5	< 100	100	8.4	15	--
	1.0	< 100	250	13	10	-	-	-	-	260	150	13	21	--
	1.5	< 100	280	9.1	9.9	-	-	-	-	< 100	51	14	22	--
	2.5	< 100	290	12	9.8	<0.11	<0.11	<0.5	<0.5	< 100	62	16	26	--
	3.5	< 100	320	12	25	-	-	-	-	< 100	64	21	29	--
	4.5	< 100	310	9.9	11	-	-	-	-	< 100	77	22	31	--
	5.5	12	320	13	10	<0.11	<0.11	<0.5	<0.5	< 100	72	23	34	--
	6.5	14	310	10	22	-	-	-	-	< 100	71	22	32	--
	7.5	< 100	300	12	10	-	-	-	-	< 100	74	26	32	--
	8.5	18	260	13	10	<0.11	<0.11	<0.5	<0.5	< 100	68	23	34	--

TABLE B-12a. DIFFUSION CELL ANALYTICAL RESULS
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

Test	Accumulated Time (days)	Sample Concentration												Note
		Chlorate (µg/L)		Chloride (mg/L)		Nitrate as N (mg/L)		Nitrate as NO_3^- (mg/L)		Perchlorate (µg/L)		Sulfate (mg/L)		
		PZ-1M	PZ-2M	PZ-1M	PZ-2M	PZ-1M	PZ-2M	PZ-1M	PZ-2M	PZ-1M	PZ-2M	PZ-1M	PZ-2M	
2nd Diffusion Test	9.5	20	340	12	11	-	-	-	-	< 100	63	26	33	--
	10.5	20	100	13	10	-	-	-	-	< 100	75	24	34	--
	11.5	20	< 100	19	12	0	-	0	-	100	< 100	29	34	--
	12.5	22	< 100	13	12	0	-	0	-	100	< 100	24	33	--
	13.5	23	< 100	12	11	0	<0.11	0	<0.5	100	< 100	24	33	--
	14.5	35	35	15	13	0	-	0	-	100	< 100	25	35	--
	15.5	22	61	33	11	-	-	-	-	< 100	< 100	26	32	--
	16.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	--
	17.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	--

Notes:

mg/L = milligrams per liter

NA = Not Available

-- = Not Applicable

[A] Groundwater sample (PZ-1M = 10x, PZ-2M = 1000x)

TABLE B-12b. ADVECTION CELL ANALYTICAL RESULS
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

Test	Accumulated Time (hours)	PZ-2M 56' Sample Concentration						Note
		Chlorate (µg/L)	Chloride (mg/L)	Nitrate as N (mg/L)	Nitrate as NO_3^- (mg/L)	Perchlorate (µg/L)	Sulfate (mg/L)	
1st Advection Test	-	1400	45	0.16	0.7	330	110	[A]
	1	1400	50	0.19	0.83	280	120	--
	2	1600	50	0.17	0.76	210	120	--
	3	1600	55	0.18	0.78	320	140	--
	4	1700	58	0.18	0.8	460	140	--
	5	1700	57	0.18	0.8	330	140	--
	6	1700	57	0.18	0.79	390	140	--
	8	1700	59	0.18	0.79	370	140	--
	10	1700	59	0.18	0.81	370	140	--
	11	1700	60	0.18	0.79	470	150	--
	12	1700	61	0.18	0.78	400	140	--
	13	1700	59	0.21	0.94	330	140	--
	14	1600	53	0.19	0.83	320	130	--
	15	1600	58	< 0.11	< 0.5	470	140	--
	25	1700	61	< 0.11	< 0.5	420	160	--
	37	1400	56	< 0.11	< 0.5	340	150	--
	49	580	53	< 0.11	< 0.5	290	140	--
	61	81	53	< 0.11	< 0.5	320	140	--
	73	< 100	54	< 0.11	< 0.5	240	140	--
2nd Advection Test	-	NA	NA	NA	NA	NA	NA	[A]
	6	2000	70	0.27	1.2	460	170	--
	13	2200	77	NA	-	520	200	--
	21	2000	69	NA	-	440	190	--
	29	1800	62	0.058	0.26	400	170	--
	37	1700	63	NA	NA	390	200	--
	45	1600	57	NA	NA	370	150	--
	53	1600	54	< 0.11	< 0.5	360	150	--
	61	1500	55	NA	NA	370	140	--
	69	1200	54	NA	NA	350	140	--
	77	780	56	< 0.11	< 0.5	360	140	--
	85	210	52	NA	NA	330	130	--

TABLE B-12b. ADVECTION CELL ANALYTICAL RESULS
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

Test	Accumulated Time (hours)	PZ-2M 56' Sample Concentration						Note
		Chlorate (µg/L)	Chloride (mg/L)	Nitrate as N (mg/L)	Nitrate as NO_3^- (mg/L)	Perchlorate (µg/L)	Sulfate (mg/L)	
2nd Advection Test	93	< 100	53	NA	NA	340	130	--
	105	14	55	< 0.11	< 0.5	250	140	--
	117	< 100	58	NA	NA	180	140	--
	129	< 100	54	NA	NA	96	130	--
	141	< 100	55	< 0.11	< 0.5	< 100	140	--
	153	< 100	55	< 0.11	< 0.5	< 100	130	--
	165	< 100	52	< 0.11	< 0.5	< 100	130	--
	177	< 100	51	< 0.11	< 0.5	< 100	130	--
	189	< 100	53	< 0.11	< 0.5	< 100	130	--
	201	< 100	54	< 0.11	< 0.5	< 100	130	--
	213	< 100	53	< 0.11	< 0.5	< 100	130	--
	237	< 100	54	< 0.11	< 0.5	< 100	130	--
	261	< 100	56	< 0.11	< 0.5	< 100	130	--
	285	< 100	53	< 0.11	< 0.5	< 100	130	--
	309	< 100	50	-	-	< 100	130	--
	333	< 100	51	< 0.11	< 0.5	< 100	130	--
	357	< 100	50	-	-	< 100	130	--
	381	< 100	51	< 0.11	< 0.5	< 100	130	--

Notes:

mg/L = milligrams per liter

NA = Not Available

-- = Not Applicable

[A] Goundwater sample

TABLE B-13. DIFFUSION AND ADVECTION CELL TEST RESULTS
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

Parameter	Symbol	Unit	PZ-1M-46.5'		PZ-2M-56.5'		PZ-2M-56.5'
			1st Diffusion Test	2nd Diffusion Test	1st Diffusion Test	2nd Diffusion Test	2nd Advection Test
Mass	M_0	mg	47.17	45.95	66.56	55.88	51.00
Seepage Velocity	V_x	ft/d	-	-	-	-	5.62E-02
Longitudinal Dispersivity	a_L	ft	-	-	-	-	1.67E-02
Effective Porosity	n	-	19	10	10	13	11
Pore Diffusion Coefficient - Sulfate	D_m	m^2/s	1.07E-09	1.07E-09	1.07E-09	1.07E-09	1.07E-09
Tortuosity	t	-	0.57	0.46	0.46	0.51	0.48
Effective Diffusion Coefficient - Sulfate	D_x	m^2/s	6.12E-10	4.94E-10	4.94E-10	5.40E-10	1.52E-09
Average Effective Diffusion Coefficient - Sulfate	D_{avg}	m^2/s	5.53E-10		5.17E-10		1.52E-09
Pore Diffusion Coefficient - Perchlorate	D_{avg}	m^2/s	1.79E-09		1.79E-09		1.79E-09
Average Effective Diffusion Coefficient - Perchlorate	D_{avg}	m^2/s	9.31E-10		8.70E-10		8.59E-10

Notes:

ft = feet
ft^2 = square feet
ft/d = feet per day
in = inches
mg = milligrams
m^2/s = square meters per second

TABLE B-14. MATRIX DIFFUSION EVALUATION AT PZ-1
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

	Symbol	Value	Unit	Note
Advective Flux from UMCf to Qal				
Dry Bulk Density (UMCf)	ρ_b	1.10	g/cc	Measured (Attachment E-7)
Total Porosity (UMCf)	n	0.61	-	Measured (Attachment E-7)
Perchlorate Soil Concentration in UMCf	C_s	33.0	mg/kg	Measured at 33.5 ft (Table E-4)
Perchlorate Water Concentration in UMCf	C_w	59.9	mg/l	Calculated from C_s, ρ_b, and n
Vertical Hydraulic Gradient	i_v	0.10	ft/ft	Measured (Table E-5)
Vertical Hydraulic Conductivity	K	4.10E-01	ft/day	Measured (Table E-6)
Specific Discharge	q_z	4.18E-02	ft/day	Calculated from K and i_v
Advective Mass Flux	F_{adv}	70.89	mg/ft^2-day	Calculated
Diffusive Flux from UMCf to Qal				
Dry Bulk Density (UMCf)	ρ_b	1.10	g/cc	Measured (Attachment E-7)
Total Porosity (UMCf)	n	0.61	-	Measured (Attachment E-7)
Perchlorate Soil Concentration in UMCf	C_{s1}	33.0	mg/kg	Measured at 33.5 ft (Table E-4)
Perchlorate Water Concentration in UMCf	C_{w1}	59.9	mg/l	Calculated from C_{s1}, ρ_b, and n for UMCf
Depth of UMCf Sample	Z_1	33.5	ft	Measured depth
Dry Bulk Density (Qal)	ρ_b	1.76	g/cc	Measured (Attachment E-7)
Total Porosity (Qal)	n	0.34	-	Measured (Attachment E-7)
Perchlorate Soil Concentration in Qal	C_{s2}	9.0	mg/kg	Measured at 31.5 ft (Table E-4)
Perchlorate Water Concentration in Qal	C_{w2}	47.3	mg/l	Calculated from C_{s2}, ρ_b, and n for alluvium
Depth of Qal Sample	Z_2	31.5	ft	Measured depth
Effective Diffusion Coefficient	D_{eff}	9.31E-10	m^2/sec	Measured (Table E-13)
Diffusive Mass Flux	F_{diff}	0.15	mg/ft^2-day	Calculated

TABLE B-14. MATRIX DIFFUSION EVALUATION AT PZ-1
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

	Symbol	Value	Unit	Note
Estimated Concentration in Alluvium From Mass Flux				
Total Mass Flux	F_{total}	71.04	mg/ft^2-day	Sum of advective and diffusive fluxes
Distance Between AWF and PZ-1	L	330	ft	Measured
Hydraulic Conductivity of Alluvium	K	353.3	ft/day	Measured at PZ-2S (Table E-6)
Horizontal Hydraulic Gradient (Upgradient of PZ-1)	i_H	0.01	ft/ft	Estimated from Figure E-7
Alluvium Mixing Zone Thickness	b	10	ft	Assumption
Alluvium Concentration From Upward Mass Flux	C	23	mg/l	Calculated
Measured Groundwater Concentrations at MW-K4 (April 2018 - June 2019)				
5/9/2018		45	mg/l	2019 Annual Report
11/6/2018		52	mg/l	2019 Annual Report
5/8/2019		23	mg/l	2019 Annual Report
Average		40	mg/l	Calculated

Notes:

Qal = Alluvium

UMCf = Upper Muddy Creek Formation

TABLE B-15. MATRIX DIFFUSION EVALUATION AT PZ-2
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

	Symbol	Value	Unit	References
Advective Flux from UMCf to Qal				
Dry Bulk Density (UMCf)	ρ_b	1.32	g/cc	Measured (Attachment E-7)
Total Posority (UMCf)	n	0.52	-	Measured (Attachment E-7)
Perchlorate Soil Concentration in UMCf	C_s	17.0	mg/kg	Measured at 45.5 ft (Table E-4)
Perchlorate Water Concentration in UMCf	C_w	42.8	mg/l	Calculated from C_s, ρ_b, and n
Vertical Hydraulic Gradient	i_v	0.09	ft/ft	Measured (Table E-5)
Vertical Hydraulic Conductivity	K	3.10E-01	ft/day	Measured (Table E-6)
Specific Discharge	q_z	2.91E-02	ft/day	Calculated from K and i_v
Advective Mass Flux	F_{adv}	35.34	mg/ft^2-day	Calculated
Diffusive Flux from UMCf to Qal				
Dry Bulk Density (UMCf)	ρ_b	1.32	g/cc	Measured (Attachment E-7)
Total Porosity (UMCf)	n	0.52	-	Measured (Attachment E-7)
Perchlorate Soil Concentration UMCf	C_{s1}	17.0	mg/kg	Measured at 45.5 ft (Table E-4)
Perchlorate Water Concentration UMCf	C_{w1}	42.8	mg/l	Calculated from C_{s1}, ρ_b, and n for UMCf
Depth of UMCf Sample	Z_1	45.5	ft	Measured depth
Dry Bulk Density (Qal)	ρ_b	1.62	g/cc	Measured (Attachment E-7)
Total Porosity (Qal)	n	0.35	-	Measured (Attachment E-7)
Perchlorate Soil Concentration in Qal	C_{s2}	9.0	mg/kg	Measured at 43.5 ft (Table E-4)
Perchlorate Water Concentration in Qal	C_{w2}	41.4	mg/l	Calculated from C_{s2}, ρ_b, and n for alluvium
Depth of Qal Sample	Z_2	43.5	ft	Measured depth
Effective Diffusion Coefficient	D_{eff}	8.70E-10	m^2/sec	Measured (Table E-13)
Diffusive Mass Flux	F_{diff}	0.02	mg/ft^2-day	Calculated

TABLE B-15. MATRIX DIFFUSION EVALUATION AT PZ-2
AWF Capture Zone and Matrix Diffusion Evaluation
Nevada Environmental Response Trust Site
Henderson, Nevada

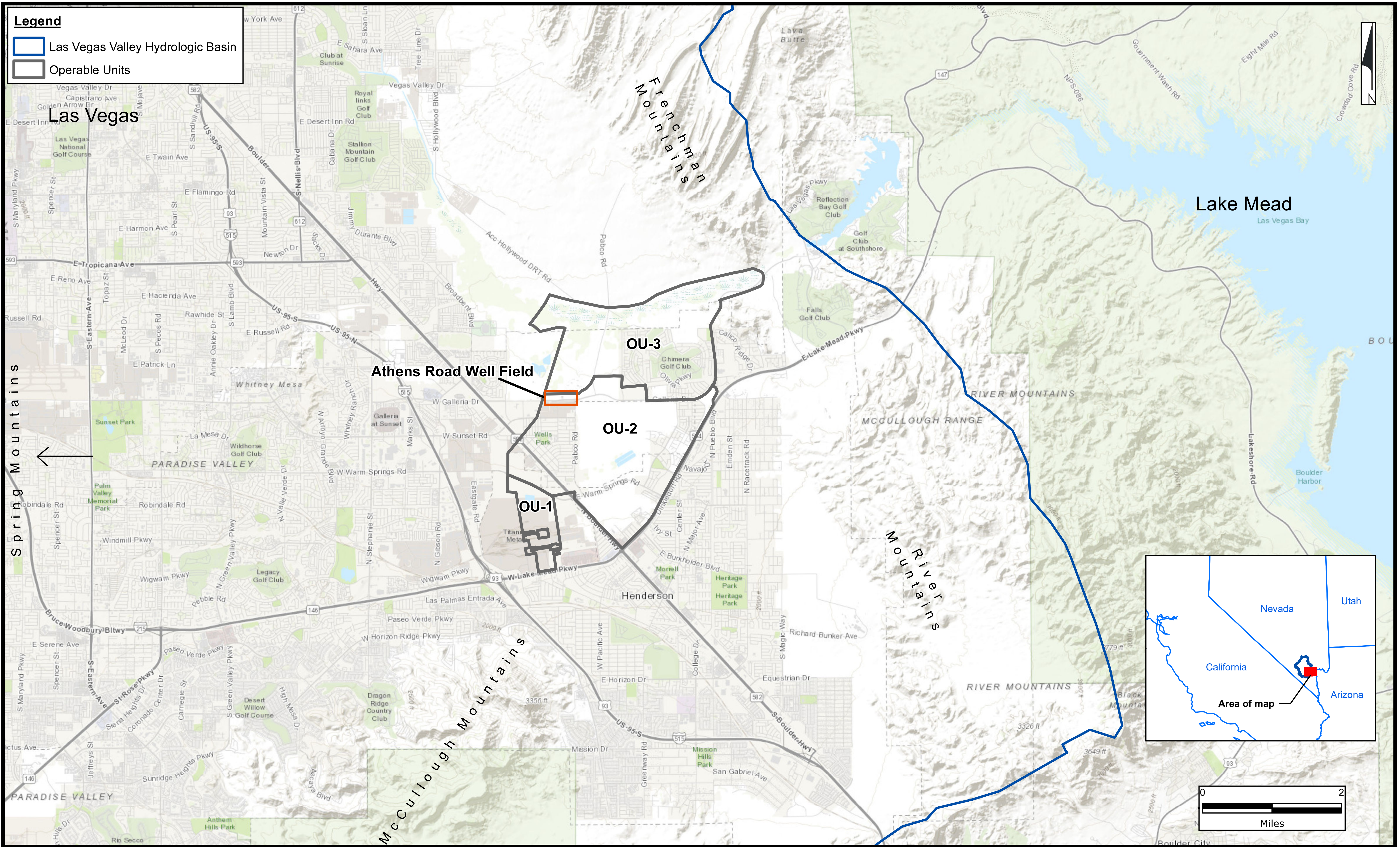
	Symbol	Value	Unit	References
Estimated Concentration in Alluvium From Mass Flux				
Total Mass Flux	F_{total}	35.36	mg/ft^2-day	Sum of advective and diffusive fluxes
Distance between AWF and PZ-2	L	420	ft	Measured
Hydraulic Conductivity of Alluvium	K	353.3	ft/day	Measured at PZ-2S (Table E-6)
Horizontal Hydraulic Gradient (Upgradient of PZ-2)	i_H	0.01	ft/ft	Estimated from Figure E-7
Alluvium Mixing Zone Thickness	b	5	ft	Assumption
Alluvium Concentration From Upward Mass Flux	C	30	mg/l	Calculated
Measured Groundwater Concentrations at ARP-6B (April 2018 - June 2019)				
5/9/2018		25	mg/l	2019 Annual Report
11/6/2018		23	mg/l	2019 Annual Report
5/10/2019		21	mg/l	2019 Annual Report
Average		23	mg/l	Calculated

Notes:

Qal = Alluvium

UMCf = Upper Muddy Creek Formation

FIGURES



Study Area Location Map

Athens Well Field Capture Evaluation and Matrix Diffusion Study
Nevada Environmental Response Trust Site
Henderson, Nevada

RAMBOLL

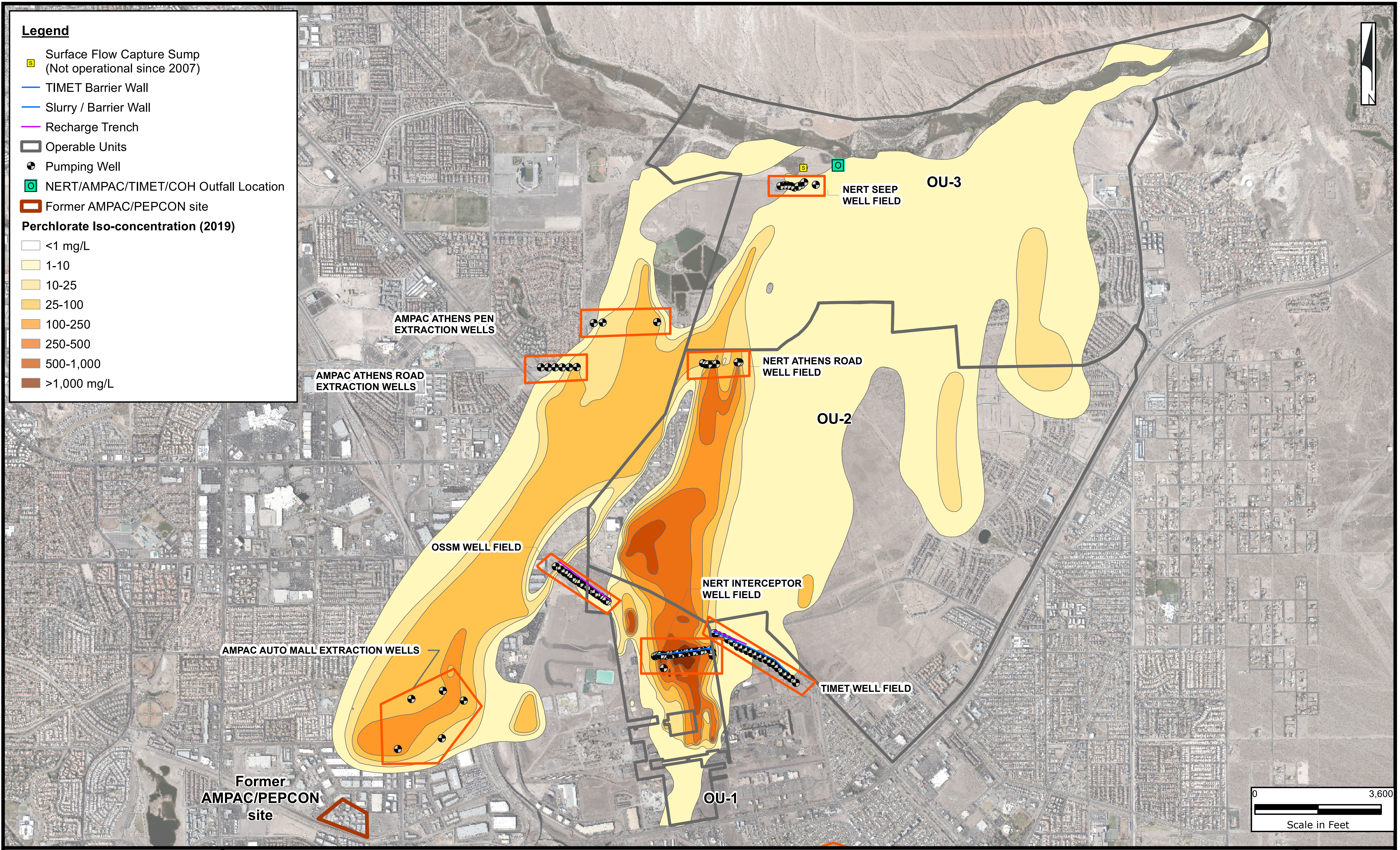
DRAFTED BY: JC

DATE: 2020-01-27

FIGURE
B-1

Contract: 169001 1200-053

H:\LePetomane\NERT\Modeling\AWF Capture Evaluation-L12\Reporting\mxd files\Figure B-1 - Location Map (Study Area).mxd



RAMBOLL

DRAFTED BY: JC | DATE: 2021-02-24

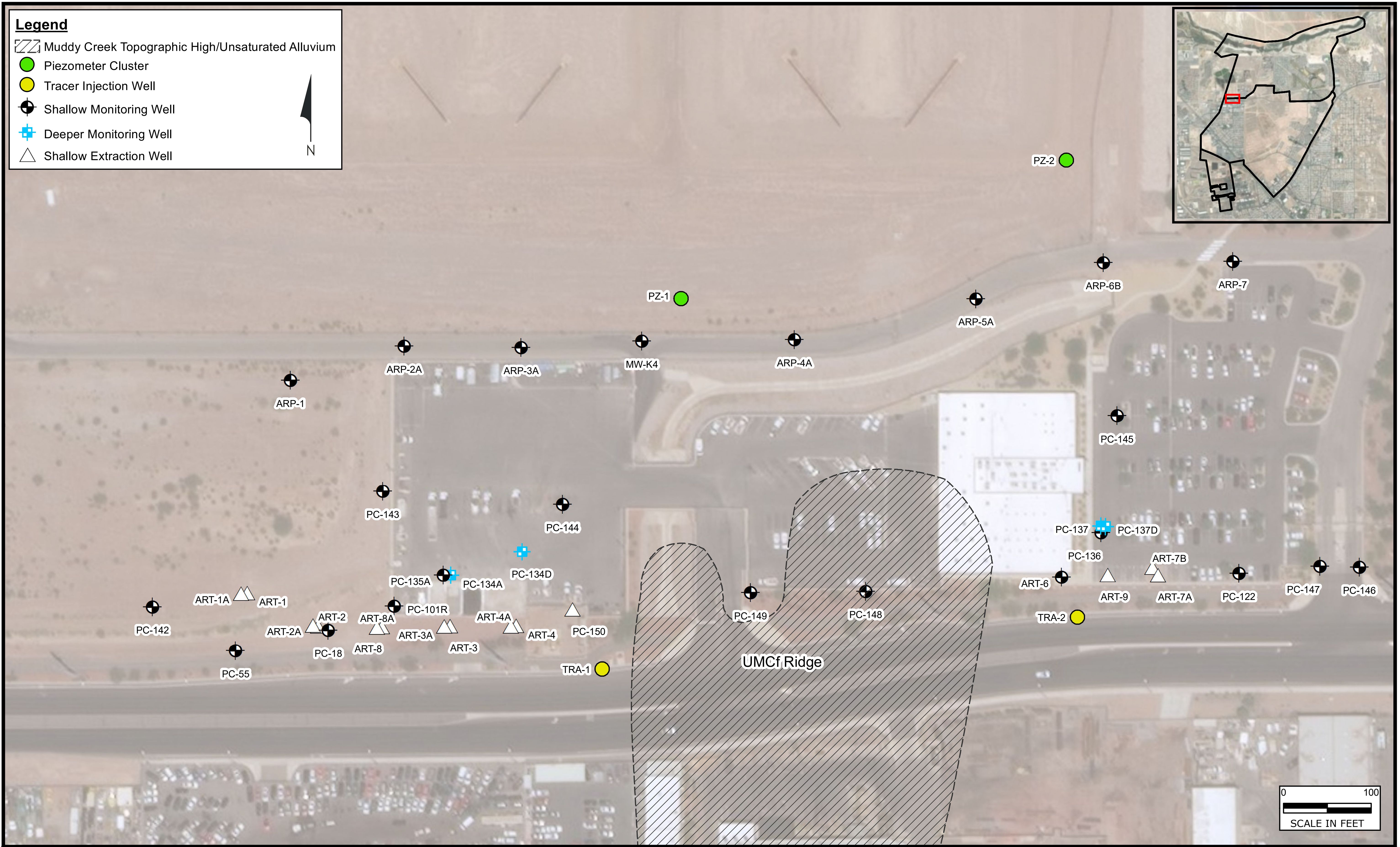
NERT and AMPAC Perchlorate Plumes and Remediation Systems

Athens Well Field Capture Evaluation and Matrix Diffusion Study
Nevada Environmental Response Trust Site
Henderson, Nevada

FIGURE
B-2

Contract: 169001 1200-053

H:\LePetomane\NERT\Modeling\AWF Capture Evaluation-L12\Reporting\mxd files\Figure B-2 - Well FIeld Location with Plume Map.mxd



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DRAFTED BY: JC

DATE: 2020-01-27

Well Location Map

Athens Well Field Capture Evaluation and Matrix Diffusion Study
Nevada Environmental Response Trust Site
Henderson, Nevada

FIGURE
B-3

Contract: 169001 1200-053

H:\LePetomane\NERT\Modeling\AWF Capture Evaluation-L12\Reporting\mxd files\Figure B-3 - Location Map_AWF and Bioremediation Wells.mxd

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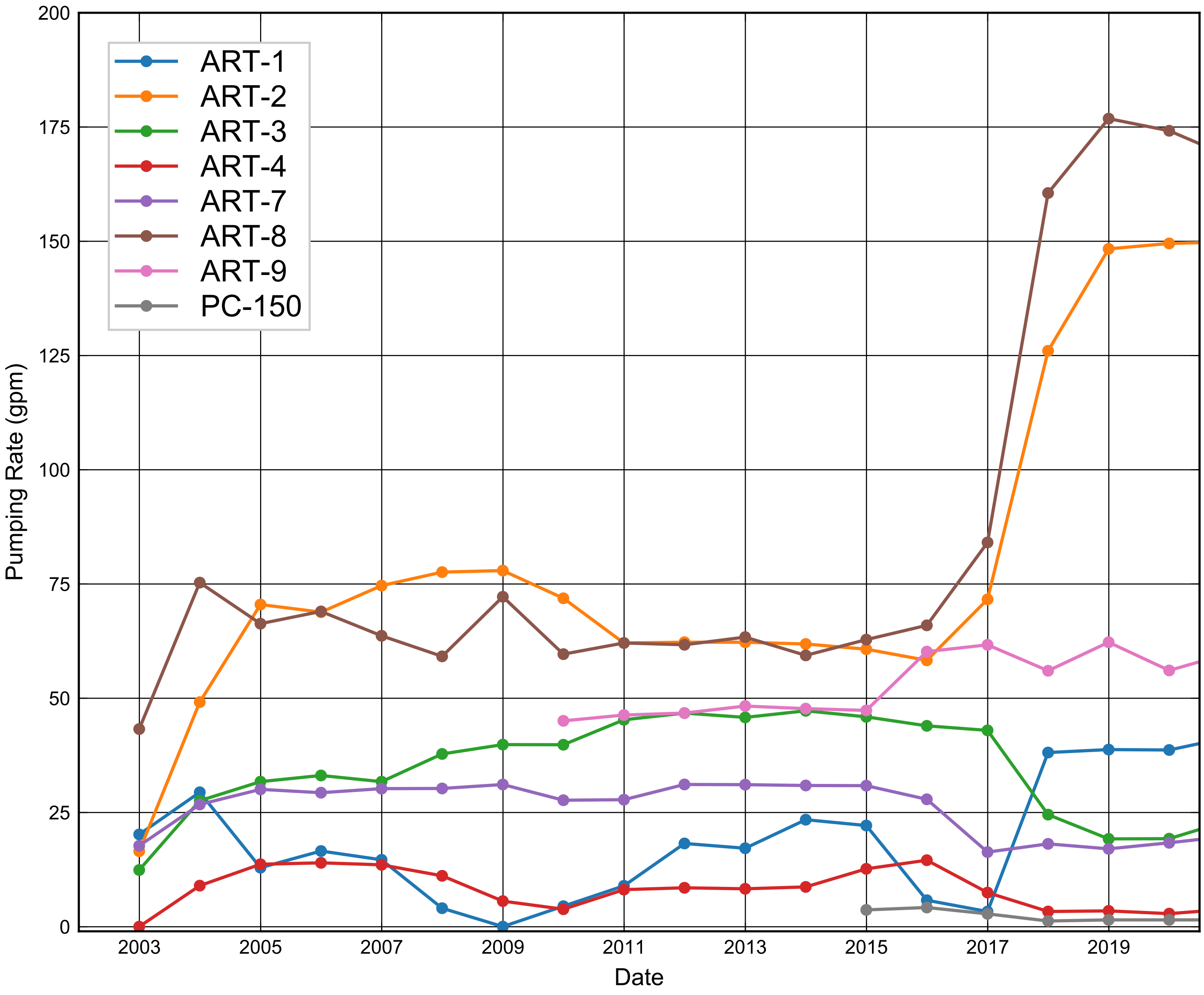
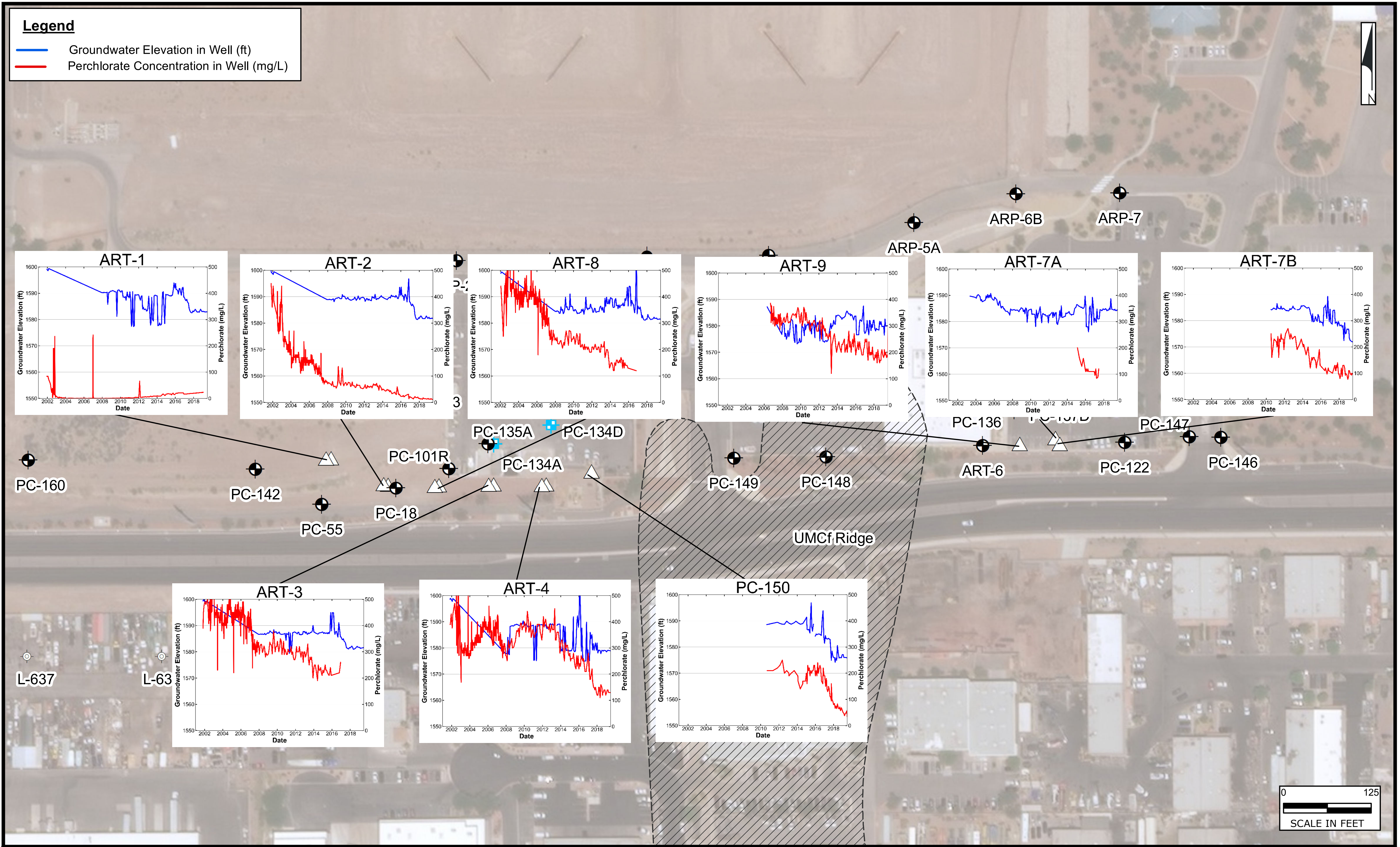


RAMBOLL

Annual Average Pumping Rates at Athens Road Well Field
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
B-4

Drafter: PR	Date: 02/23/21	Contract Number: 1690011200-053	Approved:	Revised:



Perchlorate Concentrations and Groundwater Elevations for AWF Extraction Wells

Athens Well Field Capture Evaluation and Matrix Diffusion Study
Nevada Environmental Response Trust Site
Henderson, Nevada

FIGURE
B-5a

RAMBOLL

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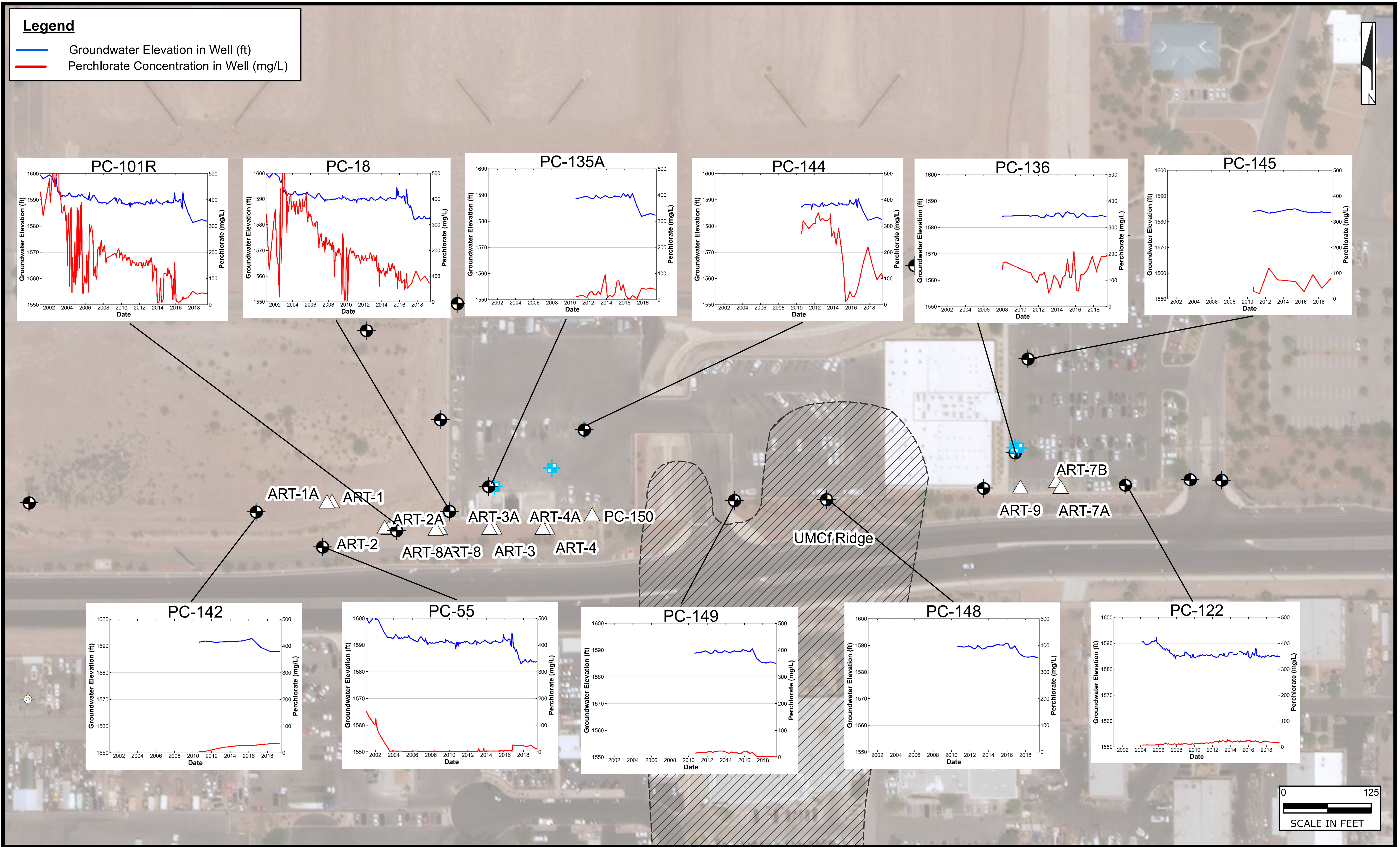
DATE: 2020-01-27
Contract: 169001 1200-053

H:\LePetomane\NERT\Modeling\AWF Capture Evaluation-L12\Reporting\mxd files\Figure B-5a - AWF_Extraction wells.mxd



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DATE: 2020-01-27

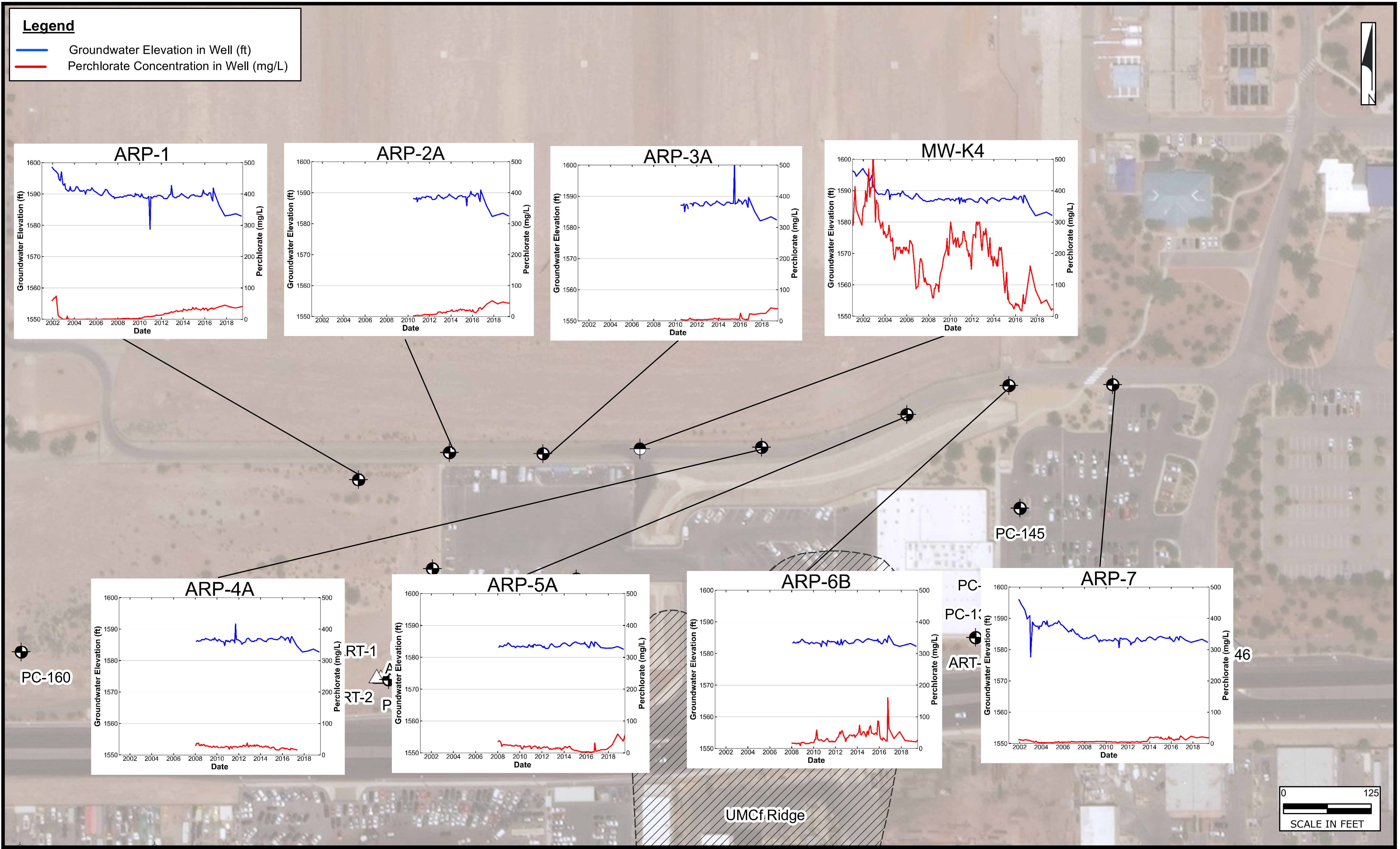
Perchlorate Concentrations and Groundwater Elevations for AWF Monitoring Wells

Athens Well Field Capture Evaluation and Matrix Diffusion Study
Nevada Environmental Response Trust Site
Henderson, Nevada

FIGURE
B-5b

Contract: 169001 1200-053

H:\LePetomane\NERT\Modeling\AWF Capture Evaluation-L12\Reporting\mxd files\Figure B-5b - AWF_ Monitoring wells.mxd



H:\LePetomane\NERT\Modeling\AWF Capture Evaluation-L12\Reporting\mxd files\Figure B-5c - AWP_Monitoring wells.mxd

RAMBOLL

DRAFTED BY: JC

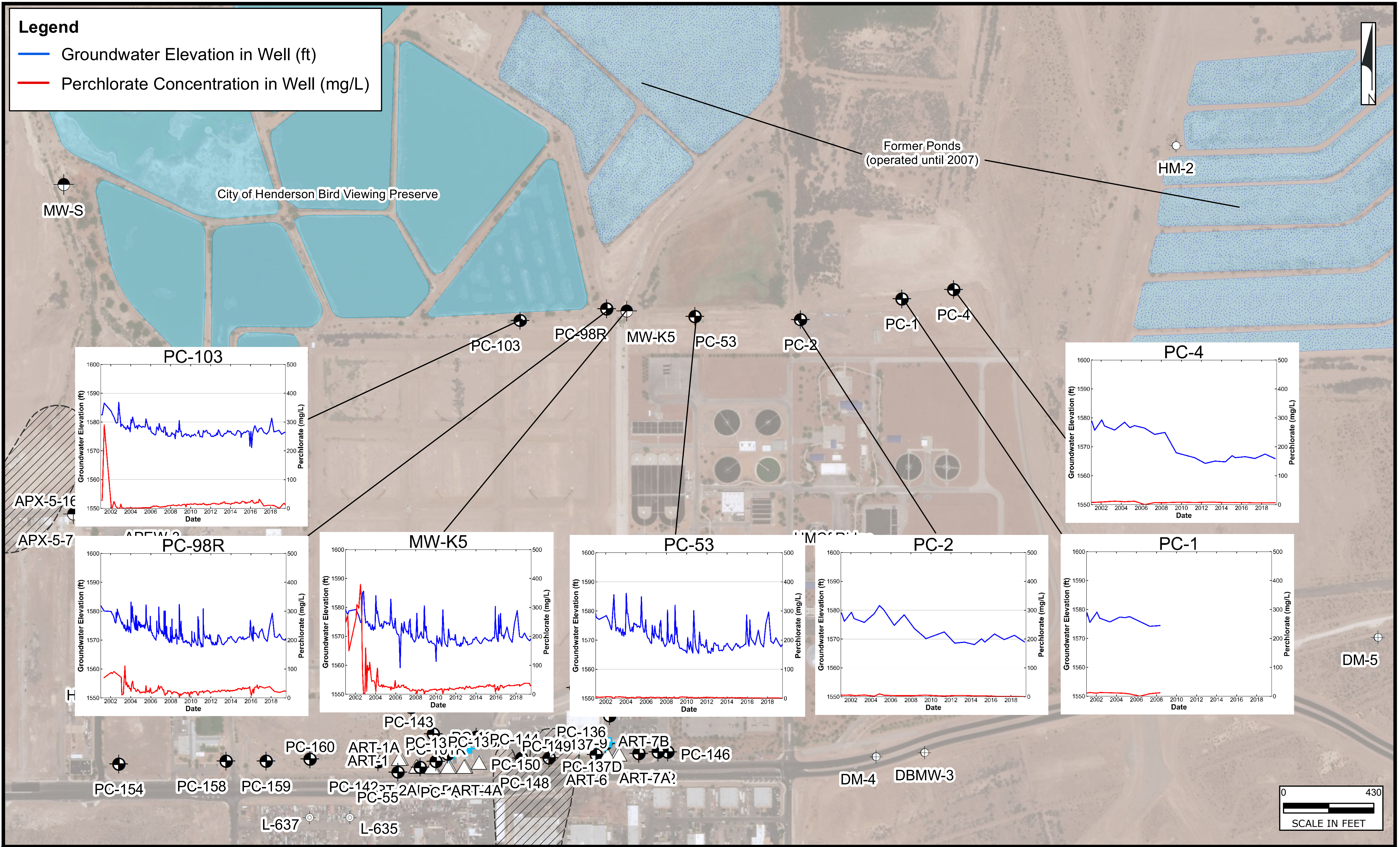
DATE: 2020-01-27

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

Athens Well Field Capture Evaluation and Matrix Diffusion Study
Nevada Environmental Response Trust Site
Henderson, Nevada

FIGURE
B-5c

Contract: 169001 1200-053



RAMBOLL

DRAFTED BY: JC

DATE: 2020-01-27

Perchlorate Concentrations and Groundwater Elevations at COH WRF Well Line

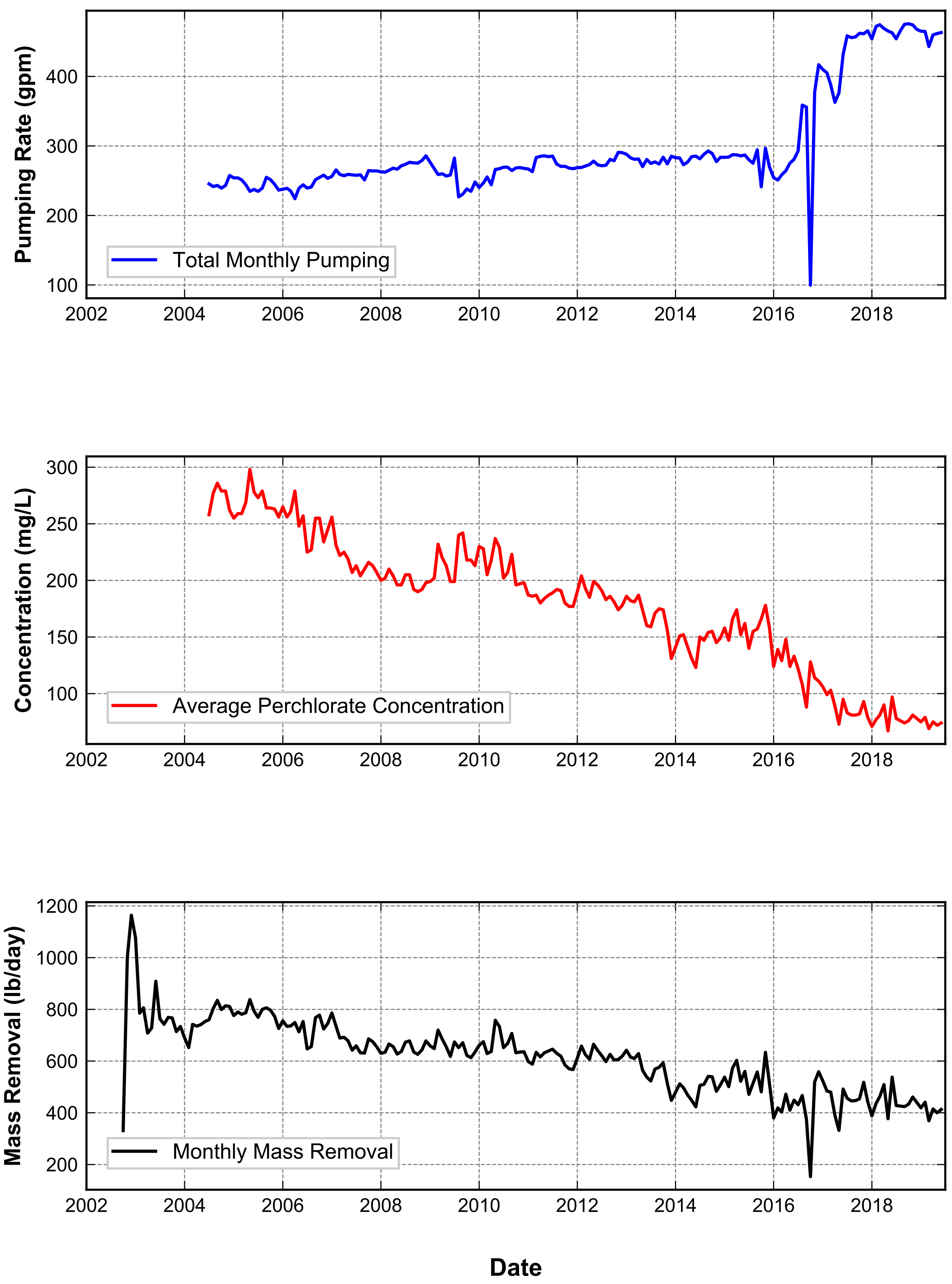
Athens Well Field Capture Evaluation and Matrix Diffusion Study
Nevada Environmental Response Trust Site
Henderson, Nevada

FIGURE
B-5d

Contract: 169001 1200-053

H:\LePetomane\NERT\Modeling\AWF Capture Evaluation-L12\Reporting\mxd files\Figure B-5d - COH WRF_Monitoring wells.mxd

Path: C:\Users\prasouli\OneDrive - Ramboll\Python Scripts 3xand2x\AWF_Historic_Mass_Removal_v1.py



Note:
gpm = gallon per minute

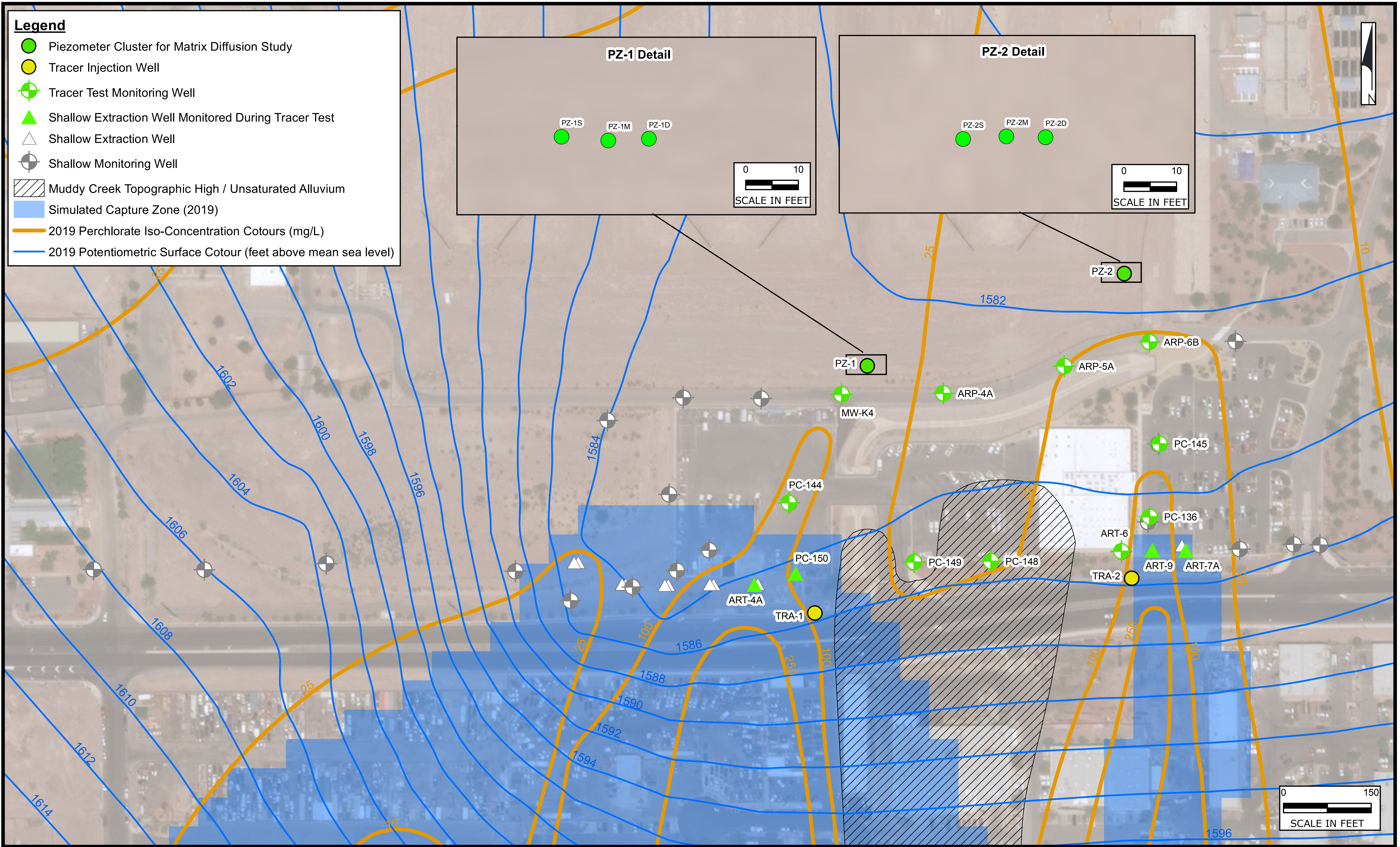
RAMBOLL

Perchlorate Mass Removal at Athens Road Well Field
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure

B-6

Drafter: PR	Date: 04/27/20	Contract Number: 1690011200-053	Approved:	Revised:



RAMBOLL

DRAFTED BY: JC

DATE: 3/17/2020

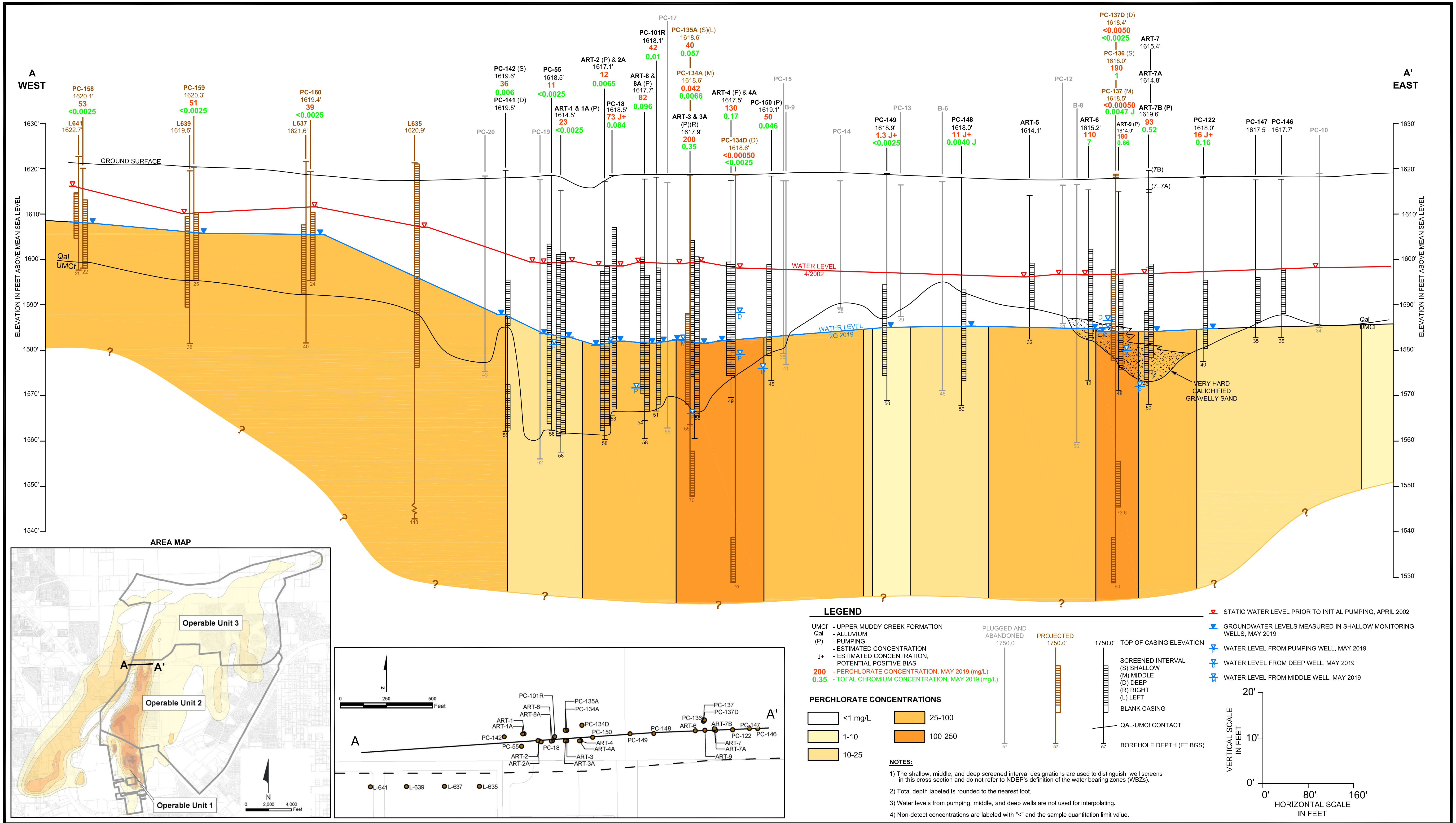
Tracer Test and Matrix Diffusion Study Locations
Athens Well Field Capture Evaluation and Matrix Diffusion Study
Nevada Environmental Response Trust Site
Henderson, Nevada

FIGURE
B-7

Contract: 169001 1200-053

H:\LePetomane\NERT\Modeling\AWF Capture Evaluation-L12\Reporting\mxd files\Figure B-7 - Test Locations Insets.mxd

Q:\DRAWINGS\1690011198_NERT\CROSS SECTION-ABC_ 2019_11x17.dwg - Mon, 23 Dec 2019 - 2:19pm



LEGEND

UMCf - UPPER MUDDY CREEK FORMATION
Qal - ALLUVIUM
(P) - PUMPING
- ESTIMATED CONCENTRATION
J+ - ESTIMATED CONCENTRATION, POTENTIAL POSITIVE BIAS
200 - PERCHLORATE CONCENTRATION, MAY 2019 (mg/L)
0.35 - TOTAL CHROMIUM CONCENTRATION, MAY 2019 (mg/L)

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 IN SHALLOW MONITORING WELLS, MAY 2019

▽ P WATER LEVEL FROM PUMPING WELL, MAY 2019

▽ D WATER LEVEL FROM DEEP WELL, MAY 2019

▽ M WATER LEVEL FROM MIDDLE WELL, MAY 2019

PERCHLORATE CONCENTRATIONS

☐ <1 mg/L	▨ 25-100
▨ 1-10	▨ 100-250
▨ 10-25	

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

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.

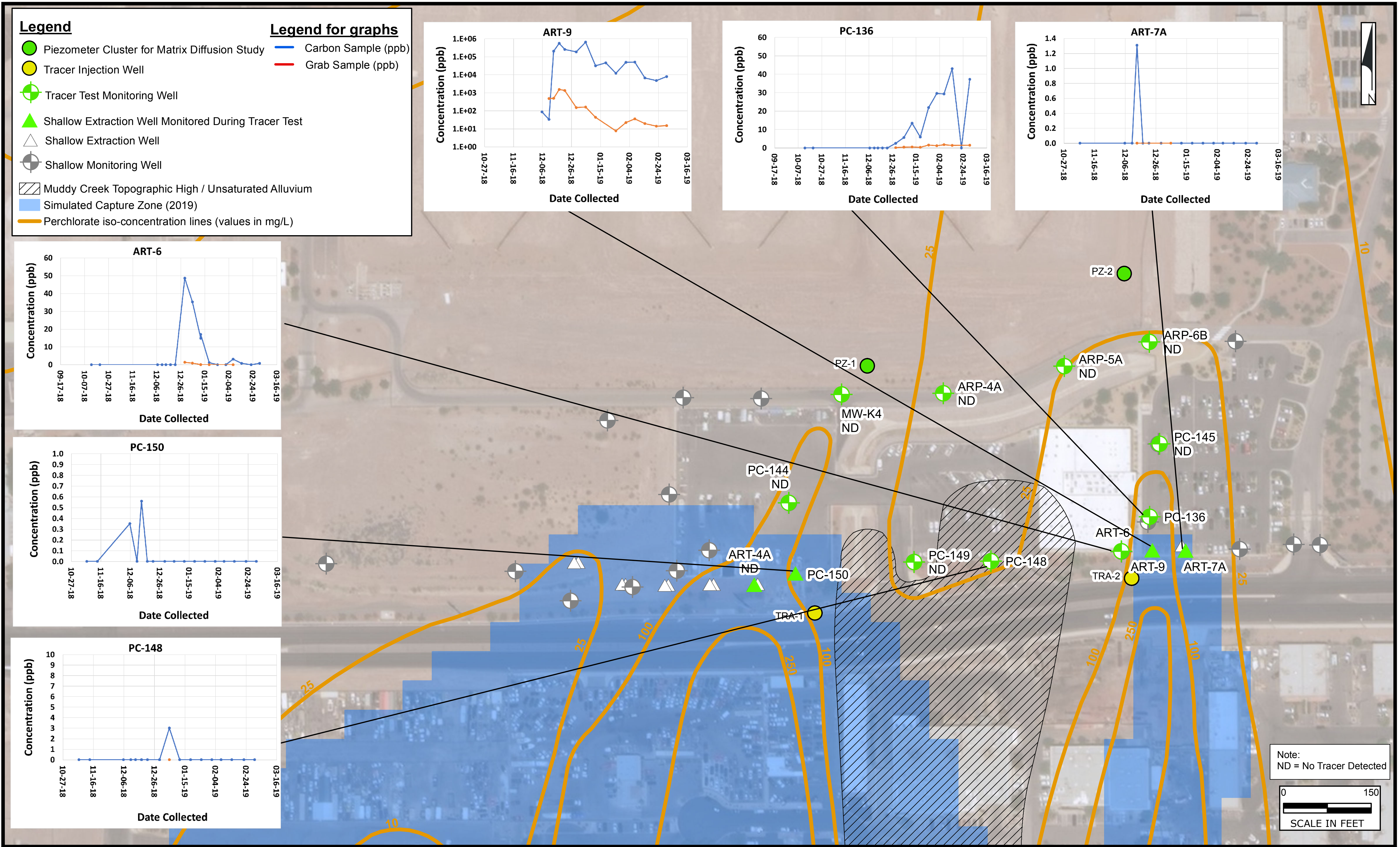
4) Non-detect concentrations are labeled with "<" and the sample quantitation limit value.

RAMBOLL

Drafter: RS
Date: 12/16/19
Contract Number: 1690011200-53
Approved:
Revised:

West-East Hydrogeologic Cross-Section A-A'
Athens Road Well Field, Second Quarter 2019
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
B-8



RAMBOLL

DRAFTED BY: JC

DATE: 3/17/2020

Tracer Test Results

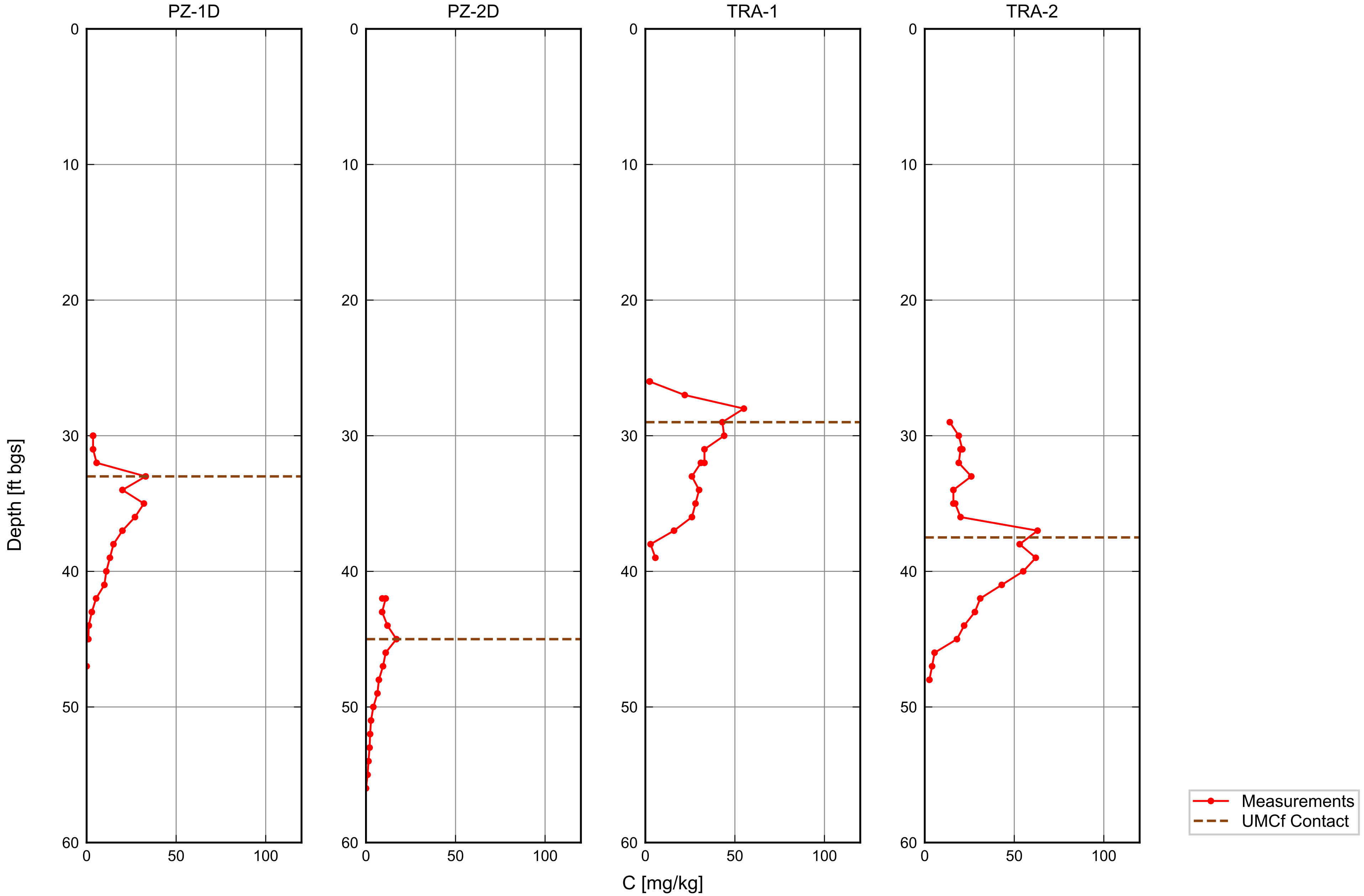
Athens Well Field Capture Evalutaion and Matrix Diffusion Study
Nevada Environmental Response Trust Site
Henderson, Nevada

FIGURE
B-9

Contract: 169001 1200-053

H:\LePetomane\NERT\Modeling\AWF Capture Evaluation-L12\Reporting\mxd files\Figure B-9 - Tracer Test Results.mxd

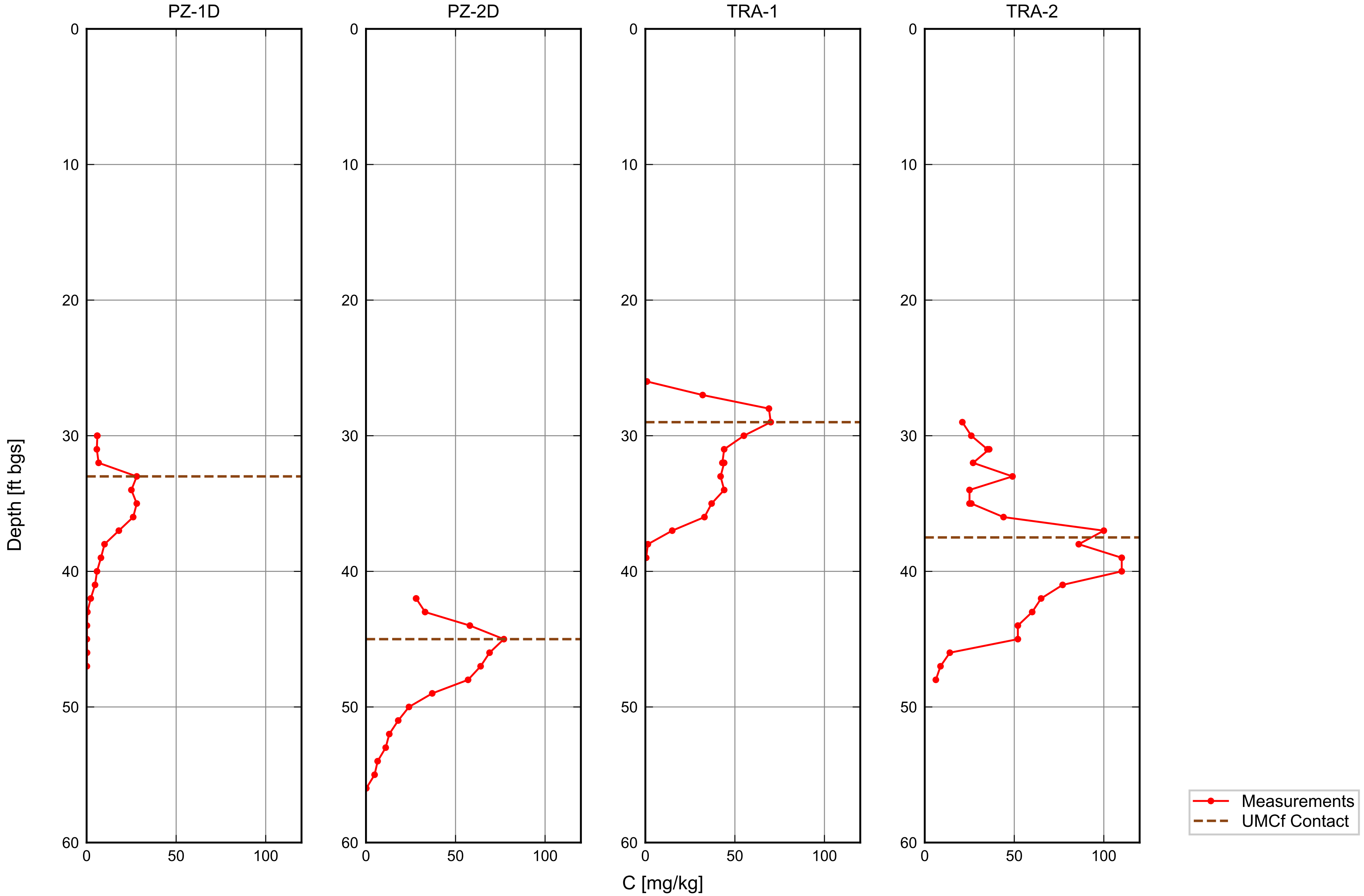
Path: C:\Users\prasouli\OneDrive - Ramboll\Python Scripts 3xand2x\AWF_SoilProfiles.py



Perchlorate Soil Concentration Profiles
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
B-10

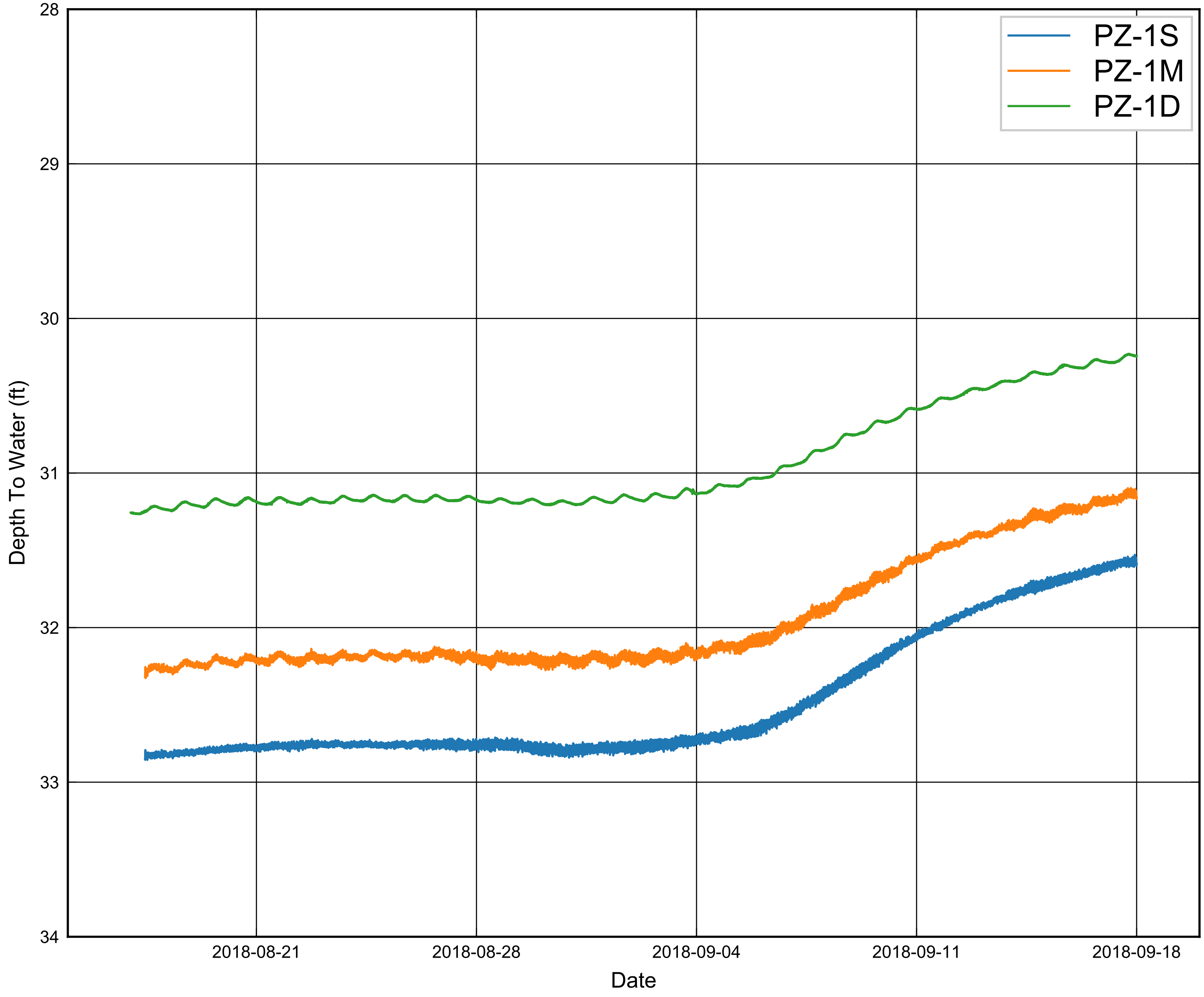
Drafter: PR | Date: 04/27/20 | Contract Number: 16900011200-053 | Approved: | Revised:



Chlorate Soil Concentration Profiles
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
B-11

Drafter: PR	Date: 04/27/20	Contract Number: 16900011200-053	Approved:	Revised:



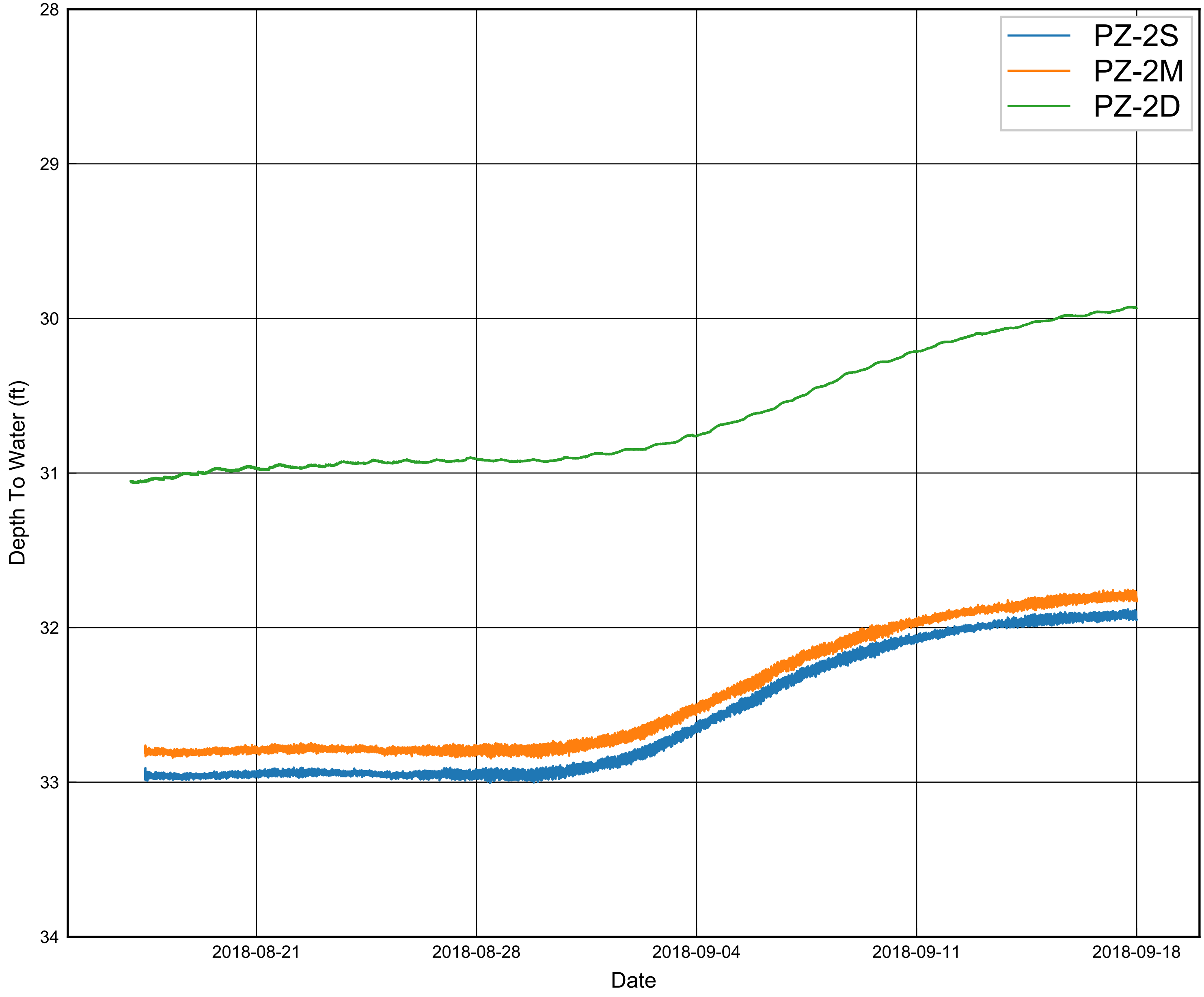
RAMBOLL

Water Levels in Piezometer Cluster PZ-1
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
B-12

Drafter: PR
Date: 04/27/20
Contract Number: 16900011200-053
Approved:
Revised:

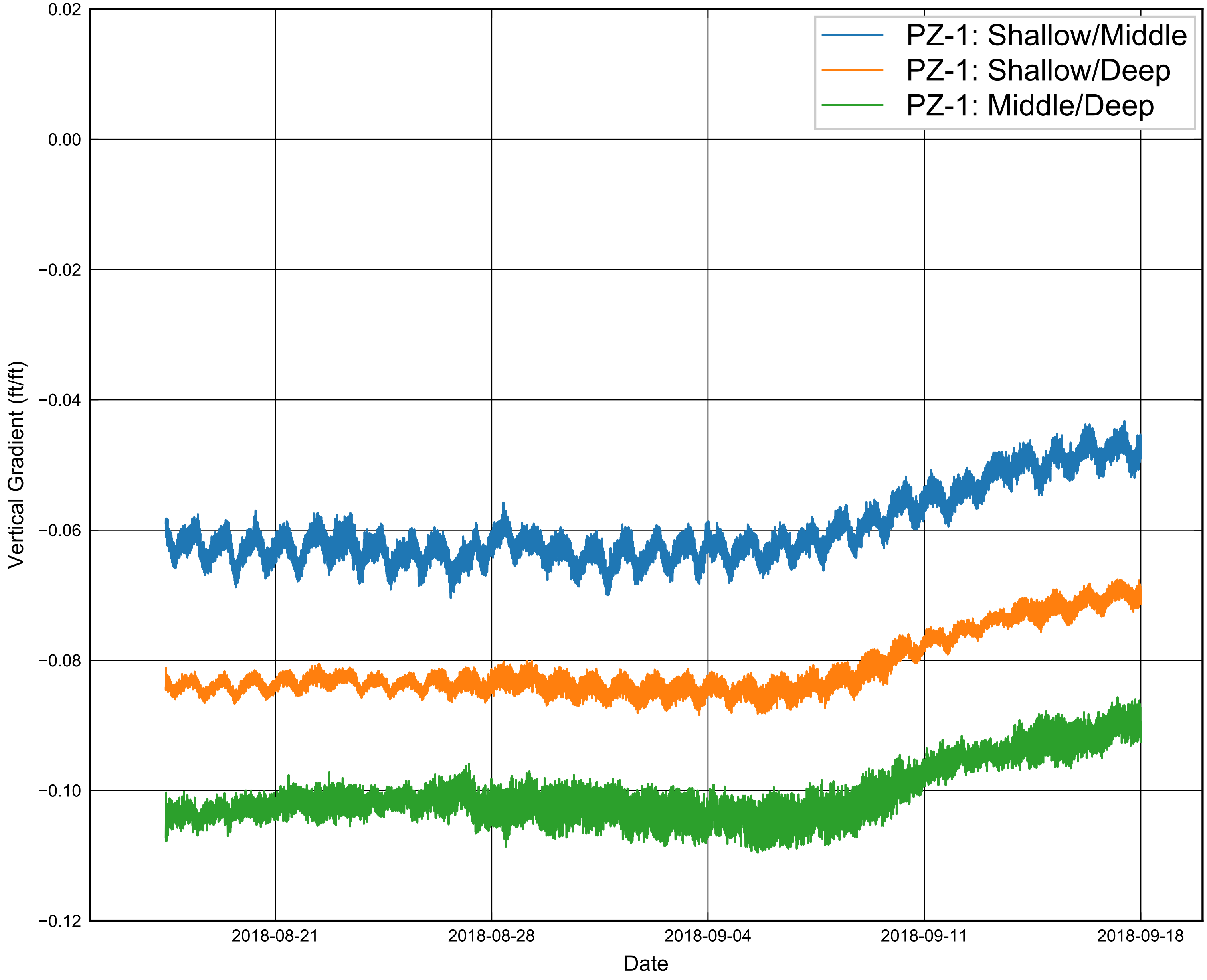
Path: C:\Users\prasouli\OneDrive - Ramboll\Python Scripts 3xand2x\AWF_transducer_GWE_v1.py



Water Levels in Piezometer Cluster PZ-2
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
B-13

Drafter: PR	Date: 04/27/20	Contract Number: 16900011200-053	Approved:	Revised:

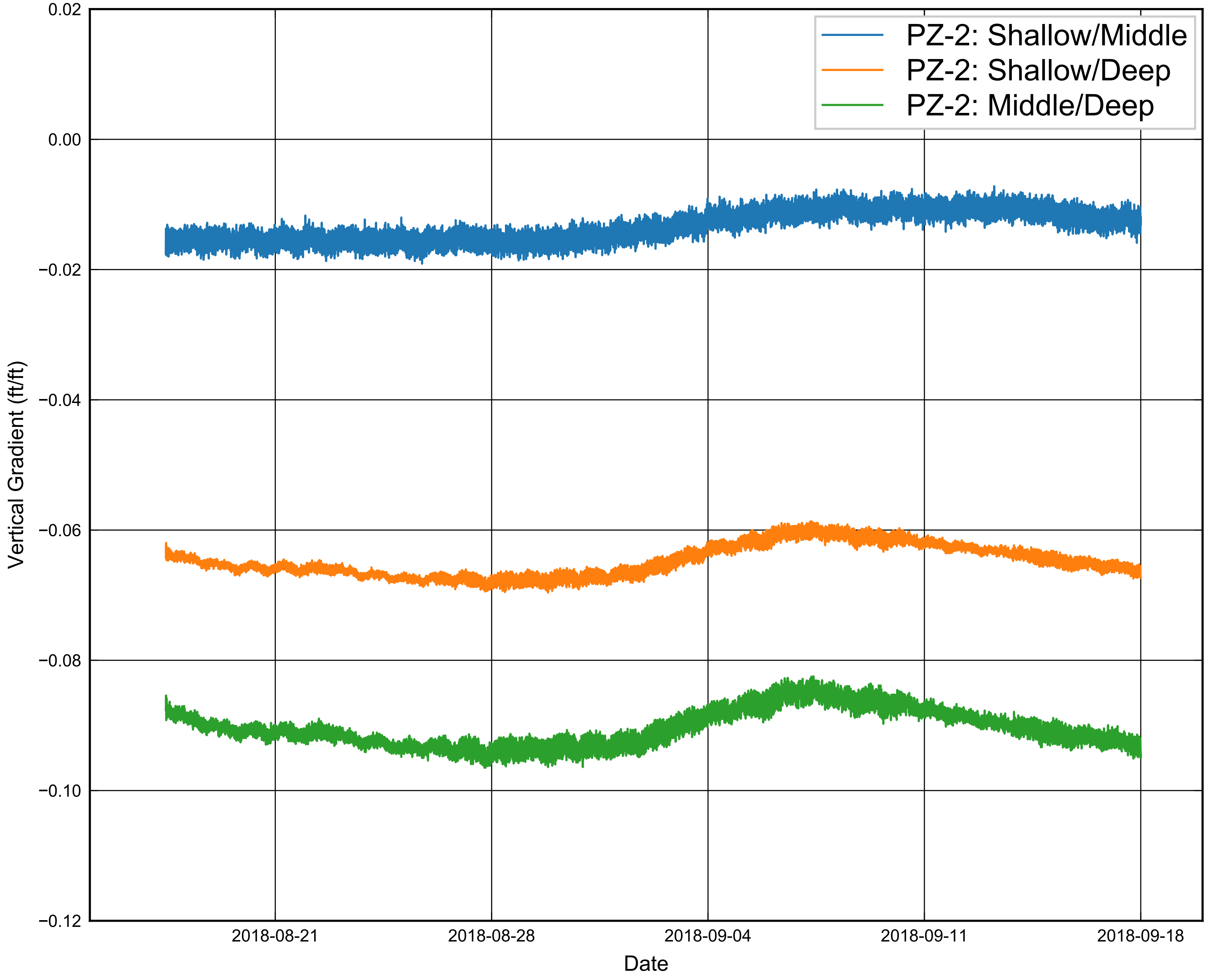


RAMBOLL

Vertical Gradient in Piezometer Cluster PZ-1
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
B-14

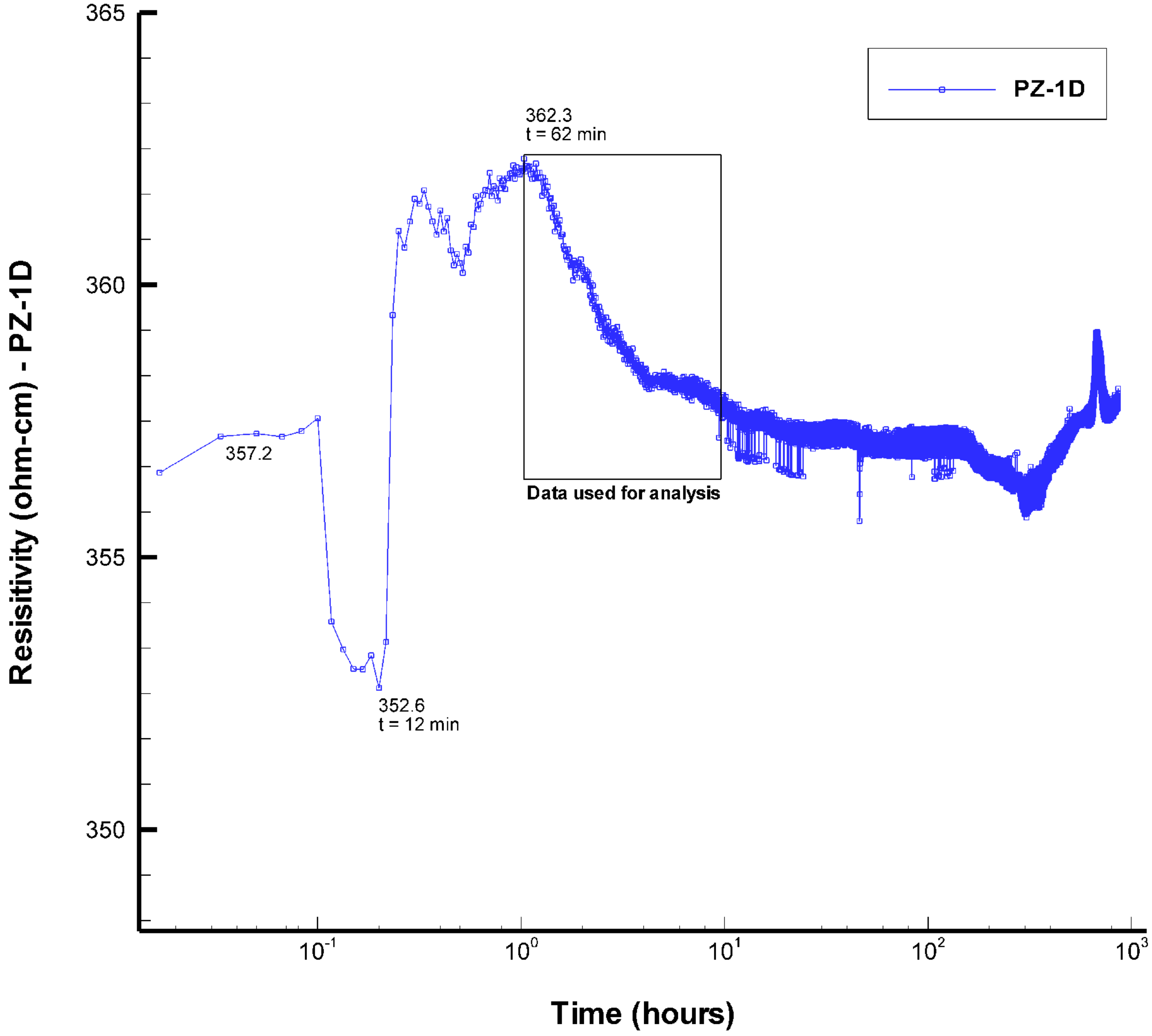
Drafter: PR Date: 04/27/20 Contract Number: 16900011200-053 Approved: Revised:



Vertical Gradient in Piezometer Cluster PZ-2
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
B-15

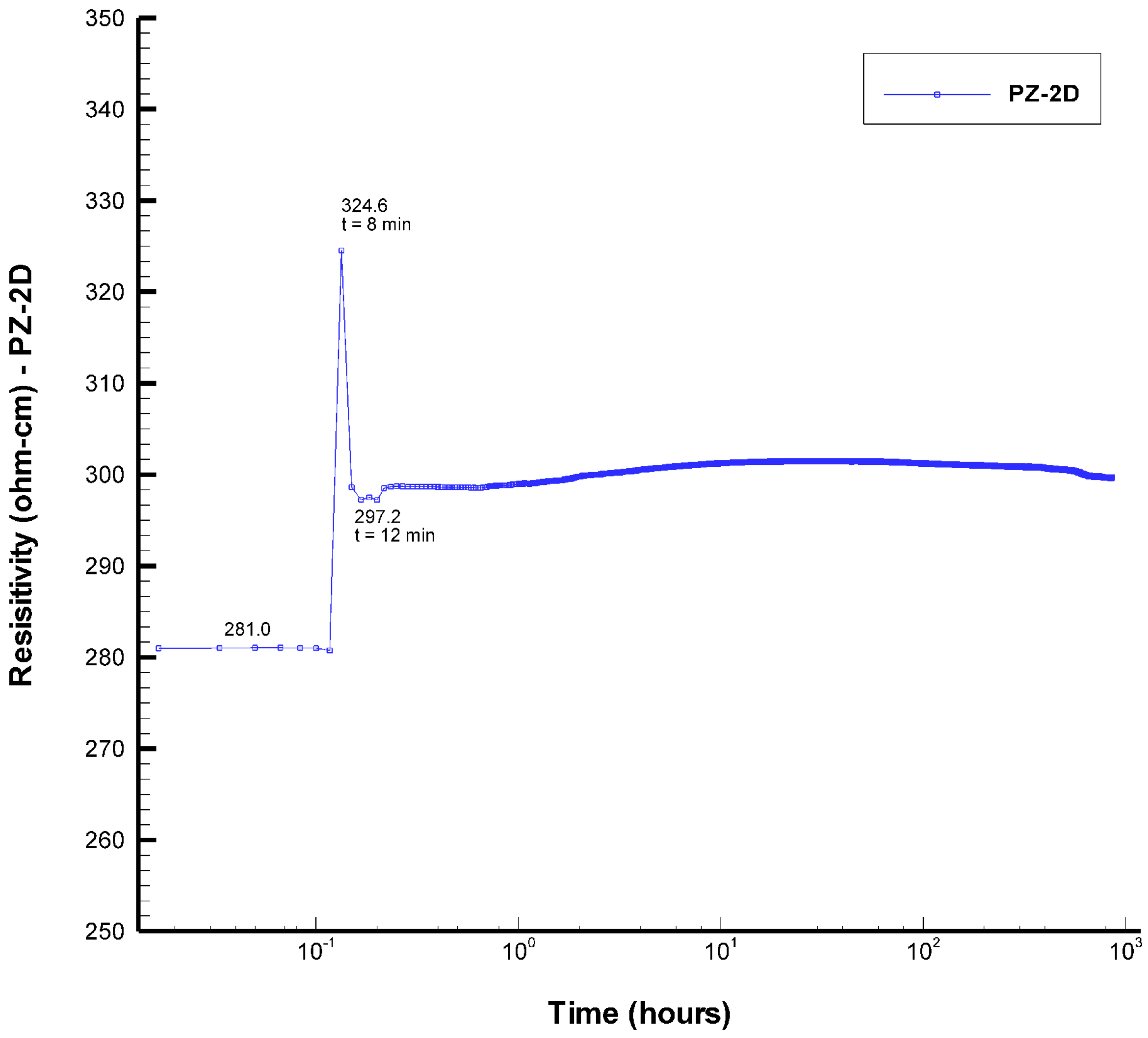
Drafter: PR   Date: 04/27/20   Contract Number: 16900011200-053   Approved: Revised:



Borehole Dilution Test Results - PZ-1D
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
B-16

Drafter: PR | Date: 04/27/20 | Contract Number: 16900011200-053 | Approved: | Revised:

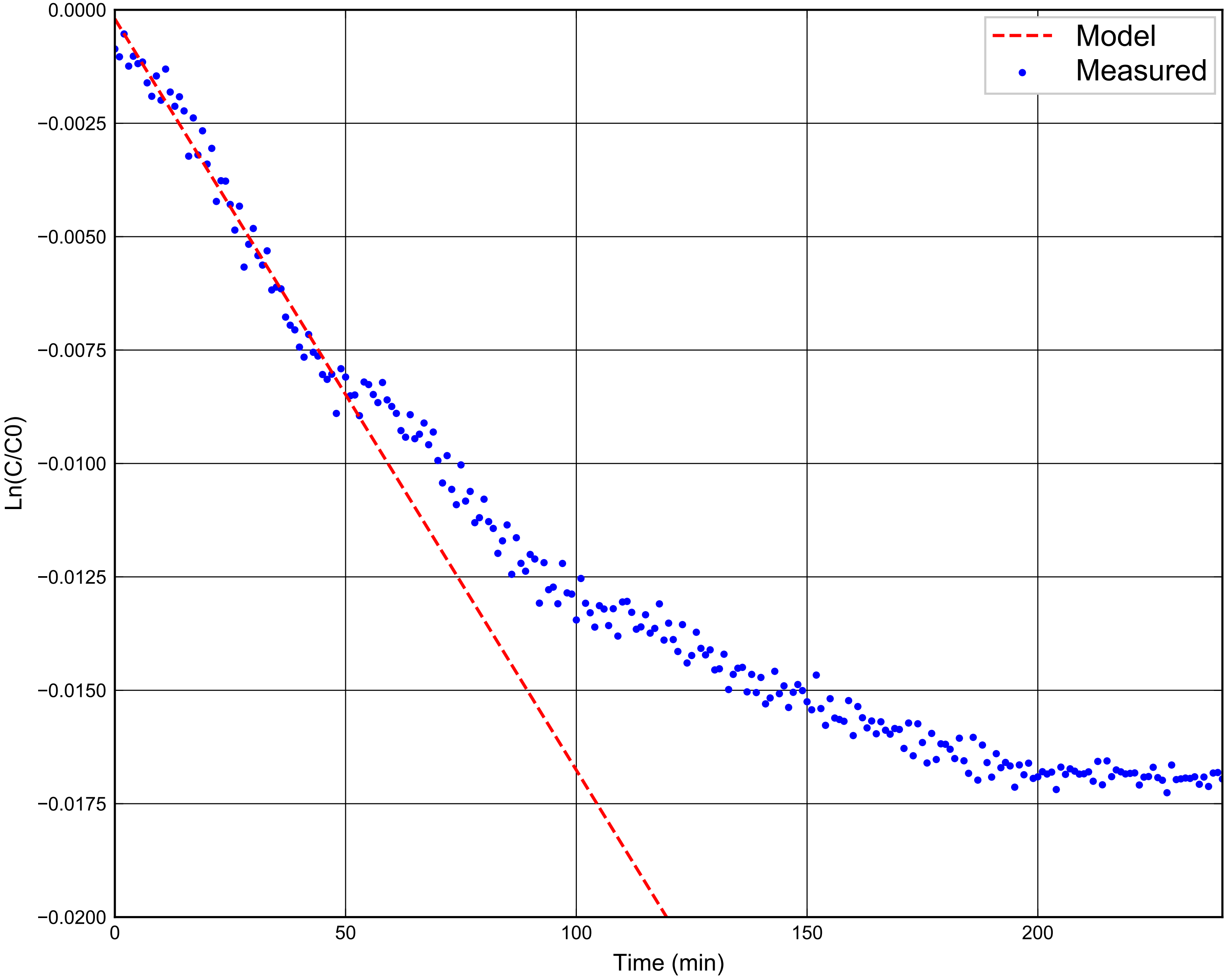


RAMBOLL

Borehole Dilution Test Results - PZ-2D
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
B-17

Drafter: PR
Date: 04/27/20
Contract Number: 16900011200-053
Approved:
Revised:



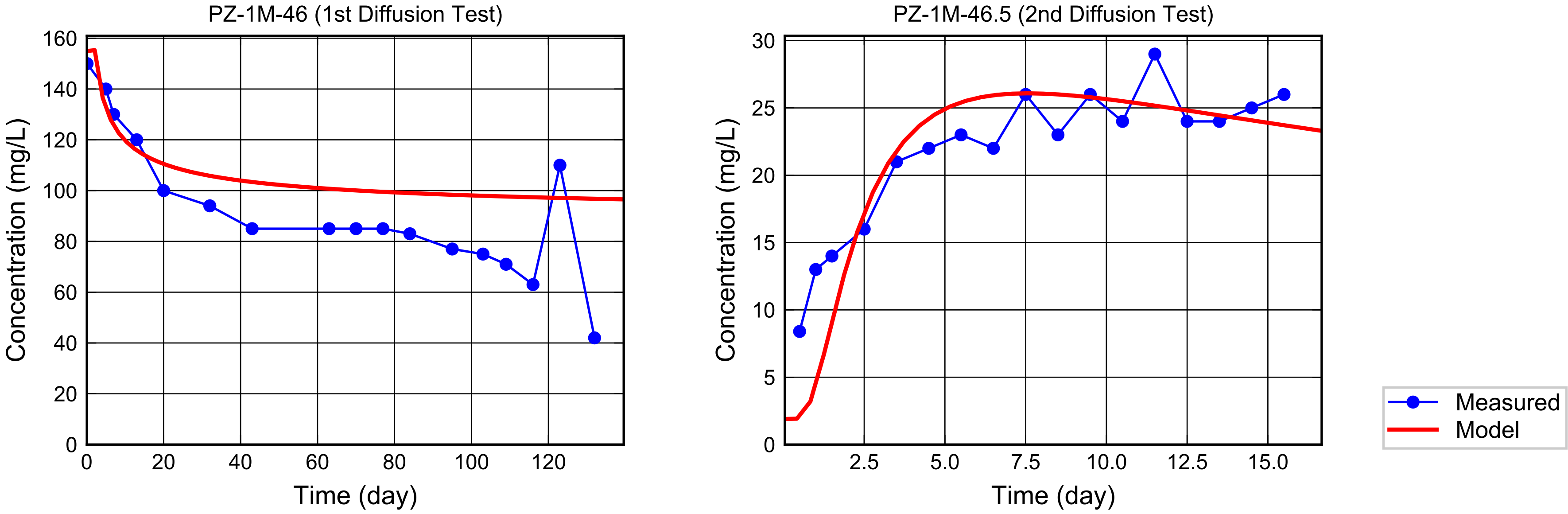
RAMBOLL

Borehole Dilution Test Analysis at PZ-1D
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure

B-18

Drafter: PR | Date: 04/27/20 | Contract Number: 16900011200-053 | Approved: | Revised:

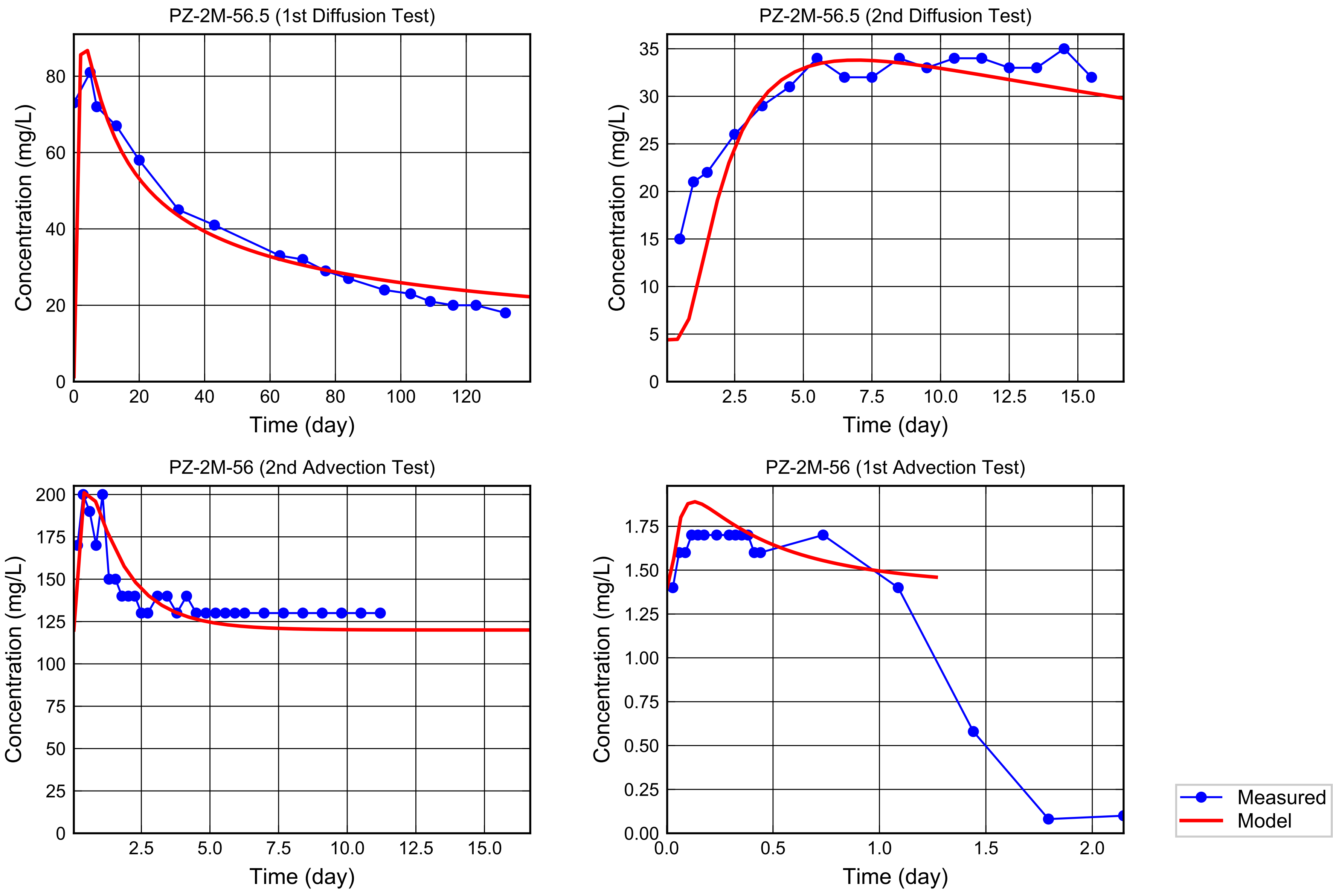


Laboratory Diffusion Tests and Simulation Results at PZ-1M
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
B-19

Drafter: PR	Date: 04/27/20	Contract Number: 16900011200-053	Approved:	Revised:

Path: C:\Users\prasouli\OneDrive - Ramboll\Python Scripts 3xand2x\AWF_DiffusionTests_v0.py



Laboratory Diffusion Tests and Simulation Results at PZ-2M
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
B-20

Drafter: PR | Date: 04/27/20 | Contract Number: 16900011200-053 | Approved: | Revised:

ATTACHMENTS

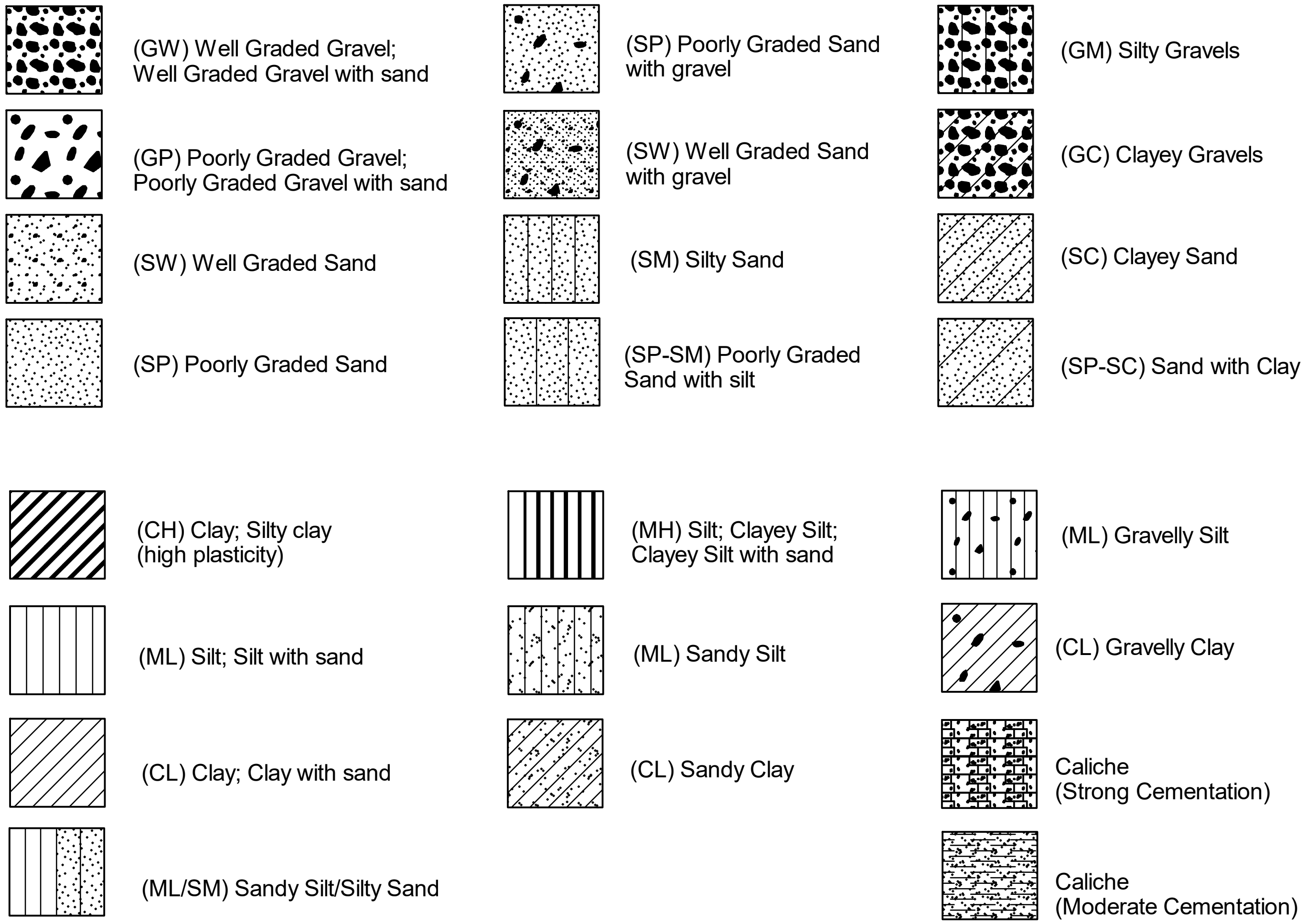
ATTACHMENT B-1
BORING LOGS AND WELL CONSTRUCTION LOGS

SOIL BORING AND WELL CONSTRUCTION LOGS (OU-2)

Boring Logs	Monitoring Well Construction Logs
TRA-1	TRA-1
PZ-1D	PZ-1D, PZ-1M, PZ-1S
TRA-2	TRA-2
PZ-2D	PZ-2D, PZ-2S
PZ-2M	PZ-2M

BORING LOGS

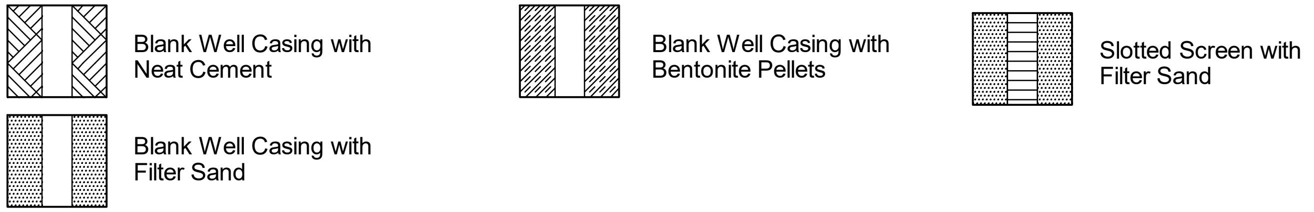
USCS SOIL CLASSIFICATION CHART



- (GW) Well Graded Gravel; Well Graded Gravel with sand
- (GP) Poorly Graded Gravel; Poorly Graded Gravel with sand
- (SW) Well Graded Sand
- (SP) Poorly Graded Sand
- (SP) Poorly Graded Sand with gravel
- (SW) Well Graded Sand with gravel
- (SM) Silty Sand
- (SP-SM) Poorly Graded Sand with silt
- (GM) Silty Gravels
- (GC) Clayey Gravels
- (SC) Clayey Sand
- (SP-SC) Sand with Clay

- (CH) Clay; Silty clay (high plasticity)
- (ML) Silt; Silt with sand
- (CL) Clay; Clay with sand
- (ML/SM) Sandy Silt/Silty Sand
- (MH) Silt; Clayey Silt; Clayey Silt with sand
- (ML) Sandy Silt
- (CL) Sandy Clay
- (ML) Gravelly Silt
- (CL) Gravelly Clay
- Caliche (Strong Cementation)
- Caliche (Moderate Cementation)

WELL CONSTRUCTION MATERIALS/ANNULAR FILL



- Blank Well Casing with Neat Cement
- Blank Well Casing with Filter Sand
- Blank Well Casing with Bentonite Pellets
- Slotted Screen with Filter Sand

ABBREVIATIONS

ft.	Feet
MSL	Mean sea level
Sch.	Schedule
PID	Photoionization detector
ppm	parts per million
USCS	Unified Soils Classification System
QAL	Alluvium
UMCf	Upper Muddy Creek Formation

RAMBOLL

2200 Powell Street, Suite 700, Emeryville, CA 94608

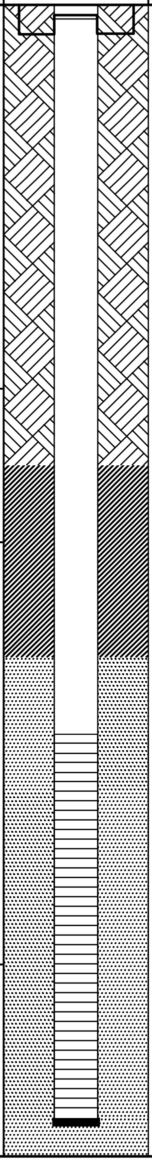
Project Number: **169001 6064**	Boring Number: **TRA-1**
Location: **Handerson, Nevada**	
Contractor: **Cascade Drilling**	Driller: **R. Longtine**
Project Name: **AWF Capture Evaluation**	
Drilling Method: **Sonic**	Date(s): **7/19/2018**
Rig Type: **Gus Pech 400RS**	
Logged By: **G. Miclette**	Checked By: **R. Russell**
Sampling Method: **Continuous**	
GS Elevation: **1619.028 ft. MSL**	TOC Elevation: **1618.583 ft. MSL**
Northing: **26728035.59**	Easting: **828948.52**
Total Depth: **40.0 feet**	Borehole Dia.: **8 inches**
Notes:	

Well Construction Details

Blank Casing (feet):	From 0.45 to 19	4-inch Schedule 40 PVC
Screen (feet):	From 19 to 29	0.020-inch Slot, Sch. 40 PVC
Annular Fill (feet):	From 0 to 12	Bentonite-Cement Grout
	From 12 to 17	Bentonite Chip Seal
	From 17 to 30	Lapis Lustre #3 Sand Pack
	From 30 to 40	Bentonite Chip Seal

Elevation (ft.)	Depth (ft)	Unit/ Formation	USCS Code	Material Description
	0			AIR KNIFE TO 10 FEET.
1615	5			
1610	10	ALLUVIUM	SM	ALLUVIUM. **SILTY SAND with gravel (SM), BROWN (7.5YR 5/3)**; very fine to very coarse grained subangular to subrounded volcanic sand, volcanic gravel up to 2", some weakly cemented clasts up to 1", loose, damp (15% gravel, 70% sand, 15% fines).
1605	14	ALLUVIUM	SP	**SAND with gravel (SP), BROWN (7.5YR 5/4)**; very fine to very coarse grained subangular to subrounded volcanic sand, gravel up to 3/4", loose, damp (15% gravel, 80% sand, 5% fines). From 16.0 feet: color becomes Brown (7.5YR 5/2), gravels predominantly 1/2". From 19.0 feet: trace clayey fines. From 20.0 feet: gravels up to 1". From 22.5 feet: gravels up to 1.5". At 24.7 feet: 3" thick caliche nodule (20% gravel, 65% sand, 15% fines).
1595	25	ALLUVIUM	ML	**SANDY SILT (ML), PALE OLIVE (10Y 6/4)**; reworked very fine to very coarse grained sand, gravel up to 3", moist (0% gravel, 45% sand, 55% fines). Following no recovery, redrilled and retained recovery from 25.0 to 32.0 feet. At 26.5 feet: 5" thick caliche nodule. At 27.2 feet: 4" thick caliche nodule. At 28.0 feet: reworked caliche.
1590	29			

Well Construction



Sample/ Recovery Key

- ▨ Hand Auger
- ☐ Air Knife
- ☐ Sonic Core Recovery
- ◫ No Recovery

▼ Equilibrated groundwater (8/16/2018)

RAMBOLL
2200 Powell Street, Suite 700, Emeryville, CA 94608

Project No.: **169001 6064**
Boring No.: **TRA-1**
Project Name: **AWF Capture Evaluation**
Date(s): **7/19/2018**

Unit/ Formation	USCS Code	Material Description
QAL	MH	**SANDY SILT (MH), PALE OLIVE (10Y 6/4)**; medium plasticity, soft to medium stiff, very fine to fined grained sand, scattered caliche nodules up to 1/4", trace clayey fines moist (0% gravel, 30% sand, 70% fines). From 32.0 feet: sand predominantly medium to very coarse grained, increased gravel content (5% gravel, 90% sand, 5% fines).
UMCF	MH	UPPER MUDDY CREEK FORMATION AT 32.5 FEET. **CLAYEY SILT (MH), LIGHT GREENISH GRAY (10Y 8/1)**; medium plasticity, soft to medium stiff, scattered moderately cemented bands, scattered iron oxide staining, moist (0% gravel, 5% sand, 95% fines). From 35.0 feet: medium to high plasticity, medium stiff, decreased sand content (0% gravel, 0% sand, 100% fines). From 38.0 feet: color becomes Light Gray (5Y 7/2).

Boring completed at a depth of 40.0 feet on 07/19/2018.

Sample/ Recovery Key

▨ Hand Auger
☐ Air Knife
☐ Sonic Core Recovery
◫ No Recovery
▼ Equilibrated groundwater (8/16/2018)

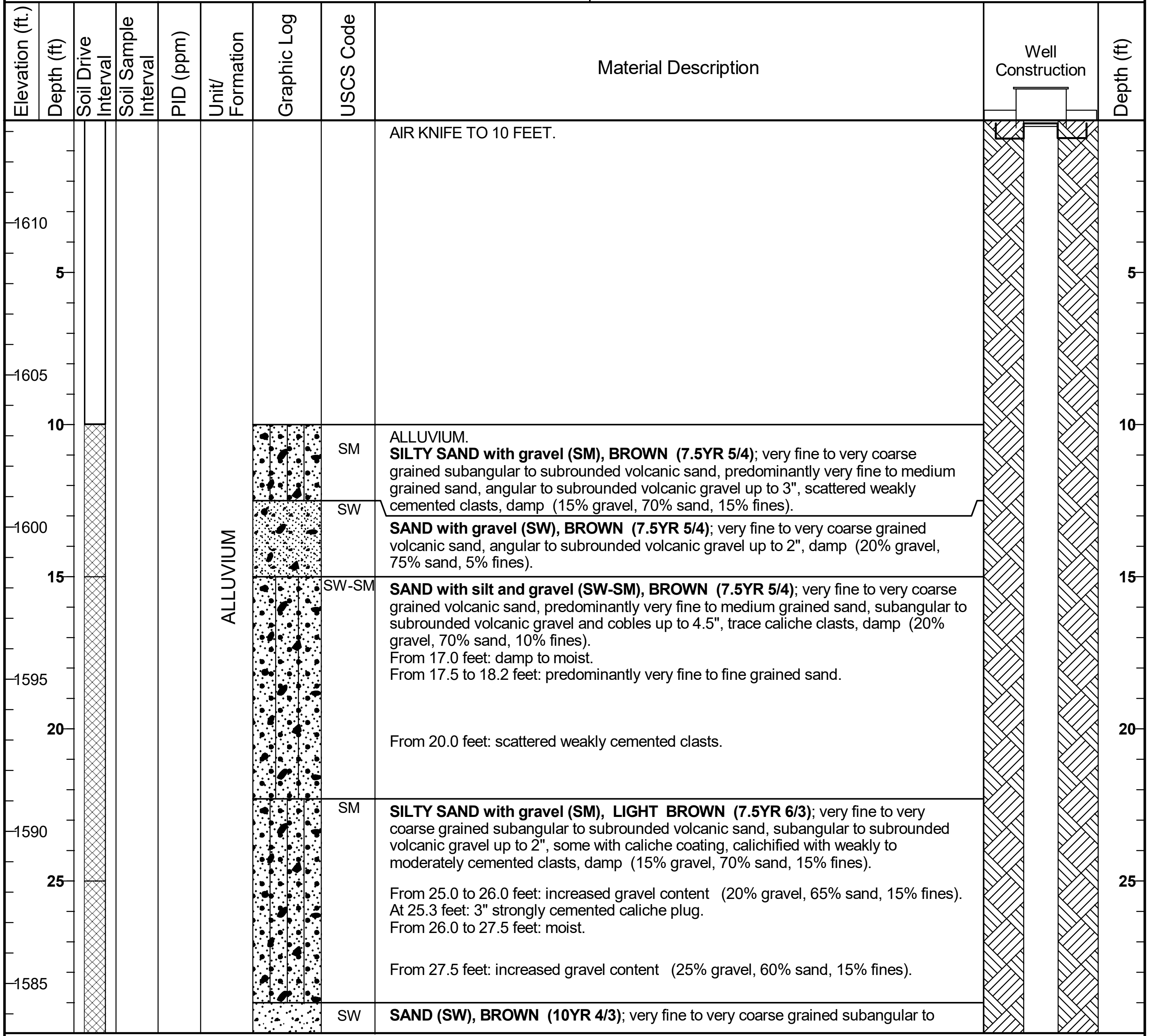
2200 Powell Street, Suite 700, Emeryville, CA 94608

Project Number: **169001 6064**		Boring Number: **PZ-1D**	
Location: **Handerson, Nevada**			
Contractor: **Cascade Drilling**	Driller: **R. Longtine**	Project Name: **AWF Capture Evaluation**	
Drilling Method: **Sonic**		Date(s): **7/10/2018**	
Rig Type: **Gus Pech 400RS**		Logged By: **J. Manheim**	Checked By: **R. Russell**
Sampling Method: **Continuous**		GS Elevation: **1613.369 ft. MSL**	TOC Elevation: **1615.355 ft. MSL**
		Northing: **26728458.78**	Easting: **829038.63**
		Total Depth: **55.0 feet**	Borehole Dia.: **8 inches**

Well Construction Details

Blank Casing (feet):	From +1.99 to 53	4-inch Schedule 40 PVC
Screen (feet):	From 53 to 54	0.010-inch Slot, Sch. 40 PVC
Annular Fill (feet):	From 0 to 46	Bentonite-Cement Grout
	From 46 to 51	Bentonite Chip Seal
	From 51 to 55	Lapis Lustre #2/12 Sand Pack

Notes:
Adjacent peizometers: PZ-1M and PZ-1S.

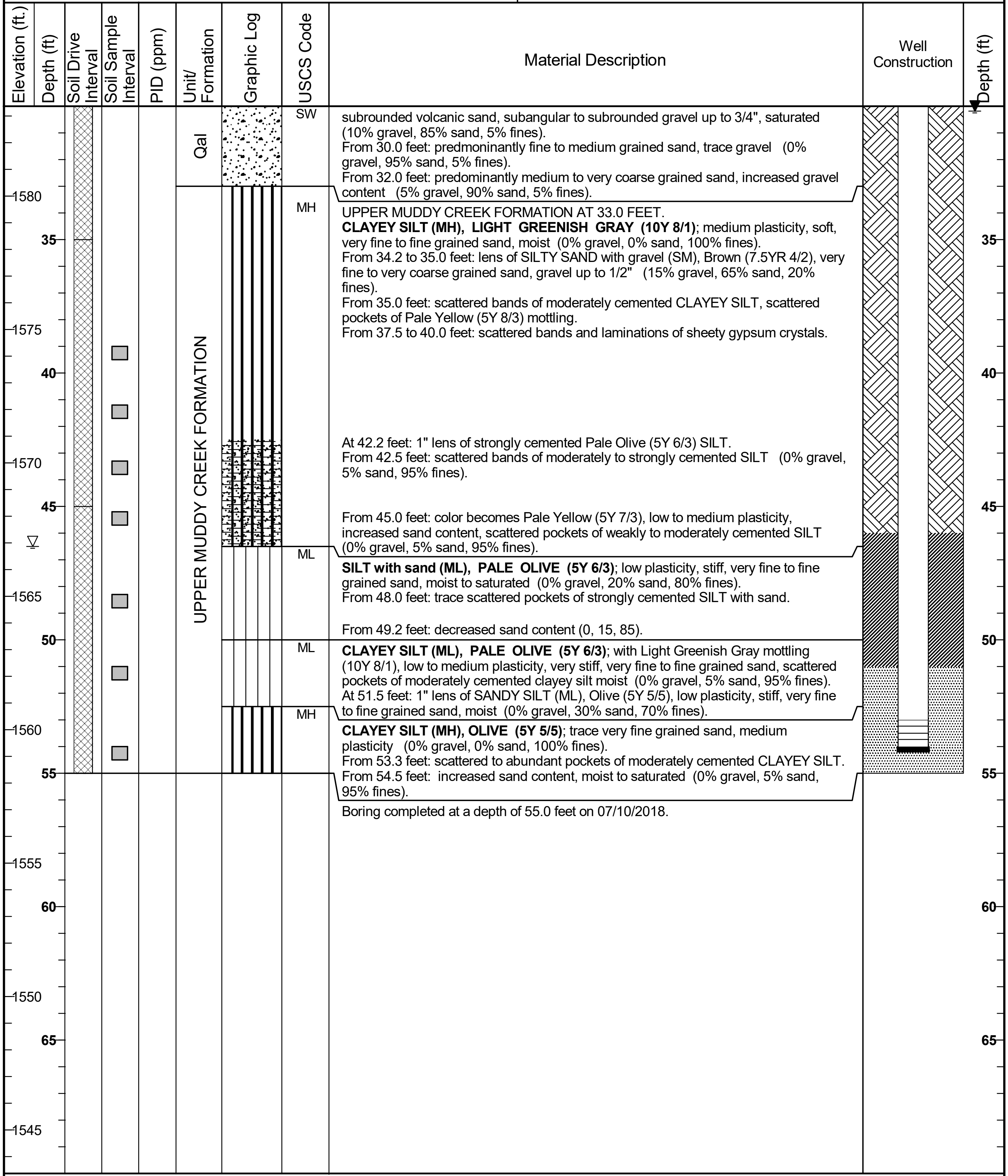


USCS Code	Material Description
	AIR KNIFE TO 10 FEET.
SM	ALLUVIUM. **SILTY SAND with gravel (SM), BROWN (7.5YR 5/4)**; very fine to very coarse grained subangular to subrounded volcanic sand, predominantly very fine to medium grained sand, angular to subrounded volcanic gravel up to 3", scattered weakly cemented clasts, damp (15% gravel, 70% sand, 15% fines).
SW	**SAND with gravel (SW), BROWN (7.5YR 5/4)**; very fine to very coarse grained volcanic sand, angular to subrounded volcanic gravel up to 2", damp (20% gravel, 75% sand, 5% fines).
SW-SM	**SAND with silt and gravel (SW-SM), BROWN (7.5YR 5/4)**; very fine to very coarse grained volcanic sand, predominantly very fine to medium grained sand, subangular to subrounded volcanic gravel and cobles up to 4.5", trace caliche clasts, damp (20% gravel, 70% sand, 10% fines). From 17.0 feet: damp to moist. From 17.5 to 18.2 feet: predominantly very fine to fine grained sand. From 20.0 feet: scattered weakly cemented clasts.
SM	**SILTY SAND with gravel (SM), LIGHT BROWN (7.5YR 6/3)**; very fine to very coarse grained subangular to subrounded volcanic sand, subangular to subrounded volcanic gravel up to 2", some with caliche coating, calichified with weakly to moderately cemented clasts, damp (15% gravel, 70% sand, 15% fines). From 25.0 to 26.0 feet: increased gravel content (20% gravel, 65% sand, 15% fines). At 25.3 feet: 3" strongly cemented caliche plug. From 26.0 to 27.5 feet: moist. From 27.5 feet: increased gravel content (25% gravel, 60% sand, 15% fines).
SW	**SAND (SW), BROWN (10YR 4/3)**; very fine to very coarse grained subangular to

Sample/ Recovery Key

▨ Hand Auger	☐ Sonic Core Recovery	■ Chemical Sample
☐ Air Knife	◫ No Recovery	▩ Physical Test Sample

▽ First saturated soil cuttings
▼ Equilibrated groundwater (10/4/2018)



subrounded volcanic sand, subangular to subrounded gravel up to 3/4", saturated (10% gravel, 85% sand, 5% fines).
From 30.0 feet: predmoninantly fine to medium grained sand, trace gravel (0% gravel, 95% sand, 5% fines).
From 32.0 feet: predominantly medium to very coarse grained sand, increased gravel content (5% gravel, 90% sand, 5% fines).

UPPER MUDDY CREEK FORMATION AT 33.0 FEET.
CLAYEY SILT (MH), LIGHT GREENISH GRAY (10Y 8/1); medium plasticity, soft, very fine to fine grained sand, moist (0% gravel, 0% sand, 100% fines).
From 34.2 to 35.0 feet: lens of SILTY SAND with gravel (SM), Brown (7.5YR 4/2), very fine to very coarse grained sand, gravel up to 1/2" (15% gravel, 65% sand, 20% fines).
From 35.0 feet: scattered bands of moderately cemented CLAYEY SILT, scattered pockets of Pale Yellow (5Y 8/3) mottling.
From 37.5 to 40.0 feet: scattered bands and laminations of sheety gypsum crystals.

At 42.2 feet: 1" lens of strongly cemented Pale Olive (5Y 6/3) SILT.
From 42.5 feet: scattered bands of moderately to strongly cemented SILT (0% gravel, 5% sand, 95% fines).

From 45.0 feet: color becomes Pale Yellow (5Y 7/3), low to medium plasticity, increased sand content, scattered pockets of weakly to moderately cemented SILT (0% gravel, 5% sand, 95% fines).

SILT with sand (ML), PALE OLIVE (5Y 6/3); low plasticity, stiff, very fine to fine grained sand, moist to saturated (0% gravel, 20% sand, 80% fines).
From 48.0 feet: trace scattered pockets of strongly cemented SILT with sand.

From 49.2 feet: decreased sand content (0, 15, 85).

CLAYEY SILT (ML), PALE OLIVE (5Y 6/3); with Light Greenish Gray mottling (10Y 8/1), low to medium plasticity, very stiff, very fine to fine grained sand, scattered pockets of moderately cemented clayey silt moist (0% gravel, 5% sand, 95% fines).
At 51.5 feet: 1" lens of SANDY SILT (ML), Olive (5Y 5/5), low plasticity, stiff, very fine to fine grained sand, moist (0% gravel, 30% sand, 70% fines).

CLAYEY SILT (MH), OLIVE (5Y 5/5); trace very fine grained sand, medium plasticity (0% gravel, 0% sand, 100% fines).
From 53.3 feet: scattered to abundant pockets of moderately cemented CLAYEY SILT.
From 54.5 feet: increased sand content, moist to saturated (0% gravel, 5% sand, 95% fines).

Boring completed at a depth of 55.0 feet on 07/10/2018.

Sample/ Recovery Key

▨ Hand Auger	☐ Sonic Core Recovery	■ Chemical Sample	▽ First saturated soil cuttings
☐ Air Knife	◫ No Recovery	▩ Physical Test Sample	▼ Equilibrated groundwater (10/4/2018)

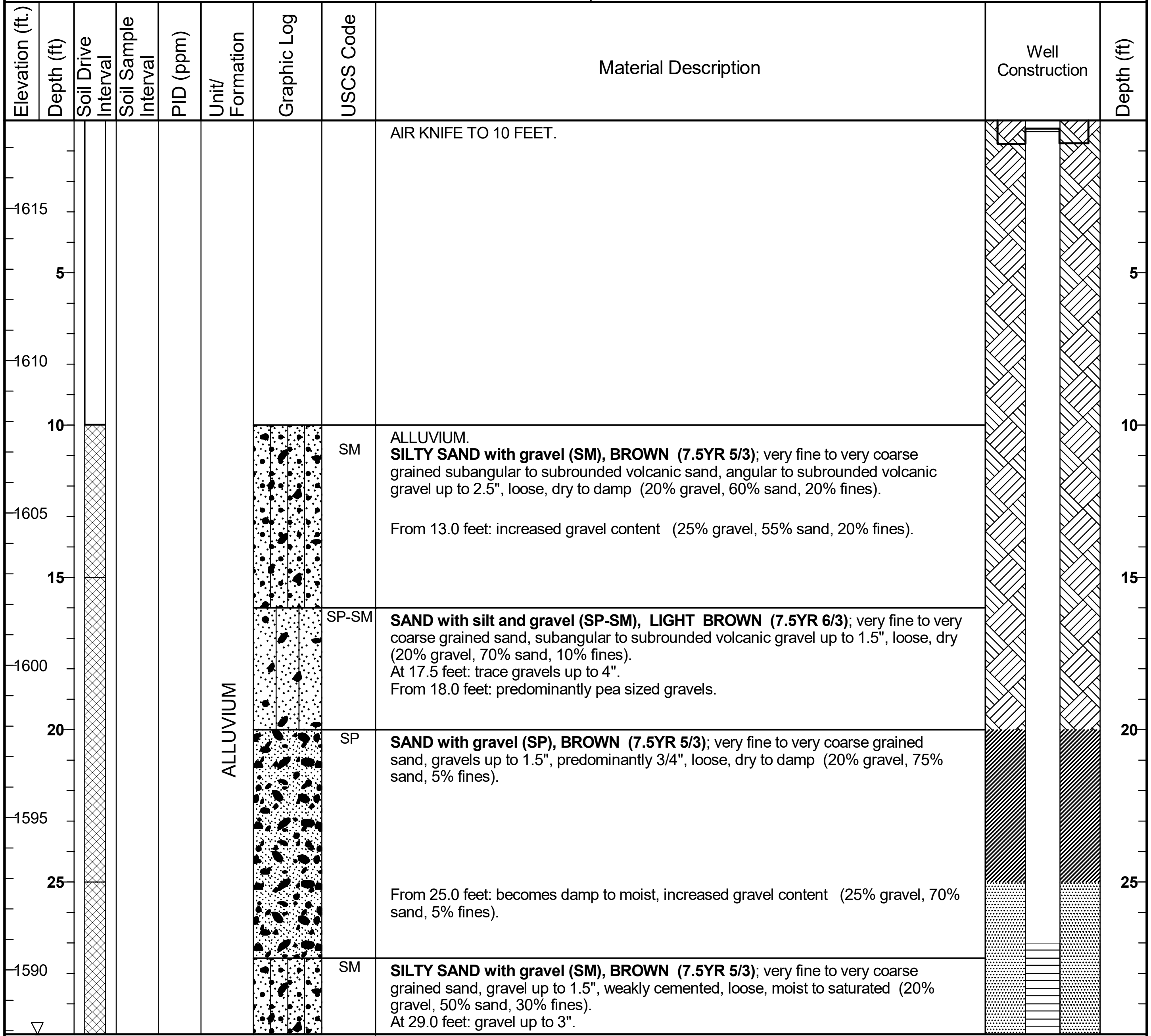
RAMBOLL

2200 Powell Street, Suite 700, Emeryville, CA 94608

Project Number: **169001 6064**		Boring Number: **TRA-2**	
Location: **Handerson, Nevada**			
Contractor: **Cascade Drilling**	Driller: **R. Longtine**	Project Name: **AWF Capture Evaluation**	
Drilling Method: **Sonic**		Date(s): **7/20/2018**	
Rig Type: **Gus Pech 400RS**		Logged By: **G. Miclette**	Checked By: **R. Russell**
Sampling Method: **Continuous**		GS Elevation: **1617.887 ft. MSL**	TOC Elevation: **1617.489 ft. MSL**
		Northing: **26728094.98**	Easting: **829490.64**
		Total Depth: **50.0 feet**	Borehole Dia.: **8 inches**
		Notes:	

Well Construction Details

Blank Casing (feet):	From 0.4 to 27	4-inch Schedule 40 PVC
Screen (feet):	From 27 to 37	0.020-inch Slot, Sch. 40 PVC
Annular Fill (feet):	From 0 to 20	Bentonite-Cement Grout
	From 20 to 25	Bentonite Chip Seal
	From 25 to 38	Lapis Lustre #3 Sand Pack
	From 38 to 50	Bentonite Chip Seal



Depth (ft)	USCS Code	Material Description
0		AIR KNIFE TO 10 FEET.
10	SM	ALLUVIUM. **SILTY SAND with gravel (SM), BROWN (7.5YR 5/3)**; very fine to very coarse grained subangular to subrounded volcanic sand, angular to subrounded volcanic gravel up to 2.5", loose, dry to damp (20% gravel, 60% sand, 20% fines). From 13.0 feet: increased gravel content (25% gravel, 55% sand, 20% fines).
16	SP-SM	**SAND with silt and gravel (SP-SM), LIGHT BROWN (7.5YR 6/3)**; very fine to very coarse grained sand, subangular to subrounded volcanic gravel up to 1.5", loose, dry (20% gravel, 70% sand, 10% fines). At 17.5 feet: trace gravels up to 4". From 18.0 feet: predominantly pea sized gravels.
20	SP	**SAND with gravel (SP), BROWN (7.5YR 5/3)**; very fine to very coarse grained sand, gravels up to 1.5", predominantly 3/4", loose, dry to damp (20% gravel, 75% sand, 5% fines). From 25.0 feet: becomes damp to moist, increased gravel content (25% gravel, 70% sand, 5% fines).
27.5	SM	**SILTY SAND with gravel (SM), BROWN (7.5YR 5/3)**; very fine to very coarse grained sand, gravel up to 1.5", weakly cemented, loose, moist to saturated (20% gravel, 50% sand, 30% fines). At 29.0 feet: gravel up to 3".

Sample/ Recovery Key

▨	Hand Auger	☐	Sonic Core Recovery
☐	Air Knife	◫	No Recovery

▽ First saturated soil cuttings

▼ Equilibrated groundwater (8/16/2018)

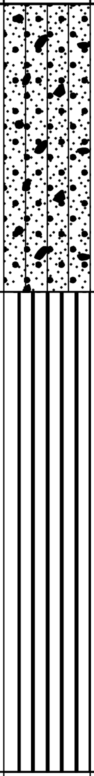
5/7/2020

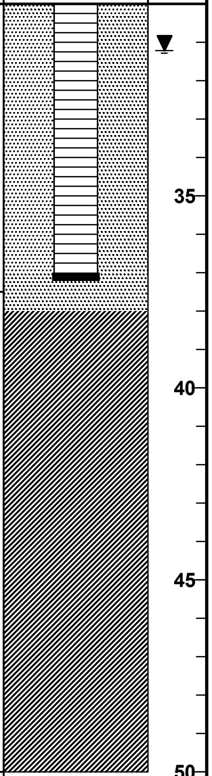
RAMBOLL

2200 Powell Street, Suite 700, Emeryville, CA 94608

Project No.: **169001 6064**	Boring No.: **TRA-2**
Project Name: **AWF Capture Evaluation**	
Date(s): **7/20/2018**	

Elevation (ft.)	Depth (ft)	Soil Drive Interval	Soil Sample Interval	PID (ppm)	Unit/ Formation	Graphic Log	USCS Code	Material Description	Well Construction	Depth (ft)
1585	35				ALLUVIUM		SM	**SILTY SAND with gravel (SM), BROWN (7.5YR 5/3)**; very fine to very coarse grained sand, predominantly very fine to medium grained, gravel up to 1", loose, saturated (15% gravel, 70% sand, 15% fines). At 34.5 feet: 3 cemented clasts up to 2.5". From 35.0 feet: sand is well graded, very fine to very coarse, saturated. At 37.0 feet: 6" cemented plug.		35
1580 1575 1570	40 45 50				UPPER MUDDY CREEK FORMATION		MH	UPPER MUDDY CREEK FORMATION AT 37.5 FEET. **CLAYEY SILT (MH), LIGHT GREENISH GRAY (10Y 8/1)**; medium plasticity, stiff, scattered iron oxide staining, moist (0% gravel, 0% sand, 100% fines). From 45.0 feet: scattered weakly cemented zones.		40 45 50
1565 1560 1555 1550	55 60 65							Boring completed at a depth of 50.0 feet on 07/20/2018.		55 60 65





Sample/ Recovery Key

▨ Hand Auger

☐ Air Knife

☐ Sonic Core Recovery

◫ No Recovery

▽ First saturated soil cuttings

▼ Equilibrated groundwater (8/16/2018)

RAMBOLL

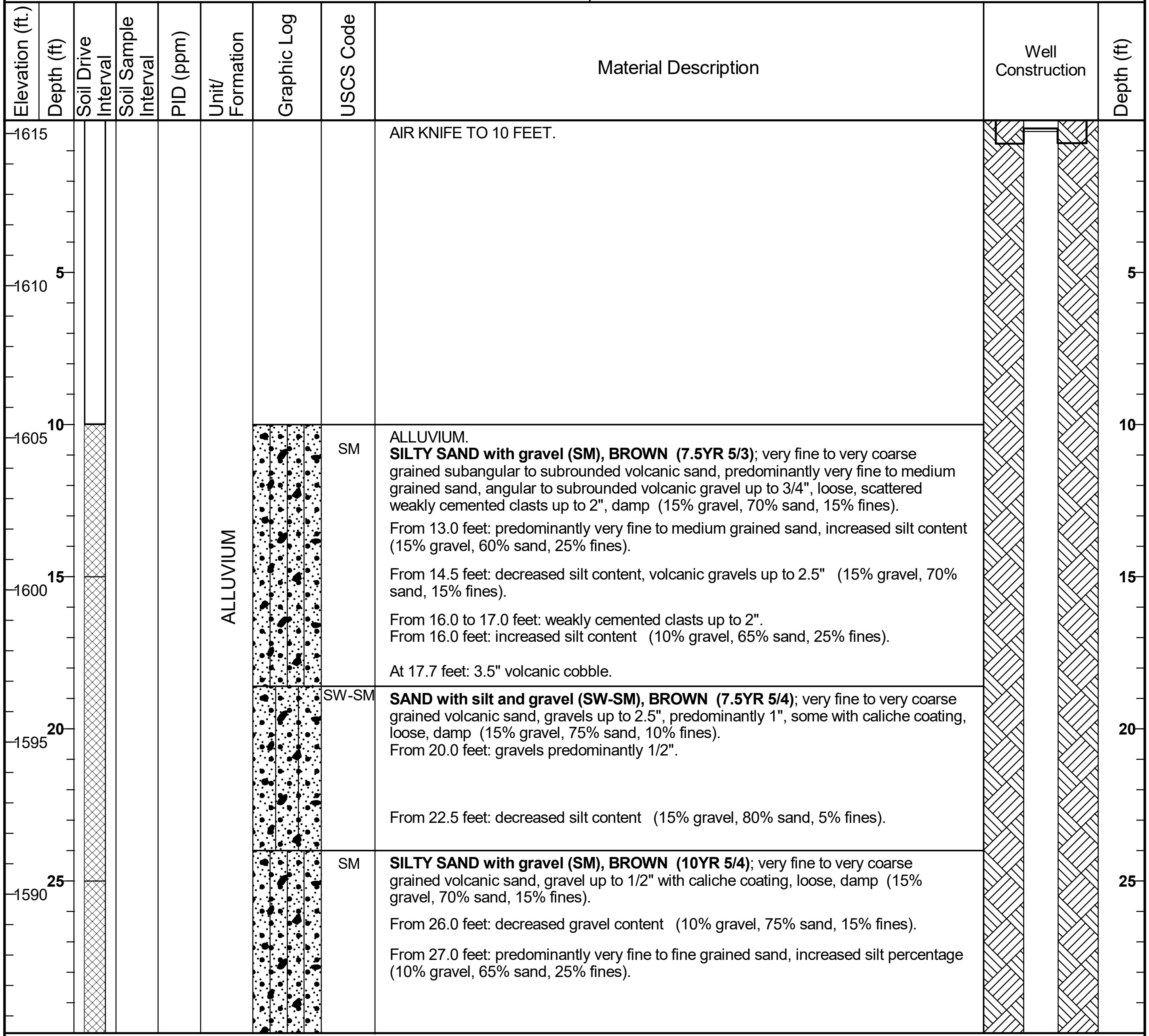
2200 Powell Street, Suite 700, Emeryville, CA 94608

Project Number: **169001 6064**		Boring Number: **PZ-2D**	
Location:	**Handerson, Nevada**		
Contractor: **Cascade Drilling**	Driller: **R. Gonzales**	Project Name: **AWF Capture Evaluation**	
Drilling Method: **Sonic**		Date(s): **7/13/2018**	
Rig Type: **Gus Pech 400RS**		Logged By: **G. Miclette**	Checked By: **R. Russell**
Sampling Method: **Continuous**		GS Elevation: **1615.444 ft. MSL**	TOC Elevation: **1614.962 ft. MSL**
		Northing: **26728616.85**	Easting: **829478.01**
		Total Depth: **76.0 feet**	Borehole Dia.: **8 inches**

Well Construction Details

Blank Casing (feet):	From 0.48 to 75	4-inch Schedule 40 PVC
Screen (feet):	From 75 to 76	0.010-inch Slot, Sch. 40 PVC
Annular Fill (feet):	From 0 to 69.5	Bentonite-Cement Grout
	From 69.5 to 74.5	Bentonite Chip Seal
	From 74.5 to 76	Lapis Lustre #2/12 Sand Pack

Notes:
Adjacent peizometers: PZ-2M and PZ-2S.



Depth (ft)	USCS Code	Material Description
0		AIR KNIFE TO 10 FEET.
10	SM	ALLUVIUM. **SILTY SAND with gravel (SM), BROWN (7.5YR 5/3)**; very fine to very coarse grained subangular to subrounded volcanic sand, predominantly very fine to medium grained sand, angular to subrounded volcanic gravel up to 3/4", loose, scattered weakly cemented clasts up to 2", damp (15% gravel, 70% sand, 15% fines). From 13.0 feet: predominantly very fine to medium grained sand, increased silt content (15% gravel, 60% sand, 25% fines). From 14.5 feet: decreased silt content, volcanic gravels up to 2.5" (15% gravel, 70% sand, 15% fines). From 16.0 to 17.0 feet: weakly cemented clasts up to 2". From 16.0 feet: increased silt content (10% gravel, 65% sand, 25% fines). At 17.7 feet: 3.5" volcanic cobble.
18.5	SW-SM	**SAND with silt and gravel (SW-SM), BROWN (7.5YR 5/4)**; very fine to very coarse grained volcanic sand, gravels up to 2.5", predominantly 1", some with caliche coating, loose, damp (15% gravel, 75% sand, 10% fines). From 20.0 feet: gravels predominantly 1/2". From 22.5 feet: decreased silt content (15% gravel, 80% sand, 5% fines).
24	SM	**SILTY SAND with gravel (SM), BROWN (10YR 5/4)**; very fine to very coarse grained volcanic sand, gravel up to 1/2" with caliche coating, loose, damp (15% gravel, 70% sand, 15% fines). From 26.0 feet: decreased gravel content (10% gravel, 75% sand, 15% fines). From 27.0 feet: predominantly very fine to fine grained sand, increased silt percentage (10% gravel, 65% sand, 25% fines).

Sample/ Recovery Key

▨ Hand Auger	☐ Sonic Core Recovery
☐ Air Knife	◫ No Recovery
▽ First saturated soil cuttings	▼ Equilibrated groundwater (10/4/2018)

Project No.: **169001 6064**	Boring No.: **PZ-2D**
Project Name: **AWF Capture Evaluation**	
Date(s): **7/13/2018**	

Elevation (ft.)	Depth (ft)	Soil Drive Interval	Soil Sample Interval	PID (ppm)	Unit/ Formation	Graphic Log	USCS Code	Material Description	Well Construction	Depth (ft)
1585					ALLUVIUM		SM			
							ML	**SANDY SILT (ML), BROWN (7.5YR 5/3)**; very fine to very coarse grained volcanic sand, predominantly very fine to medium grained sand, gravels up to 1", some caliche coating, weakly cemented clasts up to 1/2", moist to saturated (10% gravel, 35% sand, 55% fines).		
1580	▽ 35						SM	**SILTY SAND (SM), BROWN (7.5YR 5/2)**; very fine to very coarse grained volcanic sand, volcanic gravels up to 1", predominantly 1/4", some caliche coating on gravels, fully cemented / calichified discs of sand, loose saturated (10% gravel, 50% sand, 40% fines).		35
1575	40									40
					UPPER MUDDY CREEK FORMATION		ML	UPPER MUDDY CREEK FORMATION AT 44.0 FEET. **SANDY SILT (ML), STRONG BROWN (7.5YR 5/6)**; medium stiff, very fine to medium grained sand, gravels up to 1.5", predominantly 1/4", loose, saturated (10% gravel, 35% sand, 55% fines).		
1570	45						MH	**CLAYEY SILT (MH), LIGHT GREENISH GRAY (10Y 8/1)**; medium plasticity, scattered bands of moderately cemented clayey silt, scattered bands of Light Greenish Gray (SGY 7/1), moist (0% gravel, 0% sand, 100% fines).		45
1565	50									50
								From 55.0 feet: increasing sand content, color becomes Grayish Green (10Y-5GY 5/2).		
1560	55						MH	**CLAYEY SILT with sand (MH), GRAY (N 5/1)**; low to medium plasticity, stiff, very fine to fine grained sand, scattered pockets of weak to moderate cemented clayey silt, moist (0% gravel, 15% sand, 85% fines).		55
1555	60						ML	**SANDY SILT (ML), BROWN (7.5YR 5/4)**; low plasticity, stiff, very fine to fine grained sand, moist (0% gravel, 30% sand, 70% fines). From 62.1 feet: decreased sand content to silt with sand (0, 20, 80).		60
							MH	**CLAYEY SILT (MH), BROWN (7.5YR 5/3)**; medium plasticity, stiff, very fine to fine grained sand, scattered pockets of cemented clayey silt, moist to saturated (0% gravel, 10% sand, 90% fines). From 65.5 feet: color becomes brown (7.5YR 4/3). From 66.5 to 67.5 feet: increased sand content to clayey silt with sand (0% gravel, 20% sand, 80% fines).		
1550	65									65
							MH	**CLAYEY SILT with sand (MH), BROWN (7.5YR 5/4)**; medium plasticity, stiff, very fine to fine grained sand, scattered cemented clayey silt lenses up to 1.5", moist (0% gravel, 15% sand, 85% fines).		

Sample/ Recovery Key

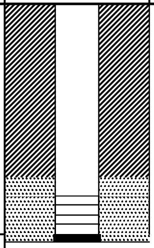
▨ Hand Auger	☐ Sonic Core Recovery
☐ Air Knife	◫ No Recovery

▽ First saturated soil cuttings

▼ Equilibrated groundwater (10/4/2018)

RAMBOLL
2200 Powell Street, Suite 700, Emeryville, CA 94608

Project No.:	**169001 6064**	Boring No.:	**PZ-2D**
Project Name:	**AWF Capture Evaluation**		
Date(s):	**7/13/2018**		

Elevation (ft.)	Depth (ft)	Soil Drive Interval	Soil Sample Interval	PID (ppm)	Unit/ Formation	Graphic Log	USCS Code	Material Description	Well Construction	Depth (ft)
1545		▨			UMCF	▮	MH	From 69.5 to 70.5 feet: CLAYEY SILT (MH), Light Greenish Gray (10Y 8/1). From 70.5 feet: increased sand content (0% gravel, 25% sand, 75% fines). From 71.5 to 72.2 feet: CLAYEY SILT (MH), Light Greenish Gray (10Y 8/1).		
1540	75									75
								Boring completed at a depth of 76.0 feet on 07/13/2018.		
1535	80									80
1530	85									85
1525	90									90
1520	95									95
1515	100									100
1510	105									105

Sample/ Recovery Key

▨ Hand Auger	☐ Sonic Core Recovery	▽ First saturated soil cuttings	Page 3 of 3
☐ Air Knife	◫ No Recovery	▼ Equilibrated groundwater (10/4/2018)	

RAMBOLL

2200 Powell Street, Suite 700, Emeryville, CA 94608

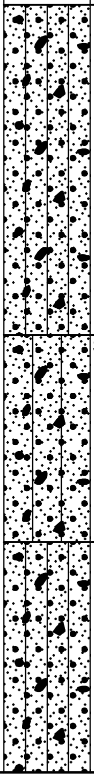
Project Number: **169001 6064**		Boring Number: **PZ-2M**	
Location: **Handerson, Nevada**			
Contractor: **Cascade Drilling**	Driller: **R. Longtine**	Project Name: **AWF Capture Evaluation**	
Drilling Method: **Sonic**		Date(s): **7/23/2018**	
Rig Type: **Gus Pech 400RS**		Logged By: **G. Miclette**	Checked By: **R. Russell**
Sampling Method: **Continuous**		GS Elevation: **1615.66 ft. MSL**	TOC Elevation: **1615.20 ft. MSL**
		Northing: **26728616.98**	Easting: **829470.53**
		Total Depth: **65.0 feet**	Borehole Dia.: **8 inches**

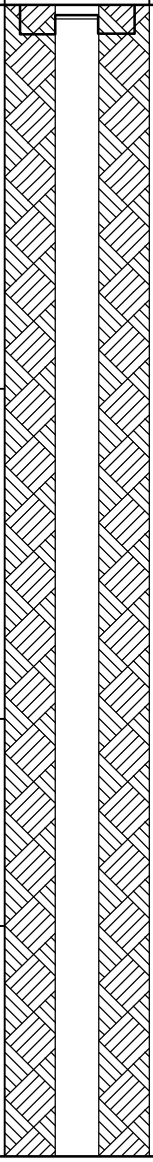
Well Construction Details

Blank Casing (feet):	From 0.46 to 55	4-inch Schedule 40 PVC
Screen (feet):	From 55 to 56	0.010-inch Slot, Sch. 40 PVC
Annular Fill (feet):	From 0 to 50	Bentonite-Cement Grout
	From 50 to 54.5	Bentonite Chip Seal
	From 54.5 to 56	Lapis Lustre #2/12 Sand Pack
	From 56 to 65	Bentonite Chip Seal

Notes:
Lithology based on adjacent soil boring PZ-2D.

Elevation (ft.)	Depth (ft)	Soil Drive Interval	Soil Sample Interval	PID (ppm)	Unit/ Formation	Graphic Log	USCS Code	Material Description	Well Construction	Depth (ft)
1615	0							AIR KNIFE TO 10 FEET. Lithology based on adjacent boring PZ-2D.		
1610	5									5
1605	10				ALLUVIUM		SM	ALLUVIUM. **SILTY SAND with gravel (SM)**		10
1600	15									15
	18.6						SW-SM	**SAND with silt and gravel (SW-SM)**		
1595	20									20
	24						SM	**SILTY SAND with gravel (SM)**		
1590	25									25





Sample/ Recovery Key

■ Chemical Sample

▒ Physical Test Sample

5/7/2020

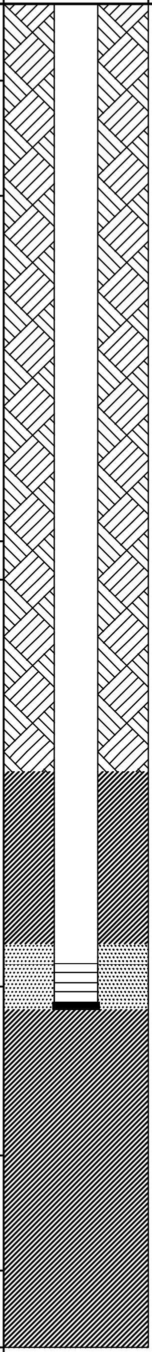
RAMBOLL

2200 Powell Street, Suite 700, Emeryville, CA 94608

Project No.: **169001 6064**	Boring No.: **PZ-2M**
Project Name: **AWF Capture Evaluation**	
Date(s): **7/23/2018**	

Elevation (ft.)	Depth (ft)	Soil Drive Interval	Soil Sample Interval	PID (ppm)	Unit/ Formation	USCS Code	Material Description	Depth (ft)
1585					ALLUVIUM	SM		
						ML	**SANDY SILT (ML)**	
1580	35					SM	**SILTY SAND (SM)**	35
1575	40							40
			▨ ▨ ▨		UPPER MUDDY CREEK FORMATION	ML	UPPER MUDDY CREEK FORMATION AT 44.0 FEET. **SANDY SILT (ML)**	
1570	45		▨ ▨ ▨ ▨ ▨ ▨ ▨			MH	**CLAYEY SILT (MH)**	45
1565	50							50
1560	55					MH	**CLAYEY SILT with sand (MH)**	55
1555	60					ML	**SANDY SILT (ML)**	60
						MH	**CLAYEY SILT (MH)**	
1550	65						Boring completed at a depth of 65.0 feet on 07/23/2018.	65

Well Construction



Sample/ Recovery Key

■ Chemical Sample

▨ Physical Test Sample

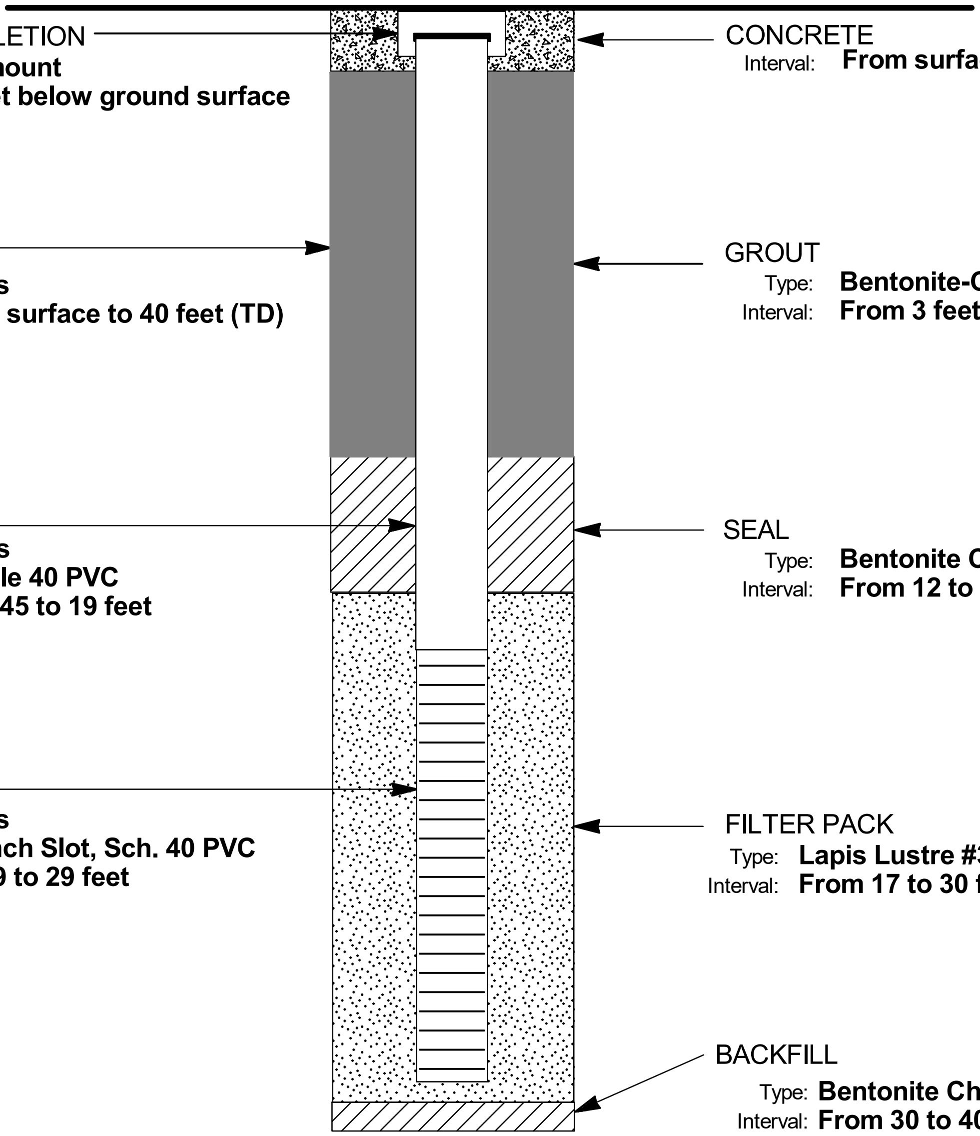
WELL CONSTRUCTION LOGS

RAMBOLL

2200 Powell Street, Suite 700, Emeryville, CA 94608

Well ID:	**TRA-1**		
Contractor: **Cascade Drilling**	Drilling Method: **Sonic**	Date(s):	**7/19/2018**
Project name:	**AWF Capture Evaluation**	Installed By:	**G. Miclette**
Project number:	**169001 6064**	Northing: **26728035.59**	Easting: **828948.52**
Location:	**Handerson, Nevada**	GS Elevation: **1619.028**	TOC Elevation: **1618.583**
Notes:		Depth to Groundwater: **28.20 feet below ground surface (8/16/2018)**	

WELL CONSTRUCTION DETAILS



SURFACE COMPLETION
Type: **Flush mount**
TOC: **0.45 feet below ground surface**

CONCRETE
Interval: **From surface to 3 feet**

BOREHOLE
Diameter: **8 inches**
Interval: **Ground surface to 40 feet (TD)**

GROUT
Type: **Bentonite-Cement**
Interval: **From 3 feet to 12 feet**

BLANK PIPE
Diameter: **4 inches**
Type: **Schedule 40 PVC**
Interval: **From 0.45 to 19 feet**

SEAL
Type: **Bentonite Chip**
Interval: **From 12 to 17 feet**

SCREEN
Diameter: **4 inches**
Type: **0.020-inch Slot, Sch. 40 PVC**
Interval: **From 19 to 29 feet**

FILTER PACK
Type: **Lapis Lustre #3 Sand Pack**
Interval: **From 17 to 30 feet**

BACKFILL
Type: **Bentonite Chip Seal**
Interval: **From 30 to 40 feet**

NOT TO SCALE

File: AWF_CAPTURE.GPJ; 5/7/20

LEGEND

■	CEMENT GROUT	⁘	FILTER PACK
▨	BENTONITE SEAL	▩	CONCRETE

Well Construction Diagram

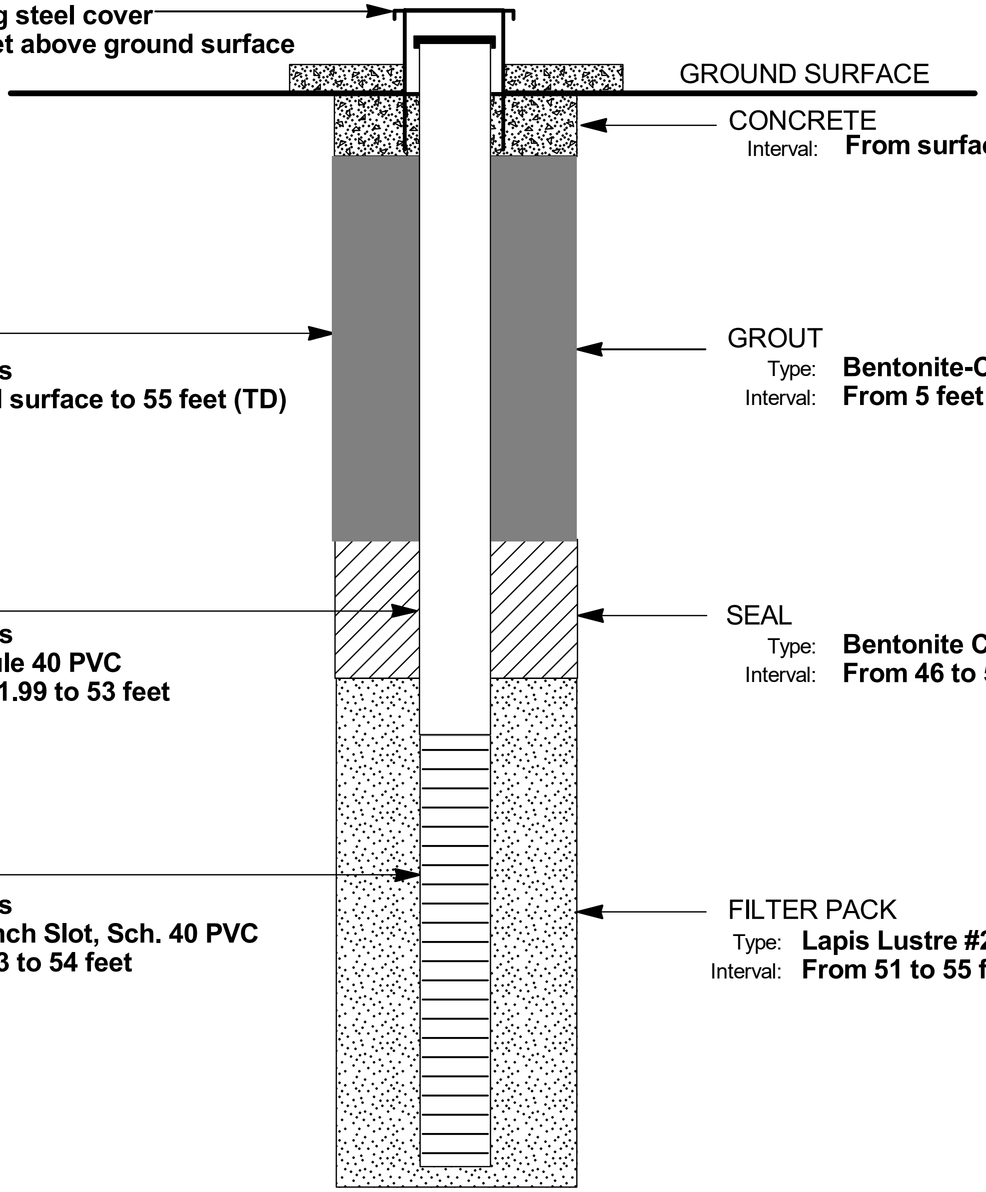
TRA-1

RAMBOLL

2200 Powell Street, Suite 700, Emeryville, CA 94608

		Well ID:	**PZ-1D**
Contractor: **Cascade Drilling**	Drilling Method: **Sonic**	Date(s):	**7/10/2018**
Project name:	**AWF Capture Evaluation**	Installed By:	**J. Manheim**
Project number:	**169001 6064**	Northing: **26728458.78**	Easting: **829038.63**
Location:	**Handerson, Nevada**	GS Elevation: **1613.369**	TOC Elevation: **1615.355**
Notes:		Depth to Groundwater:	**30.19 feet below ground surface (10/4/2018)**

WELL CONSTRUCTION DETAILS



SURFACE COMPLETION
Type: **Locking steel cover**
TOC: **1.99 feet above ground surface**

CONCRETE
Interval: **From surface to 5 feet**

BOREHOLE
Diameter: **8 inches**
Interval: **Ground surface to 55 feet (TD)**

GROUT
Type: **Bentonite-Cement**
Interval: **From 5 feet to 46 feet**

BLANK PIPE
Diameter: **4 inches**
Type: **Schedule 40 PVC**
Interval: **From +1.99 to 53 feet**

SEAL
Type: **Bentonite Chip**
Interval: **From 46 to 51 feet**

SCREEN
Diameter: **4 inches**
Type: **0.010-inch Slot, Sch. 40 PVC**
Interval: **From 53 to 54 feet**

FILTER PACK
Type: **Lapis Lustre #2/12 Sand Pack**
Interval: **From 51 to 55 feet**

NOT TO SCALE

LEGEND

■ CEMENT GROUT	⁘ FILTER PACK
▨ BENTONITE SEAL	▩ CONCRETE

Well Construction Diagram

PZ-1D

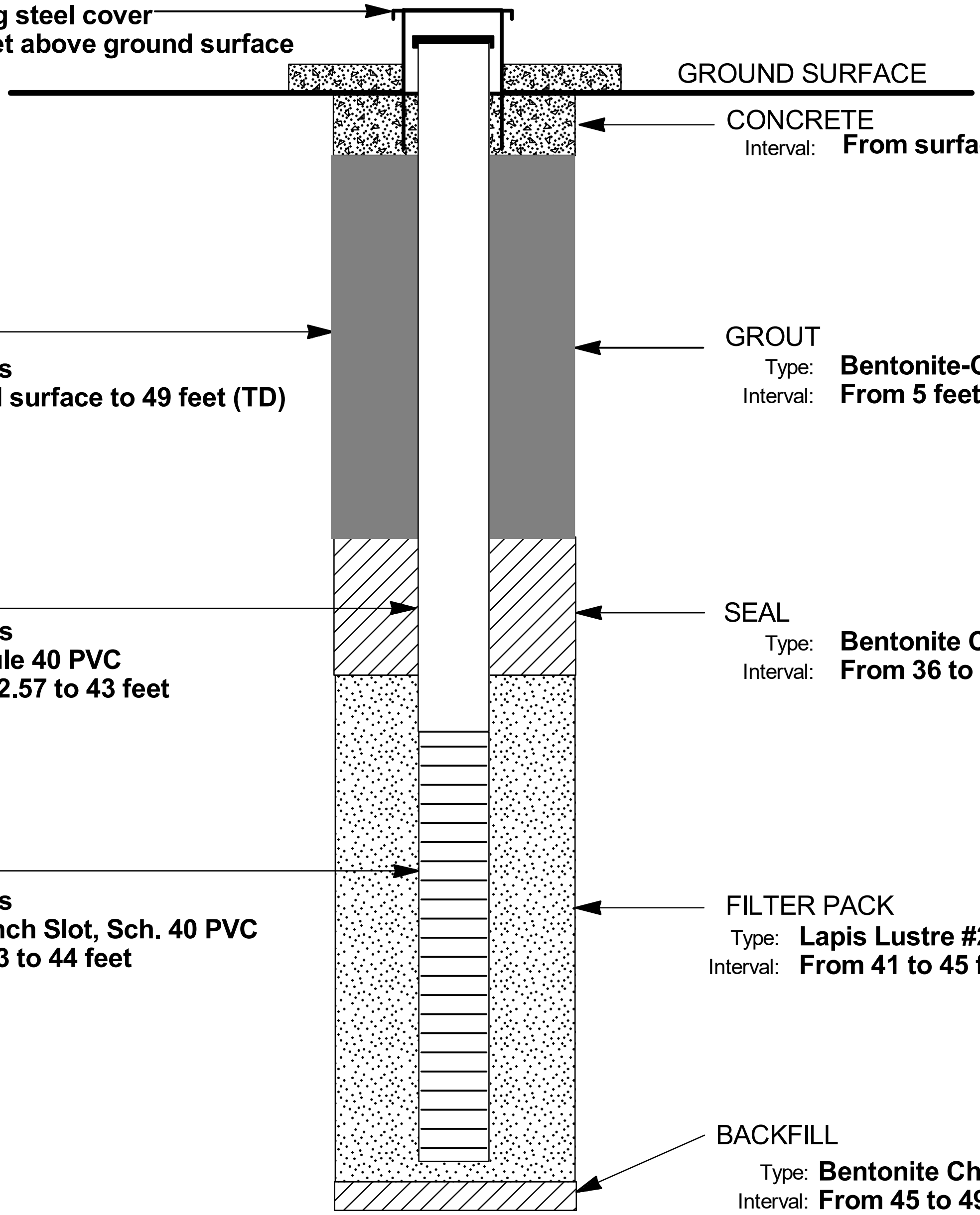
File: AWF_CAPTURE.GPJ; 5/7/20

RAMBOLL

2200 Powell Street, Suite 700, Emeryville, CA 94608

		Well ID:	**PZ-1M**
Contractor: **Cascade Drilling**	Drilling Method: **Sonic**	Date(s):	**7/14/2018**
Project name:	**AWF Capture Evaluation**	Installed By:	**G. Miclette**
Project number:	**169001 6064**	Northing: **26728458.46**	Easting: **829030.91**
Location:	**Handerson, Nevada**	GS Elevation: **1612.87**	TOC Elevation: **1615.44**
Notes:		Depth to Groundwater: **NA**	

WELL CONSTRUCTION DETAILS



SURFACE COMPLETION
Type: **Locking steel cover**
TOC: **2.57 feet above ground surface**

CONCRETE
Interval: **From surface to 5 feet**

BOREHOLE
Diameter: **8 inches**
Interval: **Ground surface to 49 feet (TD)**

GROUT
Type: **Bentonite-Cement**
Interval: **From 5 feet to 36 feet**

BLANK PIPE
Diameter: **4 inches**
Type: **Schedule 40 PVC**
Interval: **From +2.57 to 43 feet**

SEAL
Type: **Bentonite Chip**
Interval: **From 36 to 41 feet**

SCREEN
Diameter: **4 inches**
Type: **0.010-inch Slot, Sch. 40 PVC**
Interval: **From 43 to 44 feet**

FILTER PACK
Type: **Lapis Lustre #2/12 Sand Pack**
Interval: **From 41 to 45 feet**

BACKFILL
Type: **Bentonite Chip Seal**
Interval: **From 45 to 49 feet**

NOT TO SCALE

LEGEND

■	CEMENT GROUT	⁘	FILTER PACK
▨	BENTONITE SEAL	▩	CONCRETE

Well Construction Diagram

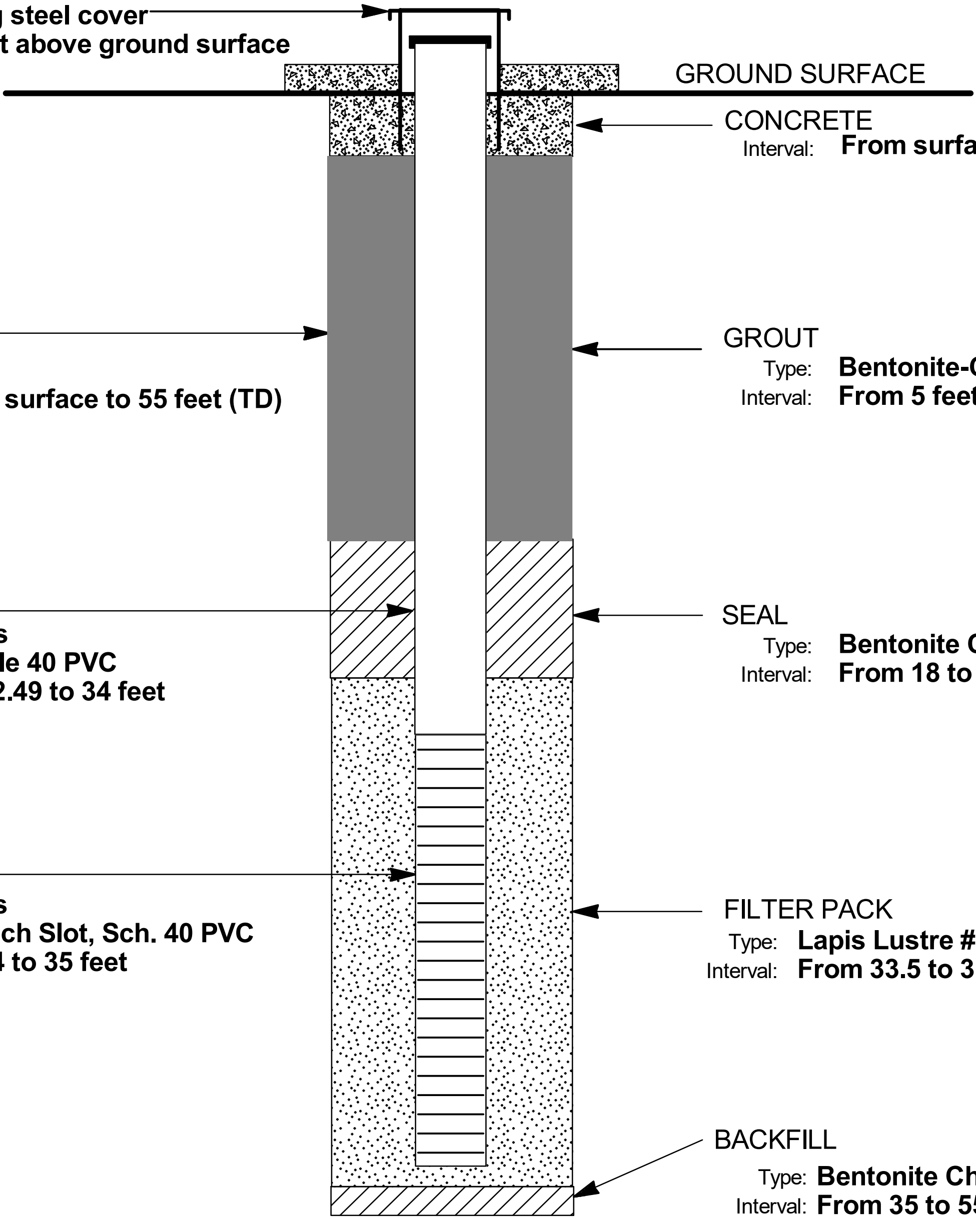
PZ-1M

RAMBOLL

2200 Powell Street, Suite 700, Emeryville, CA 94608

Well ID:	**PZ-1S**		
Contractor:	**Cascade Drilling**	Drilling Method:	**Sonic**
Date(s):	**7/12/2018**		
Project name:	**AWF Capture Evaluation**	Installed By:	**G. Miclette**
Project number:	**169001 6064**		
Northing:	**26728459.18**	Easting:	**829021.97**
Location:	**Handerson, Nevada**		
GS Elevation:	**1612.93**	TOC Elevation:	**1615.42**
Notes:			
Depth to Groundwater:	**32.88 feet below ground surface (8/16/2018)**		

WELL CONSTRUCTION DETAILS



SURFACE COMPLETION
Type: **Locking steel cover**
TOC: **2.49 feet above ground surface**

CONCRETE
Interval: **From surface to 5 feet**

BOREHOLE
Diameter: **inches**
Interval: **Ground surface to 55 feet (TD)**

GROUT
Type: **Bentonite-Cement**
Interval: **From 5 feet to 18 feet**

BLANK PIPE
Diameter: **4 inches**
Type: **Schedule 40 PVC**
Interval: **From +2.49 to 34 feet**

SEAL
Type: **Bentonite Chip**
Interval: **From 18 to 33.5 feet**

SCREEN
Diameter: **4 inches**
Type: **0.020-inch Slot, Sch. 40 PVC**
Interval: **From 34 to 35 feet**

FILTER PACK
Type: **Lapis Lustre #3 Sand Pack**
Interval: **From 33.5 to 35 feet**

BACKFILL
Type: **Bentonite Chip Seal**
Interval: **From 35 to 55 feet**

NOT TO SCALE

LEGEND
■ CEMENT GROUT
▨ BENTONITE SEAL
░ FILTER PACK
▒ CONCRETE

Well Construction Diagram

PZ-1S

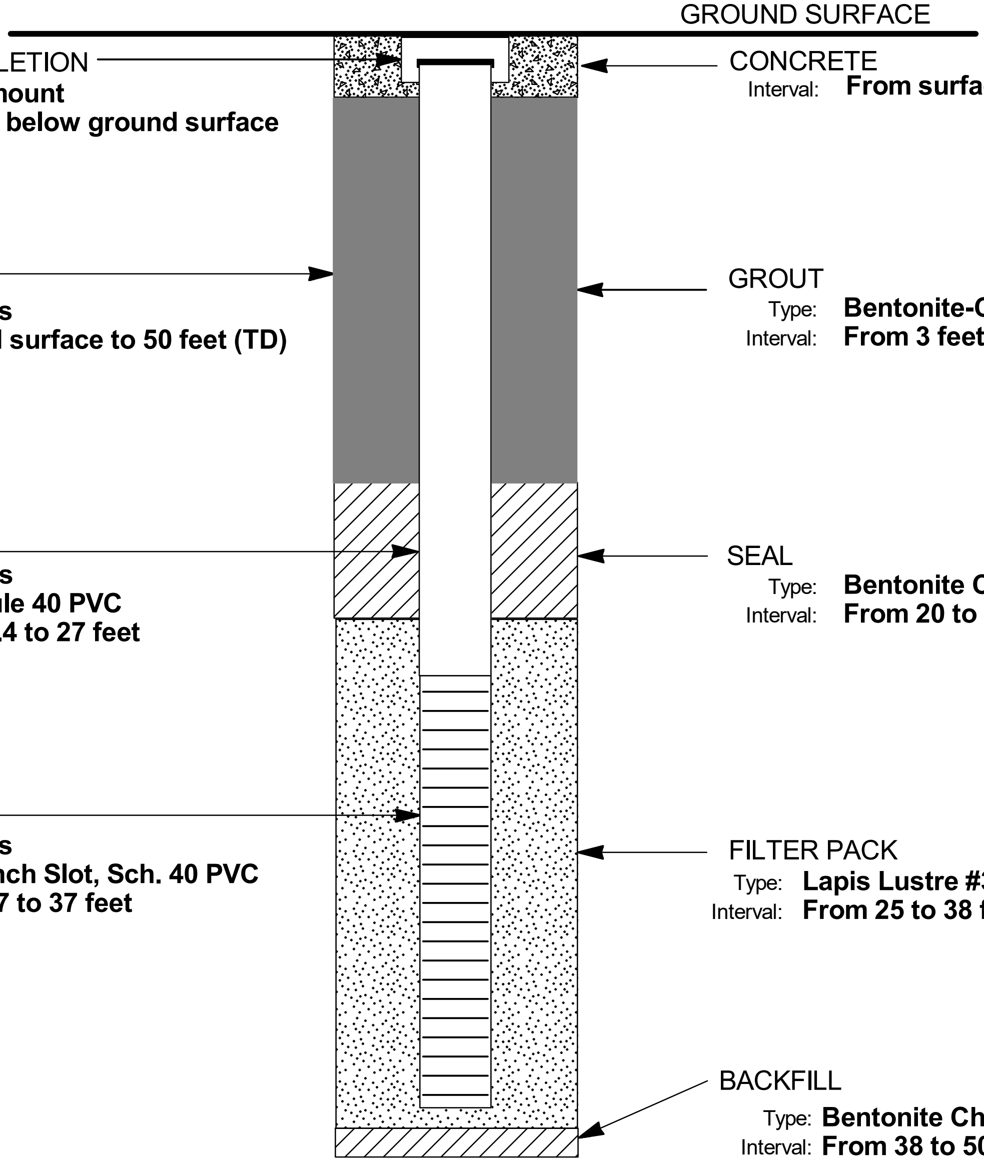
File: AWF_CAPTURE.GPJ; 5/7/20

RAMBOLL

2200 Powell Street, Suite 700, Emeryville, CA 94608

Well ID:	**TRA-2**		
Contractor: **Cascade Drilling**	Drilling Method: **Sonic**	Date(s):	**7/20/2018**
Project name:	**AWF Capture Evaluation**	Installed By:	**G. Miclette**
Project number:	**169001 6064**	Northing: **26728094.98**	Easting: **829490.64**
Location:	**Handerson, Nevada**	GS Elevation: **1617.887**	TOC Elevation: **1617.489**
Notes:		Depth to Groundwater: **31.22 feet below ground surface (8/16/2018)**	

WELL CONSTRUCTION DETAILS



GROUND SURFACE

SURFACE COMPLETION
Type: **Flush mount**
TOC: **0.4 feet below ground surface**

CONCRETE
Interval: **From surface to 3 feet**

BOREHOLE
Diameter: **8 inches**
Interval: **Ground surface to 50 feet (TD)**

GROUT
Type: **Bentonite-Cement**
Interval: **From 3 feet to 20 feet**

BLANK PIPE
Diameter: **4 inches**
Type: **Schedule 40 PVC**
Interval: **From 0.4 to 27 feet**

SEAL
Type: **Bentonite Chip**
Interval: **From 20 to 25 feet**

SCREEN
Diameter: **4 inches**
Type: **0.020-inch Slot, Sch. 40 PVC**
Interval: **From 27 to 37 feet**

FILTER PACK
Type: **Lapis Lustre #3 Sand Pack**
Interval: **From 25 to 38 feet**

BACKFILL
Type: **Bentonite Chip Seal**
Interval: **From 38 to 50 feet**

NOT TO SCALE

LEGEND

■ CEMENT GROUT
▨ BENTONITE SEAL
⁘ FILTER PACK
▩ CONCRETE

Well Construction Diagram

TRA-2

RAMBOLL

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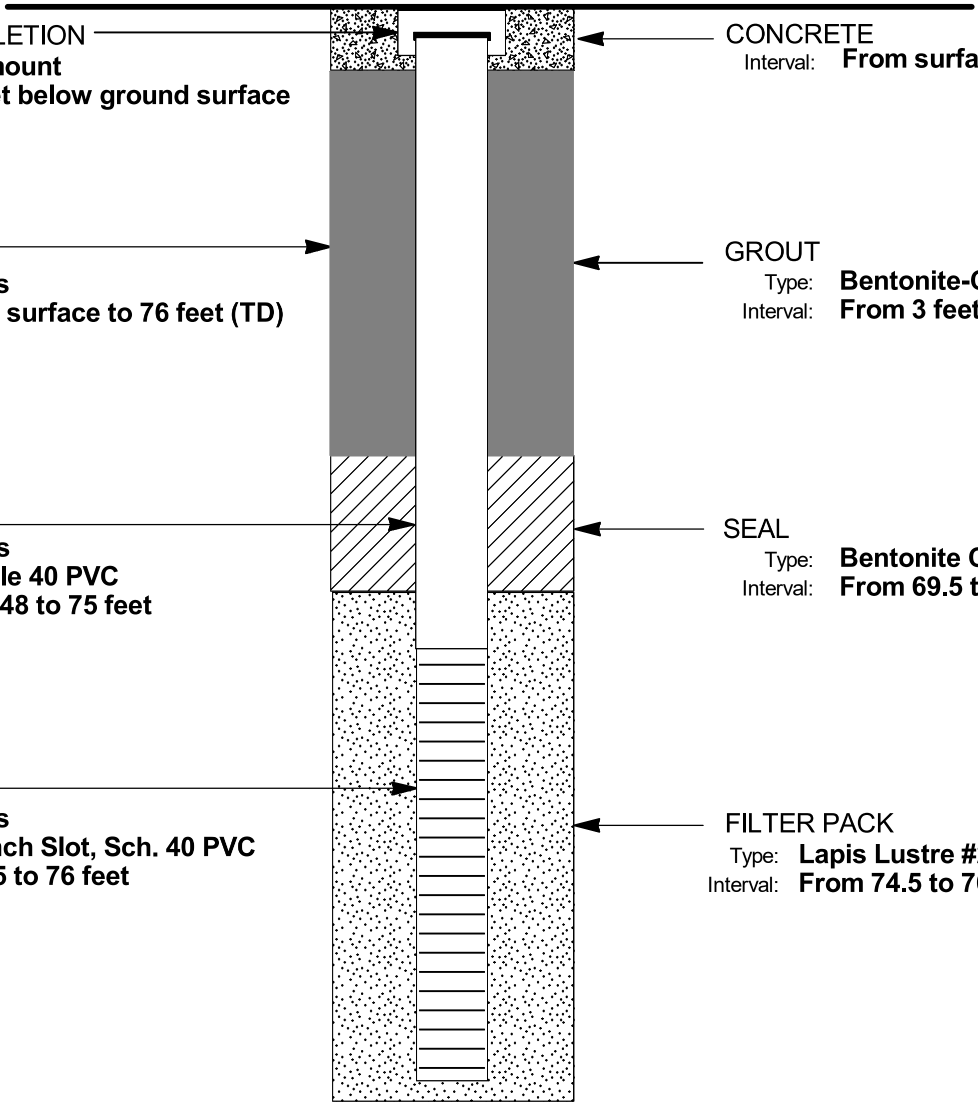
Well ID:	**PZ-2D**		
Contractor: **Cascade Drilling**	Drilling Method: **Sonic**	Date(s):	**7/13/2018**
Project name:	**AWF Capture Evaluation**	Installed By:	**G. Miclette**
Project number:	**169001 6064**	Northing: **26728616.85**	Easting: **829478.01**
Location:	**Handerson, Nevada**	GS Elevation: **1615.444**	TOC Elevation: **1614.962**
Notes:		Depth to Groundwater:	**30.12 feet below ground surface (10/4/2018)**

WELL CONSTRUCTION DETAILS

GROUND SURFACE



SURFACE COMPLETION
Type: **Flush mount**
TOC: **0.48 feet below ground surface**

CONCRETE
Interval: **From surface to 3 feet**

BOREHOLE
Diameter: **8 inches**
Interval: **Ground surface to 76 feet (TD)**

GROUT
Type: **Bentonite-Cement**
Interval: **From 3 feet to 69.5 feet**

BLANK PIPE
Diameter: **4 inches**
Type: **Schedule 40 PVC**
Interval: **From 0.48 to 75 feet**

SEAL
Type: **Bentonite Chip**
Interval: **From 69.5 to 74.5 feet**

SCREEN
Diameter: **4 inches**
Type: **0.010-inch Slot, Sch. 40 PVC**
Interval: **From 75 to 76 feet**

FILTER PACK
Type: **Lapis Lustre #2/12 Sand Pack**
Interval: **From 74.5 to 76 feet**

NOT TO SCALE

LEGEND

■	CEMENT GROUT	⁘	FILTER PACK
▨	BENTONITE SEAL	▩	CONCRETE

Well Construction Diagram

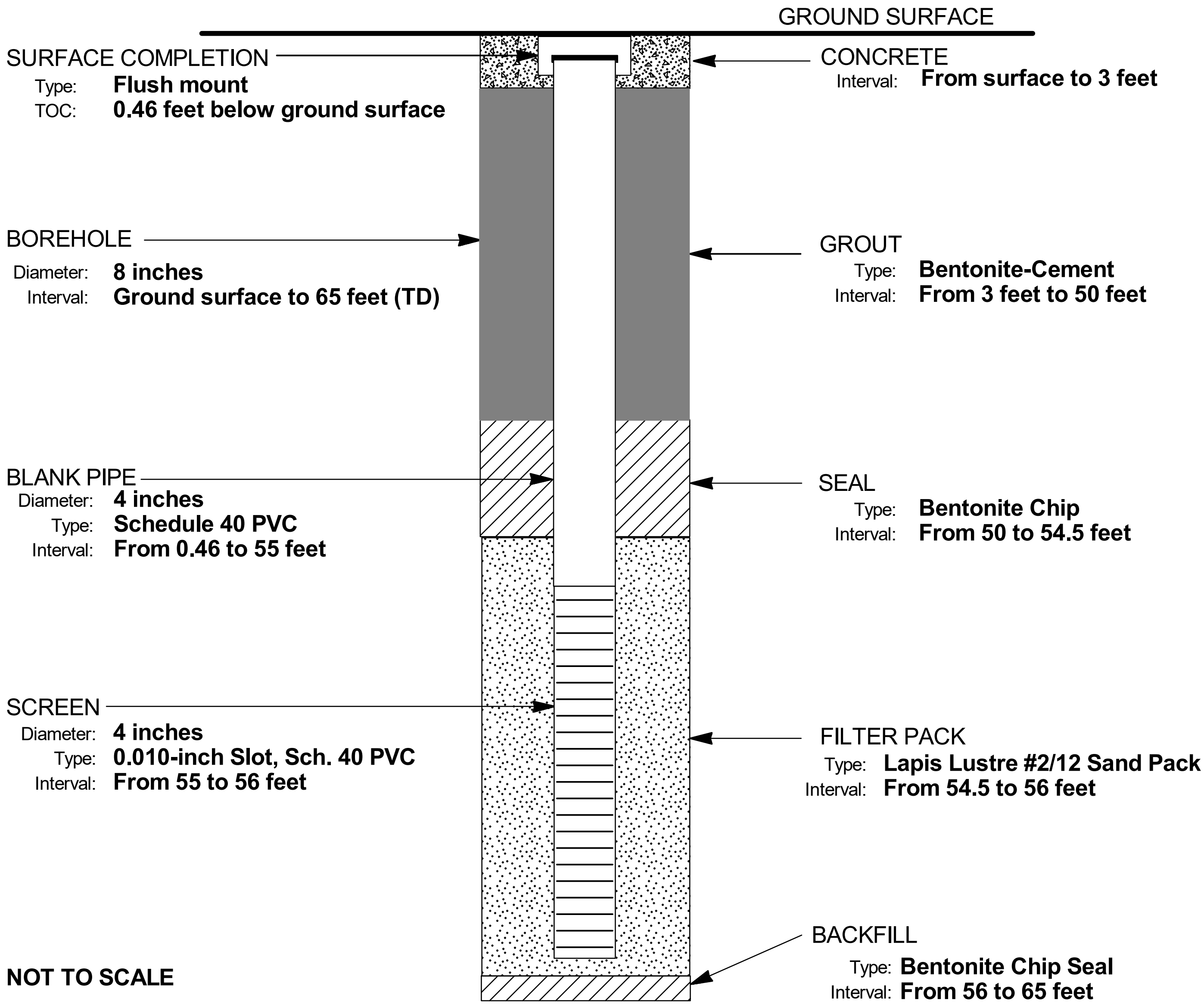
PZ-2D

File: AWF_CAPTURE.GPJ; 5/7/20

RAMBOLL
2200 Powell Street, Suite 700, Emeryville, CA 94608

		Well ID:	**PZ-2M**
Contractor: **Cascade Drilling**	Drilling Method: **Sonic**	Date(s):	**7/23/2018**
Project name:	**AWF Capture Evaluation**	Installed By:	**G. Miclette**
Project number:	**169001 6064**	Northing: **26728616.98**	Easting: **829470.53**
Location:	**Handerson, Nevada**	GS Elevation: **1615.66**	TOC Elevation: **1615.20**
Notes:		Depth to Groundwater: **NA**	

WELL CONSTRUCTION DETAILS



SURFACE COMPLETION
Type: **Flush mount**
TOC: **0.46 feet below ground surface**

CONCRETE
Interval: **From surface to 3 feet**

BOREHOLE
Diameter: **8 inches**
Interval: **Ground surface to 65 feet (TD)**

GROUT
Type: **Bentonite-Cement**
Interval: **From 3 feet to 50 feet**

BLANK PIPE
Diameter: **4 inches**
Type: **Schedule 40 PVC**
Interval: **From 0.46 to 55 feet**

SEAL
Type: **Bentonite Chip**
Interval: **From 50 to 54.5 feet**

SCREEN
Diameter: **4 inches**
Type: **0.010-inch Slot, Sch. 40 PVC**
Interval: **From 55 to 56 feet**

FILTER PACK
Type: **Lapis Lustre #2/12 Sand Pack**
Interval: **From 54.5 to 56 feet**

BACKFILL
Type: **Bentonite Chip Seal**
Interval: **From 56 to 65 feet**

NOT TO SCALE

File: AWF_CAPTURE.GPJ; 5/7/20

LEGEND

■	CEMENT GROUT	░	FILTER PACK
▨	BENTONITE SEAL	▓	CONCRETE

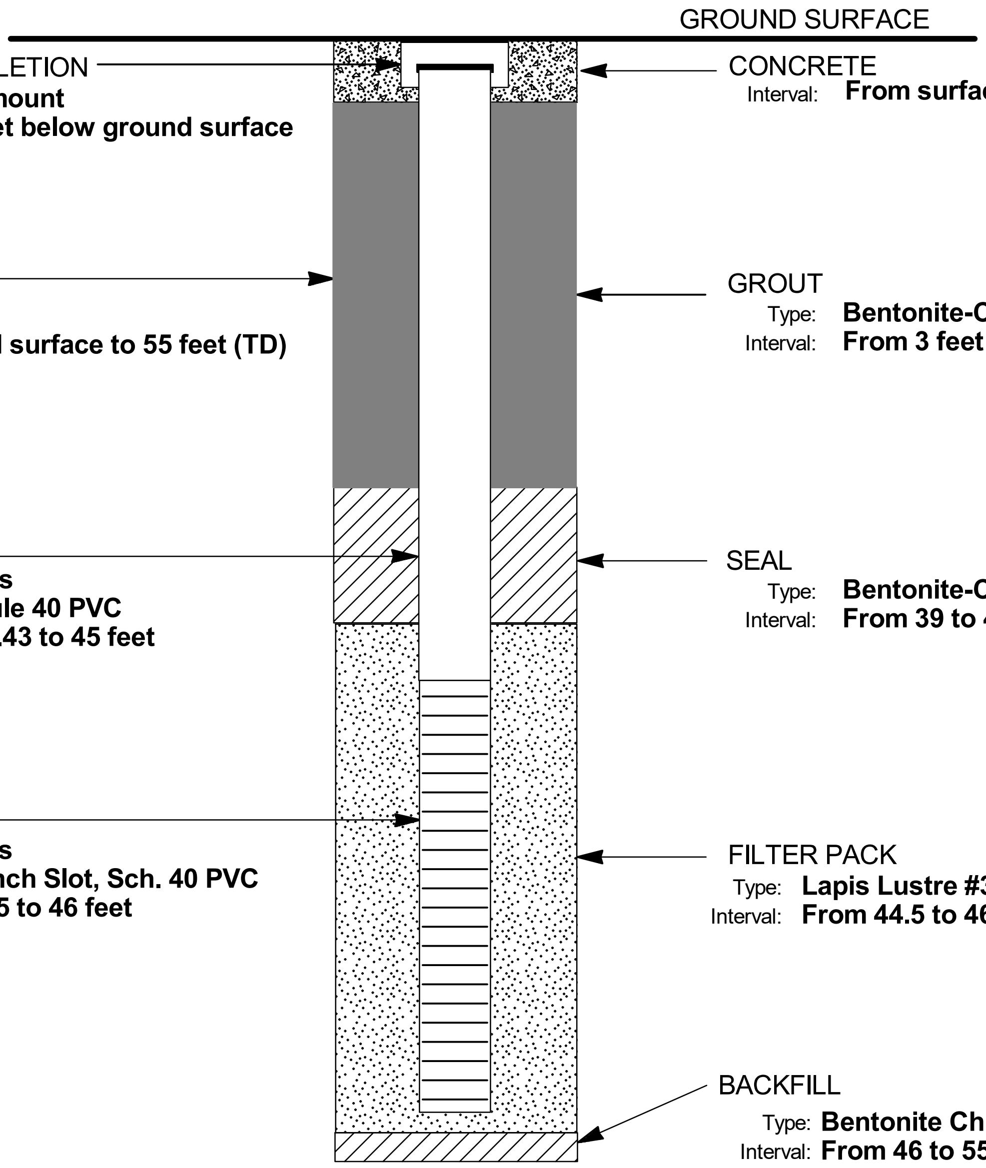
Well Construction Diagram

PZ-2M

2200 Powell Street, Suite 700, Emeryville, CA 94608

Well ID:	**PZ-2S**		
Contractor: **Cascade Drilling**	Drilling Method: **Sonic**	Date(s):	**7/24/2018**
Project name:	**AWF Capture Evaluation**	Installed By:	**G. Miclette**
Project number:	**169001 6064**	Northing: **26728616.53**	Easting: **829462.34**
Location:	**Handerson, Nevada**	GS Elevation: **1615.57**	TOC Elevation: **1615.14**
Notes:		Depth to Groundwater: **32.95 feet below ground surface (8/16/2018)**	

WELL CONSTRUCTION DETAILS



SURFACE COMPLETION
Type: **Flush mount**
TOC: **0.43 feet below ground surface**

BOREHOLE
Diameter: **inches**
Interval: **Ground surface to 55 feet (TD)**

BLANK PIPE
Diameter: **4 inches**
Type: **Schedule 40 PVC**
Interval: **From 0.43 to 45 feet**

SCREEN
Diameter: **4 inches**
Type: **0.020-inch Slot, Sch. 40 PVC**
Interval: **From 45 to 46 feet**

CONCRETE
Interval: **From surface to 3 feet**

GROUT
Type: **Bentonite-Cement**
Interval: **From 3 feet to 39 feet**

SEAL
Type: **Bentonite-Ceme**
Interval: **From 39 to 44.5 feet**

FILTER PACK
Type: **Lapis Lustre #3 Sand Pack**
Interval: **From 44.5 to 46 feet**

BACKFILL
Type: **Bentonite Chip Seal**
Interval: **From 46 to 55 feet**

NOT TO SCALE

LEGEND

■ CEMENT GROUT	░ FILTER PACK
▨ BENTONITE SEAL	▒ CONCRETE

Well Construction Diagram

PZ-2S

ATTACHMENT B-2
WELL DEVELOPMENT LOGS

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WELL DEVELOPMENT
PRELIMINARY FIELD DRAFT
REVIEW PENDING

	PUMP	BAILER	SURGE BLOCK
METHOD(S)			
TYPE	MONSOON	CHECKBALL	SUCTION
MATERIAL	PLASTIC	ST, STEEL	ST, STEEL
DIMENSION	2/5 dia	3.5 x 5'	3.5" dia x 5'
OTHER			

PROJECT: NERT AWF CAPTURE EVAL.

WELL NO.: TRA-1

JOB NO.: 1690006943-048

SITE: NERT - AWF

PREPARED BY: GM

DEVELOPMENT CRITERIA: STABLE PARAMETERS / < 10 NTUs

DECONTAMINATION METHOD: STEAM / ALCONOX SOLN

HOLE DIAMETER d_h = 8

WELL CASING

INSIDE DIAMETER d_w = 4

CASING STICKUP SU = -.5

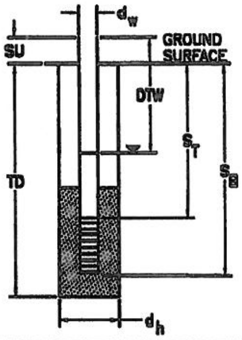
DEPTH TO:

WELL LEVEL DTW = 27.82

TOP SCREEN SU+S_T = 19

BASE SCREEN SU+S_B = 29

BOTTOM WELL SU+TD = 28.30



CASING VOLUME CALCULATION (USE CONSISTENT UNITS)

CASING VOLUME = $V_C = \pi(\frac{d_w}{2})^2$ (TD−H) = .312 gal

[28.30 − 27.82] x [(2)² x .163]

FIELD EQUIPMENT CALIBRATIONS

EQUIPMENT MODEL/TYPE	YSI	HACH 2100Q	
SERIAL NO.			
DATE CALIBRATED	7/25/20	7/25/20	
TEMP (°C)			
STANDARD/ACTUAL			

DEVELOPMENT LOG:					CUMULATIVE TOTAL REMOVED		WATER CHARACTER CRITERIA						COMMENTS
DATE	TIME BEGIN	TIME FINISH	METHOD	WATER REMOVED (gal)	GAL.	CASING VOLUMES	pH	CONDUCTIVITY	TEMP.(C°)	TURBIDITY		DTW	
7/25		0950					ONSITE					27.82	
7/25	1000	1005	B	.5	.5							28.21	BAILED DRY

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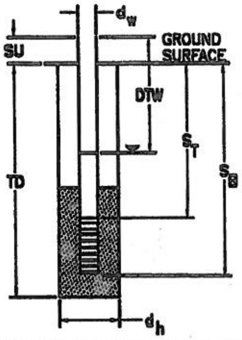
WELL DEVELOPMENT
PRELIMINARY FIELD DRAFT
REVIEW PENDING

METHOD(S)	PUMP	BAILER	SURGE BLOCK
TYPE	MONSOON	CHECKBALL	SUCTION
MATERIAL	PLASTIC	ST. STEEL	ST. STEEL
DIMENSION	~1.5 x 2'	~3.5 x 5'	~3.5 x 5'
OTHER			

PROJECT: NERT AWF CAPTURE EVALUATION
WELL NO.: PZ-15
JOB NO.: 1690006943.048
SITE: NERT - AWF
PREPARED BY: GM
DEVELOPMENT CRITERIA: STABLE PARAMETERS / <10 NTUs
DECONTAMINATION METHOD: STEAM CLEAN / ALCONOX SOLN

HOLE DIAMETER d_h = 8
WELL CASING
INSIDE DIAMETER d_w = 4
CASING STICKUP SU = 2.5
DEPTH TO:
WELL LEVEL DTW = 32.81
TOP SCREEN $SU+S_T$ = 34
BASE SCREEN $SU+S_B$ = 35
BOTTOM WELL SU+TD = 37.40
BGS



CASING VOLUME CALCULATION (USE CONSISTENT UNITS)

CASING VOLUME = $V_C = \pi(\frac{d_w}{2})^2$ (TD−H) = 2.99 gal
(37.40 − 32.81) × [(2)² × .163] x10 29.90

FIELD EQUIPMENT CALIBRATIONS

EQUIPMENT MODEL/TYPE	YSI	HACH 2100Q	
SERIAL NO.			
DATE CALIBRATED	7/25	7/25	
TEMP (°C)			
STANDARD/ACTUAL			

DEVELOPMENT LOG:					CUMULATIVE TOTAL REMOVED		WATER CHARACTER CRITERIA						COMMENTS
DATE	TIME		METHOD	WATER REMOVED (gal)									
	BEGIN	FINISH			GAL.	CASING VOLUMES	pH	CONDUCTIVITY	TEMP.(C°)	TURBIDITY		DTW	
7/26		1320						ONSITE TIME				32.81	
	1325	1326	S									32.81	
	1328	1332	B	3	3							36.90	BAILED DRY
7/26		1520	[redacted]				JUST DTW					33.90	30min/1 ft RECHARGE
7/30	0850	0910	B	3	6			Bailed Dry				32.86 ~~37.40~~	36.90 End
7/30	1530	1535	B	3	9			Bailed Dry				32.87	36.93 End
7/31	1104	1112	B	3	12			Bailed Dry				32.85	36.89 End
7/31	1355	1404	B	3	15			Bailed Dry				33.02	36.89
													Poor recovery

3

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WELL DEVELOPMENT

PRELIMINARY FIELD DRAFT
REVIEW PENDING

METHOD(S)	PUMP	BAILER	SURGE BLOCK
TYPE	MONSOON	CHECK BALL	SUCTION
MATERIAL	PLASTIC	ST. STEEL	ST. STEEL
DIMENSION	~1.5"x2'	~3.5x5'	~3.5"x5'
OTHER			

PROJECT: NERT-AWF CAPTURE EVALUAT

WELL NO.: PZ-1M

JOB NO.: 1690006943-048

SITE: NERT-AWF

PREPARED BY: GM

DEVELOPMENT CRITERIA: STABLE PARAMETERS / <10NTUS

DECONTAMINATION METHOD: STEAM / ALCONOX SOLN.

HOLE DIAMETER d_h = 8

WELL CASING

INSIDE DIAMETER d_w = 4

CASING STICKUP SU = 2.5

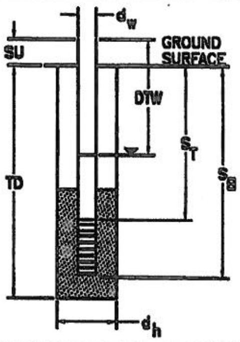
DEPTH TO:

WELL LEVEL DTW = 32.55

BGS [TOP SCREEN $SU+S_T$ = 43

BASE SCREEN $SU+S_B$ = 44]

BOTTOM WELL SU+TD = 46.37



CASING VOLUME CALCULATION (USE CONSISTENT UNITS)

CASING VOLUME = $V_C = \pi(\frac{d_w}{2})^2$ (TD−H) = 9.01 gal

(46.37−32.55)×[(2)²×.163] ×10 90.1

FIELD EQUIPMENT CALIBRATIONS

EQUIPMENT MODEL/TYPE	YSI	HACH 2100Q	
SERIAL NO.			
DATE CALIBRATED	7/25	7/25	
TEMP (°C)			
STANDARD/ACTUAL			

DEVELOPMENT LOG:

DATE	TIME		METHOD	WATER REMOVED (gal)	CUMULATIVE TOTAL REMOVED		WATER CHARACTER CRITERIA						COMMENTS
	BEGIN	FINISH			GAL.	CASING VOLUMES	pH	CONDUCTIVITY	TEMP.(C°)	TURBIDITY		DTW	
7/26		1207						ON SITE				32.55	
	1210	1211	S									32.57	
	1215	1221	B	6	6							40.81	
	1226	1227	S									39.53	
	1228	1233	B	5	11							45.90	BAIL DRY
7/26	1510	1515	B	7	18		START	DTW 36.73				45.90	"
7/30	0915	0926	B	11	29			Bailed Dry				32.29	45.85 End
7/30	1510	1525	B	9	38			Bailed Dry				31.93	45.55 End
7/31	1040	1100	B	10	48			Bailed Dry				32.42	45.08 End
7/31	1345	1355	B	9	57			Bailed Dry				34.10	45.79 End
													Poor recovery

115

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WELL DEVELOPMENT

PRELIMINARY FIELD DRAFT
REVIEW PENDING

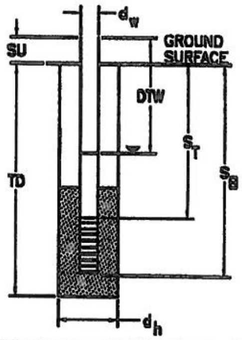
METHOD(S)	PUMP	BAILER	SURGE BLOCK
TYPE	MONSOON	CHECK BALL	SUCTION
MATERIAL	PLASTIC	ST. STEEL	ST. STEEL
DIMENSION	~1.5" x 2"	~3.5" x 5'	~3.5" x 5'
OTHER			

PROJECT: NERT-AWF CAPTURE EVAL.
WELL NO.: PZ-1D
JOB NO.: 1690006943-048
SITE: NERT-AWF
PREPARED BY: GM

DEVELOPMENT CRITERIA: STABLE PARAMETERS / <10 NTUs

DECONTAMINATION METHOD: STEAM / ALCONOX SOLN

HOLE DIAMETER d_h = 8
WELL CASING
INSIDE DIAMETER d_w = 4
CASING STICKUP SU = 2.5
DEPTH TO:
WELL LEVEL DTW = 31.36
BGS [TOP SCREEN $SU+S_T$ = 53
BASE SCREEN $SU+S_B$ = 54
BOTTOM WELL SU+TD = 56.53



CASING VOLUME CALCULATION (USE CONSISTENT UNITS)

$$\text{CASING VOLUME} = V_C = \pi\left(\frac{d_w}{2}\right)^2 (TD-H) = 16.41 \text{ gal}$$

[56.53 - 31.36] × [(2)² × .163]

×10 164.0

FIELD EQUIPMENT CALIBRATIONS

EQUIPMENT MODEL/TYPE	YSI	HACH 2100Q	
SERIAL NO.			
DATE CALIBRATED	7/25/7/30	7/25/7/30	
TEMP (°C)			
STANDARD/ACTUAL			

DEVELOPMENT LOG:

DATE	TIME BEGIN	TIME FINISH	METHOD	WATER REMOVED (gal)	CUMULATIVE TOTAL REMOVED GAL.	CUMULATIVE TOTAL REMOVED CASING VOLUMES	pH	CONDUCTIVITY	TEMP.(C°)	TURBIDITY		DTW	COMMENTS
7/25		1340						ONSITE				31.36	
	1351	1352	S									31.38	
	1356	1403	B	6	6							39.33	
	1412	1413	S									[illegible]	37.92
	1415	1428	B	9	15							55.00	BAILED DRY
7/26	1130	1148	B	21	36		START DTW	31.40				55.30	"
7/26	1449	1500	B	18	54		START DTW	33.33				55.05	"
7/30	0934	1502	P						START PUMP			31.41	
	1012		P	5	59							39.69	~1/4 gal/min
	1042		P	7.5	66.5		7.46	3216	28.39	5.09	~~[illegible]~~	40.91	"
	1112		P	7.5	74	4.6	7.81	2119	28.81	2.10		41.50	"
	1142		P	7.5	81.5	5	7.56	3481	29.15	2.31		41.65	"
	1212		P	7.5	89	5.5	7.84	4762	30.14	1.88		41.65	"
	1242		P	7.5	96.5	5.8	8.01	3277	30.19	1.93		41.66	"
	1312		P	15	111.5	~6	8.22	3031	30.43	1.86		41.66	Bumped ~1/2 gal/min
	1342		P	15	126.5	7	8.41	3012	30.54	1.51		41.80	
	1412		P	15	141.5	8	8.25	3481	30.68	1.33		41.81	
	1442		P	15	156.5	9	8.16	3077	30.71	1.26		41.81	
	1502		P	10	166.5	10	8.34	3043	30.81	1.19		41.81	
												Developed	

105 [illegible]

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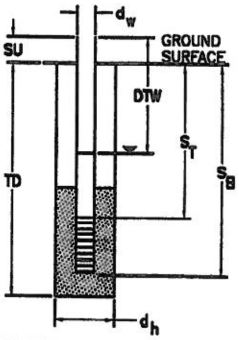
WELL DEVELOPMENT

PRELIMINARY FIELD DRAFT
REVIEW PENDING

METHOD(S)	PUMP	BAILER	SURGE BLOCK
TYPE	MONSOON	CHECK BALL	SUCTION
MATERIAL	PLASTIC	ST. STEEL	ST. STEEL
DIMENSION	~1.5" dia	3.5 x 5'	~5' x 3.5" dia
OTHER			

PROJECT: NERT-AWF CAPTURE EVALUATION
WELL NO.: TRA-2
JOB NO.: 1690006943-048
SITE: NERT-AWF
PREPARED BY: GABE M
DEVELOPMENT CRITERIA: STABLE PARAMETERS – <10 NTU
DECONTAMINATION METHOD: STEAM / ALCONOX SOLN.

HOLE DIAMETER d_h = 8
WELL CASING
INSIDE DIAMETER d_w = 4
CASING STICKUP SU = -.5
DEPTH TO:
WELL LEVEL DTW = 31.70
TOP SCREEN $SU+S_T$ = 27
BASE SCREEN $SU+S_B$ = 37
BOTTOM WELL SU+TD = 36.95



CASING VOLUME CALCULATION (USE CONSISTENT UNITS)
[TD – DTW] x [$(d_w)^2$ x .163]
CASING VOLUME = $V_C = \pi(\frac{d_w}{2})^2$ (TD–H) = 3.42 gal
[36.95 – 31.70] x [$(2)^2$ x .163]
x10 ⇒ 34.23

FIELD EQUIPMENT CALIBRATIONS

EQUIPMENT MODEL/TYPE	YSI	HACH 2100Q	
SERIAL NO.			
DATE CALIBRATED	7/25/~~[illegible]~~	7/25	
TEMP (°C)			
STANDARD/ACTUAL			

DEVELOPMENT LOG:

WATER CHARACTER CRITERIA — PUMP SET 36.80

DATE	TIME BEGIN	TIME FINISH	METHOD	WATER REMOVED (gal)	CUMULATIVE TOTAL REMOVED GAL.	CASING VOLUMES	pH	CONDUCTIVITY	TEMP.(C°)	TURBIDITY		DTW	COMMENTS
7/25	728 ~~738~~	738 ~~751~~	SURGE									31.70	BEFORE SURGE
	[illegible]	[illegible]	B	9	9							31.72	BEFORE BAIL
	757	807	SURGE									31.80	BEFORE S
	815	822	B	9	18							31.72	BEFORE B
	855	859	Pump	6	24		9.31	6.95	27.75	41.7		31.85	
		0903	"	6	30		9.29	6.85	25.9	7.69		31.90	
		0907	"	6	36		9.17	6.77	25.70	4.62		31.90	
		0909	"	3	39		9.10	6.77	25.65	3.30		31.90	
		0911	"	3	42		9.08	6.77	25.60	2.54		31.90	
		STOP	PUMP				WELL DEVELOPED						
7/25												31.72	BEFORE LEAVING

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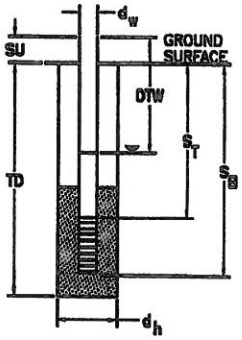
WELL DEVELOPMENT
PRELIMINARY FIELD DRAFT
REVIEW PENDING

METHOD(S)	PUMP	BAILER	SURGE BLOCK
TYPE	MONSOON	CHECKBALL	SUCTION
MATERIAL	PLASTIC	ST. STEEL	ST. STEEL
DIMENSION	~1.5"x2'	~3.5"x5'	~3.5"x5'
OTHER			

PROJECT: NERT-AWF CAPTURE EVAL.
WELL NO.: PZ-2S
JOB NO.: 1690006943-043
SITE: NERT-AWF
PREPARED BY: GM
DEVELOPMENT CRITERIA: STABLE PARAMETERS / <10 NTUS
DECONTAMINATION METHOD: STEAM CLEAN / ALCONOX SOLN.

HOLE DIAMETER d_h= 8
WELL CASING
INSIDE DIAMETER d_w= 4
CASING STICKUP SU= -.5
DEPTH TO:
WELL LEVEL DTW= 33.20
TOP SCREEN $SU+S_T$= 45
BASE SCREEN $SU+S_B$= 4.6
BOTTOM WELL SU+TD= 45.42



CASING VOLUME CALCULATION (USE CONSISTENT UNITS)

CASING VOLUME = $V_C = \pi(\frac{d_w}{2})^2$ (TD−H) = 7.96 gal
(45.42−33.20) x[(2)² x .163] x 10 79.6

FIELD EQUIPMENT CALIBRATIONS

EQUIPMENT MODEL/TYPE	YSI	HACH 2100Q	
SERIAL NO.			
DATE CALIBRATED	7/25/20	7/25/20	
TEMP (°C)			
STANDARD/ACTUAL			

DEVELOPMENT LOG:

DATE	TIME BEGIN	TIME FINISH	METHOD	WATER REMOVED (gal)	CUMULATIVE TOTAL REMOVED GAL.	CASING VOLUMES	pH	CONDUCTIVITY	TEMP.(C°)	TURBIDITY		DTW	COMMENTS
7/26			←					ONSITE		←		33.20	
	0841	0842	S	—								33.20	
	0845	0855	B	6	6							33.40	
	0900	0901	S	—								33.34	
	0905	0915	B	18	24							33.35	
	0940	0944	P	6	30		8.54	9.92	26.01	366		[illegible]	34.45 FINDING
		0948	"	6	36		8.45	9.60	25.85	300		33.65	good pump rate
		0952	"	6	42		8.32	9.76	25.80	290		33.45	
		0958	"	9	51		8.56	9.88	25.62	222		33.45	
		1004	"	9	60		8.95	9.95	25.4	325		33.45	
		1008	"	6	66		8.88	9.95	25.37	96.7		33.45	
		1012	"	6	72		8.92	9.86	25.41	145		33.45	
		1018	"	6	78		8.86	9.94	25.49	237		33.45	
		1022	"	6	84		8.88	9.95	25.51	476		33.45	
		1026	"	3	87		8.90	9.95	25.60	224		33.33	
		1030	"	3	90		8.91	9.95	25.61	181		33.33	
		1034	"	3	93		8.92	9.95	25.62	89.7		33.33	
		1038	"	3	96		8.92	9.95	25.62	123.0		33.33	
		1042	"	3	99		8.90	9.95	25.62	43.2		33.33	
		1046	"	3	102		8.91	9.95	25.60	88.6		33.33	
—							TURB NOT STABLIZING - WELL DEVELOPED						*

RAMBOLL ENVIRON
2200 Powell Street, Suite 700
Emeryville, California 94608
(510) 655-7400
Fax (510) 655-9517

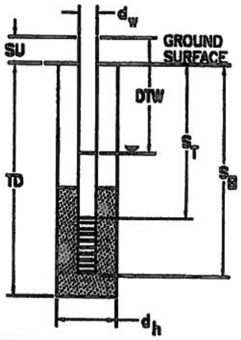
WELL DEVELOPMENT

PRELIMINARY FIELD DRAFT
REVIEW PENDING

METHOD(S)	PUMP	BAILER	SURGE BLOCK
TYPE	MONSOON	CHECK BALL	SUCTION
MATERIAL	PLASTIC	ST. STEEL	ST. STEEL
DIMENSION	~1.5' x 2'	~3.5" x 5'	~3.5" x 5"
OTHER			

PROJECT: NERT-AWF CAPTURE EVAL.
WELL NO.: PZ-2M
JOB NO.: 1690006943-048
SITE: NERT-AWF
PREPARED BY: GM
DEVELOPMENT CRITERIA: STABLE PARAMETERS / <10NTUS
DECONTAMINATION METHOD: STEAM / ALCONOX SOLN

HOLE DIAMETER d_h = 8
WELL CASING
INSIDE DIAMETER d_w = 4
CASING STICKUP SU = -.5"
DEPTH TO:
WELL LEVEL DTW = 33.05
TOP SCREEN $SU+S_T$ = 55
BASE SCREEN $SU+S_B$ = 56
BOTTOM WELL SU+TD = 55.79



CASING VOLUME CALCULATION (USE CONSISTENT UNITS)

$$\text{CASING VOLUME} = V_C = \pi\left(\frac{d_w}{2}\right)^2 (TD-H) = 14.8 \text{ gal}$$

[55.79-33.05] x [(2)² x .163]
148.2

FIELD EQUIPMENT CALIBRATIONS

EQUIPMENT MODEL/TYPE	YSI	HACH 2100Q	
SERIAL NO.			
DATE CALIBRATED	7/25 / 7/30	7/25 / 7/30	
TEMP (°C)			
STANDARD/ACTUAL			

DEVELOPMENT LOG:

DATE	TIME		METHOD	WATER REMOVED (gal)	CUMULATIVE TOTAL REMOVED		WATER CHARACTER CRITERIA						COMMENTS
	BEGIN	FINISH			GAL.	CASING VOLUMES	pH	CONDUCTIVITY	TEMP.(C°)	TURBIDITY		DTW	
7/25		1220	—	—	—	—	ON SITE		—	—	—	33.05	
	1235	1236	S	—	—	—	—	—	—	—	—	32.45	
	1238	1247	B	3	3		—	—	—	—	—	37.29	
	1249	1250	S	—	—	—	—	—	—	—	—	37.00	
	1254	1303	B	11	14	—	—	—	—	—	—	55.12	BAIL DRY
7/25	1304	1314	R	—	—	—	RECOVERED			1.9'		53.22	
7/25	1503	1509	B	9	23	~2	STARTING DTW : 43.07					55.14	BAILED DRY
7/26	0800	0812	B	17	40	3		33.08	STARTING DTW			55.25	"
7/26	1423	1433	B	15	55	4		34.80	"	"		55.08	"
7/30	0815	0831	B	16	71	5	—	Bailed Dry	—	—	DTW @ start	32.93	54.81 Dry
7/30	1540	1548	B	16	87	~6	—	Bailed Dry	—	—		34.14	55.04
7/31	0815		P	—	—	—	—	Initial	—	—		32.99	
7/31	0845		P	15	102	7						36.70	1/2 gal/min
7/31	0915		P	15	117	8	8.08	4523	27.88	6.18		41.10	"
7/31	0945		P	15	132	9	7.91	4476	27.96	4.23		43.95	"
7/31	1015		P	15	147	10	8.12	4518	28.16	3.51		44.31	"
7/31		1020	P	—	—	—	—	—	—	—	—	44.43	" End

DEVELOPED

RAMBOLL ENVIRON

2200 Powell Street, Suite 700
Emeryville, California 94608
(510) 655-7400
Fax (510) 655-9517

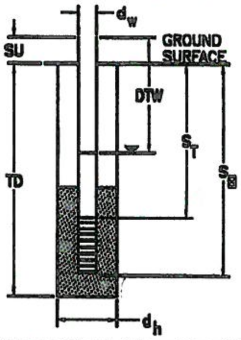
WELL DEVELOPMENT
PRELIMINARY FIELD DRAFT
REVIEW PENDING

Steerpin

METHOD(S)	**PUMP**	**BAILER**	**SURGE BLOCK**
TYPE	MONSOON	CHECK BALL	SUCTION
MATERIAL	PLASTIC	ST. STEEL	ST. STEEL
DIMENSION	~1.5 x 2'	3.5" x 5'	~3.5" x 5'
OTHER			

PROJECT: NERT AWF CAPTURE EVAL.
WELL NO.: PZ-2D
JOB NO.: 1690006943-048
SITE: NERT - AMF
PREPARED BY: GM
DEVELOPMENT CRITERIA: STABLE PARAMETERS / <10 NTU
DECONTAMINATION METHOD: STEAM / ALCONOX SOLN.

HOLE DIAMETER d_h = 8
WELL CASING
INSIDE DIAMETER d_w = 4
CASING STICKUP SU = -.5
DEPTH TO:
WELL LEVEL DTW = 31.82
TOP SCREEN $SU+S_T$ = 75
BASE SCREEN $SU+S_B$ = 76
BOTTOM WELL SU+TD = 75.49



CASING VOLUME CALCULATION (USE CONSISTENT UNITS)

CASING VOLUME = $V_C = \pi(\frac{d_w}{2})^2$ (TD−H) = 28.47 gal
[75.49 − 31.82] × [(2)² × .163]
x10 284.7 gal

FIELD EQUIPMENT CALIBRATIONS

EQUIPMENT MODEL/TYPE	YSI	HACH 2100Q	
SERIAL NO.			
DATE CALIBRATED	7/25/7/30	7/25/7/30	
TEMP (°C)			
STANDARD/ACTUAL			

DEVELOPMENT LOG:

DATE	TIME BEGIN	TIME FINISH	METHOD	WATER REMOVED (gal)	CUMULATIVE TOTAL REMOVED GAL.	CUMULATIVE TOTAL REMOVED CASING VOLUMES	pH	CONDUCTIVITY	TEMP.(C°)	TURBIDITY		DTW	COMMENTS
7/25							ON	SITE	1050			31.82	
	1050	1056	B	3	3							36.13	
	1105	1106	S									35.66	
	1120	1125	B	3	6							43.55	
	1130	1131	S									42.27	
	1137	1154	B	19	25							74.80	ALMOST BAILED DRY
		1204	R				RECOVER					72.50	
		1325	R						~16	in 1:20		58.80	
7/25	1445	1456	B	17	42		DTW @ START		50.15			~~[illegible]~~	74.10 BAILED DRY
7/26	0700	0730	B	32	74			32.00 DTW @		START OF BAIL		74.70	"
7/26	1400	1416	B	27	101			38.42 DTW @		START OF BAIL		74.45	"
7/30	0745	0808	B	33	134		Bailed Dry			DTW @ start		31.20	74.96 End
7/30	1555	1610	B	30	164			Bailed Dry				36.07	74.96 End
7/31	0728	0750	B	35	199			Bailed Dry				32.19	75.50 end
7/31	1155		P									36.10	Set up Pump
7/31	1205		P	5	204	7	7.81	4552	27.82	10.0		39.56	.5 g/min
7/31	1235		P	30	234	8	7.66	4863	27.88	7.41		40.62	.5 g/min
7/31	1305		P	30	264	9	7.72	4721	27.81	4.88		41.43	.5 g/min
7/31	1325	1330	P	20	284	10	7.88	4535	27.90	2.73		42.87	.5 g/min
										DEVELOPED			

ATTACHMENT B-3
U240 FORMS AND SAFETY DATA SHEETS FOR DYE TRACERS

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Bureau of Water Pollution Control - Underground Injection Control Program

901 S. Stewart St Ste 4001 Carson City Nevada 89701

UIC Form U240 – Chemical Use Request

The Nevada Division of Environmental Protection is requiring the following information for any entity seeking approval for chemical use, including chemicals for scale inhibitors, corrosion inhibitors, well rehab or cleaning, cooling towers, water well treatment, etc. (Note: for standard operating procedures using standard industry chemicals approved by Division of Minerals on Class 2 and geothermal wells, this form is not required, however NDEP reserves the right to require for certain situations/chemicals)

1. This form will be returned if all blanks are not completed.
2. Fill out a separate form for each chemical. Attach separate sheets if needed to answer questions.
3. A copy of the approved request shall be maintained in UIC O&M manual or UIC records for as long as the chemical is used.
4. NDEP approval below is only for the action stated on the approved form. Any changes in chemical use, location or amounts must be approved with a new request.

FACILITY AND PERMIT INFORMATION

1) UIC Permit No.: NA

3) City/Valley: Henderson

2) Project/Facility Name: NERT Project (East Galleria Dr & Pabco Rd Area)

4) County: Clark

5) The water this chemical will come in contact with is: ☐ Cooling tower water ☒ Well water ☐ other: ____________________

6) Discuss where the water (in Item #5) will be discharged: Injection well water will discharge into water table.

7) List other chemicals used in this water: None

CHEMICAL INFORMATION – Note: Chemical information shall be submitted to the Division that clearly states the chemical composition (what's in it and at what concentration/mass). If the information is not provided, the Division will not approve this chemical. Proprietary information may be submitted confidentially.

8) Chemical Name: Rhodamine WT

9) Chemical formula: $C_{29}H_{29}N_2O_5Cl_2Na$ or $C_{29}H_{29}ClN_2Na_2O_5$

10) CAS No.: 65392-81-6, 75701-30-3, 528-44-9

11) Manufacturer's name, phone and address: Sensient Colors LLC, 2515 N. Jefferson, 63106 St. Louis, MO Phone: 1 800-325-8110

12) Is the chemical radioactive? ☐ YES ☒ NO Describe:

13) Is a MSDS sheet available for this chemical? ☒ YES ☐ NO If YES, attach Is an Environmental Data Sheet (EDS) available? ☐ YES ☒ NO If YES, attach

14) At working concentration[1], is the chemical hazardous or toxic to humans, livestock, fish, wildlife? If Yes, what entity and at what concentrations?: ☐ YES ☒ NO

15) If water is discharged to surface at any time, has the NV Division of Wildlife been consulted? ☐ YES ☐ NO NA, no surface discharge

CHEMICAL FEED INFORMATION

16) Estimated use start date: November 26, 2018

17) Describe where the chemical is applied to the water: Dye will be placed in injection well TRA-2 along Galleria Drive.

18) Describe how the chemical is applied: Rhodamine WT liquid mixture will be applied via gravity feed into the well.

19) Purpose of chemical: ☐ scale inhibitor ☐ corrosions inhibitor ☐ biocide ☐ algaecide ☐ dispersant ☐ surfactant ☒ Other: Tracer

20) Describe the frequency of application: Single use at one location.

21) What is the feed rate of the chemical as it is fed into the water: Approximately 3 gallons per minute (gravity feed) with a total of approx. 1.7 gallons of dye. A minimum of 5 well volumes (approx. 35 gallons) of clean chase water will follow dye introduction.

Estimated use per month: Once

22) What is the final, effective concentration of chemical mixture immediately prior to application: 220,000 mg/L

23) What is the "working" concentration of chemical after mixing with the water in the cooling tower/well/etc.: 220,000 mg/L and will decrease over time.

24) Is the bulk storage container properly marked with the chemical name and information? ☒ YES ☐ NO

25) Describe the chemical monitoring before and after application: Background samples of groundwater have been collected to evaluate for the presence of dye prior to dye introduction. Sampling of 10 downgradient monitoring wells and 2 downgradient extraction wells will be performed for approximately 24 weeks after dye introduction.

26) Discuss the interaction between the proposed chemicals/additives and chemicals already in use, and the by-products of their interaction:

The dye is not reactive with other substances.

FORM COMPLETION

Print Name of Person Completing Form: Chris Stubbs, Ramboll US Corporation

Signature: Chris Stubbs

Date: 11/14/2018

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1. Working concentration is the chemical concentration within the final water system (e.g. cooling tower system), found under Item 23 above.

NDEP Approval Staff 2 DO NOT WRITE IN THIS SPACE 11/26/2018

Name Title Date

DocuSign Envelope ID: E23FD090-F4B6-4E06-A735-C926EDD9ABF1 f Environmental Protection
Bureau of Water Pollution Control - Underground Injection Control Program
901 S. Stewart St Ste 4001 Carson City Nevada 89701

UIC Form U240 – Chemical Use Request

The Nevada Division of Environmental Protection is requiring the following information for any entity seeking approval for chemical use, including chemicals for scale inhibitors, corrosion inhibitors, well rehab or cleaning, cooling towers, water well treatment, etc. (Note: for standard operating procedures using standard industry chemicals approved by Division of Minerals on Class 2 and geothermal wells, this form is not required, however NDEP reserves the right to require for certain situations/chemicals)

1. This form will be returned if all blanks are not completed.
2. Fill out a separate form for each chemical. Attach separate sheets if needed to answer questions.
3. A copy of the approved request shall be maintained in UIC O&M manual or UIC records for as long as the chemical is used.
4. NDEP approval below is only for the action stated on the approved form. Any changes in chemical use, location or amounts must be approved with a new request.

FACILITY AND PERMIT INFORMATION

1) UIC Permit No.: NA
3) City/Valley: Henderson
2) Project/Facility Name: NERT Project (East Galleria Dr & Pabco Rd Area)
4) County: Clark
5) The water this chemical will come in contact with is: ☐ Cooling tower water ☒ Well water ☐ other: ______
6) Discuss where the water (in Item #5) will be discharged: Injection well water will discharge into water table.
7) List other chemicals used in this water: None

CHEMICAL INFORMATION – Note: Chemical information shall be submitted to the Division that clearly states the chemical composition (what's in it and at what concentration/mass). If the information is not provided, the Division will not approve this chemical. Proprietary information may be submitted confidentially.

8) Chemical Name: Fluorescein
9) Chemical formula: $C20H12O5$
10) CAS No.: 2321-07-5
11) Manufacturer's name, phone and address: Hue Corporation, P.O. Box 509, Tustin, CA 92781 phone: 714-389-3130
12) Is the chemical radioactive? ☐ YES ☒ NO Describe:
13) Is a MSDS sheet available for this chemical? ☒ YES ☐ NO If YES, attach   Is an Environmental Data Sheet (EDS) available? ☐ YES ☒ NO If YES, attach
14) At working concentration[1], is the chemical hazardous or toxic to humans, livestock, fish, wildlife? If Yes, what entity and at what concentrations?: ☐ YES ☒ NO
15) If water is discharged to surface at any time, has the NV Division of Wildlife been consulted? ☐ YES ☐ NO NA, no surface discharge

CHEMICAL FEED INFORMATION

16) Estimated use start date: November 26, 2018
17) Describe where the chemical is applied to the water: Dye will be placed in injection well TRA-1 along Galleria Drive.
18) Describe how the chemical is applied: Fluorescein in powder form will be mixed with 5 gallons of water and gravity fed into the well.
19) Purpose of chemical: ☐ scale inhibitor ☐ corrosions inhibitor ☐ biocide ☐ algaecide ☐ dispersant ☐ surfactant ☒ Other: Tracer
20) Describe the frequency of application: Single use at one location.
21) What is the feed rate of the chemical as it is fed into the water: Approximately 3 gallons per minutes (gravity feed) with a total of approx. 5 gallons of dye. A minimum of 5 well volumes (approx. 35 gallons) of clean chase water will follow dye introduction.
Estimated use per month: Once
22) What is the final, effective concentration of chemical mixture immediately prior to application: 72,000 mg/L
23) What is the "working" concentration of chemical after mixing with the water in the cooling tower/well/etc.: 72,000 mg/L and will decrease over time.
24) Is the bulk storage container properly marked with the chemical name and information? ☒ YES ☐ NO
25) Describe the chemical monitoring before and after application: Background samples of groundwater have been collected to evaluate for the presence of dye prior to dye introduction. Sampling of 10 downgradient monitoring wells and 2 downgradient extraction wells will be performed for approximately 24 weeks after dye introduction.
26) Discuss the interaction between the proposed chemicals/additives and chemicals already in use, and the by-products of their interaction:
The dye is not reactive with other substances but may degrade into CO and/or CO_2

FORM COMPLETION

Print Name of Person Completing Form: Chris Stubbs, Ramboll US Corporation
Signature: Chris Stubbs
Date: 11/14/2018

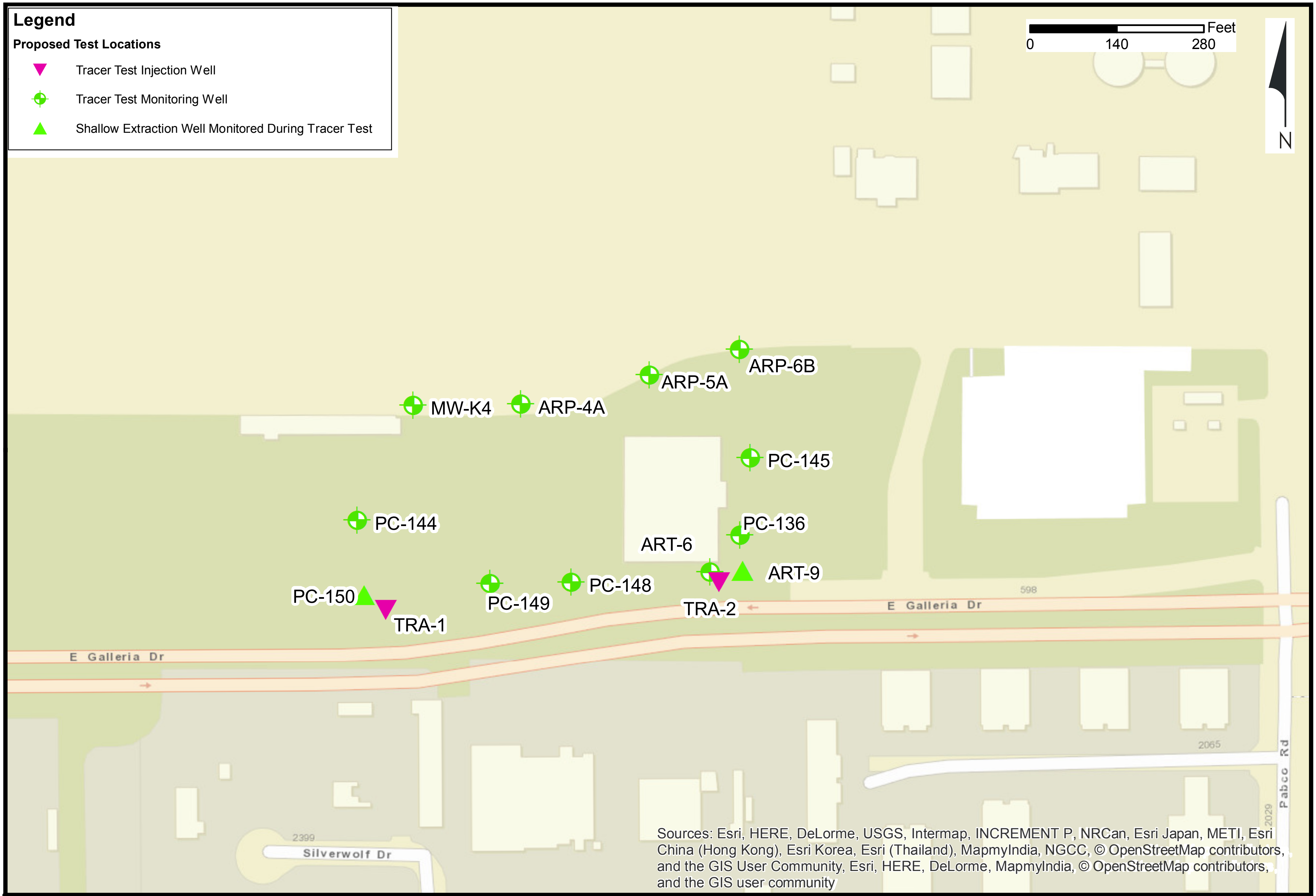
---

[1] Working concentration is the chemical concentration within the final water system (e.g. cooling tower system), found under Item 23 above.

NDEP Approval   Staff 2   DO NOT WRITE IN THIS SPACE   11/26/2018

Name   Title   Date   UIC Form 240

FIGURE



Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community, Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

RAMBOLL

Proposed Tracer Test Study Locations

Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
1

Drafter: JL	Date: 11/14/2018	Contract Number: 21-41400C	Approved:	Revised:

Path: H:\LePetomane\NERT\Modeling\AWF Capture Evaluation-L12\Permits\U240 Form\Figure 1 - Proposed Tracer Test Locations.mxd

ATTACHMENT 1
SAFETY DATA SHEETS

SAFETY DATA SHEET (SDS)
REVISION DATE: 03/03/2016

HUE CORPORATION

Color your everything, may your Hue come true

SECTION I. IDENTIFICATION OF THE SUBSTANCE/MIXTURE AND OF THE COMPANY/UNDERTAKING

PRODUCT IDENTIFIER:

PRODUCT NAME ……………………….. **HUE URANINE CONC** **(Also known as Fluorescein)**
PRODUCT NUMBER ………………… 1-C8-073PC
COLOR INDEX NAME ………………. ACID YELLOW 073
COLOR INDEX NO ……………………. 45350
C. A. S. # ………………………………. 518-47-8
CHEMICAL FAMILY……………………. XANTHENE

INTENDED USE OF THE PRODUCT:

FELT TIP, MARKER INKS, WATER BASED COATINGS AND LEAK DETECTION

NAME, ADDRESS AND TELEPHONE OF RESPONSIBLE PARTY:

HUE CORPORATION	TELEPHONE	714-389-3130
P.O. BOX 509	FAX	714-389-9731
TUSTIN, CA 92781	EMAIL	SUPPORT@HUECORPORATION.COM

EMERGENCY TELEPHONE NUMBER:

CHEMTREC (USA)	1-800-424-9300
CHEMTREC (OUTSIDE USA)	1-703-527-3887

SECTION 2. HAZARD(S) IDENTIFICATION

CLASSIFICATION OF THE SUBSTANCE OR MIXTURE:

GHS-US
ACUTE TOX. - INHALATION (CATEGORY 5)
EYE DAM./IRRITATION (CATEGORY 2B)
SKIN CORR./IRRITATION (CATEGORY 3)

GHS LABELING:

HAZARD PICTOGRAMS (GHS-US):	NO SYMBOL
SIGNAL WORD	WARNING
HAZARD STATEMENT(S)	H333 - MAY BE HARMFUL IF INHALED H320 - CAUSES EYE IRRITATION H316 - CAUSES MILD SKIN IRRITATION
PRECAUTIONARY STATEMENTS	P305 + 351 + P338 - IF IN EYES: RINSE CAUTIOUSLY WITH WATER FOR SEVERAL MINUTES. REMOVE CONTACT LENSES IF PRESENT AND EASY

	TO DO. CONTINUE RINSING. P337 + P313 - IF EYE IRRITATION OCCURS/PERSISTS: GET MEDICAL ADVICE AND ATTENTION. P261 - AVOID BREATHING DUST/FUMES/GAS/MIST/VAPORS/SPRAY P264 - WASH FACE THOROUGHLY AFTER HANDLING. P322 + P313 - IF SKIN IRRITATION OCCURS: GET MEDICAL ADVICE/ ATTENTION. P304 + 312 - IF INHALED: CALL A POISON CENTER/DOCTOR/PHYSICIAN IF YOU FEEL UNWELL
OTHER HAZARDS	NO DATA AVAILABLE
UNKNOWN ACUTE TOXICITY	NO DATA AVAILABLE

SECTION 3. COMPOSITION / INFORMATION ON INGREDIENTS

DESCRIPTION OF MIXTURE: PROPRIETARY MIXTURE OF DYES.

SUBSTANCE:

NAME	C.A.S.#	WEIGHT 100%	GHS-US CLASSIFICATION
ACID YELLOW 073	518-47-8	100%	ACUTE TOX. - INHALATION (CATEGORY 5) EYE DAM./IRRITATION (CATEGORY 2B) SKIN CORR./IRRITATION (CATEGORY 3)

SECTION 4. FIRST AID MEASURES

FIRST AID MEASURES GENERAL:

INHALATION:	REMOVE TO FRESH AIR. IF BREATHING IS DIFFICULT, GIVE OXYGEN AND GET IMMEDIATE MEDICAL ATTENTION.
SKIN:	WASH WITH MILD SOAP AND WATER. IF IRRITATION OCCURS GET MEDICAL ATTENTION. IF CLOTHING IS CONTAMINATED, RE-MOVE AND WASH BEFORE REUSE.
EYES:	FLUSH EYES WITH WATER FOR AT LEAST 15 MINUTES, HOLDING EYELIDS APART FOR THOROUGH IRRIGATION. GET IMMEDIATE MEDICAL ATTENTION.
INGESTION:	INDUCE VOMITING - SEEK IMMEDIATE MEDICAL ATTENTION.

MOST IMPORTANT SYMPTOMS AND EFFECTS, ACUTE AND DELAYED:

THIS PRODUCT IS NOT HAZARDOUS AS DEFINED BY HAZARDOUS COMMUNICATION STANDARD. HOWEVER, AS WITH ALL CHEMICAL; HANDLE WITH CARE, AVOID EYE AND SKIN CONTACT, AVOID INHALATION OF DUSTS OR VAPORS. WASH THOROUGHLY AFTER HANDLING. KEEP CONTAINERS CLOSED.

SECTION 5. FIRE-FIGHTING MEASURES

EXTINGUISHING MEDIA:

WATER, DRY CHEMICAL, CARBON DIOXIDE, FOAM.

SPECIAL HAZARDS ARISING FROM SUBSTANCE OR MEDIA:

FIREFIGHTERS SHOULD BE EQUIPPED WITH SELF-CONTAINED BREATHING APPARATUS TO GUARD AGAINST POTENTIALLY TOXIC AND IRRITATING FUMES. AVOID DUSTING. DUST CAN FORM EXPLOSIVE MIXTURES WITH AIR.

PROTECTION/ADVICE FOR FIREFIGHTER(S):

BE EQUIPPED WITH SELF-CONTAINED BREATHING APPARATUS AND PROTECTIVE CLOTHING.

SECTION 6. ACCIDENTAL RELEASE MEASURES

PERSONAL PRECAUTIONS:

REMOVE PERSONS FROM DANGER AREA.

ENVIROMENTAL PRECAUTIONS:

AVOID ANY UNCONTROLLED RELEASE OF MATERIAL. DO NOT EMPTY INTO DRAINS OR THE AQUATIC ENVIRONMENT.

EMERGENCY PROCEDURES:

NO ADDITIONAL INFORMATION

METHODS AND MATERIALS FOR CONTAMINENT AND CLEANING UP:

WHERE SPILLS ARE POSSIBLE, A COMPREHENSIVE SPILL RESPONSE PLAN SHOULD BE DEVELOPED AND IMPLEMENTED. AVOID ANY UNCONTROLLED RELEASE OF MATERIAL.

UTILIZE RECOMMENDED PROTECTIVE CLOTHING AND EQUIPMENT (SEE SECTION 8).
SPILLS SHOULD BE SWEPT UP USING AN ABSORBENT DUST CONTROL PRODUCT AND PLACED IN CONTAINERS. SPILL AREA CAN BE WASHED WITH WATER. COLLECT WATER FOR APPROVED DISPOSAL.
IN THE EVENT OF UNCONTROLLED RELEASE OF THIS MATERIAL, THE USER SHOULD DETERMINE IF THE RELEASE IS REPORTABLE UNDER APPLICABLE LAWS AND REGULATIONS.

SECTION 7. HANDLING AND STORAGE

PRECAUTIONS FOR SAFE HANDLING:

HANDLE WITH CARE. AVOID OVER EXPOSURE. USE NIOSH/OSHA APPROVED RESPIRATOR, WORK GLOVES, AND CLOTHING. WASH AFTER HANDLING. SENSITIVE INDIVIDUALS MAY EXPERIENCE RESPIRATORY ALLERGIES. MAY CAUSE SKIN IRRITATION. USE WITH LOCAL VENTILATION.

CONDITIONS FOR SAFE STORAGE, INCLUDING ANY INCOMPATIBILITIES:

USE PROCESS ENCLOSURES, LOCAL EXHAUST VENTILATION OR OTHER ENGINEERING CONTROLS TO KEEP AIRBORNE LEVELS BELOW RECOMMENDED EXPOSURE LIMITS.

KEEP AWAY FROM HEAT. KEEP AWAY FROM SOURCES OF IGNITION.

KEEP AWAY FROM STRONG OXIDIZING AND REDUSING AGENTS.

SPECIFIC END USES:

FELT TIP, MARKER INKS, WATER BASED COATINGS AND LEAK DETECTION

SECTION 8. EXPOSURE CONTROLS /PERSONAL PROTECTION

CONTROL PARAMETERS:

INGREDIENTS WITH LIMIT VALUES THAT REQUIRE MONITORING AT THE WORKPLACE - NOT REQUIRED

EXPOSURE CONTROLS:

APPROPRIATE ENGINEERING CONTROLS - THE USUAL PRECAUTIONARY MEASURES ARE TO BE ADHERED TO WHEN HANDLING CHEMICALS.

PERSONAL PROTECTIVE EQUIPMENT:

HAND PROTECTION	WEAR IMPERMEABLE RUBBER OR PLASTIC GLOVES
EYE PROTECTION	TIGHTLY SEALED SAFETY GOGGLES OR FULL FACE SIDE SHIELDS.
SKIN AND BODY	APRON, COVERALLS AND NON-LEATHER SOLED WORK SHOES. WASH DYE CONTAMINATED CLOTHES AND SKIN WITH MILD SOAP AND DETERGENTS.
RESPIRATORY	WEAR OSHA/NIOSH APPROVED DUST MASK/RESPIRATOR
HYGIENE MEASURES	HANDLE IN ACCORDANCE WITH GOOD INDUSTRIAL HYGIENE AND SAFETY PRACTICES. WASH HANDS AFTER HANDLING MATERIAL.
OTHER PROTECTION	DELUGE SAFETY SHOWER AND EYE WASH STATION SHOULD BE LOCATED NEAR WORK AREA.

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

INFORMATION ON BASIC PHYSICAL AND CHEMICAL PROPERTIES :

APPEARANCE, COLOR, ODOR	YELLOW POWDER, NO ODOR
pH	8.0 - 9.0
MELTING POINT/FREEZING POINT	ND
INITIAL BOILING POINT/BOILING RANGE	0.00
FLASHPOINT	NORMALLY STABLE, NOT COMBUSTIBLE NOR FLAMMABLE
EVAPORATION RATE	NO DATA
FLAMMABILITY (SOLID,GAS)	NORMALLY STABLE, NOT COMBUSTIBLE NOR FLAMMABLE
UPPER EXPLOSIVE LIMITS	NA
LOWER EXPLOSIVE LIMITS	NA
VAPOR PRESSURE	NA
VAPOR DENSITY	NA
RELATIVE DENSITY	NA
SOLUBILITY IN WATER	SOLUBLE
PARTITION COEFFICIENT N-OCTANOL/WATER	NO DATA

AUTO-IGNITION TEMPERATURE	NO DATA
DECOMPOSITION TEMPERATURE	NO DATA
VISCOSITY, DYNAMIC	NO DATA
VISCOSITY, CINEMATIC	NO DATA
EXPLOSIVE PROPERTIES	N/A
OXIDIZING PROPERTIES	NA
OTHER INFORMATION	NA

SECTION 10. STABILITY AND REACTIVITY

CHEMICAL STABILITY	STABLE UNDER NORMAL STORAGE AND HANDLING CONDITIONS.
CONDITIONS TO AVOID	OXIDIZING & REDUCING AGENTS MAY DESTROY COLOR.
INCOMPATIBLE MATERIALS	OXIDIZING & REDUCING AGENTS MAY DESTROY COLOR.

HAZARDOUS DECOMPOSITION PRODUCTS - CO, CO2, OXIDES OF NITROGEN AND OTHER POTENTIALLY TOXIC FUMES.

SECTION 11. TOXICOLOGICAL INFORMATION

TOXICOLOGICAL EFFECTS :

ORAL (ANIMAL	GREATER THAN 7,000 MG/KG - RAT
DERMAL (ANIMAL)	NA
EFFECTS TO EYES (ANIMAL)	EYES - RABBIT, NOT IRRITATING
SKIN IRRITATION (ANIMAL)	SKIN - RABBIT, SLIGHT IRRITANT

SKIN CORROSION/IRRITATION	NOT CLASSIFIED
SERIOUS EYE DAMAGE/IRRITATION	CAUSES EYE IRRITATION
RESPIRATORY OR SKIN SENSITIZATION	NOT CLASSIFIED
GERM CELL MUTAGENICITY	NOT CLASSIFIED
CARCINOGENICITY	NOT CLASSIFIED
REPRODUCTIVE TOXICITY	NOT CLASSIFIED
SPECIFIC TARGET ORGAN TOXICITY (SINGLE EXPOSURE)	MAY CAUSE DROWSINESS OR DIZZINESS.
ASPIRATION HAZARD	NOT CLASSIFIED
INHALATION	MAY CAUSE DROWSINESS OR DIZZINESS.
EYE CONTACT	CAUSES SERIOUS EYE IRRITATION.
INGESTION	INGESTION MAY CAUSE NAUSEA, VOMITING AND DIARRHEA

SECTION 12. ECOLOGICAL INFORMATION

TOXICITY	NA
PERSISTENCE AND DEGRADABILITY	NA
BIOACCUMULATIVE POTENTIAL	NA
MOBILITY IN SOIL	LC-50 (LETHAL CONCENTRATION) UG = MICROGRAMS/LITER CHANNEL CATFISH - 2,267,000 UG/LITER RAINBOW TROUT - 1,372,000 UG/LITER BLUEGILL - 3,433,000 UG/LITER
OTHER ADVERSE EFFECTS	NA

SECTION 13. DISPOSAL CONSIDERATION

WASTE DISPOSAL RECOMMENDATION :

EMPTY BAGS THOROUGHLY. CARRY OUT THE PROPER RECYLING, REUSAGE OR DISPOSAL.
PLEASE REFER TO THE RELEVANT EU REGULATIONS, IN PARTICULAR THE GUIDELINES/DECISIONS OF THE COUNCIL REGARDING HANDLING OF WASTES (E.G. 75/442/EEC, 91/689/EEC, 94/67/EC, 94/904/EC) AS IMPLEMENTED IN NATIONAL REGULATIONS.

REGIONAL RECOMMENDATION :

BURY OR INCINERATE ACCORDANCE WITH FEDERAL, STATE AND LOCAL REGULATIONS.

CONTAINERS SHOULD NOT BE REUSED WITHOUT PROFESSIONAL CLEANING AND RECONDITIONING.
OBSERVE ALL LABELED SAFEGUARDS UNTIL CLEANED, RECONDITIONED OR DESTROYED.

PLEASE REFER TO SECTION 8 (EXPOSURE CONTROLS /PERSONAL PROTECTION) OF THIS SDS.

SECTION 14. TRANSPORTATION INFORMATION

UN NUMBER	NONE
UN PROPER SHIPPING NAME	NONE

DEPARTMENT OF TRANSPORTATION (DOT) : NOT HAZARDOUS FOR TRANSPORTATION

TRANSPORT HAZARD CLASS(ES)

HAZARD LABLES (DOT) :

PACKING GROUP (DOT)	NA
DOT SPECIAL PROVISIONS	NA

ADDITIONAL INFORMATION:

OVERLAND TRANSPORT	NONE
TRANSPORT BY SEA	NONE
AIR TRANSPORT	NONE
DOT QUANTITY LIMITATIONS PASSENGER AIRCRAFT	NA
DOT QUANTITY LIMITATIONS CARGO AIRCRAFT	NA

SECTION 15. REGULATORY INFORMATION

US FEDERAL REGULATIONS:

THE SUBSTANCES IS LISTED ON UNITED STATES TSCA (TOXIC SUBSTANCE CONTROL ACT) INVENTORY.

US STATE REGULATIONS:

NONE

CHEMICAL IDENTITY:

518-47-8	TSCA	DSL	NDSL	EINECS	ELINCS	ENCS	CHINA	KECL	PICCS	AICS
	X	-	-	-	-	-	-	-	-	-

TSCA STATUS	IN COMPLIANCE
E C CLASSIFICATION	(67/548/EEC - 88/379/EEC) N/A
EINECS NUMBER	
REACH CLASSIFICATION	
R PHRASES	
ADDITIONAL REGULATORY INFORMATION	

SECTION 16. OTHER INFORMATION

INDICATION OF CHANGES:

NA

OTHER INFORMATION:

NA

GHS FULL TEXT PHRASES:

MAY BE HARMFUL IF INHALED	H333
CAUSES EYE IRRITATION	H320
CASUES MILD SKIN IRRITATION	H316

	HEALTH	FLAMMABILITY	REACTIVITY	PERSONAL PROT
H. M. I. S. CLASSIFICATION:	1	0	0	D

HMIS CODE: **4** - SEVERE HAZARD, **3** - SERIOUS HAZARD, **2** - MODERATE HAZARD, **1** - SLIGHT HAZARD, **0** - MINIMAL HAZARD

SAFETY DATA SHEET (SDS)
REVISION DATE: 03/03/2016

ALL INFORMATION AND DATA APPEARING ON THIS SDS ARE BELIEVED TO BE RELIABLE AND ACCURATE. HOWEVER, IT IS THE USER' S RESPONSIBILITY TO DETERMINE THE SAFETY, TOXICITY, AND SUITABILITY FOR USE OF THE PRODUCT DESCRIBED. SINCE THE ACTUAL USE BY OTHERS IS BEYOND OUR CONTROL, NO GUARANTEE, EXPRESSED OR IMPLIED, IS MADE BY HUE CORPORATION.
USER ASSUMES ALL RISK AND RESPONSIBILITY.

Safety Data Sheet
INTRACID RHODAMINE WT LIQUID

Safety Data Sheet dated: 5/13/2015 - version 1
Date of first edition: 5/13/2015

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1. IDENTIFICATION

Product identifier

Mixture identification:

Trade name: INTRACID RHODAMINE WT LIQUID

Other means of identification:

Trade code: A45171566

Recommended use of the chemical and restrictions on use

Recommended use: Industrial color additive

Restrictions on use: Not Determined

Name, address, and telephone number of the chemical manufacturer, importer, or other responsible party

Sensient Colors LLC
2515 N. Jefferson
63106 St. Louis, MO (USA)
Phone: 1 800-325-8110
Emergency Number(CHEMTREC): 1-800-424-9300

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2. HAZARD(S) IDENTIFICATION

The identity of the individual components of this product is proprietary information and is considered a trade secret pursuant to 29 CFR 1910.1200

Hazardous components as defined in the OSHA Hazard Communication Standard: components with a HEALTH hazard (carcinogens, toxic or highly toxic agents, reproductive toxins, irritants, corrosives, sensitizers, hepatotoxins, nephrotoxins, neurotoxins, etc..) and/or a PHYSICAL hazard (a combustible liquid, a compressed gas, explosive, flammable, an organic peroxide, an oxidizer, pyrophoric, unstable (reactive) or water-reactive, etc.)

⚠

Classification of the chemical

Skin Irrit. 2	Causes skin irritation.
Eye Irrit. 2B	Causes eye irritation

Label elements

Symbols:

⚠

Warning

Code	**Description**
H315	Causes skin irritation.
H320	Causes eye irritation

Code	**Description**
P264	Wash ... Thoroughly after handling.
P280	Wear protective gloves/protective clothing/eye protection/face protection.
P302+P352	IF ON SKIN: Wash with plenty of water/…
P305+P351+P338	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P321	Specific treatment (see ... On this label).
P332+P313	If skin irritation occurs: Get medical advice/attention.
P337+P313	If eye irritation persists: Get medical advice/attention.

P362+P364 Take off contaminated clothing and wash it before reuse.

Ingredient(s) with unknown acute toxicity:

None

Hazards not otherwise classified identified during the classification process:

None

3. COMPOSITION/INFORMATION ON INGREDIENTS

Substances

Not Determined

Mixtures

Hazardous components within the meaning of 29 CFR 1910.1200 and related classification:

List of components

Qty	**Name**	**Ident. Numb.**	**Classification**	**Registration Number**
10-12.5 %	RHODAMINE LIQUID	CAS:65392-81-6 EC:265-730-6	Skin Irrit. 2, H315; Eye Irrit. 2B, H320	
10-12.5 %	RHODAMINE LIQUID	CAS:75701-30-3 EC:278-292-6	Skin Irrit. 2, H315; Eye Irrit. 2B, H320	
1-3 %	TRIMELLITIC ACID	CAS:528-44-9 EC:208-432-3	Skin Irrit. 2, H315; Eye Irrit. 2A, H319; STOT SE 3, H335	

4. FIRST AID MEASURES

Description of first aid measures

In case of skin contact:

Immediately take off all contaminated clothing and shoes.

Immediately remove any contaminated clothing, shoes or stockings.

After contact with skin, wash immediately with soap and plenty of water.

In case of eye contact:

Wash immediately and thoroughly with running water, keeping eyelids regularly raised, for at least 15 minutes. Cold water may be used. Check for and remove any contact lenses at once. OBTAIN A MEDICAL EXAMINATION.

Protect the eyes with a sterile gauze or a clean, dry handkerchief.

In case of ingestion:

Do not induce vomiting, get medical attention showing the MSDS and label hazardous.

In case of inhalation:

Remove casualty to fresh air and keep warm and at rest.

Most important symptoms/effects, acute and delayed

Eye irritation

Eye damages

Skin Irritation

Erythema

Indication of any immediate medical attention and special treatment needed

In case of accident or unwellness, seek medical advice immediately (show directions for use or safety data sheet if possible).

5. FIRE-FIGHTING MEASURES

Extinguishing media

Suitable extinguishing media:

Water, CO2, foam, chemical powders, according to the materials involved in the fire.

In case of fire, use foam, dry chemical, CO2.

Unsuitable extinguishing media:

None in particular.

Specific hazards arising from the chemical

Do not inhale explosion and combustion gases.

Burning produces heavy smoke.

Hazardous combustion products: Not Determined

Explosive properties: Not Determined

Oxidising properties: Not Determined

Special protective equipment and precautions for fire-fighters

Use suitable breathing apparatus .

Collect contaminated fire extinguishing water separately. This must not be discharged into drains.

Move undamaged containers from immediate hazard area if it can be done safely.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions, protective equipment and emergency procedures

Wear personal protection equipment.

Remove persons to safety.

See protective measures under point 7 and 8.

Methods and material for containment and cleaning up

Suitable material for taking up: dry and inert absorbing material (e.g. vermiculite, sand, earth).

Wash with plenty of water.

7. HANDLING AND STORAGE

Precautions for safe handling

Avoid contact with skin and eyes, inhalation of vapours and mists.

Don't use empty container before they have been cleaned.

Before making transfer operations, assure that there aren't any incompatible material residuals in the containers.

Contamined clothing should be changed before entering eating areas.

Do not eat or drink while working.

See also section 8 for recommended protective equipment.

Conditions for safe storage, including any incompatibilities

Storage temperature: Not Determined

Incompatible materials:

None in particular.

Instructions as regards storage premises:

Adequately ventilated premises.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Control parameters

No Data Available

Appropriate engineering controls: Not Determined

Individual protection measures

Eye/face protection:

Use close fitting safety goggles, don't use eye lens.

Skin protection:

Use clothing that provides comprehensive protection to the skin, e.g. cotton, rubber, PVC or viton.

Hand protection:

Use protective gloves that provide comprehensive protection, e.g. P.V.C., neoprene or rubber.

Respiratory protection:

Not Determined

9. PHYSICAL AND CHEMICAL PROPERTIES

Information on basic physical and chemical properties

Physical State Liquid
Appearance: Liquid,
Odour: Not Determined
Odour threshold: Not Determined
pH: 10.50
Melting point/ range: Not Determined
Boiling point/ range: Not Determined
Flash point: > 100°C / 212°F
Evaporation rate: Not Determined
Upper/lower flammability or explosive limits: Not Determined
Vapour density: Not Determined
Vapour pressure: Not Determined
Density: Not Determined
Water solubility: Not Determined
Lipid solubility: Not Determined
Partition coefficient (n-octanol/water): Not Determined
Auto-ignition temperature: Not Determined
Decomposition temperature: Not Determined
Viscosity: Not Determined
Explosive properties: Not Determined
Oxidising properties: Not Determined
Flammability (Solid, Gas): Not Determined

Other information

Substance group relevant properties: Not Determined
Miscibility: Not Determined
Fat Solubility: Not Determined
Conductivity: Not Determined

10. STABILITY AND REACTIVITY

Reactivity

Stable under normal conditions.

Chemical stability

Data not Available.

Possibility of hazardous reactions

Burning produces carbon monoxide and/or carbon dioxide.

Conditions to avoid

Stable under normal conditions of temperature and pressure.

Incompatible materials

Avoid strong oxidizing agents, peroxides, acids, alkali metals.

Hazardous decomposition products

Burning produces carbon monoxide and/or carbon dioxide.

11. TOXICOLOGICAL INFORMATION

Information on toxicological effects

Toxicological information of the product: No Data Available

Substance(s) listed on the IARC Monographs:

None

Substance(s) listed as OSHA Carcinogen(s):

None

Substance(s) listed as NIOSH Carcinogen(s):

None

Substance(s) listed on the NTP report on Carcinogens:

None

12. ECOLOGICAL INFORMATION

Toxicity

Adopt good working practices, so that the product is not released into the environment.
Eco-toxicity:

List of Eco-Toxicological properties of the product

No Data Available

Persistence and degradability

Not Determined

Bioaccumulative potential

Not Determined

Mobility in soil

Not Determined

Other adverse effects

Not Determined

13. DISPOSAL CONSIDERATIONS

Waste treatment methods

Recover if possible. In so doing, comply with the local and national regulations currently in force.

14. TRANSPORT INFORMATION

UN number

ADR-UN number: N/A
DOT-UN Number: N/A
IATA-Un number: N/A
IMDG-Un number: N/A

UN proper shipping name

ADR-Shipping Name: N/A
DOT Proper Shipping Name: N/A
IATA-Technical name: N/A
IMDG-Technical name: N/A

Transport hazard class(es)

ADR-Class: N/A
DOT Hazard Class: N/A
IATA-Class: N/A
IMDG-Class: N/A

Packing group

ADR-Packing Group: N/A
Exempted for ADR: N/A
IATA-Packing group: N/A
IMDG-Packing group: N/A

Environmental hazards

Marine pollutant: No
Environmental Pollutant: Not Determined

Transport in bulk according to Annex II of MARPOL73/78 and the IBC Code

Not Determined

Special precautions

Department of Transportation (DOT):

DOT-Special Provision(s): N/A
DOT Label(s): N/A
DOT Symbol: N/A
DOT Cargo Aircraft: N/A
DOT Passenger Aircraft: N/A
DOT/TDG Bulk: N/A
DOT Non-Bulk: N/A

Road and Rail (ADR-RID):

ADR-Label: N/A
ADR-Upper number: N/A
ADR Tunnel Restriction Code: N/A

Air (IATA):

IATA-Passenger Aircraft: N/A
IATA-Cargo Aircraft: N/A
IATA-Label: N/A
IATA-Sub Risk: N/A
IATA-Erg: N/A
IATA-Special Provisioning: N/A

Sea (IMDG):

IMDG-Stowage Code: N/A
IMDG-Stowage Note: N/A
IMDG-Sub Risk: N/A
IMDG-Special Provisioning: N/A
IMDG-Page: N/A
IMDG-Label: N/A
IMDG-EMS: N/A
IMDG-MFAG: N/A

15. REGULATORY INFORMATION

USA - Federal regulations

TSCA - Toxic Substances Control Act

TSCA inventory:

All the components are listed on the TSCA inventory

TSCA listed substances:

RHODAMINE LIQUID	is listed in TSCA	Section 8b
RHODAMINE LIQUID	is listed in TSCA	Section 8b
TRIMELLITIC ACID	is listed in TSCA	Section 8b, Section 5

SARA - Superfund Amendments and Reauthorization Act

Section 302 - Extremely Hazardous Substances:

no substances listed

Section 304 - Hazardous substances:

no substances listed

Section 313 - Toxic chemical list:

no substances listed

CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act

Substance(s) listed under CERCLA:

no substances listed

CAA - Clean Air Act

CAA listed substances:

no substances listed

CWA - Clean Water Act

CWA listed substances:

no substances listed

USA - State specific regulations

California Proposition 65

Substance(s) listed under California Proposition 65:

no substances listed

Massachusetts Right to know

Substance(s) listed under Massachusetts Right to know:

no substances listed

Pennsylvania Right to know

Substance(s) listed under Pennsylvania Right to know:

no substances listed

New Jersey Right to know

Substance(s) listed under New Jersey Right to know:

no substances listed

16. OTHER INFORMATION

Code	Description
H315	Causes skin irritation.
H319	Causes serious eye irritation.
H320	Causes eye irritation
H335	May cause respiratory irritation.

Safety Data Sheet dated: 5/13/2015 - version 1

The information contained herein is based on our state of knowledge at the above-specified date. It refers solely to the product indicated and constitutes no guarantee of particular quality. The information relates only to the specific material and may not be valid for such material used in combination with any other material or in any process.

This document was prepared by a competent person who has received appropriate training.

It is the duty of the user to ensure that this information is appropriate and complete with respect to the specific use intended.

This MSDS cancels and replaces any preceding release.

Legend to abbreviations and acronyms used in the safety data sheet:

ADR: European Agreement concerning the International Carriage of Dangerous Goods by Road.
RID: Regulation Concerning the International Transport of Dangerous Goods by Rail
IMDG: International Maritime Code for Dangerous Goods
IATA: International Air Transport Association
IATA-DGR: Dangerous Goods Regulation by the "International Air Transport Association" (IATA)
ICAO: International Civil Aviation Organization
ICAO-TI: Technical Instructions by the "International Civil Aviation Organization" (ICAO)

GHS: Globally Harmonized System of Classification and Labeling of Chemicals
CLP: Classification, Labeling, Packaging
EINECS: European Inventory of Existing Commercial Chemical Substances
INCI: International Nomenclature of Cosmetic Ingredients
CAS: Chemical Abstracts Service (division of the American Chemical Society)
GefStoffVO: Ordnance on Hazardous Substances, Germany
LC50: Lethal concentration, for 50 percent of test population
LD50: Lethal dose, for 50 percent of test population
DNEL: Derived No Effect Level
PNEC: Predicted No Effect Concentration
TLV: Threshold Limiting Value
TWATLV: Threshold Limiting Value for the Time Weighted Average 8 hour day.(ACGIH Standard)
STEL: Short Term Exposure limit
STOT: Specific Target Organ Toxicity
WGK: German Water Hazard Class
KSt: Explosion coefficient
y for the damage.

ATTACHMENT B-4
NDEP PERMIT NOTIFICATION

From: Kimberly Schmidt Kuwabara
Sent: Monday, December 3, 2018 1:11 PM
To: Chris Stubbs; Jesse King; Pejman Rasouli
Cc: John Pekala
Subject: FW: NERT - Notification of Upcoming Tracer Study at AWF

With the below response from Nikita

From: Steve Clough <steve.clough@nert-trust.com>
Sent: Monday, December 03, 2018 12:09 PM
To: Kimberly Schmidt Kuwabara <kkuwabara@ramboll.com>
Subject: FW: NERT - Notification of Upcoming Tracer Study at AWF

From: Nikita Lingenfelter [mailto:nlingenfelter@ndep.nv.gov]
Sent: Monday, December 03, 2018 12:08 PM
To: Steve Clough <steve.clough@nert-trust.com>
Subject: RE: NERT - Notification of Upcoming Tracer Study at AWF

Thanks Steve!

From: Steve Clough <steve.clough@nert-trust.com>
Sent: Monday, December 03, 2018 12:06 PM
To: Nikita Lingenfelter <nlingenfelter@ndep.nv.gov>
Cc: Weiquan Dong <wdong@ndep.nv.gov>; James Dotchin <jdotchin@ndep.nv.gov>; James Carlton Parker <jcarltonparker@ndep.nv.gov>; Alan Pineda <alan.pineda@ndep.nv.gov>; Andrew Steinberg <andrew.steinberg@lepetomaneinc.com>; Brian Loffman <brian.loffman@lepetomaneinc.com>; John Pekala <jpekala@ramboll.com>; Kimberly Schmidt Kuwabara <kkuwabara@ramboll.com>
Subject: NERT - Notification of Upcoming Tracer Study at AWF

Nikita,

Pursuant to Section C.5 of NPDES Permit NV0023060, this email serves as notification to the permit issuing authority of introduction of two fluorescent tracer dyes (fluorescein and rhodamine WT) to the groundwater, some of which is anticipated to enter NERT's GWETS system at very low concentrations as part of tracer tests being conducted at the Athens Road Wellfield (AWF). The injection of these two dyes has been approved by BWPC's UIC Program, as shown in the attached signed/approved U240 forms. Both fluorescein and rhodamine WT are commonly used groundwater tracing dyes that have no adverse human or environmental properties; they have both been extensively tested. The amounts of the dyes used for this tracer study are such that it is not anticipated that they will be present in surface water at visually detectable concentrations.

Please let me know if you have any questions regarding this notification. Thanks.

Steve Clough
Remediation Director
Nevada Environmental Response Trust

510 S. Fourth Street
Henderson, NV 89015
Email: steve.clough@nert-trust.com
Office: (702) 960-4309
Cell: (702) 686-9611

ATTACHMENT B-5
OZARK UNDERGROUND LABORATORY ANALYSIS PRODECURES

Ozark
UNDERGROUND
LABORATORY 1572 Aley Lane • Protem, MO 65733 • (417) 785-4289 • fax (417) 785-4290 • contact@ozarkundergroundlab.com

PROCEDURES AND CRITERIA ANALYSIS OF FLUORESCENT DYES IN WATER AND CHARCOAL SAMPLERS:

FLUORESCEIN, EOSINE, RHODAMINE WT, AND SULFORHODAMINE B DYES

Revision Date:
March 3, 2015

Thomas Aley, PHG, PG
President
and
Shiloh L. Beeman, PG
Sr. Hydrogeologist

Ozark Underground Laboratory, Inc.
1572 Aley Lane
Protem, Missouri 65733
417-785-4289
contact@ozarkundergroundlab.com

INTRODUCTION

This document describes standard procedures and criteria currently in use at the Ozark Underground Laboratory (OUL) as of the date shown on the title page. Some samples may be subjected to different procedures and criteria because of unique conditions; such non-standard procedures and criteria are identified in reports for those samples. Standard procedures and criteria change as knowledge and experience increases and as equipment is improved or up-graded. The OUL maintains a summary of changes in standard procedures and criteria.

TRACER DYES AND SAMPLE TYPES

Dye Nomenclature

Dye manufacturers and retailers use a myriad of names for the dyes. This causes confusion among dye users and report readers. The primary dyes used at the OUL and described in this document are included in Table 1 below.

Table 1. Primary OUL Dye Nomenclature.

OUL Common Name	Color Index Number	Color Index Name	Other Names
Fluorescein	45350	Acid Yellow 73	uranine, uranine C, sodium fluorescein, fluorescein LT and fluorescent yellow/green
Eosine	45380	Acid Red 87	eosin, eosine OJ, and D&C Red 22
Rhodamine WT	None assigned	Acid Red 388	fluorescent red (but not the same as rhodamine B)
Sulforhodamine B	45100	Acid Red 52	pontacyl brilliant pink B, lissamine red 4B, and fluoro brilliant pink

The OUL routinely provides dye for tracing projects. Dyes purchased for groundwater tracing are always mixtures that contain both dye and an associated diluent. Diluents enable the manufacturer to standardize the dye mixture so that there are minimal differences among batches. Additionally, diluents are often designed to make it easier to dissolve the dye mixture in water, or to produce a product which meets a particular market need (groundwater tracing is only a tiny fraction of the dye market). The percent of dye in “as-sold” dye mixtures often varies dramatically among manufacturers and retailers, and retailers are sometimes incorrect about the percent of dye in their products. The OUL subjects all of its dyes to strict quality control (QC) testing. Table 2 summarizes the as-sold dye mixtures used by the OUL.

Table 2. As-Sold Dye Mixtures at the OUL.

OUL Common Name	Form	Dye Equivalent
Fluorescein	Powder	75% dye equivalent, 25% diluent
Eosine	Powder	75% dye equivalent, 25% diluent
Rhodamine WT	Liquid	20% dye equivalent, 80% diluent
Sulforhodamine B	Powder	75% dye equivalent, 25% diluent

Analytical results are based on the as-sold weights of the dyes provided by the OUL. The use of dyes from other sources is discouraged due to the wide variability of dye equivalents within the market. However, if alternate source dyes are used, a sample should be provided to the OUL for quality control and to determine if a correction factor is necessary for the analytical results.

Types of Samples

Typical samples that are collected for fluorescent tracer dye analysis include charcoal samplers (also called activated carbon or charcoal packets) and water samples.

The charcoal samplers are packets of fiberglass screening partially filled with 4.25 grams of activated coconut charcoal. The charcoal used by the OUL is Calgon 207C coconut shell carbon, 6 to 12 mesh, or equivalent. The most commonly used charcoal samplers are about 4 inches long by 2 inches wide. A cigar-shaped sampler is made for use in very small diameter wells (such as 1-inch diameter piezometers); this is a special order item and should be specifically requested in advance when needed. All of the samplers are closed by heat sealing.

In specialized projects, soil samples have been collected from soil cores and analyzed for fluorescent tracer dyes. Project-specific procedures have been developed for projects such as these. For additional information, please contact the OUL.

FIELD PROCEDURES

Field procedures included in this section are intended as guidance, and not firm requirements. Placement of samplers and other field procedures require adjustment to field conditions. Personnel at the OUL are available to provide additional assistance for implementation of field procedures specific to specialized field conditions.

Placement of Samplers

Charcoal samplers are placed so as to be exposed to as much water as possible. Water should flow through the packet. In springs and streams they are typically attached to a rock or other anchor in a riffle area. Attachment of the packets often uses plastic tie wires. In swifter water galvanized wire (such as electric fence wire) is often used. Other types of anchoring wire can be used. Electrical wire with plastic insulation is also good. Packets are attached so that they extend outward from the anchor rather than laying flat against it. Two or more separately anchored packets are typically used for sampling springs and streams. The placement of multiple packets is recommended in order to minimize the chance of loss during the sampling period. The use of fewer packets is discouraged except when the spring or stream is so small that there is not appropriate space for placing multiple packets.

When pumping wells are being sampled, the samplers are typically placed in sample holders made of plastic pipe fittings. Brass hose fittings can be at the end of the sample holders so that the sample holders can be installed on outside hose bibs and water which has run through the samplers can be directed to waste through a connected garden hose. The samplers can be unscrewed in the middle so that charcoal packets can be changed. The middle portions of the samplers consist of 1.5 inch diameter pipe and pipe fitting.

Charcoal packets can be lowered into monitoring wells for sampling purposes. In general, if the well is screened, samplers should be placed approximately in the middle of the screened interval. Due to the typically lower volume of water that flows through a well, only one charcoal sampler should be used per well. However, multiple packets can be placed in a single well at depths to test different depth horizons when desirable. A weight should be added near the charcoal packet to ensure that it will not float. The weight should be of such a nature that it will not affect water quality. One common approach is to anchor the packets with a white or uncolored plastic cable tie to the top of a dedicated weighted disposable bailer. We typically run nylon cord from the top of the well to the charcoal packet and its weight. ***Do not use colored cord*** since some of them are colored with fluorescent dyes. Nylon fishing line should not be used since it can be readily cut by a sharp projection in the well.

In some cases, especially with small diameter wells and appreciable well depths, the weighted disposable bailers sink very slowly or may even fail to sink because of friction and floating of the anchoring cord. In such cases a weight may be added to the top of the disposable bailer. Stainless steel weights are ideal, but are not needed in all cases. All weights should be cleaned prior to use; the cleaning approach should comply with decontamination procedures in use at the project site.

Optional Preparation of Charcoal Samplers

Charcoal packets routinely contain some fine powder that washes off rapidly when they are placed in water. While not usually necessary, the following optional preparation step is suggested if the fine charcoal powder is problematic.

Charcoal packets can be triple rinsed with distilled, demineralized, or reagent water known to be free of tracer dyes. This rinsing is typically done by soaking. With this approach, approximately 25 packets are placed in one gallon of water and soaked for at least 10 minutes. The packets are then removed from the water and excess water is shaken off the packets. The packets are then placed in a second gallon of water and again soaked for at least 10 minutes. After this soaking they are removed from the water and excess water is shaken off the packets. The packets are then placed in a third gallon of water and the procedure is again repeated. Rinsed packets are placed in plastic bags and are placed at sampling stations within three days. Packets can also be rinsed in jets of water for about one minute; this requires more water and is typically difficult to do in the field with water known to be free of tracer dyes.

Collection and Replacement of Samplers

Samplers are routinely collected and replaced at each of the sampling stations. The frequency of sampler collection and replacement is determined by the nature of the study. Collections at one week intervals are common, but shorter or longer collection frequencies are acceptable and sometimes more appropriate. Shorter sampling frequencies are often used in the early phases of a study to better characterize time of travel. As an illustration, we often collect and change charcoal packets 1, 2, 4, and 7 days after dye injection. Subsequent sampling is then weekly.

The sampling interval in wells at hazardous wastes sites should generally be no longer than about a week. Contaminants in the water can sometimes use up sorption sites on the charcoal that would otherwise adsorb the dye. This is especially important if the dye might pass in a relatively short duration pulse.

Where convenient, the collected samplers should be briefly rinsed in the water being sampled to remove dirt and accumulated organic material. This is not necessary with well samples. The packets are shaken to remove excess water. Next, the packet (or packets) are placed in a plastic bag (Whirl-Pak® bags are ideal). The bag is labeled on the outside with a black permanent type felt marker pen, such as a Sharpie®. ***Use only pens that have black ink***; colored inks may contain fluorescent dyes. The notations include station name or number and the date and time of collection. Labels must not be inserted inside the sample bags.

Collected samplers are kept in the dark to minimize algal growth on the charcoal prior to analysis work. New charcoal samplers are routinely placed when used charcoal packets are collected. The last set of samplers placed at a stream or spring is commonly not collected.

Water Samples

Water samples are often collected. They should be collected in either glass or plastic; the OUL routinely uses 50 milliliter (mL) research-grade polypropylene copolymer Perfector Scientific vials (Catalog Number 2650) for such water samples. No more than 30 mL of water is required for analysis. The sides of the vials should be labeled with the project name, sample ID, sample date and time with a black permanent felt tip pen. ***Do not label the lid only***. The vials should be placed in the dark and refrigerated immediately after collection, and maintained under refrigeration until shipment. The OUL supplies vials for the collection of water samples.

Sample Shipment

When water or charcoal samplers are collected for shipment to the OUL they should be shipped promptly. We prefer (and in some studies require) that samples be refrigerated with frozen re-usable ice packs upon collection and that they be shipped refrigerated with frozen ice packs by overnight express. ***Do not ship samplers packed in wet ice*** since this can create a potential for cross contamination when the ice melts. Our experience indicates that it is not essential for samplers to be maintained under refrigeration; yet maintaining them under refrigeration clearly minimizes some potential problems. A product known as "green ice" should not be used for maintaining the samples in a refrigerated condition since this product contains a dye which could contaminate samples if the "green ice" container were to break or leak.

We receive good overnight and second day air service from both UPS and FedEx. The U.S. Postal Service does not typically provide next day service to us. DHL does not provide overnight service to us. FedEx is recommended for international shipments. The OUL does not receive Saturday delivery.

Each shipment of charcoal samplers or water samples ***must be accompanied by a sample custody document***. The OUL provides a sheet (which bears the title "Samples for Fluorescence Analysis") that can be used if desired. These sheets can be augmented by a client's chain-of-custody forms or any other relevant documentation. OUL's custody document works well for charcoal samplers because it allows for both the placement date and time as well as the collection date and time. Many other standard chain-of-custody documents do not allow for these types of samples. Attachment 1 includes a copy of OUL's Sample Collection Data Sheet.

Please write legibly on the custody documents and ***use black ink***. Check the accuracy of the sample sheet against the samples prior to shipment to identify and correct errors that may delay the analysis of your samples following receipt at the laboratory.

Supplies Provided by the OUL

The OUL provides supplies for the collection of fluorescent tracer dyes. Supplies provided upon request are charcoal packets, Whirl-Pak® bags (to contain the charcoal packets after collection for shipment to the laboratory), and water vials. These supplies are subjected to strict QA/QC procedures to ensure the materials are free of any potential tracer dye contaminants. The charge for these materials is included in the cost of sample analysis. Upon request, coolers and re-freezable ice packs are also provided for return shipment of samples.

The OUL also has tracer dyes available for purchase. These dyes are subject to strict QA/QC testing. All analytical work is based upon the OUL as-sold weight of the dyes.

LABORATORY PROCEDURES

The following procedures are followed upon receipt of samples at the laboratory.

Receipt of Samples

Samplers shipped to the OUL are logged in and refrigerated upon receipt. Prior to cleaning and analysis, samplers are assigned a laboratory identification number.

It sometimes occurs that there are discrepancies between the sample collection data sheet and the actual samples received. When this occurs, a "Discrepancy Sheet" form is completed and sent to the shipper of the sample for resolution. The purpose of the form is to help resolve discrepancies, even when they may be minor. Many discrepancies arise from illegible custody documents. ***Please write legibly*** on the custody documents and ***use black ink***. Check the accuracy of the sample sheet against the samples prior to shipment to identify and correct errors that may delay the analysis of your samples following receipt at the laboratory.

Cleaning of Charcoal Samplers

Samplers are cleaned by spraying them with jets of clean water from a laboratory well in a carbonate aquifer. OUL uses non-chlorinated water for the cleansing to minimize dye deterioration. We do not wash samplers in public water supplies. Effective cleansing cannot generally be accomplished simply by washing in a conventional laboratory sink even if the sink is equipped with a spray unit.

The duration of packet washing depends upon the condition of the sampler. Very clean samplers may require less than a minute of washing; dirtier samplers may require several minutes of washing.

Elution of the Charcoal

There are various eluting solutions that can be used for the recovery of tracer dyes. The solutions typically include an alcohol, water, and a strong basic solution such as aqueous ammonia and /or potassium hydroxide.

The standard elution solution used at the OUL is a mixture of 5% aqua ammonia and 95% isopropyl alcohol solution and sufficient potassium hydroxide pellets to saturate the solution. The isopropyl alcohol solution is 70% alcohol and 30% water. The aqua ammonia solution is 29% ammonia. The potassium hydroxide is added until a super-saturated layer is visible in the bottom of the container. This super-saturated layer is not used for elution. Preparation of eluting solutions uses dedicated glassware which is never used in contact with dyes or dye solutions.

The eluting solution will elute fluorescein, eosine, rhodamine WT, and sulforhodamine B dyes. It is also suitable for separating fluorescein peaks from peaks of some naturally present materials found in may be found in samplers.

Fifteen mL of the eluting solution is poured over the washed charcoal in a disposable sample beaker. The sample beaker is capped. The sample is allowed to stand for 60 minutes. After this time, the liquid is carefully poured off the charcoal into a new disposable beaker which has been appropriately labeled with the laboratory identification number. A few grains of charcoal may inadvertently pass into the second beaker; no attempt is made to remove these from the second sample beaker. After the pouring, a small amount of the elutant will remain in the initial sample beaker. After the transfer of the elutant to the second sample beaker, the contents of the first sample beaker (the eluted charcoal) are discarded. Samples are kept refrigerated until analyzed.

pH Adjustment of Water Samples

The fluorescence intensity of several of the commonly used fluorescent tracer dyes is pH dependent. The pH of samples analyzed for fluorescein, eosine, and sulforhodamine B dyes are adjust to a target pH of greater than 9.5 in order to obtain maximum fluorescence intensities.

Adjustment of pH is achieved by placing samples in a high ammonia atmosphere for at least two hours in order to increase the pH of the sample. Reagent water standards are placed in the same atmosphere as the samples. If dye concentrations in a sample are off-scale and require dilution for quantification of the dye concentration, the diluting water used is OUL reagent water that has been pH adjusted in a high ammonia atmosphere. Samples that are only analyzed for rhodamine WT or sulforhodamine B are not required to be pH adjusted.

Analysis on the Shimadzu RF-5301

The OUL uses a Shimadzu spectrofluorophotometer model RF-5301. This instrument is capable of synchronous scanning. The OUL also owns a Shimadzu RF-540 spectrofluorometers that is occasionally used for special purposes.

A sample of the elutant or water is withdrawn from the sample container using a disposable polyethylene pipette. Approximately 3 mL of the sample is then placed in disposable rectangular polystyrene cuvette. The cuvette has a maximum capacity of 3.5 mL. The cuvette is designed for fluorometric analysis; all four sides and the bottom are clear. The acceptable spectral range of these cuvettes is 340 to 800 nm. The pipettes and cuvettes are discarded after one use.

The cuvette is then placed in the RF-5301. This instrument is controlled by a programmable computer and operated by proprietary software developed for dye tracing applications.

Our instruments are operated and maintained in accordance with the manufacturer's recommendations. On-site installation of our first instrument and a training session on its use was provided by the instrument supplier. Repairs are made by a Shimadzu-authorized repairman.

Our typical analysis of an elutant sample where fluorescein, eosine, rhodamine WT, or sulforhodamine B dyes may be present includes synchronous scanning of excitation and emission spectra with a 17 nm separation between excitation and emission wavelengths. For these dyes, the excitation scan is from 443 to 613 nm; the emission scan is from 460 to 630 nm. The emission fluorescence from the scan is plotted on a graph. The typical scan speed setting is “fast” on the RF-5301. The typical sensitivity setting used is "high."

Table 3. Excitation and emission slit width settings routinely used for dye analysis.

Parameter	**Excitation Slit (nm)**	**Emission Slit (nm)**
ES, FL, RWT, and SRB in elutant	3	1.5
ES, FL, RWT, and SRB in water	5	3

Note: ES = Eosine. FL = Fluorescein. RWT = Rhodamine WT. SRB = Sulforhodamine B.

The instrument produces a plot of the synchronous scan for each sample; the plot shows emission fluorescence only. The synchronous scans are subjected to computer peak picks using proprietary software; peaks are picked to the nearest 0.1 nm. Instrument operators have the ability to manually adjust peaks as necessary based upon computer-picked peaks and experience. All samples run on the RF-5301 are stored electronically with sample information. All samples analyzed are recorded in a bound journal.

Quantification

We calculate the magnitude of fluorescence peaks for fluorescein, eosine, rhodamine WT, and sulforhodamine B dyes in both elutant and water samples. Dye quantities are expressed in microgram per liter (parts per billion; ppb). The dye concentrations are calculated by separating fluorescence peaks due to dyes from background fluorescence on the charts, and then calculating the area within the fluorescence peak. This area is proportional to areas obtained from standard solutions.

We run dye concentration standards each day the RF-5301 is used. Six standards are used; the standard or standards appropriate for the analysis work being conducted are selected. All standards are based upon the as-sold weights of the dyes. The standards are as follows:

1) 10 ppb fluorescein and 100 ppb rhodamine WT in well water from the Jefferson City-Cotter Formation
2) 10 ppb eosine in well water from the Jefferson City-Cotter Formation
3) 100 ppb sulforhodamine B in well water from the Jefferson City-Cotter Formation.
4) 10 ppb fluorescein and 100 ppb rhodamine WT in elutant.
5) 10 ppb eosine in elutant.
6) 100 ppb sulforhodamine B in elutant.

Preparation of Standards

Dye standards are prepared as follows:

Step 1. A small sample of the as-sold dye is placed in a pre-weighed sample vial and the vial is again weighed to determine the weight of the dye. We attempt to use a sample weighing between 1 and 5 grams. This sample is then diluted with well water to make a 1% dye solution by weight (based upon the as-sold weight of the dye). The resulting dye solution is allowed to sit for at least four hours to ensure that all dye is fully dissolved.

Step 2. One part of each dye solution from Step 1 is placed in a mixing container with 99 parts of well water. Separate mixtures are made for fluorescein, rhodamine WT, eosine, and sulforhodamine B. The resulting solutions contain 100 mg/L dye (100 parts per million dye mixture). The typical prepared volume of this mixture is appropriate for the sample bottles being used; we commonly prepare about 50 mL of the Step 2 solutions. The dye solution from Step 1 that is used in making the Step 2 solution is withdrawn with a digital Finnpipette which is capable of measuring volumes between 0.200 and 1.000 mL at intervals of 0.005 mL. The calibration certificate with this instrument indicates that the accuracy (in percent) is as follows:

At 0.200 mL, 0.90%
At 0.300 mL, 0.28%
At 1.000 mL, 0.30%

The Step 2 solution is called the long term standard. OUL experience indicates that Step 2 solutions, if kept refrigerated, will not deteriorate appreciably over periods of less than a year. Furthermore, these Step 2 solutions may last substantially longer than one year.

Step 3. A series of intermediate-term dye solutions are made. Approximately 45 mL. of each intermediate-term dye solution is made. All volume measurements of less than 5 mL are made with a digital Finnpipette. (see description in Step 2). All other volume measurements are made with Rheinland Kohn Geprufte Sicherheit 50 mL capacity pump dispenser which will pump within plus or minus 1% of the set value. The following solutions are made; all concentrations are based on the as-sold weight of the dyes:

1) 1 ppm fluorescein dye and 10 ppm rhodamine WT dye.
2) 1 ppm eosine.
3) 10 ppm sulforhodamine B dye.

Step 4. A series of six short-term dye standards are made from solutions in Step 3. These standards were identified earlier in this section. In the experience of the OUL these standards have a useful shelf life in excess of one week. However, in practice, Step 4 elutant standards are made weekly, and Step 4 water standards are made daily.

Dilution of Samples

Samples with peaks that have arbitrary fluorescence unit values of 500 or more are diluted a hundred fold to ensure accurate quantification.

Some water samples have high turbidity or color which interferes with accurate detection and measurement of dye concentrations. It is often possible to dilute these samples and then measure the dye concentration in the diluted sample.

The typical dilutions are either 10 fold (1:10) or 100 fold (1:100). A 1:10 dilution involves combining one part of the test sample with 9 parts of water (if the sample is water) or elutant (if the sample is elutant). A 1:100 dilution involves combining one part of the test sample is combined with 99 parts of water or elutant, based upon the sample media. Typically, 0.300 mL of the test solution is combined with 29.700 mL of water (or elutant as appropriate) to yield a new test solution.

All volume measurements of less than 5 mL are made with a digital Finnpipette. All other volume measurements are made with Rheinland Kohn Geprufte Sicherheit 50 mL capacity pump dispenser which will pump within plus or minus 1% of the set value.

The water used for dilution is from a carbonate aquifer. All dilution water is pH adjusted to greater than pH 9.5 by holding it in open containers in a high ammonia concentration chamber. This adjustment takes a minimum of two hours.

Quality Control

Laboratory blanks are run for every sample where the last two digits of the laboratory numbers are 00, 20, 40, 60, or 80. A charcoal packet is placed in a pumping well sampler and at least 25 gallons of unchlorinated water is passed through the sampler at a rate of about 2.5 gallons per minute. The sampler is then subjected to the same analytical protocol as all other samplers.

System functioning tests of the analytical instruments are conducted in accordance with the manufacturer's recommendations. Spiked samples are also analyzed when appropriate for quality control purposes.

All materials used in sampling and analysis work are routinely analyzed for the presence of any compounds that might create fluorescence peaks in or near the acceptable wavelength ranges for any of the tracer dyes. This testing includes approximately 1% of materials used.

Project specific QA/QC samples may include sample replicates and sample duplicates. A replicate sample is when a single sample is analyzed twice. A sample duplicate is where two samples are collected in a single location and both are analyzed. Sampe replicates and duplicates are run for QA/QC purposes upon request of the client. These results are reported in the Certificate of Analysis.

Reports

Sample analysis results are typically reported in a Certificate of Analysis. However, specialized reports are provided in accordance with the needs of the client. Certificates of Analysis typically provide a listing of station number, sample ID, and dye concentrations if detected. Standard data format includes deliverables in MS Excel and Adobe Acrobat (.pdf) format. Hard copy of the data package, and copies of the analytical charts are available upon request.

Work at the OUL is directed by Mr. Thomas Aley. Mr. Aley has 45 years of professional experience in hydrology and hydrogeology. He is certified as a Professional Hydrogeologist (Certificate #179) by the American Institute of Hydrology and licensed as a Professional Geologist in Arkansas, Arkansas, Kentucky, and Alabama. Additional details regarding laboratory qualifications are available upon request.

Waste Disposal

All laboratory wastes are disposed of according to applicable state and federal regulations. Waste elutant and water samples are collected in 15 gallon poly drums and disposed with a certified waste disposal facilityas non-hazardous waste.

In special cases, wastes for a particular project may be segregated and returned to the client upon completion of the project. These projects may have samples that contain contaminants that the client must account for all materials generated and disposed. These situations are managed on a case-by-case basis.

CRITERIA FOR DETERMINATION OF POSITIVE DYE RECOVERIES

Normal Emission Ranges and Detection Limits

The OUL has established normal emission fluorescence wavelength ranges for each of the four dyes described in this document. The normal acceptable range equals mean values plus and minus two standard deviations. These values are derived from actual groundwater tracing studies conducted by the OUL.

The detection limits are based upon concentrations of dye necessary to produce emission fluorescence peaks where the signal to noise ratio is 3. The detection limits are realistic for most field studies since they are based upon results from actual field samples rather than being based upon values from spiked samples in a matrix of reagent water or the elutants from unused activated carbon samplers. In some cases detection limits may be smaller than reported if the water being sampled has very little fluorescent material in it. In some cases detection limits may be greater than reported; this most commonly occurs if the sample is turbid due to suspended material or a coloring agent such as tannic compounds. Turbid samples are typically allowed to settle, centrifuged, or, if these steps are not effective, diluted prior to analysis.

Table 4 provides normal emission wavelength ranges and detection limits for the four dyes when analyzed on the OUL's RF-5301.

Table 4. RF-5301 Spectrofluorophotometer. Normal emission wavelength ranges and detection limits for fluorescein, eosine, rhodamine WT, and sulforhodamine B dyes in water and elutant samples.

Fluorescent Dye	**Normal Acceptable Emission Wavelength Range (nm)**		**Detection Limit (ppb)**	
	Elutant	**Water**	**Elutant**	**Water**
Eosine	539.3 to 545.1	532.5 to 537.0	0.050	0.015
Fluorescein	514.1 to 519.2	505.9 to 509.7	0.025	0.002
Rhodamine WT	564.6 to 571.2	571.9 to 577.2	0.170	0.015
Sulforhodamine B	575.2 to 582.0	580.1 to 583.7	0.080	0.008

Note: Detection limits are based upon the as-sold weight of the dye mixtures normally used by the OUL.
Fluorescein and eosine detection limits in water are based on samples pH adjusted to greater than 9.5.

It is important to note that the normal acceptable emission wavelength ranges are subject to change based on instrument maintenance, a change in instrumentation, or slight changes in dye formulation. Significant changes in normal acceptable emission wavelength ranges will be updated in this document as they occur.

Fluorescence Background

Due to the nature of fluorescence analysis, it is important to identify and characterize any potential background fluorescence at dye introduction and monitoring locations prior to the introduction of any tracer dyes.

There is generally little or no detectable fluorescence background in or near the general range of eosine, rhodamine WT, and sulforhodamine B dyes encountered in most groundwater tracing studies. There is often some fluorescence background in or near the range of fluorescein dye present at some of the stations used in groundwater tracing studies.

Criteria for Determining Dye Recoveries

The following sections identify normal criteria used by the OUL for determining dye recoveries. The primary instrument in use is a Shimadzu RF-5301.

EOSINE

Normal Criteria Used by the OUL for Determining Eosine Dye Recoveries in Elutants from Charcoal Samplers

Criterion 1. There must be at least one fluorescence peak in the range of 539.3 to 545.1 nm in the sample.

Criterion 2. The dye concentration associated with the fluorescence peak must be at least 3 times the detection limit. The eosine detection limit in elutant samples is 0.050 ppb, thus this dye concentration limit equals 0.150 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Criterion 4. The shape of the fluorescence peak must be typical of eosine. Much background fluorescence yields low, broad, and asymmetrical fluorescence peaks rather than the more narrow and symmetrical fluorescence peaks typical of eosine. In addition, there must be no other factors which suggest that the fluorescence peak may not be eosine dye from our groundwater tracing work.

Normal Criteria Used by the OUL for Determining Eosine Dye Recoveries in Water Samples

Criterion 1. In most cases, the associated charcoal samplers for the station should also contain eosine dye in accordance with the criteria listed above. This criterion may be waived if no charcoal sampler exists.

Criterion 2. There must be no factors which suggest that the fluorescence peak may not be eosine dye from our groundwater tracing work. The fluorescence peak should generally be in the range of 532.5 to 537.0 nm.

Criterion 3. The dye concentration associated with the fluorescence peak must be at least three times the detection limit. Our eosine detection limit in water samples is 0.015 ppb, thus this dye concentration limit equals 0.045 ppb.

Criterion 4. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

FLUORESCEIN

Normal Criteria Used by the OUL for Determining Fluorescein Dye Recoveries in Elutants from Charcoal Samplers

Criterion 1. There must be at least one fluorescence peak in the range of 514.1 to 519.2 nm in the sample.

Criterion 2. The dye concentration associated with the fluorescence peak must be at least 3 times the detection limit. The fluorescein detection limit in elutant samples is 0.025 ppb, thus this dye concentration limit equals 0.075 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Criterion 4. The shape of the fluorescence peak must be typical of fluorescein. Much background fluorescence yields low, broad, and asymmetrical fluorescence peaks rather than the more narrow and symmetrical fluorescence peaks typical of fluorescein. In addition, there must be no other factors which suggest that the fluorescence peak may not be fluorescein dye from our groundwater tracing work.

Normal Criteria Used by the OUL for Determining Fluorescein Dye Recoveries in Water Samples

Criterion 1. In most cases, the associated charcoal samplers for the station should also contain fluorescein dye in accordance with the criteria listed above. This criterion may be waived if no charcoal sampler exists.

Criterion 2. There must be no factors which suggest that the fluorescence peak may not be fluorescein dye from our groundwater tracing work. The fluorescence peak should generally be in the range of 505.9 to 509.7 nm.

Criterion 3. The dye concentration associated with the fluorescence peak must be at least three times the detection limit. Our fluorescein detection limit in water samples is 0.002 ppb, thus this dye concentration limit equals 0.006 ppb.

Criterion 4. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

RHODAMINE WT

Normal Criteria Used by the OUL for Determining Rhodamine WT Dye Recoveries in Elutants from Charcoal Samplers

Criterion 1. There must be at least one fluorescence peak in the sample in the range of 564.6 to 571.2 nm.

Criterion 2. The dye concentration associated with the rhodamine WT peak must be at least 3 times the detection limit. The detection limit in elutant samples is 0.170 ppb, thus this dye concentration limit equals 0.510 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Criterion 4. The shape of the fluorescence peak must be typical of rhodamine WT. In addition, there must be no other factors which suggest that the fluorescence peak may not be dye from the groundwater tracing work under investigation.

Normal Criteria Used by the OUL for Determining Rhodamine WT Dye Recoveries in Water Samples

Criterion 1. In most cases, the associated charcoal samplers for the station should also contain rhodamine WT dye in accordance with the criteria listed above. These criteria may be waived if no charcoal sampler exists.

Criterion 2. There must be no factors which suggest that the fluorescence peak may not be rhodamine WT dye from the tracing work under investigation. The fluorescence peak should generally be in the range of 571.9 to 577.2 nm.

Criterion 3. The dye concentration associated with the fluorescence peak must be at least three times the detection limit. Our rhodamine WT detection limit in water samples is 0.015 ppb, thus this dye concentration limit is 0.045 ppb.

Criterion 4. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

SULFORHODAMINE B

Normal Criteria Used by the OUL for Determining Sulforhodamine B Dye Recoveries in Elutants from Charcoal Samplers

Criterion 1. There must be at least one fluorescence peak in the sample in the range of 575.2 to 582.0 nm.

Criterion 2. The dye concentration associated with the sulforhodamine B peak must be at least 3 times the detection limit. The detection limit in elutant samples is 0.080 ppb, thus this dye concentration limit equals 0.240 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Criterion 4. The shape of the fluorescence peak must be typical of sulforhodamine B. In addition, there must be no other factors which suggest that the fluorescence peak may not be dye from the groundwater tracing work under investigation.

Normal Criteria Used by the OUL for Determining Sulforhodamine B dye Recoveries in Water Samples

Criterion 1. In most cases, the associated charcoal samplers for the station should also contain sulforhodamine B dye in accordance with the criteria listed earlier. This criterion may be waived if no charcoal sampler exists.

Criterion 2. There must be no factors which suggest that the fluorescence peak may not be sulforhodamine B dye from the tracing work under investigation. The fluorescence peak should generally be in the range of 580.1 to 583.7 nm.

Criterion 3. The dye concentration associated with the fluorescence peak must be at least three times the detection limit. The detection limit in water is 0.008 ppb, thus this dye concentration limit equals 0.024 ppb.

Criterion 4. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Standard Footnotes

Sometimes not all the criteria are met for a straight forward determination of tracer dye in a sample. For these reasons, the emission graph is scrutinized carefully by the analytical technician and again during the QA/QC process. Sometimes the emission graphs require interpretation as to whether or not a fluorescence peak represents the tracer dye or not. Background samples from each of the sampling stations aid in the interpretation of the emission fluorescence graphs. When the results do not meet all the criteria for a positive dye detection, often the fluorescence peak is quantified and flagged with a footnote to the result as not meeting all the criteria for a positive dye detection. Standard footnotes are as follows:

Single asterisk (*): A fluorescence peak is present that does not meet all the criteria for a positive dye recovery. However, it has been calculated as though it were the tracer dye.

Double asterisk (**): A fluorescence peak is present that does not meet all the criteria for this dye. However, it has been calculated as a positive dye recovery.

Other footnotes specific to the fluorescence signature are sometimes also used. These footnotes are often developed for a specific project.

The quantification of fluorescence peaks that do not meet all the criteria for a positive dye detection can be important for interpretation of the dataset as a whole.

ATTACHMENT 1
Sample Collection Data Sheet

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 fax (417) 785-4290 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project ________________________________ **Week No:** ___ **Samples Collected By:** ________________________________

Samples Shipped By: ________________________________ **Samples Received By:** ________________________________

Date Samples Shipped: ______________ **Date Samples Received:** ______________ **Time Samples Received:** ___________ **Return Cooler? Yes** ☐ **No** ☐

Bill to: ________________________________ **Send Results to:** ________________________________

Analyze for: ☐ **Fluorescein** ☐ **Eosine** ☐ **Rhodamine WT** ☐ **Other** ________________ **Ship cooler to:** ________________________________

OUL use only		***Please indicate stations where dye was visible in the field*** *for field technician use - use black ink only*						*OUL use only*
# CHAR REC'D	**LAB NUMBER**	**STATION NUMBER 1-4 Numbers**	**STATION NAME**	**PLACED**		**COLLECTED**		**# WATER REC'D**
				DATE	**TIME**	**DATE**	**TIME**	

COMMENTS ____

____

This sheet filled out by OUL staff? Yes ☐ **No** ☐ **Charts for samples on this page proofed by OUL:** ________________________________

OUL Project No. _______ **Date Analyzed:** ________________ **Analyzed By:** ________________________________

Page ___ of ____

ATTACHMENT B-6
OZARK LABORATORY REPORTS

Ozark
UNDERGROUND
LABORATORY 1572 Aley Lane • Protem, MO 65733 • (417) 785-4289 • fax (417) 785-4290 • contact@ozarkundergroundlab.com

Certificate of Analysis

Date of certificate: October 18, 2018

Client: Ramboll

Project name: AWF Capture Study

Project number: 1690006943-048

Contact people: cstubbs@ramboll.com
prasouli@ramboll.com
lackerman@ramboll.com

Samples collected by: J. King

Date samples shipped: October 12, 2018

Date samples rec'd at OUL: October 15, 2018

Date analyzed by OUL: October 17, 2018

Included with certificate of analysis:
Table of results and copy of sample collection data sheet

Results for charcoal samplers analyzed for the presence of fluorescein and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D2465	1	CH-MWK4-20181012	10/5/18 1225	10/12/18 1235	ND		ND	
D2466	2	CH-PC-144-20181012	10/5/18 1314	10/12/18 1253	ND		ND	
D2467	6	CH-ARP-6B-20181012	10/5/18 1340	10/12/18 1318	ND		ND	
D2468	7	CH-PC-145-20181012	10/5/18 1422	10/12/18 1336	ND		ND	
D2469	8	CH-PC-136-20181012	10/5/18 1453	10/12/18 1350	ND		ND	
D2470	9	CH-ART-6-20181012	10/5/18 1529	10/12/18 1416	ND		ND	
D2471	11	CH-TRA-2-20181012	10/5/18 1553	10/12/18 1433	ND		ND	
D2472	4	CH-TRA-1-20181012	10/5/18 1609	10/12/18 1446	ND		ND	

Note: Dye concentrations are based upon standards used at the OUL. The standard concentrations are based upon the as sold weight of the dye that the OUL uses. If the client is not using OUL dyes, the client should provide the OUL with a sample of the dye to compare to the OUL dyes.

Footnotes:

ND = No dye detected

Thomas J. Aley, PHG and RG

F:\docs\COA\Ramboll_AWF Capture Study_01

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 fax (417) 785-4290 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project AWF Capture Study Week No: 1 Samples Collected By: J. King

Samples Shipped By: J. King Samples Received By: C. Aley / OUL

Date Samples Shipped: 10/12/18 Date Samples Received: 10-15-18 Time Samples Received: 1400 Return Cooler? Yes ☒ No ☐

Bill to: 1690006443-048 Send Results to: cstubbs@ramboll.com, prasouli@ramboll, Lackerman@Ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other ______ Ship cooler to: ____

OUL use only		***Please indicate stations where dye was visible in the field*** *for field technician use - use black ink only*						OUL use only
# CHAR REC'D	LAB NUMBER Charcoal	STATION NUMBER 1-4 Numbers	STATION NAME	PLACED		COLLECTED		# WATER REC'D
				DATE	TIME	DATE	TIME	
1	D2465	1	CH-MWK4-20181012	10/5/18	1225	10/12/18	1235	*
*		1	GW-MWK4-20181012		—		1238	1
1	D2466	2	CH-PC-144-20181012		1314		1253	*
*		2	GW-PC-144-20181012		—		1256	1
1	D2467	6	CH-ARP-6B-20181012		1340		1318	*
*		6	GW-ARP-6B-20181012		—		1321	1
1	D2468	7	CH-PC-145-20181012		1422		1336	*
*		7	GW-PC-145-20181012		—		1340	1
1	D2469	8	CH-PC-136-20181012		1453		1350	*
*		8	GW-PC-136-20181012		—		1352	1
1	D2470	9	CH-ART-6-20181012		1529		1416	*
*		9	GW-ART-6-20181012		—		1419	1
1	D2471	11	CH-TRA-2-20181012		1553		1433	*
*		11	GW-TRA-2-20181012		—		1435	1
1	D2472	4	CH-TRA-1-20181012		1609		1446	*

* Station, water + Charcoal Samples, listed separately on COC.

This sheet filled out by OUL staff? Yes ☐ No ☒ Charts for samples on this page proofed by OUL: AC/OUL

OUL Project No. 1745 Date Analyzed: 10/17/18 Analyzed By: ME/OUL

Page 1 of 1 OUL

Relinquished by ______ time date - 1600 10/12/18

Ozark UNDERGROUND LABORATORY 1572 Aley Lane • Protem, MO 65733 • (417) 785-4289 • fax (417) 785-4290 • contact@ozarkundergroundlab.com

Certificate of Analysis

Date of certificate: October 24, 2018
Client: Ramboll
Project name: AWF Capture Study
Project number: 1690006943-048
Contact people: cstubbs@ramboll.com
prasouli@ramboll.com
lackerman@ramboll.com

Samples collected by: J. King
Date samples shipped: October 19, 2018
Date samples rec'd at OUL: October 22, 2018
Date analyzed by OUL: October 23, 2018
Included with certificate of analysis:
Table of results and copy of sample collection data sheets

Results for charcoal samplers analyzed for the presence of fluorescein and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D2566	1	CH-MW-K4-20181019	10/12/18 1243	10/19/18 1235	ND		ND	
D2567	2	CH-PC-144-20181019	10/12/18 1306	10/19/18 1246	ND		ND	
D2568	6	CH-ARP-6B-20181019	10/12/18 1324	10/19/18 1257	ND		ND	
D2569	7	CH-PC-145-20181019	10/12/18 1343	10/19/18 1308	ND		ND	
D2570	8	CH-PC-136-20181019	10/12/18 1358	10/19/18 1323	ND		ND	
D2571	8	CH-PC-136-20181019-FD	10/12/18 1358	10/19/18 1324	ND		ND	
D2572	9	CH-ART-6-20181019	10/12/18 1423	10/19/18 1339	ND		ND	
D2573	11	CH-TRA-2-20181019	10/12/18 1553	10/19/18 1433	ND		ND	
D2574	4	CH-TRA-1-20181019	10/12/18 1452	10/19/18 1406	ND		ND	

Note: Dye concentrations are based upon standards used at the OUL. The standard concentrations are based upon the as sold weight of the dye that the OUL uses. If the client is not using OUL dyes, the client should provide the OUL with a sample of the dye to compare to the OUL dyes.

Footnotes:

ND = No dye detected

Thomas Aley

Thomas J. Aley, PHG and RG

OZARK UNDERGROUND LABORATORY, INC.
1572 Aley Lane Protem, MO 65733 (417) 785-4289 fax (417) 785-4290 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project AWF Capture Study **Week No:** ___ **Samples Collected By:** J. King
Samples Shipped By: J. King **Samples Received By:** M. Rickinger - OUL
Date Samples Shipped: 10/19/18 **Date Samples Received:** 10/22/18 **Time Samples Received:** 1400 **Return Cooler?** Yes ☐ No ☒
Bill to: 1690006943-048 **Send Results to:** CStubbs@ramboll.com; prasouli@ramboll.com; LAckerman@ramboll.com
Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other ________ **Ship cooler to:** ___

OUL use only		Please indicate stations where dye was visible in the field for field technician use - use black ink only						OUL use only
# CHAR REC'D	LAB NUMBER Charcoal	STATION NUMBER 1-4 Numbers	STATION NAME	PLACED		COLLECTED		# WATER REC'D
				DATE	TIME	DATE	TIME	
1	D2566	1	CH - MW - K4 - 20181019	10/12	1243	10/19	1235	*
*	—	1	GW - MW - K4 - 20181019		—		1238	1
1	D2567	2	CH - PC-144 - 20181019		1306		1246	*
*	—	2	GW - PC-144 - 20181019		—		1248	1
1	D2568	6	CH - ARP-6B - 20181019		1324		1257	*
*	—	6	GW - ARP-6B - 20181019		—		1300	1
1	D2569	7	CH - PC-145 - 20181019		1343		1308	*
*	—	7	GW - PC-145 - 20181019		—		1311	1
1	D2570	8	CH - PC-136 - 20181019		1358		1323	*
*	—	8	GW - PC-136 - 20181019		—		1326	1
1	D2571	8	CH - PC-136 - 20181019 - FD		1358		1324	*
*	—	8	GW - PC-136 - 20181019 - FD		—		1327	1
1	D2572	9	CH - ART-6 - 20181019		1423		1339	*
*	—	9	GW - ART-6 - 20181099	↓	—	↓	1343	1

COMMENTS ____

This sheet filled out by OUL staff? Yes ☐ No ☒ **Charts for samples on this page proofed by OUL:** AC/OUL
OUL Project No. 1745 **Date Analyzed:** 10/23/18 **Analyzed By:** Lisa Gilcrease/OUL

Page 1 of 2 OUL

OZARK UNDERGROUND LABORATORY, INC.
1572 Aley Lane Protem, MO 65733 (417) 785-4289 fax (417) 785-4290 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project AWF Capture Study **Week No:** ___ **Samples Collected By:** ________

Samples Shipped By: ________ **Samples Received By:** M. Riclinger - OUL

Date Samples Shipped: ________ **Date Samples Received:** 10-22-18 **Time Samples Received:** 1400 **Return Cooler?** Yes ☐ No ☐

Bill to: 1690006943-048 **Send Results to:** ________

Analyze for: ☐ Fluorescein ☐ Eosine ☐ Rhodamine WT ☐ Other ________ **Ship cooler to:** ___

Please indicate stations where dye was visible in the field
for field technician use - use black ink only

OUL use only								*OUL use only*
# CHAR REC'D	**LAB NUMBER** Charcoal	**STATION NUMBER 1-4 Numbers**	**STATION NAME**	**PLACED**		**COLLECTED**		**# WATER REC'D**
				DATE	**TIME**	**DATE**	**TIME**	
1	D2573	11	CH - TRA-2 - 20181019	10/12	1553	10/19	1433	*
*	—	11	GW - TRA-2 - 20181019	↓	—	10/19	1435	1
1	D2574	4	CH - TRA-1 - 20181019		1452	10/19	1406	*
*	—	4	GW - TRA-1 - 20181019		—	10/19	—	0

COMMENTS No water sample for GW-TRA-1-20181019

This sheet filled out by OUL staff? Yes ☐ No ☒ **Charts for samples on this page proofed by OUL:** PR/OUL

OUL Project No. 1745 **Date Analyzed:** 10/23/18 **Analyzed By:** Lisa Gilcrease

Page 2 of 2 OUL

Relinquished by:

Date/time: 10/19/18 1530

Ozark UNDERGROUND LABORATORY 1572 Aley Lane • Protem, MO 65733 • (417) 785-4289 • fax (417) 785-4290 • contact@ozarkundergroundlab.com

Certificate of Analysis

Date of certificate: November 9, 2018

Client: Ramboll

Project name: AWF Capture Study

Project number: 1690006943-048

Contact people: cstubbs@ramboll.com
prasouli@ramboll.com
lackerman@ramboll.com

Samples collected by: J. King and G. Mclette

Date samples shipped: November 6, 2018

Date samples rec'd at OUL: November 7, 2018

Date analyzed by OUL: November 9, 2018

Included with certificate of analysis:
Table of results and copy of sample collection data sheet

Results for charcoal samplers analyzed for the presence of fluorescein and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D3010	3	PC-150	10/30/18 1130	11/6/18 0930	ND		ND	
D3011	5	PC-149	10/30/18 1200	11/6/18 1010	ND		ND	
D3012	15	PC-148	10/30/18 1225	11/6/18 1015	ND		ND	
D3013	12	ART-4A	10/30/18 1240	11/6/18 0950	ND		ND	
D3014	16	ART-7A	10/30/18 1304	11/6/18 1030	ND		ND	
D3015	10	ART-9	10/30/18 1415	11/6/18 1040	ND		ND	
D3016	14	ARP-5A	10/30/18 1435	11/6/18 1050	ND		ND	
D3017	13	ARP-4A	10/30/18 1455	11/6/18 1105	ND		ND	

Note: Dye concentrations are based upon standards used at the OUL. The standard concentrations are based upon the as sold weight of the dye that the OUL uses. If the client is not using OUL dyes, the client should provide the OUL with a sample of the dye to compare to the OUL dyes.

Footnotes:

ND = No dye detected

Thomas J. Aley, PHG and RG

Thomas Aley

F:\docs\COA\Ramboll_AWF Capture Study_03

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 fax (417) 785-4290 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project AWF Trace Test 1690006443-C4 Week No: 1 Samples Collected By: J. Kiernan / G. Mickette

Samples Shipped By: G. Mickette Fed Ex Samples Received By: KC/OUL

Date Samples Shipped: 11/6/18 Date Samples Received: 11/7/2018 Time Samples Received: 1445 Return Cooler? Yes ☐ No ☐

Bill to: Send Results to:

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other Ship cooler to:

OUL use only		***Please indicate stations where dye was visible in the field*** *for field technician use - use black ink only*						*OUL use only*
# CHAR REC'D	LAB NUMBER Charcoal	STATION NUMBER 1-4 Numbers	STATION NAME	PLACED		COLLECTED		# WATER REC'D
				DATE	TIME	DATE	TIME	
1	D3010	3	PC-150	10/30/18	1130	11/6/18	0930	0
1	D3011	5	PC-149	10/30/18	1200	11/6/18	1010	1
1	D3012	15	PC-148	10/30/18	1225	11/6/18	1015	1
1	D3013	12	ABT-4A	10/30/18	1240	11/6/18	0950	1
1	D3014	16	ABT-7A	10/30/18	1304	11/6/18	1030	1
1	D3015	10	ABT-9	10/30/18	1415	11/6/18	1040	1
1	D3016	14	ABP-5A	10/30/18	1435	11/6/18	1050	1
1	D3017	13	ABP-4A	10/30/18	1455	11/6/18	1105	1

COMMENTS

This sheet filled out by OUL staff? Yes ☐ No ☒ Charts for samples on this page proofed by OUL: AC/OUL

OUL Project No. 1745 Date Analyzed: 11/9/2018 Analyzed By: KC/OUL

Page 1 of 1 /OUL

Ozark
UNDERGROUND
LABORATORY 1572 Aley Lane • Protem, MO 65733 • (417) 785-4289 • fax (417) 785-4290 • contact@ozarkundergroundlab.com

Certificate of Analysis

Date of certificate: November 27, 2018
Client: Ramboll
Project name: AWF Capture Study
Project number: 1690006943-048
Contact people: cstubbs@ramboll.com
prasouli@ramboll.com
lackerman@ramboll.com

Samples collected by: G. Mclette
Date samples shipped: November 13, 2018
Date samples rec'd at OUL: November 16, 2018
Date analyzed by OUL: November 26, 2018
Included with certificate of analysis:
Table of results, copy of sample collection data sheet and discrepancy sheet

Results for charcoal samplers analyzed for the presence of fluorescein and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D3195	3	PC-150	11/6/18 0930	11/13/18 1355	ND		ND	
D3196	12	ART-4A	11/6/18 0950	11/13/18 1410	ND		ND	
D3197	5	PC-149	11/6/18 1010	11/13/18 1425	ND		ND	
D3198	15	PC-148	11/6/18 1015	11/13/18 1435	ND		ND	
D3199	16	APT-7A	11/6/18 1030	11/13/18 1500	ND		ND	
D3200	Laboratory control charcoal blank							
D3201	10	ART-9	11/6/18 1040	11/13/18 1515	ND		ND	
D3202	14	ARP-5A	11/6/18 1050	11/13/18 1540	ND		ND	
D3203	13	ARP-4A	11/6/18 1105	11/13/18 1555	ND		ND	

Note: Dye concentrations are based upon standards used at the OUL. The standard concentrations are based upon the as sold weight of the dye that the OUL uses. If the client is not using OUL dyes, the client should provide the OUL with a sample of the dye to compare to the OUL dyes.

Footnotes:

ND = No dye detected

Thomas J. Aley, PHG and RG Thomas Aley

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 fax (417) 785-4290 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project AWF TRACER TEST 1690006943-048 **Week No:** 2 **Samples Collected By:** G. MICLETTE

Samples Shipped By: G. MICLETTE **Samples Received By:** C. Aley / OUL

Date Samples Shipped: 11/13/18 **Date Samples Received:** 11-16-18 **Time Samples Received:** 1415 **Return Cooler?** Yes ☐ No ☐

Bill to: Ramboll c/o OUL **Send Results to:**

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other ______ **Ship cooler to:**

OUL *use only*		***Please indicate stations where dye was visible in the field*** *for field technician use - use black ink only*						*OUL use only*
# CHAR REC'D	**LAB NUMBER** Charcoal	**STATION NUMBER 1-4 Numbers**	**STATION NAME**	**PLACED**		**COLLECTED**		**# WATER REC'D**
				DATE	**TIME**	**DATE**	**TIME**	
1	D3195	3	PC-150	11/6/18	0930	11/13/18	1355	0
1	D3196	12	ART-4A	↓	0950	↓	1410	1
1	D3197	5	PC-149	↓	1010	↓	1425	1
1	D3198	15	PC-148	↓	1015	↓	1435	1
1	D3199	16	APT-7A	↓	1030	↓	1500	1
1	D3201	10	~~ART-9A~~ ART-9	↓	1040	↓	1515	1
1	D3202	14	ARP-5A	↓	1050	↓	1540	1
1	D3203	13	ARP-4A	11/6/18	1105	11/13/18	1555	1

COMMENTS OUL Charcoal Blank D3200

This sheet filled out by OUL staff? Yes ☐ No ☒ **Charts for samples on this page proofed by OUL:** CA

OUL Project No. 1745 **Date Analyzed:** 11/26/2018 **Analyzed By:** KC/OUL

Page 1 of 1 OUL

OZARK UNDERGROUND LABORATORY, INC.

DISCREPANCIES BETWEEN CHAIN-OF-CUSTODY SHEETS AND ACTUAL SAMPLES RECEIVED Page 1 of 1

Company & Project Name: Ramboll / AWF Tracer Test **Date Rec'd by OUL:** 11-16-18 **Wk #** 2

Lab #	Sta #	Station Name	Date Pulled	Problem	Solution
		PC -149	11/13 1425	Water sample vial was cracked.	·OUL transferred sample to a new vial and labeled with information from old vial.

Comments: No discrepancies

Ozark UNDERGROUND LABORATORY 1572 Aley Lane • Protem, MO 65733 • (417) 785-4289 • fax (417) 785-4290 • contact@ozarkundergroundlab.com

Certificate of Analysis

Date of certificate: December 13, 2018

Client: Ramboll

Project name: Athens Well Field Capture Study

Project number: 1690006943-048

Contact people: Chris Stubbs (cstubbs@ramboll.com)
Pejman Rasouli (prasouli@ramboll.com)
Lisa Ackerman (lackerman@ramboll.com)
emeryvillelabdata@ramboll.com

Samples collected by: J. King

Date samples shipped: December 6, 2018

Date samples rec'd at OUL: December 7, 2018

Date analyzed by OUL: December 12, 2018

Included with certificate of analysis:
Table of results, copy of sample collection data sheet and discrepancy sheet

Results for charcoal samplers analyzed for the presence of fluorescein and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D3717	1	MW-K4	12/5/18 1016	12/6/18 1457	ND		ND	
D3718	2	PC-144	12/5/18 1045	12/6/18 1505	ND		ND	
D3719	13	ARP-4A	11/6/18 1105	12/5/18 1510	ND		ND	
D3720	Laboratory control charcoal blank							
D3721	14	ARP-5A	11/6/18 1050	12/5/18 1532	ND		ND	
D3722	6	ARP-6B	12/5/18 1053	12/6/18 1513	ND		ND	
D3723	7	PC-145	12/5/18 1113	12/6/18 1521	ND		ND	
D3724	8	PC-136	12/5/18 1126	12/6/18 1528	ND		ND	
D3725	9	ART-6	12/5/18 1132	12/6/18 1538	ND		ND	
D3726	10	ART-9	11/6/18 1040	12/5/18 1544	ND		568.3	88.3
D3727	16	ART-7A	11/6/18 1030	12/5/18 1550	ND		ND	
D3728	15	PC-148	11/6/18 1015	12/5/18 1605	ND		ND	

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D3729	5	PC-149	11/6/18 1010	12/5/18 1611	ND		ND	
D3730	3	PC-150	11/6/18 0930	12/5/18 1621	514.8	0.353	ND	
D3731	12	ART-4A	11/6/18 0950	12/5/18 1637	ND		ND	

Note: Dye concentrations are based upon standards used at the OUL. The standard concentrations are based upon the as sold weight of the dye that the OUL uses. If the client is not using OUL dyes, the client should provide the OUL with a sample of the dye to compare to the OUL dyes.

Footnotes:

ND = No dye detected

Thomas J. Aley, PHG and RG

Thomas Aley

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 0 **Samples Collected By:** J. King

Samples Shipped By: FedEx **Samples Received By:** Amber Comstock/OUL

Date Samples Shipped: 12/6/18 **Date Samples Received:** 12/7/18 **Time Samples Received:** 1400 **Return Cooler? Yes** ☐ **No** ☒

Bill to: Ramboll - per contract **Send Results to:**

Analyze for: ☒ **Fluorescein** ☐ **Eosine** ☒ **Rhodamine WT** ☐ **Other** **Ship cooler to:** N/A

OUL use only			***Please indicate stations where dye was visible in the field***						OUL use only
# CHAR REC'D	LAB NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1	D3717	1	MW-K4		12-5-18	1016	12-6-18	1457	1
1	D3718	2	PC-144		12-5-18	1045	12-6-18	1505	1
1	D3719	13	ARP-4A	No water sample	11-6-18	1105	12-5-18	1510	0
1	D3721	14	ARP-5A		11-6-18	1050	12-5-18	1532	1
1	D3722	6	ARP-6B		12-5-18	1053	12-6-18	1513	1
1	D3723	7	PC-145		12-5-18	1113	12-6-18	1521	1
1	D3724	8	PC-136		12-5-18	1126	12-6-18	1528	1
1	D3725	9	ART-6		12-5-18	1132	12-6-18	1538	1
1	D3726	10	ART-9	No water sample	11-6-18	1040	12-5-18	1544	0
1	D3727	16	ART-7A		11-6-18	1030	12-5-18	1550	1
1	D3728	15	PC-148		11-6-18	1015	12-5-18	1605	1
1	D3729	5	PC-149		11-6-18	1010	12-5-18	1611	1
1	D3730	3	PC-150	No water sample	11-6-18	0930	12-5-18	1621	0
1	D3731	12	ART-4A		11-6-18	0950	12-5-18	1637	1

COMMENTS Analyze per standard protocol D3720 = OUL charcoal blank

This sheet filled out by OUL staff? Yes ☒ **No** ☐ **Charts for samples on this page proofed by OUL:** AC/OUL

OUL Project No. 1745 **Date Analyzed:** 12/12/18 **Analyzed By:** Lisa Gilcrease

Relinquished by: 12/6/18 1700

Page 1 of 1

AC/OUL

OZARK UNDERGROUND LABORATORY, INC.

DISCREPANCIES BETWEEN CHAIN-OF-CUSTODY SHEETS AND ACTUAL SAMPLES RECEIVED Page 1 of 1

Company & Project Name: Ramboll / AWF-NERT **Date Rec'd by OUL:** 12/7/18 **Wk #** 0

Lab #	Sta #	Station Name	Date Pulled	Problem	Solution

Comments: No dates or times on samples.

Ozark UNDERGROUND LABORATORY 1572 Aley Lane • Protem, MO 65733 • (417) 785-4289 • fax (417) 785-4290 • contact@ozarkundergroundlab.com

Certificate of Analysis

Date of certificate: December 18, 2018

Client: Ramboll

Project name: Athens Well Field Capture Study

Project number: 1690006943-048

Contact people: Chris Stubbs (cstubbs@ramboll.com)
Pejman Rasouli (prasouli@ramboll.com)
Lisa Ackerman (lackerman@ramboll.com)
emeryvillelabdata@ramboll.com

Samples collected by: J. King

Date samples shipped: December 10, 2018

Date samples rec'd at OUL: December 11, 2018

Date analyzed by OUL: December 17, 2018

Included with certificate of analysis:
Table of results, copies of sample collection data sheet

Results for charcoal and water samples analyzed for the presence of fluorescein and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

All results are for charcoal unless otherwise indicated.

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D3809	1	MW-K4	12/6/18 1459	12/10/18 0851	ND		ND	
D3810	2	PC-144	12/6/18 1507	12/10/18 0900	ND		ND	
D3811	13	ARP-4A	12/5/18 1519	12/10/18 0910	ND		ND	
D3812	14	ARP-5A	12/5/18 1534	12/10/18 0920	ND		ND	
D3813	6	ARP-6B	12/6/18 1515	12/10/18 0929	ND		ND	
D3814	7	PC-145	12/6/18 1523	12/10/18 0938	ND		ND	
D3815	8	PC-136	12/6/18 1530	12/10/18 0945	ND		ND	
D3816	9	ART-6	12/6/18 1540	12/10/18 0953	ND		ND	
D3817	10	ART-9	12/5/18 1547	12/10/18 1014	ND		569.8	33.5
D3818	16	ART-7A	12/5/18 1554	12/10/18 1030	ND		ND	
D3819	15	PC-148	12/5/18 1606	12/10/18 1039	ND		ND	

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D3820	Laboratory control charcoal blank							
D3821	5	PC-149	12/5/18 1614	12/10/18 1047	ND		ND	
D3822	3	PC-150	12/5/18 1631	12/10/18 1106	ND		ND	
D3823	12	ART-4A	12/5/18 1639	12/10/18 1119	ND		ND	
D3904	10	ART-9	**Water**	12/10/18 1014	ND		573.8	490

Note: Dye concentrations are based upon standards used at the OUL. The standard concentrations are based upon the as sold weight of the dye that the OUL uses. If the client is not using OUL dyes, the client should provide the OUL with a sample of the dye to compare to the OUL dyes.

Footnotes:

ND = No dye detected

Thomas J. Aley, PHG and RG

Thomas Aley

OZARK UNDERGROUND LABORATORY, INC.
1572 Aley Lane Protem, MO 65733 (417) 785-4289 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 1 **Samples Collected By:** J. King

Samples Shipped By: FedEx **Samples Received By:** KC/OUL

Date Samples Shipped: 12/10/18 **Date Samples Received:** 12/11/2018 **Time Samples Received:** 1200 **Return Cooler?** Yes ☐ No ☒

Bill to: Ramboll - per contract **Send Results to:** CStubbs@ramboll.com, prasouli@ramboll.com, jdKing@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other ______ **Ship cooler to:** N/A

OUL use only			*Please indicate stations where dye was visible in the field*						*OUL use only*
# CHAR REC'D	LAB NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1	D3809	1	MW-K4		12-6-18	1459	12-10-18	0851	1
1	D3810	2	PC-144		12-6-18	1507	12-10-18	0900	1
1	D3811	13	ARP-4A	No Water Sample	12-5-18	1519	12-10-18	0910	0
1	D3812	14	ARP-5A		12-5-18	1534	12-10-18	0920	1
1	D3813	6	ARP-6B		12-6-18	1515	12-10-18	0929	1
1	D3814	7	PC-145		12-6-18	1523	12-10-18	0938	1
1	D3815	8	PC-136		12-6-18	1530	12-10-18	0945	1
1	D3816	9	ART-6		12-6-18	1540	12-10-18	0953	1
1	D3817	10	ART-9		12-5-18	1547	12-10-18	1014	1
1	D3818	16	ART-7A		12-5-18	1554	12-10-18	1030	1
1	D3819	15	PC-148		12-5-18	1606	12-10-18	1039	1
1	D3821	5	PC-149		12-5-18	1614	12-10-18	1047	1
1	D3822	3	PC-150	No water sample	12-5-18	1631	12-10-18	1106	0
1	D3823	12	ART-4A		12-5-18	1639	12-10-18	1119	1

COMMENTS Analyze per standard protocol D3820 = OUL charcoal blank

This sheet filled out by OUL staff? Yes ☒ No ☐ **Charts for samples on this page proofed by OUL:** CA

OUL Project No. 1745 **Date Analyzed:** 12-17-18 **Analyzed By:** MR/OUL

Page 1 of 1/OUL

Relinquished By: 12/10/18 1400

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SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 1 **Samples Collected By:** J. King

Samples Shipped By: FedEx **Samples Received By:** KC/OUL

Date Samples Shipped: 12/10/18 **Date Samples Received:** 12/11/2018 **Time Samples Received:** 1200 **Return Cooler?** Yes ☐ No ☒

Bill to: Ramboll - per contract **Send Results to:** CStubbs@ramboll.com, prasauli@ramboll.com, jdKing@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other ______ **Ship cooler to:** N/A

OUL use only			*Please indicate stations where dye was visible in the field*						*OUL use only*
# CHAR REC'D	LAB NUMBER Water	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1		1	MW-K4		12-6-18	1459	12-10-18	0851	1
1		2	PC-144		12-6-18	1507	12-10-18	0900	1
1		13	ARP-4A	No Water Sample	12-5-18	1519	12-10-18	0910	0
1		14	ARP-5A		12-5-18	1534	12-10-18	0920	1
1		6	ARP-6B		12-6-18	1515	12-10-18	0929	1
1		7	PC-145		12-6-18	1523	12-10-18	0938	1
1		8	PC-136		12-6-18	1530	12-10-18	0945	1
1		9	ART-6		12-6-18	1540	12-10-18	0953	1
1	D3904	10	ART-9		12-5-18	1547	12-10-18	1014	1
1		16	ART-7A		12-5-18	1554	12-10-18	1030	1
1		15	PC-148		12-5-18	1606	12-10-18	1039	1
1		5	PC-149		12-5-18	1614	12-10-18	1047	1
1		3	PC-150	No water sample	12-5-18	1631	12-10-18	1106	0
1		12	ART-4A		12-5-18	1639	12-10-18	1119	1

COMMENTS Analyze per standard protocol

This sheet filled out by OUL staff? Yes ☒ No ☐ **Charts for samples on this page proofed by OUL:** ca

OUL Project No. 1745 **Date Analyzed:** 12-17-18 **Analyzed By:** mr/OUL

Page 1 of 1/OUL

Relinquished By: 12/10/18 1400

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UNDERGROUND
LABORATORY 1572 Aley Lane • Protem, MO 65733 • (417) 785-4289 • fax (417) 785-4290 • contact@ozarkundergroundlab.com

Certificate of Analysis

Date of certificate: December 26, 2018
Client: Ramboll
Project name: Athens Well Field Capture Study
Project number: 1690006943-048
Contact people: Chris Stubbs (cstubbs@ramboll.com)
Pejman Rasouli (prasouli@ramboll.com)
Lisa Ackerman (lackerman@ramboll.com)
emeryvillelabdata@ramboll.com

Samples collected by: J. King
Date samples shipped: December 13 and 17, 2018
Date samples rec'd at OUL: December 14 and 19, 2018
Date analyzed by OUL: December 20, 21 and 24, 2018
Included with certificate of analysis:
Table of results, copies of sample collection data sheets

Results for charcoal and water samples analyzed for the presence of fluorescein and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

All results are for charcoal unless otherwise indicated.

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D3889	1	MW-K4	12/10/18 0853	12/13/18 1329	ND		ND	
D3890	2	PC-144	12/10/18 0905	12/13/18 1338	ND		ND	
D3891	13	ARP-4A	12/10/18 0914	12/13/18 1344	ND		ND	
D3892	14	ARP-5A	12/10/18 0922	12/13/18 1352	ND		ND	
D3893	6	ARP-6B	12/10/18 0931	12/13/18 1359	ND		ND	
D3894	7	PC-145	12/10/18 0940	12/13/18 1409	ND		ND	
D3895	8	PC-136	12/10/18 0947	12/13/18 1415	ND		ND	
D3896	9	ART-6	12/10/18 0956	12/13/18 1423	ND		ND	
D3897	10	ART-9	12/10/18 1019	12/13/18 1432	ND		566.7	206,000
D3898	16	ART-7A	12/10/18 1032	12/13/18 1451	ND		566.4	1.31
D3899	15	PC-148	12/10/18 1041	12/13/18 1459	ND		ND	
D3900	Laboratory control charcoal blank							
D3901	5	PC-149	12/10/18 1049	12/13/18 1515	ND		ND	

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D3902	3	PC-150	12/10/18 1113	12/13/18 1523	513.4 *	0.561	ND	
D3903	12	ART-4A	12/10/18 1121	12/13/18 1534	ND		ND	
D3988	1	MW-K4	12/13/18 1331	12/17/18 0902	ND		ND	
D3989	2	PC-144	12/13/18 1340	12/17/18 0910	ND		ND	
D3990	13	ARP-4A	12/13/18 1346	12/17/18 0918	ND		ND	
D3991	14	ARP-5A	12/13/18 1354	12/17/18 0925	ND		ND	
D3992	6	ARP-6B	12/13/18 1402	12/17/18 0934	ND		ND	
D3992D	6	ARP-6B_FD	12/13/18 1403	12/17/18 0935	ND		ND	
D3993	7	PC-145	12/13/18 1411	12/17/18 0943	ND		ND	
D3994	8	PC-136	12/13/18 1419	12/17/18 0951	ND		ND	
D3994D	8	PC-136_FD	12/13/18 1420	12/17/18 0952	ND		ND	
D3995	9	ART-6	12/13/18 1427	12/17/18 0959	ND		ND	
D3995D	9	ART-6_FD	12/13/18 1428	12/17/18 1000	ND		ND	
D3996	10	ART-9	12/13/18 1445	12/17/18 1009	ND		566.6	567,000
D3997	16	ART-7A	12/13/18 1453	12/17/18 1017	ND		ND	
D3998	15	PC-148	12/13/18 1503	12/17/18 1026	ND		ND	
D3998D	15	PC-148_FD	12/13/18 1504	12/17/18 1027	ND		ND	
D3999	5	PC-149	12/13/18 1517	12/17/18 1034	ND		ND	
D4000	Laboratory control charcoal blank							
D4001	3	PC-150	12/13/18 1529	12/17/18 1150	ND		ND	
D4002	12	ART-4A	12/13/18 1536	12/17/18 1202	ND		ND	
D4009	10	ART-9	**Water**	12/13/18 1432	ND		573.8	500
D4010	16	ART-7A	**Water**	12/13/18 1451	ND		ND	
D4046	10	ART-9	**Water**	12/17/18 1009	ND		573.9	1,540

Note: Dye concentrations are based upon standards used at the OUL. The standard concentrations are based upon the as sold weight of the dye that the OUL uses. If the client is not using OUL dyes, the client should provide the OUL with a sample of the dye to compare to the OUL dyes.

Footnotes:

ND = No dye detected

* = A fluorescence peak is present that does not meet all the criteria for a positive dye result. However, it has been calculated as though it was the tracer dye.

Thomas J. Aley, PHG and RG Thomas Aley

OZARK UNDERGROUND LABORATORY, INC.

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SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) Week No: 1 Samples Collected By: J. King

Samples Shipped By: FedEx Samples Received By: Amber Comstock/OUL

Date Samples Shipped: 12/13/18 Date Samples Received: 12/14/18 Time Samples Received: 1300 Return Cooler? Yes ☐ No ☒

Bill to: Ramboll - per contract Send Results to: cs6665@ramboll.com; prasouli@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other ______ Ship cooler to: N/A

OUL use only			*Please indicate stations where dye was visible in the field*						OUL use only
# CHAR REC'D	LAB NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1	D3889	1	MW-K4		12-10-18	0853	12-13-18	1329	1
1	D3890	2	PC-144		12-10-18	0905	12-13-18	1338	1
1	D3891	13	ARP-4A	No WATER Sample	12-10-18	0914	12-13-18	1344	0
1	D3892	14	ARP-5A		12-10-18	0922	12-13-18	1352	1
1	D3893	6	ARP-6B		12-10-18	0931	12-13-18	1359	1
1	D3894	7	PC-145		12-10-18	0940	12-13-18	1409	1
1	D3895	8	PC-136		12-10-18	0947	12-13-18	1415	1
1	D3896	9	ART-6		12-10-18	0956	12-13-18	1423	1
1	D3897	10	ART-9		12-10-18	1019	12-13-18	1432	1
1	D3898	16	ART-7A		12-10-18	1032	12-13-18	1451	1
1	D3899	15	PC-148		12-10-18	1041	12-13-18	1459	1
1	D3901	5	PC-149		12-10-18	1049	12-13-18	1515	1
1	D3902	3	PC-150	No water sample	12-10-18	1113	12-13-18	1523	0
1	D3903	12	ART-4A		12-10-18	1121	12-13-18	1534	1

COMMENTS Analyze per standard protocol D3900 = OUL charcoal blank

This sheet filled out by OUL staff? Yes ~~☒~~ No ☒ Charts for samples on this page proofed by OUL: CA

OUL Project No. 1745 Date Analyzed: 12/20/18 Analyzed By: KC

Page 1 of 1 AC/OUL

Relinquished by 12/13/18 1800

OZARK UNDERGROUND LABORATORY, INC.
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SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 1 **Samples Collected By:** J. King
Samples Shipped By: FedEx **Samples Received By:** Amber Comstock/OUL
Date Samples Shipped: 12/13/18 **Date Samples Received:** 12/14/18 **Time Samples Received:** 1300 **Return Cooler?** Yes ☐ No ☒
Bill to: Ramboll - per contract **Send Results to:** csb66s@ramboll.com; prasbuli@ramboll.com
Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other ______ **Ship cooler to:** N/A

OUL use only			*Please indicate stations where dye was visible in the field*						OUL use only
# CHAR REC'D	LAB water NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED DATE	PLACED TIME	COLLECTED DATE	COLLECTED TIME	WATER REC'D
1		1	MW-K4		12-10-18	0853	12-13-18	1329	1
1		2	PC-144		12-10-18	0905	12-13-18	1338	1
1		13	ARP-4A	No water sample	12-10-18	0914	12-13-18	1344	0
1		14	ARP-5A		12-10-18	0922	12-13-18	1352	1
1		6	ARP-6B		12-10-18	0931	12-13-18	1359	1
1		7	PC-145		12-10-18	0940	12-13-18	1409	1
1		8	PC-136		12-10-18	0947	12-13-18	1415	1
1		9	ART-6		12-10-18	0956	12-13-18	1423	1
1	D4009	10	ART-9		12-10-18	1019	12-13-18	1432	1
1	D4010	16	ART-7A		12-10-18	1032	12-13-18	1451	1
1		15	PC-148		12-10-18	1041	12-13-18	1459	1
1		5	PC-149		12-10-18	1049	12-13-18	1515	1
1		3	PC-150	No water sample	12-10-18	1113	12-13-18	1523	0
1		12	ART-4A		12-10-18	1121	12-13-18	1534	1

COMMENTS Analyze per standard protocol
This sheet filled out by OUL staff? Yes ☒ No ☒ **Charts for samples on this page proofed by OUL:** CA
OUL Project No. 1745 **Date Analyzed:** 12/24/18 **Analyzed By:** AC/OUL
Page 1 of 1 AC/OUL
Relinquished by 12/13/18 1800

1 of 2

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) Week No: 2 Samples Collected By:

Samples Shipped By: FedEx Samples Received By: C. Aley / OUL

Date Samples Shipped: 12/17/18 Date Samples Received: 12/19/18 Time Samples Received: 1430 Return Cooler? Yes ☐ No ☒

Bill to: Ramboll - per contract Send Results to:

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other Ship cooler to: N/A

	OUL use only			Please indicate stations where dye was visible in the field						OUL use only
	# CHAR REC'D	LAB Charcoal NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
						DATE	TIME	DATE	TIME	
	1	D3988	1	MW-K4		12-13-18	1331	12-17-18	0902	1
	1	D3989	2	PC-144		12-13-18	1340	12-17-18	0910	1
	1	D3990	13	ARP-4A	NO WATER Sample	12-13-18	1346	12-17-18	0918	0
	1	D3991	14	ARP-5A		12-13-18	1354	12-17-18	0925	1
	1	D3992	6	ARP-6B		12-13-18	1402	12-17-18	0934	1
D	1	D3992D	6	ARP-6B_FD	Duplicate	12-13-18	1403	12-17-18	0935	1
	1	D3993	7	PC-145		12-13-18	1411	12-17-18	0943	1
	1	D3994	8	PC-136		12-13-18	1419	12-17-18	0951	1
D	1	D3994D	8	PC-136_FD	Duplicate	12-13-18	1420	12-17-18	0952	1
	1	D3995	9	ART-6		12-13-18	1427	12-17-18	0959	1
D	1	D3995D	9	ART-6_FD	Duplicate	12-13-18	1428	12-17-18	1000	1
	1	D3996	10	ART-9		12-13-18	1445	12-17-18	1009	1
	1	D3997	16	ART-7A		12-13-18	1453	12-17-18	1017	1
	1	D3998	15	PC-148		12-13-18	1503	12-17-18	1026	1

COMMENTS Analyze per standard protocol

This sheet filled out by OUL staff? Yes ☒ No ☒ Charts for samples on this page proofed by OUL: CA

OUL Project No. 1745 Date Analyzed: 12/21/18 Analyzed By: KC/OUL

Page 1 of 1

12/17/18 1600

p.1/2 OUL

2 of 2

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) Week No: 2 **Samples Collected By:**

Samples Shipped By: FedEx **Samples Received By:** C. Aley / OUL

Date Samples Shipped: 12/17/18 Date Samples Received: 12/19/18 **Time Samples Received:** 1430 **Return Cooler? Yes** ☐ **No** ☒

Bill to: Ramboll - per contract **Send Results to:**

Analyze for: ☒ Fluorescein ☐ Eosine ☒ **Rhodamine WT** ☐ **Other** **Ship cooler to:** N/A

OUL use only			*Please indicate stations where dye was visible in the field*						OUL use only
					PLACED		COLLECTED		
# CHAR REC'D	LAB charcoal NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	DATE	TIME	DATE	TIME	WATER REC'D
D 1	D3998D	15	PC-148_FD	*Duplicate*	12-13-18	1504	12-17-18	1027	1
1	D3999	5	PC-149		12-13-18	1517	12-17-18	1034	1
1	D4001	3	PC-150	*No water sample*	12-13-18	1529	12-17-18	1150	0
1	D4002	12	ART-4A		12-13-18	1536	12-17-18	1202	1

COMMENTS Analyze per standard protocol OUL Charcoal Blank - D 4000

This sheet filled out by OUL staff? Yes ~~☒~~ No ☒ **Charts for samples on this page proofed by OUL:** CA

OUL Project No. 1745 **Date Analyzed:** 12/21/2018 **Analyzed By:** KC/OUL

Page 2 of 2

12/17/18 1600

p. 2 of 2 OUL

1of2

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 2 **Samples Collected By:**

Samples Shipped By: FedEx **Samples Received By:** C. Aley / OUL

Date Samples Shipped: 12/17/18 **Date Samples Received:** 12/19/18 **Time Samples Received:** 1430 **Return Cooler?** Yes ☐ No ☒

Bill to: Ramboll - per contract **Send Results to:**

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other **Ship cooler to:** N/A

OUL use only			***Please indicate stations where dye was visible in the field***						OUL use only
# CHAR REC'D	~~LAB~~ water NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1		1	MW-K4		12-13-18	1331	12-17-18	0902	1
1		2	PC-144		12-13-18	1340	12-17-18	0910	1
1		13	ARP-4A	NO WATER SAMPLE	12-13-18	1346	12-17-18	0918	0
1		14	ARP-5A		12-13-18	1354	12-17-18	0925	1
1		6	ARP-6B		12-13-18	1402	12-17-18	0934	1
1		6	ARP-6B_FD	*Duplicate*	12-13-18	1403	12-17-18	0935	1
1		7	PC-145		12-13-18	1411	12-17-18	0943	1
1		8	PC-136		12-13-18	1419	12-17-18	0951	1
1		8	PC-136_FD	*Duplicate*	12-13-18	1420	12-17-18	0952	1
1		9	ART-6		12-13-18	1427	12-17-18	0959	1
1		9	ART-6_FD	*Duplicate*	12-13-18	1428	12-17-18	1000	1
1	D4046	10	ART-9		12-13-18	1445	12-17-18	1009	1
1		16	ART-7A		12-13-18	1453	12-17-18	1017	1
1		15	PC-148		12-13-18	1503	12-17-18	1026	1

COMMENTS Analyze per standard protocol

This sheet filled out by OUL staff? Yes ~~☒~~ No ☒ **Charts for samples on this page proofed by OUL:** CA

OUL Project No. 1745 **Date Analyzed:** 12/24/18 **Analyzed By:** AC/OUL

Page 1 of 1

12/17/18 1600

p.1 of 2 OUL

Ozark
UNDERGROUND
LABORATORY 1572 Aley Lane • Protem, MO 65733 • (417) 785-4289 • fax (417) 785-4290 • contact@ozarkundergroundlab.com

Certificate of Analysis

Date of certificate: December 28, 2018

Client: Ramboll

Project name: Athens Well Field Capture Study

Project number: 1690006943-048

Contact people: Chris Stubbs (cstubbs@ramboll.com)
Pejman Rasouli (prasouli@ramboll.com)
Lisa Ackerman (lackerman@ramboll.com)
emeryvillelabdata@ramboll.com

Samples collected by: J. King

Date samples shipped: December 21, 2018

Date samples rec'd at OUL: December 22, 2018

Date analyzed by OUL: December 27 and 28, 2018

Included with certificate of analysis:
Table of results, copies of sample collection data sheet

Results for charcoal and water samples analyzed for the presence of fluorescein and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

All results are for charcoal unless otherwise indicated.

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4053	1	MW-K4	12/17/18 0905	12/21/18 0743	ND		ND	
D4054	2	PC-144	12/17/18 0914	12/21/18 0753	ND		ND	
D4054D	2	PC-144_FD	12/17/18 0915	12/21/18 0754	ND		ND	
D4055	13	ARP-4A	12/17/18 0921	12/21/18 0803	ND		ND	
D4056	14	ARP-5A	12/17/18 0927	12/21/18 0812	ND		ND	
D4057	6	ARP-6B	12/17/18 0937	12/21/18 0819	ND		ND	
D4058	7	PC-145	12/17/18 0945	12/21/18 0829	ND		ND	
D4059	8	PC-136	12/17/18 0954	12/21/18 0837	ND		ND	
D4060	Laboratory control charcoal blank							
D4061	9	ART-6	12/17/18 1003	12/21/18 0844	ND		ND	
D4062	10	ART-9	12/17/18 1011	12/21/18 0852	ND		566.7	257,000
D4063	16	ART-7A	12/17/18 1019	12/21/18 0859	ND		ND	
D4064	15	PC-148	12/17/18 1030	12/21/18 0910	ND		ND	

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4065	5	PC-149	12/17/18 1036	12/21/18 0920	ND		ND	
D4066	3	PC-150	12/17/18 1156	12/21/18 1021	ND		ND	
D4067	12	ART-4A	12/17/18 1204	12/21/18 1032	ND		ND	
D4101	10	ART-9	**Water**	12/21/18 0852	ND		573.8	1,340

Note: Dye concentrations are based upon standards used at the OUL. The standard concentrations are based upon the as sold weight of the dye that the OUL uses. If the client is not using OUL dyes, the client should provide the OUL with a sample of the dye to compare to the OUL dyes.

Footnotes:

ND = No dye detected

Thomas J. Aley, PHG and RG

Thomas Aley

OZARK UNDERGROUND LABORATORY, INC.
[illegible] ergroundlab.com
[illegible] FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) Week No. 2 Samples Collected By: J. King
Samples Shipped By: FedEx Samples Received By: C. Aley/OUL
Date Samples Shipped: 12/21/18 Date Samples Received: 12/22/18 Time Samples Received: 1200 Return Cooler? Yes ☐ No ☒
Bill to: Ramboll - per contract Send Results to:
Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other Ship cooler to: N/A

	OUL use only			*Please indicate stations where dye was visible in the field*						OUL use only
	# CHAR REC'D	LAB NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
						DATE	TIME	DATE	TIME	
	1	D4053	1	MW-K4		12-17-18	0905	12-21-18	0743	1
	1	D4054	2	PC-144		12-17-18	0914	12-21-18	0753	1
D	1	D4054	2	PC-144_FD	Duplicate	12-17-18	0915	12-21-18	0754	1
	1	D4055	13	ARP-4A		12-17-18	0921	12-21-18	0803	0
	1	D4056	14	ARP-5A		12-17-18	0927	12-21-18	0812	1
	1	D4057	6	ARP-6B		12-17-18	0937	12-21-18	0819	1
	1	D4058	7	PC-145		12-17-18	0945	12-21-18	0829	1
	1	D4059	8	PC-136		12-17-18	0954	12-21-18	0837	1
	1	D4061	9	ART-6		12-17-18	1003	12-21-18	0844	1
	1	D4062	10	ART-9		12-17-18	1011	12-21-18	0852	1
	1	D4063	16	ART-7A		12-17-18	1019	12-21-18	0859	1
	1	D4064	15	PC-148		12-17-18	1030	12-21-18	0910	1
	1	D4065	5	PC-149		12-17-18	1036	12-21-18	0920	1
	1	D4066	3	PC-150	No water sample	12-17-18	1156	12-21-18	1021	0
	1	D4067	12	ART-4A		12-17-18	1204	12-21-18	1032	1

COMMENTS Analyze per standard protocol D4060 = OUL charcoal blank
This sheet filled out by OUL staff? Yes ~~☒~~ No ☒ Charts for samples on this page proofed by OUL: AC|OUL
OUL Project No. 1745 Date Analyzed: 12-27-18 and 12-28-18 Analyzed By: Lisa Gilcrease + AC
Page 1 of 1 OUL
Relinquished by 12/24/18 1200

OZARK UNDERGROUND LABORATORY, INC.
[illegible] (417) [illegible] e-mail contact@ozarkundergroundlab.com
SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) Week No. 2 Samples Collected By: J. King
Samples Shipped By: FedEx Samples Received By: C. Aley / OUL
Date Samples Shipped: 12/21/18 Date Samples Received: 12/22/18 Time Samples Received: 1200 Return Cooler? Yes ☐ No ☒
Bill to: Ramboll - per contract Send Results to:
Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other Ship cooler to: N/A

OUL use only			*Please indicate stations where dye was visible in the field*						OUL use only
# CHAR REC'D	LAB water NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1		1	MW-K4		12-17-18	0905	12-21-18	0743	1
1		2	PC-144		12-17-18	0914	12-21-18	0753	1
1		2	PC-144_FD	*Duplicate*	12-17-18	0915	12-21-18	0754	1
1		13	ARP-4A		12-17-18	0921	12-21-18	0803	0
1		14	ARP-5A		12-17-18	0927	12-21-18	0812	1
1		6	ARP-6B		12-17-18	0937	12-21-18	0819	1
1		7	PC-145		12-17-18	0945	12-21-18	0829	1
1		8	PC-136		12-17-18	0954	12-21-18	0837	1
1		9	ART-6		12-17-18	1003	12-21-18	0844	1
1	D4101	10	ART-9		12-17-18	1011	12-21-18	0852	1
1		16	ART-7A		12-17-18	1019	12-21-18	0859	1
1		15	PC-148		12-17-18	1030	12-21-18	0910	1
1		5	PC-149		12-17-18	1036	12-21-18	0920	1
1		3	PC-150	*No water sample*	12-17-18	1156	12-21-18	1021	0
1		12	ART-4A		12-17-18	1204	12-21-18	1032	1

COMMENTS Analyze per standard protocol
This sheet filled out by OUL staff? Yes ~~☒~~ No ☒ Charts for samples on this page proofed by OUL: AC/OUL
OUL Project No. 1745 Date Analyzed: 12/27/2018 Analyzed By: KC/OUL

Relinquished by 12/24/18 1200

Page 1 of 1 OUL

Ozark UNDERGROUND LABORATORY 1572 Aley Lane • Protem, MO 65733 • (417) 785-4289 • fax (417) 785-4290 • contact@ozarkundergroundlab.com

Certificate of Analysis

Date of certificate: January 4, 2019

Client: Ramboll

Project name: Athens Well Field Capture Study

Project number: 1690006943-048

Contact people: Chris Stubbs (cstubbs@ramboll.com)
Pejman Rasouli (prasouli@ramboll.com)
Lisa Ackerman (lackerman@ramboll.com)
emeryvillelabdata@ramboll.com

Samples collected by: J. King

Date samples shipped: December 29, 2018

Date samples rec'd at OUL: January 2, 2019

Date analyzed by OUL: January 3, 2019

Included with certificate of analysis:
Table of results, copies of sample collection data sheet

Results for charcoal and water samples analyzed for the presence of fluorescein and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

All results are for charcoal unless otherwise indicated.

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4137	1	MW-K4	12/21/18 0747	12/28/18 1611	ND		ND	
D4138	2	PC-144	12/21/18 0757	12/28/18 1622	ND		ND	
D4139	13	ARP-4A	12/21/18 0805	12/28/18 1631	ND		ND	
D4140	Laboratory control charcoal blank							
D4141	14	ARP-5A	12/21/18 0814	12/28/18 1638	ND		ND	
D4142	6	ARP-6B	12/21/18 0822	12/28/18 1646	ND		ND	
D4143	7	PC-145	12/21/18 0831	12/28/18 1655	ND		ND	
D4144	8	PC-136	12/21/18 0839	12/28/18 1701	ND		569.0	2.55
D4145	9	ART-6	12/21/18 0848	12/29/18 0702	ND		568.0	48.6
D4146	10	ART-9	12/21/18 0856	12/29/18 0711	ND		566.8	191,000
D4147	16	ART-7A	12/21/18 0903	12/29/18 0721	ND		ND	
D4148	15	PC-148	12/21/18 0913	12/29/18 0731	ND		ND	

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4149	15	PC-148_FD	12/21/18 0914	12/29/18 0732	ND		ND	
D4150	5	PC-149	12/21/18 0922	12/29/18 0741	ND		ND	
D4151	3	PC-150	12/21/18 1027	12/29/18 0748	ND		ND	
D4152	12	ART-4A	12/21/18 1034	12/29/18 0802	ND		ND	
D4153	8	PC-136	**Water**	12/28/18 1701	ND		572.8	0.206
D4154	9	ART-6	**Water**	12/29/18 0702	ND		573.7	1.40
D4155	10	ART-9	**Water**	12/29/18 0711	ND		573.9	153

Note: Dye concentrations are based upon standards used at the OUL. The standard concentrations are based upon the as sold weight of the dye that the OUL uses. If the client is not using OUL dyes, the client should provide the OUL with a sample of the dye to compare to the OUL dyes.

Footnotes:

ND = No dye detected

Thomas J. Aley, PHG and RG

Thomas Aley

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) Week No: 3 Samples Collected By: J. King

Samples Shipped By: FedEx Samples Received By: M. Ridinger / Oul

Date Samples Shipped: 12/29/18 Date Samples Received: 1/2/19 Time Samples Received: 1330 Return Cooler? Yes ☐ No ☒

Bill to: Ramboll - per contract Send Results to: CStubbs@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other Ship cooler to: N/A

OUL use only			*Please indicate stations where dye was visible in the field*						OUL use only
# CHAR REC'D	LAB Charcoal NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1	D4137	1	MW-K4		12-21-18	0747	12-28-18	1611	1
1	D4138	2	PC-144		12-21-18	0757	12-28-18	1622	1
1	D4139	13	ARP-4A	No water sample	12-21-18	0805	12-28-18	1631	0
1	D4141	14	ARP-5A		12-21-18	0814	12-28-18	1638	1
1	D4142	6	ARP-6B		12-21-18	0822	12-28-18	1646	1
1	D4143	7	PC-145		12-21-18	0831	12-28-18	1655	1
1	D4144	8	PC-136		12-21-18	0839	12-28-18	1701	1
1	D4145	9	ART-6		12-21-18	0848	12-29-18	0702	1
1	D4146	10	ART-9		12-21-18	0856	12-29-18	0711	1
1	D4147	16	ART-7A		12-21-18	0903	12-29-18	0721	1
1	D4148	15	PC-148		12-21-18	0913	12-29-18	0731	1
1	D4149	15	PC-148_FD	Duplicate	12-21-18	0914	12-29-18	0732	1
1	D4150	5	PC-149		12-21-18	0922	12-29-18	0741	1
1	D4151	3	PC-150	No water sample	12-21-18	1027	12-29-18	0748	0
1	D4152	12	ART-4A		12-21-18	1034	12-29-18	0802	1

COMMENTS Analyze per standard protocol Oul Charcoal Blank 4140

This sheet filled out by OUL staff? Yes ☒ No ☐ Charts for samples on this page proofed by OUL: Ca

OUL Project No. 1745 Date Analyzed: 1/3/2019 Analyzed By: Lisa Gilcrease

Page 1 of 1 Oul

Relinquished by 0930 12/29/18

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 3 **Samples Collected By:** J. King

Samples Shipped By: FedEx **Samples Received By:** M. Ridinger / OUL

Date Samples Shipped: 12/29/18 **Date Samples Received:** 1/2/19 **Time Samples Received:** 1330 **Return Cooler?** Yes ☐ No ☒

Bill to: Ramboll - per contract **Send Results to:** CStubbs@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other **Ship cooler to:** N/A

OUL use only			*Please indicate stations where dye was visible in the field*						*OUL use only*
# CHAR REC'D	**LAB NUMBER**	**STATION NUMBER**	**STATION NAME**	**NOTES/COMMENT**	**PLACED**		**COLLECTED**		**WATER REC'D**
					DATE	**TIME**	**DATE**	**TIME**	
1		1	MW-K4		12-21-18	0747	12-28-18	1611	1
1		2	PC-144		12-21-18	0757	12-28-18	1622	1
1		13	ARP-4A	No water sample	12-21-18	0805	12-28-18	1631	0
1		14	ARP-5A		12-21-18	0814	12-28-18	1638	1
1		6	ARP-6B		12-21-18	0822	12-28-18	1646	1
1		7	PC-145		12-21-18	0831	12-28-18	1655	1
1	D4153	8	PC-136		12-21-18	0839	12-28-18	1701	1
1	D4154	9	ART-6		12-21-18	0848	12-29-18	0702	1
1	D4155	10	ART-9		12-21-18	0856	12-29-18	0711	1
1		16	ART-7A		12-21-18	0903	12-29-18	0721	1
1		15	PC-148		12-21-18	0913	12-29-18	0731	1
1		15	PC-148_FD	Duplicate	12-21-18	0914	12-29-18	0732	1
1		5	PC-149		12-21-18	0922	12-29-18	0741	1
1		3	PC-150	No water sample	12-21-18	1027	12-29-18	0748	0
1		12	ART-4A		12-21-18	1034	12-29-18	0802	1

COMMENTS Analyze per standard protocol

This sheet filled out by OUL staff? Yes ☒ No ☐ **Charts for samples on this page proofed by OUL:**

OUL Project No. 1745 **Date Analyzed:** 1-3-19 **Analyzed By:** Lisa Gilcrease

Relinquished by 0930 12/29/18

Page 1 of 1 Oul

Ozark
UNDERGROUND
LABORATORY 1572 Aley Lane • Protem, MO 65733 • (417) 785-4289 • fax (417) 785-4290 • contact@ozarkundergroundlab.com

Certificate of Analysis

Date of certificate: January 9, 2019
Client: Ramboll
Project name: Athens Well Field Capture Study
Project number: 1690006943-048
Contact people: Chris Stubbs (cstubbs@ramboll.com)
Pejman Rasouli (prasouli@ramboll.com)
Lisa Ackerman (lackerman@ramboll.com)
emeryvillelabdata@ramboll.com

Samples collected by: G. Miclette
Date samples shipped: January 4, 2019
Date samples rec'd at OUL: January 7, 2019
Date analyzed by OUL: January 9, 2019
Included with certificate of analysis:
Table of results, copies of sample collection data sheet and discrepancy sheet

Results for charcoal and water samples analyzed for the presence of fluorescein and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

All results are for charcoal unless otherwise indicated.

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4169	1	MW-K4	12/28/18 1614	1/4/19 1432	ND		ND	
D4170	2	PC-144	12/28/18 1625	1/4/19 1452	ND		ND	
D4171	2	PC-144_FD	12/28/18 1626	1/4/19 1453	ND		ND	
D4172	13	ARP-4A	12/28/18 1633	1/4/19 1511	ND		ND	
D4173	14	ARP-5A	12/28/18 1641	1/4/19 1516	ND		ND	
D4174	6	ARP-6B	12/28/18 1648	1/4/19 1529	ND		ND	
D4175	7	PC-145	12/28/18 1657	1/4/19 1538	ND		ND	
D4176	8	PC-136	12/28/18 1705	1/4/19 1547	ND		568.2	5.64
D4177	9	ART-6	12/29/18 0704	1/4/19 1556	ND		568.2	35.3
D4178	10	ART-9	12/29/18 0716	1/4/19 1608	ND		566.6	654,000
D4179	15	PC-148	12/29/18 0734	1/4/19 1638	ND		568.4	3.02
D4180	Laboratory control charcoal blank							

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4181	5	PC-149	12/29/18 0743	1/4/19 1646	ND		ND	
D4182	3	PC-150	12/29/18 0756	1/4/19 1702	ND		ND	
D4183	12	ART-4A	12/29/18 0804	1/4/19 1710	ND		ND	
D4242	8	PC-136	**Water**	1/4/19 1547	ND		574.8	0.462
D4243	9	ART-6	**Water**	1/4/19 1556	ND		574.2	0.874
D4244	10	ART-9	**Water**	1/4/19 1608	ND		573.7	162
D4245	16	ART-7A	**Water**	1/4/19 1617	ND		ND	
D4246	15	PC-148	**Water**	1/4/19 1638	ND		ND	

Note: Dye concentrations are based upon standards used at the OUL. The standard concentrations are based upon the as sold weight of the dye that the OUL uses. If the client is not using OUL dyes, the client should provide the OUL with a sample of the dye to compare to the OUL dyes.

Footnotes:

ND = No dye detected

Thomas J. Aley, PHG and RG

Thomas Aley

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 4 **Samples Collected By:** G. Miclette

Samples Shipped By: FedEx **Samples Received By:** KC / OUL

Date Samples Shipped: 1 / 4 / 2019 **Date Samples Received:** 1 / 7 / 2019 **Time Samples Received:** 1300 **Return Cooler?** Yes ☐ No ☒

Bill to: Ramboll - per contract **Send Results to:** cstubbs@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other ________ **Ship cooler to:** N/A

OUL use only			***Please indicate stations where dye was visible in the field***						*OUL use only*
# CHAR REC'D	LAB Charcoal NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1	D4169	1	MW-K4		12-28-18	1614	1-4-19	1432	1
1	D4170	2	PC-144		12-28-18	1625	1-4-19	1452	1
1	D4171	2	PC-144_FD	*Duplicate*	12-28-18	1626	1-4-19	1453	1
1	D4172	13	ARP-4A	*No water sample*	12-28-18	1633	1-4-19	1511	0
1	D4173	14	ARP-5A		12-28-18	1641	1-4-19	1516	1
1	D4174	6	ARP-6B		12-28-18	1648	1-4-19	1529	1
1	D4175	7	PC-145		12-28-18	1657	1-4-19	1538	1
1	D4176	8	PC-136		12-28-18	1705	1-4-19	1547	1
1	D4177	9	ART-6		12-29-18	0704	1-4-19	1556	1
1	D4178	10	ART-9		12-29-18	0716	1-4-19	1608	1
0	—	16	ART-7A ⊛	*NO CARBON SAMPLE	12-29-18	0723	1-4-19	1617	1
1	D4179	15	PC-148		12-29-18	0734	1-4-19	1638	1
1	D4181	5	PC-149		12-29-18	0743	1-4-19	1646	1
1	D4182	3	PC-150	*No water sample*	12-29-18	0756	1-4-19	1702	0
1	D4183	12	ART-4A		12-29-18	0804	1-4-19	1710	1

COMMENTS Analyze per standard protocol OUL Charcoal Blank - D4180 ⊛ See OUL discrepancy sheet.

This sheet filled out by OUL staff? Yes ☒ No ☐ **Charts for samples on this page proofed by OUL:**

OUL Project No. 1745 **Date Analyzed:** 1-9-19 **Analyzed By:** Lisa Gilcrease

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SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 4 **Samples Collected By:** G. Miclette

Samples Shipped By: FedEx **Samples Received By:** KC / OUL

Date Samples Shipped: 1 / 4 / 2019 **Date Samples Received:** 1 / 7 / 2019 **Time Samples Received:** 1300 **Return Cooler?** Yes ☐ No ☒

Bill to: Ramboll - per contract **Send Results to:** cstubbs@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other _____ **Ship cooler to:** N/A

OUL use only			*Please indicate stations where dye was visible in the field*						*OUL use only*
# CHAR REC'D	**WATER LAB NUMBER**	**STATION NUMBER**	**STATION NAME**	**NOTES/COMMENT**	**PLACED**		**COLLECTED**		**WATER REC'D**
					DATE	**TIME**	**DATE**	**TIME**	
1		1	MW-K4		12-28-18	1614	1-4-19	1432	1
1		2	PC-144		12-28-18	1625	1-4-19	1452	1
1		2	PC-144_FD	*Duplicate*	12-28-18	1626	1-4-19	1453	1
1		13	ARP-4A	*No water sample*	12-28-18	1633	1-4-19	1511	0
1		14	ARP-5A		12-28-18	1641	1-4-19	1516	1
1		6	ARP-6B		12-28-18	1648	1-4-19	1529	1
1		7	PC-145		12-28-18	1657	1-4-19	1538	1
1	D4242	8	PC-136		12-28-18	1705	1-4-19	1547	1
1	D4243	9	ART-6		12-29-18	0704	1-4-19	1556	1
1	D4244	10	ART-9		12-29-18	0716	1-4-19	1608	1
0	D4245	16	ART-7A	*NO CARBON SAMPLE	12-29-18	0723	1-4-19	1617	1
1	D4246	15	PC-148		12-29-18	0734	1-4-19	1638	1
1		5	PC-149		12-29-18	0743	1-4-19	1646	1
1		3	PC-150	*No water sample*	12-29-18	0756	1-4-19	1702	0
1		12	ART-4A		12-29-18	0804	1-4-19	1710	1

COMMENTS Analyze per standard protocol

This sheet filled out by OUL staff? Yes ☒ No ☐ **Charts for samples on this page proofed by OUL:** CG

OUL Project No. 1745 **Date Analyzed:** 1-9-19 **Analyzed By:** Lisa Gilcrease

OZARK UNDERGROUND LABORATORY, INC.

DISCREPANCIES BETWEEN CHAIN-OF-CUSTODY SHEETS AND ACTUAL SAMPLES RECEIVED **Page** 1 **of** 1

Company & Project Name: Ramboll / AWF **Date Rec'd by OUL:** 1/7/2019 **Wk #** ______

Lab #	Sta #	Station Name	Date Pulled	Problem	Solution
D4245		ART-7A	1-4-19	@1617 Vial cracked	. OUL transferred sample to a new vial.
D4181	5	PC-149	1-4-19 1646	No sample received labeled PC-149. OUL did receive a sample labled PC-147 with the collection date and time matching the COC for PC-149.	OUL will analyze and use info on COC.

Comments

Ozark
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LABORATORY 1572 Aley Lane • Protem, MO 65733 • (417) 785-4289 • fax (417) 785-4290 • contact@ozarkundergroundlab.com

Certificate of Analysis

Date of certificate: January 18, 2019

Client: Ramboll

Project name: Athens Well Field Capture Study

Project number: 1690006943-048

Contact people: Chris Stubbs (cstubbs@ramboll.com)
Pejman Rasouli (prasouli@ramboll.com)
Lisa Ackerman (lackerman@ramboll.com)
emeryvillelabdata@ramboll.com

Samples collected by: G. Miclette

Date samples shipped: January 12, 2019

Date samples rec'd at OUL: January 14, 2019

Date analyzed by OUL: January 15 and 17, 2019

Included with certificate of analysis:
Table of results, copies of sample collection data sheet and discrepancy sheet

Results for charcoal and water samples analyzed for the presence of fluorescein and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

All results are for charcoal unless otherwise indicated.

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4301	1	MW-K4	1/4/19 1434	1/11/19 1130	ND		ND	
D4302	2	PC-144	1/4/19 1455	1/11/19 1142	ND		ND	
D4303	2	ARP-4A	1/4/19 1513	1/11/19 1156	ND		ND	
D4304	13	ARP-5A	1/4/19 1518	1/11/19 1203	ND		ND	
D4305	14	ARP-6B	1/4/19 1533	1/11/19 1215	ND		ND	
D4306	6	PC-145	1/4/19 1541	1/11/19 1232	ND		ND	
D4307	7	PC-136	1/4/19 1551	1/11/19 1240	ND		567.4	13.4
D4308	8	ART-6	1/4/19 1600	1/11/19 1250	ND		567.8	14.9
D4309	9	ART-6_FD	1/4/19 1601	1/11/19 1251	ND		568.0	17.0
D4310	10	ART-9	1/4/19 1611	1/11/19 1303	ND		566.6	32,200
D4311	16	ART-7A	1/4/19 1620	1/11/19 1320	ND		ND	
D4312	15	PC-148	1/4/19 1641	1/11/19 1335	ND		ND	

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4313	5	PC-149	1/4/19 1649	1/11/19 1341	ND		ND	
D4314	3	PC-150	1/4/19 1704	1/11/19 1356	ND		ND	
D4315	12	ART-4A	1/4/19 1712	1/11/19 1411	ND		ND	
D4333	7	PC-136	**Water**	1/11/19 1240	ND		574.2	0.602
D4334	8	ART-6	**Water**	1/11/19 1250	ND		573.4	0.095
D4335	9	ART-6_FD	**Water**	1/11/19 1251	ND		576.4	0.045
D4336	10	ART-9	**Water**	1/11/19 1303	ND		573.8	43.6

Note: Dye concentrations are based upon standards used at the OUL. The standard concentrations are based upon the as sold weight of the dye that the OUL uses. If the client is not using OUL dyes, the client should provide the OUL with a sample of the dye to compare to the OUL dyes.

Footnotes:

ND = No dye detected

Thomas J. Aley, PHG and RG

Thomas Aley

* 1-12-19
per shipping label

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 5 **Samples Collected By:** G. Miclette

Samples Shipped By: FedEx **Samples Received By:** C. Aley / OUL

Date Samples Shipped: 1 / 11 / 2019* **Date Samples Received:** 1 / 14 / 19 **Time Samples Received:** 1330 **Return Cooler?** Yes ☐ No ☒

Bill to: Ramboll - per contract **Send Results to:** cstubbs@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other ______ **Ship cooler to:** N/A

OUL use only			*Please indicate stations where dye was visible in the field*						*OUL use only*
# CHAR REC'D	LAB Charcoal NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1	D4301	1	MW-K4		1-4-19	1434	1-11-19	1130	1
1	D4302	2	PC-144		1-4-19	1455	1-11-19	1142	1
1	D4303	2	ARP-4A	No water sample	1-4-19	1513	1-11-19	1156	0
1	D4304	13	ARP-5A		1-4-19	1518	1-11-19	1203	1
1	D4305	14	ARP-6BA ⊛		1-4-19	1533	1-11-19	1215	1
1	D4306	6	PC-145		1-4-19	1541	1-11-19	1232	1
1	D4307	7	PC-136		1-4-19	1551	1-11-19	1240	1
1	D4308	8	ART-6		1-4-19	1600	1-11-19	1250	1
1	D4309	9	ART-6_FD	Duplicate	1-4-19	1601	1-11-19	1251	1
1	D4310	10	ART-9		1-4-19	1611	1-11-19	1303	1
1	D4311	16	ART-7A		1-4-19	1620	1-11-19	1320	1
1	D4312	15	PC-148		1-4-19	1641	1-11-19	1335	1
1	D4313	5	PC-149 ⊛		1-4-19	1649	1-11-19	1341	1
1	D4314	3	PC-150	No water sample	1-4-19	1704	1-11-19	1356	0
1	D4315	12	ART-4A		1-4-19	1712	1-11-19	1411	1

COMMENTS Analyze per standard protocol ⊛ See OUL discrepancy sheet.

This sheet filled out by OUL staff? Yes ~~☒~~ No ☒ **Charts for samples on this page proofed by OUL:** AE/OUL

OUL Project No. 1745 **Date Analyzed:** 1-15-19 **Analyzed By:** MR/OUL

Page 1 of 1 OUL

* 1-12-19
per shipping label

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SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 5 **Samples Collected By:** G. Miclette
Samples Shipped By: FedEx **Samples Received By:** Cr Aley / OUL
Date Samples Shipped: 1 / 11 / 2019* **Date Samples Received:** 1/14/19 **Time Samples Received:** 1330 **Return Cooler?** Yes ☐ No ☒
Bill to: Ramboll - per contract **Send Results to:** cstubbs@ramboll.com
Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other **Ship cooler to:** N/A

OUL use only			*Please indicate stations where dye was visible in the field*						*OUL use only*
# CHAR REC'D	~~LAB~~ Water NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED DATE	PLACED TIME	COLLECTED DATE	COLLECTED TIME	WATER REC'D
1		1	MW-K4		1-4-19	1434	1-11-19	1130	1
1		2	PC-144		1-4-19	1455	1-11-19	1142	1
1		2	ARP-4A	No water sample	1-4-19	1513	1-11-19	1156	0
1		13	ARP-5A		1-4-19	1518	1-11-19	1203	1
1		14	ARP-6BA ⊛		1-4-19	1533	1-11-19	1215	1
1		6	PC-145		1-4-19	1541	1-11-19	1232	1
1	D4333	7	PC-136		1-4-19	1551	1-11-19	1240	1
1	D4334	8	ART-6		1-4-19	1600	1-11-19	1250	1
1	D4335	9	ART-6_FD	Duplicate	1-4-19	1601	1-11-19	1251	1
1	D4336	10	ART-9		1-4-19	1611	1-11-19	1303	1
1		16	ART-7A		1-4-19	1620	1-11-19	1320	1
1		15	PC-148		1-4-19	1641	1-11-19	1335	1
1		5	PC-149 ⊛		1-4-19	1649	1-11-19	1341	1
1		3	PC-150	No water sample	1-4-19	1704	1-11-19	1356	0
1		12	ART-4A		1-4-19	1712	1-11-19	1411	1

COMMENTS Analyze per standard protocol ⊛ See OUL discrepancy sheet.
This sheet filled out by OUL staff? Yes ~~☒~~ No ☒ **Charts for samples on this page proofed by OUL:** AC/OUL
OUL Project No. 1745 **Date Analyzed:** 1/17/19 **Analyzed By:** Lisa Gilcrease

Page 1 of 1 OUL

OZARK UNDERGROUND LABORATORY, INC.

DISCREPANCIES BETWEEN CHAIN-OF-CUSTODY SHEETS AND ACTUAL SAMPLES RECEIVED **Page** 1 **of** 1

Company & Project Name: Ramboll NERT AWF **Date Rec'd by OUL:** 1-14-19 **Wk #** 5

Lab #	Sta #	Station Name	Date Pulled	Problem	Solution
D4305	14	ARP-6B	1/11/19	Station name on COC is "ARP-6BA"; on the sample labels; "ARP-6B"	Per e-mail from J. King, ARP-6B is correct
D4313	5	PC-149	1/11/19	COC lists a sample "PC-149" OUL did not receive a sample labeled PC-149	Is sample received as PC-147 the sample noted as PC-149 on COC?
		PC-147	1/11/19	OUL received sample labeled "PC-147"; sample not listed on COC.	Per e-mail from J. King, PC-147 should be PC-149

Comments:

Ozark
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LABORATORY 1572 Aley Lane • Protem, MO 65733 • (417) 785-4289 • fax (417) 785-4290 • contact@ozarkundergroundlab.com

Certificate of Analysis

Date of certificate: January 25, 2019

Client: Ramboll

Project name: Athens Well Field Capture Study

Project number: 1690006943-048

Contact people: Chris Stubbs (cstubbs@ramboll.com)
Pejman Rasouli (prasouli@ramboll.com)
Lisa Ackerman (lackerman@ramboll.com)
emeryvillelabdata@ramboll.com

Samples collected by: G. Miclette

Date samples shipped: January 18, 2019

Date samples rec'd at OUL: January 21, 2019

Date analyzed by OUL: January 22 and 23, 2019

Included with certificate of analysis:
Table of results, copies of sample collection data sheet

Results for charcoal and water samples analyzed for the presence of fluorescein and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

All results are for charcoal unless otherwise indicated.

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4426	1	MW-K4	1/11/19 1132	1/18/19 1220	ND		ND	
D4427	2	PC-144	1/11/19 1145	1/18/19 1230	ND		ND	
D4428	2	ARP-4A	1/11/19 1157	1/18/19 1237	ND		ND	
D4429	13	ARP-5A	1/11/19 1208	1/18/19 1246	ND		ND	
D4430	14	ARP-5A_FD	1/11/19 1209	1/18/19 1247	ND		ND	
D4431	6	ARP-6B	1/11/19 1218	1/18/19 1420	ND		ND	
D4432	7	PC-145	1/11/19 1235	1/18/19 1432	ND		ND	
D4433	8	PC-136	1/11/19 1243	1/18/19 1441	ND		567.8	5.99
D4434	9	ART-6	1/11/19 1254	1/18/19 1448	ND		567.2	1.17
D4435	10	ART-9	1/11/19 1307	1/18/19 1458	ND		566.5	46,400
D4436	16	ART-7A	1/11/19 1323	1/18/19 1518	ND		ND	
D4437	15	PC-148	1/11/19 1338	1/18/19 1530	ND		ND	

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4438	5	PC-149	1/11/19 1350	1/18/19 1537	ND		ND	
D4439	3	PC-150	1/11/19 1406	1/18/19 1548	ND		ND	
D4440	Laboratory control charcoal blank							
D4441	12	ART-4A	1/11/19 1420	1/18/19 1600	ND		ND	
D4456	8	PC-136	**Water**	1/18/19 1441	ND		572.8	0.393
D4457	9	ART-6	**Water**	1/18/19 1448	ND		ND	

Note: Dye concentrations are based upon standards used at the OUL. The standard concentrations are based upon the as sold weight of the dye that the OUL uses. If the client is not using OUL dyes, the client should provide the OUL with a sample of the dye to compare to the OUL dyes.

Footnotes:

ND = No dye detected

Thomas J. Aley, PHG and RG

Thomas Aley

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1572 Aley Lane Protem, MO 65733 (417) 785-4289 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 6 **Samples Collected By:** G. Miclette

Samples Shipped By: FedEx **Samples Received By:** Amber Comstock/OUL

Date Samples Shipped: 1 / 18 / 2019 **Date Samples Received:** 1/21/19

Return Cooler? Yes ☐ No ☒ **Time Samples Received:** 1330

Bill to: Ramboll - per contract **Send Results to:** cstubbs@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other **Ship cooler to:** N/A

OUL use only			*Please indicate stations where dye was visible in the field*						OUL use only
# CHAR REC'D	LAB Charcoal NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1	D4426	1	MW-K4		1-11-19	1132	1-18-19	1220	1
1	D4427	2	PC-144		1-11-19	1145	1-18-19	1230	1
1	D4428	2	ARP-4A	No water sample	1-11-19	1157	1-18-19	1237	0
1	D4429	13	ARP-5A		1-11-19	1208	1-18-19	1246	1
1	D4430	14	ARP-5A_FD	Duplicate	1-11-19	1209	1-18-19	1247	1
1	D4431	6	ARP-6B		1-11-19	1218	1-18-19	1420	1
1	D4432	7	PC-145		1-11-19	1235	1-18-19	1432	1
1	D4433	8	PC-136		1-11-19	1243	1-18-19	1441	1
1	D4434	9	ART-6		1-11-19	1254	1-18-19	1448	1
1	D4435	10	ART-9	No water sample	1-11-19	1307	1-18-19	1458	0
1	D4436	16	ART-7A		1-11-19	1323	1-18-19	1518	1
1	D4437	15	PC-148		1-11-19	1338	1-18-19	1530	1
1	D4438	5	PC-149		1-11-19	1350	1-18-19	1537	1
1	D4439	3	PC-150	No water sample	1-11-19	1406	1-18-19	1548	0
1	D4441	12	ART-4A		1-11-19	1420	1-18-19	1600	1

COMMENTS Analyze per standard protocol OUL Charcoal Blank D4440

This sheet filled out by OUL staff? Yes ☒ No ☒

Charts for samples on this page proofed by OUL: AC/OUL

OUL Project No. 1745 **Date Analyzed:** 1/22/19 **Analyzed By:** Lisa Gilcrease

Page 1 of 1 AC/OUL

OZARK UNDERGROUND LABORATORY, INC.
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SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 6 **Samples Collected By:** G. Miclette
Samples Shipped By: FedEx **Samples Received By:** Amber Comstock/OUL
Date Samples Shipped: 1 / 18 / 2019 **Date Samples Received:** 1/21/19
Return Cooler? Yes ☐ No ☒ **Time Samples Received:** 1330
Bill to: Ramboll - per contract **Send Results to:** cstubbs@ramboll.com
Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other ______ **Ship cooler to:** N/A

OUL use only			***Please indicate stations where dye was visible in the field***						OUL use only
# CHAR REC'D	Water LAB NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1		1	MW-K4		1-11-19	1132	1-18-19	1220	1
1		2	PC-144		1-11-19	1145	1-18-19	1230	1
1		2	ARP-4A		1-11-19	1157	1-18-19	1237	0
1		13	ARP-5A	No water sample	1-11-19	1208	1-18-19	1246	1
1		14	ARP-5A_FD	Duplicate	1-11-19	1209	1-18-19	1247	1
1		6	ARP-6B		1-11-19	1218	1-18-19	1420	1
1		7	PC-145		1-11-19	1235	1-18-19	1432	1
1	D4456	8	PC-136		1-11-19	1243	1-18-19	1441	1
1	D4457	9	ART-6		1-11-19	1254	1-18-19	1448	1
1		10	ART-9		1-11-19	1307	1-18-19	1458	0
1		16	ART-7A	No water sample	1-11-19	1323	1-18-19	1518	1
1		15	PC-148		1-11-19	1338	1-18-19	1530	1
1		5	PC-149		1-11-19	1350	1-18-19	1537	1
1		3	PC-150		1-11-19	1406	1-18-19	1548	0
1		12	ART-4A	No water sample	1-11-19	1420	1-18-19	1600	1

COMMENTS Analyze per standard protocol

This sheet filled out by OUL staff? Yes ~~☒~~ No ☒ **Charts for samples on this page proofed by OUL:** AC/OUL
OUL Project No. 1745 **Date Analyzed:** 1-23-19 **Analyzed By:** MR/OUL

Page 1 of 1 AC/OUL

Ozark
UNDERGROUND
LABORATORY 1572 Aley Lane • Protem, MO 65733 • (417) 785-4289 • fax (417) 785-4290 • contact@ozarkundergroundlab.com

Certificate of Analysis

Date of certificate: February 1, 2019
Client: Ramboll
Project name: Athens Well Field Capture Study
Project number: 1690006943-048
Contact people: Chris Stubbs (cstubbs@ramboll.com)
Pejman Rasouli (prasouli@ramboll.com)
Lisa Ackerman (lackerman@ramboll.com)
emeryvillelabdata@ramboll.com

Samples collected by: G. Miclette
Date samples shipped: January 26, 2019
Date samples rec'd at OUL: January 29, 2019
Date analyzed by OUL: January 30, 2019
Included with certificate of analysis:
Table of results, copies of sample collection data sheet

Results for charcoal and water samples analyzed for the presence of fluorescein and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

All results are for charcoal unless otherwise indicated.

OUL	Station	Station Name	Date/Time	Date/Time	Fluorescein		RWT	
Number	Number		Placed	Collected	Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4579	1	MW-K4	1/18/19 1223	1/25/19 1320	ND		ND	
D4580	Laboratory control charcoal blank							
D4581	2	PC-144	1/18/19 1233	1/25/19 1330	ND		ND	
D4582	2	ARP-4A	1/18/19 1240	1/25/19 1344	ND		ND	
D4583	13	ARP-5A	1/18/19 1250	1/25/19 1350	ND		ND	
D4584	14	ARP-6B_FD	1/18/19 1422	1/25/19 1359	ND		ND	
D4585	6	ARP-6B	1/18/19 1423	1/25/19 1400	ND		ND	
D4586	7	PC-145	1/18/19 1435	1/25/19 1412	ND		ND	
D4587	8	PC-136	1/18/19 1443	1/25/19 1419	ND		567.6	22.0
D4588	9	ART-6	1/18/19 1451	1/25/19 1434	ND		ND	
D4589	10	ART-9	1/18/19 1500	1/25/19 1444	ND		566.5	12,300
D4590	16	ART-7A	1/18/19 1520	1/25/19 1453	ND		ND	

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	**Conc. (ppb)**	**Peak (nm)**	**Conc. (ppb)**
D4591	15	PC-148	1/18/19 1532	1/25/19 1504	ND		ND	
D4592	5	PC-149	1/18/19 1540	1/25/19 1512	ND		ND	
D4593	3	PC-150	1/18/19 1450	1/25/19 1521	ND		ND	
D4594	12	ART-4A	1/18/19 1602	1/25/19 1533	ND		ND	
D4609	8	PC-136	**Water**	1/25/19 1419	ND		572.8	1.56
D4610	10	ART-9	**Water**	1/25/19 1444	ND		573.2	7.80

Note: Dye concentrations are based upon standards used at the OUL. The standard concentrations are based upon the as sold weight of the dye that the OUL uses. If the client is not using OUL dyes, the client should provide the OUL with a sample of the dye to compare to the OUL dyes.

Footnotes:

ND = No dye detected

Thomas J. Aley, PHG and RG

Thomas Aley

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 7 **Samples Collected By:** G. Miclette

Samples Shipped By: FedEx **Samples Received By:** L. Gilcrease / OUL

Date Samples Shipped: 1 / 24* / 2019 **Date Samples Received:** 1 / 29 / 19 **Time Samples Received:** 1300

*1/26/19 on Shipping label LG.

Return Cooler? Yes ☐ No ☒

Bill to: Ramboll - per contract **Send Results to:** cstubbs@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other **Ship cooler to:** N/A

OUL use only			*Please indicate stations where dye was visible in the field*						OUL use only
# CHAR REC'D	LAB Charcoal NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED DATE	PLACED TIME	COLLECTED DATE	COLLECTED TIME	WATER REC'D
1	D4579	1	MW-K4		1-18-19	1223	1-25-19	1320	1
1	D4581	2	PC-144		1-18-19	1233	1-25-19	1330	1
1	D4582	2	ARP-4A	No water sample	1-18-19	1240	1-25-19	1344	0
1	D4583	13	ARP-5A		1-18-19	1250	1-25-19	1350	1
1	D4584	14	ARP-6B_FD	Duplicate	1-18-19	1422	1-25-19	1359	1
1	D4585	6	ARP-6B		1-18-19	1423	1-25-19	1400	1
1	D4586	7	PC-145		1-18-19	1435	1-25-19	1412	1
1	D4587	8	PC-136		1-18-19	1443	1-25-19	1419	1
1	D4588	9	ART-6		1-18-19	1451	1-25-19	1434	1
1	D4589	10	ART-9		1-18-19	1500	1-25-19	1444	1
1	D4590	16	ART-7A		1-18-19	1520	1-25-19	1453	1
1	D4591	15	PC-148		1-18-19	1532	1-25-19	1504	1
1	D4592	5	PC-149		1-18-19	1540	1-25-19	1512	1
1	D4593	3	PC-150	No water sample	1-18-19	1450	1-25-19	1521	0
1	D4594	12	ART-4A		1-18-19	1602	1-25-19	1533	1

D4580 - OUL Charcoal blank

COMMENTS Analyze per standard protocol

This sheet filled out by OUL staff? Yes ☒ No ☐ **Charts for samples on this page proofed by OUL:** Ca

OUL Project No. 1745 **Date Analyzed:** 1-30-19 **Analyzed By:** MR / OUL

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SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 7 **Samples Collected By:** G. Miclette

Samples Shipped By: FedEx **Samples Received By:** L. Gilcrease / OUL

Date Samples Shipped: 1 / 24* / 2019 *1/26/19 on Shipping label LG.* **Date Samples Received:** 1 / 29 / 19 **Time Samples Received:** 1300

Return Cooler? Yes ☐ No ☒

Bill to: Ramboll - per contract **Send Results to:** cstubbs@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other ______ **Ship cooler to:** N/A

OUL use only			***Please indicate stations where dye was visible in the field***						*OUL use only*
# CHAR REC'D	LAB Water NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1		1	MW-K4		1-18-19	1223	1-25-19	1320	1
1		2	PC-144		1-18-19	1233	1-25-19	1330	1
1		2	ARP-4A	No water sample	1-18-19	1240	1-25-19	1344	0
1		13	ARP-5A		1-18-19	1250	1-25-19	1350	1
1		14	ARP-6B_FD	Duplicate	1-18-19	1422	1-25-19	1359	1
1		6	ARP-6B		1-18-19	1423	1-25-19	1400	1
1		7	PC-145		1-18-19	1435	1-25-19	1412	1
1	D4609	8	PC-136		1-18-19	1443	1-25-19	1419	1
1		9	ART-6		1-18-19	1451	1-25-19	1434	1
1	D4610	10	ART-9		1-18-19	1500	1-25-19	1444	1
1		16	ART-7A		1-18-19	1520	1-25-19	1453	1
1		15	PC-148		1-18-19	1532	1-25-19	1504	1
1		5	PC-149		1-18-19	1540	1-25-19	1512	1
1		3	PC-150	No water sample	1-18-19	1450	1-25-19	1521	0
1		12	ART-4A		1-18-19	1602	1-25-19	1533	1

COMMENTS Analyze per standard protocol

This sheet filled out by OUL staff? Yes ☒ No ☐ **Charts for samples on this page proofed by OUL:** CA

OUL Project No. 1745 **Date Analyzed:** 1/30/19 **Analyzed By:** LG/OUL

Page 1 of 1 /OUL

Ozark UNDERGROUND LABORATORY 1572 Aley Lane • Protem, MO 65733 • (417) 785-4289 • fax (417) 785-4290 • contact@ozarkundergroundlab.com

Certificate of Analysis

Date of certificate: February 6, 2019

Client: Ramboll

Project name: Athens Well Field Capture Study

Project number: 1690006943-048

Contact people: Chris Stubbs (cstubbs@ramboll.com)
Pejman Rasouli (prasouli@ramboll.com)
Lisa Ackerman (lackerman@ramboll.com)
emeryvillelabdata@ramboll.com

Samples collected by: G. Miclette

Date samples shipped: February 1, 2019

Date samples rec'd at OUL: February 4, 2019

Date analyzed by OUL: February 5 and 6, 2019

Included with certificate of analysis:
Table of results, copies of sample collection data sheet

Results for charcoal and water samples analyzed for the presence of fluorescein and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

All results are for charcoal unless otherwise indicated.

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4647	1	MW-K4	1/25/19 1322	2/1/19 1200	ND		ND	
D4648	2	PC-144	1/25/19 1332	2/1/19 1209	ND		ND	
D4649	2	PC-144_FD	1/25/19 1333	2/1/19 1210	ND		ND	
D4650	13	ARP-4A	1/25/19 1346	2/1/19 1216	ND		ND	
D4651	14	ARP-5A	1/25/19 1353	2/1/19 1221	ND		ND	
D4652	6	ARP-6B	1/25/19 1401	2/1/19 1231	ND		ND	
D4653	7	PC-145	1/25/19 1415	2/1/19 1239	ND		ND	
D4654	8	PC-136	1/25/19 1422	2/1/19 1249	ND		567.2	29.6
D4655	9	ART-6	1/25/19 1437	2/1/19 1259	ND		ND	
D4656	10	ART-9	1/25/19 1447	2/1/19 1310	ND		566.5	49,400
D4657	16	ART-7A	1/25/19 1456	2/1/19 1319	ND		ND	
D4658	15	PC-148	1/25/19 1507	2/1/19 1331	ND		ND	

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4659	5	PC-149	1/25/19 1515	2/1/19 1340	ND		ND	
D4660	Laboratory control charcoal blank							
D4661	3	PC-150	1/25/19 1528	2/1/19 1351	ND		ND	
D4662	12	ART-4A	1/25/19 1538	2/1/19 1403	ND		ND	
D4686	8	PC-136	**Water**	2/1/19 1249	ND		573.2	1.22
D4687	10	ART-9	**Water**	2/1/19 1310	ND		573.8	22.7

Note: Dye concentrations are based upon standards used at the OUL. The standard concentrations are based upon the as sold weight of the dye that the OUL uses. If the client is not using OUL dyes, the client should provide the OUL with a sample of the dye to compare to the OUL dyes.

Footnotes:

ND = No dye detected

Thomas J. Aley, PHG and RG

Thomas Aley

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 8 **Samples Collected By:** G. Miclette

Samples Shipped By: FedEx **Samples Received By:** Amber Comstock/OUL

Date Samples Shipped: 2 / 1 / 2019 **Date Samples Received:** 2/4/19 **Time Samples Received:** 1200 **Return Cooler?** Yes ☐ No ☒

Bill to: Ramboll - per contract **Send Results to:** cstubbs@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other **Ship cooler to:** N/A

OUL use only			***Please indicate stations where dye was visible in the field***						*OUL use only*
# CHAR REC'D	LAB Charcoal NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1	D4647	1	MW-K4		1-25-19	1322	2-1-2019	1200	1
1	D4648	2	PC-144		1-25-19	1332	2-1-2019	1209	1
1	D4649	2	PC-144_FD	*Duplicate*	1-25-19	1333	2-1-2019	1210	1
1	D4650	13	ARP-4A	*No water sample*	1-25-19	1346	2-1-2019	1216	0
1	D4651	14	ARP-5A		1-25-19	1353	2-1-2019	1221	1
1	D4652	6	ARP-6B		1-25-19	1401	2-1-2019	1231	1
1	D4653	7	PC-145		1-25-19	1415	2-1-2019	1239	1
1	D4654	8	PC-136		1-25-19	1422	2-1-2019	1249	1
1	D4655	9	ART-6		1-25-19	1437	2-1-2019	1259	1
1	D4656	10	ART-9		1-25-19	1447	2-1-2019	1310	1
1	D4657	16	ART-7A		1-25-19	1456	2-1-2019	1319	1
1	D4658	15	PC-148		1-25-19	1507	2-1-2019	1331	1
1	54659	5	PC-149		1-25-19	1515	2-1-2019	1340	1
1	D4661	3	PC-150	*No water sample*	1-25-19	1528	2-1-2019	1351	0
1	D4662	12	ART-4A		1-25-19	1538	2-1-2019	1403	1

D4660- OUL Charcoal blank.

COMMENTS Analyze per standard protocol

This sheet filled out by OUL staff? Yes ~~☒~~ **No** ☒ **Charts for samples on this page proofed by OUL:** Ca

OUL Project No. 1745 **Date Analyzed:** 2-5-19 **Analyzed By:** MR/OUL

Page 1 of 1

AC/OUL

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SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 8 **Samples Collected By:** G. Miclette

Samples Shipped By: FedEx **Samples Received By:** Amber Comstock/OUL

Date Samples Shipped: 2 / 1 / 2019 **Date Samples Received:** 2/4/19 **Time Samples Received:** 1200 **Return Cooler?** Yes ☐ No ☒

Bill to: Ramboll - per contract **Send Results to:** cstubbs@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other ______ **Ship cooler to:** N/A

OUL use only			***Please indicate stations where dye was visible in the field***						OUL use only
# CHAR REC'D	LAB Water NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1		1	MW-K4		1-25-19	1322	2-1-2019	1200	1
1		2	PC-144		1-25-19	1332	2-1-2019	1209	1
1		2	PC-144_FD	*Duplicate*	1-25-19	1333	2-1-2019	1210	1
1		13	ARP-4A	*No water sample*	1-25-19	1346	2-1-2019	1216	0
1		14	ARP-5A		1-25-19	1353	2-1-2019	1221	1
1		6	ARP-6B		1-25-19	1401	2-1-2019	1231	1
1		7	PC-145		1-25-19	1415	2-1-2019	1239	1
1	D4686	8	PC-136		1-25-19	1422	2-1-2019	1249	1
1		9	ART-6		1-25-19	1437	2-1-2019	1259	1
1	D4687	10	ART-9		1-25-19	1447	2-1-2019	1310	1
1		16	ART-7A		1-25-19	1456	2-1-2019	1319	1
1		15	PC-148		1-25-19	1507	2-1-2019	1331	1
1		5	PC-149		1-25-19	1515	2-1-2019	1340	1
1		3	PC-150	*No water sample*	1-25-19	1528	2-1-2019	1351	0
1		12	ART-4A		1-25-19	1538	2-1-2019	1403	1

COMMENTS Analyze per standard protocol

This sheet filled out by OUL staff? Yes ~~☒~~ No ☒ **Charts for samples on this page proofed by OUL:** Ac

OUL Project No.______ **Date Analyzed:** 2-6-19 **Analyzed By:** Lisa Gilcrease

Page 1 of 1 AC/OUL

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LABORATORY 1572 Aley Lane • Protem, MO 65733 • (417) 785-4289 • fax (417) 785-4290 • contact@ozarkundergroundlab.com

Certificate of Analysis

Date of certificate: February 14, 2019
Client: Ramboll
Project name: Athens Well Field Capture Study
Project number: 1690006943-048
Contact people: Chris Stubbs (cstubbs@ramboll.com)
Pejman Rasouli (prasouli@ramboll.com)
Lisa Ackerman (lackerman@ramboll.com)
emeryvillelabdata@ramboll.com

Samples collected by: G. Miclette
Date samples shipped: February 8, 2019
Date samples rec'd at OUL: February 11, 2019
Date analyzed by OUL: February 13, 2019
Included with certificate of analysis:
Table of results, copies of sample collection data sheet

Results for charcoal and water samples analyzed for the presence of fluorescein and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

All results are for charcoal unless otherwise indicated.

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4747	1	MW-K4	2/1/19 1205	2/7/19 1340	ND		ND	
D4748	2	PC-144	2/1/19 1211	2/7/19 1348	ND		ND	
D4749	13	ARP-4A	2/1/19 1218	2/7/19 1359	ND		ND	
D4750	14	ARP-5A	2/1/19 1224	2/7/19 1407	ND		ND	
D4751	14	ARP-5A_FD	2/1/19 1225	2/7/19 1408	ND		ND	
D4752	6	ARP-6B	2/1/19 1234	2/7/19 1420	ND		ND	
D4753	7	PC-145	2/1/19 1242	2/7/19 1429	ND		ND	
D4754	8	PC-136	2/1/19 1253	2/7/19 1439	ND		567.0	29.3
D4755	9	ART-6	2/1/19 1303	2/7/19 1450	ND		569.0	3.12
D4756	10	ART-9	2/1/19 1314	2/7/19 1503	ND		567.0	51,300
D4757	16	ART-7A	2/1/19 1323	2/7/19 1514	ND		ND	
D4758	15	PC-148	2/1/19 1334	2/7/19 1524	ND		ND	

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4759	5	PC-149	2/1/19 1342	2/7/19 1535	ND		ND	
D4760	Laboratory control charcoal blank							
D4761	3	PC-150	2/1/19 1355	2/7/19 1547	ND		ND	
D4762	12	ART-4A	2/1/19 1407	2/7/19 1600	ND		ND	
D4784	8	PC-136	**Water**	2/7/19 1439	ND		573.2	1.81
D4785	9	ART-6	**Water**	2/7/19 1450	ND		ND	
D4786	10	ART-9	**Water**	2/7/19 1503	ND		573.2	36.0

Note: Dye concentrations are based upon standards used at the OUL. The standard concentrations are based upon the as sold weight of the dye that the OUL uses. If the client is not using OUL dyes, the client should provide the OUL with a sample of the dye to compare to the OUL dyes.

Footnotes:

ND = No dye detected

Thomas J. Aley, PHG and RG

Thomas Aley

⊛ Shipping bill
says 2/8/19
ca/oul

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1572 Aley Lane Protem, MO 65733 (417) 785-4289 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 9 **Samples Collected By:** G. Miclette

Samples Shipped By: FedEx **Samples Received By:** C. Aley / OUL

Date Samples Shipped: ⊛ 2 / 7 / 2019 **Date Samples Received:** 2/11/19 **Time Samples Received:** 1230 **Return Cooler?** Yes ☐ No ☒

Bill to: Ramboll - per contract **Send Results to:** cstubbs@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other **Ship cooler to:** N/A

OUL use only			*Please indicate stations where dye was visible in the field*						*OUL use only*
# CHAR REC'D	LAB Charcoal NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1	D4747	1	MW-K4		2-1-19	1205	2-7-19	1340	1
1	D4748	2	PC-144		2-1-19	1211	2-7-19	1348	1
1	D4749	13	ARP-4A	No water sample	2-1-19	1218	2-7-19	1359	0
1	D4750	14	ARP-5A		2-1-19	1224	2-7-19	1407	1
1	D4751	14	ARP-5A_FD	Duplicate	2-1-19	1225	2-7-19	1408	1
1	D4752	6	ARP-6B		2-1-19	1234	2-7-19	1420	1
1	D4753	7	PC-145		2-1-19	1242	2-7-19	1429	1
1	D4754	8	PC-136		2-1-19	1253	2-7-19	1439	1
1	D4755	9	ART-6		2-1-19	1303	2-7-19	1450	1
1	D4756	10	ART-9		2-1-19	1314	2-7-19	1503	1
1	D4757	16	ART-7A		2-1-19	1323	2-7-19	1514	1
1	D4758	15	PC-148		2-1-19	1334	2-7-19	1524	1
1	D4759	5	PC-149		2-1-19	1342	2-7-19	1535	1
1	D4761	3	PC-150	No water sample	2-1-19	1355	2-7-19	1547	0
1	D4762	12	ART-4A		2-1-19	1407	2-7-19	1600	1

D4760 - OUL Charcoal blank

COMMENTS Analyze per standard protocol

This sheet filled out by OUL staff? Yes ~~☒~~ [✓ No ☐] **Charts for samples on this page proofed by OUL:** Ca

OUL Project No. 1745 **Date Analyzed:** 2/13/2019 **Analyzed By:** KC/OUL

Page 1 of 1 oul

(*) Shipping bill
Says 2/8/19
ca/oul.

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 9 **Samples Collected By:** G. Miclette

Samples Shipped By: FedEx **Samples Received By:** C. Aley / OUL

Date Samples Shipped: (*) 2 / 7 / 2019 **Date Samples Received:** 2 / 11 / 19 **Time Samples Received:** 1230 **Return Cooler?** Yes ☐ No ☒

Bill to: Ramboll - per contract **Send Results to:** cstubbs@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other ______ **Ship cooler to:** N/A

OUL use only			***Please indicate stations where dye was visible in the field***						*OUL use only*
# CHAR REC'D	LAB Water NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1		1	MW-K4		2-1-19	1205	2-7-19	1340	1
1		2	PC-144		2-1-19	1211	2-7-19	1348	1
1		13	ARP-4A	*No water sample*	2-1-19	1218	2-7-19	1359	0
1		14	ARP-5A		2-1-19	1224	2-7-19	1407	1
1		14	ARP-5A_FD	*Duplicate*	2-1-19	1225	2-7-19	1408	1
1		6	ARP-6B		2-1-19	1234	2-7-19	1420	1
1		7	PC-145		2-1-19	1242	2-7-19	1429	1
1	D4784	8	PC-136		2-1-19	1253	2-7-19	1439	1
1	D4785	9	ART-6		2-1-19	1303	2-7-19	1450	1
1	D4786	10	ART-9		2-1-19	1314	2-7-19	1503	1
1		16	ART-7A		2-1-19	1323	2-7-19	1514	1
1		15	PC-148		2-1-19	1334	2-7-19	1524	1
1		5	PC-149		2-1-19	1342	2-7-19	1535	1
1		3	PC-150	*No water sample*	2-1-19	1355	2-7-19	1547	0
1		12	ART-4A		2-1-19	1407	2-7-19	1600	1

COMMENTS Analyze per standard protocol

This sheet filled out by OUL staff? Yes ~~☒~~ [✓ No ☐] **Charts for samples on this page proofed by OUL:** CA

OUL Project No. 1745 **Date Analyzed:** 2/13/2019 **Analyzed By:** KC/OUL

Page 1 of 1 OUL

Ozark UNDERGROUND LABORATORY 1572 Aley Lane • Protem, MO 65733 • (417) 785-4289 • fax (417) 785-4290 • contact@ozarkundergroundlab.com

Certificate of Analysis

Date of certificate: February 20, 2019

Client: Ramboll

Project name: Athens Well Field Capture Study

Project number: 1690006943-048

Contact people: Chris Stubbs (cstubbs@ramboll.com)
Pejman Rasouli (prasouli@ramboll.com)
Lisa Ackerman (lackerman@ramboll.com)
emeryvillelabdata@ramboll.com

Samples collected by: G. Miclette

Date samples shipped: February 14, 2019

Date samples rec'd at OUL: February 18, 2019

Date analyzed by OUL: February 19 and 20, 2019

Included with certificate of analysis:
Table of results, copies of sample collection data sheet

Results for charcoal and water samples analyzed for the presence of fluorescein and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

All results are for charcoal unless otherwise indicated.

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4814	1	MW-K4	2/7/19 1344	2/14/19 1355	ND		ND	
D4815	2	PC-144	2/7/19 1350	2/14/19 1405	ND		ND	
D4816	13	ARP-4A	2/7/19 1403	2/14/19 1416	ND		ND	
D4817	14	ARP-5A	2/7/19 1412	2/14/19 1425	ND		ND	
D4818	6	ARP-6B	2/7/19 1423	2/14/19 1434	ND		ND	
D4819	7	PC-145	2/7/19 1431	2/14/19 1443	ND		ND	
D4820	Laboratory control charcoal blank							
D4821	7	PC-145_FD	2/7/19 1433	2/14/19 1444	ND		ND	
D4822	8	PC-136	2/7/19 1443	2/14/19 1454	ND		567.1	43.1
D4823	9	ART-6	2/7/19 1454	2/14/19 1502	ND		570.6 *	0.762
D4824	10	ART-9	2/7/19 1506	2/14/19 1514	ND		566.5	6,770
D4825	16	ART-7A	2/7/19 1518	2/14/19 1525	ND		ND	

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4826	15	PC-148	2/7/19 1527	2/14/19 1536	ND		ND	
D4827	5	PC-149	2/7/19 1539	2/14/19 1547	ND		ND	
D4828	3	PC-150	2/7/19 1550	2/14/19 1558	ND		ND	
D4829	12	ART-4A	2/7/19 1604	2/14/19 1609	ND		ND	
D4833	8	PC-136	**Water**	2/14/19 1454	ND		572.8	1.41
D4834	10	ART-9	**Water**	2/14/19 1514	ND		573.8	19.9

Note: Dye concentrations are based upon standards used at the OUL. The standard concentrations are based upon the as sold weight of the dye that the OUL uses. If the client is not using OUL dyes, the client should provide the OUL with a sample of the dye to compare to the OUL dyes.

Footnotes:

ND = No dye detected

* = A fluorescence peak is present that does not meet all the criteria for a positive dye result. However, it has been calculated as though it was the tracer dye.

Thomas J. Aley, PHG and RG

Thomas Aley

OZARK UNDERGROUND LABORATORY, INC.
1572 Aley Lane Protem, MO 65733 (417) 785-4289 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 10 **Samples Collected By:** G. Miclette
Samples Shipped By: FedEx **Samples Received By:** KC / OUL
Date Samples Shipped: 2 / 14 / 2019 **Date Samples Received:** 2 / 18 / 2019 **Time Samples Received:** 1330
Return Cooler? Yes ☐ No ☒
Bill to: Ramboll - per contract **Send Results to:** cstubbs@ramboll.com
Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other **Ship cooler to:** N/A

OUL use only			*Please indicate stations where dye was visible in the field*						*OUL use only*
# CHAR REC'D	LAB Charcoal NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1	D4814	1	MW-K4		2-7-19	1344	2-14-19	1355	1
1	D4815	2	PC-144		2-7-19	1350	2-14-19	1405	1
1	D4816	13	ARP-4A	*No water sample*	2-7-19	1403	2-14-19	1416	0
1	D4817	14	ARP-5A		2-7-19	1412	2-14-19	1425	1
1	D4818	6	ARP-6B		2-7-19	1423	2-14-19	1434	1
1	D4819	7	PC-145		2-7-19	1431	2-14-19	1443	1
1	D4821	7	PC-145_FD	*Duplicate*	2-7-19	1433	2-14-19	1444	1
1	D4822	8	PC-136		2-7-19	1443	2-14-19	1454	1
1	D4823	9	ART-6		2-7-19	1454	2-14-19	1502	1
1	D4824	10	ART-9		2-7-19	1506	2-14-19	1514	1
1	D4825	16	ART-7A		2-7-19	1518	2-14-19	1525	1
1	D4826	15	PC-148		2-7-19	1527	2-14-19	1536	1
1	D4827	5	PC-149		2-7-19	1539	2-14-19	1547	1
1	D4828	3	PC-150	*No water sample*	2-7-19	1550	2-14-19	1558	0
1	D4829	12	ART-4A		2-7-19	1604	2-14-19	1609	1

COMMENTS Analyze per standard protocol OUL Charcoal Blank - D4820

This sheet filled out by OUL staff? Yes ☒ No ☐ **Charts for samples on this page proofed by OUL:** KC
OUL Project No. 1745 **Date Analyzed:** 2/19/19 **Analyzed By:** MR / OUL

Page 1 of 1 /OUL

OZARK UNDERGROUND LABORATORY, INC.

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SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 10 **Samples Collected By:** G. Miclette

Samples Shipped By: FedEx **Samples Received By:** KC/OUL

Date Samples Shipped: 2 / 14 / 2019 **Date Samples Received:** 2 / 18 / 2019 **Time Samples Received:** 1330

Return Cooler? Yes ☐ No ☒

Bill to: Ramboll - per contract **Send Results to:** cstubbs@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other ______ **Ship cooler to:** N/A

OUL use only			*Please indicate stations where dye was visible in the field*						*OUL use only*
# CHAR REC'D	LAB NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1		1	MW-K4		2-7-19	1344	2-14-19	1355	1
1		2	PC-144		2-7-19	1350	2-14-19	1405	1
1		13	ARP-4A	No water sample	2-7-19	1403	2-14-19	1416	0
1		14	ARP-5A		2-7-19	1412	2-14-19	1425	1
1		6	ARP-6B		2-7-19	1423	2-14-19	1434	1
1		7	PC-145		2-7-19	1431	2-14-19	1443	1
1		7	PC-145_FD	Duplicate	2-7-19	1433	2-14-19	1444	1
1	D4833	8	PC-136		2-7-19	1443	2-14-19	1454	1
1		9	ART-6		2-7-19	1454	2-14-19	1502	1
1	D4834	10	ART-9		2-7-19	1506	2-14-19	1514	1
1		16	ART-7A		2-7-19	1518	2-14-19	1525	1
1		15	PC-148		2-7-19	1527	2-14-19	1536	1
1		5	PC-149		2-7-19	1539	2-14-19	1547	1
1		3	PC-150	No water sample	2-7-19	1550	2-14-19	1558	0
1		12	ART-4A		2-7-19	1604	2-14-19	1609	1

COMMENTS Analyze per standard protocol

This sheet filled out by OUL staff? Yes ☒ No ☐ **Charts for samples on this page proofed by OUL:** KC

OUL Project No. 1745 **Date Analyzed:** 2/20/19 **Analyzed By:** Lisa Gilcrease

Certificate of Analysis

Date of certificate: March 4, 2019
Client: Ramboll
Project name: Athens Well Field Capture Study
Project number: 1690006943-048
Contact people: Chris Stubbs (cstubbs@ramboll.com)
Pejman Rasouli (prasouli@ramboll.com)
Lisa Ackerman (lackerman@ramboll.com)
emeryvillelabdata@ramboll.com

Samples collected by: G. Miclette
Date samples shipped: February 22, 2019
Date samples rec'd at OUL: February 25, 2019
Date analyzed by OUL: March 1, 2019
Included with certificate of analysis:
Table of results, copies of sample collection data sheet

Results for charcoal and water samples analyzed for the presence of fluorescein and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

All results are for charcoal unless otherwise indicated.

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4933	1	MW-K4	2/14/19 1358	2/22/19 1126	ND		ND	
D4934	2	PC-144	2/14/19 1408	2/22/19 1140	ND		ND	
D4935	2	PC-144_FD	2/14/19 1409	2/22/19 1141	ND		ND	
D4936	13	ARP-4A	2/14/19 1419	2/22/19 1151	ND		ND	
D4937	14	ARP-5A	2/14/19 1428	2/22/19 1200	ND		ND	
D4938	6	ARP-6B	2/14/19 1437	2/22/19 1211	ND		ND	
D4939	7	PC-145	2/14/19 1447	2/22/19 1220	ND		ND	
D4940	Laboratory control charcoal blank							
D4941	8	PC-136	2/14/19 1458	2/22/19 1232	ND		ND	
D4942	9	ART-6	2/14/19 1505	2/22/19 1241	ND		ND	
D4943	10	ART-9	2/14/19 1518	2/22/19 1253	ND		566.6	4,830
D4944	16	ART-7A	2/14/19 1528	2/22/19 1303	ND		ND	

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D4945	15	PC-148	2/14/19 1539	2/22/19 1315	ND		ND	
D4946	5	PC-149	2/14/19 1550	2/22/19 1324	ND		ND	
D4947	3	PC-150	2/14/19 1601	2/22/19 1336	ND		ND	
D4948	12	ART-4A	2/14/19 1613	2/22/19 1353	ND		ND	
D5155	10	ART-9	**Water**	2/22/19 1253	ND		573.2	14.0

Note: Dye concentrations are based upon standards used at the OUL. The standard concentrations are based upon the as sold weight of the dye that the OUL uses. If the client is not using OUL dyes, the client should provide the OUL with a sample of the dye to compare to the OUL dyes.

Footnotes:

ND = No dye detected

Thomas J. Aley, PHG and RG

Thomas Aley

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 11 **Samples Collected By:** G. Miclette

Samples Shipped By: FedEx **Samples Received By:** Amber Comstock/OUL

Date Samples Shipped: 2 / 22 / 2019 **Date Samples Received:** 2/25/19 **Time Samples Received:** 1230

Return Cooler? Yes ☐ **No** ☒

Bill to: Ramboll - per contract **Send Results to:** cstubbs@ramboll.com

Analyze for: ☒ **Fluorescein** ☐ **Eosine** ☒ **Rhodamine WT** ☐ **Other** **Ship cooler to:** N/A

OUL use only			*Please indicate stations where dye was visible in the field*						OUL use only
# CHAR REC'D	LAB NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1	D4933	1	MW-K4		2-14-19	1358	2-22-19	1126	1
1	D4934	2	PC-144		2-14-19	1408	2-22-19	1140	1
1	D4935	2	PC-144_FD	*Duplicate*	2-14-19	1409	2-22-19	1141	1
1	D4936	13	ARP-4A	*No water sample*	2-14-19	1419	2-22-19	1151	0
1	D4937	14	ARP-5A		2-14-19	1428	2-22-19	1200	1
1	D4938	6	ARP-6B		2-14-19	1437	2-22-19	1211	1
1	D4939	7	PC-145		2-14-19	1447	2-22-19	1220	1
1	D4941	8	PC-136		2-14-19	1458	2-22-19	1232	1
1	D4942	9	ART-6		2-14-19	1505	2-22-19	1241	1
1	D4943	10	ART-9		2-14-19	1518	2-22-19	1253	1
1	D4944	16	ART-7A		2-14-19	1528	2-22-19	1303	1
1	D4945	15	PC-148		2-14-19	1539	2-22-19	1315	1
1	D4946	5	PC-149		2-14-19	1550	2-22-19	1324	1
1	D4947	3	PC-150	*No water sample*	2-14-19	1601	2-22-19	1336	0
1	D4948	12	ART-4A		2-14-19	1613	2-22-19	1353	1

COMMENTS Analyze per standard protocol D4940-OUL charcoal blank

This sheet filled out by OUL staff? Yes ☒ **No** ☒ **Charts for samples on this page proofed by OUL:** AC/OUL

OUL Project No. 1745 **Date Analyzed:** 3/1/2019 **Analyzed By:** KC/OUL

Page **1** of **1** AC/OUL

OZARK UNDERGROUND LABORATORY, INC.

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SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 11 **Samples Collected By:** G. Miclette

Samples Shipped By: FedEx **Samples Received By:** Amber Comstock/OUL

Date Samples Shipped: 2 / 22 / 2019 **Date Samples Received:** 2/25/19 **Time Samples Received:** 1230

Return Cooler? Yes ☐ No ☒

Bill to: Ramboll - per contract **Send Results to:** cstubbs@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other **Ship cooler to:** N/A

OUL use only			*Please indicate stations where dye was visible in the field*						OUL use only
# CHAR REC'D	LAB water NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1		1	MW-K4		2-14-19	1358	2-22-19	1126	1
1		2	PC-144		2-14-19	1408	2-22-19	1140	1
1		2	PC-144_FD	*Duplicate*	2-14-19	1409	2-22-19	1141	1
1		13	ARP-4A	*No water sample*	2-14-19	1419	2-22-19	1151	0
1		14	ARP-5A		2-14-19	1428	2-22-19	1200	1
1		6	ARP-6B		2-14-19	1437	2-22-19	1211	1
1		7	PC-145		2-14-19	1447	2-22-19	1220	1
1		8	PC-136		2-14-19	1458	2-22-19	1232	1
1		9	ART-6		2-14-19	1505	2-22-19	1241	1
1	D5155	10	ART-9		2-14-19	1518	2-22-19	1253	1
1		16	ART-7A		2-14-19	1528	2-22-19	1303	1
1		15	PC-148		2-14-19	1539	2-22-19	1315	1
1		5	PC-149		2-14-19	1550	2-22-19	1324	1
1		3	PC-150	*No water sample*	2-14-19	1601	2-22-19	1336	0
1		12	ART-4A		2-14-19	1613	2-22-19	1353	1

COMMENTS Analyze per standard protocol

This sheet filled out by OUL staff? Yes ☒ No ☒ **Charts for samples on this page proofed by OUL:** AC/OUL

OUL Project No. 1745 **Date Analyzed:** 3/1/2019 **Analyzed By:** KC/OUL

Page 1 of 1 AC/OUL

Ozark UNDERGROUND LABORATORY 1572 Aley Lane • Protem, MO 65733 • (417) 785-4289 • fax (417) 785-4290 • contact@ozarkundergroundlab.com

Certificate of Analysis

Date of certificate: March 7, 2019

Client: Ramboll

Project name: Athens Well Field Capture Study

Project number: 1690006943-048

Contact people: Chris Stubbs (cstubbs@ramboll.com)
Pejman Rasouli (prasouli@ramboll.com)
Lisa Ackerman (lackerman@ramboll.com)
emeryvillelabdata@ramboll.com

Samples collected by: G. Miclette

Date samples shipped: March 1, 2019

Date samples rec'd at OUL: March 4, 2019

Date analyzed by OUL: March 6, 2019

Included with certificate of analysis:
Table of results, copies of sample collection data sheet

Results for charcoal and water samples analyzed for the presence of fluorescein and rhodamine WT (RWT) dyes.

Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

All results are for charcoal unless otherwise indicated.

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D5162	1	MW-K4	2/22/19 1130	3/1/19 1312	ND		ND	
D5163	2	PC-144	2/22/19 1144	3/1/19 1323	ND		ND	
D5164	13	ARP-4A	2/22/19 1153	3/1/19 1332	ND		ND	
D5165	14	ARP-5A	2/22/19 1203	3/1/19 1341	ND		ND	
D5166	14	ARP-5A_FD	2/22/19 1205	3/1/19 1343	ND		ND	
D5167	6	ARP-6B	2/22/19 1214	3/1/19 1351	ND		ND	
D5168	7	PC-145	2/22/19 1223	3/1/19 1403	ND		ND	
D5169	8	PC-136	2/22/19 1235	3/1/19 1410	ND		567.2	37.3
D5170	9	ART-6	2/22/19 1244	3/1/19 1424	ND		568.2 *	0.761
D5171	10	ART-9	2/22/19 1256	3/1/19 1435	ND		566.6	8,040
D5172	16	ART-7A	2/22/19 1306	3/1/19 1446	ND		ND	
D5173	15	PC-148	2/22/19 1318	3/1/19 1455	ND		ND	

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		RWT	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D5174	5	PC-149	2/22/19 1327	3/1/19 1504	ND		ND	
D5175	3	PC-150	2/22/19 1340	3/1/19 1516	ND		ND	
D5176	12	ART-4A	2/22/19 1358	3/1/19 1527	ND		ND	
D5223	8	PC-136	**Water**	3/1/19 1410	ND		572.2	1.52
D5224	10	ART-9	**Water**	3/1/19 1435	ND		573.6	15.0

Note: Dye concentrations are based upon standards used at the OUL. The standard concentrations are based upon the as sold weight of the dye that the OUL uses. If the client is not using OUL dyes, the client should provide the OUL with a sample of the dye to compare to the OUL dyes.

Footnotes:

ND = No dye detected

* = A fluorescence peak is present that does not meet all the criteria for a positive dye result. However, it has been calculated as though it was the tracer dye.

Thomas J. Aley, PHG and RG

Thomas Aley

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 12 **Samples Collected By:** G. Miclette

Samples Shipped By: FedEx **Samples Received By:** Amber Comstock/OUL

Date Samples Shipped: 3 / 1 / 2019 **Date Samples Received:** 3 / 4 / 19 **Time Samples Received:** 1230pm **Return Cooler?** Yes ☐ No ☒

Bill to: Ramboll - per contract **Send Results to:** cstubbs@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other ____ **Ship cooler to:** N/A

OUL use only			*Please indicate stations where dye was visible in the field*						*OUL use only*
# CHAR REC'D	LAB Charcoal NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1	D5162	1	MW-K4		2-22-19	1130	3-1-19	1312	1
1	D5163	2	PC-144		2-22-19	1144	3-1-19	1323	1
1	D5164	13	ARP-4A	*No water sample*	2-22-19	1153	3-1-19	1332	0
1	D5165	14	ARP-5A		2-22-19	1203	3-1-19	1341	1
1	D5166	14	ARP-5A_FD	*Duplicate*	2-22-19	1205	3-1-19	1343	1
1	D5167	6	ARP-6B		2-22-19	1214	3-1-19	1351	1
1	D5168	7	PC-145		2-22-19	1223	3-1-19	1403	1
1	D5169	8	PC-136		2-22-19	1235	3-1-19	1410	1
1	D5170	9	ART-6		2-22-19	1244	3-1-19	1424	1
1	D5171	10	ART-9		2-22-19	1256	3-1-19	1435	1
1	D5172	16	ART-7A		2-22-19	1306	3-1-19	1446	1
1	D5173	15	PC-148		2-22-19	1318	3-1-19	1455	1
1	D5174	5	PC-149		2-22-19	1327	3-1-19	1504	1
1	D5175	3	PC-150	*No water sample*	2-22-19	1340	3-1-19	1516	0
1	D5176	12	ART-4A		2-22-19	1358	3-1-19	1527	1

COMMENTS Analyze per standard protocol

This sheet filled out by OUL staff? Yes ☒ No ☒ **Charts for samples on this page proofed by OUL:** KC

OUL Project No. 1745 **Date Analyzed:** 3/6/19 **Analyzed By:** MR/OUL

Page **1** of **1**

KC/OUL

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 email: contact@ozarkundergroundlab.com

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project: Ramboll - NERT Athens Well Field (AWF) **Week No:** 12 **Samples Collected By:** G. Miclette

Samples Shipped By: FedEx **Samples Received By:** Amber Comstock/OUL

Date Samples Shipped: 3 / 1 / 2019 **Date Samples Received:** 3 / 4 / 19 **Time Samples Received:** 1230pm **Return Cooler?** Yes ☐ No ☒

Bill to: Ramboll - per contract **Send Results to:** cstubbs@ramboll.com

Analyze for: ☒ Fluorescein ☐ Eosine ☒ Rhodamine WT ☐ Other ____ **Ship cooler to:** N/A

OUL use only			*Please indicate stations where dye was visible in the field*						*OUL use only*
# CHAR REC'D	LAB water NUMBER	STATION NUMBER	STATION NAME	NOTES/COMMENT	PLACED		COLLECTED		WATER REC'D
					DATE	TIME	DATE	TIME	
1		1	MW-K4		2-22-19	1130	3-1-19	1312	1
1		2	PC-144		2-22-19	1144	3-1-19	1323	1
1		13	ARP-4A	*No water sample*	2-22-19	1153	3-1-19	1332	0
1		14	ARP-5A		2-22-19	1203	3-1-19	1341	1
1		14	ARP-5A_FD	*Duplicate*	2-22-19	1205	3-1-19	1343	1
1		6	ARP-6B		2-22-19	1214	3-1-19	1351	1
1		7	PC-145		2-22-19	1223	3-1-19	1403	1
1	D5223	8	PC-136		2-22-19	1235	3-1-19	1410	1
1		9	ART-6		2-22-19	1244	3-1-19	1424	1
1	D5224	10	ART-9		2-22-19	1256	3-1-19	1435	1
1		16	ART-7A		2-22-19	1306	3-1-19	1446	1
1		15	PC-148		2-22-19	1318	3-1-19	1455	1
1		5	PC-149		2-22-19	1327	3-1-19	1504	1
1		3	PC-150	*No water sample*	2-22-19	1340	3-1-19	1516	0
1		12	ART-4A		2-22-19	1358	3-1-19	1527	1

COMMENTS Analyze per standard protocol

This sheet filled out by OUL staff? Yes ☒ No ☒ **Charts for samples on this page proofed by OUL:** KC

OUL Project No. 1745 **Date Analyzed:** 3/6/19 **Analyzed By:** MR/OUL

Page 1 of 1

KC/OUL

ATTACHMENT B-7
CORELAB LABORATORY REPORTS

Core Lab
RESERVOIR OPTIMIZATION

Petroleum Services Division
3437 Landco Dr.
Bakersfield, California 93308
Tel: 661-325-5657
Fax: 661-325-5808
www.corelab.com

November 30, 2018

Chris Stubbs
Ramboll US Corporation
2200 Powell Street, Suite 700
Emeryville, CA 94608

Subject: Petrophysical Properties
File No.: 1802475

Dear Mr. Stubbs:

Enclosed are final data for the 15 samples submitted to our laboratory from project NERT AWF Capture Evaluation in Henderson, Nevada.

Appropriate ASTM, EPA or API methodologies were used for this project and SOP's are available on request. The sample for this project is currently in storage and will be retained for thirty days past completion of testing at no charge. At the end of thirty days, the sample will be disposed. You may contact me regarding continued storage, disoposal, or return of the sample.

Thank you for this opportunity to be of service to Ramboll US Corporation. Please do not hesitate to contact us at (661-325-5657) if you have any questions regarding these results or if we can be of any additional service.

Sincerely,
Core Laboratories

Allison B

Allison Burich
Core Analyst

Table 1
Physical Properties Data

Petroleum Services

Ramboll US Corporation

Core Lab File No. 1802475

Project Name : NERT AWF Capture Evaluation
Project Number : 1690006943-048

			METHODS:	API RP40 ASTM D2216		API RP40 D5550		API RP 40 ASTM D425M	
Sample ID.	Depth ft.	Sample Date	Sample [1] Orientation	Moisture Content % dry weight	Density		Specific Gravity	Porosity [2]	
					Dry Bulk g/cm^3	Grain gm/cc		Total %	Effective[3] %Vb [4]
PZ1D-14-14.2	14.20	07/10/18	V	4.91	1.78	2.67	2.67	33.25	24.22
PZ1D-27.5-27.8	27.60	07/10/18	V	8.01	1.79	2.68	2.68	33.07	17.90
PZ1D-32-32.3	32.20	07/10/18	V	16.74	1.76	2.70	2.70	34.88	18.85
PZ1D-33.3-33.8	33.50	07/10/18	V	95.13	0.74	2.73	2.73	72.95	28.45
PZ1D-35-35.5	35.30	07/10/18	V	58.86	1.02	2.70	2.70	62.39	10.08
PZ1D-36-36.5	36.20	07/10/18	V	45.28	1.19	2.72	2.72	56.36	10.35
PZ1D-37-37.5	37.20	07/10/18	V	68.14	0.94	2.66	2.66	64.74	13.07
PZ1D-38-38.5	38.20	07/10/18	V	42.83	1.22	2.75	2.75	55.66	8.99
PZ1D-39-39.5	39.30	07/10/18	V	42.83	1.23	2.75	2.75	55.18	8.56
PZ1D-41.2-41.7	41.50	07/10/18	V	60.41	1.01	2.74	2.74	63.15	15.88
PZ1D-43.3-43.8	43.60	07/10/18	V	59.81	1.01	2.74	2.74	63.21	12.21
PZ1D-45.2-45.7	45.50	07/10/18	V	96.44	0.72	2.69	2.69	73.21	18.29
PZ1D-48.3-48.8	48.50	07/10/18	V	42.41	1.20	2.69	2.69	55.26	13.32
PZ1D51-51.5	51.20	07/10/18	V	38.57	1.28	2.69	2.69	52.35	10.98
PZ1D5-54.54.5	54.30	07/10/18	V	39.33	1.27	2.73	2.73	53.34	5.71

Table 1
Physical Properties Data

Ramboll US Corporation

Core Lab File No.	1802475
Project Name :	NERT AWF Capture Evaluation
Project Number :	1690006943-048

(1) Sample Orientation: H = horizontal; V = vertical.
(2) Total Porosity = no pore fluids in place; all interconnected pore channels.
(3) Effective Porosity = drainage porosity.
(4) Vb = Bulk Volume, cc.

Table 2

HYDRAULIC CONDUCTIVITY

PETROLEUM SERVICES

Ramboll US Corporation Core Lab File No. 1802475

Project Name : NERT AWF Capture Evaluation
Project Number : 1690006943-048

METHODS: API RP 40; ASTM D5084; EPA 9100

Sample ID.	Depth, ft.	Sample Date	Sample Orientation [1]	100 psi Net Confining Stress: Effective [2,3] Permeability to Water, millidarcy	100 psi Net Confining Stress: Saturated Hydraulic Conductivity, [2,3] cm/s
PZ1D-27.5-27.8	27.60	07/10/18	V	380	3.71E-04
PZ1D-32-32.3	32.20	07/10/18	V	32.0	3.34E-05
PZ1D-33.3-33.8	33.50	07/10/18	V	0.159	1.61E-07
PZ1D-36-36.5	36.20	07/10/18	V	0.068	6.53E-08
PZ1D-38-38.5	38.20	07/10/18	V	0.151	1.55E-07
PZ1D-41.2-41.7	41.50	07/10/18	V	0.115	1.09E-07
PZ1D-45.2-45.7	45.50	07/10/18	V	0.108	1.04E-07
PZ1D51-51.5	51.20	07/10/18	V	0.046	4.75E-08

(1) Sample Orientation: H = horizontal; V = vertical
(2) Native State or Effective = With as-received pore fluids in place.
(3) Permeability to water and hydraulic conductivity measured at saturated conditions.

RAMBOLL ENVIRON

CHAIN-OF-CUSTODY FORM

UST PROJECT OR IS EDF REQUIRED? YES NO IF YES, GLOBAL ID# ______ MSA # ______ WORK ORDER # ______

PROJECT NAME/FACILITY ID NERT AWF capture Evaluation DATE 7/10/2018 FIELD PERSON# J. Manheim / A. Manion

PROJECT LOCATION Henderson, NV PROJECT MANAGER C. Stubbs

PROJECT NUMBER 1690006943-048 LABORATORY CORE LABS

Sampler J. Manheim

Signature J Manheim

SAMPLE ID NUMBER	SAMPLE DATE	SAMPLE TIME	SAMPLE DEPTH (F)	AIR SAMPLE VOLUME (L)	MATRIX: (A)IR; (G)AS; (W)ATER	NUMBER OF CONTAINERS	FILTERED/UNFILTERED (F/U)	PRESERVATION (SEE KEY)	Analysis Required Hold*		COMMENTS
PT-PZ1D-14.0-14.3-20180710	7/10/2018	0848	14.0-14.3	NA	S	2	U	None	X	✓	
PT-PZ1D-27.5-27.8-20180710		0905	27.5-27.8			2			X	✓	*Hold pending
PT-PZ1D-32.0-32.3-20180710		0920	32.0-32.3			2			X	✓	instruction from
PT-PZ1D-33.3-33.8-20180710		0944	33.3-33.8			1			X	✓	Pejman Basouli –
PT-PZ1D-35.0-35.5-20180710		0952	35.0-35.5						X	✓	prasouli@ramboll.com
PT-PZ1D-36.0-36.5-20180710		1003	36.0-36.5						X	✓	or Chris Stubbs –
PT-PZ1D-37.0-37.5-20180710	↓	1012	37.0-37.5	↓	↓	↓	↓	↓	X	✓	cstubbs@ramboll.com
PT-PZ1D-38.0-38.5-20180710	7/10/2018	1018	38.0-38.5	NA	S	1	U	None	X	✓	
TOTAL						11			8		

RELINQUISHED BY	TIME/DATE	RECEIVED BY COMPANY	TIME/DATE		
Ramboll - J. Manheim	1000 7/11/18	FedEx	1000 7/11/18	TURNAROUND TIME (CIRCLE ONE)	SAME DAY 24 HOURS 48 HOURS 72 HOURS 5 DAYS [✓ NORMAL]
RELINQUISHED BY	TIME/DATE	RECEIVED BY COMPANY Tracey Bishop Core Lab	1318 7/12/18		
RELINQUISHED BY	TIME/DATE	RECEIVED BY COMPANY	TIME/DATE	SAMPLE INTEGRITY INTACT Y N TEMP______	SAMPLE INTEGRITY INTACT Y N

SWBU Office Locations:

☐ 18100 Von Karman Avenue, Suite 600, Irvine, CA 92612	+1 949 261 5151	+1 949 261 6202
☐ 350 S Grand Avenue, Suite 2800, Los Angeles, CA 90071	+1 213 943 6300	+1 213 943 6301
☐ 2111 East Highland Avenue, Suite 402, Phoenix, AZ 85016	+1 602 734 7700	+1 602 734-7701

Page 1 of 1

RAMBOLL ENVIRON

CHAIN-OF-CUSTODY FORM

UST PROJECT OR IS EDF REQUIRED? YES NO IF YES, GLOBAL ID# ______ MSA # ______ WORK ORDER # ______

PROJECT NAME/FACILITY ID NERT AWF Capture Evaluation DATE 7/10/2018 FIELD PERSON# J. Manheim/A. Manion

PROJECT LOCATION Henderson, NV PROJECT MANAGER C. Stubbs

PROJECT NUMBER 1690006943-048 LABORATORY CORE LABS

Sampler J. Manheim

Signature J Manheim

Analysis Required

SAMPLE ID NUMBER	SAMPLE DATE	SAMPLE TIME	SAMPLE DEPTH (F)	AIR SAMPLE VOLUME (L)	MATRIX: (A)IR; (G)AS; (W)ATER	NUMBER OF CONTAINERS	FILTERED/UNFILTERED (F/U)	PRESERVATION (SEE KEY)	Hold*		COMMENTS
PT-PZ1D-39.0-39.5-20180710	7/10/18	1025	39.0-39.5	NA	S	1	U	None	X	✓	
PT-PZ1D-41.2-41.7-20180710	↓	1031	41.2-41.7	↓	↓	↓	↓	↓	X	✓	*Hold pending
PT-PZ1D-43.3-43.8-20180710	↓	1037	43.3-43.8	↓	↓	↓	↓	↓	X	✓	instruction
PT-PZ1D-45.2-45.7-20180710	↓	1045	45.2-45.7	↓	↓	↓	↓	↓	X	✓	from Pejman
PT-PZ1D-48.3-48.8-20180710	↓	1050	48.3-48.8	↓	↓	↓	↓	↓	X	✓	Rasouli –
PT-PZ1D-51.0-51.5-20180710	↓	1057	51.0-51.5	↓	↓	↓	↓	↓	X	✓	prasouli@ramboll.com
PT-PZ1D-54.0-54.5-20180710	7/10/18	1102	54.0-54.5	NA	S	1	U	None	X	✓	or chris Stubbs –
											cstubbs@ramboll.com
TOTAL						7			7		

RELINQUISHED BY	TIME/DATE	RECEIVED BY COMPANY	TIME/DATE	TURNAROUND TIME (CIRCLE ONE)	
Ramboll - J. Manheim	1000 7/11/18	FedEx	1000 7/11/18	SAME DAY 24 HOURS 48 HOURS	72 HOURS 5 DAYS [✓ NORMAL]
		Tracey Bishop Core Lab	1311 7-12-18		
				SAMPLE INTEGRITY INTACT Y N TEMP______	SAMPLE INTEGRITY INTACT Y N

SWBU Office Locations:
☐ 18100 Von Karman Avenue, Suite 600, Irvine, CA 92612 +1 949 261 5151 +1 949 261 6202
☐ 350 S Grand Avenue, Suite 2800, Los Angeles, CA 90071 +1 213 943 6300 +1 213 943 6301
☐ 2111 East Highland Avenue, Suite 402, Phoenix, AZ 85016 +1 602 734 7700 +1 602 734-7701

Page 1 of 1

Petroleum Services Division
3437 Landco Dr.
Bakersfield, California 93308
Tel: 661-325-5657
Fax: 661-325-5808
www.corelab.com

December 26, 2018

Jessica Donovan/Chris Stubbs
Ramboll US Corporation
2200 Powell Street, Suite 700
Emeryville, CA 94608

Subject: Petrophysical Properties
File No.: 1802753

Dear Mr. Stubbs:

Enclosed are final data for the 10 samples submitted to our laboratory from project NERT AWF Capture Evaluation in Henderson, Nevada.

Moisture Content, Density, Porosity, and Hydraulic Conductivity were performed on requested samples where there was suitable recovery. Appropriate ASTM, EPA or API methodologies were used for this project and SOP's are available on request. The sample for this project is currently in storage and will be retained for thirty days past completion of testing at no charge. At the end of thirty days, the sample will be disposed. You may contact me regarding continued storage, disoposal, or return of the sample.

Thank you for this opportunity to be of service to Ramboll US Corporation. Please do not hesitate to contact us at (661-325-5657) if you have any questions regarding these results or if we can be of any additional service.

Sincerely,
Core Laboratories

Allison Burich
Core Analyst

Table 1
Physical Properties Data

Petroleum Services

Ramboll US Corporation

Core Lab File No: 1802753

Project Name : NERT AWF Capture Evaluation
Project Number : 1690006943-048 (Task M25)

METHODS: ASTM D2216 ASTM D5550 ASTM D425M

Sample ID.	Depth ft.	Sample[1] Orientation	Moisture Content	Density		Specific Gravity	Porosity[2]	
			% dry weight	Dry Bulk g/cm^3	Grain gm/cc		Total %	Effective[3] %Vb[4]
PT-PZ-2M 42.0-42.3	42.20	H	12.0	1.95	2.66	2.66	26.6	13.6
PT-PZ-2M-43.0-43.4	43.20	V	18.9	1.73	2.67	2.67	35.2	10.9
PT-PZ-2M-44.0-44.3	44.20	H	26.9	1.62	2.31	2.31	29.7	17.1
PT-PZ-2M-45.0-45.4	45.20	V	38.3	1.32	2.77	2.77	52.4	6.35
PT-PZ-2M-46.0-46.4	46.20	H	37.0	1.34	2.76	2.76	51.5	5.52
PT-PZ-2M-47.0-47.4	47.20	V	56.2	1.07	2.74	2.74	61.1	9.59
PT-PZ-2M-48.0-48.4	48.20	H	48.0	1.18	2.76	2.76	57.3	6.30
PT-PZ-2M-49.0-49.4	49.20	V	38.3	1.32	2.78	2.78	52.4	4.55
PT-PZ-2M-50.0-50.4	50.20	H	33.8	1.41	2.77	2.77	49.0	4.39
PT-PZ-2M51.0-51.4	51.20	V	48.1	1.17	2.69	2.69	56.5	10.8

(1) Sample Orientation: H = horizontal; V = vertical.
(2) Total Porosity = no pore fluids in place; all interconnected pore channels.
(3) Effective Porosity = drainage porosity.
(4) Vb = Bulk Volume, cc.
(5) Native State or Effective = With as-received pore fluids in place.
(6) Permeability to water and hydraulic conductivity measured at saturated conditions.
-- Not Requested

Table 2

HYDRAULIC CONDUCTIVITY

Ramboll US Corporation

Core Lab File No: 1802753

Project Name : NERT AWF Capture Evaluation
Project Number : 1690006943-048 (Task M25)

METHODS: **API RP 40; ASTM D5084; EPA 9100**

			100 psi Net Confining Stress	
Sample ID.	Depth, ft.	Sample Orientation [1]	Effective [2,3] Permeability to Water, millidarcy	Saturated Hydraulic Conductivity, [2,3] cm/s
PT-PZ-2M-43.0-43.4	43.20	V	2.47	2.49E-06
PT-PZ-2M-45.0-45.4	45.20	V	0.089	9.06E-08
PT-PZ-2M-47.0-47.4	47.20	V	0.126	1.22E-07
PT-PZ-2M-49.0-49.4	49.20	V	0.160	1.56E-07
PT-PZ-2M51.0-51.4	51.20	V	0.138	1.35E-07

(1) Sample Orientation: H = horizontal; V = vertical
(2) Native State or Effective = With as-received pore fluids in place.
(3) Permeability to water and hydraulic conductivity measured at saturated conditions.

RAMBOLL

UST PROJECT OR IS EDF REQUIRED? YES NO IF YES, GLOBAL ID# MSA # WORK ORDER #

PROJECT NAME/FACILITY ID NERT AWF Capture Evaluation DATE 7/23/2018 FIELD PERSON# G. Miclette

PROJECT LOCATION Henderson, NV PROJECT MANAGER C. Stubbs

PROJECT NUMBER 1690006943-048 LABORATORY CORE LABS

Sampler J. Manheim

Signature J Manheim

NO = NONE

	SAMPLE ID NUMBER	SAMPLE DATE	SAMPLE TIME	SAMPLE DEPTH (F)	AIR SAMPLE VOLUME (L)	MATRIX: (A)IR; (G)AS; (W)ATER	NUMBER OF CONTAINERS	FILTERED/UNFILTERED (F/U)	PRESERVATION (SEE KEY)	HOLD*	Analysis Required														COMMENTS
✓	PT-PZ-2M-42.0-42.3-20180723	7/23/2018	0940	42.0-42.3	NA	S	2	U	None	X															
*	PT-PZ-2M-43.0-43.4-20180723		0942	43.0-43.4			2			X	JAR IS MARKED 43.3														*Hold pending
✓	PT-PZ-2M-44.0-44.3-20180723		0944	44.0-44.3			2			X															instruction from
✓	PT-PZ-2M-45.0-45.4-20180723		1020	45.0-45.4			1			X															Pejman Rasouli —
✓	PT-PZ-2M-46.0-46.4-20180723		1022	46.0-46.4			1			X															prasouli@Ramboll.com
✓	PT-PZ-2M-47.0-47.4-20180723		1024	47.0-47.4			1			X															or Chris Stubbs —
✓	PT-PZ-2M-48.0-48.4-20180723		1026	48.0-48.4			1			X															cstubbs@Ramboll.com
✓	PT-PZ-2M-49.0-49.4-20180723		1028	49.0-49.4			1			X															
✓	PT-PZ-2M-50.0-50.4-20180723		1030	50.0-50.4			1			X															
✓	PT-PZ-2M-51.0-51.4-20180723	7/23/2018	1032	51.0-51.4	NA	S	1	U	None	X															
	TOTAL						13			10															

RELINQUISHED BY J Manheim	TIME/DATE 8/2/2018 1400	RECEIVED BY COMPANY FedEx	TIME/DATE 8/2/18 1400	TURNAROUND TIME (CIRCLE ONE)	SAME DAY 24 HOURS 48 HOURS
RELINQUISHED BY	TIME/DATE	RECEIVED BY COMPANY Tracey Bishop - Core Lab	TIME/DATE 8-3-18 1038		72 HOURS 5 DAYS NORMAL
RELINQUISHED BY	TIME/DATE	RECEIVED BY COMPANY	TIME/DATE	SAMPLE INTEGRITY INTACT Y N TEMP______	SAMPLE INTEGRITY INTACT Y N

SWBU Office Locations:
☐ 18100 Von Karman Avenue, Suite 600, Irvine, CA 92612 +1 949 261 5151 +1 949 261 6202
☐ 350 S Grand Avenue, Suite 2800, Los Angeles, CA 90071 +1 213 943 6300 +1 213 943 6301
☐ 2111 East Highland Avenue, Suite 402, Phoenix, AZ 85016 +1 602 734 7700 +1 602 734-7701

Page ____ of ____

Petroleum Services Division
3437 Landco Dr.
Bakersfield, California 93308
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www.corelab.com

September 28, 2018

Chris Stubbs
Ramboll US Corporation
2200 Powell Street, Suite 700
Emeryville, CA 94608

Subject: TOC and LPSA
File No.: 1802472

Dear Mr. Stubbs:

Enclosed are final data for the 15 samples submitted to our laboratory from project NERT AWF Capture Evaluation in Henderson, Nevada.

Grain size analysis and TOC were performed on requested samples where there was suitable recovery. Appropriate ASTM, EPA or API methodologies were used for this project and SOP's are available on request. The sample for this project is currently in storage and will be retained for thirty days past completion of testing at no charge. At the end of thirty days, the sample will be disposed. You may contact me regarding continued storage, disoposal, or return of the sample.

Thank you for this opportunity to be of service to Ramboll US Corporation. Please do not hesitate to contact us at (661-325-5657) if you have any questions regarding these results or if we can be of any additional service.

Sincerely,
Core Laboratories

Chris Florence
Sr. Core Analyst

TOC & FOC

Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802475

			METHODS:	Walkley-Black	
Sample ID.	Depth ft.	Sample Date	Sample [1] Orientation	Total Organic Carbon mg/kg	Fractional Organic Carbon g/g
PZ-1D_14-14.3	14-14.3	08/29/18	H	2800	2.80E-03
PZ-1D_27.5-27.8	27.5-27.8	08/29/18	V	2600	2.60E-03
PZ-1D_32-32.3	32-32.3	08/29/18	V	2600	2.60E-03
PZ-1D_33.3-33.8	33.3-33.8	08/29/18	V	5700	5.70E-03
PZ-1D_35-35.5	35-35.5	08/29/18	H	5900	5.90E-03
PZ-1D_36-36.5	36-36.5	08/29/18	V	5500	5.50E-03
PZ-1D_37-37.5	37-37.5	08/29/18	H	5900	5.90E-03
PZ-1D_38-38.5	38-38.5	08/29/18	V	5600	5.60E-03
PZ-1D_39-39.5	39-39.5	08/29/18	H	6300	6.30E-03
PZ-1D_41.2-41.7	41.2-41.7	08/29/18	V	5100	5.10E-03
PZ-1D_43.3-43.8	43.3-43.8	08/29/18	H	5400	5.40E-03
PZ-1D_45.2-45.7	45.2-45.7	08/29/18	V	4600	4.60E-03
PZ-1D_48.3-48.8	48.3-48.8	08/29/18	H	4300	4.30E-03
PZ-1D_51-51.5	51-51.5	08/29/18	V	5000	5.00E-03
PZ-1D_54-55.5	54-55.5	08/29/18	H	5900	5.90E-03

(1) Sample Orientation: H = horizontal; V = vertical.

Core Lab
RESERVOIR OPTIMIZATION

SIEVE and LASER PARTICLE SIZE SUMMARY

(METHODOLOGY: ASTM D422/D4464M)

Petroleum Services

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802475
Date: 9/28/2018

Sample ID	Grain Size Description** (Mean from Folk)	Median Grain Size, mm	Component Percentages								
				Sand Size							
			Granule	VCoarse	Coarse	Medium	Fine	VFine	Silt	Clay	Silt & Clay
PZ-1D_14-14.3	Granule	3.0650	63.99	18.63	9.60	4.08	1.56	0.70	1.10	0.34	1.44
PZ-1D_27.5-27.8	Granule	2.0941	51.76	24.95	12.86	5.46	2.09	0.94	1.47	0.46	1.93
PZ-1D_32-32.3	Very Coarse Grain Sand	1.2696	27.94	32.38	17.24	7.36	3.23	2.01	7.28	2.55	9.83
PZ-1D_33.3-33.8	Coarse Grain Sand	0.8252	0.00	40.11	27.99	14.25	7.47	3.39	5.29	1.49	6.78
PZ-1D_35-35.5	Silt	0.0057	0.00	0.00	0.00	0.00	0.00	0.00	60.78	39.22	100.00
PZ-1D_36-36.5	Silt	0.0046	0.00	0.00	0.00	0.00	0.00	0.00	56.11	43.89	100.00
PZ-1D_37-37.5	Silt	0.0049	0.00	0.00	0.00	0.00	0.00	0.00	57.31	42.69	100.00
PZ-1D_38-38.5	Silt	0.0060	0.00	0.00	0.00	0.00	0.00	0.00	63.29	36.71	100.00
PZ-1D_39-39.5	Silt	0.0050	0.00	0.00	0.00	0.00	0.00	0.00	59.05	40.95	100.00
PZ-1D_41.2-41.7	Silt	0.0051	0.00	0.00	0.00	0.00	0.00	0.00	58.20	41.80	100.00
PZ-1D_43.3-43.8	Silt	0.0055	0.00	0.00	0.00	0.00	0.00	0.00	62.77	37.23	100.00
PZ-1D_45.2-45.7	Silt	0.0367	0.00	0.01	0.99	5.04	10.48	18.65	53.39	11.44	64.82
PZ-1D_48.3-48.8	Silt	0.0425	0.00	0.00	0.00	2.82	12.45	23.91	51.29	9.53	60.82
PZ-1D_51-51.5	Silt	0.0116	0.00	0.00	0.00	0.00	0.00	0.01	75.83	24.16	99.99
PZ-1D_54-55.5	Silt	0.0061	0.00	0.00	0.00	0.00	0.00	0.00	64.12	35.88	100.00

**Wentworth Scale

SIEVE and LASER PARTICLE SIZE SUMMARY

(METHODOLOGY: ASTM D422/D4464M)

Petroleum Services

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802475
Date: 9/28/2018

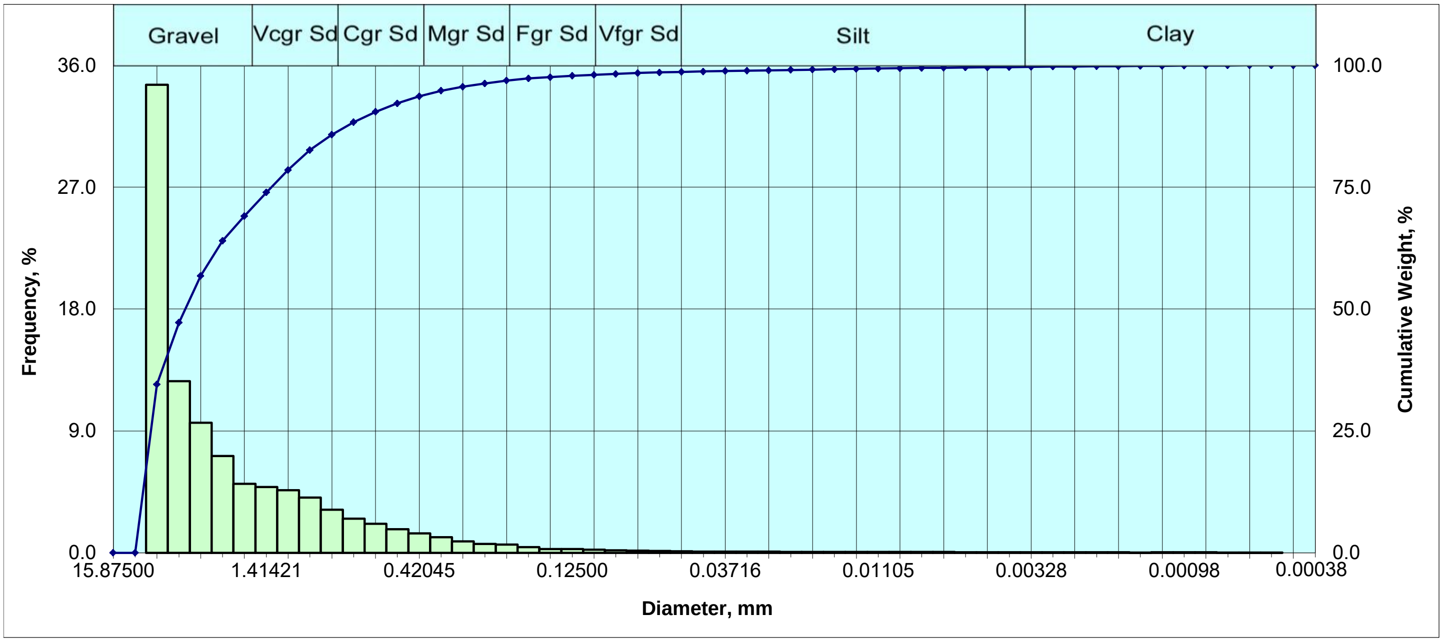
Sample ID	Grain Size Description** (Mean from Trask)	Median Grain Size, mm	Component Percentages						Silt & Clay
				Sand Sized					
			Granule	Coarse	Medium	Fine	Silt	Clay	
PZ-1D_14-14.3	Coarse Grain Sand	3.0650	34.57	29.42	29.65	4.79	1.13	0.44	1.57
PZ-1D_27.5-27.8	Coarse Grain Sand	2.0941	28.80	22.96	39.72	6.42	1.51	0.58	2.10
PZ-1D_32-32.3	Medium Grain Sand	1.2696	14.25	13.69	52.30	9.43	7.15	3.17	10.33
PZ-1D_33.3-33.8	Medium Grain Sand	0.8252	0.00	0.00	72.42	20.28	5.30	2.00	7.29
PZ-1D_35-35.5	Silt	0.0057	0.00	0.00	0.00	0.00	50.62	49.38	100.00
PZ-1D_36-36.5	Silt	0.0046	0.00	0.00	0.00	0.00	43.65	56.35	100.00
PZ-1D_37-37.5	Silt	0.0049	0.00	0.00	0.00	0.00	45.68	54.32	100.00
PZ-1D_38-38.5	Silt	0.0060	0.00	0.00	0.00	0.00	52.31	47.69	100.00
PZ-1D_39-39.5	Silt	0.0050	0.00	0.00	0.00	0.00	46.66	53.34	100.00
PZ-1D_41.2-41.7	Silt	0.0051	0.00	0.00	0.00	0.00	47.71	52.29	100.00
PZ-1D_43.3-43.8	Silt	0.0055	0.00	0.00	0.00	0.00	49.71	50.29	100.00
PZ-1D_45.2-45.7	Silt	0.0367	0.00	0.00	1.75	28.43	54.56	15.26	69.82
PZ-1D_48.3-48.8	Silt	0.0425	0.00	0.00	0.00	33.84	53.23	12.92	66.16
PZ-1D_51-51.5	Silt	0.0116	0.00	0.00	0.00	0.00	68.20	31.80	100.00
PZ-1D_54-55.5	Silt	0.0061	0.00	0.00	0.00	0.00	52.98	47.02	100.00

**USCS Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802475
Sample ID: PZ-1D_14-14.3

Sieve and Laser Particle Size Analysis



Particle Size Distribution

	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	34.573	34.57
	6	0.131890	3.35000	-1.75	12.665	47.24
	8	0.092913	2.36000	-1.25	9.597	56.83
	10	0.078740	2.00000	-1.00	7.156	63.99
V Crse Sand	12	0.066212	1.68179	-0.75	5.094	69.08
	14	0.055678	1.41421	-0.50	4.852	73.94
	16	0.046819	1.18921	-0.25	4.613	78.55
	18	0.039370	1.00000	0.00	4.068	82.62
Coarse Sand	20	0.033106	0.84090	0.25	3.186	85.80
	25	0.027839	0.70711	0.50	2.531	88.33
	30	0.023410	0.59460	0.75	2.140	90.47
	35	0.019685	0.50000	1.00	1.745	92.22
Medium Sand	40	0.016553	0.42045	1.25	1.424	93.64
	45	0.013919	0.35355	1.50	1.157	94.80
	50	0.011705	0.29730	1.75	0.844	95.64
	60	0.009843	0.25000	2.00	0.650	96.30
Fine Sand	70	0.008277	0.21022	2.25	0.600	96.90
	80	0.006960	0.17678	2.50	0.417	97.31
	100	0.005852	0.14865	2.75	0.270	97.58
	120	0.004921	0.12500	3.00	0.274	97.86
V. Fine Sand	140	0.004138	0.10511	3.25	0.223	98.08
	170	0.003480	0.08839	3.50	0.189	98.27
	200	0.002926	0.07433	3.75	0.165	98.43
	230	0.002461	0.06250	4.00	0.124	98.56
Silt	270	0.002069	0.05256	4.25	0.106	98.66
	325	0.001740	0.04419	4.50	0.094	98.76
	400	0.001463	0.03716	4.75	0.076	98.83
	450	0.001230	0.03125	5.00	0.076	98.91
	500	0.001035	0.02628	5.25	0.081	98.99
	635	0.000870	0.02210	5.50	0.073	99.06
		0.000732	0.01858	5.75	0.066	99.13
		0.000615	0.01562	6.00	0.070	99.20
		0.000517	0.01314	6.25	0.074	99.27
		0.000435	0.01105	6.50	0.071	99.34
		0.000366	0.00929	6.75	0.063	99.41
		0.000308	0.00781	7.00	0.056	99.46
		0.000259	0.00657	7.25	0.051	99.52
		0.000217	0.00552	7.50	0.048	99.56
		0.000183	0.00465	7.75	0.047	99.61
		0.000154	0.00391	8.00	0.047	99.66
Clay		0.000129	0.00328	8.25	0.046	99.70
		0.000109	0.00276	8.50	0.043	99.75
		0.000091	0.00232	8.75	0.038	99.78
		0.000077	0.00195	9.00	0.032	99.82
		0.000065	0.00164	9.25	0.028	99.84
		0.000054	0.00138	9.50	0.027	99.87
		0.000046	0.00116	9.75	0.029	99.90
		0.000038	0.00098	10.00	0.031	99.93
		0.000032	0.00082	10.25	0.030	99.96
		0.000027	0.00069	10.50	0.024	99.99
		0.000023	0.00058	10.75	0.012	100.00
		0.000019	0.00049	11.00	0.002	100.00
		0.000016	0.00041	11.25	0.000	100.00
		0.000015	0.00038	11.50	0.000	100.00

Sorting Statistics (Folk)

Parameter	Trask	Inman	Folk
Median	Granule sized		
(in)	0.1207	0.1207	0.1207
(mm)	3.0650	3.0650	3.0650
Mean	Granule sized		
(in)	0.1462	0.1026	0.1083
(mm)	3.7138	2.6072	2.7517
Sorting	Poor		
	2.110	1.486	1.454
Skewness	Finely skewed		
	0.938	0.554	0.254
Kurtosis	Platykurtic		
	0.313	0.580	0.893

Component Percentages

Gravel	Sand	Silt	Clay	Silt + Clay
63.99	34.57	1.10	0.34	1.44

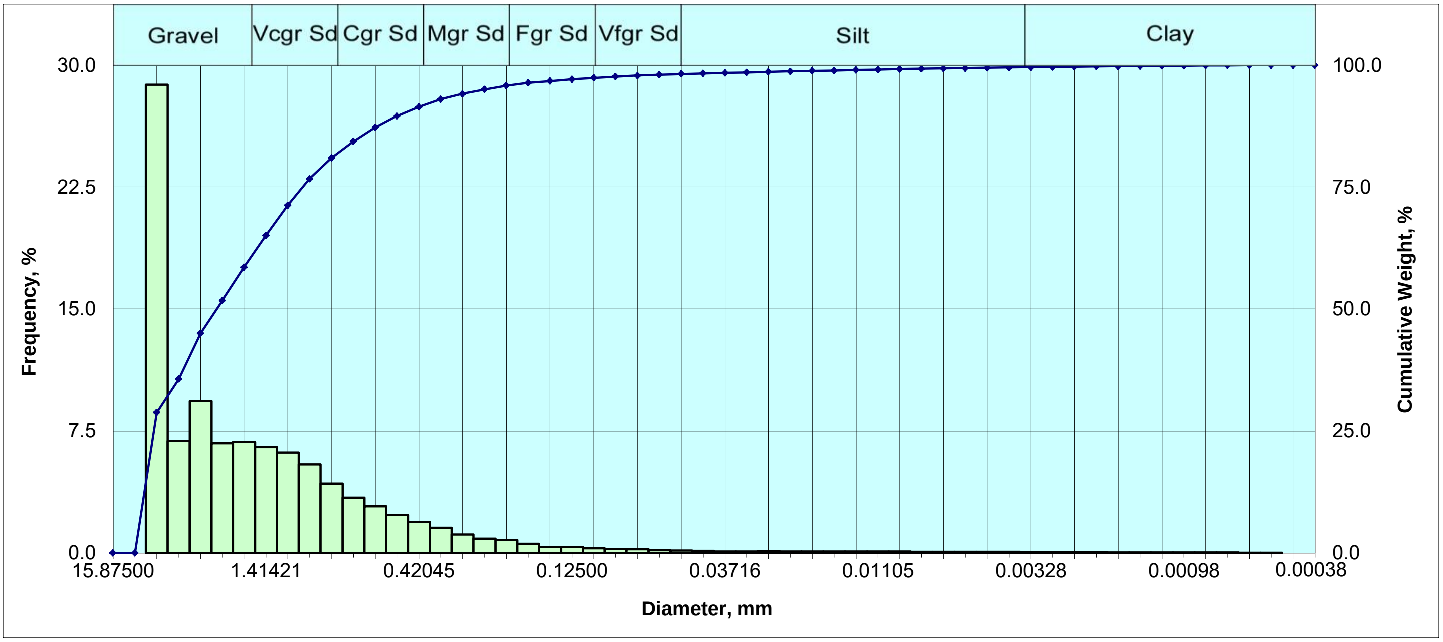
Percentile [Weight, %]	Particle Diameter [in.]	[mm]	[phi]
5	0.3470	8.8130	-3.1396
10	0.3199	8.1261	-3.0226
16	0.2875	7.3017	-2.8682
25	0.2388	6.0652	-2.6006
30	0.2117	5.3782	-2.4271
50	0.1207	3.0650	-1.6159
60	0.0866	2.2008	-1.1380
75	0.0536	1.3624	-0.4461
84	0.0367	0.9310	0.1032
90	0.0244	0.6195	0.6908
95	0.0134	0.3402	1.5554

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802475
Sample ID: PZ-1D_27.5-27.8

Sieve and Laser Particle Size Analysis



Particle Size Distribution

	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	28.801	28.80
	6	0.131890	3.35000	-1.75	6.883	35.68
	8	0.092913	2.36000	-1.25	9.333	45.02
	10	0.078740	2.00000	-1.00	6.747	51.76
V Crse Sand	12	0.066212	1.68179	-0.75	6.824	58.59
	14	0.055678	1.41421	-0.50	6.500	65.09
	16	0.046819	1.18921	-0.25	6.179	71.27
	18	0.039370	1.00000	0.00	5.449	76.72
Coarse Sand	20	0.033106	0.84090	0.25	4.267	80.98
	25	0.027839	0.70711	0.50	3.390	84.37
	30	0.023410	0.59460	0.75	2.866	87.24
	35	0.019685	0.50000	1.00	2.338	89.58
Medium Sand	40	0.016553	0.42045	1.25	1.908	91.48
	45	0.013919	0.35355	1.50	1.550	93.03
	50	0.011705	0.29730	1.75	1.131	94.17
	60	0.009843	0.25000	2.00	0.871	95.04
Fine Sand	70	0.008277	0.21022	2.25	0.804	95.84
	80	0.006960	0.17678	2.50	0.559	96.40
	100	0.005852	0.14865	2.75	0.361	96.76
	120	0.004921	0.12500	3.00	0.368	97.13
V. Fine Sand	140	0.004138	0.10511	3.25	0.298	97.43
	170	0.003480	0.08839	3.50	0.253	97.68
	200	0.002926	0.07433	3.75	0.221	97.90
	230	0.002461	0.06250	4.00	0.166	98.07
Silt	270	0.002069	0.05256	4.25	0.143	98.21
	325	0.001740	0.04419	4.50	0.126	98.34
	400	0.001463	0.03716	4.75	0.102	98.44
	450	0.001230	0.03125	5.00	0.102	98.54
	500	0.001035	0.02628	5.25	0.109	98.65
	635	0.000870	0.02210	5.50	0.097	98.75
		0.000732	0.01858	5.75	0.088	98.83
		0.000615	0.01562	6.00	0.093	98.93
		0.000517	0.01314	6.25	0.099	99.03
		0.000435	0.01105	6.50	0.095	99.12
		0.000366	0.00929	6.75	0.085	99.21
		0.000308	0.00781	7.00	0.075	99.28
		0.000259	0.00657	7.25	0.069	99.35
		0.000217	0.00552	7.50	0.065	99.42
		0.000183	0.00465	7.75	0.063	99.48
		0.000154	0.00391	8.00	0.063	99.54
Clay		0.000129	0.00328	8.25	0.062	99.60
		0.000109	0.00276	8.50	0.057	99.66
		0.000091	0.00232	8.75	0.051	99.71
		0.000077	0.00195	9.00	0.043	99.75
		0.000065	0.00164	9.25	0.038	99.79
		0.000054	0.00138	9.50	0.036	99.83
		0.000046	0.00116	9.75	0.039	99.87
		0.000038	0.00098	10.00	0.042	99.91
		0.000032	0.00082	10.25	0.040	99.95
		0.000027	0.00069	10.50	0.032	99.98
		0.000023	0.00058	10.75	0.017	100.00
		0.000019	0.00049	11.00	0.002	100.00
		0.000016	0.00041	11.25	0.000	100.00
		0.000015	0.00038	11.50	0.000	100.00

Sorting Statistics (Folk)

Parameter	Trask	Inman	Folk
Median	**Granule sized**		
(in)	0.0824	0.0824	0.0824
(mm)	2.0941	2.0941	2.0941
Mean	**Granule sized**		
(in)	0.1267	0.0876	0.0859
(mm)	3.2183	2.2255	2.1808
Sorting	**Poor**		
	2.253	1.624	1.586
Skewness	**Near symmetrical**		
	1.140	0.309	0.071
Kurtosis	**Platykurtic**		
	0.293	0.571	0.893

Component Percentages

Gravel	Sand	Silt	Clay	Silt + Clay
51.76	46.30	1.47	0.46	1.93

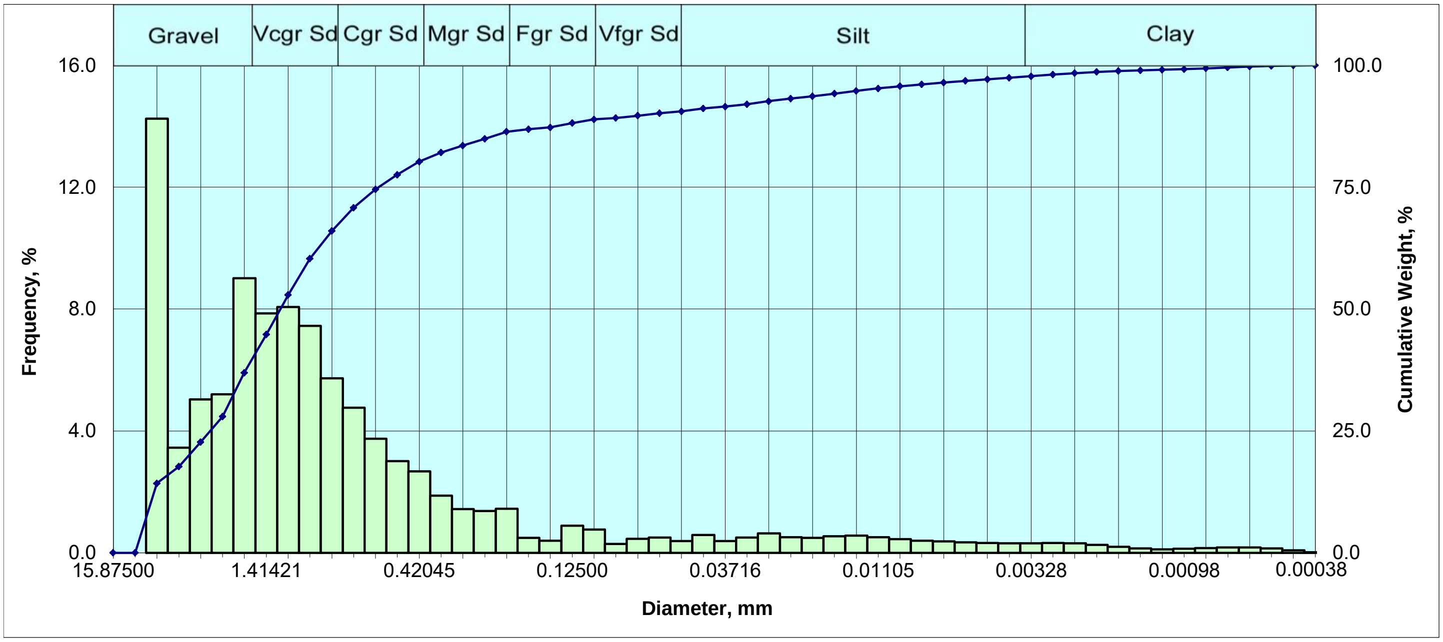
Percentile [Weight, %]	Particle Diameter		
	[in.]	[mm]	[phi]
5	0.3416	8.6754	-3.1169
10	0.3091	7.8508	-2.9728
16	0.2701	6.8612	-2.7785
25	0.2117	5.3769	-2.4268
30	0.1774	4.5062	-2.1719
50	0.0824	2.0941	-1.0664
60	0.0639	1.6237	-0.6992
75	0.0417	1.0596	-0.0835
84	0.0284	0.7218	0.4703
90	0.0190	0.4824	1.0518
95	0.0099	0.2520	1.9884

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802475
Sample ID: PZ-1D_32-32.3

Sieve and Laser Particle Size Analysis



Particle Size Distribution

	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	14.249	14.25
	6	0.131890	3.35000	-1.75	3.451	17.70
	8	0.092913	2.36000	-1.25	5.040	22.74
	10	0.078740	2.00000	-1.00	5.204	27.94
V Crse Sand	12	0.066212	1.68179	-0.75	9.011	36.96
	14	0.055678	1.41421	-0.50	7.857	44.81
	16	0.046819	1.18921	-0.25	8.072	52.88
	18	0.039370	1.00000	0.00	7.445	60.33
Coarse Sand	20	0.033106	0.84090	0.25	5.725	66.05
	25	0.027839	0.70711	0.50	4.761	70.81
	30	0.023410	0.59460	0.75	3.746	74.56
	35	0.019685	0.50000	1.00	3.010	77.57
Medium Sand	40	0.016553	0.42045	1.25	2.675	80.25
	45	0.013919	0.35355	1.50	1.876	82.12
	50	0.011705	0.29730	1.75	1.436	83.56
	60	0.009843	0.25000	2.00	1.375	84.93
Fine Sand	70	0.008277	0.21022	2.25	1.449	86.38
	80	0.006960	0.17678	2.50	0.485	86.87
	100	0.005852	0.14865	2.75	0.400	87.27
	120	0.004921	0.12500	3.00	0.892	88.16
V. Fine Sand	140	0.004138	0.10511	3.25	0.765	88.92
	170	0.003480	0.08839	3.50	0.291	89.22
	200	0.002926	0.07433	3.75	0.459	89.67
	230	0.002461	0.06250	4.00	0.495	90.17
Silt	270	0.002069	0.05256	4.25	0.389	90.56
	325	0.001740	0.04419	4.50	0.587	91.15
	400	0.001463	0.03716	4.75	0.381	91.53
	450	0.001230	0.03125	5.00	0.496	92.02
	500	0.001035	0.02628	5.25	0.633	92.66
	635	0.000870	0.02210	5.50	0.511	93.17
		0.000732	0.01858	5.75	0.487	93.65
		0.000615	0.01562	6.00	0.544	94.20
		0.000517	0.01314	6.25	0.558	94.76
		0.000435	0.01105	6.50	0.515	95.27
		0.000366	0.00929	6.75	0.445	95.72
		0.000308	0.00781	7.00	0.395	96.11
		0.000259	0.00657	7.25	0.370	96.48
		0.000217	0.00552	7.50	0.345	96.83
		0.000183	0.00465	7.75	0.318	97.14
		0.000154	0.00391	8.00	0.307	97.45
Clay		0.000129	0.00328	8.25	0.316	97.77
		0.000109	0.00276	8.50	0.324	98.09
		0.000091	0.00232	8.75	0.308	98.40
		0.000077	0.00195	9.00	0.259	98.66
		0.000065	0.00164	9.25	0.194	98.85
		0.000054	0.00138	9.50	0.140	98.99
		0.000046	0.00116	9.75	0.117	99.11
		0.000038	0.00098	10.00	0.128	99.24
		0.000032	0.00082	10.25	0.156	99.39
		0.000027	0.00069	10.50	0.179	99.57
		0.000023	0.00058	10.75	0.179	99.75
		0.000019	0.00049	11.00	0.147	99.90
		0.000016	0.00041	11.25	0.085	99.98
		0.000015	0.00038	11.50	0.019	100.00

Sorting Statistics (Folk)

Parameter	Trask	Inman	Folk
Median	Very coarse sand sized		
(in)	0.0500	0.0500	0.0500
(mm)	1.2696	1.2696	1.2696
Mean	Very coarse sand sized		
(in)	0.0548	0.0420	0.0445
(mm)	1.3922	1.0675	1.1310
Sorting	Very poor		
	1.948	1.920	2.374
Skewness	Finely skewed		
	0.891	1.063	0.284
Kurtosis	Very leptokurtic		
	0.133	1.430	1.988

Component Percentages

Gravel	Sand	Silt	Clay	Silt + Clay
27.94	62.23	7.28	2.55	9.83

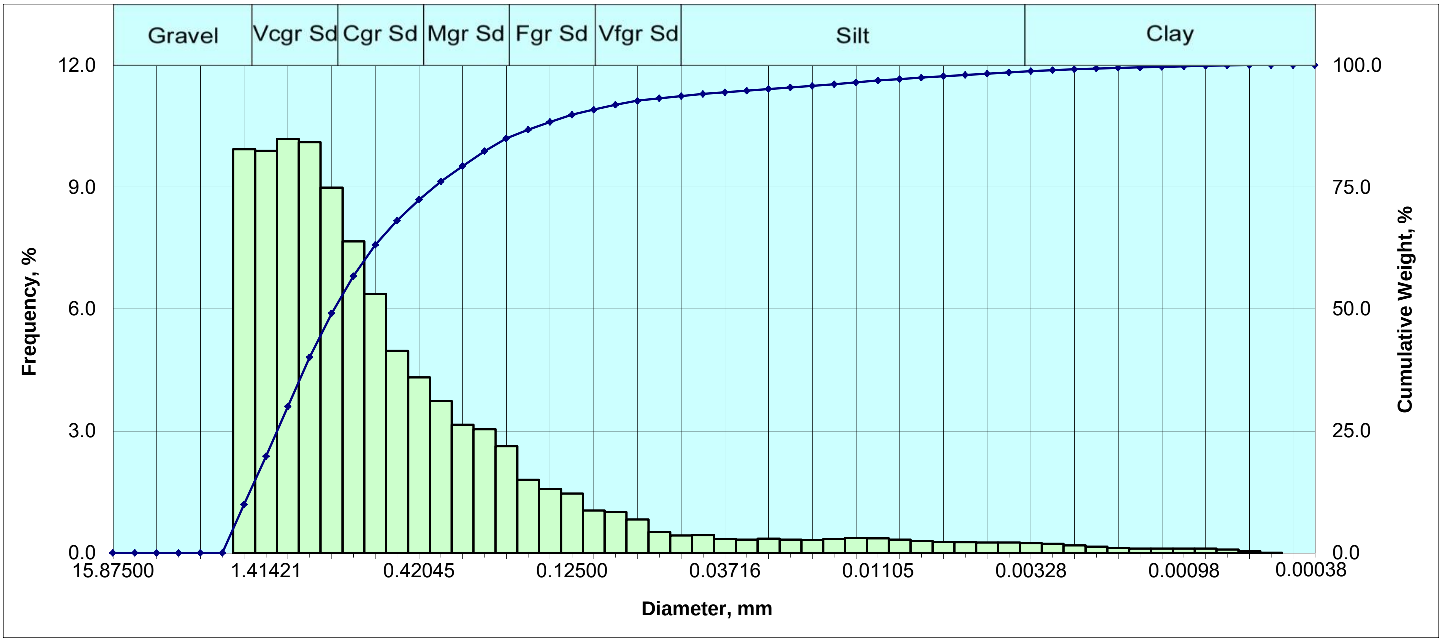
Percentile [Weight, %]	Particle Diameter		
	[in.]	[mm]	[phi]
5	0.3084	7.8333	-2.9696
10	0.2428	6.1665	-2.6245
16	0.1590	4.0398	-2.0143
25	0.0868	2.2037	-1.1399
30	0.0759	1.9274	-0.9467
50	0.0500	1.2696	-0.3444
60	0.0397	1.0084	-0.0120
75	0.0229	0.5808	0.7839
84	0.0111	0.2821	1.8258
90	0.0026	0.0666	3.9092
95	0.0005	0.0121	6.3630

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802475
Sample ID: PZ-1D_33.3-33.8

Sieve and Laser Particle Size Analysis



Particle Size Distribution						
	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	9.933	9.93
	14	0.055678	1.41421	-0.50	9.892	19.82
	16	0.046819	1.18921	-0.25	10.183	30.01
	18	0.039370	1.00000	0.00	10.104	40.11
Coarse Sand	20	0.033106	0.84090	0.25	8.987	49.10
	25	0.027839	0.70711	0.50	7.663	56.76
	30	0.023410	0.59460	0.75	6.371	63.13
	35	0.019685	0.50000	1.00	4.972	68.11
Medium Sand	40	0.016553	0.42045	1.25	4.318	72.42
	45	0.013919	0.35355	1.50	3.734	76.16
	50	0.011705	0.29730	1.75	3.156	79.31
	60	0.009843	0.25000	2.00	3.046	82.36
Fine Sand	70	0.008277	0.21022	2.25	2.630	84.99
	80	0.006960	0.17678	2.50	1.801	86.79
	100	0.005852	0.14865	2.75	1.573	88.36
	120	0.004921	0.12500	3.00	1.465	89.83
V. Fine Sand	140	0.004138	0.10511	3.25	1.048	90.88
	170	0.003480	0.08839	3.50	1.002	91.88
	200	0.002926	0.07433	3.75	0.828	92.71
	230	0.002461	0.06250	4.00	0.517	93.22
Silt	270	0.002069	0.05256	4.25	0.430	93.65
	325	0.001740	0.04419	4.50	0.442	94.09
	400	0.001463	0.03716	4.75	0.345	94.44
	450	0.001230	0.03125	5.00	0.329	94.77
	500	0.001035	0.02628	5.25	0.354	95.12
	635	0.000870	0.02210	5.50	0.325	95.45
		0.000732	0.01858	5.75	0.317	95.76
		0.000615	0.01562	6.00	0.347	96.11
		0.000517	0.01314	6.25	0.371	96.48
		0.000435	0.01105	6.50	0.358	96.84
		0.000366	0.00929	6.75	0.326	97.17
		0.000308	0.00781	7.00	0.296	97.46
		0.000259	0.00657	7.25	0.276	97.74
		0.000217	0.00552	7.50	0.265	98.00
		0.000183	0.00465	7.75	0.258	98.26
		0.000154	0.00391	8.00	0.254	98.51
Clay		0.000129	0.00328	8.25	0.244	98.76
		0.000109	0.00276	8.50	0.223	98.98
		0.000091	0.00232	8.75	0.190	99.17
		0.000077	0.00195	9.00	0.152	99.32
		0.000065	0.00164	9.25	0.121	99.44
		0.000054	0.00138	9.50	0.105	99.55
		0.000046	0.00116	9.75	0.104	99.65
		0.000038	0.00098	10.00	0.108	99.76
		0.000032	0.00082	10.25	0.105	99.87
		0.000027	0.00069	10.50	0.084	99.95
		0.000023	0.00058	10.75	0.044	99.99
		0.000019	0.00049	11.00	0.006	100.00
		0.000016	0.00041	11.25	0.000	100.00
		0.000015	0.00038	11.50	0.000	100.00

Sorting Statistics (Folk)			
Parameter	**Trask**	**Inman**	**Folk**
Median	**Coarse sand sized**		
(in)	0.0325	0.0325	0.0325
(mm)	0.8252	0.8252	0.8252
Mean	**Coarse sand sized**		
(in)	0.0330	0.0230	0.0258
(mm)	0.8371	0.5846	0.6558
Sorting	**Poor**		
	1.864	1.376	1.603
Skewness	**Strongly fine skewed**		
	0.845	1.353	0.489
Kurtosis	**Lepokurtic**		
	0.297	1.194	1.378

Component Percentages				
Gravel	**Sand**	**Silt**	**Clay**	**Silt + Clay**
0.00	93.22	5.29	1.49	6.78

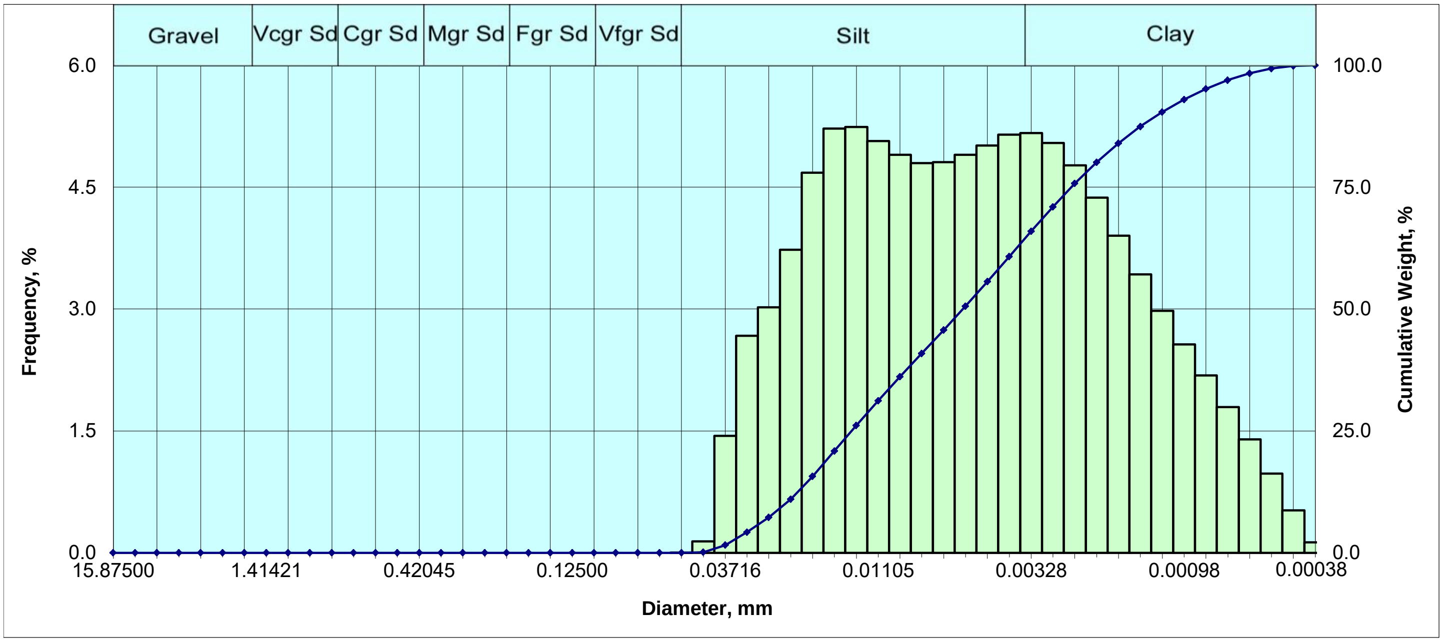
Percentile [Weight, %]	Particle Diameter		
	[in.]	[mm]	[phi]
5	0.0724	1.8398	-0.8796
10	0.0661	1.6800	-0.7484
16	0.0598	1.5177	-0.6019
25	0.0512	1.2999	-0.3784
30	0.0468	1.1894	-0.2502
50	0.0325	0.8252	0.2773
60	0.0256	0.6499	0.6217
75	0.0147	0.3743	1.4178
84	0.0089	0.2252	2.1509
90	0.0048	0.1217	3.0383
95	0.0011	0.0280	5.1591

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802475
Sample ID: PZ-1D_35-35.5

Sieve and Laser Particle Size Analysis



Particle Size Distribution

	Diameter [US Mesh]	Diameter [in.]	Diameter [mm]	Diameter [ϕ]	Weight % [Incl.]	Weight % [Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.000	0.00
Coarse Sand	20	0.033106	0.84090	0.25	0.000	0.00
	25	0.027839	0.70711	0.50	0.000	0.00
	30	0.023410	0.59460	0.75	0.000	0.00
	35	0.019685	0.50000	1.00	0.000	0.00
Medium Sand	40	0.016553	0.42045	1.25	0.000	0.00
	45	0.013919	0.35355	1.50	0.000	0.00
	50	0.011705	0.29730	1.75	0.000	0.00
	60	0.009843	0.25000	2.00	0.000	0.00
Fine Sand	70	0.008277	0.21022	2.25	0.000	0.00
	80	0.006960	0.17678	2.50	0.000	0.00
	100	0.005852	0.14865	2.75	0.000	0.00
	120	0.004921	0.12500	3.00	0.000	0.00
V. Fine Sand	140	0.004138	0.10511	3.25	0.000	0.00
	170	0.003480	0.08839	3.50	0.000	0.00
	200	0.002926	0.07433	3.75	0.000	0.00
	230	0.002461	0.06250	4.00	0.000	0.00
Silt	270	0.002069	0.05256	4.25	0.000	0.00
	325	0.001740	0.04419	4.50	0.139	0.14
	400	0.001463	0.03716	4.75	1.441	1.58
	450	0.001230	0.03125	5.00	2.672	4.25
	500	0.001035	0.02628	5.25	3.023	7.28
	635	0.000870	0.02210	5.50	3.730	11.01
		0.000732	0.01858	5.75	4.679	15.68
		0.000615	0.01562	6.00	5.222	20.91
		0.000517	0.01314	6.25	5.240	26.15
		0.000435	0.01105	6.50	5.067	31.21
		0.000366	0.00929	6.75	4.898	36.11
		0.000308	0.00781	7.00	4.796	40.91
		0.000259	0.00657	7.25	4.809	45.72
		0.000217	0.00552	7.50	4.901	50.62
		0.000183	0.00465	7.75	5.014	55.63
		0.000154	0.00391	8.00	5.147	60.78
Clay		0.000129	0.00328	8.25	5.168	65.95
		0.000109	0.00276	8.50	5.043	70.99
		0.000091	0.00232	8.75	4.770	75.76
		0.000077	0.00195	9.00	4.373	80.13
		0.000065	0.00164	9.25	3.904	84.04
		0.000054	0.00138	9.50	3.428	87.46
		0.000046	0.00116	9.75	2.980	90.44
		0.000038	0.00098	10.00	2.563	93.01
		0.000032	0.00082	10.25	2.181	95.19
		0.000027	0.00069	10.50	1.794	96.98
		0.000023	0.00058	10.75	1.396	98.38
		0.000019	0.00049	11.00	0.975	99.35
		0.000016	0.00041	11.25	0.521	99.87
		0.000015	0.00038	11.50	0.127	100.00

Sorting Statistics (Folk)

Parameter	Trask	Inman	Folk
Median	**Silt sized**		
(in)	0.0002	0.0002	0.0002
(mm)	0.0057	0.0057	0.0057
Mean	**Silt sized**		
(in)	0.0003	0.0002	0.0002
(mm)	0.0080	0.0055	0.0056
Sorting	**Poor**		
	2.391	1.742	1.654
Skewness	**Near symmetrical**		
	1.012	0.101	0.046
Kurtosis	**Platykurtic**		
	0.256	0.484	0.842

Component Percentages

Gravel	Sand	Silt	Clay	Silt + Clay
0.00	0.00	60.78	39.22	100.00

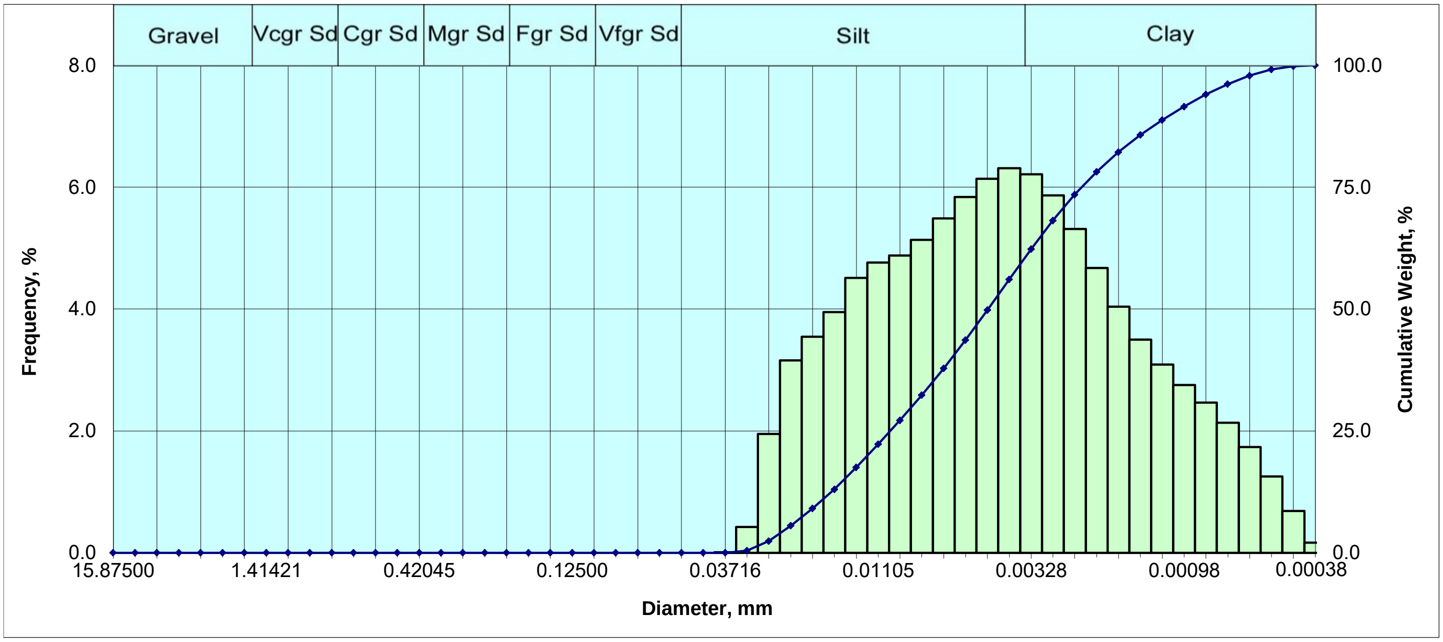
Percentile [Weight, %]	Particle Diameter [in.]	Particle Diameter [mm]	Particle Diameter [phi]
5	0.0012	0.0300	5.0579
10	0.0009	0.0232	5.4282
16	0.0007	0.0184	5.7640
25	0.0005	0.0137	6.1915
30	0.0005	0.0115	6.4361
50	0.0002	0.0057	7.4660
60	0.0002	0.0040	7.9593
75	0.0001	0.0024	8.7072
84	0.0001	0.0016	9.2475
90	0.0000	0.0012	9.7100
95	0.0000	0.0008	10.2267

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802475
Sample ID: PZ-1D_36-36.5

Sieve and Laser Particle Size Analysis



Particle Size Distribution						
	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.000	0.00
Coarse Sand	20	0.033106	0.84090	0.25	0.000	0.00
	25	0.027839	0.70711	0.50	0.000	0.00
	30	0.023410	0.59460	0.75	0.000	0.00
	35	0.019685	0.50000	1.00	0.000	0.00
Medium Sand	40	0.016553	0.42045	1.25	0.000	0.00
	45	0.013919	0.35355	1.50	0.000	0.00
	50	0.011705	0.29730	1.75	0.000	0.00
	60	0.009843	0.25000	2.00	0.000	0.00
Fine Sand	70	0.008277	0.21022	2.25	0.000	0.00
	80	0.006960	0.17678	2.50	0.000	0.00
	100	0.005852	0.14865	2.75	0.000	0.00
	120	0.004921	0.12500	3.00	0.000	0.00
V. Fine Sand	140	0.004138	0.10511	3.25	0.000	0.00
	170	0.003480	0.08839	3.50	0.000	0.00
	200	0.002926	0.07433	3.75	0.000	0.00
	230	0.002461	0.06250	4.00	0.000	0.00
Silt	270	0.002069	0.05256	4.25	0.000	0.00
	325	0.001740	0.04419	4.50	0.000	0.00
	400	0.001463	0.03716	4.75	0.009	0.01
	450	0.001230	0.03125	5.00	0.424	0.43
	500	0.001035	0.02628	5.25	1.953	2.39
	635	0.000870	0.02210	5.50	3.155	5.54
		0.000732	0.01858	5.75	3.544	9.08
		0.000615	0.01562	6.00	3.947	13.03
		0.000517	0.01314	6.25	4.512	17.54
		0.000435	0.01105	6.50	4.765	22.31
		0.000366	0.00929	6.75	4.880	27.19
		0.000308	0.00781	7.00	5.137	32.33
		0.000259	0.00657	7.25	5.488	37.81
		0.000217	0.00552	7.50	5.842	43.65
		0.000183	0.00465	7.75	6.141	49.80
		0.000154	0.00391	8.00	6.314	56.11
Clay		0.000129	0.00328	8.25	6.213	62.32
		0.000109	0.00276	8.50	5.863	68.19
		0.000091	0.00232	8.75	5.315	73.50
		0.000077	0.00195	9.00	4.674	78.17
		0.000065	0.00164	9.25	4.040	82.21
		0.000054	0.00138	9.50	3.500	85.71
		0.000046	0.00116	9.75	3.087	88.80
		0.000038	0.00098	10.00	2.755	91.56
		0.000032	0.00082	10.25	2.467	94.02
		0.000027	0.00069	10.50	2.136	96.16
		0.000023	0.00058	10.75	1.735	97.89
		0.000019	0.00049	11.00	1.255	99.15
		0.000016	0.00041	11.25	0.684	99.83
		0.000015	0.00038	11.50	0.168	100.00

Sorting Statistics (Folk)			
Parameter	Trask	Inman	Folk
Median	Silt sized		
(in)	0.0002	0.0002	0.0002
(mm)	0.0046	0.0046	0.0046
Mean	Silt sized		
(in)	0.0002	0.0002	0.0002
(mm)	0.0061	0.0046	0.0046
Sorting	Poor		
	2.138	1.606	1.546
Skewness	Near symmetrical		
	1.020	0.093	0.033
Kurtosis	Mesokurtic		
	0.234	0.527	0.917

Component Percentages				
Gravel	Sand	Silt	Clay	Silt + Clay
0.00	0.00	56.11	43.89	100.00

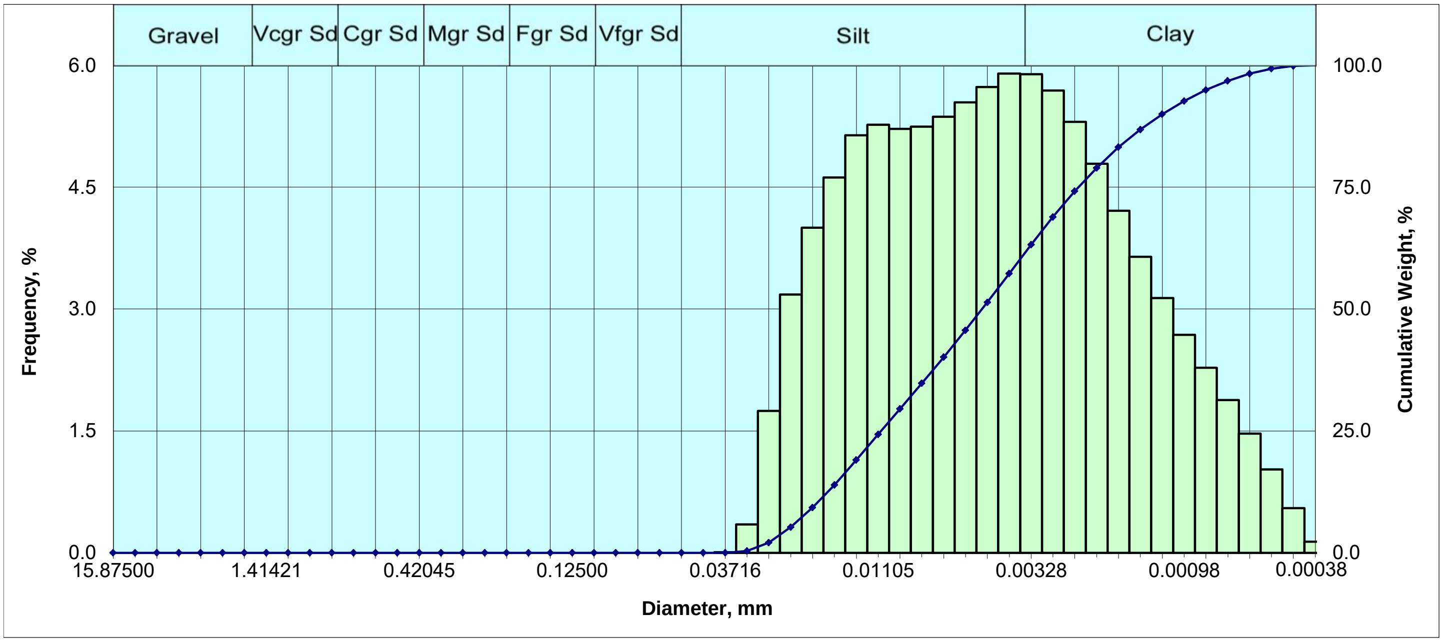
Percentile [Weight, %]	Particle Diameter		
	[in.]	[mm]	[phi]
5	0.0009	0.0228	5.4540
10	0.0007	0.0179	5.8043
16	0.0006	0.0140	6.1595
25	0.0004	0.0101	6.6325
30	0.0003	0.0085	6.8814
50	0.0002	0.0046	7.7574
60	0.0001	0.0035	8.1514
75	0.0001	0.0022	8.8256
84	0.0001	0.0015	9.3721
90	0.0000	0.0011	9.8535
95	0.0000	0.0008	10.3590

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802475
Sample ID: PZ-1D_37-37.5

Sieve and Laser Particle Size Analysis



Particle Size Distribution

	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.000	0.00
Coarse Sand	20	0.033106	0.84090	0.25	0.000	0.00
	25	0.027839	0.70711	0.50	0.000	0.00
	30	0.023410	0.59460	0.75	0.000	0.00
	35	0.019685	0.50000	1.00	0.000	0.00
Medium Sand	40	0.016553	0.42045	1.25	0.000	0.00
	45	0.013919	0.35355	1.50	0.000	0.00
	50	0.011705	0.29730	1.75	0.000	0.00
	60	0.009843	0.25000	2.00	0.000	0.00
Fine Sand	70	0.008277	0.21022	2.25	0.000	0.00
	80	0.006960	0.17678	2.50	0.000	0.00
	100	0.005852	0.14865	2.75	0.000	0.00
	120	0.004921	0.12500	3.00	0.000	0.00
V. Fine Sand	140	0.004138	0.10511	3.25	0.000	0.00
	170	0.003480	0.08839	3.50	0.000	0.00
	200	0.002926	0.07433	3.75	0.000	0.00
	230	0.002461	0.06250	4.00	0.000	0.00
Silt	270	0.002069	0.05256	4.25	0.000	0.00
	325	0.001740	0.04419	4.50	0.000	0.00
	400	0.001463	0.03716	4.75	0.007	0.01
	450	0.001230	0.03125	5.00	0.349	0.36
	500	0.001035	0.02628	5.25	1.746	2.10
	635	0.000870	0.02210	5.50	3.179	5.28
		0.000732	0.01858	5.75	4.002	9.28
		0.000615	0.01562	6.00	4.618	13.90
		0.000517	0.01314	6.25	5.138	19.04
		0.000435	0.01105	6.50	5.269	24.31
		0.000366	0.00929	6.75	5.216	29.52
		0.000308	0.00781	7.00	5.244	34.77
		0.000259	0.00657	7.25	5.368	40.14
		0.000217	0.00552	7.50	5.544	45.68
		0.000183	0.00465	7.75	5.735	51.41
		0.000154	0.00391	8.00	5.899	57.31
Clay		0.000129	0.00328	8.25	5.890	63.20
		0.000109	0.00276	8.50	5.691	68.89
		0.000091	0.00232	8.75	5.306	74.20
		0.000077	0.00195	9.00	4.790	78.99
		0.000065	0.00164	9.25	4.211	83.20
		0.000054	0.00138	9.50	3.645	86.85
		0.000046	0.00116	9.75	3.137	89.98
		0.000038	0.00098	10.00	2.682	92.67
		0.000032	0.00082	10.25	2.280	94.94
		0.000027	0.00069	10.50	1.878	96.82
		0.000023	0.00058	10.75	1.465	98.29
		0.000019	0.00049	11.00	1.027	99.32
		0.000016	0.00041	11.25	0.550	99.87
		0.000015	0.00038	11.50	0.135	100.00

Sorting Statistics (Folk)

Parameter	Trask	Inman	Folk
Median	**Silt sized**		
(in)	0.0002	0.0002	0.0002
(mm)	0.0049	0.0049	0.0049
Mean	**Silt sized**		
(in)	0.0003	0.0002	0.0002
(mm)	0.0065	0.0048	0.0048
Sorting	**Poor**		
	2.187	1.602	1.525
Skewness	**Near symmetrical**		
	1.017	0.114	0.043
Kurtosis	**Platykurtic**		
	0.252	0.492	0.868

Component Percentages

Gravel	Sand	Silt	Clay	Silt + Clay
0.00	0.00	57.31	42.69	100.00

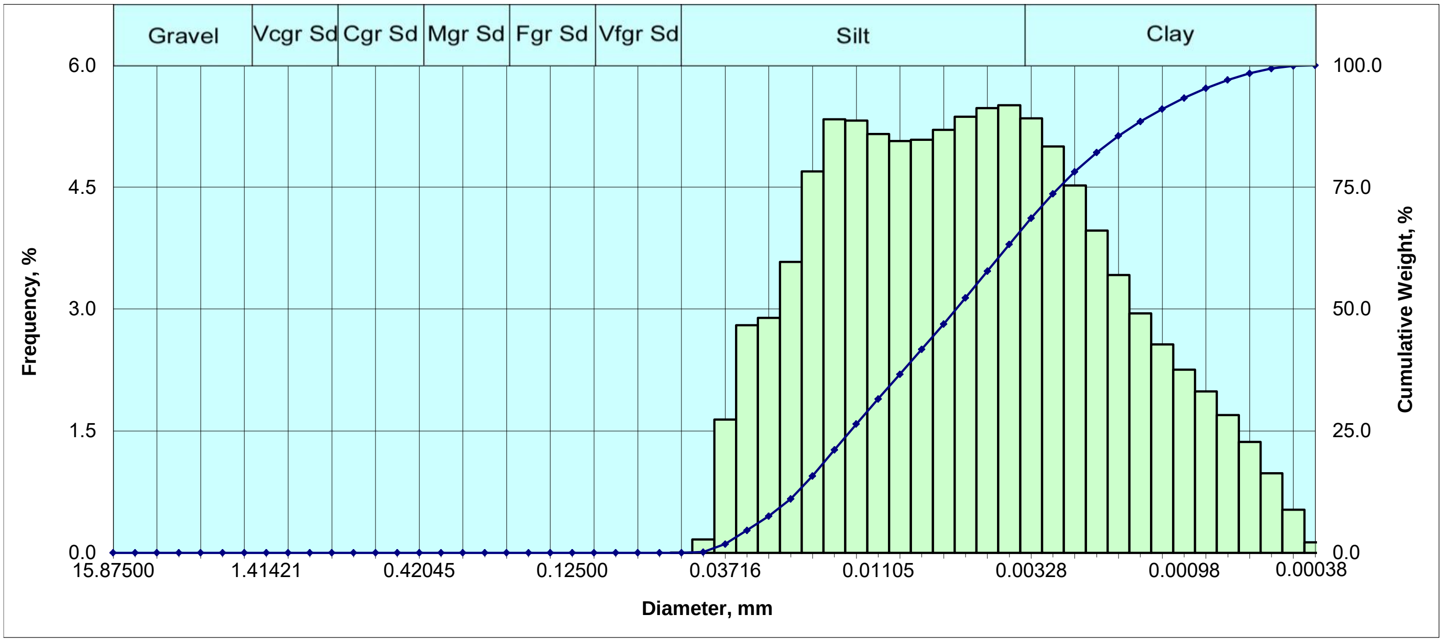
Percentile [Weight, %]	Particle Diameter [in.]	Particle Diameter [mm]	Particle Diameter [phi]
5	0.0009	0.0225	5.4761
10	0.0007	0.0181	5.7861
16	0.0006	0.0146	6.0970
25	0.0004	0.0108	6.5308
30	0.0004	0.0092	6.7710
50	0.0002	0.0049	7.6842
60	0.0001	0.0036	8.1087
75	0.0001	0.0023	8.7888
84	0.0001	0.0016	9.3012
90	0.0000	0.0012	9.7514
95	0.0000	0.0008	10.2568

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802475
Sample ID: PZ-1D_38-38.5

Sieve and Laser Particle Size Analysis



Particle Size Distribution						
	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.000	0.00
Coarse Sand	20	0.033106	0.84090	0.25	0.000	0.00
	25	0.027839	0.70711	0.50	0.000	0.00
	30	0.023410	0.59460	0.75	0.000	0.00
	35	0.019685	0.50000	1.00	0.000	0.00
Medium Sand	40	0.016553	0.42045	1.25	0.000	0.00
	45	0.013919	0.35355	1.50	0.000	0.00
	50	0.011705	0.29730	1.75	0.000	0.00
	60	0.009843	0.25000	2.00	0.000	0.00
Fine Sand	70	0.008277	0.21022	2.25	0.000	0.00
	80	0.006960	0.17678	2.50	0.000	0.00
	100	0.005852	0.14865	2.75	0.000	0.00
	120	0.004921	0.12500	3.00	0.000	0.00
V. Fine Sand	140	0.004138	0.10511	3.25	0.000	0.00
	170	0.003480	0.08839	3.50	0.000	0.00
	200	0.002926	0.07433	3.75	0.000	0.00
	230	0.002461	0.06250	4.00	0.000	0.00
Silt	270	0.002069	0.05256	4.25	0.000	0.00
	325	0.001740	0.04419	4.50	0.165	0.17
	400	0.001463	0.03716	4.75	1.642	1.81
	450	0.001230	0.03125	5.00	2.800	4.61
	500	0.001035	0.02628	5.25	2.893	7.50
	635	0.000870	0.02210	5.50	3.579	11.08
		0.000732	0.01858	5.75	4.695	15.77
		0.000615	0.01562	6.00	5.336	21.11
		0.000517	0.01314	6.25	5.320	26.43
		0.000435	0.01105	6.50	5.153	31.58
		0.000366	0.00929	6.75	5.068	36.65
		0.000308	0.00781	7.00	5.083	41.73
		0.000259	0.00657	7.25	5.208	46.94
		0.000217	0.00552	7.50	5.366	52.31
		0.000183	0.00465	7.75	5.473	57.78
		0.000154	0.00391	8.00	5.508	63.29
Clay		0.000129	0.00328	8.25	5.348	68.64
		0.000109	0.00276	8.50	5.003	73.64
		0.000091	0.00232	8.75	4.520	78.16
		0.000077	0.00195	9.00	3.967	82.13
		0.000065	0.00164	9.25	3.419	85.55
		0.000054	0.00138	9.50	2.945	88.49
		0.000046	0.00116	9.75	2.566	91.06
		0.000038	0.00098	10.00	2.256	93.31
		0.000032	0.00082	10.25	1.988	95.30
		0.000027	0.00069	10.50	1.697	97.00
		0.000023	0.00058	10.75	1.364	98.36
		0.000019	0.00049	11.00	0.978	99.34
		0.000016	0.00041	11.25	0.531	99.87
		0.000015	0.00038	11.50	0.130	100.00

Sorting Statistics (Folk)			
Parameter	**Trask**	**Inman**	**Folk**
Median	**Silt sized**		
(in)	0.0002	0.0002	0.0002
(mm)	0.0060	0.0060	0.0060
Mean	**Silt sized**		
(in)	0.0003	0.0002	0.0002
(mm)	0.0082	0.0057	0.0058
Sorting	**Poor**		
	2.291	1.686	1.627
Skewness	**Near symmetrical**		
	1.009	0.138	0.062
Kurtosis	**Platykurtic**		
	0.253	0.536	0.887

Component Percentages				
Gravel	**Sand**	**Silt**	**Clay**	**Silt + Clay**
0.00	0.00	63.29	36.71	100.00

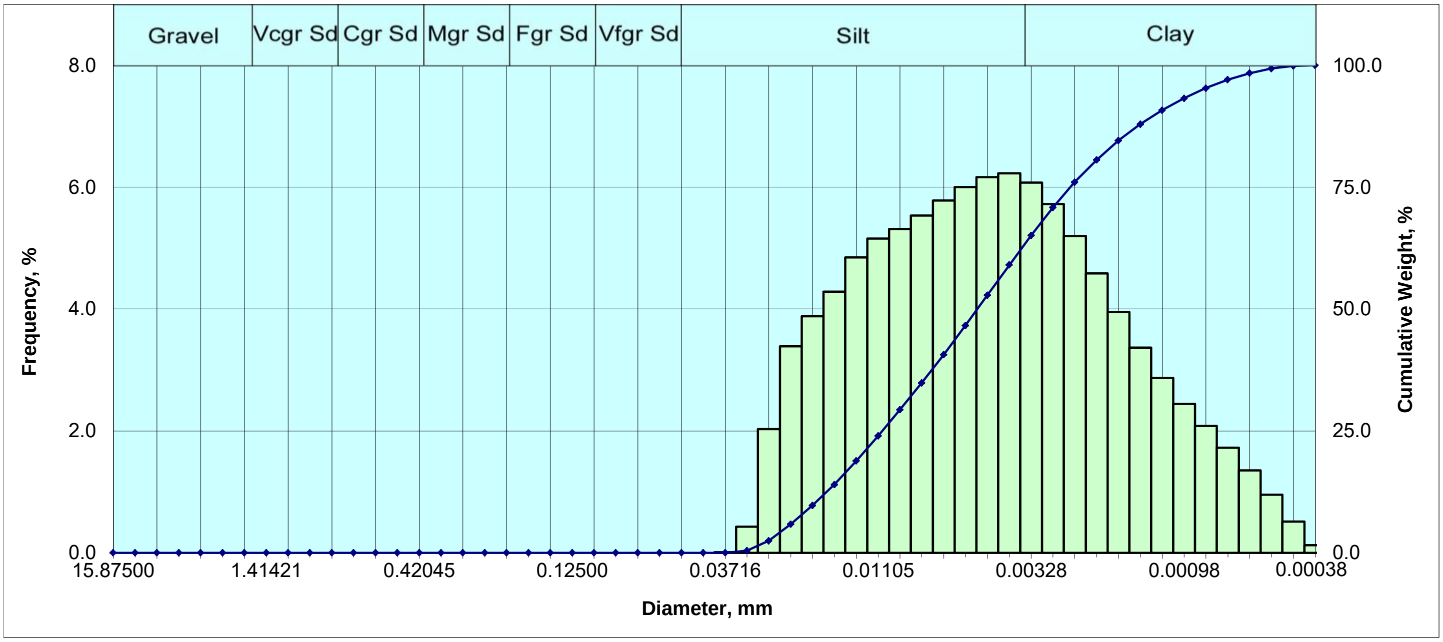
Percentile [Weight, %]	Particle Diameter		
	[in.]	[mm]	[phi]
5	0.0012	0.0306	5.0315
10	0.0009	0.0234	5.4200
16	0.0007	0.0185	5.7598
25	0.0005	0.0138	6.1785
30	0.0005	0.0117	6.4185
50	0.0002	0.0060	7.3871
60	0.0002	0.0043	7.8456
75	0.0001	0.0026	8.5709
84	0.0001	0.0018	9.1317
90	0.0000	0.0013	9.6418
95	0.0000	0.0008	10.2094

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802475
Sample ID: PZ-1D_39-39.5

Sieve and Laser Particle Size Analysis



Particle Size Distribution

	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.000	0.00
Coarse Sand	20	0.033106	0.84090	0.25	0.000	0.00
	25	0.027839	0.70711	0.50	0.000	0.00
	30	0.023410	0.59460	0.75	0.000	0.00
	35	0.019685	0.50000	1.00	0.000	0.00
Medium Sand	40	0.016553	0.42045	1.25	0.000	0.00
	45	0.013919	0.35355	1.50	0.000	0.00
	50	0.011705	0.29730	1.75	0.000	0.00
	60	0.009843	0.25000	2.00	0.000	0.00
Fine Sand	70	0.008277	0.21022	2.25	0.000	0.00
	80	0.006960	0.17678	2.50	0.000	0.00
	100	0.005852	0.14865	2.75	0.000	0.00
	120	0.004921	0.12500	3.00	0.000	0.00
V. Fine Sand	140	0.004138	0.10511	3.25	0.000	0.00
	170	0.003480	0.08839	3.50	0.000	0.00
	200	0.002926	0.07433	3.75	0.000	0.00
	230	0.002461	0.06250	4.00	0.000	0.00
Silt	270	0.002069	0.05256	4.25	0.000	0.00
	325	0.001740	0.04419	4.50	0.000	0.00
	400	0.001463	0.03716	4.75	0.009	0.01
	450	0.001230	0.03125	5.00	0.428	0.44
	500	0.001035	0.02628	5.25	2.027	2.46
	635	0.000870	0.02210	5.50	3.386	5.85
		0.000732	0.01858	5.75	3.880	9.73
		0.000615	0.01562	6.00	4.284	14.01
		0.000517	0.01314	6.25	4.846	18.86
		0.000435	0.01105	6.50	5.159	24.02
		0.000366	0.00929	6.75	5.317	29.33
		0.000308	0.00781	7.00	5.536	34.87
		0.000259	0.00657	7.25	5.783	40.65
		0.000217	0.00552	7.50	6.002	46.66
		0.000183	0.00465	7.75	6.164	52.82
		0.000154	0.00391	8.00	6.227	59.05
Clay		0.000129	0.00328	8.25	6.073	65.12
		0.000109	0.00276	8.50	5.722	70.84
		0.000091	0.00232	8.75	5.202	76.04
		0.000077	0.00195	9.00	4.587	80.63
		0.000065	0.00164	9.25	3.952	84.58
		0.000054	0.00138	9.50	3.366	87.95
		0.000046	0.00116	9.75	2.867	90.81
		0.000038	0.00098	10.00	2.443	93.26
		0.000032	0.00082	10.25	2.080	95.34
		0.000027	0.00069	10.50	1.723	97.06
		0.000023	0.00058	10.75	1.351	98.41
		0.000019	0.00049	11.00	0.952	99.36
		0.000016	0.00041	11.25	0.512	99.87
		0.000015	0.00038	11.50	0.125	100.00

Sorting Statistics (Folk)

Parameter	Trask	Inman	Folk
Median	**Silt sized**		
(in)	0.0002	0.0002	0.0002
(mm)	0.0050	0.0050	0.0050
Mean	**Silt sized**		
(in)	0.0003	0.0002	0.0002
(mm)	0.0066	0.0050	0.0050
Sorting	**Poor**		
	2.109	1.557	1.501
Skewness	**Near symmetrical**		
	1.007	0.122	0.047
Kurtosis	**Mesokurtic**		
	0.242	0.533	0.909

Component Percentages

Gravel	Sand	Silt	Clay	Silt + Clay
0.00	0.00	59.05	40.95	100.00

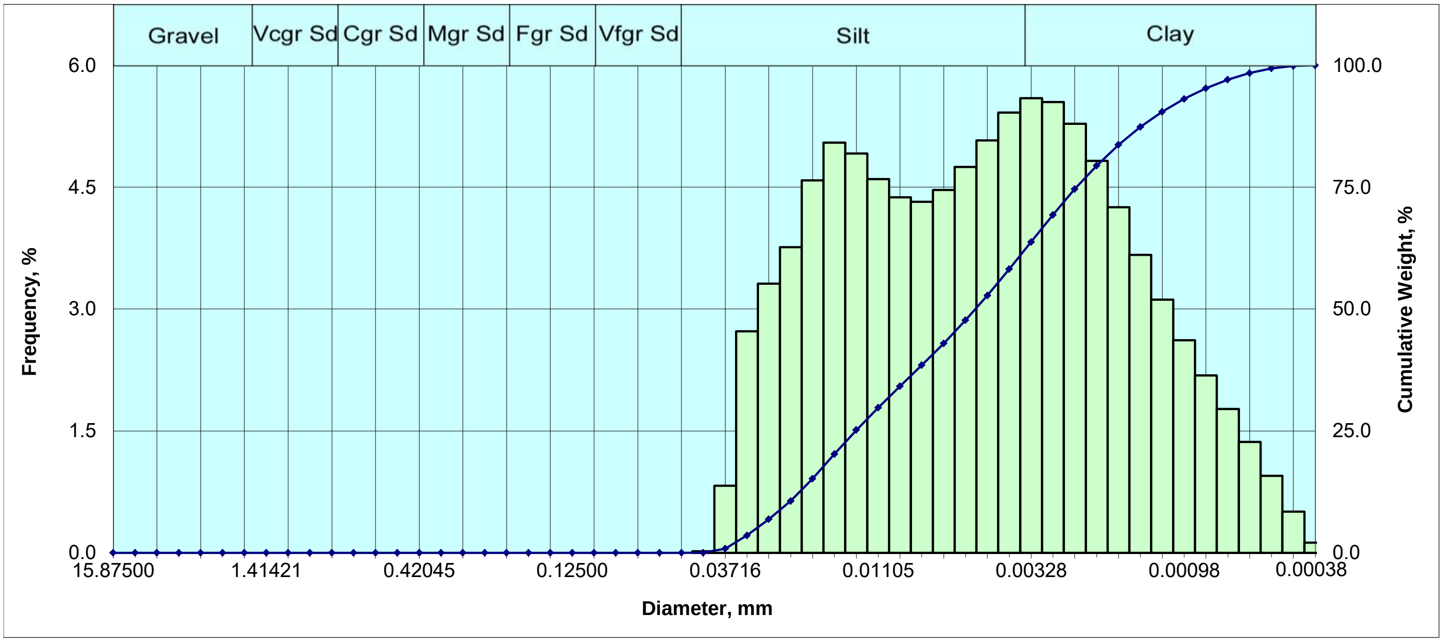
Percentile [Weight, %]	Particle Diameter		
	[in.]	[mm]	[phi]
5	0.0009	0.0231	5.4330
10	0.0007	0.0184	5.7645
16	0.0006	0.0146	6.0973
25	0.0004	0.0107	6.5430
30	0.0004	0.0091	6.7778
50	0.0002	0.0050	7.6302
60	0.0001	0.0038	8.0365
75	0.0001	0.0024	8.6963
84	0.0001	0.0017	9.2104
90	0.0000	0.0012	9.6744
95	0.0000	0.0008	10.2063

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802475
Sample ID: PZ-1D_41.2-41.7

Sieve and Laser Particle Size Analysis



Particle Size Distribution						
	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.000	0.00
Coarse Sand	20	0.033106	0.84090	0.25	0.000	0.00
	25	0.027839	0.70711	0.50	0.000	0.00
	30	0.023410	0.59460	0.75	0.000	0.00
	35	0.019685	0.50000	1.00	0.000	0.00
Medium Sand	40	0.016553	0.42045	1.25	0.000	0.00
	45	0.013919	0.35355	1.50	0.000	0.00
	50	0.011705	0.29730	1.75	0.000	0.00
	60	0.009843	0.25000	2.00	0.000	0.00
Fine Sand	70	0.008277	0.21022	2.25	0.000	0.00
	80	0.006960	0.17678	2.50	0.000	0.00
	100	0.005852	0.14865	2.75	0.000	0.00
	120	0.004921	0.12500	3.00	0.000	0.00
V. Fine Sand	140	0.004138	0.10511	3.25	0.000	0.00
	170	0.003480	0.08839	3.50	0.000	0.00
	200	0.002926	0.07433	3.75	0.000	0.00
	230	0.002461	0.06250	4.00	0.000	0.00
Silt	270	0.002069	0.05256	4.25	0.000	0.00
	325	0.001740	0.04419	4.50	0.020	0.02
	400	0.001463	0.03716	4.75	0.823	0.84
	450	0.001230	0.03125	5.00	2.728	3.57
	500	0.001035	0.02628	5.25	3.314	6.88
	635	0.000870	0.02210	5.50	3.760	10.64
		0.000732	0.01858	5.75	4.584	15.23
		0.000615	0.01562	6.00	5.050	20.28
		0.000517	0.01314	6.25	4.915	25.19
		0.000435	0.01105	6.50	4.599	29.79
		0.000366	0.00929	6.75	4.377	34.17
		0.000308	0.00781	7.00	4.321	38.49
		0.000259	0.00657	7.25	4.467	42.96
		0.000217	0.00552	7.50	4.750	47.71
		0.000183	0.00465	7.75	5.076	52.78
		0.000154	0.00391	8.00	5.419	58.20
Clay		0.000129	0.00328	8.25	5.596	63.80
		0.000109	0.00276	8.50	5.550	69.35
		0.000091	0.00232	8.75	5.280	74.63
		0.000077	0.00195	9.00	4.823	79.45
		0.000065	0.00164	9.25	4.255	83.71
		0.000054	0.00138	9.50	3.668	87.37
		0.000046	0.00116	9.75	3.115	90.49
		0.000038	0.00098	10.00	2.618	93.11
		0.000032	0.00082	10.25	2.184	95.29
		0.000027	0.00069	10.50	1.770	97.06
		0.000023	0.00058	10.75	1.364	98.43
		0.000019	0.00049	11.00	0.947	99.37
		0.000016	0.00041	11.25	0.505	99.88
		0.000015	0.00038	11.50	0.124	100.00

Sorting Statistics (Folk)			
Parameter	Trask	Inman	Folk
Median	Silt sized		
(in)	0.0002	0.0002	0.0002
(mm)	0.0051	0.0051	0.0051
Mean	Silt sized		
(in)	0.0003	0.0002	0.0002
(mm)	0.0078	0.0054	0.0053
Sorting	Poor		
	2.402	1.742	1.645
Skewness	Near symmetrical		
	1.075	0.029	-0.013
Kurtosis	Platykurtic		
	0.253	0.468	0.829

Component Percentages				
Gravel	Sand	Silt	Clay	Silt + Clay
0.00	0.00	58.20	41.80	100.00

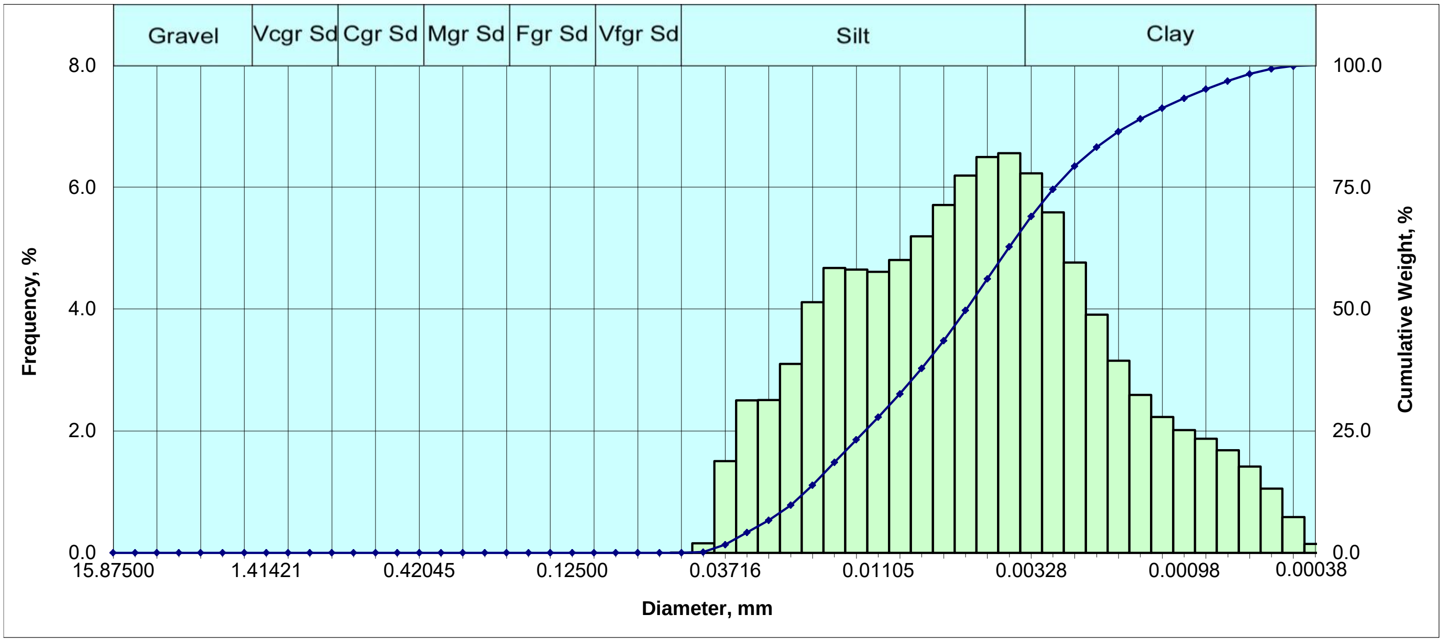
Percentile [Weight, %]	Particle Diameter		
	[in.]	[mm]	[phi]
5	0.0011	0.0291	5.1026
10	0.0009	0.0228	5.4539
16	0.0007	0.0181	5.7855
25	0.0005	0.0132	6.2393
30	0.0004	0.0110	6.5109
50	0.0002	0.0051	7.6076
60	0.0001	0.0037	8.0757
75	0.0001	0.0023	8.7678
84	0.0001	0.0016	9.2685
90	0.0000	0.0012	9.7078
95	0.0000	0.0008	10.2141

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802475
Sample ID: PZ-1D_43.3-43.8

Sieve and Laser Particle Size Analysis



Particle Size Distribution						
	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.000	0.00
Coarse Sand	20	0.033106	0.84090	0.25	0.000	0.00
	25	0.027839	0.70711	0.50	0.000	0.00
	30	0.023410	0.59460	0.75	0.000	0.00
	35	0.019685	0.50000	1.00	0.000	0.00
Medium Sand	40	0.016553	0.42045	1.25	0.000	0.00
	45	0.013919	0.35355	1.50	0.000	0.00
	50	0.011705	0.29730	1.75	0.000	0.00
	60	0.009843	0.25000	2.00	0.000	0.00
Fine Sand	70	0.008277	0.21022	2.25	0.000	0.00
	80	0.006960	0.17678	2.50	0.000	0.00
	100	0.005852	0.14865	2.75	0.000	0.00
	120	0.004921	0.12500	3.00	0.000	0.00
V. Fine Sand	140	0.004138	0.10511	3.25	0.000	0.00
	170	0.003480	0.08839	3.50	0.000	0.00
	200	0.002926	0.07433	3.75	0.000	0.00
	230	0.002461	0.06250	4.00	0.000	0.00
Silt	270	0.002069	0.05256	4.25	0.000	0.00
	325	0.001740	0.04419	4.50	0.153	0.15
	400	0.001463	0.03716	4.75	1.506	1.66
	450	0.001230	0.03125	5.00	2.502	4.16
	500	0.001035	0.02628	5.25	2.507	6.67
	635	0.000870	0.02210	5.50	3.099	9.77
		0.000732	0.01858	5.75	4.113	13.88
		0.000615	0.01562	6.00	4.674	18.55
		0.000517	0.01314	6.25	4.648	23.20
		0.000435	0.01105	6.50	4.611	27.81
		0.000366	0.00929	6.75	4.806	32.62
		0.000308	0.00781	7.00	5.196	37.81
		0.000259	0.00657	7.25	5.707	43.52
		0.000217	0.00552	7.50	6.192	49.71
		0.000183	0.00465	7.75	6.497	56.21
		0.000154	0.00391	8.00	6.558	62.77
Clay		0.000129	0.00328	8.25	6.229	69.00
		0.000109	0.00276	8.50	5.587	74.59
		0.000091	0.00232	8.75	4.763	79.35
		0.000077	0.00195	9.00	3.907	83.26
		0.000065	0.00164	9.25	3.152	86.41
		0.000054	0.00138	9.50	2.590	89.00
		0.000046	0.00116	9.75	2.231	91.23
		0.000038	0.00098	10.00	2.016	93.24
		0.000032	0.00082	10.25	1.871	95.12
		0.000027	0.00069	10.50	1.685	96.80
		0.000023	0.00058	10.75	1.418	98.22
		0.000019	0.00049	11.00	1.054	99.27
		0.000016	0.00041	11.25	0.584	99.86
		0.000015	0.00038	11.50	0.144	100.00

Sorting Statistics (Folk)			
Parameter	**Trask**	**Inman**	**Folk**
Median	Silt sized		
(in)	0.0002	0.0002	0.0002
(mm)	0.0055	0.0055	0.0055
Mean	Silt sized		
(in)	0.0003	0.0002	0.0002
(mm)	0.0075	0.0057	0.0056
Sorting	Poor		
	2.127	1.599	1.580
Skewness	Near symmetrical		
	1.056	0.091	0.012
Kurtosis	Mesokurtic		
	0.233	0.612	0.970

Component Percentages				
Gravel	Sand	Silt	Clay	Silt + Clay
0.00	0.00	62.77	37.23	100.00

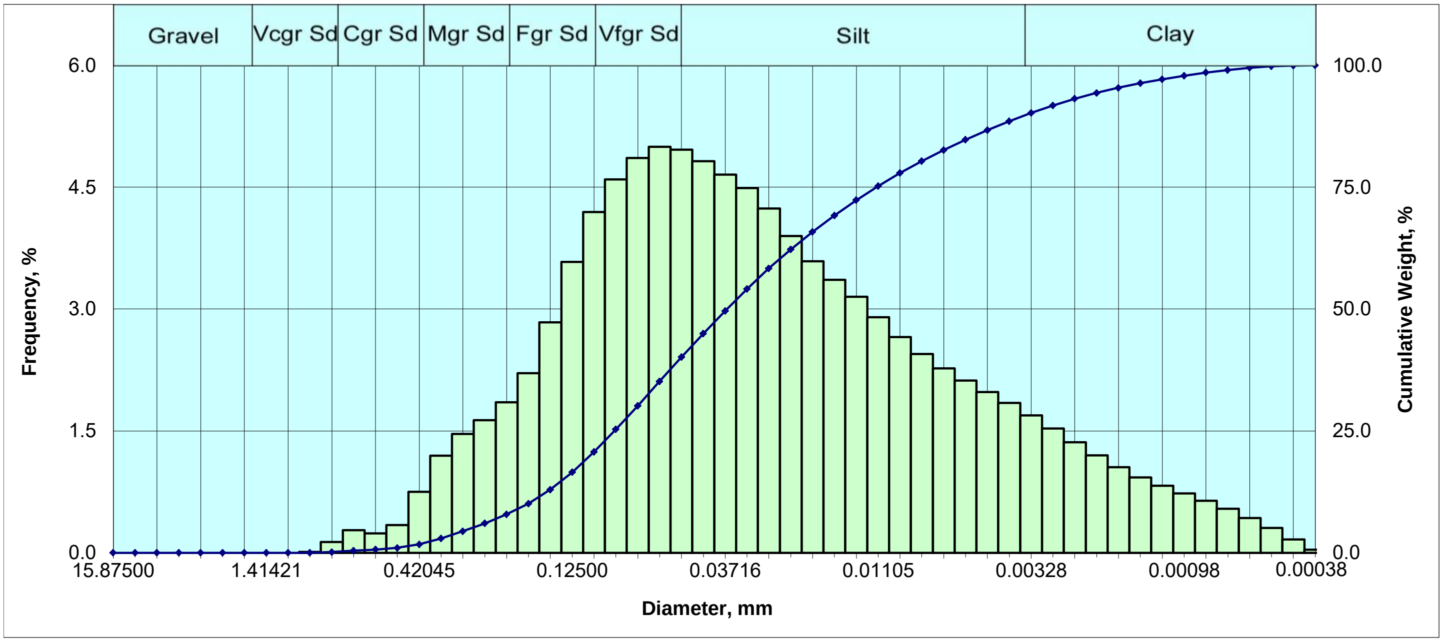
Percentile [Weight, %]	Particle Diameter [in.]	[mm]	[phi]
5	0.0012	0.0296	5.0789
10	0.0009	0.0219	5.5131
16	0.0007	0.0172	5.8581
25	0.0005	0.0123	6.3424
30	0.0004	0.0102	6.6085
50	0.0002	0.0055	7.5102
60	0.0002	0.0042	7.8891
75	0.0001	0.0027	8.5201
84	0.0001	0.0019	9.0552
90	0.0001	0.0013	9.6070
95	0.0000	0.0008	10.2333

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802475
Sample ID: PZ-1D_45.2-45.7

Sieve and Laser Particle Size Analysis



Particle Size Distribution

	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.011	0.01
Coarse Sand	20	0.033106	0.84090	0.25	0.132	0.14
	25	0.027839	0.70711	0.50	0.280	0.42
	30	0.023410	0.59460	0.75	0.239	0.66
	35	0.019685	0.50000	1.00	0.341	1.00
Medium Sand	40	0.016553	0.42045	1.25	0.750	1.75
	45	0.013919	0.35355	1.50	1.197	2.95
	50	0.011705	0.29730	1.75	1.461	4.41
	60	0.009843	0.25000	2.00	1.634	6.04
Fine Sand	70	0.008277	0.21022	2.25	1.854	7.90
	80	0.006960	0.17678	2.50	2.209	10.11
	100	0.005852	0.14865	2.75	2.837	12.95
	120	0.004921	0.12500	3.00	3.581	16.53
V. Fine Sand	140	0.004138	0.10511	3.25	4.196	20.72
	170	0.003480	0.08839	3.50	4.597	25.32
	200	0.002926	0.07433	3.75	4.860	30.18
	230	0.002461	0.06250	4.00	4.998	35.18
Silt	270	0.002069	0.05256	4.25	4.962	40.14
	325	0.001740	0.04419	4.50	4.822	44.96
	400	0.001463	0.03716	4.75	4.656	49.62
	450	0.001230	0.03125	5.00	4.489	54.11
	500	0.001035	0.02628	5.25	4.237	58.34
	635	0.000870	0.02210	5.50	3.900	62.24
		0.000732	0.01858	5.75	3.589	65.83
		0.000615	0.01562	6.00	3.360	69.19
		0.000517	0.01314	6.25	3.153	72.35
		0.000435	0.01105	6.50	2.901	75.25
		0.000366	0.00929	6.75	2.655	77.90
		0.000308	0.00781	7.00	2.447	80.35
		0.000259	0.00657	7.25	2.271	82.62
		0.000217	0.00552	7.50	2.120	84.74
		0.000183	0.00465	7.75	1.979	86.72
		0.000154	0.00391	8.00	1.843	88.56
Clay		0.000129	0.00328	8.25	1.693	90.25
		0.000109	0.00276	8.50	1.530	91.78
		0.000091	0.00232	8.75	1.362	93.15
		0.000077	0.00195	9.00	1.200	94.35
		0.000065	0.00164	9.25	1.053	95.40
		0.000054	0.00138	9.50	0.927	96.33
		0.000046	0.00116	9.75	0.824	97.15
		0.000038	0.00098	10.00	0.730	97.88
		0.000032	0.00082	10.25	0.641	98.52
		0.000027	0.00069	10.50	0.542	99.06
		0.000023	0.00058	10.75	0.430	99.49
		0.000019	0.00049	11.00	0.305	99.80
		0.000016	0.00041	11.25	0.164	99.96
		0.000015	0.00038	11.50	0.040	100.00

Sorting Statistics (Folk)

Parameter	Trask	Inman	Folk
Median	**Silt sized**		
(in)	0.0014	0.0014	0.0014
(mm)	0.0367	0.0367	0.0367
Mean	**Silt sized**		
(in)	0.0020	0.0011	0.0012
(mm)	0.0504	0.0275	0.0303
Sorting	**Very poor**		
	2.824	2.224	2.220
Skewness	**Finely skewed**		
	0.865	0.325	0.192
Kurtosis	**Mesokurtic**		
	0.224	0.645	1.001

Component Percentages

Gravel	Sand	Silt	Clay	Silt + Clay
0.00	35.18	53.39	11.44	64.82

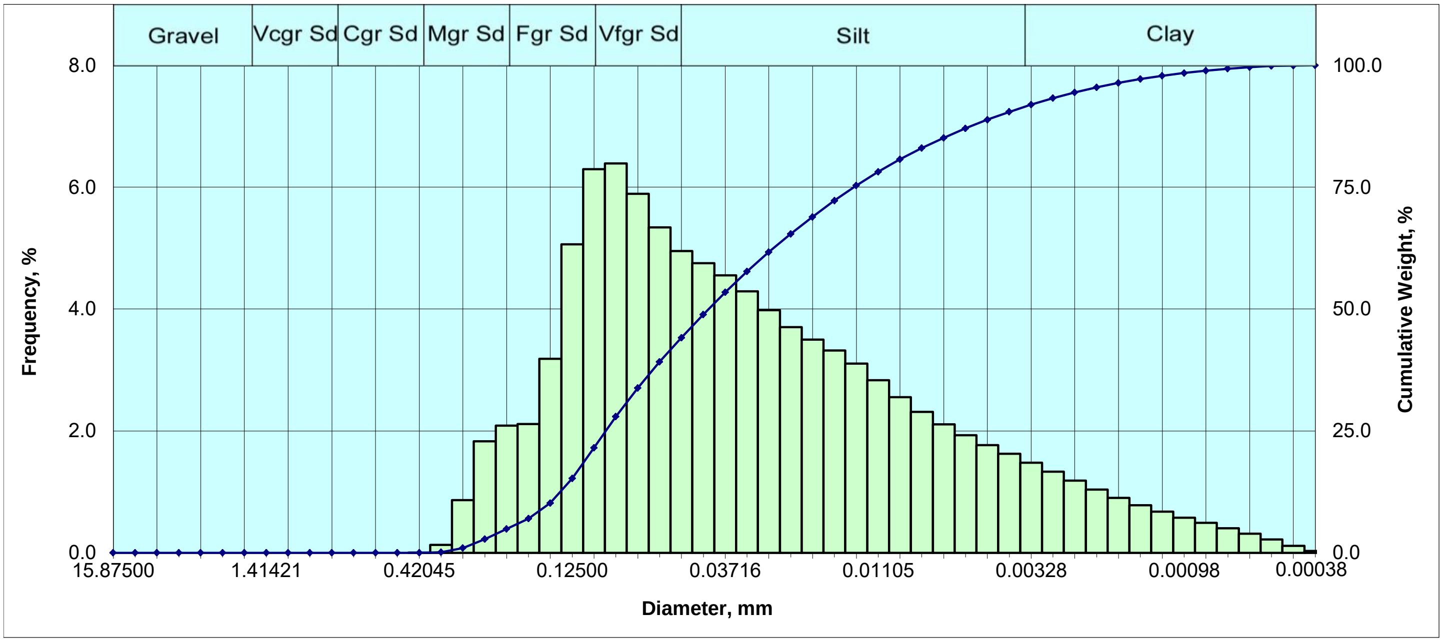
Percentile [Weight, %]	Particle Diameter [in.]	[mm]	[phi]
5	0.0110	0.2802	1.8353
10	0.0070	0.1784	2.4867
16	0.0051	0.1285	2.9604
25	0.0035	0.0895	3.4812
30	0.0029	0.0748	3.7400
50	0.0014	0.0367	4.7697
60	0.0010	0.0245	5.3509
75	0.0004	0.0112	6.4769
84	0.0002	0.0059	7.4077
90	0.0001	0.0034	8.2095
95	0.0001	0.0018	9.1500

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802475
Sample ID: PZ-1D_48.3-48.8

Sieve and Laser Particle Size Analysis



Particle Size Distribution						
	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.000	0.00
Coarse Sand	20	0.033106	0.84090	0.25	0.000	0.00
	25	0.027839	0.70711	0.50	0.000	0.00
	30	0.023410	0.59460	0.75	0.000	0.00
	35	0.019685	0.50000	1.00	0.000	0.00
Medium Sand	40	0.016553	0.42045	1.25	0.002	0.00
	45	0.013919	0.35355	1.50	0.129	0.13
	50	0.011705	0.29730	1.75	0.864	0.99
	60	0.009843	0.25000	2.00	1.827	2.82
Fine Sand	70	0.008277	0.21022	2.25	2.089	4.91
	80	0.006960	0.17678	2.50	2.115	7.03
	100	0.005852	0.14865	2.75	3.183	10.21
	120	0.004921	0.12500	3.00	5.062	15.27
V. Fine Sand	140	0.004138	0.10511	3.25	6.295	21.57
	170	0.003480	0.08839	3.50	6.390	27.95
	200	0.002926	0.07433	3.75	5.890	33.84
	230	0.002461	0.06250	4.00	5.339	39.18
Silt	270	0.002069	0.05256	4.25	4.955	44.14
	325	0.001740	0.04419	4.50	4.751	48.89
	400	0.001463	0.03716	4.75	4.554	53.44
	450	0.001230	0.03125	5.00	4.290	57.73
	500	0.001035	0.02628	5.25	3.981	61.72
	635	0.000870	0.02210	5.50	3.703	65.42
		0.000732	0.01858	5.75	3.498	68.92
		0.000615	0.01562	6.00	3.321	72.24
		0.000517	0.01314	6.25	3.106	75.34
		0.000435	0.01105	6.50	2.831	78.17
		0.000366	0.00929	6.75	2.556	80.73
		0.000308	0.00781	7.00	2.313	83.04
		0.000259	0.00657	7.25	2.106	85.15
		0.000217	0.00552	7.50	1.928	87.08
		0.000183	0.00465	7.75	1.769	88.85
		0.000154	0.00391	8.00	1.625	90.47
Clay		0.000129	0.00328	8.25	1.479	91.95
		0.000109	0.00276	8.50	1.331	93.28
		0.000091	0.00232	8.75	1.182	94.46
		0.000077	0.00195	9.00	1.038	95.50
		0.000065	0.00164	9.25	0.902	96.40
		0.000054	0.00138	9.50	0.781	97.19
		0.000046	0.00116	9.75	0.674	97.86
		0.000038	0.00098	10.00	0.578	98.44
		0.000032	0.00082	10.25	0.490	98.93
		0.000027	0.00069	10.50	0.402	99.33
		0.000023	0.00058	10.75	0.311	99.64
		0.000019	0.00049	11.00	0.216	99.86
		0.000016	0.00041	11.25	0.115	99.97
		0.000015	0.00038	11.50	0.028	100.00

Sorting Statistics (Folk)			
Parameter	Trask	Inman	Folk
Median	Silt sized		
(in)	0.0017	0.0017	0.0017
(mm)	0.0425	0.0425	0.0425
Mean	Silt sized		
(in)	0.0022	0.0012	0.0013
(mm)	0.0548	0.0298	0.0336
Sorting	Very poor		
	2.677	2.041	2.022
Skewness	Finely skewed		
	0.845	0.495	0.278
Kurtosis	Mesokurtic		
	0.283	0.620	0.954

Component Percentages				
Gravel	Sand	Silt	Clay	Silt + Clay
0.00	39.18	51.29	9.53	60.82

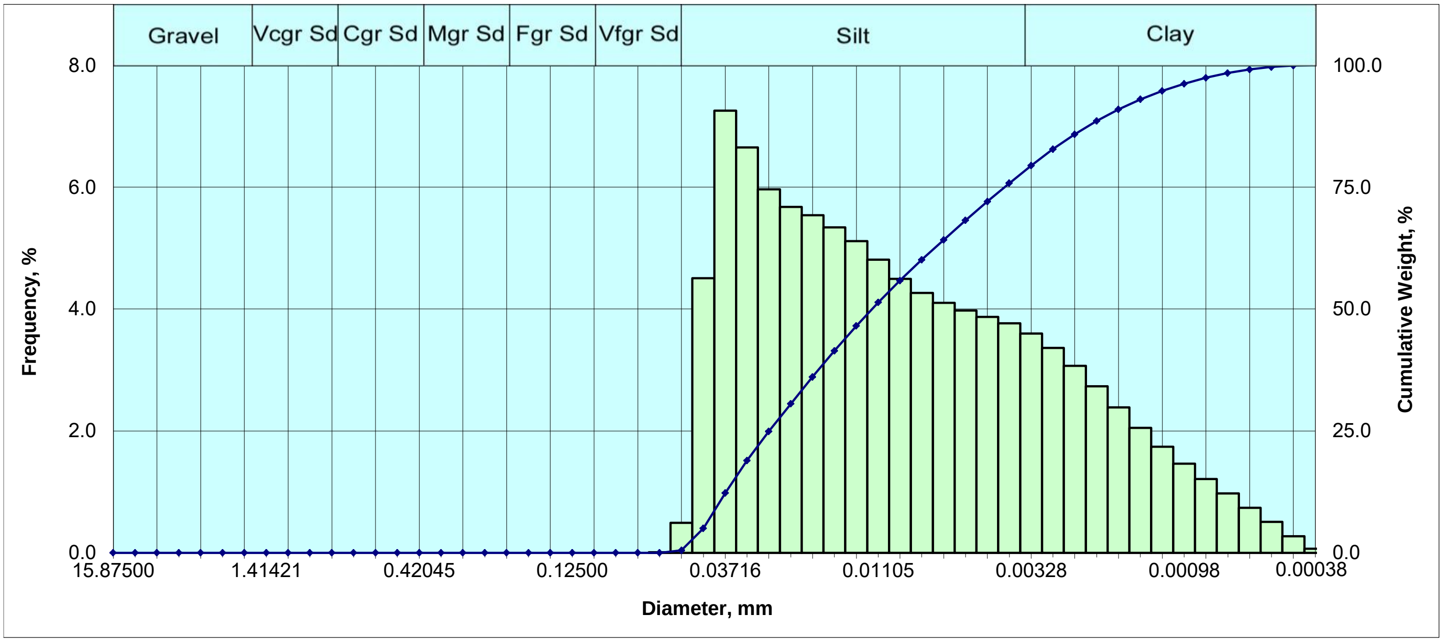
Percentile [Weight, %]	Particle Diameter		
	[in.]	[mm]	[phi]
5	0.0082	0.2088	2.2597
10	0.0059	0.1505	2.7322
16	0.0048	0.1227	3.0269
25	0.0038	0.0961	3.3790
30	0.0033	0.0835	3.5820
50	0.0017	0.0425	4.5571
60	0.0011	0.0284	5.1369
75	0.0005	0.0134	6.2201
84	0.0003	0.0072	7.1082
90	0.0002	0.0041	7.9229
95	0.0001	0.0021	8.8735

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802475
Sample ID: PZ-1D_51-51.5

Sieve and Laser Particle Size Analysis



Particle Size Distribution						
	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.000	0.00
Coarse Sand	20	0.033106	0.84090	0.25	0.000	0.00
	25	0.027839	0.70711	0.50	0.000	0.00
	30	0.023410	0.59460	0.75	0.000	0.00
	35	0.019685	0.50000	1.00	0.000	0.00
Medium Sand	40	0.016553	0.42045	1.25	0.000	0.00
	45	0.013919	0.35355	1.50	0.000	0.00
	50	0.011705	0.29730	1.75	0.000	0.00
	60	0.009843	0.25000	2.00	0.000	0.00
Fine Sand	70	0.008277	0.21022	2.25	0.000	0.00
	80	0.006960	0.17678	2.50	0.000	0.00
	100	0.005852	0.14865	2.75	0.000	0.00
	120	0.004921	0.12500	3.00	0.000	0.00
V. Fine Sand	140	0.004138	0.10511	3.25	0.000	0.00
	170	0.003480	0.08839	3.50	0.000	0.00
	200	0.002926	0.07433	3.75	0.000	0.00
	230	0.002461	0.06250	4.00	0.007	0.01
Silt	270	0.002069	0.05256	4.25	0.491	0.50
	325	0.001740	0.04419	4.50	4.505	5.00
	400	0.001463	0.03716	4.75	7.255	12.26
	450	0.001230	0.03125	5.00	6.654	18.91
	500	0.001035	0.02628	5.25	5.966	24.88
	635	0.000870	0.02210	5.50	5.678	30.56
		0.000732	0.01858	5.75	5.538	36.09
		0.000615	0.01562	6.00	5.342	41.44
		0.000517	0.01314	6.25	5.116	46.55
		0.000435	0.01105	6.50	4.810	51.36
		0.000366	0.00929	6.75	4.496	55.86
		0.000308	0.00781	7.00	4.263	60.12
		0.000259	0.00657	7.25	4.101	64.22
		0.000217	0.00552	7.50	3.978	68.20
		0.000183	0.00465	7.75	3.873	72.07
		0.000154	0.00391	8.00	3.767	75.84
Clay		0.000129	0.00328	8.25	3.597	79.44
		0.000109	0.00276	8.50	3.363	82.80
		0.000091	0.00232	8.75	3.067	85.87
		0.000077	0.00195	9.00	2.733	88.60
		0.000065	0.00164	9.25	2.384	90.98
		0.000054	0.00138	9.50	2.048	93.03
		0.000046	0.00116	9.75	1.740	94.77
		0.000038	0.00098	10.00	1.460	96.23
		0.000032	0.00082	10.25	1.211	97.44
		0.000027	0.00069	10.50	0.973	98.42
		0.000023	0.00058	10.75	0.741	99.16
		0.000019	0.00049	11.00	0.509	99.67
		0.000016	0.00041	11.25	0.269	99.93
		0.000015	0.00038	11.50	0.066	100.00

Sorting Statistics (Folk)			
Parameter	**Trask**	**Inman**	**Folk**
Median	**Silt sized**		
(in)	0.0005	0.0005	0.0005
(mm)	0.0116	0.0116	0.0116
Mean	**Silt sized**		
(in)	0.0006	0.0004	0.0004
(mm)	0.0151	0.0094	0.0101
Sorting	**Poor**		
	2.536	1.854	1.728
Skewness	**Finely skewed**		
	0.887	0.387	0.221
Kurtosis	**Platykurtic**		
	0.294	0.426	0.807

Component Percentages				
Gravel	**Sand**	**Silt**	**Clay**	**Silt + Clay**
0.00	0.01	75.83	24.16	99.99

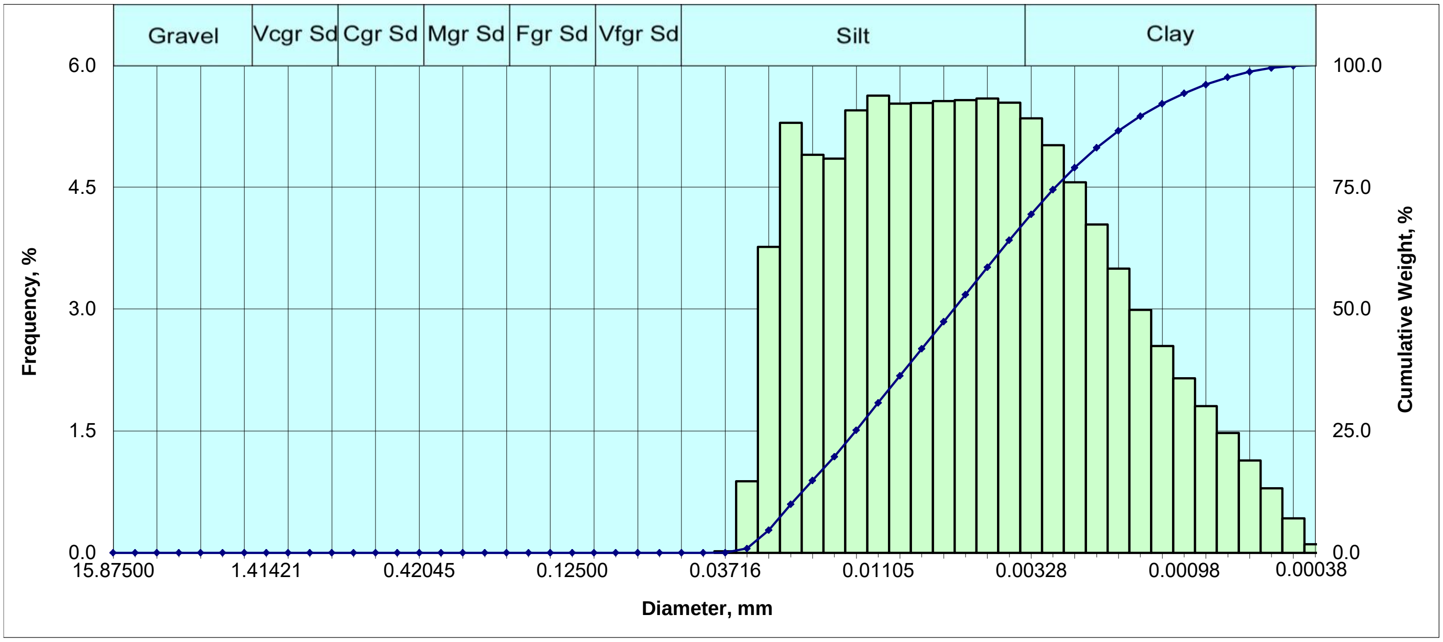
Percentile [Weight, %]	Particle Diameter		
	[in.]	[mm]	[phi]
5	0.0017	0.0442	4.4998
10	0.0015	0.0394	4.6674
16	0.0013	0.0338	4.8852
25	0.0010	0.0262	5.2549
30	0.0009	0.0225	5.4735
50	0.0005	0.0116	6.4247
60	0.0003	0.0079	6.9923
75	0.0002	0.0041	7.9404
84	0.0001	0.0026	8.5927
90	0.0001	0.0018	9.1415
95	0.0000	0.0011	9.7862

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802475
Sample ID: PZ-1D_54-55.5

Sieve and Laser Particle Size Analysis



Particle Size Distribution						
	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.000	0.00
Coarse Sand	20	0.033106	0.84090	0.25	0.000	0.00
	25	0.027839	0.70711	0.50	0.000	0.00
	30	0.023410	0.59460	0.75	0.000	0.00
	35	0.019685	0.50000	1.00	0.000	0.00
Medium Sand	40	0.016553	0.42045	1.25	0.000	0.00
	45	0.013919	0.35355	1.50	0.000	0.00
	50	0.011705	0.29730	1.75	0.000	0.00
	60	0.009843	0.25000	2.00	0.000	0.00
Fine Sand	70	0.008277	0.21022	2.25	0.000	0.00
	80	0.006960	0.17678	2.50	0.000	0.00
	100	0.005852	0.14865	2.75	0.000	0.00
	120	0.004921	0.12500	3.00	0.000	0.00
V. Fine Sand	140	0.004138	0.10511	3.25	0.000	0.00
	170	0.003480	0.08839	3.50	0.000	0.00
	200	0.002926	0.07433	3.75	0.000	0.00
	230	0.002461	0.06250	4.00	0.000	0.00
Silt	270	0.002069	0.05256	4.25	0.000	0.00
	325	0.001740	0.04419	4.50	0.000	0.00
	400	0.001463	0.03716	4.75	0.019	0.02
	450	0.001230	0.03125	5.00	0.880	0.90
	500	0.001035	0.02628	5.25	3.767	4.67
	635	0.000870	0.02210	5.50	5.291	9.96
		0.000732	0.01858	5.75	4.899	14.86
		0.000615	0.01562	6.00	4.851	19.71
		0.000517	0.01314	6.25	5.447	25.15
		0.000435	0.01105	6.50	5.629	30.78
		0.000366	0.00929	6.75	5.531	36.31
		0.000308	0.00781	7.00	5.538	41.85
		0.000259	0.00657	7.25	5.559	47.41
		0.000217	0.00552	7.50	5.574	52.98
		0.000183	0.00465	7.75	5.594	58.58
		0.000154	0.00391	8.00	5.542	64.12
Clay		0.000129	0.00328	8.25	5.348	69.47
		0.000109	0.00276	8.50	5.018	74.48
		0.000091	0.00232	8.75	4.560	79.04
		0.000077	0.00195	9.00	4.039	83.08
		0.000065	0.00164	9.25	3.499	86.58
		0.000054	0.00138	9.50	2.990	89.57
		0.000046	0.00116	9.75	2.545	92.12
		0.000038	0.00098	10.00	2.149	94.27
		0.000032	0.00082	10.25	1.806	96.07
		0.000027	0.00069	10.50	1.473	97.54
		0.000023	0.00058	10.75	1.138	98.68
		0.000019	0.00049	11.00	0.792	99.47
		0.000016	0.00041	11.25	0.422	99.90
		0.000015	0.00038	11.50	0.103	100.00

Sorting Statistics (Folk)			
Parameter	**Trask**	**Inman**	**Folk**
Median	Silt sized		
(in)	0.0002	0.0002	0.0002
(mm)	0.0061	0.0061	0.0061
Mean	Silt sized		
(in)	0.0003	0.0002	0.0002
(mm)	0.0080	0.0058	0.0059
Sorting	Poor		
	2.207	1.628	1.546
Skewness	Near symmetrical		
	0.984	0.196	0.088
Kurtosis	Platykurtic		
	0.253	0.484	0.867

Component Percentages				
Gravel	**Sand**	**Silt**	**Clay**	**Silt + Clay**
0.00	0.00	64.12	35.88	100.00

Percentile [Weight, %]	Particle Diameter		
	[in.]	[mm]	[phi]
5	0.0010	0.0260	5.2645
10	0.0009	0.0221	5.5020
16	0.0007	0.0179	5.8052
25	0.0005	0.0132	6.2423
30	0.0004	0.0113	6.4625
50	0.0002	0.0061	7.3608
60	0.0002	0.0045	7.8102
75	0.0001	0.0027	8.5262
84	0.0001	0.0019	9.0614
90	0.0001	0.0013	9.5391
95	0.0000	0.0009	10.0964

**All Grain Sizes Classed using Wentworth Scale

RAMBOLL ENVIRON

CHAIN-OF-CUSTODY FORM

UST PROJECT OR IS EDF REQUIRED? YES NO IF YES, GLOBAL ID# ______ MSA # ______ WORK ORDER # ______

PROJECT NAME/FACILITY ID NERT AWF Capture Evaluation DATE 7/10/2018 FIELD PERSON# J. Manheim / A. Manion

PROJECT LOCATION Henderson, NV PROJECT MANAGER C. Stubbs

PROJECT NUMBER 1690006943-048 LABORATORY CORE LABS

Sampler J. Manheim

Signature J. Manheim

Analysis Required

SAMPLE ID NUMBER	SAMPLE DATE	SAMPLE TIME	SAMPLE DEPTH (F)	AIR SAMPLE VOLUME (L)	MATRIX: (A)IR; (G)AS; (W)ATER	NUMBER OF CONTAINERS	FILTERED/UNFILTERED (F/U)	PRESERVATION (SEE KEY)	Hold*		COMMENTS
PT-PZ1D-14.0-14.3-20180710	7/10/2018	0848	14.0-14.3	NA	S	2	U	None	X	✓	
PT-PZ1D-27.5-27.8-20180710		0905	27.5-27.8			2			X	✓	*Hold pending
PT-PZ1D-32.0-32.3-20180710		0920	32.0-32.3			2			X	✓	instruction from
PT-PZ1D-33.3-33.8-20180710		0944	33.3-33.8			1			X	✓	Pejman Basouli —
PT-PZ1D-35.0-35.5-20180710		0952	35.0-35.5						X	✓	prasouli@ramboll.com
PT-PZ1D-36.0-36.5-20180710		1003	36.0-36.5						X	✓	or Chris Stubbs —
PT-PZ1D-37.0-37.5-20180710	↓	1012	37.0-37.5	↓	↓	↓	↓	↓	X	✓	cstubbs@ramboll.com
PT-PZ1D-38.0-38.5-20180710	7/10/2018	1018	38.0-38.5	NA	S	1	U	None	X	✓	
TOTAL						11			8		

RELINQUISHED BY Ramboll - J. Manheim	TIME/DATE 1000 7/11/18	RECEIVED BY COMPANY FedEx	TIME/DATE 1000 7/11/18	TURNAROUND TIME (CIRCLE ONE)	SAME DAY 24 HOURS 48 HOURS
RELINQUISHED BY	TIME/DATE	RECEIVED BY COMPANY Tracey Bishop Core Lab	TIME/DATE 1318 7/12/18		72 HOURS 5 DAYS [✓ NORMAL]
RELINQUISHED BY	TIME/DATE	RECEIVED BY COMPANY	TIME/DATE	SAMPLE INTEGRITY INTACT Y N TEMP______	SAMPLE INTEGRITY INTACT Y N

SWBU Office Locations:
☐ 18100 Von Karman Avenue, Suite 600, Irvine, CA 92612 +1 949 261 5151 +1 949 261 6202
☐ 350 S Grand Avenue, Suite 2800, Los Angeles, CA 90071 +1 213 943 6300 +1 213 943 6301
☐ 2111 East Highland Avenue, Suite 402, Phoenix, AZ 85016 +1 602 734 7700 +1 602 734-7701

Page 1 of 1

RAMBOLL ENVIRON

CHAIN-OF-CUSTODY FORM

UST PROJECT OR IS EDF REQUIRED? YES NO IF YES, GLOBAL ID# ______ MSA # ______ WORK ORDER # ______

PROJECT NAME/FACILITY ID: NERT AWF Capture Evaluation DATE: 7/10/2018 FIELD PERSON#: J. Manheim/A. Manion

PROJECT LOCATION: Henderson, NV PROJECT MANAGER: C. Stubbs

PROJECT NUMBER: 1690006943-048 LABORATORY: CORE LABS

Sampler: J. Manheim

Signature: J Manheim

SAMPLE ID NUMBER	SAMPLE DATE	SAMPLE TIME	SAMPLE DEPTH (F)	AIR SAMPLE VOLUME (L)	MATRIX: (A)IR; (G)AS; (W)ATER	NUMBER OF CONTAINERS	FILTERED/UNFILTERED (F/U)	PRESERVATION (SEE KEY)	Analysis Required: Hold*		COMMENTS
PT-PZ1D-39.0-39.5-20180710	7/10/18	1025	39.0-39.5	NA	S	1	U	None	☒	✓	
PT-PZ1D-41.2-41.7-20180710	↓	1031	41.2-41.7	↓	↓	↓	↓	↓	☒	✓	*Hold pending instruction from Pejman Rasouli — prasouli@ramboll.com or Chris Stubbs — cstubbs@ramboll.com
PT-PZ1D-43.3-43.8-20180710		1037	43.3-43.8						☒	✓	
PT-PZ1D-45.2-45.7-20180710		1045	45.2-45.7						☒	✓	
PT-PZ1D-48.3-48.8-20180710		1050	48.3-48.8						☒	✓	
PT-PZ1D-51.0-51.5-20180710		1057	51.0-51.5						☒	✓	
PT-PZ1D-54.0-54.5-20180710	7/10/18	1102	54.0-54.5	NA	S	1	U	None	☒	✓	
TOTAL						7			7		

RELINQUISHED BY	TIME/DATE	RECEIVED BY COMPANY	TIME/DATE		
Ramboll - J. Manheim	1000 7/11/18	FedEx	1000 7/11/18	TURNAROUND TIME (CIRCLE ONE)	SAME DAY 24 HOURS 48 HOURS 72 HOURS 5 DAYS [✓ NORMAL]
RELINQUISHED BY	TIME/DATE	RECEIVED BY COMPANY: Tracey Bishop Core Lab	TIME/DATE: 1311 7-12-18		
RELINQUISHED BY	TIME/DATE	RECEIVED BY COMPANY	TIME/DATE	SAMPLE INTEGRITY INTACT Y N TEMP______	SAMPLE INTEGRITY INTACT Y N

SWBU Office Locations:
☐ 18100 Von Karman Avenue, Suite 600, Irvine, CA 92612 +1 949 261 5151 +1 949 261 6202
☐ 350 S Grand Avenue, Suite 2800, Los Angeles, CA 90071 +1 213 943 6300 +1 213 943 6301
☐ 2111 East Highland Avenue, Suite 402, Phoenix, AZ 85016 +1 602 734 7700 +1 602 734-7701

To: Larry Kunkel, Core Laboratories
3470 Landco Drive, Bakersfield, CA 93308

NERT Project Work Order No. CL-2018-004
Nevada Environmental Reponse Trust (NERT)
Henderson, Nevada

Ramboll Project No.: 169000 6943-048 (Task M25)

PHYSICAL TESTING REQUEST
for AWF Sample Shipment Group 1 (sent 7/10/18)

Date: **August 24, 2018**
Submitted by: Ramboll, 2200 Powell Street, Suite 700
Emeryville, CA 94608

Ramboll Contact: Chris Stubbs, (510) 420-2552

											HYDRAULIC CONDUCTIVITY		
Boring	**Soil Sample Depth (ft bgs)**	**Soil Sample Name**	**Container type (number)**	**Grain Size**	**Atterberg Limits**	**Dry Bulk Density**	**Grain Density/ Specific Gravity**	**Porosity, Effective & Total**	**Moisture Content**	**Total Organic Carbon**	**Vertical (to water)**	**Height of Unsaturated Soil Above Water Table**	**Height of Saturated Soil Below Water Table**
PZ-1D	14.0 - 14.3	PT-PZ1D-14.0-14.3	Glass jar	X		X	X	X	X	X		14.23	0
PZ-1D	27.5 - 27.8	PT-PZ1D-27.5-27.8	Glass jar	X		X	X	X	X	X	X	27.73	0
PZ-1D	32.0 - 32.3	PT-PZ1D-32.0-32.3	Glass jar	X		X	X	X	X	X	X	31.36	0.79
PZ-1D	33.3 - 33.8	PT-PZ1D-33.3-33.8	wrapped core	X		X	X	X	X	X	X	31.36	2.19
PZ-1D	35.0 - 35.5	PT-PZ1D-35.0-35.5	wrapped core	X		X	X	X	X	X		31.36	3.89
PZ-1D	36.0 - 36.5	PT-PZ1D-36.0-36.5	wrapped core	X		X	X	X	X	X	X	31.36	4.89
PZ-1D	37.0 - 37.5	PT-PZ1D-37.0-37.5	wrapped core	X		X	X	X	X	X		31.36	5.89
PZ-1D	38.0 - 38.5	PT-PZ1D-38.0-38.5	wrapped core	X		X	X	X	X	X	X	31.36	6.89
PZ-1D	39.0 - 39.5	PT-PZ1D-39.0-39.5	wrapped core	X		X	X	X	X	X		31.36	7.89
PZ-1D	41.2 - 41.7	PT-PZ1D-41.2-41.7	wrapped core	X		X	X	X	X	X	X	31.36	10.09
PZ-1D	43.3 - 43.8	PT-PZ1D-43.3-43.8	wrapped core	X		X	X	X	X	X		31.36	12.19
PZ-1D	45.2 - 45.7	PT-PZ1D-45.2-45.7	wrapped core	X		X	X	X	X	X	X	31.36	14.09
PZ-1D	48.3 - 48.8	PT-PZ1D-48.3-48.8	wrapped core	X		X	X	X	X	X		31.36	17.19
PZ-1D	51.0 - 51.5	PT-PZ1D-51.0-51.5	wrapped core	X		X	X	X	X	X	X	31.36	19.89
PZ-1D	54.0 - 55.5	PT-PZ1D-54.0-55.5	wrapped core	X		X	X	X	X	X		31.36	23.39
			TOTALS:	**15**		**15**	**15**	**15**	**15**	**15**	**8**		

Notes:
SOIL SAMPLES ARE LIKELY CONTAMINATED (perchlorate, metals, VOCs).

Core Lab
RESERVOIR OPTIMIZATION

Petroleum Services Division
3437 Landco Dr.
Bakersfield, California 93308
Tel: 661-325-5657
Fax: 661-325-5808
www.corelab.com

September 28, 2018

Jessica Donovan/Chris Stubbs
Ramboll US Corporation
2200 Powell Street, Suite 700
Emeryville, CA 94608

Subject: TOC and LPSA
File No.: 1802753

Dear Mr. Stubbs:

Enclosed are final data for the 10 samples submitted to our laboratory from project NERT AWF Capture Evaluation in Henderson, Nevada.

Grain size analysis and TOC were performed on requested samples where there was suitable recovery. Appropriate ASTM, EPA or API methodologies were used for this project and SOP's are available on request. The sample for this project is currently in storage and will be retained for thirty days past completion of testing at no charge. At the end of thirty days, the sample will be disposed. You may contact me regarding continued storage, disoposal, or return of the sample.

Thank you for this opportunity to be of service to Ramboll US Corporation. Please do not hesitate to contact us at (661-325-5657) if you have any questions regarding these results or if we can be of any additional service.

Sincerely,
Core Laboratories

Chris Florence

Chris Florence
Sr. Core Analyst

TOC & FOC

Ramboll US Corporation

CL File No.: 1802753

Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

			METHODS:	Walkley-Black	
Sample ID.	Depth ft.	Sample Date	Sample [1] Orientation	Total Organic Carbon mg/kg	Fractional Organic Carbon g/g
PZ-2M_42-42.3	42-42.3	08/29/18	H	1000	1.00E-03
PZ-2M_43-43.3	43-43.3	08/29/18	V	1000	1.00E-03
PZ-2M_44-44.3	44-44.3	08/29/18	H	2700	2.70E-03
PZ-2M_45-45.4	45-45.4	08/29/18	V	4000	4.00E-03
PZ-2M_46-46.4	46-46.4	08/29/18	H	5300	5.30E-03
PZ-2M_47-47.4	47-47.4	08/29/18	V	5300	5.30E-03
PZ-2M_48-48.4	48-48.4	08/29/18	H	3800	3.80E-03
PZ-2M_49-49.4	49-49.4	08/29/18	V	4500	4.50E-03
PZ-2M_50-50.4	50-50.4	08/29/18	H	3200	3.20E-03
PZ-2M_51-51.4	51-51.4	08/29/18	V	5800	5.80E-03

(1) Sample Orientation: H = horizontal; V = vertical.

SIEVE and LASER PARTICLE SIZE SUMMARY

(METHODOLOGY: ASTM D422/D4464M)

Petroleum Services

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802753
Date: 9/28/2018

Sample ID	Grain Size Description** (Mean from Folk)	Median Grain Size, mm	Component Percentages								
				Sand Size							
			Granule	VCoarse	Coarse	Medium	Fine	VFine	Silt	Clay	Silt & Clay
PZ-2M_42-42.3	Very Coarse Grain Sand	1.4733	37.20	30.47	16.49	5.85	2.52	1.91	4.11	1.44	5.55
PZ-2M_43-43.3	Coarse Grain Sand	0.9776	23.41	25.90	15.91	8.13	5.64	7.23	11.42	2.35	13.78
PZ-2M_44-44.3	Granule	3.0042	61.73	20.62	8.65	3.16	1.32	1.15	2.54	0.84	3.37
PZ-2M_45-45.4	Silt	0.0039	0.00	0.00	0.00	0.00	0.00	0.00	49.49	50.51	100.00
PZ-2M_46-46.4	Silt	0.0040	0.00	0.00	0.00	0.00	0.00	0.00	51.00	49.00	100.00
PZ-2M_47-47.4	Silt	0.0048	0.00	0.00	0.00	0.00	0.00	0.00	56.92	43.08	100.00
PZ-2M_48-48.4	Silt	0.0039	0.00	0.00	0.00	0.00	0.00	0.00	49.79	50.21	100.00
PZ-2M_49-49.4	Silt	0.0039	0.00	0.00	0.00	0.00	0.00	0.00	50.35	49.65	100.00
PZ-2M_50-50.4	Silt	0.0047	0.00	0.00	0.00	0.00	0.00	0.00	56.66	43.34	100.00
PZ-2M_51-51.4	Silt	0.0046	0.00	0.00	0.00	0.00	0.00	0.00	55.93	44.07	100.00

**Wentworth Scale

SIEVE and LASER PARTICLE SIZE SUMMARY

(METHODOLOGY: ASTM D422/D4464M)

Petroleum Services

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802753
Date: 9/28/2018

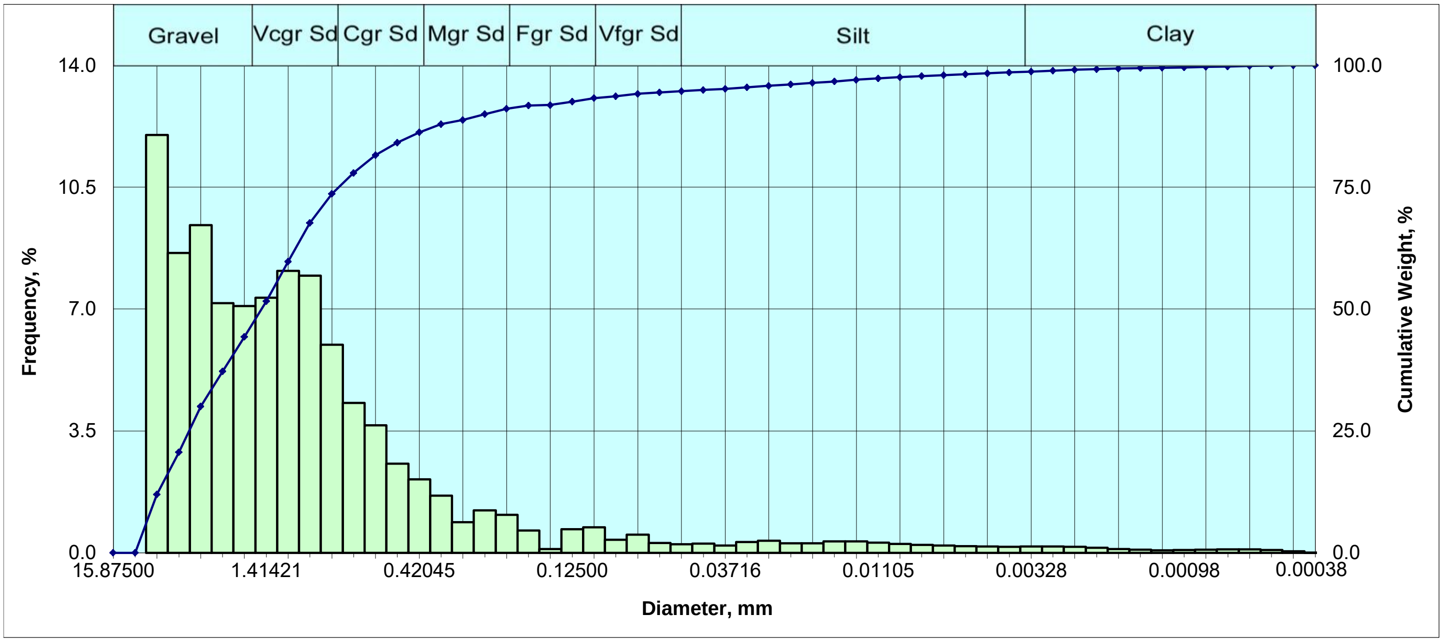
Sample ID	Grain Size Description** (Mean from Trask)	Median Grain Size, mm	Component Percentages						
				Sand Sized					
			Granule	Coarse	Medium	Fine	Silt	Clay	Silt & Clay
PZ-2M_42-42.3	Medium Grain Sand	1.4733	12.00	25.20	49.07	7.90	4.03	1.79	5.83
PZ-2M_43-43.3	Medium Grain Sand	0.9776	12.91	10.50	44.15	17.13	12.19	3.12	15.31
PZ-2M_44-44.3	Coarse Grain Sand	3.0042	30.75	30.98	30.26	4.41	2.56	1.04	3.60
PZ-2M_45-45.4	Clay	0.0039	0.00	0.00	0.00	0.00	35.46	64.54	100.00
PZ-2M_46-46.4	Clay	0.0040	0.00	0.00	0.00	0.00	36.01	63.99	100.00
PZ-2M_47-47.4	Silt	0.0048	0.00	0.00	0.00	0.00	45.34	54.66	100.00
PZ-2M_48-48.4	Silt	0.0039	0.00	0.00	0.00	0.00	37.28	62.72	100.00
PZ-2M_49-49.4	Silt	0.0039	0.00	0.00	0.00	0.00	36.67	63.33	100.00
PZ-2M_50-50.4	Silt	0.0047	0.00	0.00	0.00	0.00	44.38	55.62	100.00
PZ-2M_51-51.4	Silt	0.0046	0.00	0.00	0.00	0.00	43.08	56.92	100.00

**USCS Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802753
Sample ID: PZ-2M_42-42.3

Sieve and Laser Particle Size Analysis



Particle Size Distribution

	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	12.004	12.00
	6	0.131890	3.35000	-1.75	8.615	20.62
	8	0.092913	2.36000	-1.25	9.412	30.03
	10	0.078740	2.00000	-1.00	7.171	37.20
V Crse Sand	12	0.066212	1.68179	-0.75	7.089	44.29
	14	0.055678	1.41421	-0.50	7.328	51.62
	16	0.046819	1.18921	-0.25	8.100	59.72
	18	0.039370	1.00000	0.00	7.957	67.68
Coarse Sand	20	0.033106	0.84090	0.25	5.972	73.65
	25	0.027839	0.70711	0.50	4.301	77.95
	30	0.023410	0.59460	0.75	3.662	81.61
	35	0.019685	0.50000	1.00	2.555	84.17
Medium Sand	40	0.016553	0.42045	1.25	2.106	86.27
	45	0.013919	0.35355	1.50	1.645	87.92
	50	0.011705	0.29730	1.75	0.880	88.80
	60	0.009843	0.25000	2.00	1.217	90.01
Fine Sand	70	0.008277	0.21022	2.25	1.090	91.10
	80	0.006960	0.17678	2.50	0.644	91.75
	100	0.005852	0.14865	2.75	0.111	91.86
	120	0.004921	0.12500	3.00	0.679	92.54
V. Fine Sand	140	0.004138	0.10511	3.25	0.736	93.27
	170	0.003480	0.08839	3.50	0.373	93.65
	200	0.002926	0.07433	3.75	0.524	94.17
	230	0.002461	0.06250	4.00	0.278	94.45
Silt	270	0.002069	0.05256	4.25	0.248	94.70
	325	0.001740	0.04419	4.50	0.262	94.96
	400	0.001463	0.03716	4.75	0.210	95.17
	450	0.001230	0.03125	5.00	0.308	95.48
	500	0.001035	0.02628	5.25	0.350	95.83
	635	0.000870	0.02210	5.50	0.277	96.10
		0.000732	0.01858	5.75	0.277	96.38
		0.000615	0.01562	6.00	0.325	96.71
		0.000517	0.01314	6.25	0.330	97.04
		0.000435	0.01105	6.50	0.295	97.33
		0.000366	0.00929	6.75	0.253	97.58
		0.000308	0.00781	7.00	0.225	97.81
		0.000259	0.00657	7.25	0.206	98.01
		0.000217	0.00552	7.50	0.191	98.21
		0.000183	0.00465	7.75	0.178	98.38
		0.000154	0.00391	8.00	0.175	98.56
Clay		0.000129	0.00328	8.25	0.180	98.74
		0.000109	0.00276	8.50	0.182	98.92
		0.000091	0.00232	8.75	0.170	99.09
		0.000077	0.00195	9.00	0.144	99.23
		0.000065	0.00164	9.25	0.112	99.35
		0.000054	0.00138	9.50	0.086	99.43
		0.000046	0.00116	9.75	0.075	99.51
		0.000038	0.00098	10.00	0.079	99.59
		0.000032	0.00082	10.25	0.091	99.68
		0.000027	0.00069	10.50	0.099	99.78
		0.000023	0.00058	10.75	0.095	99.87
		0.000019	0.00049	11.00	0.076	99.95
		0.000016	0.00041	11.25	0.043	99.99
		0.000015	0.00038	11.50	0.010	100.00

Sorting Statistics (Folk)

Parameter	Trask	Inman	Folk
Median	Very coarse sand sized		
(in)	0.0580	0.0580	0.0580
(mm)	1.4733	1.4733	1.4733
Mean	Very coarse sand sized		
(in)	0.0726	0.0567	0.0571
(mm)	1.8440	1.4406	1.4515
Sorting	Poor		
	1.902	1.509	1.884
Skewness	Finely skewed		
	1.031	0.912	0.195
Kurtosis	Very leptokurtic		
	0.197	1.471	1.648

Component Percentages

Gravel	Sand	Silt	Clay	Silt + Clay
37.20	57.25	4.11	1.44	5.55

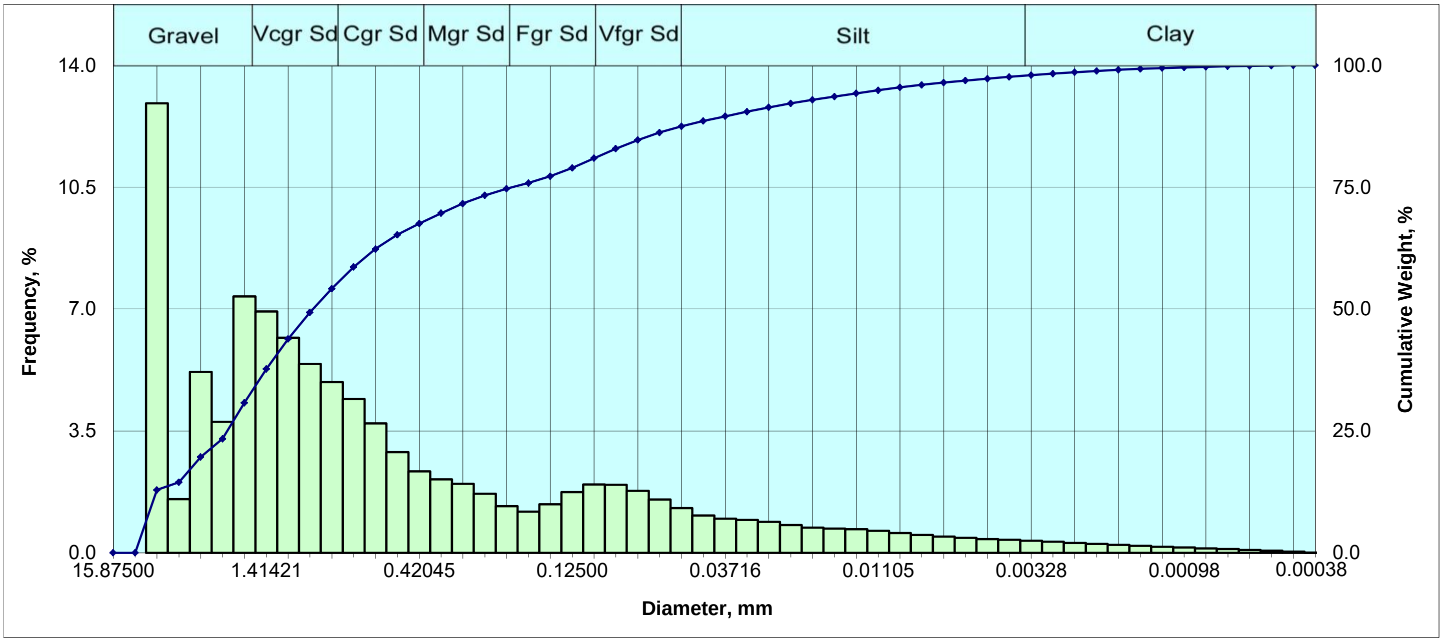
Percentile [Weight, %]	Particle Diameter [in.]	[mm]	[phi]
5	0.2961	7.5215	-2.9110
10	0.2182	5.5429	-2.4706
16	0.1614	4.1006	-2.0358
25	0.1137	2.8892	-1.5307
30	0.0930	2.3633	-1.2408
50	0.0580	1.4733	-0.5591
60	0.0466	1.1825	-0.2419
75	0.0314	0.7988	0.3241
84	0.0199	0.5061	0.9824
90	0.0099	0.2505	1.9969
95	0.0017	0.0428	4.5462

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802753
Sample ID: PZ-2M_43-43.3

Sieve and Laser Particle Size Analysis



Particle Size Distribution						
	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	12.905	12.91
	6	0.131890	3.35000	-1.75	1.539	14.44
	8	0.092913	2.36000	-1.25	5.198	19.64
	10	0.078740	2.00000	-1.00	3.766	23.41
V Crse Sand	12	0.066212	1.68179	-0.75	7.367	30.78
	14	0.055678	1.41421	-0.50	6.933	37.71
	16	0.046819	1.18921	-0.25	6.176	43.88
	18	0.039370	1.00000	0.00	5.424	49.31
Coarse Sand	20	0.033106	0.84090	0.25	4.898	54.21
	25	0.027839	0.70711	0.50	4.414	58.62
	30	0.023410	0.59460	0.75	3.715	62.34
	35	0.019685	0.50000	1.00	2.888	65.22
Medium Sand	40	0.016553	0.42045	1.25	2.335	67.56
	45	0.013919	0.35355	1.50	2.111	69.67
	50	0.011705	0.29730	1.75	1.982	71.65
	60	0.009843	0.25000	2.00	1.698	73.35
Fine Sand	70	0.008277	0.21022	2.25	1.334	74.68
	80	0.006960	0.17678	2.50	1.179	75.86
	100	0.005852	0.14865	2.75	1.389	77.25
	120	0.004921	0.12500	3.00	1.739	78.99
V. Fine Sand	140	0.004138	0.10511	3.25	1.959	80.95
	170	0.003480	0.08839	3.50	1.956	82.91
	200	0.002926	0.07433	3.75	1.783	84.69
	230	0.002461	0.06250	4.00	1.535	86.22
Silt	270	0.002069	0.05256	4.25	1.278	87.50
	325	0.001740	0.04419	4.50	1.075	88.58
	400	0.001463	0.03716	4.75	0.975	89.55
	450	0.001230	0.03125	5.00	0.942	90.49
	500	0.001035	0.02628	5.25	0.891	91.39
	635	0.000870	0.02210	5.50	0.800	92.19
		0.000732	0.01858	5.75	0.723	92.91
		0.000615	0.01562	6.00	0.693	93.60
		0.000517	0.01314	6.25	0.674	94.27
		0.000435	0.01105	6.50	0.627	94.90
		0.000366	0.00929	6.75	0.569	95.47
		0.000308	0.00781	7.00	0.514	95.98
		0.000259	0.00657	7.25	0.467	96.45
		0.000217	0.00552	7.50	0.428	96.88
		0.000183	0.00465	7.75	0.396	97.28
		0.000154	0.00391	8.00	0.370	97.65
Clay		0.000129	0.00328	8.25	0.344	97.99
		0.000109	0.00276	8.50	0.316	98.31
		0.000091	0.00232	8.75	0.286	98.59
		0.000077	0.00195	9.00	0.255	98.85
		0.000065	0.00164	9.25	0.225	99.07
		0.000054	0.00138	9.50	0.197	99.27
		0.000046	0.00116	9.75	0.172	99.44
		0.000038	0.00098	10.00	0.149	99.59
		0.000032	0.00082	10.25	0.128	99.72
		0.000027	0.00069	10.50	0.105	99.82
		0.000023	0.00058	10.75	0.082	99.90
		0.000019	0.00049	11.00	0.057	99.96
		0.000016	0.00041	11.25	0.031	99.99
		0.000015	0.00038	11.50	0.007	100.00

Sorting Statistics (Folk)			
Parameter	Trask	Inman	Folk
Median	Coarse sand sized		
(in)	0.0385	0.0385	0.0385
(mm)	0.9776	0.9776	0.9776
Mean	Coarse sand sized		
(in)	0.0420	0.0194	0.0244
(mm)	1.0663	0.4935	0.6198
Sorting	Very poor		
	3.098	2.629	2.751
Skewness	Strongly fine skewed		
	0.638	0.673	0.374
Kurtosis	Lepokurtic		
	0.150	0.802	1.191

Component Percentages				
Gravel	Sand	Silt	Clay	Silt + Clay
23.41	62.81	11.42	2.35	13.78

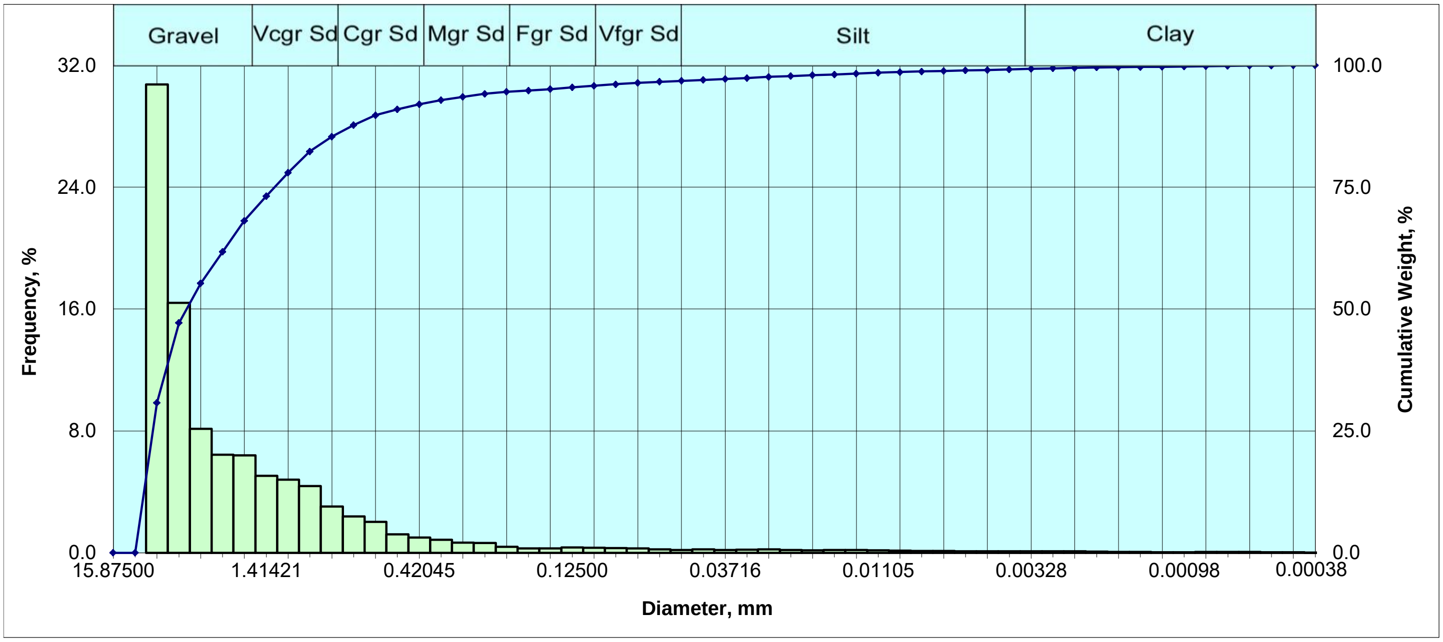
Percentile [Weight, %]	Particle Diameter		
	[in.]	[mm]	[phi]
5	0.3016	7.6597	-2.9373
10	0.2291	5.8194	-2.5409
16	0.1202	3.0538	-1.6106
25	0.0760	1.9313	-0.9495
30	0.0675	1.7153	-0.7785
50	0.0385	0.9776	0.0328
60	0.0262	0.6653	0.5878
75	0.0079	0.2012	2.3130
84	0.0031	0.0798	3.6482
90	0.0014	0.0344	4.8634
95	0.0004	0.0107	6.5400

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802753
Sample ID: PZ-2M_44-44.3

Sieve and Laser Particle Size Analysis



Particle Size Distribution						
	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	30.750	30.75
	6	0.131890	3.35000	-1.75	16.410	47.16
	8	0.092913	2.36000	-1.25	8.131	55.29
	10	0.078740	2.00000	-1.00	6.435	61.73
V Crse Sand	12	0.066212	1.68179	-0.75	6.391	68.12
	14	0.055678	1.41421	-0.50	5.059	73.18
	16	0.046819	1.18921	-0.25	4.793	77.97
	18	0.039370	1.00000	0.00	4.372	82.34
Coarse Sand	20	0.033106	0.84090	0.25	3.030	85.37
	25	0.027839	0.70711	0.50	2.385	87.76
	30	0.023410	0.59460	0.75	2.025	89.78
	35	0.019685	0.50000	1.00	1.213	90.99
Medium Sand	40	0.016553	0.42045	1.25	0.997	91.99
	45	0.013919	0.35355	1.50	0.857	92.85
	50	0.011705	0.29730	1.75	0.673	93.52
	60	0.009843	0.25000	2.00	0.636	94.16
Fine Sand	70	0.008277	0.21022	2.25	0.392	94.55
	80	0.006960	0.17678	2.50	0.288	94.84
	100	0.005852	0.14865	2.75	0.286	95.12
	120	0.004921	0.12500	3.00	0.353	95.48
V. Fine Sand	140	0.004138	0.10511	3.25	0.329	95.80
	170	0.003480	0.08839	3.50	0.315	96.12
	200	0.002926	0.07433	3.75	0.281	96.40
	230	0.002461	0.06250	4.00	0.227	96.63
Silt	270	0.002069	0.05256	4.25	0.190	96.82
	325	0.001740	0.04419	4.50	0.216	97.03
	400	0.001463	0.03716	4.75	0.177	97.21
	450	0.001230	0.03125	5.00	0.196	97.41
	500	0.001035	0.02628	5.25	0.227	97.63
	635	0.000870	0.02210	5.50	0.182	97.82
		0.000732	0.01858	5.75	0.156	97.97
		0.000615	0.01562	6.00	0.174	98.15
		0.000517	0.01314	6.25	0.180	98.33
		0.000435	0.01105	6.50	0.159	98.49
		0.000366	0.00929	6.75	0.135	98.62
		0.000308	0.00781	7.00	0.121	98.74
		0.000259	0.00657	7.25	0.114	98.86
		0.000217	0.00552	7.50	0.107	98.96
		0.000183	0.00465	7.75	0.101	99.06
		0.000154	0.00391	8.00	0.100	99.16
Clay		0.000129	0.00328	8.25	0.103	99.27
		0.000109	0.00276	8.50	0.106	99.37
		0.000091	0.00232	8.75	0.100	99.47
		0.000077	0.00195	9.00	0.085	99.56
		0.000065	0.00164	9.25	0.066	99.62
		0.000054	0.00138	9.50	0.050	99.67
		0.000046	0.00116	9.75	0.043	99.72
		0.000038	0.00098	10.00	0.045	99.76
		0.000032	0.00082	10.25	0.052	99.81
		0.000027	0.00069	10.50	0.057	99.87
		0.000023	0.00058	10.75	0.055	99.93
		0.000019	0.00049	11.00	0.044	99.97
		0.000016	0.00041	11.25	0.025	99.99
		0.000015	0.00038	11.50	0.006	100.00

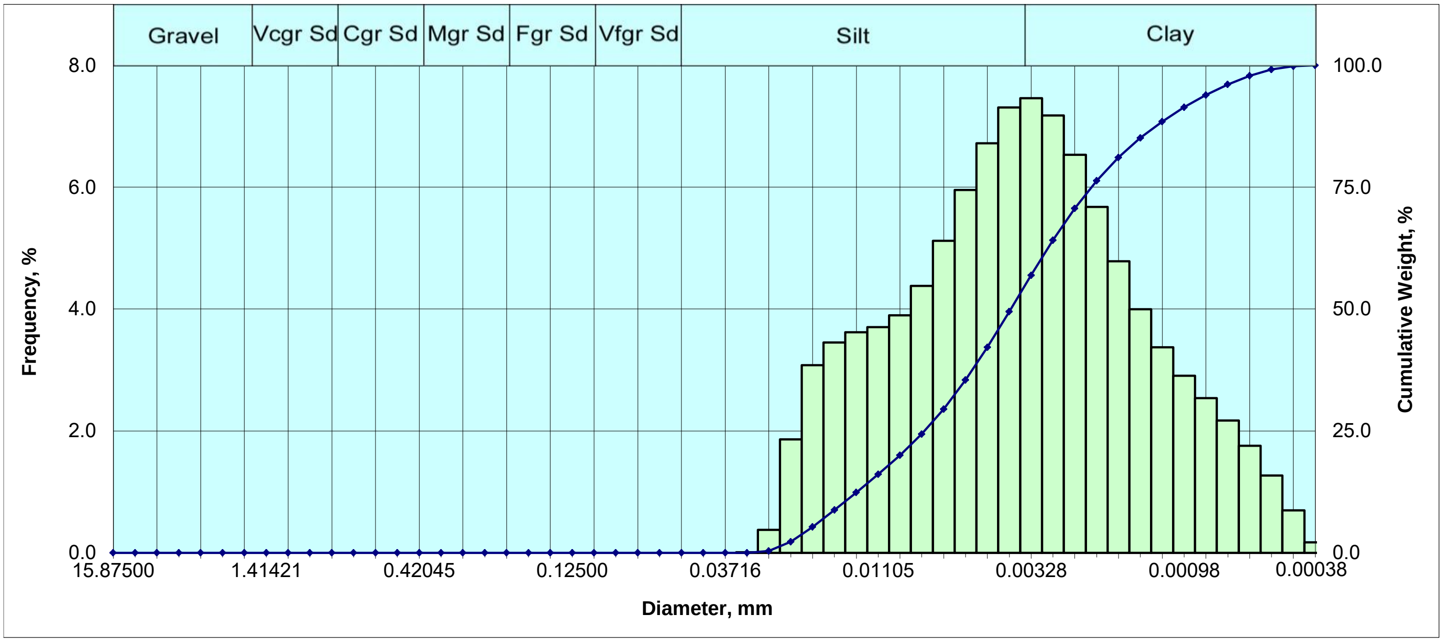
Sorting Statistics (Folk)			
Parameter	Trask	Inman	Folk
Median	Granule sized		
(in)	0.1183	0.1183	0.1183
(mm)	3.0042	3.0042	3.0042
Mean	Granule sized		
(in)	0.1371	0.0997	0.1056
(mm)	3.4834	2.5330	2.6813
Sorting	Poor		
	2.060	1.472	1.609
Skewness	Strongly fine skewed		
	0.911	0.912	0.317
Kurtosis	Lepokurtic		
	0.292	0.957	1.133

Component Percentages				
Gravel	Sand	Silt	Clay	Silt + Clay
61.73	34.90	2.54	0.84	3.37

Percentile [Weight, %]	Particle Diameter [in.]	[mm]	[phi]
5	0.3436	8.7276	-3.1256
10	0.3132	7.9553	-2.9919
16	0.2767	7.0284	-2.8132
25	0.2220	5.6382	-2.4952
30	0.1916	4.8658	-2.2827
50	0.1183	3.0042	-1.5870
60	0.0825	2.0966	-1.0680
75	0.0523	1.3286	-0.4099
84	0.0359	0.9129	0.1315
90	0.0227	0.5775	0.7920
95	0.0063	0.1607	2.6374

**All Grain Sizes Classed using Wentworth Scale

Sieve and Laser Particle Size Analysis



Particle Size Distribution						
	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.000	0.00
Coarse Sand	20	0.033106	0.84090	0.25	0.000	0.00
	25	0.027839	0.70711	0.50	0.000	0.00
	30	0.023410	0.59460	0.75	0.000	0.00
	35	0.019685	0.50000	1.00	0.000	0.00
Medium Sand	40	0.016553	0.42045	1.25	0.000	0.00
	45	0.013919	0.35355	1.50	0.000	0.00
	50	0.011705	0.29730	1.75	0.000	0.00
	60	0.009843	0.25000	2.00	0.000	0.00
Fine Sand	70	0.008277	0.21022	2.25	0.000	0.00
	80	0.006960	0.17678	2.50	0.000	0.00
	100	0.005852	0.14865	2.75	0.000	0.00
	120	0.004921	0.12500	3.00	0.000	0.00
V. Fine Sand	140	0.004138	0.10511	3.25	0.000	0.00
	170	0.003480	0.08839	3.50	0.000	0.00
	200	0.002926	0.07433	3.75	0.000	0.00
	230	0.002461	0.06250	4.00	0.000	0.00
Silt	270	0.002069	0.05256	4.25	0.000	0.00
	325	0.001740	0.04419	4.50	0.000	0.00
	400	0.001463	0.03716	4.75	0.000	0.00
	450	0.001230	0.03125	5.00	0.007	0.01
	500	0.001035	0.02628	5.25	0.377	0.38
	635	0.000870	0.02210	5.50	1.861	2.24
		0.000732	0.01858	5.75	3.078	5.32
		0.000615	0.01562	6.00	3.453	8.78
		0.000517	0.01314	6.25	3.622	12.40
		0.000435	0.01105	6.50	3.704	16.10
		0.000366	0.00929	6.75	3.900	20.00
		0.000308	0.00781	7.00	4.383	24.38
		0.000259	0.00657	7.25	5.123	29.51
		0.000217	0.00552	7.50	5.955	35.46
		0.000183	0.00465	7.75	6.720	42.18
		0.000154	0.00391	8.00	7.311	49.49
Clay		0.000129	0.00328	8.25	7.462	56.96
		0.000109	0.00276	8.50	7.175	64.13
		0.000091	0.00232	8.75	6.531	70.66
		0.000077	0.00195	9.00	5.677	76.34
		0.000065	0.00164	9.25	4.784	81.12
		0.000054	0.00138	9.50	3.995	85.12
		0.000046	0.00116	9.75	3.375	88.49
		0.000038	0.00098	10.00	2.906	91.40
		0.000032	0.00082	10.25	2.540	93.94
		0.000027	0.00069	10.50	2.171	96.11
		0.000023	0.00058	10.75	1.756	97.87
		0.000019	0.00049	11.00	1.270	99.14
		0.000016	0.00041	11.25	0.694	99.83
		0.000015	0.00038	11.50	0.171	100.00

Sorting Statistics (Folk)			
Parameter	**Trask**	**Inman**	**Folk**
Median	**Clay sized**		
(in)	0.0002	0.0002	0.0002
(mm)	0.0039	0.0039	0.0039
Mean	**Silt sized**		
(in)	0.0002	0.0002	0.0002
(mm)	0.0049	0.0040	0.0040
Sorting	**Poor**		
	1.938	1.467	1.437
Skewness	**Near symmetrical**		
	1.023	0.019	-0.013
Kurtosis	**Mesokurtic**		
	0.205	0.584	0.997

Component Percentages				
Gravel	**Sand**	**Silt**	**Clay**	**Silt + Clay**
0.00	0.00	49.49	50.51	100.00

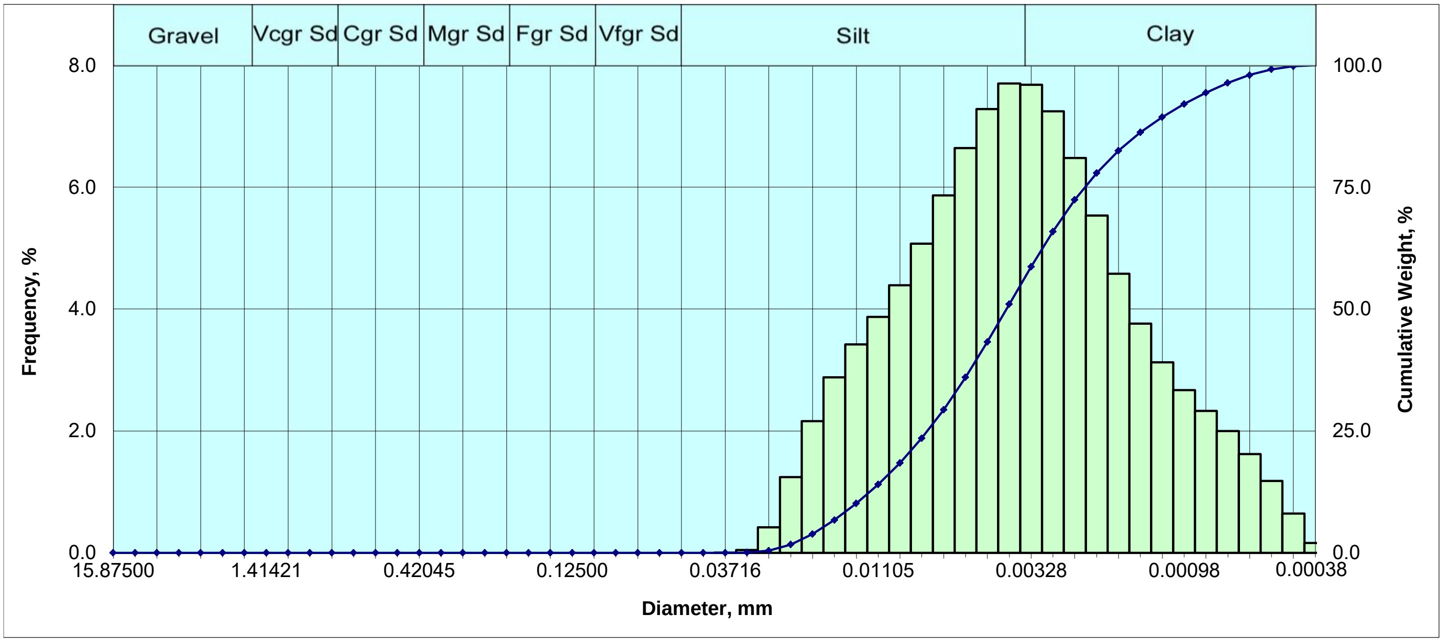
Percentile [Weight, %]	Particle Diameter		
	[in.]	[mm]	[phi]
5	0.0007	0.0189	5.7217
10	0.0006	0.0148	6.0798
16	0.0004	0.0111	6.4926
25	0.0003	0.0077	7.0279
30	0.0003	0.0065	7.2692
50	0.0002	0.0039	8.0157
60	0.0001	0.0031	8.3509
75	0.0001	0.0020	8.9370
84	0.0001	0.0015	9.4256
90	0.0000	0.0011	9.8744
95	0.0000	0.0008	10.3669

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802753
Sample ID: PZ-2M_46-46.4

Sieve and Laser Particle Size Analysis



Particle Size Distribution	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.000	0.00
Coarse Sand	20	0.033106	0.84090	0.25	0.000	0.00
	25	0.027839	0.70711	0.50	0.000	0.00
	30	0.023410	0.59460	0.75	0.000	0.00
	35	0.019685	0.50000	1.00	0.000	0.00
Medium Sand	40	0.016553	0.42045	1.25	0.000	0.00
	45	0.013919	0.35355	1.50	0.000	0.00
	50	0.011705	0.29730	1.75	0.000	0.00
	60	0.009843	0.25000	2.00	0.000	0.00
Fine Sand	70	0.008277	0.21022	2.25	0.000	0.00
	80	0.006960	0.17678	2.50	0.000	0.00
	100	0.005852	0.14865	2.75	0.000	0.00
	120	0.004921	0.12500	3.00	0.000	0.00
V. Fine Sand	140	0.004138	0.10511	3.25	0.000	0.00
	170	0.003480	0.08839	3.50	0.000	0.00
	200	0.002926	0.07433	3.75	0.000	0.00
	230	0.002461	0.06250	4.00	0.000	0.00
Silt	270	0.002069	0.05256	4.25	0.000	0.00
	325	0.001740	0.04419	4.50	0.000	0.00
	400	0.001463	0.03716	4.75	0.000	0.00
	450	0.001230	0.03125	5.00	0.046	0.05
	500	0.001035	0.02628	5.25	0.418	0.46
	635	0.000870	0.02210	5.50	1.240	1.70
		0.000732	0.01858	5.75	2.159	3.86
		0.000615	0.01562	6.00	2.881	6.75
		0.000517	0.01314	6.25	3.422	10.17
		0.000435	0.01105	6.50	3.870	14.04
		0.000366	0.00929	6.75	4.393	18.43
		0.000308	0.00781	7.00	5.072	23.50
		0.000259	0.00657	7.25	5.865	29.37
		0.000217	0.00552	7.50	6.645	36.01
		0.000183	0.00465	7.75	7.282	43.29
		0.000154	0.00391	8.00	7.702	51.00
Clay		0.000129	0.00328	8.25	7.683	58.68
		0.000109	0.00276	8.50	7.244	65.92
		0.000091	0.00232	8.75	6.478	72.40
		0.000077	0.00195	9.00	5.534	77.94
		0.000065	0.00164	9.25	4.580	82.52
		0.000054	0.00138	9.50	3.759	86.28
		0.000046	0.00116	9.75	3.128	89.40
		0.000038	0.00098	10.00	2.670	92.07
		0.000032	0.00082	10.25	2.330	94.40
		0.000027	0.00069	10.50	1.996	96.40
		0.000023	0.00058	10.75	1.621	98.02
		0.000019	0.00049	11.00	1.177	99.20
		0.000016	0.00041	11.25	0.645	99.84
		0.000015	0.00038	11.50	0.159	100.00

Sorting Statistics (Folk)			
Parameter	Trask	Inman	Folk
Median	Silt sized		
(in)	0.0002	0.0002	0.0002
(mm)	0.0040	0.0040	0.0040
Mean	Silt sized		
(in)	0.0002	0.0002	0.0002
(mm)	0.0048	0.0040	0.0040
Sorting	Poor		
	1.867	1.369	1.363
Skewness	Near symmetrical		
	1.003	0.085	0.030
Kurtosis	Mesokurtic		
	0.220	0.636	1.018

Component Percentages				
Gravel	Sand	Silt	Clay	Silt + Clay
0.00	0.00	51.00	49.00	100.00

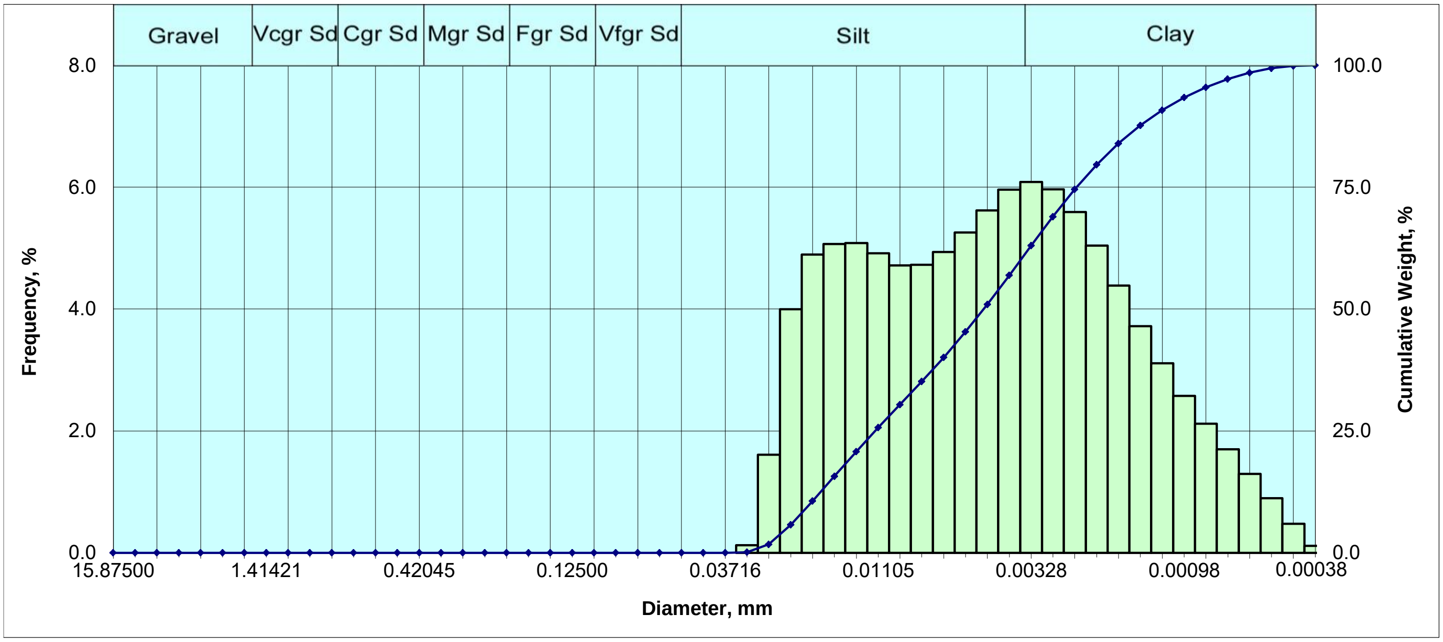
Percentile [Weight, %]	Particle Diameter		
	[in.]	[mm]	[phi]
5	0.0007	0.0174	5.8435
10	0.0005	0.0133	6.2367
16	0.0004	0.0103	6.6064
25	0.0003	0.0075	7.0598
30	0.0003	0.0065	7.2720
50	0.0002	0.0040	7.9651
60	0.0001	0.0032	8.2924
75	0.0001	0.0021	8.8620
84	0.0001	0.0015	9.3435
90	0.0000	0.0011	9.8022
95	0.0000	0.0008	10.3203

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802753
Sample ID: PZ-2M_47-47.4

Sieve and Laser Particle Size Analysis



Particle Size Distribution

	Diameter [US Mesh]	Diameter [in.]	Diameter [mm]	Diameter [ϕ]	Weight % [Incl.]	Weight % [Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.000	0.00
Coarse Sand	20	0.033106	0.84090	0.25	0.000	0.00
	25	0.027839	0.70711	0.50	0.000	0.00
	30	0.023410	0.59460	0.75	0.000	0.00
	35	0.019685	0.50000	1.00	0.000	0.00
Medium Sand	40	0.016553	0.42045	1.25	0.000	0.00
	45	0.013919	0.35355	1.50	0.000	0.00
	50	0.011705	0.29730	1.75	0.000	0.00
	60	0.009843	0.25000	2.00	0.000	0.00
Fine Sand	70	0.008277	0.21022	2.25	0.000	0.00
	80	0.006960	0.17678	2.50	0.000	0.00
	100	0.005852	0.14865	2.75	0.000	0.00
	120	0.004921	0.12500	3.00	0.000	0.00
V. Fine Sand	140	0.004138	0.10511	3.25	0.000	0.00
	170	0.003480	0.08839	3.50	0.000	0.00
	200	0.002926	0.07433	3.75	0.000	0.00
	230	0.002461	0.06250	4.00	0.000	0.00
Silt	270	0.002069	0.05256	4.25	0.000	0.00
	325	0.001740	0.04419	4.50	0.000	0.00
	400	0.001463	0.03716	4.75	0.000	0.00
	450	0.001230	0.03125	5.00	0.126	0.13
	500	0.001035	0.02628	5.25	1.612	1.74
	635	0.000870	0.02210	5.50	3.996	5.73
		0.000732	0.01858	5.75	4.896	10.63
		0.000615	0.01562	6.00	5.070	15.70
		0.000517	0.01314	6.25	5.085	20.79
		0.000435	0.01105	6.50	4.914	25.70
		0.000366	0.00929	6.75	4.718	30.42
		0.000308	0.00781	7.00	4.727	35.14
		0.000259	0.00657	7.25	4.938	40.08
		0.000217	0.00552	7.50	5.259	45.34
		0.000183	0.00465	7.75	5.621	50.96
		0.000154	0.00391	8.00	5.961	56.92
Clay		0.000129	0.00328	8.25	6.086	63.01
		0.000109	0.00276	8.50	5.964	68.97
		0.000091	0.00232	8.75	5.595	74.57
		0.000077	0.00195	9.00	5.039	79.61
		0.000065	0.00164	9.25	4.384	83.99
		0.000054	0.00138	9.50	3.722	87.71
		0.000046	0.00116	9.75	3.111	90.82
		0.000038	0.00098	10.00	2.575	93.40
		0.000032	0.00082	10.25	2.118	95.52
		0.000027	0.00069	10.50	1.699	97.22
		0.000023	0.00058	10.75	1.297	98.51
		0.000019	0.00049	11.00	0.895	99.41
		0.000016	0.00041	11.25	0.476	99.88
		0.000015	0.00038	11.50	0.116	100.00

Sorting Statistics (Folk)

Parameter	Trask	Inman	Folk
Median	Silt sized		
(in)	0.0002	0.0002	0.0002
(mm)	0.0048	0.0048	0.0048
Mean	Silt sized		
(in)	0.0003	0.0002	0.0002
(mm)	0.0068	0.0050	0.0050
Sorting	Poor		
	2.225	1.618	1.527
Skewness	Near symmetrical		
	1.063	0.070	0.002
Kurtosis	Platykurtic		
	0.254	0.463	0.841

Component Percentages

Gravel	Sand	Silt	Clay	Silt + Clay
0.00	0.00	56.92	43.08	100.00

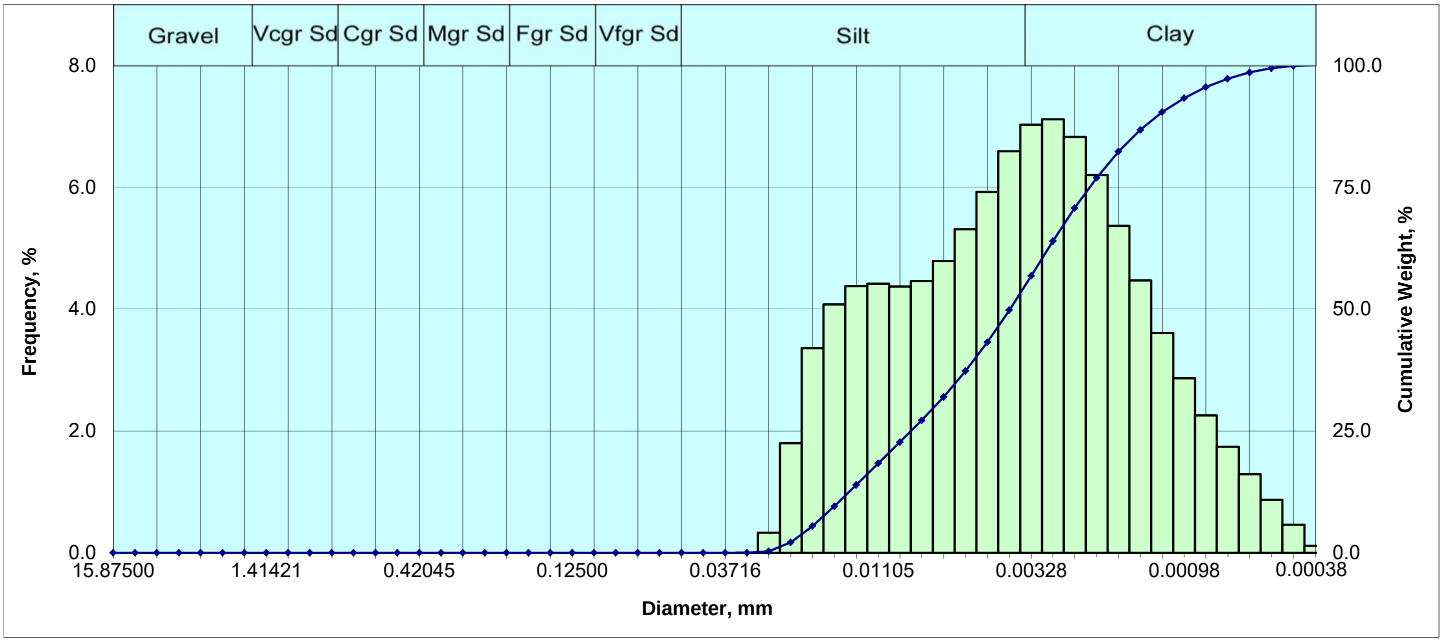
Percentile [Weight, %]	Particle Diameter [in.]	Particle Diameter [mm]	Particle Diameter [phi]
5	0.0009	0.0229	5.4507
10	0.0007	0.0190	5.7153
16	0.0006	0.0155	6.0136
25	0.0004	0.0113	6.4617
30	0.0004	0.0094	6.7261
50	0.0002	0.0048	7.7040
60	0.0001	0.0036	8.1210
75	0.0001	0.0023	8.7698
84	0.0001	0.0016	9.2506
90	0.0000	0.0012	9.6795
95	0.0000	0.0009	10.1849

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802753
Sample ID: PZ-2M_48-48.4

Sieve and Laser Particle Size Analysis



Particle Size Distribution						
	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.000	0.00
Coarse Sand	20	0.033106	0.84090	0.25	0.000	0.00
	25	0.027839	0.70711	0.50	0.000	0.00
	30	0.023410	0.59460	0.75	0.000	0.00
	35	0.019685	0.50000	1.00	0.000	0.00
Medium Sand	40	0.016553	0.42045	1.25	0.000	0.00
	45	0.013919	0.35355	1.50	0.000	0.00
	50	0.011705	0.29730	1.75	0.000	0.00
	60	0.009843	0.25000	2.00	0.000	0.00
Fine Sand	70	0.008277	0.21022	2.25	0.000	0.00
	80	0.006960	0.17678	2.50	0.000	0.00
	100	0.005852	0.14865	2.75	0.000	0.00
	120	0.004921	0.12500	3.00	0.000	0.00
V. Fine Sand	140	0.004138	0.10511	3.25	0.000	0.00
	170	0.003480	0.08839	3.50	0.000	0.00
	200	0.002926	0.07433	3.75	0.000	0.00
	230	0.002461	0.06250	4.00	0.000	0.00
Silt	270	0.002069	0.05256	4.25	0.000	0.00
	325	0.001740	0.04419	4.50	0.000	0.00
	400	0.001463	0.03716	4.75	0.000	0.00
	450	0.001230	0.03125	5.00	0.006	0.01
	500	0.001035	0.02628	5.25	0.329	0.33
	635	0.000870	0.02210	5.50	1.798	2.13
		0.000732	0.01858	5.75	3.356	5.49
		0.000615	0.01562	6.00	4.074	9.56
		0.000517	0.01314	6.25	4.376	13.94
		0.000435	0.01105	6.50	4.415	18.35
		0.000366	0.00929	6.75	4.371	22.72
		0.000308	0.00781	7.00	4.459	27.18
		0.000259	0.00657	7.25	4.789	31.97
		0.000217	0.00552	7.50	5.307	37.28
		0.000183	0.00465	7.75	5.922	43.20
		0.000154	0.00391	8.00	6.590	49.79
Clay		0.000129	0.00328	8.25	7.023	56.81
		0.000109	0.00276	8.50	7.114	63.93
		0.000091	0.00232	8.75	6.826	70.75
		0.000077	0.00195	9.00	6.204	76.96
		0.000065	0.00164	9.25	5.370	82.33
		0.000054	0.00138	9.50	4.471	86.80
		0.000046	0.00116	9.75	3.610	90.41
		0.000038	0.00098	10.00	2.864	93.27
		0.000032	0.00082	10.25	2.255	95.53
		0.000027	0.00069	10.50	1.740	97.27
		0.000023	0.00058	10.75	1.290	98.56
		0.000019	0.00049	11.00	0.871	99.43
		0.000016	0.00041	11.25	0.459	99.89
		0.000015	0.00038	11.50	0.112	100.00

Sorting Statistics (Folk)			
Parameter	**Trask**	**Inman**	**Folk**
Median	Clay sized		
(in)	0.0002	0.0002	0.0002
(mm)	0.0039	0.0039	0.0039
Mean	Silt sized		
(in)	0.0002	0.0002	0.0002
(mm)	0.0053	0.0043	0.0042
Sorting	Poor		
	2.031	1.489	1.423
Skewness	Near symmetrical		
	1.081	-0.039	-0.066
Kurtosis	Platykurtic		
	0.228	0.504	0.898

Component Percentages				
Gravel	Sand	Silt	Clay	Silt + Clay
0.00	0.00	49.79	50.21	100.00

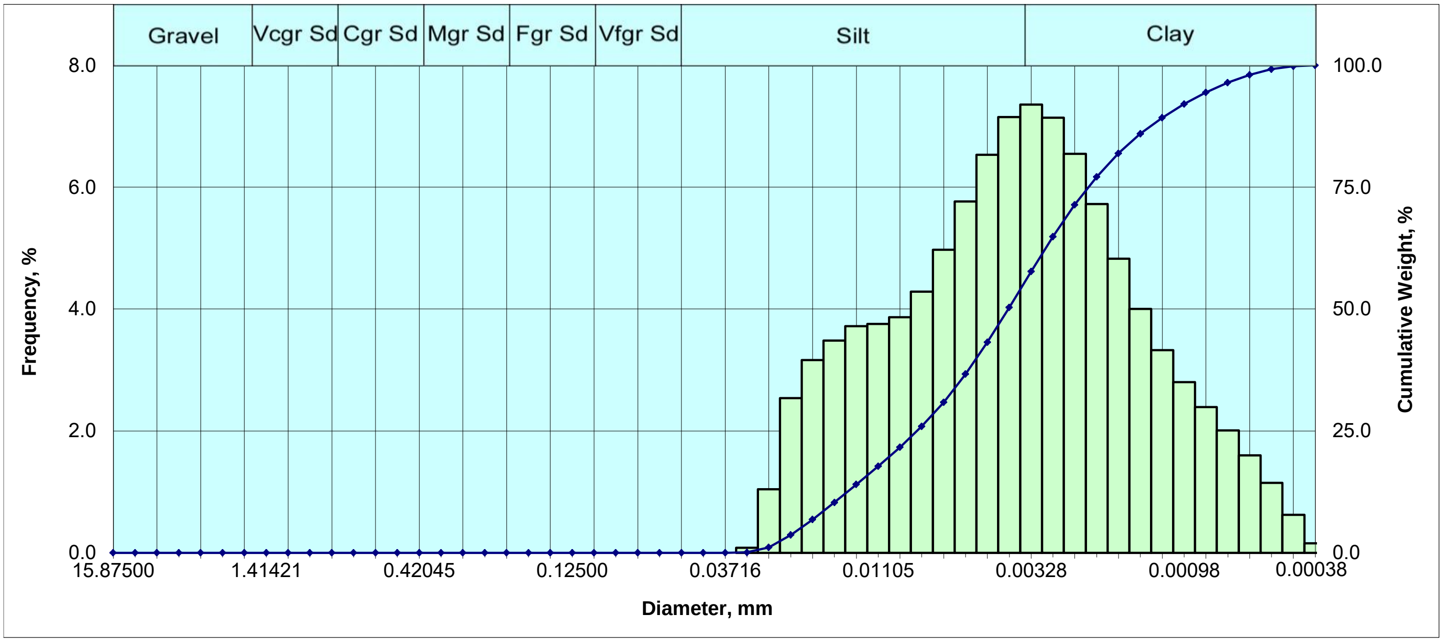
Percentile [Weight, %]	Particle Diameter		
	[in.]	[mm]	[phi]
5	0.0008	0.0191	5.7108
10	0.0006	0.0154	6.0231
16	0.0005	0.0122	6.3614
25	0.0003	0.0085	6.8722
30	0.0003	0.0071	7.1418
50	0.0002	0.0039	8.0068
60	0.0001	0.0031	8.3566
75	0.0001	0.0021	8.9163
84	0.0001	0.0015	9.3385
90	0.0000	0.0012	9.7194
95	0.0000	0.0009	10.1875

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802753
Sample ID: PZ-2M_49-49.4

Sieve and Laser Particle Size Analysis



Particle Size Distribution						
	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.000	0.00
Coarse Sand	20	0.033106	0.84090	0.25	0.000	0.00
	25	0.027839	0.70711	0.50	0.000	0.00
	30	0.023410	0.59460	0.75	0.000	0.00
	35	0.019685	0.50000	1.00	0.000	0.00
Medium Sand	40	0.016553	0.42045	1.25	0.000	0.00
	45	0.013919	0.35355	1.50	0.000	0.00
	50	0.011705	0.29730	1.75	0.000	0.00
	60	0.009843	0.25000	2.00	0.000	0.00
Fine Sand	70	0.008277	0.21022	2.25	0.000	0.00
	80	0.006960	0.17678	2.50	0.000	0.00
	100	0.005852	0.14865	2.75	0.000	0.00
	120	0.004921	0.12500	3.00	0.000	0.00
V. Fine Sand	140	0.004138	0.10511	3.25	0.000	0.00
	170	0.003480	0.08839	3.50	0.000	0.00
	200	0.002926	0.07433	3.75	0.000	0.00
	230	0.002461	0.06250	4.00	0.000	0.00
Silt	270	0.002069	0.05256	4.25	0.000	0.00
	325	0.001740	0.04419	4.50	0.000	0.00
	400	0.001463	0.03716	4.75	0.000	0.00
	450	0.001230	0.03125	5.00	0.083	0.08
	500	0.001035	0.02628	5.25	1.041	1.12
	635	0.000870	0.02210	5.50	2.540	3.66
		0.000732	0.01858	5.75	3.161	6.83
		0.000615	0.01562	6.00	3.485	10.31
		0.000517	0.01314	6.25	3.718	14.03
		0.000435	0.01105	6.50	3.756	17.78
		0.000366	0.00929	6.75	3.864	21.65
		0.000308	0.00781	7.00	4.285	25.93
		0.000259	0.00657	7.25	4.971	30.90
		0.000217	0.00552	7.50	5.767	36.67
		0.000183	0.00465	7.75	6.530	43.20
		0.000154	0.00391	8.00	7.149	50.35
Clay		0.000129	0.00328	8.25	7.357	57.71
		0.000109	0.00276	8.50	7.139	64.85
		0.000091	0.00232	8.75	6.550	71.40
		0.000077	0.00195	9.00	5.725	77.12
		0.000065	0.00164	9.25	4.827	81.95
		0.000054	0.00138	9.50	4.002	85.95
		0.000046	0.00116	9.75	3.326	89.28
		0.000038	0.00098	10.00	2.801	92.08
		0.000032	0.00082	10.25	2.393	94.47
		0.000027	0.00069	10.50	2.007	96.48
		0.000023	0.00058	10.75	1.600	98.08
		0.000019	0.00049	11.00	1.146	99.22
		0.000016	0.00041	11.25	0.623	99.85
		0.000015	0.00038	11.50	0.153	100.00

Sorting Statistics (Folk)			
Parameter	**Trask**	**Inman**	**Folk**
Median	**Silt sized**		
(in)	0.0002	0.0002	0.0002
(mm)	0.0039	0.0039	0.0039
Mean	**Silt sized**		
(in)	0.0002	0.0002	0.0002
(mm)	0.0051	0.0043	0.0042
Sorting	**Poor**		
	1.973	1.498	1.463
Skewness	**Near symmetrical**		
	1.046	-0.020	-0.044
Kurtosis	**Mesokurtic**		
	0.205	0.572	0.985

Component Percentages				
Gravel	**Sand**	**Silt**	**Clay**	**Silt + Clay**
0.00	0.00	50.35	49.65	100.00

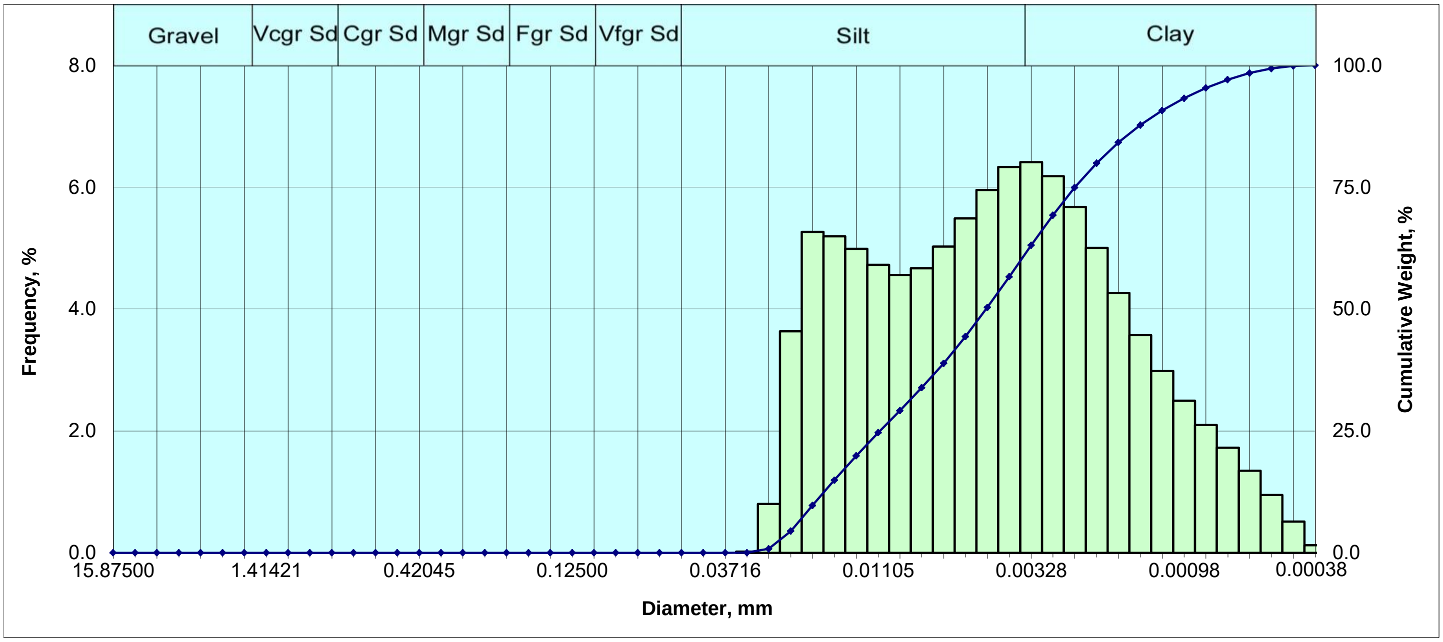
Percentile [Weight, %]	Particle Diameter [in.]	[mm]	[phi]
5	0.0008	0.0206	5.6004
10	0.0006	0.0159	5.9759
16	0.0005	0.0120	6.3758
25	0.0003	0.0081	6.9418
30	0.0003	0.0068	7.2012
50	0.0002	0.0039	7.9867
60	0.0001	0.0031	8.3256
75	0.0001	0.0021	8.9022
84	0.0001	0.0015	9.3727
90	0.0000	0.0011	9.8105
95	0.0000	0.0008	10.3119

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802753
Sample ID: PZ-2M_50-50.4

Sieve and Laser Particle Size Analysis



Particle Size Distribution

	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.000	0.00
Coarse Sand	20	0.033106	0.84090	0.25	0.000	0.00
	25	0.027839	0.70711	0.50	0.000	0.00
	30	0.023410	0.59460	0.75	0.000	0.00
	35	0.019685	0.50000	1.00	0.000	0.00
Medium Sand	40	0.016553	0.42045	1.25	0.000	0.00
	45	0.013919	0.35355	1.50	0.000	0.00
	50	0.011705	0.29730	1.75	0.000	0.00
	60	0.009843	0.25000	2.00	0.000	0.00
Fine Sand	70	0.008277	0.21022	2.25	0.000	0.00
	80	0.006960	0.17678	2.50	0.000	0.00
	100	0.005852	0.14865	2.75	0.000	0.00
	120	0.004921	0.12500	3.00	0.000	0.00
V. Fine Sand	140	0.004138	0.10511	3.25	0.000	0.00
	170	0.003480	0.08839	3.50	0.000	0.00
	200	0.002926	0.07433	3.75	0.000	0.00
	230	0.002461	0.06250	4.00	0.000	0.00
Silt	270	0.002069	0.05256	4.25	0.000	0.00
	325	0.001740	0.04419	4.50	0.000	0.00
	400	0.001463	0.03716	4.75	0.000	0.00
	450	0.001230	0.03125	5.00	0.017	0.02
	500	0.001035	0.02628	5.25	0.803	0.82
	635	0.000870	0.02210	5.50	3.637	4.46
		0.000732	0.01858	5.75	5.269	9.73
		0.000615	0.01562	6.00	5.194	14.92
		0.000517	0.01314	6.25	4.989	19.91
		0.000435	0.01105	6.50	4.729	24.64
		0.000366	0.00929	6.75	4.557	29.19
		0.000308	0.00781	7.00	4.670	33.86
		0.000259	0.00657	7.25	5.024	38.89
		0.000217	0.00552	7.50	5.486	44.38
		0.000183	0.00465	7.75	5.953	50.33
		0.000154	0.00391	8.00	6.332	56.66
Clay		0.000129	0.00328	8.25	6.411	63.07
		0.000109	0.00276	8.50	6.181	69.25
		0.000091	0.00232	8.75	5.679	74.93
		0.000077	0.00195	9.00	5.002	79.93
		0.000065	0.00164	9.25	4.267	84.20
		0.000054	0.00138	9.50	3.575	87.77
		0.000046	0.00116	9.75	2.983	90.76
		0.000038	0.00098	10.00	2.495	93.25
		0.000032	0.00082	10.25	2.096	95.35
		0.000027	0.00069	10.50	1.722	97.07
		0.000023	0.00058	10.75	1.346	98.42
		0.000019	0.00049	11.00	0.948	99.37
		0.000016	0.00041	11.25	0.510	99.88
		0.000015	0.00038	11.50	0.125	100.00

Sorting Statistics (Folk)

Parameter	Trask	Inman	Folk
Median	**Silt sized**		
(in)	0.0002	0.0002	0.0002
(mm)	0.0047	0.0047	0.0047
Mean	**Silt sized**		
(in)	0.0003	0.0002	0.0002
(mm)	0.0066	0.0050	0.0049
Sorting	**Poor**		
	2.170	1.593	1.506
Skewness	**Near symmetrical**		
	1.071	0.081	-0.001
Kurtosis	**Platykurtic**		
	0.250	0.469	0.859

Component Percentages

Gravel	Sand	Silt	Clay	Silt + Clay
0.00	0.00	56.66	43.34	100.00

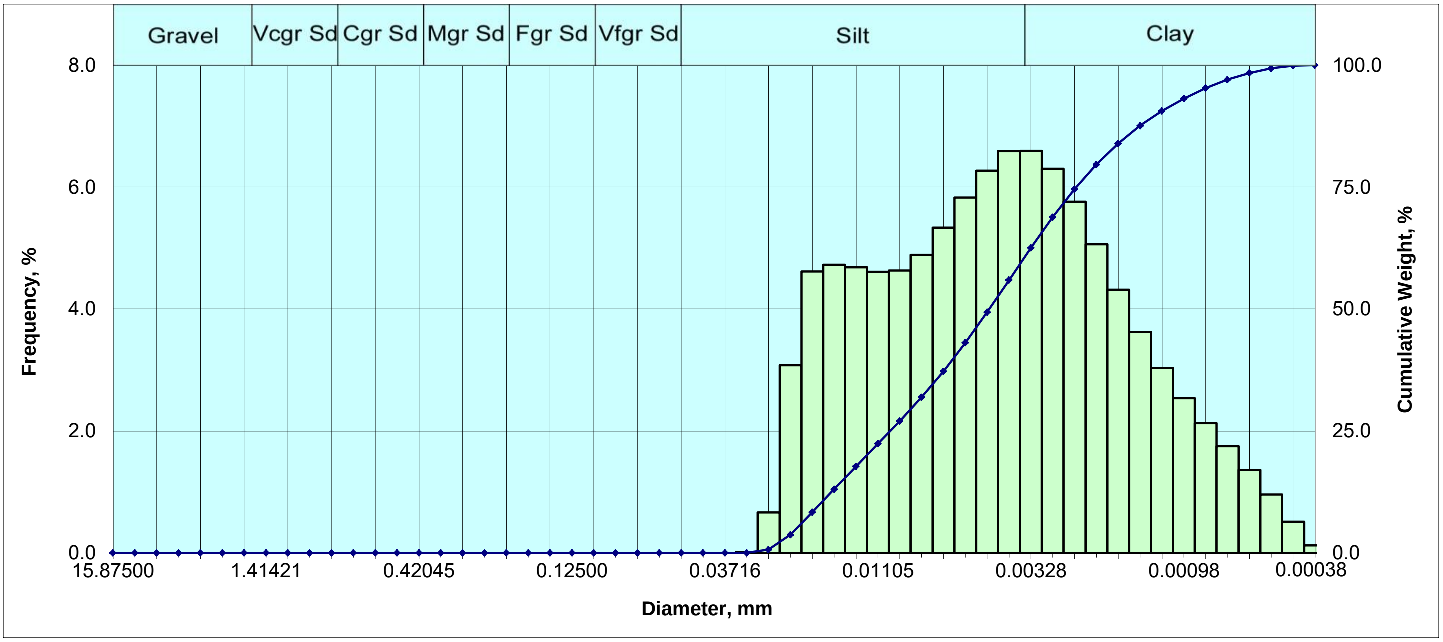
Percentile [Weight, %]	Particle Diameter		
	[in.]	[mm]	[phi]
5	0.0009	0.0217	5.5238
10	0.0007	0.0184	5.7622
16	0.0006	0.0151	6.0506
25	0.0004	0.0109	6.5184
30	0.0004	0.0090	6.7901
50	0.0002	0.0047	7.7350
60	0.0001	0.0036	8.1248
75	0.0001	0.0023	8.7532
84	0.0001	0.0017	9.2373
90	0.0000	0.0012	9.6823
95	0.0000	0.0008	10.2053

**All Grain Sizes Classed using Wentworth Scale

Company: Ramboll US Corporation
Project Name: NERT AWF Capture Evaluation
Project Number: 169 000 6943-048 (Task M25)

CL File No.: 1802753
Sample ID: PZ-2M_51-51.4

Sieve and Laser Particle Size Analysis



Particle Size Distribution						
	Diameter				Weight %	
	[US Mesh]	[in.]	[mm]	[ϕ]	[Incl.]	[Cum.]
Granule	5/8 in.	0.625000	15.87500	-4.00	0.000	0.00
	3/8 in.	0.375000	9.50000	-3.25	0.000	0.00
	4	0.187008	4.75000	-2.25	0.000	0.00
	6	0.131890	3.35000	-1.75	0.000	0.00
	8	0.092913	2.36000	-1.25	0.000	0.00
	10	0.078740	2.00000	-1.00	0.000	0.00
V Crse Sand	12	0.066212	1.68179	-0.75	0.000	0.00
	14	0.055678	1.41421	-0.50	0.000	0.00
	16	0.046819	1.18921	-0.25	0.000	0.00
	18	0.039370	1.00000	0.00	0.000	0.00
Coarse Sand	20	0.033106	0.84090	0.25	0.000	0.00
	25	0.027839	0.70711	0.50	0.000	0.00
	30	0.023410	0.59460	0.75	0.000	0.00
	35	0.019685	0.50000	1.00	0.000	0.00
Medium Sand	40	0.016553	0.42045	1.25	0.000	0.00
	45	0.013919	0.35355	1.50	0.000	0.00
	50	0.011705	0.29730	1.75	0.000	0.00
	60	0.009843	0.25000	2.00	0.000	0.00
Fine Sand	70	0.008277	0.21022	2.25	0.000	0.00
	80	0.006960	0.17678	2.50	0.000	0.00
	100	0.005852	0.14865	2.75	0.000	0.00
	120	0.004921	0.12500	3.00	0.000	0.00
V. Fine Sand	140	0.004138	0.10511	3.25	0.000	0.00
	170	0.003480	0.08839	3.50	0.000	0.00
	200	0.002926	0.07433	3.75	0.000	0.00
	230	0.002461	0.06250	4.00	0.000	0.00
Silt	270	0.002069	0.05256	4.25	0.000	0.00
	325	0.001740	0.04419	4.50	0.000	0.00
	400	0.001463	0.03716	4.75	0.000	0.00
	450	0.001230	0.03125	5.00	0.014	0.01
	500	0.001035	0.02628	5.25	0.666	0.68
	635	0.000870	0.02210	5.50	3.077	3.76
		0.000732	0.01858	5.75	4.614	8.37
		0.000615	0.01562	6.00	4.726	13.10
		0.000517	0.01314	6.25	4.687	17.78
		0.000435	0.01105	6.50	4.609	22.39
		0.000366	0.00929	6.75	4.630	27.02
		0.000308	0.00781	7.00	4.892	31.91
		0.000259	0.00657	7.25	5.335	37.25
		0.000217	0.00552	7.50	5.827	43.08
		0.000183	0.00465	7.75	6.269	49.35
		0.000154	0.00391	8.00	6.588	55.93
Clay		0.000129	0.00328	8.25	6.595	62.53
		0.000109	0.00276	8.50	6.303	68.83
		0.000091	0.00232	8.75	5.759	74.59
		0.000077	0.00195	9.00	5.061	79.65
		0.000065	0.00164	9.25	4.317	83.97
		0.000054	0.00138	9.50	3.623	87.59
		0.000046	0.00116	9.75	3.029	90.62
		0.000038	0.00098	10.00	2.537	93.16
		0.000032	0.00082	10.25	2.131	95.29
		0.000027	0.00069	10.50	1.749	97.04
		0.000023	0.00058	10.75	1.364	98.40
		0.000019	0.00049	11.00	0.958	99.36
		0.000016	0.00041	11.25	0.515	99.87
		0.000015	0.00038	11.50	0.126	100.00

Sorting Statistics (Folk)			
Parameter	**Trask**	**Inman**	**Folk**
Median	**Silt sized**		
(in)	0.0002	0.0002	0.0002
(mm)	0.0046	0.0046	0.0046
Mean	**Silt sized**		
(in)	0.0002	0.0002	0.0002
(mm)	0.0062	0.0048	0.0047
Sorting	**Poor**		
	2.095	1.551	1.480
Skewness	**Near symmetrical**		
	1.050	0.074	0.002
Kurtosis	**Platykurtic**		
	0.237	0.499	0.893

Component Percentages				
Gravel	**Sand**	**Silt**	**Clay**	**Silt + Clay**
0.00	0.00	55.93	44.07	100.00

Percentile [Weight, %]	Particle Diameter		
	[in.]	[mm]	[phi]
5	0.0008	0.0211	5.5632
10	0.0007	0.0176	5.8314
16	0.0006	0.0141	6.1497
25	0.0004	0.0101	6.6354
30	0.0003	0.0084	6.8969
50	0.0002	0.0046	7.7730
60	0.0001	0.0035	8.1490
75	0.0001	0.0023	8.7687
84	0.0001	0.0016	9.2520
90	0.0000	0.0012	9.6952
95	0.0000	0.0008	10.2136

**All Grain Sizes Classed using Wentworth Scale

RAMBOLL

UST PROJECT OR IS EDF REQUIRED? YES NO IF YES, GLOBAL ID# MSA # WORK ORDER #

PROJECT NAME/FACILITY ID NERT AWF Capture Evaluation DATE 7/23/2018 FIELD PERSON# G. Miclette

PROJECT LOCATION Henderson, NV PROJECT MANAGER C. Stubbs

PROJECT NUMBER 1690006943-048 LABORATORY CORE LABS

Sampler J. Manheim

Signature J Manheim

SAMPLE ID NUMBER	SAMPLE DATE	SAMPLE TIME	SAMPLE DEPTH (F)	AIR SAMPLE VOLUME (L)	MATRIX: (A)IR; (G)AS; (W)ATER	NUMBER OF CONTAINERS	FILTERED/UNFILTERED (F/U)	PRESERVATION (SEE KEY)	HOLD*	Analysis Required	COMMENTS
✓ PT-PZ-2M-42.0-42.3-20180723	7/23/2018	0940	42.0-42.3	NA	S	2	U	None	X		
PT-PZ-2M-43.0-43.4-20180723		0942	43.0-43.4			2			X	JAR IS MARKED 43.3	*Hold pending
✓ PT-PZ-2M-44.0-44.3-20180723		0944	44.0-44.3			2			X		instruction from
✓ PT-PZ-2M-45.0-45.4-20180723		1020	45.0-45.4			1			X		Pejman Rasouli —
✓ PT-PZ-2M-46.0-46.4-20180723		1022	46.0-46.4			1			X		prasouli@Ramboll.com
✓ PT-PZ-2M-47.0-47.4-20180723		1024	47.0-47.4			1			X		or Chris Stubbs —
✓ PT-PZ-2M-48.0-48.4-20180723		1026	48.0-48.4			1			X		cstubbs@Ramboll.com
✓ PT-PZ-2M-49.0-49.4-20180723		1028	49.0-49.4			1			X		
✓ PT-PZ-2M-50.0-50.4-20180723		1030	50.0-50.4			1			X		
✓ PT-PZ-2M-51.0-51.4-20180723	7/23/2018	1032	51.0-51.4	NA	S	1	U	None	X		
TOTAL						13			10		

NO = NONE

RELINQUISHED BY J Manheim	TIME/DATE 8/2/2018 1400	RECEIVED BY COMPANY FedEx	TIME/DATE 8/2/18 1400
RELINQUISHED BY	TIME/DATE	RECEIVED BY COMPANY Tracey Bishop - Core Lab	TIME/DATE 8-3-18 1038
RELINQUISHED BY	TIME/DATE	RECEIVED BY COMPANY	TIME/DATE

TURNAROUND TIME (CIRCLE ONE)

SAME DAY 72 HOURS
24 HOURS 5 DAYS
48 HOURS NORMAL

SAMPLE INTEGRITY
INTACT Y N TEMP________

SAMPLE INTEGRITY
INTACT Y N

SWBU Office Locations:
☐ 18100 Von Karman Avenue, Suite 600, Irvine, CA 92612 +1 949 261 5151 +1 949 261 6202
☐ 350 S Grand Avenue, Suite 2800, Los Angeles, CA 90071 +1 213 943 6300 +1 213 943 6301
☐ 2111 East Highland Avenue, Suite 402, Phoenix, AZ 85016 +1 602 734 7700 +1 602 734-7701

Page _____ of _____

To: Larry Kunkel, Core Laboratories
3470 Landco Drive, Bakersfield, CA 93308

NERT Project Work Order No. CL-2018-004
Nevada Environmental Reponse Trust (NERT)
Henderson, Nevada

Ramboll Project No.: 169000 6943-048 (Task M25)

PHYSICAL TESTING REQUEST
for AWF Sample Shipment Group 2 (sent 7/23/18)

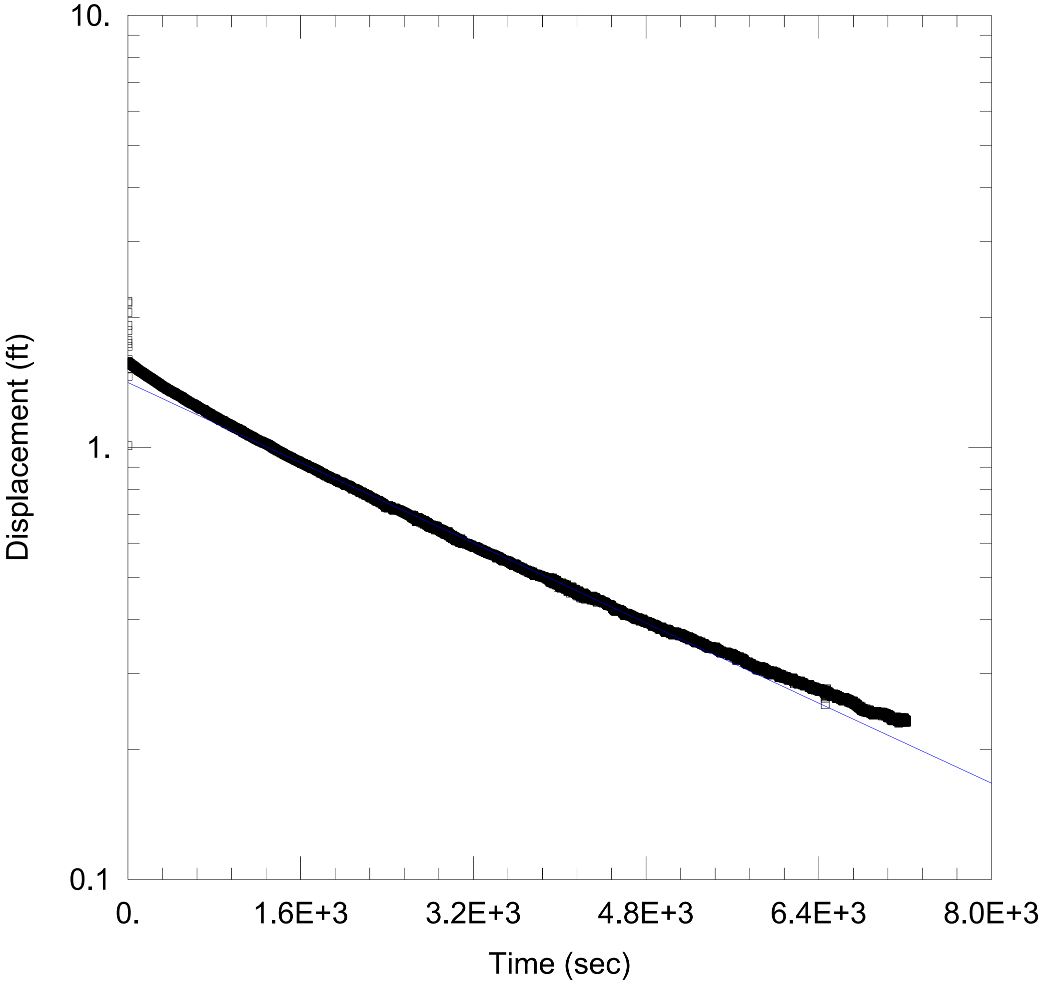
Date: **August 24, 2018**
Submitted by: Ramboll, 2200 Powell Street, Suite 700
Emeryville, CA 94608

Ramboll Contact: Chris Stubbs, (510) 420-2552

Boring	Soil Sample Depth (ft bgs)	Soil Sample Name	Container type (number)	Grain Size	Atterberg Limits	Dry Bulk Density	Grain Density/ Specific Gravity	Porosity, Effective & Total	Moisture Content	Total Organic Carbon	HYDRAULIC CONDUCTIVITY		
											Vertical (to water)	Height of Unsaturated Soil Above Water Table	Height of Saturated Soil Below Water Table
PZ-2M	42.0 - 42.3	PT-PZ2M-42.0-42.3	Glass jar	X		X	X	X	X	X		33.05	9.1
PZ-2M	43.0 - 43.3	PT-PZ2M-43.0-43.3	Glass jar	X		X	X	X	X	X	X	33.05	10.1
PZ-2M	44.0 - 44.3	PT-PZ2M-44.0-44.3	Glass jar	X		X	X	X	X	X		33.05	11.1
PZ-2M	45.0 - 45.4	PT-PZ2M-45.0-45.4	wrapped core	X		X	X	X	X	X	X	33.05	12.15
PZ-2M	46.0 - 46.4	PT-PZ2M-46.0-46.4	wrapped core	X		X	X	X	X	X		33.05	13.15
PZ-2M	47.0 - 47.4	PT-PZ2M-47.0-47.4	wrapped core	X		X	X	X	X	X	X	33.05	14.15
PZ-2M	48.0 - 48.4	PT-PZ2M-48.0-48.4	wrapped core	X		X	X	X	X	X		33.05	15.15
PZ-2M	49.0 - 49.4	PT-PZ2M-49.0-49.4	wrapped core	X		X	X	X	X	X	X	33.05	16.15
PZ-2M	50.0 - 50.4	PT-PZ2M-50.0-50.4	wrapped core	X		X	X	X	X	X		33.05	17.15
PZ-2M	51.0 - 51.4	PT-PZ2M-51.0-51.4	wrapped core	X		X	X	X	X	X	X	33.05	18.15
			TOTALS:	**10**		**10**	**10**	**10**	**10**	**10**	**5**		

Notes:
SOIL SAMPLES ARE LIKELY CONTAMINATED (perchlorate, metals, VOCs).

ATTACHMENT B-8
SLUG TEST ANALYSIS RESULTS USING AQTESOLV



WELL TEST ANALYSIS

Data Set: \...\PZ-1D_FH1.aqt
Date: 06/07/19 Time: 16:24:22

PROJECT INFORMATION

Company: Ramboll
Test Well: PZ-2S

AQUIFER DATA

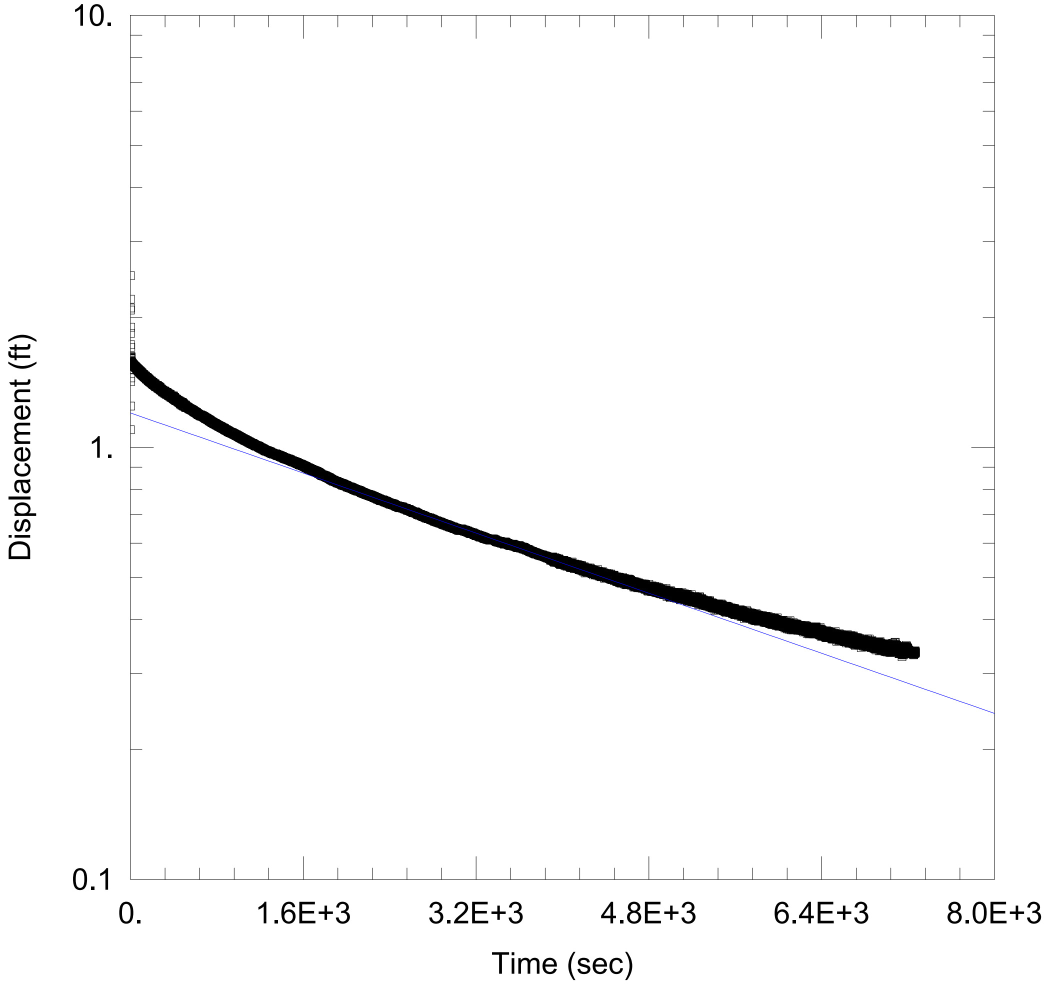
Saturated Thickness: 100. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (PZ-1D)

Initial Displacement: 1.74 ft
Total Well Penetration Depth: 23.86 ft
Casing Radius: 0.167 ft
Static Water Column Height: 23.86 ft
Screen Length: 1. ft
Well Radius: 0.333 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Zlotnik-Goss-Duffield
K = 0.4067 ft/day
y0 = 1.413 ft



WELL TEST ANALYSIS

Data Set: \...\PZ-2D_FH1.aqt
Date: 06/07/19 Time: 16:20:37

PROJECT INFORMATION

Company: Ramboll
Test Well: PZ-2D

AQUIFER DATA

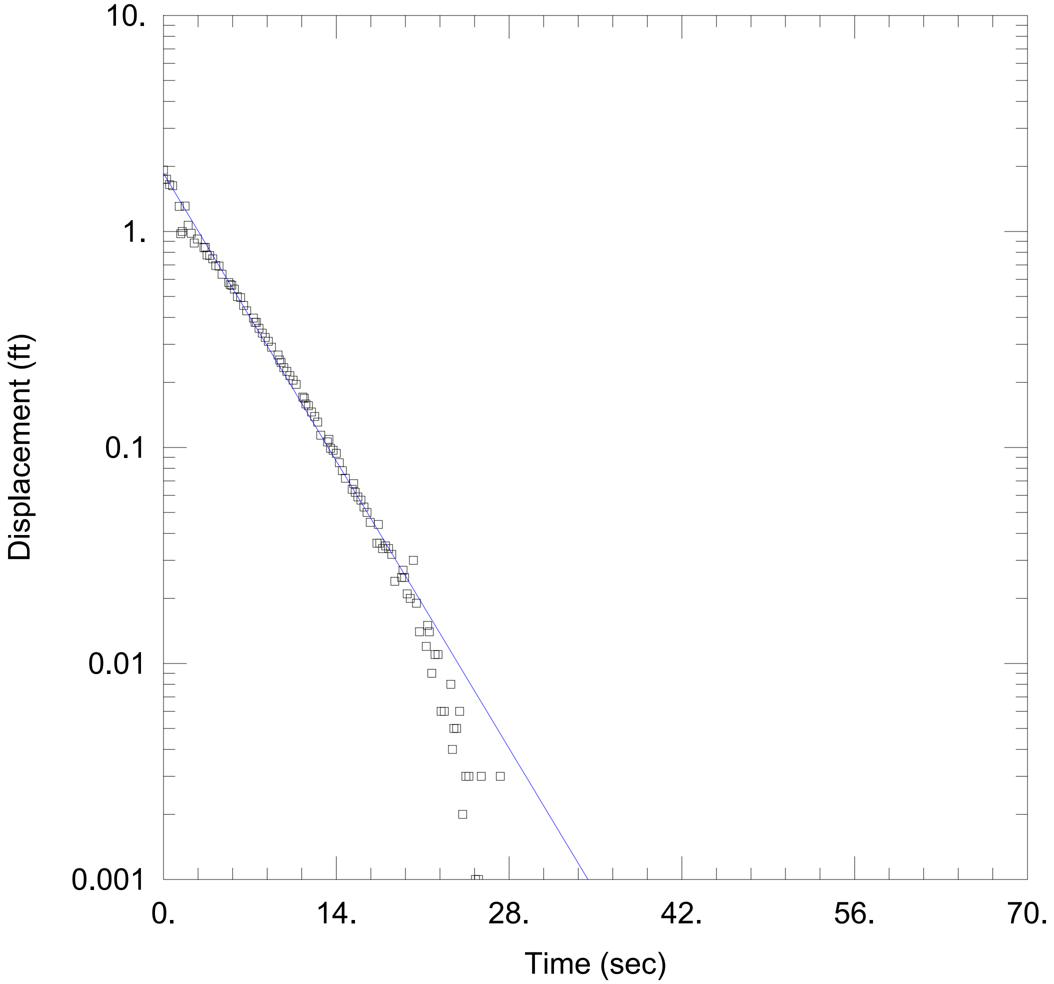
Saturated Thickness: 100. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (PZ-2D)

Initial Displacement: 1.73 ft Static Water Column Height: 46. ft
Total Well Penetration Depth: 46. ft Screen Length: 1. ft
Casing Radius: 0.167 ft Well Radius: 0.333 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Zlotnik-Goss-Duffield
K = 0.3064 ft/day y0 = 1.202 ft



WELL TEST ANALYSIS

Data Set: \...\PZ-2S_FH1_SlugA.aqt
Date: 06/07/19 Time: 16:31:17

PROJECT INFORMATION

Company: Ramboll
Test Well: PZ-2S

AQUIFER DATA

Saturated Thickness: 100. ft
Anisotropy Ratio (Kz/Kr): 1.

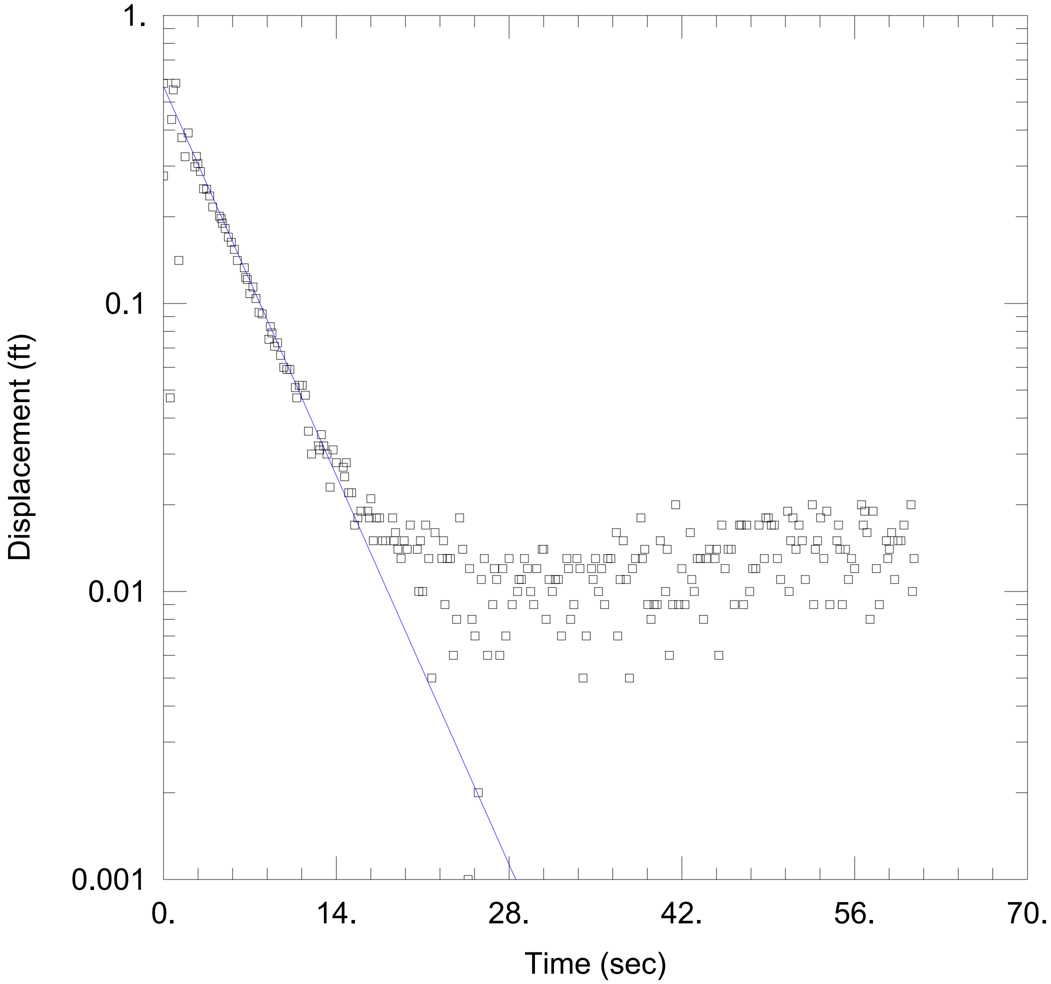
WELL DATA (PZ-2S)

Initial Displacement: 1.74 ft
Static Water Column Height: 13.05 ft
Total Well Penetration Depth: 13.05 ft
Screen Length: 1. ft
Casing Radius: 0.167 ft
Well Radius: 0.333 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Zlotnik-Goss-Duffield

K = 330.9 ft/day
y0 = 1.855 ft



WELL TEST ANALYSIS

Data Set: \...\PZ-2S_FH1_SlugB.aqt
Date: 06/07/19 Time: 16:29:29

PROJECT INFORMATION

Company: Ramboll
Test Well: PZ-2S

AQUIFER DATA

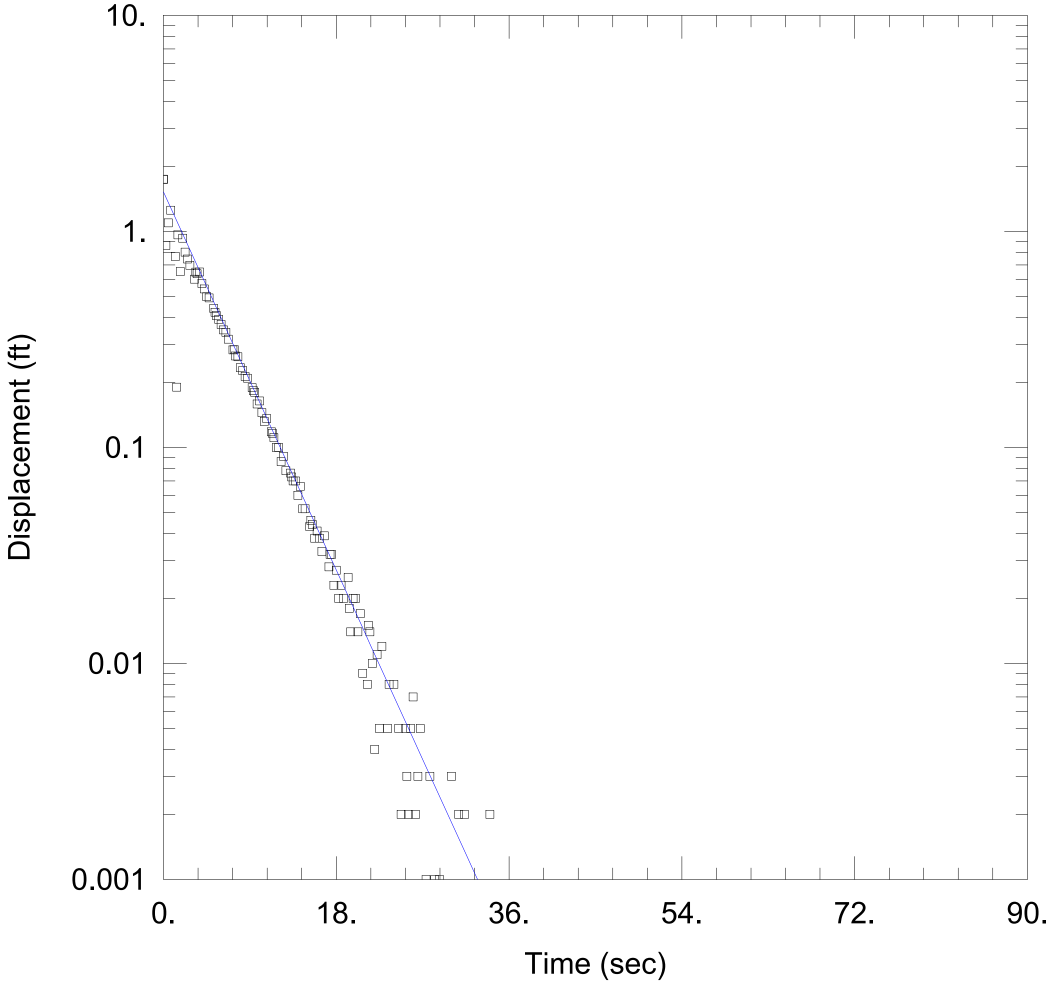
Saturated Thickness: 100. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (PZ-2S)

Initial Displacement: 0.58 ft
Static Water Column Height: 13.05 ft
Total Well Penetration Depth: 13.05 ft
Screen Length: 1. ft
Casing Radius: 0.167 ft
Well Radius: 0.333 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Zlotnik-Goss-Duffield
K = 335.9 ft/day
y0 = 0.5669 ft



WELL TEST ANALYSIS

Data Set: \...\PZ-2S_FH2_SlugA.aqt

Date: 06/07/19 Time: 16:32:52

PROJECT INFORMATION

Company: Ramboll

Test Well: PZ-2S

AQUIFER DATA

Saturated Thickness: 100. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (PZ-2S)

Initial Displacement: 1.74 ft Static Water Column Height: 13.05 ft

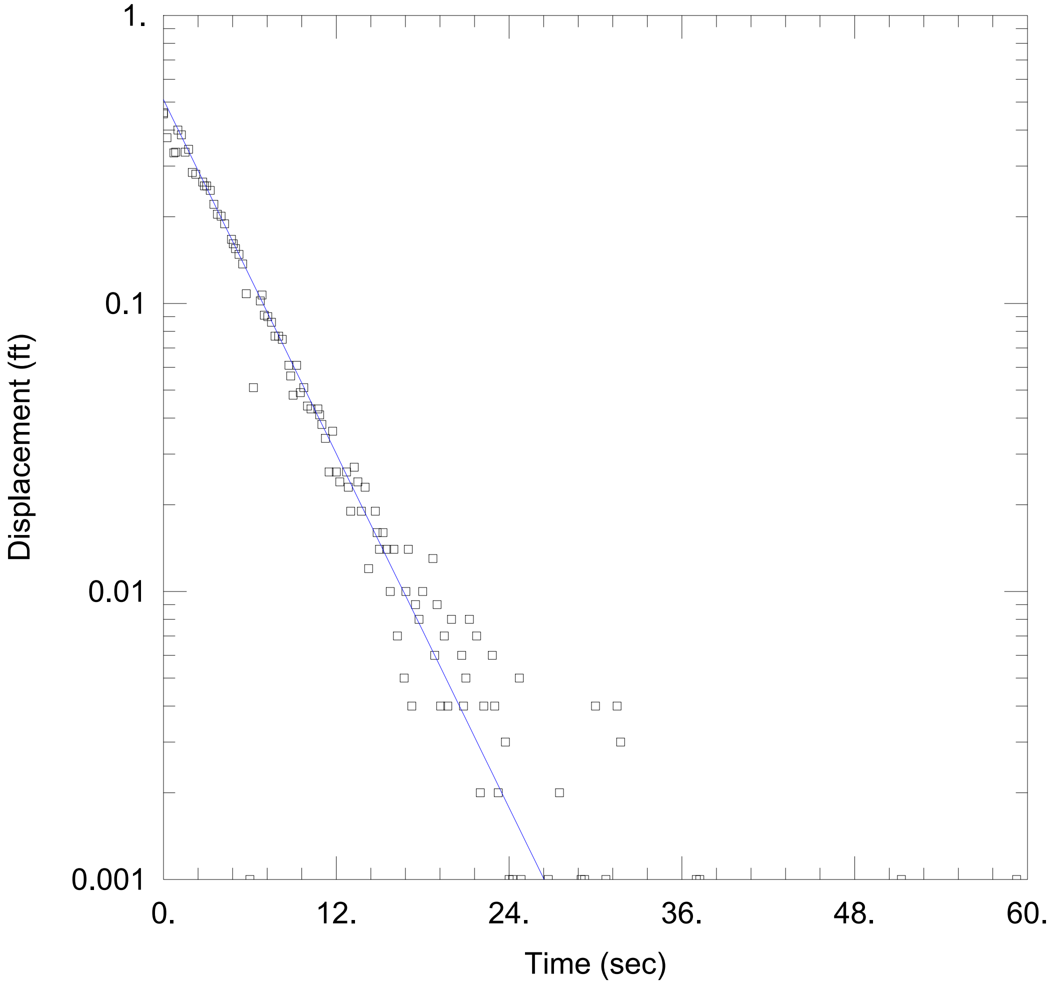
Total Well Penetration Depth: 13.05 ft Screen Length: 1. ft

Casing Radius: 0.167 ft Well Radius: 0.333 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Zlotnik-Goss-Duffield

K = 338.7 ft/day y0 = 1.524 ft



WELL TEST ANALYSIS

Data Set: \...\PZ-2S_FH2_SlugB.aqt
Date: 06/07/19 Time: 16:27:50

PROJECT INFORMATION

Company: Ramboll
Test Well: PZ-2S

AQUIFER DATA

Saturated Thickness: 100. ft Anisotropy Ratio (Kz/Kr): 1.

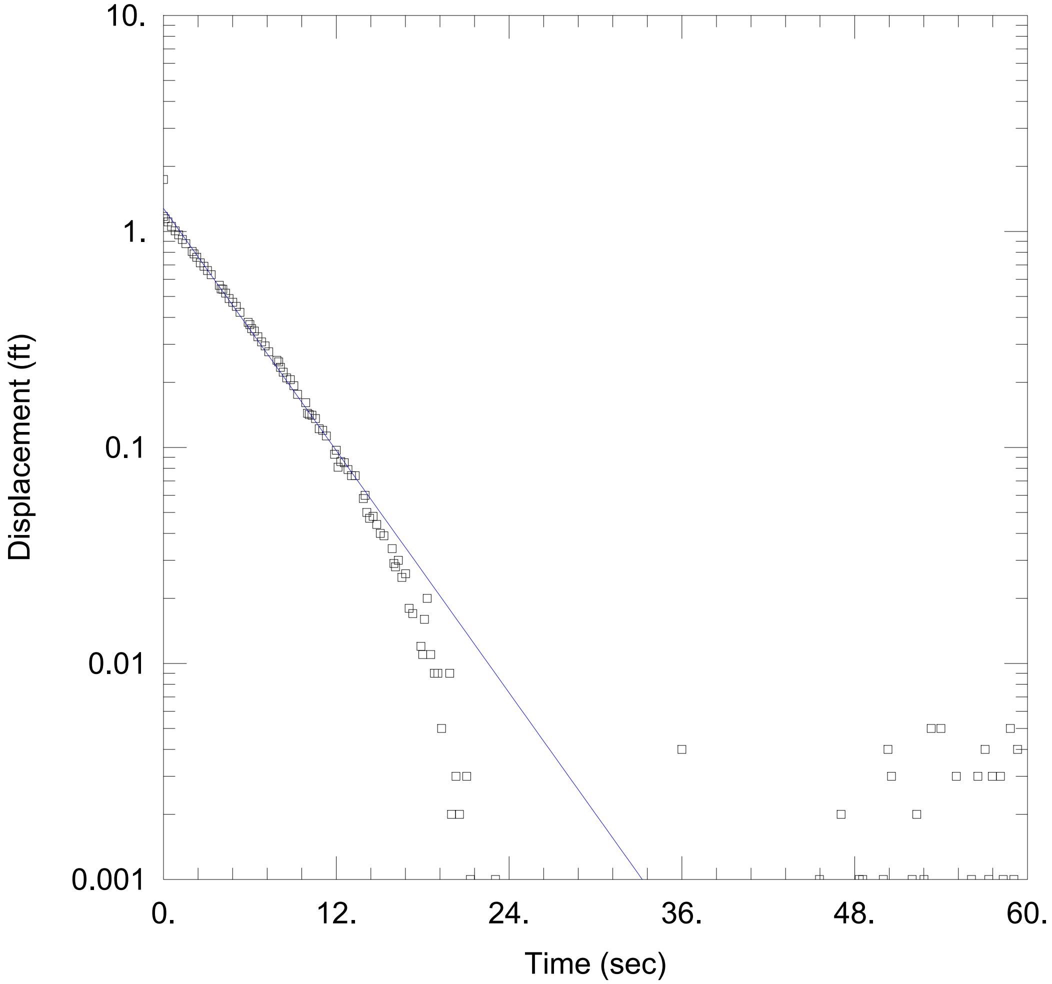
WELL DATA (PZ-2S)

Initial Displacement: 0.46 ft
Total Well Penetration Depth: 13.05 ft
Casing Radius: 0.167 ft
Static Water Column Height: 13.05 ft
Screen Length: 1. ft
Well Radius: 0.333 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Zlotnik-Goss-Duffield

K = 356.7 ft/day
y0 = 0.5098 ft



WELL TEST ANALYSIS

Data Set: \...\PZ-2S_RH1_SlugA.aqt
Date: 06/07/19 Time: 16:32:13

PROJECT INFORMATION

Company: Ramboll
Test Well: PZ-2S

AQUIFER DATA

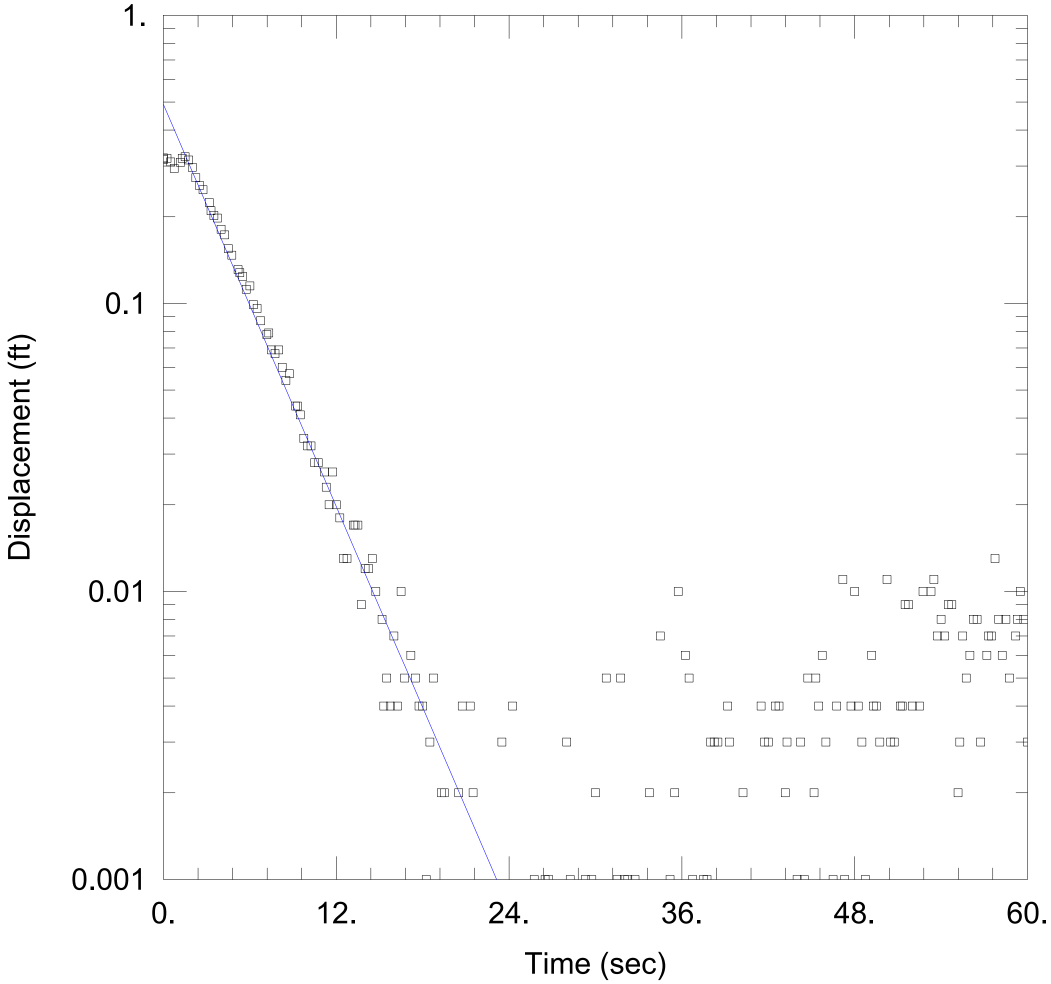
Saturated Thickness: 100. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (PZ-2S)

Initial Displacement: 1.74 ft
Total Well Penetration Depth: 13.05 ft
Casing Radius: 0.167 ft
Static Water Column Height: 13.05 ft
Screen Length: 1. ft
Well Radius: 0.333 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Zlotnik-Goss-Duffield
K = 325.4 ft/day
y0 = 1.278 ft



WELL TEST ANALYSIS

Data Set: \...\PZ-2S_RH1_SlugB.aqt
Date: 06/07/19 Time: 16:26:24

PROJECT INFORMATION

Company: Ramboll
Test Well: PZ-2S

AQUIFER DATA

Saturated Thickness: 100. ft Anisotropy Ratio (Kz/Kr): 1.

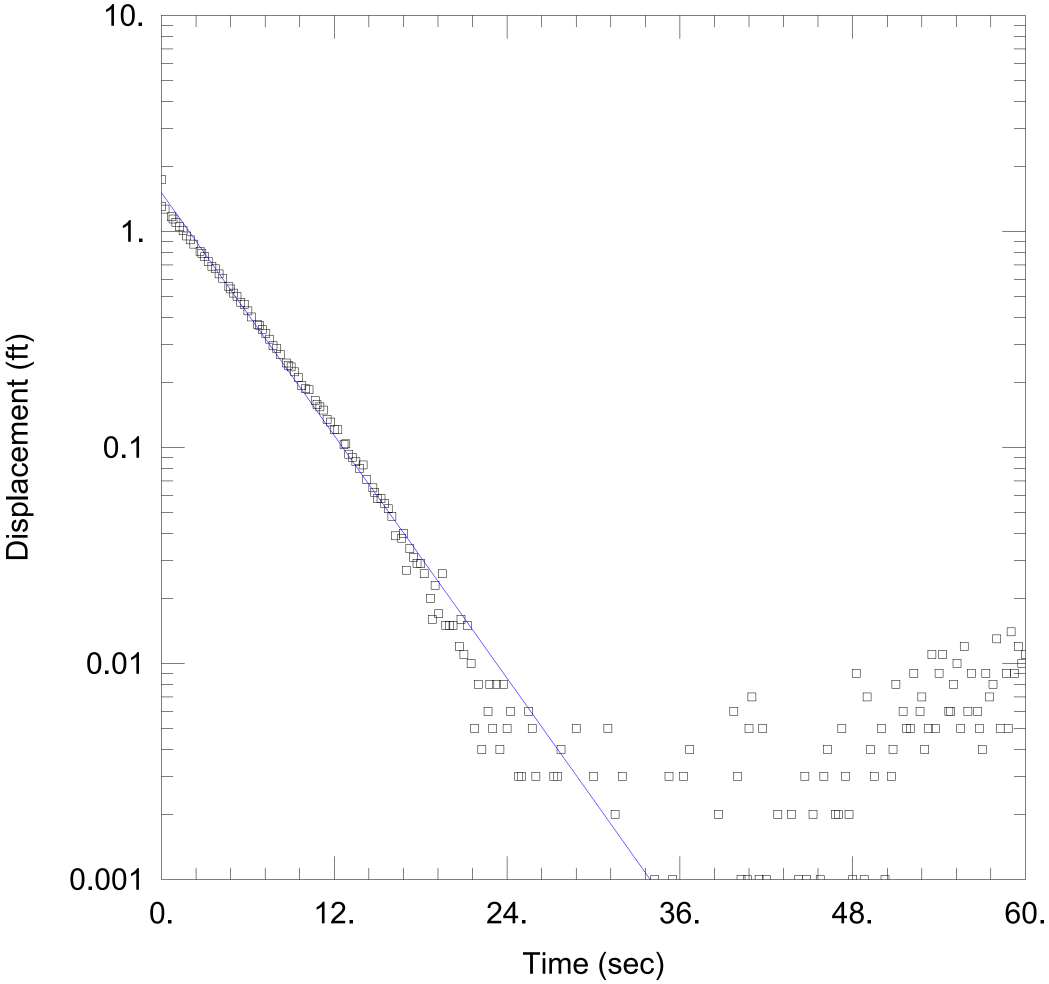
WELL DATA (PZ-2S)

Initial Displacement: 0.32 ft
Total Well Penetration Depth: 13.05 ft
Casing Radius: 0.167 ft
Static Water Column Height: 13.05 ft
Screen Length: 1. ft
Well Radius: 0.333 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Zlotnik-Goss-Duffield

K = 405. ft/day
y0 = 0.4902 ft



WELL TEST ANALYSIS

Data Set: \...\PZ-2S_RH2_SlugA.aqt
Date: 06/07/19 Time: 16:38:25

PROJECT INFORMATION

Company: Ramboll
Test Well: PZ-2S

AQUIFER DATA

Saturated Thickness: 100. ft
Anisotropy Ratio (Kz/Kr): 1.

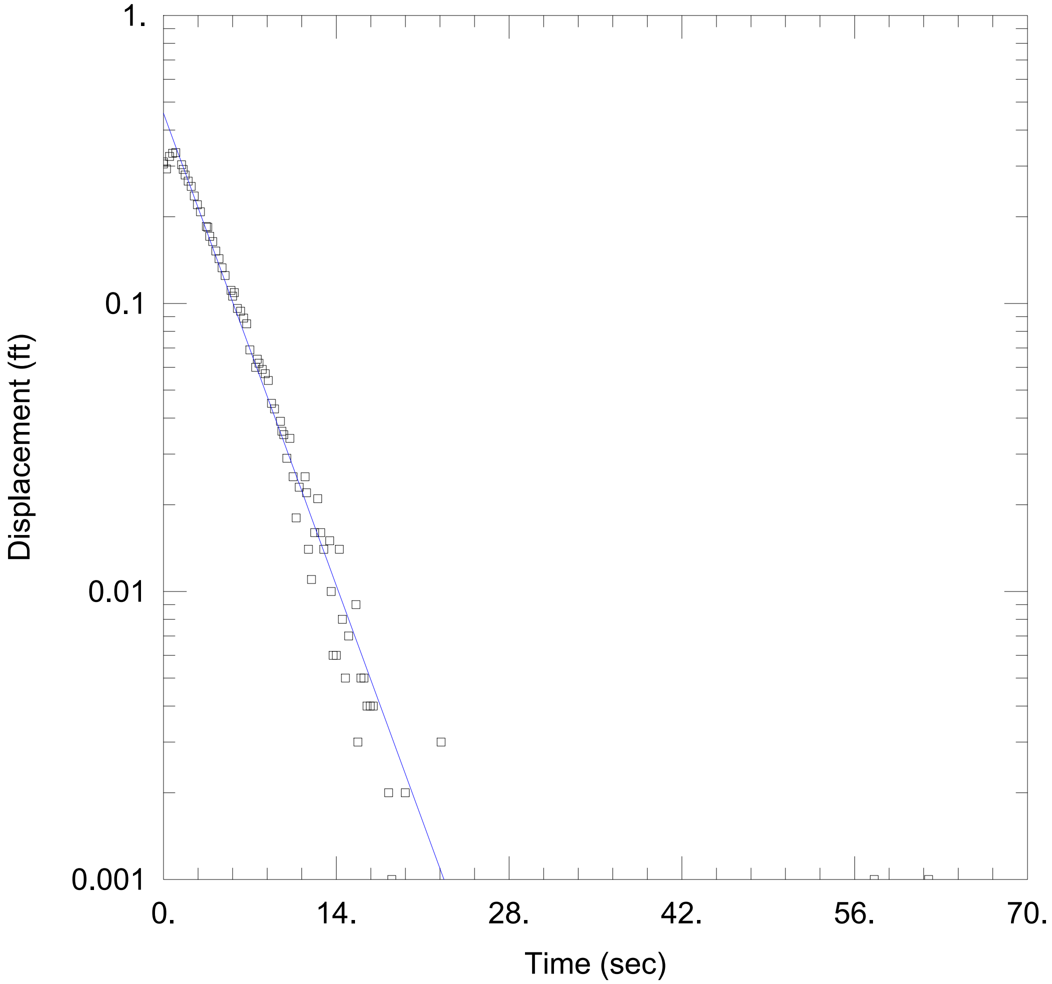
WELL DATA (PZ-2S)

Initial Displacement: 1.74 ft
Static Water Column Height: 13.05 ft
Total Well Penetration Depth: 13.05 ft
Screen Length: 1. ft
Casing Radius: 0.167 ft
Well Radius: 0.333 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Zlotnik-Goss-Duffield

K = 326.2 ft/day
y0 = 1.511 ft



WELL TEST ANALYSIS

Data Set: \...\PZ-2S_RH2_SlugB.aqt

Date: 06/07/19 Time: 16:28:36

PROJECT INFORMATION

Company: Ramboll

Test Well: PZ-2S

AQUIFER DATA

Saturated Thickness: 100. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (PZ-2S)

Initial Displacement: 0.31 ft

Static Water Column Height: 13.05 ft

Total Well Penetration Depth: 13.05 ft

Screen Length: 1. ft

Casing Radius: 0.167 ft

Well Radius: 0.333 ft

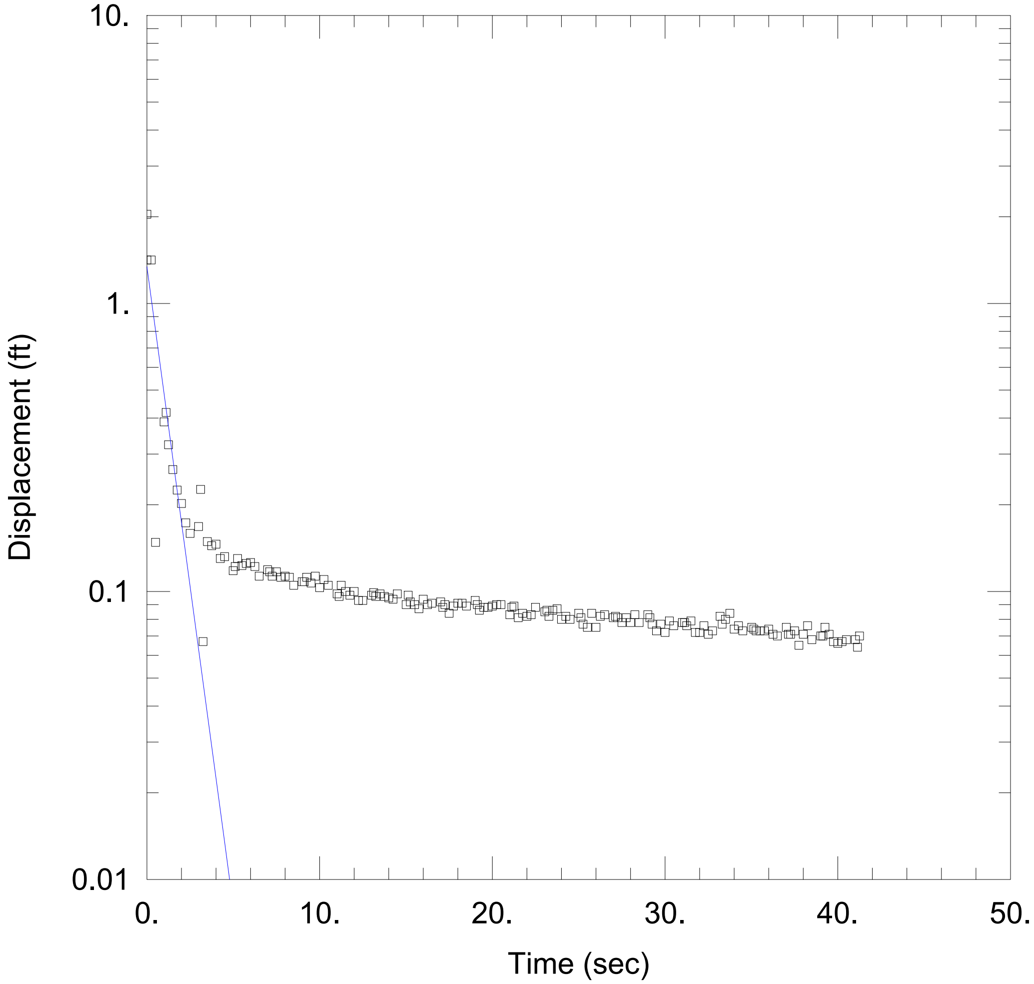
SOLUTION

Aquifer Model: Unconfined

Solution Method: Zlotnik-Goss-Duffield

K = 407.5 ft/day

y0 = 0.4573 ft



WELL TEST ANALYSIS

Data Set: \...\TRA-2_FH1.aqt

Date: 06/07/19 Time: 16:43:11

PROJECT INFORMATION

Company: Ramboll

Test Well: TRA-2

AQUIFER DATA

Saturated Thickness: 100. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (TRA-2)

Initial Displacement: 1.416 ft

Total Well Penetration Depth: 5.78 ft

Casing Radius: 0.167 ft

Static Water Column Height: 5.78 ft

Screen Length: 5.78 ft

Well Radius: 0.333 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Zlotnik-Goss-Duffield

K = 430.3 ft/day y0 = 1.342 ft

ATTACHMENT B-9
EVALUATION OF EXPERIMENTAL PROTOCOLS FOR CHARACTERIZING DIFFUSION IN SEDIMENTARY ROCKS

Evaluation of Experimental Protocols for Characterizing Diffusion in Sedimentary Rocks

NWMO TR-2007-11 **December 2007**

P. Vilks and N.H. Miller

Atomic Energy of Canada Limited

nwmo
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Evaluation of Experimental Protocols for Characterizing Diffusion in Sedimentary Rocks

NWMO TR-2007-11

December 2007

P. Vilks and N.H. Miller
Atomic Energy of Canada Limited

ABSTRACT

Title: **Evaluation of Experimental Protocols for Characterizing Diffusion in Sedimentary Rocks**
Report No.: **NWMO TR-2007-11**
Author(s): P. Vilks and N.H. Miller
Company: Atomic Energy of Canada Limited
Date: December 2007

Abstract

Laboratory protocols have been developed, and preliminary testing has been undertaken to estimate the porosity, pore size, effective diffusion coefficients, pore water composition and permeability using archived core samples from Ordovician-aged shale and limestone formations from southern Ontario. Porosity was estimated by a water immersion technique and pore size distribution was determined using mercury intrusion porosimetry. Through-diffusion cell experiments were used to estimate effective diffusion coefficients, as well as rock capacities and effective tortuosities which provide a measure of pore geometry. Sample permeability was estimated with the High Pressure Radionuclide Migration Apparatus by pumping water through core samples under a confining pressure. In addition, thirty-day leaching experiments with deionized water were used to extract salts in accessible pore spaces for use in estimating pore fluid compositions based on sample porosity.

Archived core samples of Queenston shale and Cobourg (Lindsay) limestone were used to test the experimental protocols, and to perform a preliminary assessment of mass transport properties of these formations. The Queenston shale was found to have an average porosity of 0.066 ± 0.005, and average iodide and tritium diffusion coefficients of $(1.2 \pm 0.3) \times 10^{-12}$ and $(1.1 \pm 0.3) \times 10^{-11}$ (m^2/s). The Cobourg limestone had an average porosity of 0.017 ± 0.003, and average iodide and tritium diffusion coefficients of $(1.2 \pm 2.4) \times 10^{-12}$ and $(3.9 \pm 4.8) \times 10^{-12}$ (m^2/s). The average pore diameters of shale and limestone were 6.2 ± 0.9 nm and 7.7 ± 1.6 nm, respectively. The matrix permeability of these samples was very low, with average values of $(4.5 \pm 5) \times 10^{-21}$ (m^2) for Queenston shale and $(9.4 \pm 7.0) \times 10^{-22}$ (m^2) for Cobourg limestone. Porosity and pore geometry variation accounted for differences in diffusivity and permeability between shale and limestone. Leaching experiments to extract soluble salts indicated that the pore waters in Ordovician sediments are highly saline, with Total Dissolved Solid (TDS) values estimated to range from 180 to 270 g/L. These compositions are consistent with the compositions of groundwaters from wells within Ordovician-aged formations in southern Ontario.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

1. INTRODUCTION

A geoscientific assessment has been completed on the suitability of the Paleozoic sedimentary rock sequence occurring beneath southern Ontario to host a Deep Geologic Repository (DGR) for used nuclear fuel (Mazurek 2004). The assessment involved a review of international radioactive waste management programs in sedimentary media and a compilation of existing and publicly available geoscientific information for southern Ontario. Based on an initial assessment using simple criteria (existence of low hydraulic conductivity rock mass, formation depth below ground surface, formation thickness, and simple formation geometry), suitable bedrock formations were identified as the Middle/Upper Ordovician age (ca. 470 - 443 Ma) shales (Blue Mountain, Georgian Bay and Queenston Formations) and underlying limestones (Simcoe Group, i.e*.,* the Gull River, Bobcaygeon, Verulam and Lindsay Formations). One of the important conclusions from this initial assessment is that these deeper subsurface formations contain stagnant water, and that solute transport was expected to be dominated by diffusion, even in those formations which have higher permeabilities. Mazurek (2004) indicated that future work to determine the suitability of Ordovician sediments to host a DGR should include the acquisition of formation specific data to support the quantification of solute transport retardation, such as mineralogy, porosity, diffusivity, ion exchange and sorption characteristics, pore-water composition and redox state.

The suitability of sedimentary formations as host rocks for the disposal of radioactive waste in deep geologic repositories is currently being assessed internationally. Radioactive waste management programs in Switzerland, France, Belgium, Spain and Japan are focused on clay-rich sedimentary rocks as potential host formations. However, direct measurements of porosity and diffusion coefficient values for shales and limestones from southern Ontario are limited in the published literature. Barone et al. (1990), reported porosity values of 0.102 to 0.114 and a Cl effective diffusion coefficient (D_e) of 1.5×10^{-11} m^2/s for the upper Ordovician Queenston shale from southern Ontario (Burlington), taken from a depth of 11 to 12 m. Mazurek (2004, after Golder Associates 2003) reported porosity values of 0.005 to 0.03, and Cl D_e values of 5×10^{-13} to 3×10^{-12} m^2/s for Gull River limestones.

Examples from the international literature of diffusion parameters determined for sedimentary rocks, including clay, argillite, limestone and sandstone are summarized in Table 1. Porosity values for sedimentary rock are one to two orders of magnitude higher than in crystalline igneous rocks, which typically have porosities between 0.002 and 0.003. Based on the limited data available, shales in southern Ontario appear to have porosities similar to Scotian Shelf shales, and many European argillite formations. Although in some cases sedimentary D_e values are similar to those determined for crystalline igneous rocks, often the sedimentary values are one to two orders of magnitude higher. This suggests that the experimental times to study diffusion in sedimentary rocks will be shorter than was required for Lac du Bonnet granite (Vilks et al. 2004). The reported Cl D_e value for Queenston shale from southern Ontario is slightly higher than the Cl and I D_e values reported for the Opalinus clay and other Canadian clays. In clay- rich rocks, diffusion parallel to bedding planes is reported to be higher than diffusion normal to bedding planes by a factor 2 to 5 (Van Loon and Soler 2004, Mazurek et al. 2003). The diffusion properties of limestone cover a broader range compared to clays and shales, which is not surprising given the range of rock textures that can be observed in limestones.

Table 1: Diffusion Parameters for Sedimentary Rocks from the Literature

Formation/Rock Type	**Ref**	**Porosity**	**Method**	**D_e for HTO**	**D_e for I**	**D_e for Cl**	
Boom Clay - Mol	7	0.37		7.70E-11			⊥ bedding
Boom Clay - Mol	7			1.50E-10			∥ bedding
Spanish Reference Clay	7	0.39		1.20E-10			⊥ bedding
Avonlea bentonite	8				3.0E-10		
Avonlea bentonite	9				3E-12 - 6E-11		
compacted bentonite	5	0.05 to 0.11 0.32	α I fluid sat		5.3E-12 - 9.4E-12		
Lake Agassiz clay	8				5.7E-13		
Lake Agassiz clay	3	0.1	calc.		9.0E-12 - 5.3E-11		
Callovo-Oxfordian argillite	7	0.15		1.40E-11			⊥ bedding
Callovo-Oxfordian argillite	7			2.00E-11			∥ bedding
Callovo-Oxfordian argillite, Andra URL	4	0.025 to 0.20	α HTO	2.6E-12 - 4.5E-11			
Couche Silteuse - argillite, France	7	0.08		1.00E-11			
Opalinus Clay - Benken	12	0.13 to 0.14 0.041 0.06 to 0.08	α HTO α Cl α I	5.40E-12	4.5E-13 - 6.6E-13	6.7E-13	⊥ bedding
Opalinus Clay - Benken	12	0.13 to 0.15 0.045	α HTO α Cl	3.15E-11		3.4E-12	∥ bedding
Opalinus Clay - Mont Terri	12	0.14 to 0.17 0.08 0.08 to 0.11	α HTO α Cl α I	1.40E-11	3.3E-12 - 4.8E-12	4.1E-12	⊥ bedding
Opalinus Clay - Mont Terri	12	0.15 to 0.17 0.082	α HTO α Cl	5.40E-11		1.6E-11	∥ bedding
Opalinus Clay - Mont Terri	11	0.09 to 0.11 0.05 0.07 to 0.10	α HTO α Cl α I	1.2E-11 - 1.5E-11	3.2E-12 - 4.6E-12	4.0E-12 - 5.5E-12	⊥ bedding
Opalinus Clay - Benken	7	0.124		1.00E-11			⊥ bedding
Opalinus Clay - Benken	7			5.00E-11			∥ bedding
Opalinus Clay - Mont Terri	7	0.157		1.50E-11			⊥ bedding
Opalinus Clay - Mont Terri	7			6.30E-11			∥ bedding
Opalinus Clay - Mont Terri	10	0.125 to 0.145	fluid loss	1.00E-11			in-situ ∥ bedding

Table 1: Concluded

Formation/Rock Type	Ref	Porosity	Method	D_e for HTO	D_e for I	D_e for Cl	
Palfris Formation, Wellenberg	7	0.29		2.00E-12			⊥ bedding
shales from Scotian shelf	6	0.015 to 0.12	fluid sat.				
Toarcian/Domerian argillite	7	0.1		4.00E-12			⊥ bedding
Toarcian/Domerian argillite	7			1.50E-11			∥ bedding
Upper Ordovician Shales, S. Ontario	1	0.108	fluid sat.			1.5E-11	
limestones	2	0.03 to 0.43	fluid sat.		6.8E-13-2.9E-10		
Oxfordian limestone - Andra URL	4	0.03 to 0.24	α I	2.6E-12-1E-10			
sandstones	2	0.11 to 0.25	fluid sat.		1.7E-11 - 7.1E-11		

α I	Refers to porosity determined by iodide rock capacity
α Cl	Refers to porosity determined by chloride rock capacity
α HTO	Refers to porosity determined by tritium rock capacity

References:

1. Barone et al. 1990
2. Boving and Grathwohl 2001
3. Choi et al. 1993
4. Descostes et al. 2004
5. Eriksen and Jansson 1996
6. Katsube et al. 1992
7. Mazurek et al. 2003
8. Oscarson and Hume 1994
9. Oscarson et al. 1992
10. Palut et al. 2003
11. Van Loon et al. 2003
12. Van Loon and Soler 2004

Any comparison of the diffusion properties of tritium with those of anions (I, Cl) must take into consideration that tritium can access all water-containing connected porosity (because water contains hydrogen atoms). In contrast, anions may be excluded from a fraction of the total connected porosity as a result of repulsion by the dominantly negative charged mineral surfaces (anion exclusion). Consequently, tritium-derived porosities (from rock capacity factors) and tritium D_e values will often be higher than those determined using anions as tracers.

The current research was undertaken to develop and test laboratory protocols to measure bulk diffusive transport properties in sedimentary rocks, with an emphasis on shales and limestones. Experimental techniques for characterizing rock diffusion parameters for crystalline rock in were previously developed within the Deep Geologic Repository Technology Program (DGRTP) (e.g., Vilks et al. 1999, 2004). The approach to developing experimental procedures for sedimentary rock was to build on this experience by comparing these methods to published work on the estimation of diffusion parameters in sedimentary rock (e.g. Boving and Grathwohl 2001, Descostes et al. 2004, Mazurek et al. 2003, Van Loon and Soler 2004). Sedimentary rocks have larger porosities, and different rock fabrics and mineralogy than crystalline rocks. Therefore, initial tests with samples of sedimentary rock (Queenston shale and Whirlpool sandstone) to estimate porosity and diffusivity were performed to determine whether the differences between sedimentary and igneous crystalline rocks may affect the application of experimental techniques previously used for igneous rocks, and to develop alternative techniques when necessary.

Initial experiments with shale samples focused on applying existing experimental procedures to measure diffusivity and porosity, to determine whether these samples would be subject to alteration caused by swelling or some other process. For example, tunnels built in shales and shaley rocks in Southern Ontario have shown evidence of stress-dependent long-term swelling deformation (Hawlader et al. 2005). Because shales are composed mostly of clay (illite), swelling may be induced by water migration or changes in water chemistry. The application of stress can also affect swelling (Hawlader et al. 2005). If swelling of shale samples occurs, steps need to be taken to control it, and/or to understand its effect on porosity and diffusivity.

Shales have a significantly higher porosity than crystalline rock, which might impact porosity estimation by the water immersion technique. A significant fraction of this porosity might include small constricted pore spaces associated with clay minerals. In this study it was determined that it is necessary to measure dry sample weight by oven drying, as recommended by Katsube et al. (1992), instead of drying under a vacuum at room temperature, as was done for granites (Vilks et al. 2004).

Sedimentary rocks often contain significant amounts of carbonates or sulphates as major rock forming minerals or as matrix and fracture filling cement. If the formation contains saline groundwaters, the pores of the rocks may contain saline pore fluids. In the diffusion experiments, the tracer fluid itself may result in changes in the porosity, pore structure, and/or connectivity if dissolution or precipitation of minerals occurs within the rock matrix as a result of interaction with the tracer fluid. In order to obtain more representative results the ionic strength and/or the chemical composition of solutions used in diffusion experiments can be adjusted to minimize rock-water interactions during the experiment.

As a result of the presence of sedimentary structures such as bedding planes, fossils, secondary porosity, etc., the Representative Elementary Volume (REV) of sedimentary rocks is likely different than granitic rocks. In this study, the effect of sample size on diffusivity measurements was assessed for shales by determining the variation of estimated diffusivity values with sample thickness.

This report describes the testing of laboratory procedures for estimating the porosity, diffusivity, permeability and pore water chemistry of sedimentary rocks. It recommends test protocols for characterizing the bulk diffusion parameters for sedimentary rocks, and it presents initial estimates of porosity, pore size, effective diffusivity, permeability and pore water chemistry determined using archived core samples from both the Queenston formation (shale) and from the Cobourg Formation (argillaceous limestone).

2. METHODS

2.1 SAMPLE COLLECTION AND PRESERVATION

The primary goal is to obtain and store representative rock samples without altering their porosity and pore geometry. The preservation of pore water chemistry is of interest, but is of secondary importance in diffusivity measurements, as long as chemical/biological processes do not lead to changes in porosity during sample storage. In general, the selection of sampling locations should consider the experimental objectives.

2.1.1 Recommended Sampling Methods

Sample size: In diffusion cell experiments, the diameter of the sample core determines the surface area through which tracer can diffuse. Although cores with diameters as small as 22 mm have been successfully used for diorite samples from Äspö, the small surface areas have contributed to significantly lower diffusive fluxes, resulting in very long times to achieve steady-state diffusion. The 47 mm diameter cores used for samples of Lac du Bonnet granite and granodiorite produced much faster diffusion rates. Therefore, it is recommended that samples of sedimentary rock be drilled to produce cores with diameters of 47 mm and larger. If radial diffusion experiments are to be performed, core sections with a 200 to 300 mm diameter would be required, but are not commonly drilled.

The sample length required to achieve a REV depends upon the texture of the sample being studied. For example, coarse grained rocks require a longer sample length than fine grained rocks because larger grains produce a greater variability in pore geometry in a given rock volume. Increasing sample size incorporates this variability into the bulk diffusivity measurement. In sedimentary rocks, samples with fossils may require special attention when evaluating the REV, because void spaces created by fossils may produce fast diffusion paths. Typically, diffusion measurements on shales or clays have used sample thickness' of 10 mm. Tests using sample thickness' of 5, 10, 20, and 30 mm should be performed to determine whether the 10 mm thickness is appropriate for the lithology being investigated. The need to evaluate REV would be determined by variations in lithology (e.g. from fossiliferous to fine-grained) and the presence of secondary porosity created by digenesis or tectonic deformation.

Drilling procedures: Standard drilling procedures can be used for collecting core samples for diffusion experiments. The intent is to recover core as quickly as possible with minimal thermal effects on the sample. Martin and Stimpson (1994) found that stress-induced damage in samples of granite becomes significant below depths of about 200 m. They argued that the stress-induced damage occurred during the drilling process, at which time the 3-dimensional stress concentrations at the face of the drill bit magnified the effects of the in-situ stress conditions by a factor of 2, enough to produce microcracks. The amount of stress induced damage was not related to core diameter, or to poor quality rock sampling procedures.

Because knowledge of pore fluid compositions is valuable for formulating tracer and eluant solutions, and for better understanding diffusivity under in-situ conditions, it is important to understand the effect of drilling on pore fluid chemistry. Because diffusivity in Ordovician shales and limestones is assumed to be low, drilling fluids are not expected to exchange significantly with pore fluids over the 2 to 8 hour time period required to recover a 1 m core section. However, to confirm that assumption it might be useful to add uranine or another distinctive tracer to the drilling fluid.

Sample preservation: After drilling, it is important to store sample core in such a way as to minimize any further changes to the rock structure and porosity. Over long time periods it is best to store rock samples in core boxes as intact cores (~ 1 m sections). Smaller sub-samples for diffusivity, porosity and permeability measurements are cut shortly before use. The porosity of thin (10 mm) slices of granite core was found to increase by 37 to 46 percent during a two year storage time, whereas intact core showed no effects from aging (Vilks et al. 1999). It is not known whether a similar alteration process would affect sedimentary rocks. If sample cores are to be drilled specifically for diffusion and pore water studies, then the pore fluid content must be preserved by minimizing sample drying. Although drying is likely to leave the salt content behind, the drying process could induce some irreversible reactions that will prevent the total recovery of pore fluid salts during the leaching process. To minimize drying, one possible preservation procedure involves wrapping fresh core in multiple layers of thin plastic immediately after being cut. The cores are then placed in plastic tubes, and the ends are sealed. For further protection, the plastic tubes are placed in a plastic sleeve that is heat-sealed. Other examples of preservation methods include wrapping fresh core with saran wrap, covered with wet tissue for Queenston shale (Barone et al. 1990), and wrapping shale in kerosene-saturated paper, covered with aluminum foil (Fam and Dusseault 1998).

2.1.2 Archived Samples Used in this Study

In the current study, rock samples were obtained from archived cores that had been subject to routine handling procedures, without any attempt to prevent the drying of pore fluids.

Samples of Upper Ordovician Queenston shale were obtained from core SI 2005-1 (Figure 1), which was drilled during February 2005 in Niagara Falls, Ontario. Prior to sampling the core was stored in standard wooden core boxes, with no protection against drying. The core was in good condition, allowing selection of large pieces for diffusion studies. The core diameter was 63.3 mm. The Whirlpool sandstone was located at a core depth of 72.4 m, while Queenston shale samples were taken at depths ranging from 73.5 to 110.5 m. The Queenston shale is situated in the westernmost part of the Taconic clastic wedge of eastern North America, and was formed in a depositional environment that consisted of a wide, shallow, prograding shore that was probably affected by tides, recurring storms, drainage channels, and temporary sub aerial exposure (Brogly et al. 1998).

Samples of Upper Ordovician Cobourg (Lindsay) limestone (Figure 2) were taken from core DW-46 (Box #5), which had been drilled in 1978 as part of geotechnical investigations and stored in an unheated core shed. As with the Queenston Formation core from Niagara Falls, no steps had been taken to preserve moisture content within the core or to prevent exposure to freeze-thaw cycles. Three core samples were selected and shipped by OPG for characterization of diffusion properties. The core diameter is 54.5 m, and the sample depths ranged from 36.4 to 55.9 m. The Cobourg limestone is a nearshore deposit containing calcareous mud and layers of fossils reworked by storm wave action. A visual inspection of hand specimens suggests that sedimentary structures could influence the direction of diffusive mass transport.

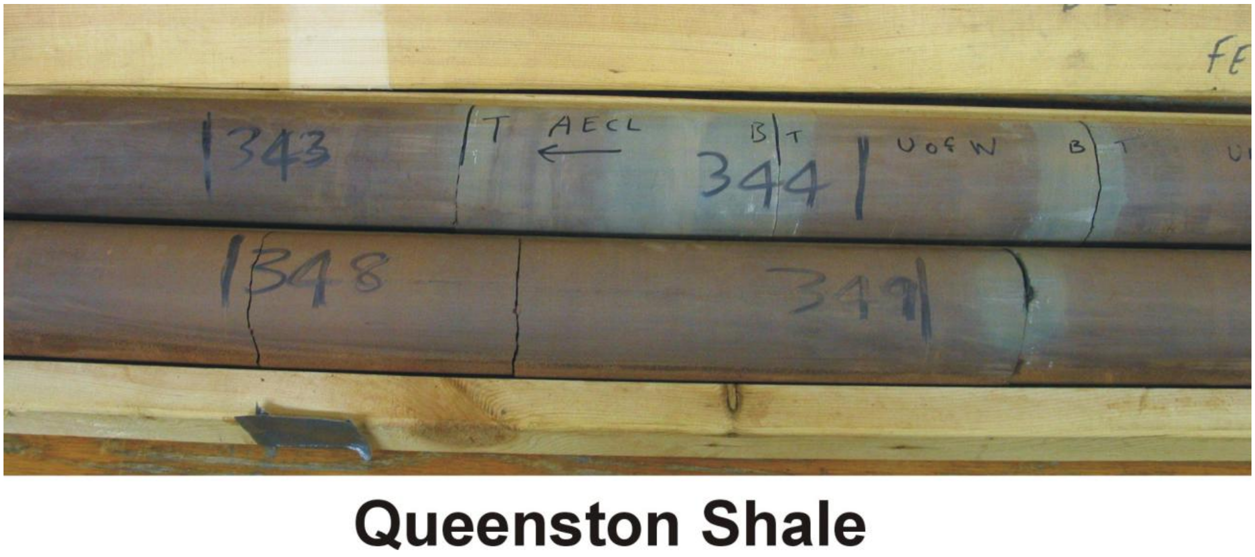

Figure 1: Core SI 2005-1, with Queenston Shale

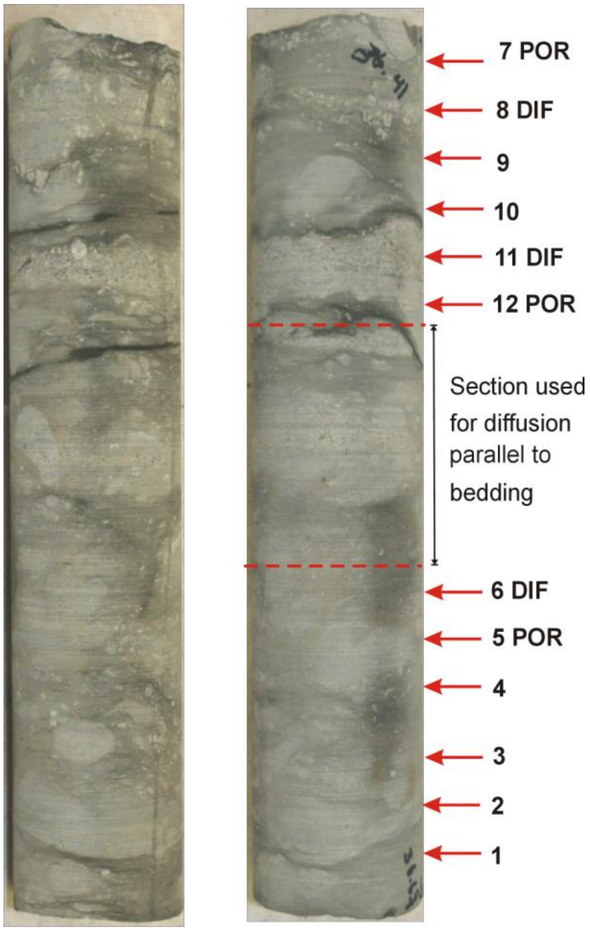

Figure 2: Core DW-46 Cobourg (Lindsay) Limestone, with Marked Sample Locations

2.2 POROSITY ESTIMATION BY WATER IMMERSION

2.2.1 Background

All methods developed for estimating connected porosity involve filling the connected voids with a quantifiable substance or tracer. The usefulness of a given method depends on the ability of the tracer to penetrate all relevant pore space, and on the ability to quantify the tracer. The principal method used in the current study is the water immersion technique. Examples of other methods include (1) helium porosity (Valkiainen et al. 1995), which involves the filling of rock pore spaces with helium gas under controlled conditions (Dorsch 1997), (2) mercury porosimetry (Barone et al. 1990) for porosities greater than 1%, and (3) leaching tests using tritium (HTO) or helium (Olin et al. 1997).

The water immersion technique (also referred to as fluid saturation), refined by Melnyk and Skeet (1986) for rocks with porosities less than 5 %, has been widely used in many studies with crystalline rocks (Vilks et al. 2004). An inter-laboratory comparison has indicated that the water immersion technique is one of the most reliable techniques for rocks of low porosity (Rasilainen et al. 1996). The water immersion technique is also applied to sedimentary rocks (API 1960, Katsube et al. 1992). In the water immersion technique, a rock sample is saturated with distilled de-aerated water under vacuum and then the weight of water in pore spaces is determined by monitoring the weight of the rock sample while it dries. Melnyk and Skeet 1986, determined the actual dry weight of the sample by drying it under vacuum until a constant weight was achieved. They avoided heating the sample because of concerns that heating to temperatures as low as 70^{o}C could cause significant damage to the rock porosity. However, in an extensive evaluation of porosity estimation methodology on shales from the Scotian Shelf, Katsube et al. 1992, found that vacuum drying was not sufficient to remove all water from pore spaces. They found that the optimum method for determining dry weight of these shales was to heat the sample to 105^{0}C or 116^{0}C, as a last step in the porosity measurement process. Heating to this temperature is sufficient to remove water from open pore spaces, but does not remove the water adsorbed to mineral surfaces and found in the interlayer spaces of clay minerals. A higher temperature range of 200 to 260^{o}C is required for removing the more strongly held water. Repeated measurements produced consistent porosities, and any progressive porosity increases could be attributed to damage by sample handling. The samples, which showed the most change with repeated measurements, were those with a high content of illite, smectite or organic matter.

A series of preliminary experiments were carried out with samples of Queenston shale to estimate porosity using the method of Melnyk and Skeet 1986, and procedures used by Katsube et al. 1992, for shales from the Scotian Shelf. Experimental results showed that the archived Queenston shale samples have properties that render them unsuitable for analyses using the method of Melnyk and Skeet (1986). Archived samples of the Queenston shale were found to be prone to disintegrate after being wetted (Figure 3), making subsequent sample handling more difficult compared to crystalline rock or sandstone. Clay-bearing rocks, such as shales, are known to swell or disintegrate when exposed to atmospheric wetting and drying (Franklin and Dusseault, 1989). It should be noted that the Queenston shale samples did not show this behaviour when mounted in diffusion cell sample holders (Figure 4). The water immersion method has been modified to account for the larger porosity and the fragile nature of the Queenston shale samples, as described in the following section.

Figure 3: Examples of Queenston Shale Core Slices Showing Disintegration after Wetting

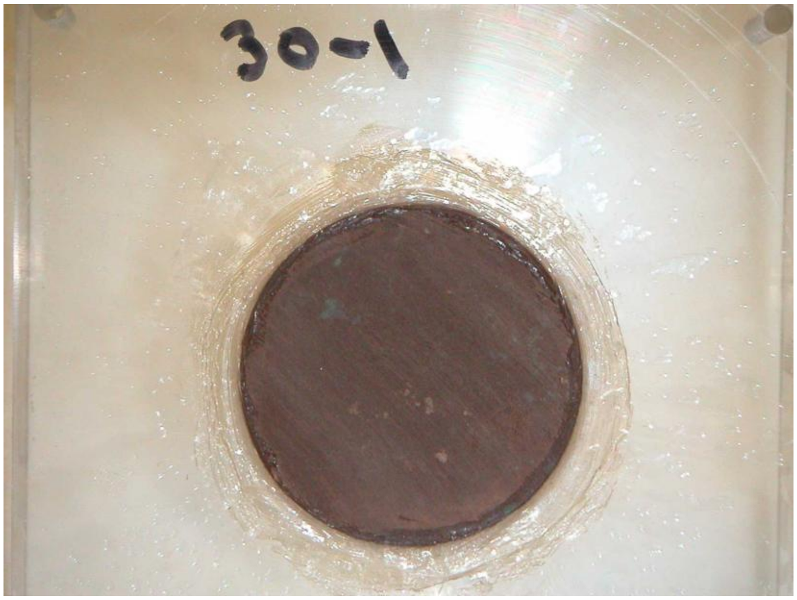

Figure 4: Queenston Shale Sample Mounted in a Diffusion Cell and Showing No Sample Disintegration after Wetting

2.2.2 Modified Water Immersion Method for Sedimentary Rocks

The main differences in the modified method for estimating porosity of shales are that the sample dry weight is determined by oven drying instead of vacuum drying, and sample saturation and subsequent handling have been modified to account for the fragile nature of shale samples.

The initial mass of a rock sample used for porosity estimation is between 20 and 70 g. In the case of the Queenston shale samples used in the preliminary experiments, the samples consisted of 45 mm diameter core cut into slices with thickness' ranging from 5 mm to 30 mm. Core slices are cut with a water-cooled diamond saw. Each sample is washed with deionized water before use. In the method used for crystalline rocks, the samples were also sonified during the washing procedure to assist in the removal of loose particles. However, due to the fragile nature of the Queenston shale after wetting, the sonification step was eliminated. While the removal of loose particles was thought to be important for crystalline rocks because they had very low porosities around 0.3 percent, the impact of loose material would have a minor affect on sedimentary rocks that have higher porosities with water contents that are easier to determine.

Before saturating the rock samples with water, they are placed in a vacuum cell and evacuated for at least 24 hours (Figure 5). Within the vacuum cell, each sample is contained in a separate plastic cup that has holes cut in the bottom to allow access to water (Figure 6), and which keeps the sample pieces together if the sample disintegrates. During this time, 500 mL of demineralised water are degassed under vacuum. Once the initial drying stage is complete, the vacuum cell containing the rock samples is isolated from the vacuum pump, and degassed water is slowly allowed to enter the vacuum cell and completely immerse the rock samples. The samples are kept under water for at least 24 hours to allow full water penetration of the pore spaces. Queenston shale samples were likely to break apart while sitting in the water. In this case, the larger usable pieces are selected for continuation of the porosity measurements. The samples are maintained in a wet condition until their water saturated weight is determined.

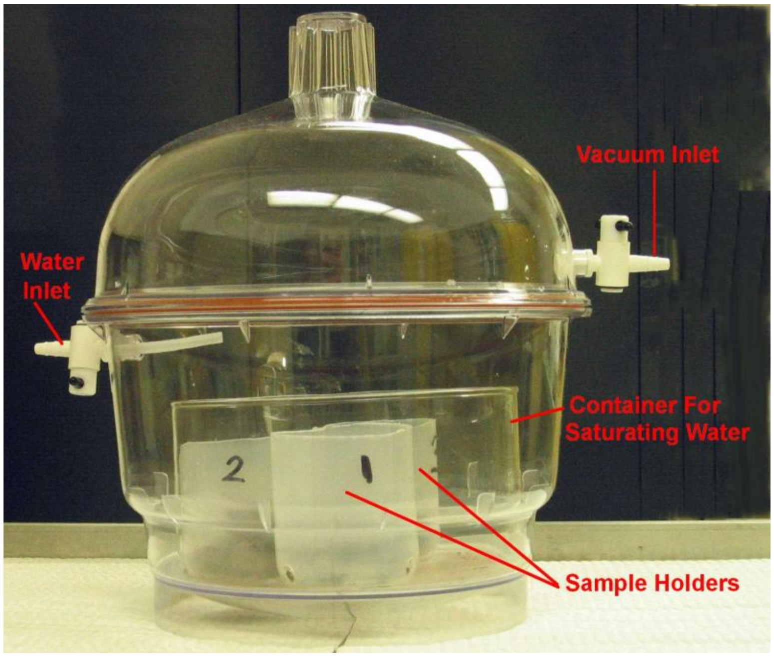

Figure 5: Vacuum Cell for Saturating Rock Samples

Figure 6: Plastic Cups for Containing Rock Samples in Vacuum Cell

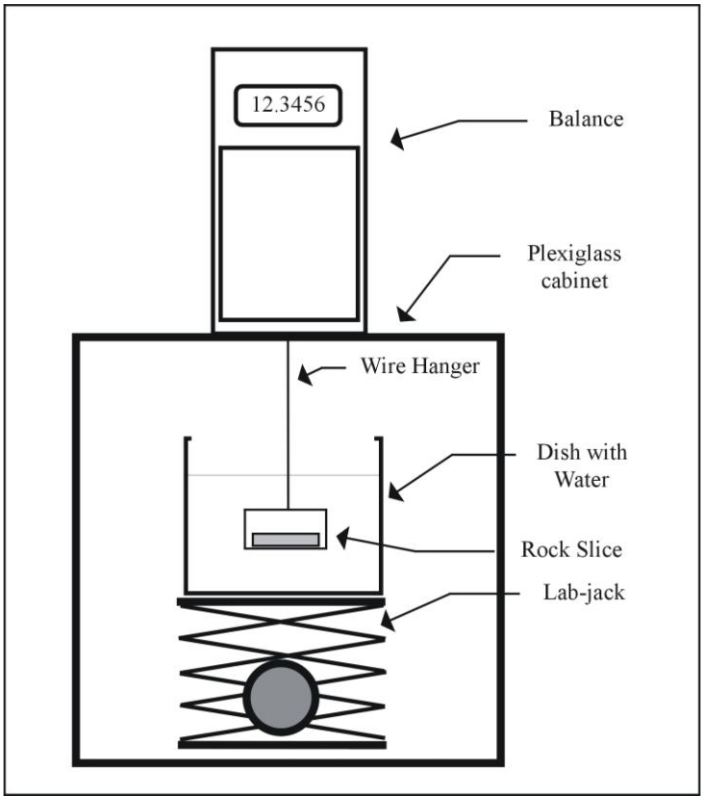

Figure 7: Schematic Diagram of Set-up for Determining Sample Volume

The rock sample volume (V_s) and the water-saturated but surface-dry weight (W_s) are determined in the next two sequential steps. After running a daily balance calibration check, a large dish filled with demineralised water is positioned under a balance (Figure 7) so that the under-the-balance hanger is immersed under water exactly to a marked level. After ensuring that no bubbles are clinging to the surface of the hanger, the balance is tarred. The lab-jack holding the water dish is lowered to remove the hanger from the water, and the largest piece(s) of sample are placed onto the hanger. The lab-jack is then raised so that the hanger is immersed exactly to the mark. After ensuring that there are no clinging air bubbles, the weight (W_{VS}) is recorded. The lab-jack is raised and lowered at least five times to determine the repeatability of the measured weight.

Because the rock sample contains water within its pores, as well as on the surface, it is necessary to eliminate the surface water, which may produce an erroneously high porosity if included. To determine the water-saturated but surface-dry weight (W_s), the water bath is lowered out of the way after the sample volume has been determined. After removing the sample, the hanger is dried and the balance is tarred. Excess water is gently wiped from the sample with a damp lint free tissue and the sample is replaced on the under-the-balance hanger. The sample weight is monitored while its surface dries using the Collect program to accumulate the weight loss data from the balance until the weight loss is small (<0.0005 g) or constant. A one hour drying time is usually sufficient. An example of a weight loss versus time curve is given in Figure 8. In the initial stage, weight loss is due mainly to evaporation from the sample surface. As the surface begins to dry, pore water starts moving toward the surface and contributes to the overall weight loss. When the sample is completely dry the weight loss represents only pore water. The sample weight (W_s) representing the point at which the surface is dry and the sample is still totally saturated is given by the intersection of the two lines representing drying from only the surface and drying only from pore spaces (Figure 8).

The dry weight (W_D) of the sample is determined by heating the rock samples in an oven at 105^{o}C (after Katsube et al. 1992) for about 48 hours to remove all water from pore spaces. After heating, the rock samples are removed from the oven and left at atmospheric conditions for one hour. The samples are then repeatedly weighed until a constant weight (+/- 0.0005 grams) is obtained.

The sample porosity is calculated as follows:

$\mathbf{W_D}$	Dry weight
$\mathbf{W_S}$	Water-saturated surface-dry weight
$\mathbf{W_{VS}}$	Water saturated submerged weight
$\mathbf{V_S}$	Sample Volume
$\mathbf{V_W}$	Volume of water in rock sample pores
ρ_{H2O}	Density of water at room temperature (22^{o}) = 0.99777 g/cc
ε	Porosity

$$V_s = (W_S - W_{VS})/\rho_{H2O} \qquad (1)$$

$$V_w = (W_S - W_D)/\rho_{H2O} \qquad (2)$$

$$\varepsilon = V_W/V_S \qquad (3)$$

Note that this method assumes that the rock samples are fully saturated after 24 hours. Also, the drying process may not eliminate water adsorbed to mineral surfaces, which might be a factor in clay-rich rocks that have a high specific surface area. Also, rocks that originally contained high salinity pore fluids will contain precipitated salts. These salts will dissolve when the rock is saturated with deionized water, producing a high density pore fluid. This higher density is not a factor in determining the volume of water that is evaporated from the rock because the salts are left behind. However, since the salts take up pore space the amount of water released during drying may underestimate the total connected porosity. For example, a simple gravimetric test shows that the water content in a 100 mL volumetric flask is 8.9 percent lower when the NaCl concentration is 250 g/L, compared to deionized water.

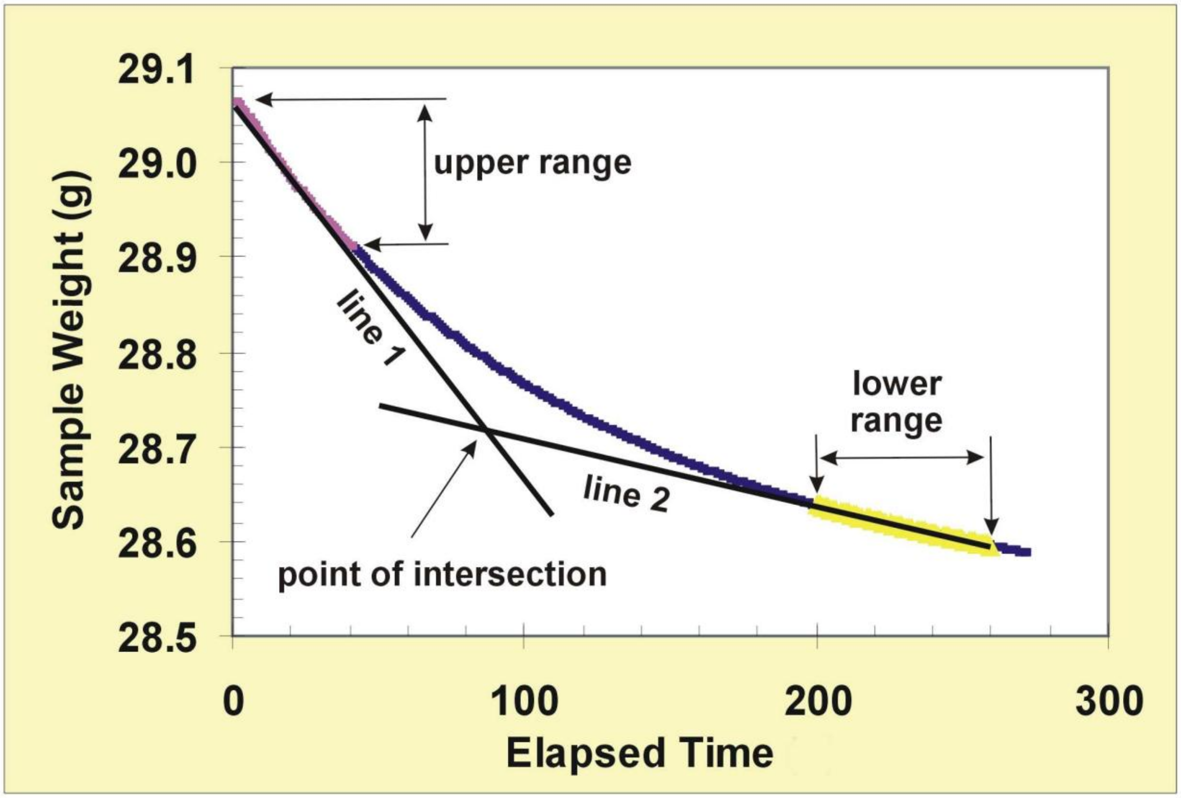

Figure 8: Example of Drying Curve to Determine the Water-saturated but Surface-dry Weight (Ws) for a Queenston Shale Sample

2.3 MERCURY INTRUSION POROSIMETRY

Mercury Intrusion Porosimetry (MIP) is a technique used to measure pore structure, as defined by a pore size distribution, in a variety of solid materials with pore diameters ranging from 3 nm to over 100 μm. Pore size and volume are determined by submerging the sample using a confined quantity of mercury, and then increasing the pressure of the mercury hydraulically. The detection of the free mercury diminution in the pentrometer stem (Figure 9) is based on a capacitance system and is equal to the mercury filling the pores. As the applied pressure is increased the total amount of intruded mercury increases as the mercury is forced into smaller and smaller pores. Determination of the pore size by mercury penetration is based on the behavior of non-wetting liquids in capillaries. A liquid cannot spontaneously enter a small pore which has a wetting angle of more than 90 degrees because of the surface tension (capillary depression). However this resistance may be overcome by exerting a certain external pressure. In the derivation of pore size from exerted pressure, it is assumed that pores are cylindrical.

Samples of sandstone, shale and limestone were analyzed using a Micromeritics Autopore #9220 Mercury Intrusion Porosimeter (Figure 10). Before use, instrument calibration is checked, using Micromeritics Silica-Alumina Reference material P/N 004-16822-00, available from FOLIO Instruments INC. 159 Place Frontenac, Suite 1, Pointe Claire, Que. H9R 4Z7.

Figure 9: Penetrometer Stems Used to Hold Samples During MIP Analyses

Figure 10: Micromeritics Autopore #9220 Mercury Intrusion Porosimeter

Before analysis, samples must be dried to remove excess moisture, typically by placing in an oven at 95 degrees Celsius for 24 hours. After weighing, the sample is placed in a previously weighed penetrometer stem. The penetrometer is placed in a low pressure port on the porosimeter. The penetrometer is evacuated to 50 micrometers of mercury for a specified time period. Liquid mercury then automatically fills the penetrometer and surrounds the sample. The pressure placed on the mercury and sample is slowly increased to the crossover pressure (approximately 200 kPa). The computer controls the pressure steps and records the incremental intrusion. After completing this low pressure test, the penetrometer is removed, cleaned of any loose dirt, grease or mercury, and then weighed. The penetrometer is then placed into the high-pressure chamber and de-aired. The high-pressure test is started by increasing the pressure in a series of pre-defined steps up to 414 MPa (60,000 psi) and then decreasing it back down to 200 kPa (30 psi). The computer controls this operation, keeping track of the mercury intrusion at each pressure step. The computer calculates the pore size distribution, prints the data and also saves it to disk.

2.4 THROUGH-DIFFUSION CELL MEASUREMENTS OF DIFFUSIVITY AND ROCK CAPACITY

2.4.1 Definitions of Diffusion Coefficients

Diffusivity is a measure of the ability of a species to move through a medium under the influence of its concentration gradient. Diffusivity is quantified as a diffusion coefficient, D. Diffusivity can be measured under steady-state or transient conditions, and each has its advantages and area of applicability.

The processes of diffusion are described by Fick's first and second laws. In generalized situations, such as the conduction of heat in a solid, or the diffusion of species in a single phase medium such as water, Fick's first law states that the mass of a diffusing substance passing through a given cross section per unit time is proportional to the concentration gradient. In one dimension:

$$J = -D \cdot \frac{\partial C}{\partial x} \tag{4}$$

where

J is the mass flux, [mol/m^{2}sec],
D is the diffusion coefficient [m^2/s],
C is the species concentration [mol/m^3], and
$\partial C/\partial x$ is the concentration gradient;

Fick's second law is more general, and relates concentration with both space and time. In one dimension:

$$\frac{\partial C}{\partial t} = D \cdot \frac{\partial^2 C}{\partial x^2} \tag{5}$$

When evaluating diffusion through a fluid in a two phase system such as groundwater in a porous rock, it becomes necessary to modify Fick’s laws, to account for the fact that the water only occupies a fraction of the total volume occupied by the rock. The modification is applied by redefining the diffusion coefficient (D) to include factors such as the porosity and the pore geometry, which is defined by a combination of tortuosity and constrictivity.

The diffusion coefficients that are used in Eqs. 4 and 5 to describe diffusivity in heterogeneous media have been defined to account for various combinations of the effects of porosity, tortuosity and constrictivity. The type of diffusion coefficient used depends on the particular application.

Because species diffuse through water in pore spaces, all diffusion coefficients applied to heterogeneous media can be related to free water diffusion coefficients (D_w). Free water diffusion coefficients have been measured for numerous cations and ions. Values of free water diffusion coefficients vary between 1.03 x 10^{-9} and 9.59 x10^{-9} m^2/s (e.g., Harvey 1996).

For certain applications, diffusion may be considered as a function of species concentration only in pore water. For example, this may be useful if diffusion data is available in the form of a diffusion profile, which shows changes in a species pore water concentration as a function of distance (e.g., Gimmi and Waber 2004). Diffusion in pore water is commonly described with a pore water diffusion coefficient, which accounts for the effects of tortuosity (τ) and constrictivity (δ) within connected pore spaces. This type of diffusion coefficient may be used as one of the input parameters in certain computer models that have porosity and diffusion as separate input parameters. The pore water diffusion coefficient (D_p) is defined as follows (Ohlsson and Neretnieks 1995):

$$D_p = \frac{D_w \delta}{\tau^2} \tag{6}$$

Diffusion can also be treated by considering a volume of rock as a whole. In this case, the connected porosity must be included in the calculation of the diffusive flux to account for the small volume of connected pore space compared to the volume of the whole rock. The effective or empirical diffusion coefficient (D_e) is commonly used to describe diffusive fluxes. Some authors (Bradbury et al. 1982) have also referred to this as the intrinsic diffusion coefficient (D_i). The effective diffusion coefficient is defined as (Choi and Oscarson 1996, Skagius and Neretnieks 1982, and Ohlsson and Neretnieks 1995):

$$D_e = \frac{D_w \delta \varepsilon_t}{\tau^2} \tag{7}$$

The through-transport porosity (ε_t) determines the diffusive flux through rock when steady state has been achieved. However, the storage capacity of the rock must also be considered. The storage capacity results from the dead end porosity (ε_d), and sorption for those species which are likely to adsorb onto mineral surfaces. The storage capacity is quantified by the rock capacity factor (α), which has been defined as (Bradbury and Green 1985):

$$\alpha = \varepsilon_c + \rho \cdot k_d \tag{8}$$

where ρ is the bulk density of the rock, k_d is the sorption coefficient, and the total connected porosity (ε_c) is given by:

$$\varepsilon_c = \varepsilon_t + \varepsilon_d \tag{9}$$

The rock capacity term can be incorporated into Fick's second law to describe concentration variation with space and time within a rock.

$$\frac{\partial C}{\partial t} = \frac{D_e}{\alpha} \cdot \frac{\partial^2 c}{\partial x^2} \tag{10}$$

The apparent diffusion coefficient (D_a) has been defined as (Bradbury and Green 1985, Choi and Oscarson 1996, Oscarson and Hume 1994 and Ohlsson and Neretnieks 1995):

$$D_a = \frac{D_e}{\alpha} = \frac{D_p \varepsilon_t}{(\varepsilon_c + \rho k_d)} \tag{11}$$

In the case of a nonsorbing tracer, such as iodide, the rock capacity term (α) is equal to the total connected porosity (ε_c). If the transport porosity (ε_t) is the same as the ε_c, the apparent diffusion coefficient for the nonsorbing tracer will be the same as the pore water diffusion coefficient (D_p).

The constrictivity (δ) and tortuosity (τ) are difficult, if not impossible, to determine separately by experimental means. Because of the difficulty in separating δ and τ, the term 'tortuosity' is often found in experimental work to have been used to describe the quantity $\tau / \sqrt{\delta}$. Melnyk and Skeet (1987) and Katsube et al. (1986) referred to the quantity $\tau / \sqrt{\delta}$ as an 'effective tortuosity' and define it as:

$$\tau_D^2 = \frac{\tau^2}{\delta} \tag{12}$$

The effective tortuosity values can be calculated from measured values of effective diffusion coefficients and estimated values of transport porosity, using Eq. 7, and assuming that ε_t and ε_c are identical. Effective tortuosity values may vary depending upon the tracer because the porosity used for diffusion may vary from one tracer to another. The porosity value used in Eq. 7 could be derived from water immersion or from diffusion experiments. Unless stated otherwise, effective tortuosities in this report were calculated using either measured or average values of porosity estimated by water immersion.

In this report the convention for reporting effective tortuosity focuses on the increased path length a solute must diffuse. By this convention the diffusion coefficient is reduced by effective tortuosity values greater than one. In the other commonly used convention for reporting tortuosity, the focus is on reporting tortuosity as a value by which the diffusion coefficient is reduced. By this convention the combined effects of tortuosity and constrictivity are reported as values of δ/τ^2, with the diffusion coefficient being reduced by tortuosity values less than one.

2.4.2 Experimental Theory

In through-diffusion cell experiments, a rock sample is positioned between two solution reservoirs of equal hydraulic head. A concentration gradient is then established across the rock sample by addition of a tracer to one of the reservoirs. Once the system has reached a steady-state, the flux of tracer across the sample is measured and the effective diffusion coefficient of the tracer in the rock sample is determined. Vilks et al. (1999) have described a method used to estimate diffusion parameters from laboratory experiments on crystalline rocks, which is based on the work of Cramer et al. (1997), Bradbury et al. (1982), Wadden and Katsube (1982), Skagius and Neretnieks (1982), and Katsube et al. (1986). Following the initial breakthrough of tracer, the amount of tracer diffusing through the sample into the elution reservoir eventually reaches a steady-state, provided that the physical properties of the rock remain constant during the diffusion experiment (Figure 11). The mass of tracer (M_t) diffusing through the sample under steady-state conditions at time (t) is described by the following equation:

$$M_t = D_e(C_oA/L)\ t - \alpha(ALC_o/6) \quad (13)$$

where

D_e = effective diffusion coefficient for a given tracer in the rock sample,
A = surface area through which the tracer diffuses,
L = diffusion path length (i.e., thickness of rock sample),
C_o = concentration of a given tracer in the tracer reservoir, and
α = rock capacity factor

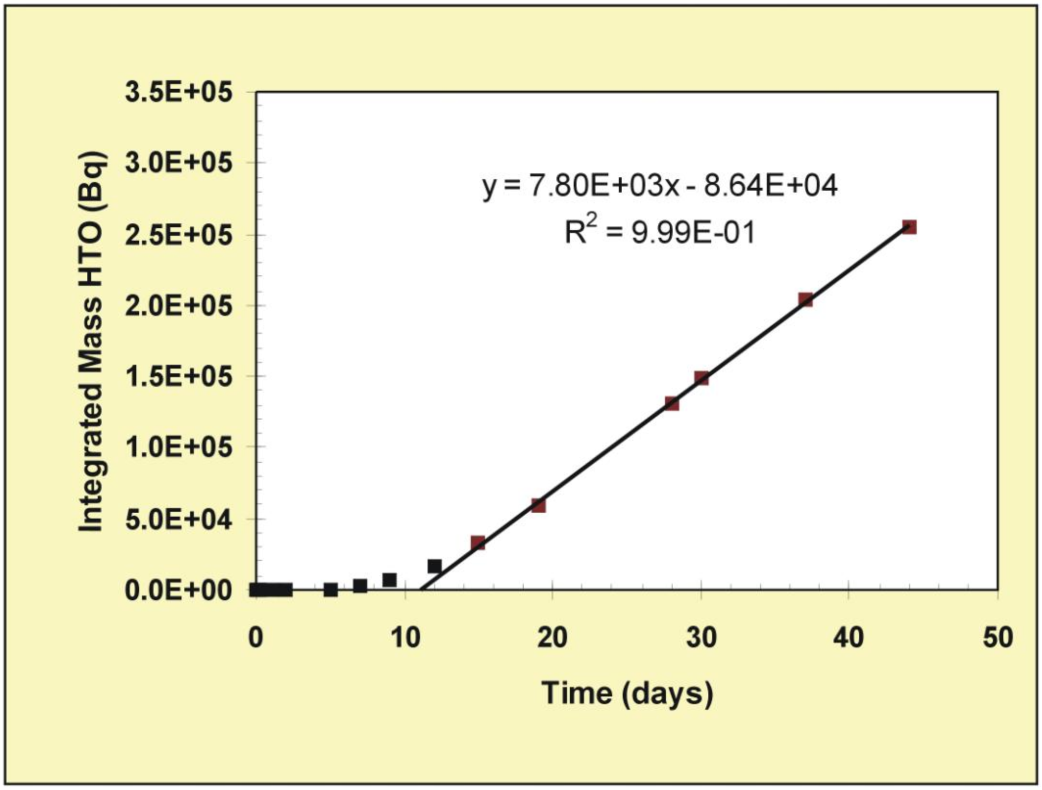

Figure 11: Example of Tracer Mass Diffusion in a Through-diffusion Experiment

When steady-state has been achieved a plot of M_t versus time will produce a straight line with a slope:

$$\text{Slope} = D_e(C_oA/L) \quad (14)$$

and an intercept:

$$\text{Intercept} = -\alpha(ALC_o/6) \quad (15)$$

Because C_o , A and L are known, the slope of the line can be used to calculate D_e. The intercept of the straight line can be used to calculate the dimensionless rock capacity factor (α), which represents the amount of tracer retained in the rock sample before steady-state is achieved. The magnitude of α depends upon the total connected porosity accessed by the tracer (ε_c) and on the amount of tracer that is adsorbed by the rock sample. Therefore, D_e and α are the basic parameters that can be estimated from through-diffusion data, without additional assumptions.

The error associated with estimated values of D_e is estimated from the uncertainty in the diffusive flux, which is obtained from the slope of the linear portion of the M_t versus time plot. This uncertainty is calculated from linear regression analysis. The error associated with values of rock capacity determined from diffusion experiments can also be estimated from the uncertainty of the intercept of the M_t versus time plots using linear regression analysis.

Through-diffusion type cells have been commonly used for crystalline rock samples, as well as for limestone and sandstone samples (Boving and Grathwohl 2001). If sample integrity is of concern, stainless steel filters may be used to separate the sample from the tracer and elution reservoirs. For example, these filters were employed for Oxfordian limestone and Callovo-Oxfordian argillite samples by Descostes et al. 2004, and for insuring the stability of compacted bentonite (Eriksen and Jansson 1996, Wold and Eriksen 2000). The diffusion and sorption properties of the stainless steel filters must be considered when interpreting the experimental results. If samples of compacted bentonite or shale, for example, are not fully saturated with water before being mounted in the diffusion cell, they may develop a swelling pressure upon saturation. Stainless steel diffusion cells have been designed to contain this swelling pressure (Sawatsky and Oscarson 1991, Choi et al. 1993). Diffusion cells used for natural clay samples have also been modified to allow for the application of a uniaxial stress to the clay sample by applying a known torque to the diffusion cell (Van Loon et al. 2003). Because through-diffusion experiments require long times to reach steady-state, it is advantageous to run several samples in parallel.

2.4.3 Through-diffusion Cell Experiments for Sedimentary Rocks

Laboratory diffusion experiments are performed using the diffusion cell schematically illustrated in Figure 12. The diffusion cell can hold a rock sample with diameter between 47 and 85 mm and a length of 5 to 60 mm. The sample is mounted within the diffusion cell sample holder using silicon cement (Figure 4 and Figure 13). In order to ensure that the sample is fully saturated before starting the diffusion experiment, the diffusion cell is filled with tracer-free eluant solution, which is allowed to penetrate the sample for several days. During this step the water level in the tracer reservoir is about 1 cm higher than in the elution reservoir to produce a hydraulic gradient to help force water into the sample. The diffusion experiment is initiated by replacing the tracer-free solution in the 1 L tracer reservoir with actual tracer and ensuring that the water level in the elution reservoir matches that in the tracer reservoir. Both reservoirs are open to atmospheric pressure. The elution reservoir is sampled to determine tracer diffusion through the rock sample. With each sampling, the volume of sampled solution is replaced by tracer-free eluant to maintain the height of solution in the elution reservoir at the same level as in the tracer reservoir. If tracer diffusion through the sample is very slow and the tracer concentration in the elution reservoir is less than 0.1 percent of that in the tracer reservoir, the elution reservoir is sampled on a periodic basis. However, if the diffusion process is likely to be faster, the elution reservoir is continuously sampled with a fraction collector to ensure that tracer concentrations in the elution reservoir do not become too high, thereby reducing the tracer concentration gradient across the sample. The tracer concentration in the elution reservoir is kept low because of the continuous flushing with tracer-free eluant. As tracers diffuse through the rock sample, eventually a steady-state diffusive flux across the sample is achieved. The data characterizing the evolution of tracer concentrations in the elution reservoir to a steady-state, are used to calculate the rock capacity factor and effective diffusion coefficient of the rock sample (Vilks et al. 2004).

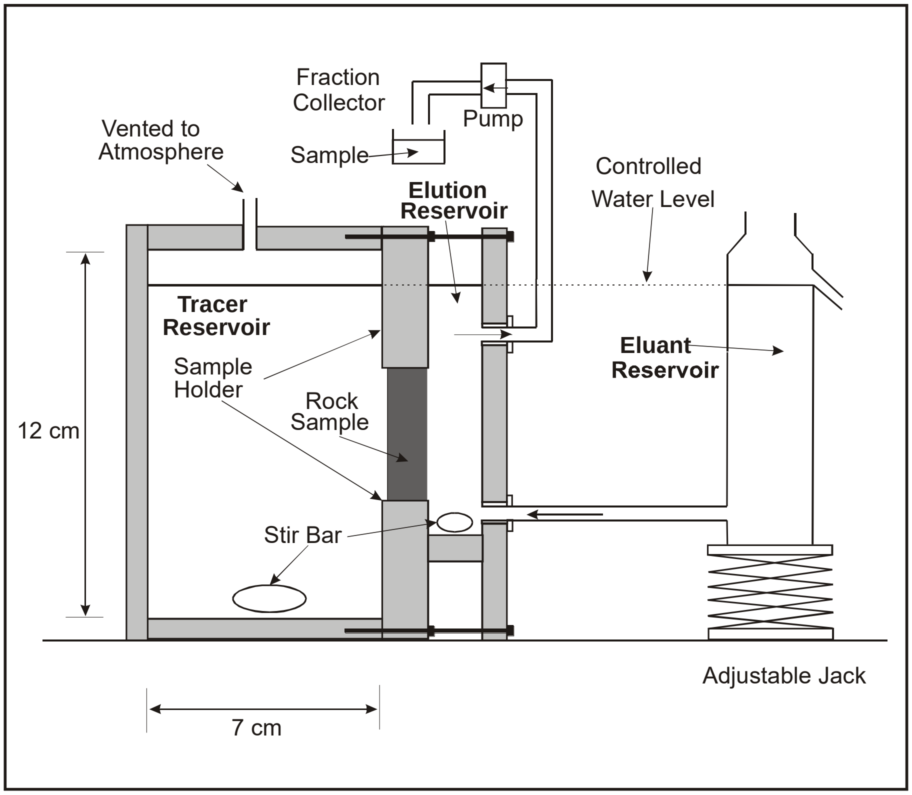

Figure 12: Schematic Diagram of a Laboratory Diffusion Cell

The conservative tracers used in these experiments are tritium to characterize diffusivity within all porosity accessible to water, and iodide to define diffusion in porosity readily accessible to anions. Uranine and Li are used as easily detectable, weakly sorbing tracers. As a result of the high clay content of the shales, significant retardation of uranine and Li in the shales is expected. The actual tracer solutions used in the initial experiments contained 9.1 g/L NaI, 6.9 g/L $LiNO_3$, 1.0 g/L uranine, and 1.3×10^8 Bq/L tritium. The eluant solutions contained 17.0 g/L of KNO_3 to closely match the ionic strength and density of the tracer solutions to minimize density gradients and osmotic effects.

A final set of diffusion experiments was performed using solutions formulated to more closely match pore water compositions in shales and limestone. An estimation of the pore water compositions has been made in this initial study using simple leaching experiments (see Section 2.7). The intent of using solutions that closely match pore fluids was to minimize changes to porosity resulting from water rock interactions, and to measure diffusion under conditions of high ionic strength closely matching in-situ conditions. The tracers used in these experiments were KI (166 g/L) and tritium (1.3×10^8 Bq/L). In addition to the iodide and tritium, the tracer solutions used for limestone contained 12 g/L NaCl, 11 g/L KCl, 33 g/L $CaCl_2$, and 17 g/L $MgCl_2$, while the tracer solution for shale contained 117 g/L NaCl and 7 g/L $CaSO_4$. The tracer solutions used in this experiment were identical to the compositions used by the University of New Brunswick to study iodide diffusion through identical shale and limestone samples to facilitate a comparison of the bulk rock diffusion properties determined in this experiment to those measured for similar core samples using a newly-developed X-ray Radiography method at the University of New Brunswick. The eluant used in these experiments contained NaCl with concentrations intended to match the TDS of eluant solutions used by the University of New Brunswick.

Figure 14 shows a series of diffusion cell experiments underway. The tubing attached to each tracer reservoir is connected to a flask open to the atmosphere. This arrangement prevents evaporative loss from the tracer reservoirs while ensuring that each tracer reservoir is subject to the same fluctuations in atmospheric pressure experienced by the elution reservoirs. Note that in this particular experimental configuration, the elution reservoirs are not being continuously sampled by a fraction collector.

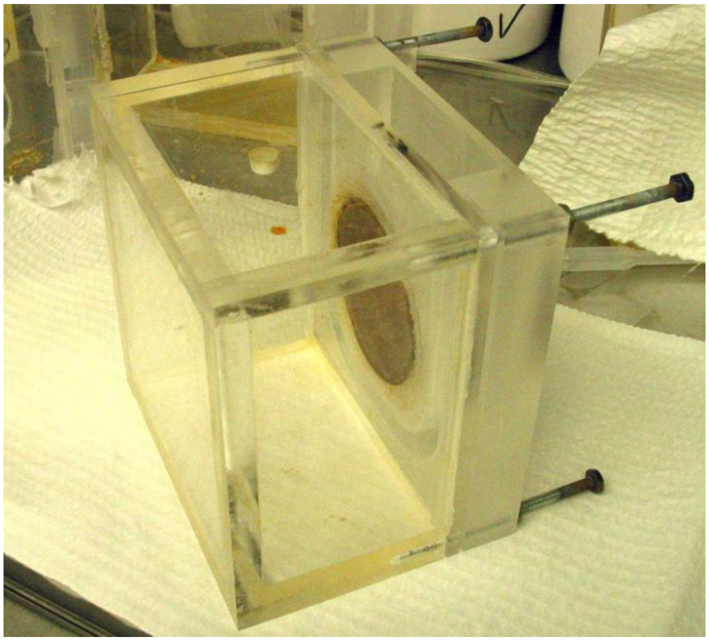

Figure 13: Diffusion Cell Loaded with Sample of Queenston Shale

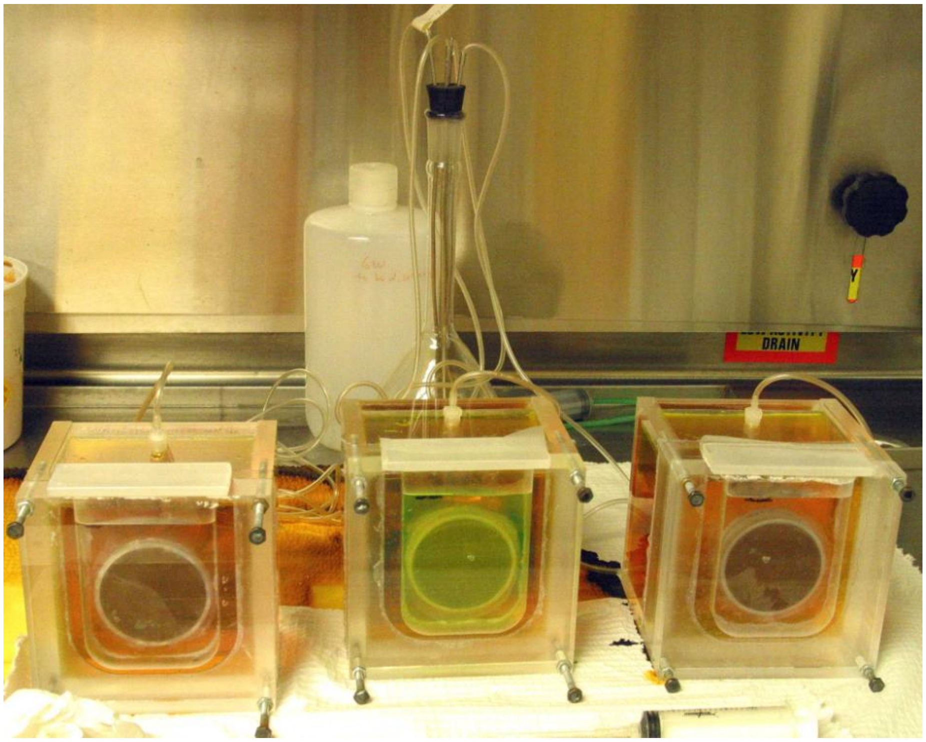

Figure 14: Three Diffusion Experiments in Progress

2.5 RADIAL DIFFUSION EXPERIMENTS

Radial diffusion experiments may be performed if core of suitable size is available. Radial diffusion experiments are conducted to test the effects of rock heterogeneity and its effect on REV. The samples used in radial diffusion experiments are larger than those in the standard diffusion cell experiments, allowing diffusion measurements over longer distances. In the radial experiments, the diffusive flux from the entire sample is used to determine an average effective diffusion coefficient that takes into account all of the sample heterogeneity. This value can be compared to effective diffusion coefficients estimated from diffusion profiles that sample specific sections of the rock sample, chosen to reflect sample variability. The diffusion profiles obtained from these controlled laboratory tests provide a useful comparison to element concentration gradients observed in nature, which have been attributed to natural diffusion processes (e.g. Gimmi and Waber 2004).

A radial diffusion experiment consists of a 150 mm long core with a 200 to 300 mm diameter. A 36 mm diameter hole is cut along the central axis of the core to serve as a tracer reservoir (Figure 15). A radial Plexiglas diffusion cell (Figure 15) is constructed to provide a several mm wide space around the outside of the core that would function as the elution reservoir. A Plexiglas plate is secured to the bottom of the core using silicon to seal the bottom of the tracer reservoir. Another Plexiglas plate is cemented to the top of the core to provide an additional barrier between the tracer and elution reservoirs. This plate has an opening in the middle to allow access to the tracer reservoir, and another opening at the edge to allow access to the elution reservoir. Once the core is placed into the diffusion cell, a lid is attached to the top of the cell to provide an airtight seal. This makes it possible to draw a vacuum inside the cell to help saturate the rock before the diffusion experiment. While the entire contents of the diffusion cell can be isolated from the atmosphere, the tops of the tracer and elution reservoirs are left open to the same atmosphere within the diffusion cell.

Once the rock core has been placed into the diffusion cells, the core is allowed to saturate with de-aerated water under a vacuum. Diffusion experiments are initiated by removing the filling solution from the tracer reservoir and replacing it with tracer solution. The levels of the tracer and elution reservoirs are carefully checked to make sure they are at the same hydraulic head. Periodically, the elution reservoir is sampled by removing 20 mL of solution, which is immediately replaced by 20 mL of tracer-free solution.

A radial diffusion experiment is terminated by removing the tracer and eluant solutions and then cutting small diameter cores (20 mm diameter) at right angles to the core axis. These cores are cut into 5 mm long pieces, which are leached in 10 mL volumes of deionized water for 30 days to estimate tracer concentrations. After converting the measured tracer concentrations to pore water concentrations (Vilks et al. 2004), the results are used to construct diffusion profiles.

Radial diffusion experiments were not performed with sedimentary rocks in this study because large diameter (200 to 300 mm) core was not available. However, the methodology is included here for completeness, as an additional experimental method which could be applied to determine the diffusive properties of sedimentary rocks.

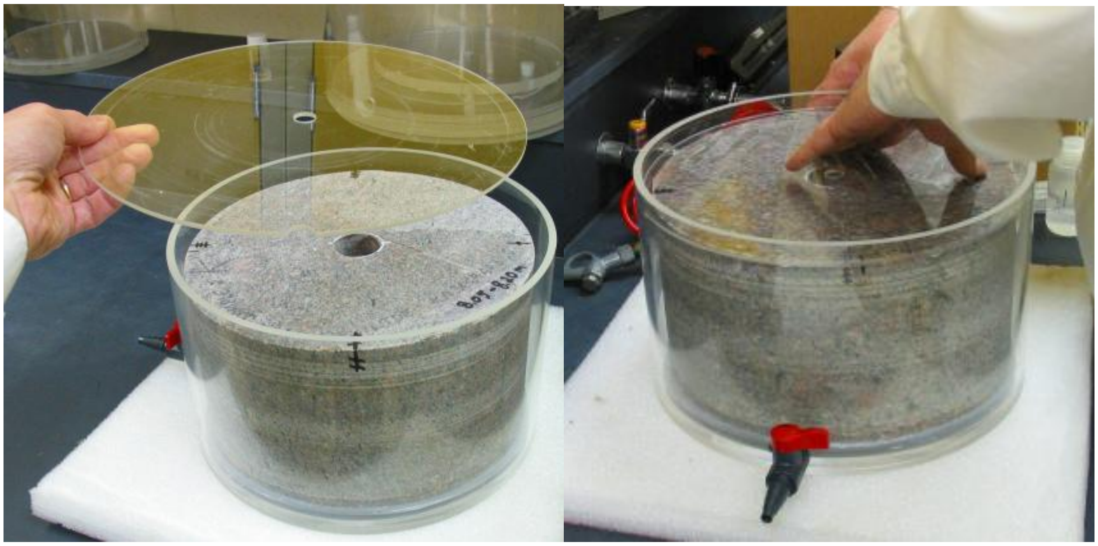

Figure 15: Installing a Radial Diffusion Experiment

2.6 PERMEABILITY ESTIMATION

Permeabilities of selected core samples are estimated at various confining pressures using the High Pressure Radioisotope Migration apparatus (HPRM), described by Drew and Vandergraaf 1989. The HPRM consists of a core holder assembly, which is placed in a pressure vessel that can be operated with a maximum pressure of about 20 MPa. Core samples, with lengths of 2.0 cm, are placed between two stainless steel cylinders (Figure 16), each containing a centre drilled hole. The core samples and stainless steel cylinders are coated with a pliable coating to isolate the circumference of the core from the water used as the pressure medium in the pressure vessel (Figure 17). Once the core and stainless steel cylinders are connected to the lines used to pass sample fluid through the core, the pressure vessel is assembled and partially filled with water. A confining pressure is applied to the pressure vessel, which subjects the core sample to a tri-axial pressure along its length and both ends. Water is then pumped through the core at a constant flow rate and the pressure differential between the inlet and outlet side of the core is measured. Provided that the inlet pressure is not allowed to exceed the confining pressure, water flow is always from one end of the core to the other end, following the interconnected pore spacings. The flow rate is determined by measuring the mass of water collected at the outlet over a given time interval. The HPRM equipment is illustrated in Figure 18.

The permeability of the core is given by

$$k = \frac{QL\mu}{A\Delta P} \tag{16}$$

where

k is the permeability in m^2,
Q is the volumetric flow rate in m^3/s,
L is the length of the core in m,
μ is the viscosity of the transport solution in $N{\cdot}s/m^2$,
A is the cross sectional area of the core in m^2, and
ΔP is the pressure differential between the inlet and outlet of the core in N/m^2;

Rock samples used for permeability estimation have a 25 mm diameter. These can be drilled from selected core samples using an orientation that is either parallel or perpendicular to the bedding planes.

In addition to sample dimensions, the parameters measured to calculate permeability consist of:

- The volumetric flow rate, Q, which is determined by collecting water for a measured time period. The volume of collected water is determined gravimetrically using a balance that is checked with weights that have their mass traceable to an ASTM Class 1 calibrated weight set.
- Pressure drop across sample, ΔP, is determined by a pressure transducer measuring the pressure of water being applied to one end of the sample. The pressure transducer is calibrated with a deadweight tester on a regular basis.

The error associated with a permeability measurement is the sum of errors from (1) the area of the sample cross section, (2) the sample length, (3) the pressure drop across the sample, and (4) the measured flow rate. The error attributed to the area of the cross section is about 1.6 percent. The error associated with sample length depends upon the total sample length, and varies between 4 and 5 percent for the samples used in this study. The error attributed to the pressure drop across the sample also depends on the magnitude of the pressure drop, typically varying between 1 and 20 percent. The error associated with the flow rate measurement is influenced by the total measured mass of fluid, as well as the time used to collect a given volume of fluid. Errors associated with flow rate measurements varied from 0.4 to 20 percent.

Figure 16: Rock Core Sample (shale) Enclosed by End Pieces to be Used in a Permeability Measurement

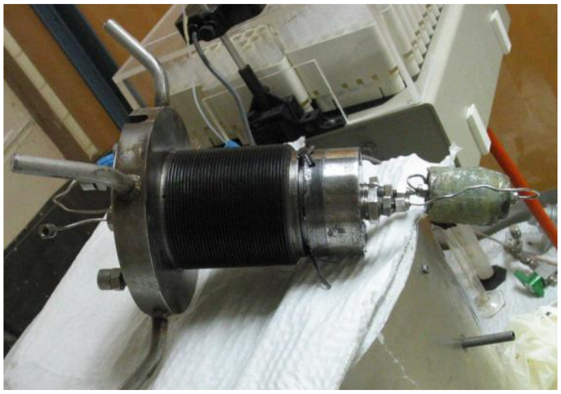

Figure 17: Rock Core Sample Coated with Silicon and Ready to be Loaded in Pressure Vessel for Permeability Measurement

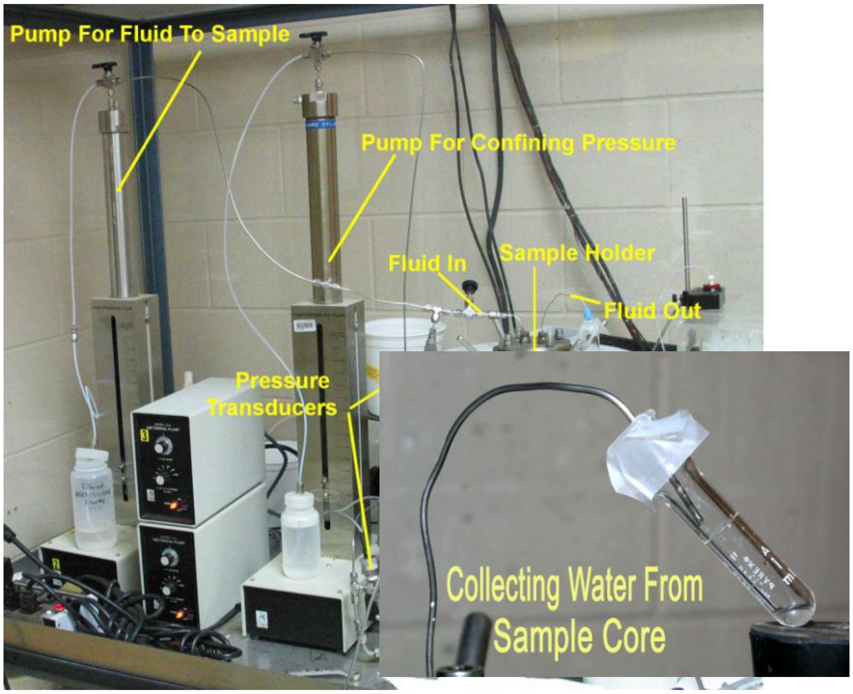

Figure 18: HPRM Facility for Measuring Permeability

2.7 ESTIMATION OF PORE FLUID COMPOSITION

An understanding of pore fluid chemistry in sedimentary rocks is important for formulating the composition of solutions used in laboratory diffusion experiments. The ionic strength of pore fluids will influence the porosity available for the diffusion of anions. In dilute waters the diffuse double layer around mineral surfaces will be relatively thick, and restrict the porosity available to the diffusion of iodide. In saline waters the double layer thickness will be significantly reduced, providing more porosity for anion diffusion (Appelo and Postma, 1994). To minimize any experimental artifacts due to differing ionic strengths between the tracer and effluent solutions and the pore water itself, the pH, the Eh and ion composition of solutions used in diffusion experiments can be designed to be as similar to the pore water composition as possible. This also minimizes water-rock interactions such as dissolution or precipitation reactions that could alter the porosity of the core sample during the course of the experiment Therefore, to obtain diffusion parameters that are relevant to in-situ conditions, synthetic porewaters can be used to match the chemical composition of the tracer and effluent solutions to in-situ pore water compositions as closely as possible.

Pore fluid compositions can be estimated by extracting pore fluids from rock samples or by assuming that groundwater collected from rock formations provides a reasonable approximation to pore fluid chemistry. However, this latter assumption may not be well founded, given that the rock matrix may have a very low permeability compared to water conducting fractures. Profiles of chloride and stable isotopes measured in pore waters across a low-permeability stratigraphic sequence have shown that these parameters vary across different formations (Gimmi and Waber 2004), and may not be the same as the waters sampled in boreholes from higher-permeability water-conducting features. An estimation of the in-situ pore water composition can be obtained using rock core from the formation of interest.

The extraction of pore fluids from low porosity rocks is not straightforward and may involve uncertainty associated with the understanding of rock matrix porosity and the possible sample penetration by drilling fluids. The major components of pore fluids will consist of soluble salts. A simple method of extracting these salts involves leaching small rock coupons in a known volume of deionized water for a period of about 30 days (Vilks et al. 1999).

The following method was tested with samples of Queenston shale, Whirlpool sandstone and Cobourg limestone, to estimate pore fluid compositions. These estimates can then be used to design synthetic pore waters for use in the diffusion experiments. Rock samples are first crushed into gravel-sized pieces. The intent is to facilitate the extraction of salts in connected pore spaces by increasing the sample surface area. However, the sample is not crushed to a fine powder to avoid breaking mineral grains and exposing fluid inclusions. The crushed rock is suspended in 20 to 25 mL of deionized water and stored in centrifuge tubes (Figure 19). The samples are periodically shaken to homogenize the leachate composition. The samples are allowed to leach for at least 30 days, after which they are centrifuged. The supernatant is then removed and analyzed for anions and cations. Blank solutions with deionized water and no rock sample are included to check for contamination. After the first leach, a second leach may be initiated by adding another 25 mL of deionized water and allowing the samples leach for another 30 days.

Figure 19: Shale Samples Being Leached to Determine Pore Fluid Composition

3. RESULTS

3.1 POROSITY

Porosity values estimated using the water immersion method are given in Table 2 for samples of Queenston shale. The parameters that appear in the left column are defined by Eqs. 1 to 3 in Section 2.2.2. The average shale porosity was 6.63 ± 0.48 percent.

Table 2: Porosity Values Derived from Queenston Shale

Depth (m)	**84.0**	**84.0**	**93.4**	**101.7**	**101.7**	**104.8**	**104.8**
W_D	14.3909	21.2236	18.1422	34.9703	29.1124	28.0417	25.6109
Ws	14.7257	21.7978	18.6365	35.8692	29.8948	28.7179	26.2070
Wvs	9.2717	13.6539	11.6537	22.5950	18.7964	17.8961	16.3976
Vs	5.4662	8.1621	6.9984	13.3038	11.1231	10.8460	9.8313
Vw	0.3355	0.5755	0.4954	0.9009	0.7841	0.6777	0.5974
Porosity	**0.061**	**0.071**	**0.071**	**0.068**	**0.070**	**0.062**	**0.061**

In contrast to Queenston shale, samples of Lindsay limestone displayed excellent stability and could be handled in the same way as samples of crystalline rock. In the interests of method development, limestone porosity was estimated by water immersion using both the original protocol used for crystalline rock (dry weight determined by vacuum drying) and the newer method modified for sedimentary rocks. Following the original protocol, samples of Cobourg limestone were dried under vacuum for over 30 days. Samples were periodically weighed to follow the drying process (Figure 20). Rapid water loss occurred within the first 6 days, followed by a period of slow drying. Although the drying curves appeared to level off after about 30 days, a prolonged drying period would probably have produced further weight loss. After the period of vacuum drying, the samples were placed in an oven to determine the oven-dried weight.

Porosity values estimated for Cobourg limestone are summarized in Table 3. Dry weights determined by oven drying were consistently lower by 0.2% than those measured by vacuum drying. Extending the vacuum drying times to several years would not significantly affect the outcome. The porosities determined by oven drying were about 30 percent higher than those estimated using vacuum drying. Assuming that oven drying produces a better estimate of dry weight, the estimated average porosity of Cobourg limestone was 1.71 ± 0.27 percent.

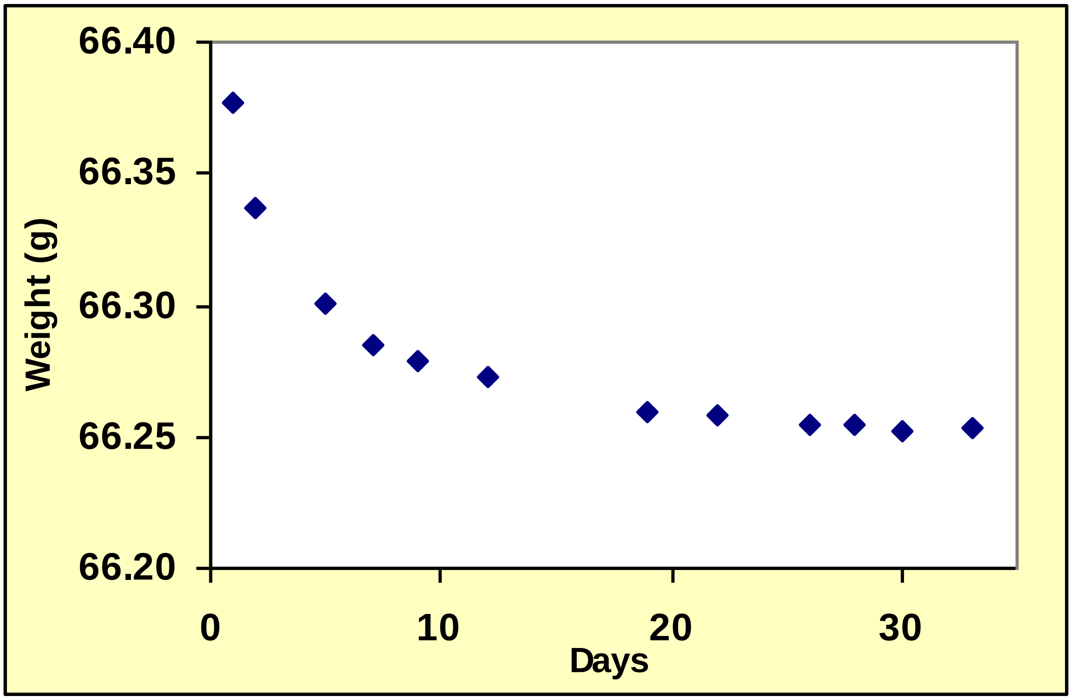

Figure 20: Example of Drying Curve (Core #4) to Determine the Dry Weight of Limestone Sample

Table 3: Porosity Values Derived for Cobourg Limestone

	Core #4	Core #9	Core #10	Rectangle
W_D (Vacuum Dry)	66.2529	56.7595	60.5911	71.4187
W_D (Oven Dry)	66.1451	56.6581	60.4513	71.2465
Ws	66.5106	56.9745	60.9055	71.7455
Wvs	41.8176	35.7976	38.2322	45.0774
Vs	24.7482	21.2242	22.7240	26.7277
Vw (Vacuum Dry)	0.2583	0.2155	0.3151	0.3276
Vw (Oven Dry)	0.3663	0.3171	0.4552	0.5002
Porosity (Vacuum Dry Wt)	**0.0104**	**0.0102**	**0.0139**	**0.0123**
Porosity (Oven Dry Wt)	**0.0148**	**0.0149**	**0.0200**	**0.0187**

3.2 MERCURY INTRUSION POROSIMETRY RESULTS

Typical pore size distributions determined by mercury intrusion porosimetry for Queenston shale and Cobourg limestone are illustrated in Figure 21. The plots clearly show that sandstone is dominated by large pore sizes, while shale and limestone have significantly smaller pores in the nanometer range. MIP data are summarized in Table 4 for shale, and in Table 5 for limestone. As indicated by the pore size distribution plots, the median pore diameter for shale and limestone are very small, ranging from 4.9 to 10 nm. The MIP porosity values for shale were a factor 1.6 to 2.2 lower than the porosities estimated by water immersion. The difference can likely be attributed to the inability of mercury to penetrate pore spaces smaller than 3 nm. The MIP porosity determined for Cobourg limestone is closer to that estimated by water immersion, being only a factor 1.2 to 1.7 lower. Interestingly, the MIP porosity values for limestone were in most cases higher than water immersion estimates if one were to use vacuum drying to determine the dry sample weight. This supports the conclusion that vacuum drying is not sufficient to determine a dry sample weight.

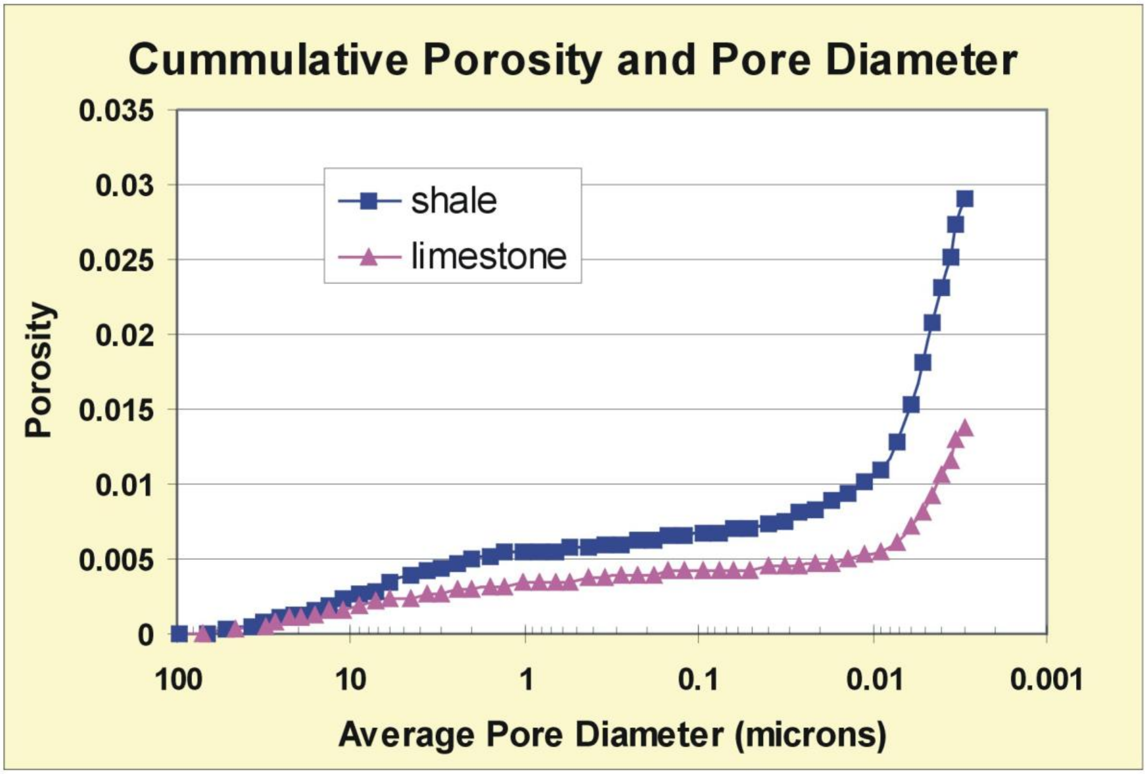

Figure 21: Typical Pore Size Distributions for Shale and Limestone

Table 4: MIP Data for Queenston Shale

Depth (m)	84.0	84.0	93.4	101.7	101.7	104.8	104.8
Rock Type	Shale	Shale	Shale	Shale	Shale	Shale	Shale
Median Pore Diameter (nm)	5.9	6.4	6.8	4.9	5.5	6.2	7.6
Bulk Density (g/mL)	2.6537	2.6148	2.6207	2.6334	2.6231	2.2354	2.6022
Porosity (%)	3.83	4.12	4.25	3.43	3.83	2.79	3.62
% of stem used	23	25	27	21	23	18	19

Table 5: MIP Data for Cobourg Limestone

	Core #4	Core #9	Core #10	Rectangle
Median Pore Diameter (nm)	7.5	7.1	10	6.3
Bulk Density (g/mL)	2.6532	2.6431	2.6461	2.6399
Porosity (%)	1.22	1.23	1.19	1.38
% of stem used	6	8	7	9

3.3 THROUGH-DIFFUSION CELL MEASUREMENTS

3.3.1 Effect of Sample Thickness

The thickness of core samples used in diffusion experiments can be varied in order to optimize experimental times, while obtaining data that are statistically meaningful and capture the Representative Elementary Volume (REV). The REV is the minimum sample volume that captures all of the physical features of the rock that determine the rock parameter being estimated. Figure 22 illustrates iodide mass diffusion plots for sample of Queenston shale with thicknesses of 5 mm, 10 mm, and 30 mm. An experiment was performed with a sample with a 20 mm thickness, but unfortunately it was unusable for this comparison because the diffusion results indicated the presence of a fracture. The time required to reach steady-state diffusion progressively increases with increased sample thickness. While an experiment with a 5 mm sample could be completed in about 15 to 20 days, 60 to 90 days were required to reach steady-state in an experiment with a 30 mm sample. Experimental times for a weakly sorbing tracer, such as uranine, would be about a factor of 3 longer. A comparison of diffusion parameters determined with samples of Queenston shale having different thicknesses (identified as REV) is given in the bottom part of Table 7 (in Section 3.3.3). Effective diffusion coefficients determined with 10 mm samples were about 3 to 15 percent lower than those obtained with 5 mm samples. If the experiment with the 30 cm sample thickness had been given more time to reach steady-state, it would have produced similar results to the 10 mm sample. A sample thickness of 10 mm is the most common thickness reported in the literature for use in diffusion studies of shales. Because the results suggest that an experimental thickness of 10 mm is sufficient to capture the REV, the standard sample thickness for use in diffusion experiments with shale samples was set to 10 mm.

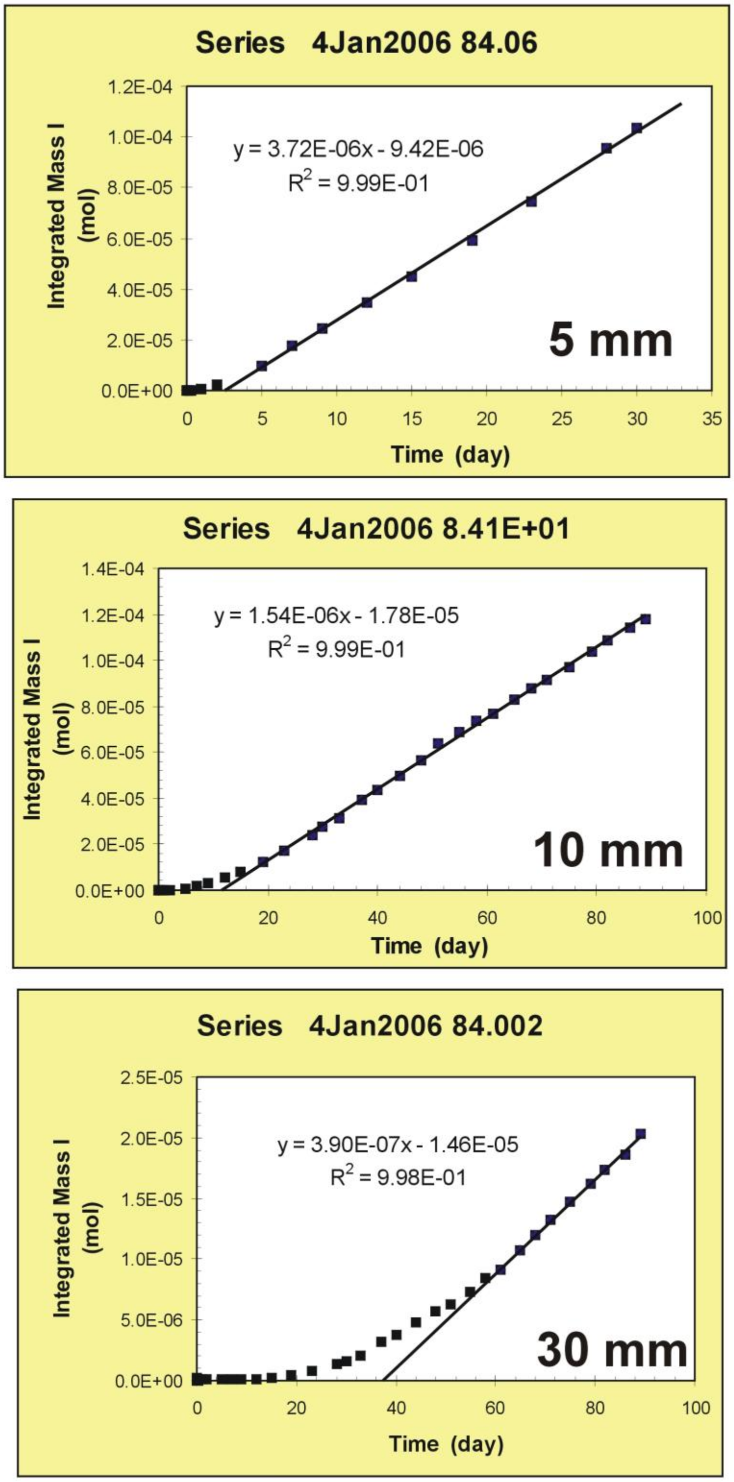

Figure 22: Iodide Mass Diffusion Plots for Samples of Queenston Shale with Thicknesses of 5, 10, and 30 mm

The effect of sample thickness on diffusion parameters estimated for limestone can be seen in the bottom part of Table 8 (in Section 3.3.3), with samples designated as REV. As for the shale samples, experimental times of 10 to 25 days were adequate for samples with a thickness of 10 mm. Significantly longer experimental times (40 to 100 days) were required for samples with thickness' of 20 and 30 mm. Iodide and tritium diffusion coefficients were observed to decrease with increasing sample thickness. The iodide effective diffusion coefficient decreased by 15 percent as the sample thickness was increased from 6 mm to 10 mm, and decreased a further 16 percent as sample thickness was increased to 20 mm. The 20 mm and 30 mm samples produced identical iodide effective diffusion coefficients. Although the tritium effective diffusion coefficient decreased by 19 percent as sample thickness was increased to 10 mm, the effective diffusion coefficients were not significantly different in the samples with thicknesses of 10 mm to 30 mm. A standard sample thickness of 10 mm was used for estimating diffusion parameters for Cobourg limestone, to be consistent with measurements made with shale samples and because the diffusion results did not show a significant reduction in the tritium diffusion coefficients in samples thicker than 10 mm.

3.3.2 Stability of Shale Samples

During sampling of the core, the Queenston shale was found to be a stable, relatively hard material. Striking the core with a hammer caused it to break along planes that were roughly perpendicular to the core axis. However, when core slices up to several cm in thickness were immersed in water, it was found that the core began to break up within several hours, depending upon the salt content of the water. The break-up pattern (Figure 23) did not appear to follow bedding planes, and instead followed irregular features that appear similar to a blocky, quasi-nodular structure that can be seen in cores. The origins of this structure might be related to a combination of processes that could include particulate transport, local intense mudcracking and early diagenetic processes (Brogly et al., 1998). After prolonged contact (weeks) with water, the broken pieces of shale remained intact, without further disintegration. This suggests that the alteration process only occurred along the aforementioned features, with little or no penetration of the shale matrix.

Figure 23: Core Slice of Queenston Shale Immersed in 170 g/L KNO_3 Showing a Parting Pattern Typical of Unconfined Samples Immersed in Water

As mentioned previously, this sample instability has been accounted for in the revised procedure used to estimate rock porosity. Although it was anticipated that sample instability could pose a problem for diffusion experiments, shale samples mounted in sample holders (Figure 4 and Figure 13) appeared to remain stable when contacted with tracers and eluant solution. Because the shale samples in the diffusion cells were exposed to 17 g/L KNO_3 solutions, it was initially believed that the higher salinity of these solutions (compared to deionized water) may have played a role in stabilizing the shale samples. However, when unconfined samples were placed in 17 g/L and even 170 g/L (Figure 23) solutions, they still disintegrated. The only difference with deionized water was that the presence of salt slowed the disintegration rate slightly.

In most cases, any changes in the shale samples were not significant enough to produce changes in diffusion rates for time periods up to 90 days, as illustrated in Figure 22. If sample disintegration had begun some time during the diffusion test, one would expect to observe an increase in the slope of the mass flux. Although sample disintegration was not observed, changes in sample properties did occur in some cases. For example, Figure 24 shows that iodide diffusion reached a steady state after about 30 days. However, some time after 50 days, there was a change in sample properties resulting in a reduced diffusive flux. This sort of effect has been observed in altered crystalline rock and may be attributable to changes in pore geometry caused by clay swelling or other mineral alteration. In sedimentary rocks, it might be expected that sample alteration due to the dissolution or precipitation of salts may be more frequently observed in diffusion experiments. The impact of these effects could be minimized by (1) designing experiments with shorter diffusion times, (2) matching the composition of experimental solutions with actual pore fluid compositions as closely as possible, and (3) ensuring that the number of experiments that are initiated is large enough to allow for the failure of some tests.

When a shale sample is loaded into a diffusion cell, the zones of weakness observed in Figure 23 are not visible upon close inspection. However, once the diffusion experiment is initiated, the presence of a fracture or a parting plane may become evident very quickly, and observed as a rapid tracer breakthrough and resulting diffusion coefficients and rock capacity values that are significantly higher than measured for similar samples. Such experiments could be terminated and restarted with fresh samples. On the other hand, diffusion coefficients determined from samples containing fractures could be used to place an upper bound on the range of De values in sedimentary rocks. Figure 24 and Figure 25 illustrate an example of iodide and tritium diffusion in a “defective” sample that contained a fast flow path. Although shortly after being initiated it was suspected that this sample contained a fast transport path, the experiment was maintained to document the effects of a “defective sample”. Interestingly, after 50 days the fast transport path appears to have become obstructed and the resulting decrease in diffusion produced iodide and tritium De values that are similar to samples without fractures.

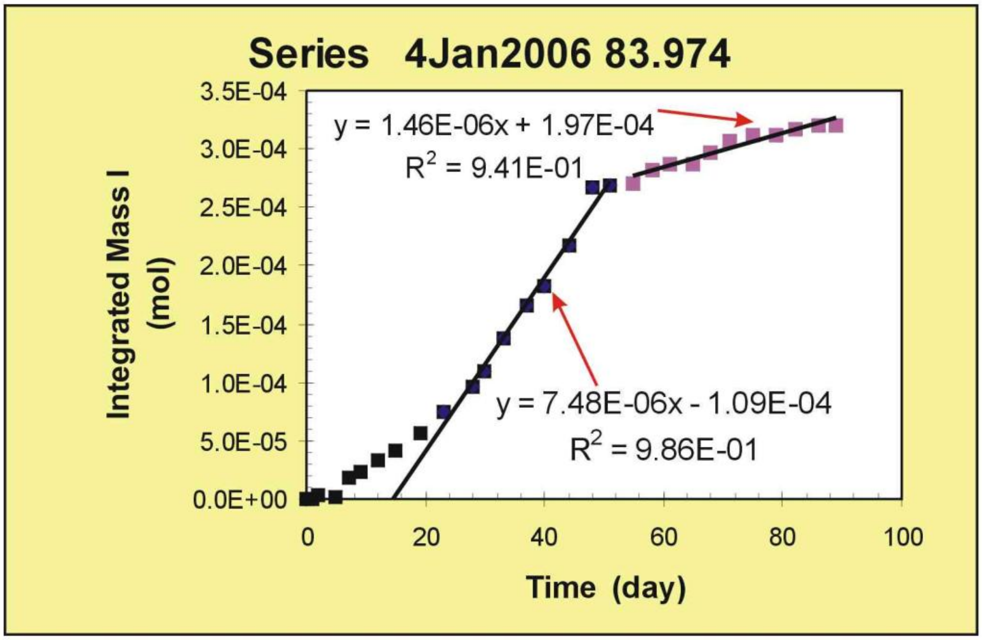

Figure 24: Iodide Diffusion in a Shale Sample (REV 20 mm) Containing a Zone of Fast Transport

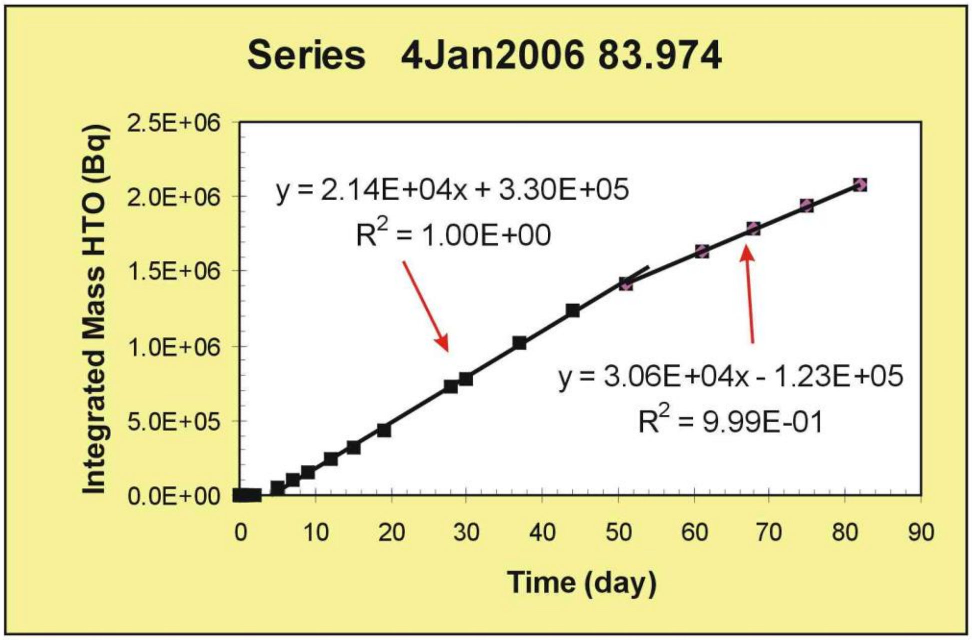

Figure 25: Tritium Diffusion in a Shale Sample (REV 20 mm) Containing a Zone of Fast Transport

3.3.3 Effective Diffusion Coefficients for Shales and Limestone

A total of 24 diffusion cell experiments were performed to characterize diffusion parameters in shales and limestones, as summarized in Table 6. With the exception of samples used to check REV, the standard sample thickness used in diffusion experiments was 10 mm (Section 3.3.1). With the Queenston shale, samples were selected from a range of depths to examine whether sample depth has any effect on estimated diffusion coefficients. Most samples were core slices and therefore were used to estimate diffusion perpendicular to bedding planes. Two shale samples were cut as slabs parallel to the core axis, with the intention of measuring diffusion parallel to bedding. This cutting operation was performed dry, without using water or any other coolant in order to prevent sample spalling as a result of rewetting. The choice of samples of Cobourg limestone followed a similar approach. Finally, two shale and two limestone samples were used to evaluate the effect of pore water composition on estimated diffusion coefficients.

Table 6: Sample Matrix for Diffusion Cell Experiments

Formation	Comment	No. of Samples
Queenston Sh.	78 m depth:	2
	84 m depth: check REV	4
	105 m depth:	2
	87 m depth: diffusion parallel to bedding	1
	96 m depth: diffusion parallel to bedding	1
	88.5 m depth: synthetic pore water	2
Cobourg Limestone	36.5 m depth:	3
	36.5 m depth: check diffusion parallel to bedding	1
	43.8 m depth:	1
	43.8 m depth: check diffusion parallel to bedding	1
	55.7 m depth: check REV	4
	55.9 m depth: synthetic pore water	2

The results of iodide and tritium diffusion experiments are summarized in Table 7 for Queenston shale and Table 8 for Cobourg limestone. Effective tortuosity values were calculated using Eq. (7) and porosity values estimated by water immersion.

In Queenston shale samples there appears to be a 30% decrease in iodide and tritium diffusion coefficients with increasing sample depth from 85 to 105m, which may suggest that greater burial depth has reduced the diffusive properties of shale. In the limestone samples, the iodide and tritium diffusion coefficients were higher by a factor 2.6 to 2.9 in samples taken from greater depths. However, the number of measurements was insufficient to conclude whether this variation can be attributed to slight changes in lithology or to the effects of burial depth.

Table 7: Iodide and Tritium Diffusion Parameters for Queenston Shale

Sample	Iodide D_e (m^2/s)	% I Rock Cap.	I τ_D	Tritium D_e (m^2/s)	% HTO Rock Cap.	HTO τ_D
RESULTS USING SOLUTIONS WITH TDS OF 17 g/L						
78 m	(1.26±0.03) X 10^{-12}	4.1±0.2	12	(1.0±0.2) X 10^{-11}	13±9	9.2
78 m	(1.66±0.03) X 10^{-12}	4.5±0.2	11	(1.3±0.2) X 10^{-11}	17±9	8.4
84 m	(1.04±0.01) X 10^{-12}	4.9±0.2	11	(1.12±0.02) X 10^{-11}	6±2	7.6
105 m	(8.7±0.2) X 10^{-13}	2.9±0.1	10	(7.3±1.2) X 10^{-12}	9±6	7.8
105 m	(1.12±0.02) X 10^{-12}	3.4±0.1	8.9	(8.9±1.3) X 10^{-12}	9±8	7.1
87 ‖ bed	(1.6±0.2) X 10^{-12}	2.43±0.01	9.2	(1.5±0.6) X 10^{-11}	8.9±0.2	6.4
96 ‖ bed	(9.4±0.5) X 10^{-13}	2.44±0.05	12	(1.28±0.04) X 10^{-11}	4.6±0.7	7.0
with fracture	(9.0±0.4) X 10^{-12}	19±2	3.8	(1.81±0.02) X 10^{-11}	9.3±0.8	5.9
REV 5 mm	(1.23±0.02) X 10^{-12}	5.9±0.6	11	(1.25±0.02) X 10^{-11}	9±4	7.2
REV 10 mm	(1.04±0.01) X 10^{-12}	4.9±0.2	11	(1.2±0.2) X 10^{-11}	9±3	7.1
REV 30 mm	(7.5±0.1) X 10^{-13}	1.52±0.04	14	(9.02±0.02) X 10^{-12}	6.4±0.3	8.3
RESULTS USING SOLUTIONS WITH TDS OF 290 g/L						
88.5 m	(2.44±0.06) X 10^{-12}	3.6±0.6	7.4	(1.86±0.02) X 10^{-11}	9.6±0.3	5.9
88.5 m	(2.55±0.04) X 10^{-12}	3.1±0.4	7.3	(1.90±0.02) X 10^{-11}	10.7±0.2	5.8

The respective average values of iodide and tritium effective diffusion coefficients for shale samples measured perpendicular to bedding were (1.2 ± 0.3) x 10^{-12} and (1.0 ± 0.2) x 10^{-11} m^2/s. Diffusion coefficient values measured parallel to bedding in shales for iodide and tritium were (1.3 ± 0.5) x 10^{-12} and (1.4 ± 0.2) x 10^{-11} m^2/s, respectively. These values were not significantly different from those measured perpendicular to bedding, indicating that diffusion in Queenston shales is isotropic. In the limestone, the respective average diffusion coefficients for iodide and tritium measured perpendicular to bedding were (2.5 ± 1.5) x 10^{-13} and (2.2 ± 1.5) x 10^{-12} m^2/s, while those measured parallel to bedding were (3.4 ± 4.4) x 10^{-12} and (8.4 ± 8.5) x 10^{-11} m^2/s for iodide and tritium respectively. It should be noted that only two samples were used for estimating diffusion parallel to bedding, and that the difference in diffusion coefficient values between these two samples was about an order of magnitude. This indicates that diffusivity parallel to bedding in Cobourg limestone could be highly variable, and on average could be over an order of magnitude higher than perpendicular to bedding. A larger number of measurements would be required to verify these initial findings.

Table 8: Iodide and Tritium Diffusion Parameters for Cobourg Limestone

Sample	Iodide De (m²/s)	% I Rock Cap.	I τ_D	Tritium De (m²/s)	% HTO Rock Cap.	HTO τ_D
RESULTS USING SOLUTIONS WITH TDS OF 17 g/L						
36.6 m	(2.04±0.07) X 10^{-13}	1.21±0.05	12	(1.6±0.1) X 10^{-12}	2.4±2.1	9.5
36.4 m	(1.60±0.02) X 10^{-13}	0.53±0.02	14	(1.2±0.1) X 10^{-12}	0.4±1.6	11
36.5 m	(9.5±0.3) X 10^{-14}	0.44±0.02	21	(5.7±0.1) X 10^{-13}	1.3±0.6	18
43.8 m	(4.20±0.05) X 10^{-13}	1.40±0.01	9.2	(4.2±0.2) X 10^{-12}	3.5±0.3	6.2
55.7 m	(3.81±0.04) X 10^{-13}	1.11±0.02	9.4	(3.2±0.3) X 10^{-12}	1.5±0.5	7.0
36.5 ∥ bed	(2.75±0.07) X 10^{-13}	1.52±0.03	12	(2.4±0.3) X 10^{-12}	2.4±1.3	8.6
43.8 ∥ bed	(7±4) X 10^{-12}	9.7±0.7	2.3	(1.4±0.3) X 10^{-11}	7±3	3.4
REV 6 mm	(4.46±0.07) X 10^{-13}	2.11±0.03	8.7	(4.0±0.9) X 10^{-12}	2.5±1.2	6.3
REV 10 mm	(3.81±0.04) X 10^{-13}	1.11±0.02	9.4	(3.2±0.3) X 10^{-12}	1.5±0.5	7.0
REV 20 mm	(3.19±0.07) X 10^{-13}	0.98±0.01	10	(3.1±0.2) X 10^{-12}	3.4±0.1	7.2
REV 30 mm	(3.18±0.02) X 10^{-13}	1.03±0.01	10	(2.7±0.1) X 10^{-12}	4.9±0.3	7.6
RESULTS USING SOLUTIONS WITH TDS OF 239 g/L						
55.9 m	(1.37±0.02) X 10^{-12}	3.0±0.2	5.0	(7.81±0.35) X 10^{-12}	6.8±4.6	4.7
55.9 m	(6.16±0.09) X 10^{-13}	1.3±0.1	7.5	(3.96±0.01) X 10^{-12}	3.8±1.3	6.4

The effect of pore water chemistry on diffusion measurements can be assessed by comparing diffusion parameters determined with synthetic pore water with measurements made on 10 mm samples using 17 g/L solutions. Since the diffusion coefficients measured with synthetic pore water represent diffusion perpendicular to bedding, a comparison with measurements using the 17 g/L solutions should focus on average values of measurements made perpendicular to bedding. This distinction does not make much difference for shales, but is important for limestone. In the experiments using the synthetic pore water (bottom sections of Tables 7 and 8) the average iodide and tritium De values were a factor 1.9 higher in Queenston shale. In limestone the experiments with synthetic pore water had average iodide and tritium De values that were higher by factors of 4 and 2.7, respectively. The rock capacities determined by diffusion experiments provide a measure of the porosity used by the tracers for diffusion. The iodide and tritium rock capacities in shale were not significantly different when using synthetic pore water. However, in limestone the iodide and tritium rock capacities determined with synthetic pore water were on average a factor 2.3 higher, although the difference was almost within the error of the average values.

3.4 PERMEABILITY

Samples used for permeability estimation were selected to avoid visible fractures. Therefore, the reported values represent the permeability of the rock matrix, and are likely to be lower than values estimated from borehole intervals, which may contain water-conducting features. In addition to the previously described archived core samples, permeability measurements were also performed on a recently drilled sample of Queenston shale from the Bruce Nuclear site, near Kincardine, Ontario. This sample (DGR1-459.27) was supplied by INTERA Engineering Ltd. (Ottawa, Ontario), and was shipped wrapped in plastic to preserve the pore water content.

Results of permeability measurements at different confining pressures are provided in Table 9 and Table 10. For each measurement, the tables provide values for the pressure drop across the sample, ΔP, and the flow rate measured from the water that had passed through the sample. The parameters given in the table can be used to calculate the permeability using Eq. 16.

Table 9 and Figure 26 (A) show that estimated permeability values decrease by a factor 3 to 5 as the confining pressure is increased from 4 to 15 MPa. Depending upon burial depth and hydraulic pressures, the permeability values estimated at the higher confining pressures may be more representative of in-situ conditions. When samples are removed from depth, stress relief and possible damage during drilling may increase porosity, resulting in higher permeability values estimated with rock samples in the laboratory. The observed changes in permeability with increasing confining pressure provide a measure of rock alteration as a result of stress relief. In comparison, samples of granite from the Underground Laboratory in Manitoba (Vilks et al. 2004) showed a permeability decrease of one order of magnitude as confining pressure was increased to about 15 MPa. These granite samples had been significantly altered as a result of removal from in-situ conditions of high stress (maximum stress ranging from 30 to 60 MPa). Table 10 and Figure 26 (B) illustrate the variability in permeability values of fresh Queenston shale from the Bruce Nuclear site as a function of confining pressure. The increase in confining pressure to 15 MPa reduced the measured permeability by a factor of 26.

Average permeability values in the archived samples, taken over all confining pressures, were $(8.1 \pm 6) \times 10^{-21}$ m^2 for Queenston shale perpendicular to bedding, $(1.6 \pm 0.7) \times 10^{-21}$ m^2 for Queenston shale parallel to bedding, $(1.9 \pm 1.2) \times 10^{-22}$ m^2 for Cobourg limestone perpendicular to bedding, and $(1.1 \pm 0.7) \times 10^{-21}$ m^2 for Cobourg limestone parallel to bedding. It is interesting to note that the permeability of Queenston shale perpendicular to bedding was on average a factor 4 higher than parallel to bedding. Normally one would expect that there would be better flow parallel to bedding planes. However, the Queenston formation contains irregular parting planes that cross cut bedding and may be related to digenetic processes (Figure 23). For example, the Queenston formation contains gypsum as thin laminae, which can either lie parallel to or cut across bedding planes (Brogly et al. 1998). These parting planes are likely to increase permeability perpendicular to bedding, particularly in core samples used in laboratory measurements. In contrast, the Cobourg limestone samples displayed a permeability perpendicular to bedding that was almost an order of magnitude lower than parallel to bedding. The permeability of Cobourg limestone is lower than that of Queenston shale, which is consistent with the lower porosity of the limestone samples, and the lack of observable fracturing. The fresh samples of Queenston shale had average permeabilities of $(5.5 \pm 6.1) \times 10^{-20}$ m^2 perpendicular to bedding and $(7.2 \pm 9.7) \times 10^{-21}$ m^2 parallel to bedding.

Table 9: Permeability Measurements of Archived Core Samples

Sample	Surface Area (cm^2)	Core Length (cm)	Confining Pressure (MPa)	ΔP (MPa)	Flow Rate (m^3/s)	Permeability (m^2)
Queenston 101.6 m, ⊥ bedding	4.91	1.00	4.5	3.2	3.0×10^{-12}	$(2.2\pm0.2) \times 10^{-20}$
			4.5	3.4	1.2×10^{-12}	$(8.3\pm1.0) \times 10^{-21}$
			6.7	3.0	2.1×10^{-12}	$(1.6\pm0.1) \times 10^{-20}$
			9.1	3.2	8.7×10^{-13}	$(6.2\pm0.5) \times 10^{-21}$
			9.2	3.3	6.1×10^{-13}	$(4.2\pm0.4) \times 10^{-21}$
			10.5	4.3	9.4×10^{-13}	$(5.0\pm0.3) \times 10^{-21}$
			11.5	4.4	8.0×10^{-13}	$(4.2\pm0.3) \times 10^{-21}$
			12.1	4.7	1.1×10^{-12}	$(5.1\pm0.4) \times 10^{-21}$
			14.9	4.8	1.6×10^{-12}	$(7.5\pm0.9) \times 10^{-21}$
			14.9	5.6	7.2×10^{-13}	$(2.9\pm0.2) \times 10^{-21}$
Queenston 80.4 m, ∥ bedding	4.91	1.20	4.10	2.70	2.2×10^{-13}	$(2.2\pm0.2) \times 10^{-21}$
			4.00	2.55	2.1×10^{-13}	$(2.3\pm0.2) \times 10^{-21}$
			6.70	2.50	2.0×10^{-13}	$(2.2\pm0.2) \times 10^{-21}$
			6.80	2.40	1.6×10^{-13}	$(1.8\pm0.1) \times 10^{-21}$
			11.00	2.70	2.2×10^{-13}	$(2.2\pm0.2) \times 10^{-21}$
			11.20	3.50	2.0×10^{-13}	$(1.6\pm0.1) \times 10^{-21}$
			14.20	3.90	1.1×10^{-13}	$(7.6\pm0.9) \times 10^{-22}$
			14.20	4.80	2.5×10^{-13}	$(1.5\pm0.1) \times 10^{-21}$
			14.20	5.40	1.2×10^{-13}	$(6.1\pm0.7) \times 10^{-22}$
			14.80	6.90	1.5×10^{-13}	$(5.8\pm0.3) \times 10^{-22}$
Cobourg ⊥ bedding	4.91	1.50	4.70	3.60	3.7×10^{-14}	$(3.5\pm0.3) \times 10^{-22}$
			4.49	3.70	2.3×10^{-16}	$< 10^{-22}$
			8.10	7.00	1.5×10^{-15}	$< 10^{-22}$
			9.50	9.00	5.2×10^{-14}	$(2.0\pm0.2) \times 10^{-22}$
Cobourg ∥ bedding	4.91	1.50	5.10	3.40	1.8×10^{-13}	$(1.8\pm0.1) \times 10^{-21}$
			5.10	3.40	1.3×10^{-13}	$(1.4\pm0.1) \times 10^{-21}$
			5.10	3.50	1.5×10^{-13}	$(1.5\pm0.1) \times 10^{-21}$
			7.90	3.65	1.9×10^{-13}	$(1.8\pm0.2) \times 10^{-21}$
			8.50	3.70	2.3×10^{-13}	$(2.1\pm0.1) \times 10^{-21}$
			9.00	3.80	9.0×10^{-14}	$(8.2\pm1.4) \times 10^{-22}$
			8.80	3.80	2.4×10^{-13}	$(2.2\pm0.1) \times 10^{-21}$
			13.50	3.85	4.3×10^{-14}	$(3.8\pm0.8) \times 10^{-22}$
			13.50	3.85	1.3×10^{-13}	$(1.2\pm0.1) \times 10^{-21}$
			13.80	3.80	4.4×10^{-14}	$(4.0\pm0.8) \times 10^{-22}$
			12.65	3.70	1.9×10^{-13}	$(1.7\pm0.1) \times 10^{-21}$
			14.60	3.80	8.4×10^{-14}	$(7.6\pm1.0) \times 10^{-22}$
			14.80	4.20	1.5×10^{-14}	$(1.2\pm0.9) \times 10^{-22}$
			14.80	4.15	5.9×10^{-14}	$(4.9\pm0.5) \times 10^{-22}$
			15.00	9.90	2.6×10^{-13}	$(9.0\pm0.6) \times 10^{-22}$
			14.80	9.60	1.8×10^{-13}	$(6.4\pm0.3) \times 10^{-22}$

Table 10: Permeability Measurements of Fresh Queenston Shale Samples

Sample	Surface Area (cm^2)	Core Length (cm)	Confining Pressure (MPa)	ΔP (MPa)	Flow Rate (m^3/s)	Permeability (m^2)
Queenston from Bruce Site DGR1-459.27 ⊥ bedding	4.91	0.85	6.6	3.0	2.2×10^{-11}	$(1.5 \pm 0.1) \times 10^{-19}$
			6.6	4.9	4.0×10^{-11}	$(4.6 \pm 0.1) \times 10^{-19}$
			6.6	4.8	3.0×10^{-11}	$(1.2 \pm 0.1) \times 10^{-19}$
			6.6	4.7	2.2×10^{-11}	$(9.1 \pm 0.7) \times 10^{-20}$
			9.3	5.0	3.5×10^{-11}	$(1.4 \pm 0.1) \times 10^{-19}$
			9.3	5.4	6.0×10^{-12}	$(2.2 \pm 0.2) \times 10^{-20}$
			9.5	5.5	6.0×10^{-12}	$(2.5 \pm 0.1) \times 10^{-20}$
			11.9	5.5	7.1×10^{-12}	$(1.4 \pm 0.1) \times 10^{-20}$
			15.0	5.8	4.1×10^{-12}	$(1.3 \pm 0.2) \times 10^{-20}$
			15.1	5.9	3.9×10^{-12}	$(1.0 \pm 0.1) \times 10^{-20}$
			15.4	6.7	3.1×10^{-12}	$(9.0 \pm 0.4) \times 10^{-21}$
			15.5	7.5	3.1×10^{-12}	$(7.8 \pm 0.4) \times 10^{-21}$
			15.7	7.7	4.1×10^{-12}	$(1.0 \pm 0.1) \times 10^{-20}$
			15.0	7.0	2.0×10^{-12}	$(5.6 \pm 0.3) \times 10^{-21}$
Queenston from Bruce Site DGR1-459.27 ‖ bedding	4.91	0.60	1.6	0.7	2.2×10^{-12}	$(4.4 \pm 0.5) \times 10^{-20}$
			1.7	0.4	6.6×10^{-13}	$(2.3 \pm 0.4) \times 10^{-20}$
			2.3	1.4	4.7×10^{-13}	$(4.7 \pm 0.5) \times 10^{-21}$
			2.7	2.3	8.1×10^{-13}	$(4.9 \pm 0.5) \times 10^{-21}$
			5.0	2.5	1.2×10^{-12}	$(6.7 \pm 0.8) \times 10^{-21}$
			4.9	2.6	7.6×10^{-13}	$(4.0 \pm 0.6) \times 10^{-21}$
			5.0	2.7	1.2×10^{-12}	$(6.3 \pm 0.5) \times 10^{-21}$
			5.3	2.7	1.4×10^{-12}	$(7.2 \pm 0.7) \times 10^{-21}$
			9.8	2.8	1.3×10^{-12}	$(6.5 \pm 0.6) \times 10^{-21}$
			8.1	3.4	8.4×10^{-13}	$(3.4 \pm 0.3) \times 10^{-21}$
			10.2	3.4	1.6×10^{-12}	$(6.5 \pm 0.9) \times 10^{-21}$
			9.8	3.6	1.2×10^{-12}	$(4.5 \pm 0.3) \times 10^{-21}$
			13.9	3.9	9.6×10^{-13}	$(3.4 \pm 0.5) \times 10^{-21}$
			14.5	3.9	8.3×10^{-13}	$(3.0 \pm 0.5) \times 10^{-21}$
			14.7	3.9	1.1×10^{-12}	$(4.1 \pm 0.6) \times 10^{-21}$
			15.1	4.0	9.7×10^{-13}	$(3.4 \pm 0.3) \times 10^{-21}$
			15.7	4.4	8.7×10^{-13}	$(2.7 \pm 0.2) \times 10^{-21}$
			16.0	4.9	8.6×10^{-13}	$(2.4 \pm 0.3) \times 10^{-21}$
			15.9	5.0	4.4×10^{-13}	$(1.2 \pm 0.2) \times 10^{-21}$
			12.7	5.4	6.7×10^{-13}	$(1.7 \pm 0.1) \times 10^{-21}$

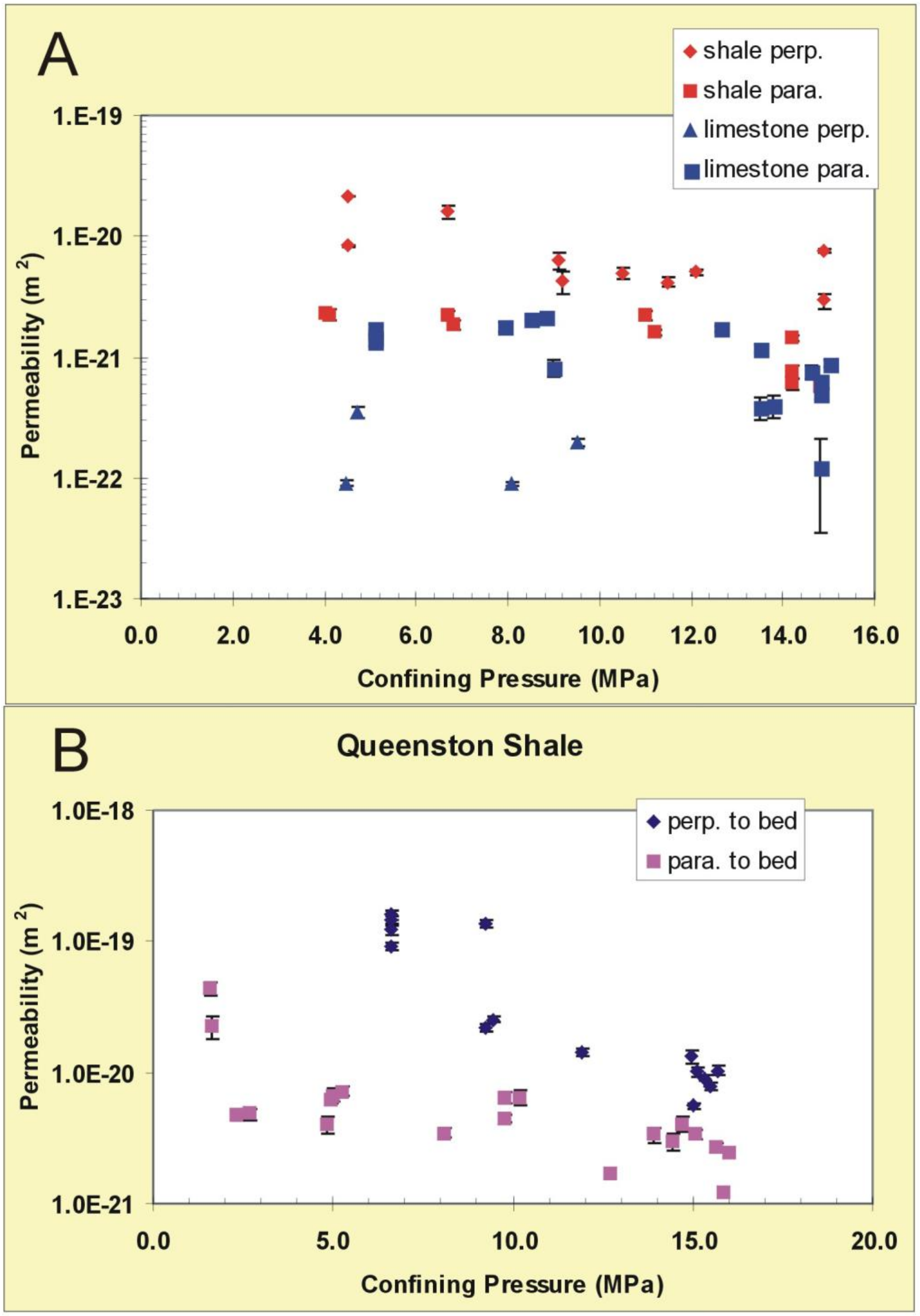

Figure 26: Effect of Confining Pressure on Permeability (Perp = perpendicular to bedding; para = parallel) for Archived Samples (A) and Shale from Bruce Site (B)

3.5 PORE FLUID COMPOSITION

The concentrations of anions and cations determined in the leachates were converted to pore water concentrations by a factor that was determined by the sample weight, the 20 to 25 mL volume of the leaching solutions, the rock density, and the estimated sample porosity. The rock density was determined from porosity measurements, which gave average values of 2.56 for sandstone, 2.66 for shale, and 2.65 for limestone. The estimated porosity for sandstone was 0.054 and the average porosities for shale and limestone were 0.060 and 0.017, respectively. Estimated pore water concentrations from the initial leaching tests are summarized in Table 11 for sandstone and shale and Table 12 for limestone. The sandstone had a TDS of 176 g/L and an ionic strength of 4.2 mol/L. The shale TDS varied from 180 to 273 g/L, corresponding to ionic strengths of 3.6 to 6.0 mol/L. Limestone had TDS values ranging from 184 to 270 g/L, corresponding to ionic strengths between 4.1 and 5.3 mol/L. The calculated charge imbalances for the Queenston shale leachates and two of the Cobourg limestone leachates were 10% or less, which is considered to be within the analytical uncertainty. The charge imbalances for the other two leachates of Cobourg limestone were greater than 10%, which may indicate either that a major species has not be analyzed, or may be indicative of analytical error in one or more of the species. Fluoride and iodide were not detected in the leachates, implying that their respective pore water concentrations were below 68 and 81 mg/L. The results in Table 11 and Table 12 are most sensitive to the porosity value used in the calculation. For example, if there is a factor 2 increase in porosity, the estimated pore water concentrations will decrease by a factor of 2. Results from the second leaching test showed negligible additional salt concentrations, except for SO_4. Relatively high SO_4 concentrations in the second leachate suggest that there is an additional source of SO_4 other than pore water salts. Dissolution of gypsum or the oxidation of sulfides are possibilities that warrant further investigation, especially for the Queenston shale, in which anhydrite/gypsum nodules were observable in hand specimen.

Table 11: Pore Water Concentrations of Anions and Cations Leached From Queenston Shale

Rock Type	Sample Depth (m)	Cl mg/L	Br mg/L	SO_4 mg/L	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	Sr mg/L	[1]Percent Charge Imbalance
Queenston SH	73.584	143441	0	519	69123	5714	15982	2357	300	2
Queenston SH	84.04	113784	648	1493	63585	5062	11713	1631	243	10
Queenston SH	84.064	130500	1560	7644	64628	5717	18643	2424	360	6
Queenston SH	90.221	122091	266	7161	62219	4578	14870	1957	325	4
Queenston SH	101.719	106554	1131	11216	57951	5515	14488	1729	290	8
Queenston SH	101.72	107646	1492	10275	58104	5749	13456	1651	275	6
Queenston SH	101.721	103844	1509	10140	55587	5742	13439	1649	275	6
Queenston SH	104.83	94533	1289	13505	49722	4911	13505	1780	264	5

[1] Negative ion balance implies an apparent excess of anions

Table 12: Pore Water Concentrations of Anions and Cations Leached From Cobourg Limestone

Rock Type	Sample Depth (m)	Cl mg/L	Br mg/L	SO_4 mg/L	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	Sr mg/L	[1]Percent Charge Imbalance
Sample 4	36.5	153540	285	25707	49077	3692	27109	9582	1239	-11
Sample 9	36.5	121610	247	22479	53949	4181	31021	11689	1439	22
Sample 10	36.5	115164	206	23267	43521	3030	23100	8704	1255	3
Rectangle	36.5	93365	92	21785	36614	2783	21053	7323	879	7

[1] Negative ion balance implies an apparent excess of anions.

4. DISCUSSION

4.1 DIFFUSIVE PROPERTIES OF SEDIMENTARY ROCKS

This study has shown that the water immersion method, using oven drying to determine dry weight, provides a good estimate of total porosity. Porosity values estimated by this method are bracketed by porosity values estimated by rock capacities determined from diffusion experiments. Porosity determined by iodide rock capacity (diffusion) was a factor 1.3 to 4 lower than that estimated by water immersion. This could be due to anion exclusion at negatively charged mineral surfaces, which reduces the total pore space available to iodide diffusion. Porosity determined by tritium rock capacity (diffusion) was similar to that estimated by water immersion. This can be attributed to the ability of hydrogen ions to diffuse into very small spaces readily accessible to water, but not necessarily to charged species such as iodide. While mercury intrusion porosimetry provides useful insight into pore sizes, it underestimated the total porosity because mercury could not be forced into pore spaces smaller than 3 nm. In summary, the water immersion method provides porosity estimates that are consistent with other methods, and it is a relatively simple method that uses commonly available laboratory equipment and can be adapted to a variety of sample shapes and sizes.

Table 13 compares values of iodide and tritium effective diffusion coefficients and water immersion porosity estimated in this study with values reported in the literature. Iodide and tritium diffusion coefficients estimated in this study for Queenston shale fell within the range of 5×10^{-13} to 1×10^{-11} (m^2/s) reported for shales in Table 1. The estimated iodide and tritium diffusion coefficient values for Cobourg limestone are at the low end of values reported for limestone, from 7×10^{-13} to 1×10^{-10} (m^2/s). It should be noted that the upper range of diffusion coefficient values for Cobourg limestone was determined using only one sample in which diffusion was measured parallel to bedding. Compared to other limestone formations as reported in Table 1, the tested samples of Cobourg limestone had very low diffusivity. The porosity of Queenston shale fell within the lower range of porosities reported for shales (from 1.5 to 20 percent). The porosity of Cobourg limestone was just below the porosity range (from 3 to 43 percent) reported for limestone, which is consistent with its low measured diffusivity.

Table 13: Compare Diffusion Coefficients and Porosities to Literature Values

	This Study		Literature	
	Shales	**Limestone**	**Shales**	**Limestone**
Iodide De (m^2/s)	8.7×10^{-13} to 1.7×10^{-12}	9.5×10^{-14} to 6.6×10^{-12}	5×10^{-13} to 5×10^{-12}	7×10^{-13} to 3×10^{-10}
Tritium De (m^2/s)	7.3×10^{-12} to 1.5×10^{-11}	5.7×10^{-13} to 1.4×10^{-11}	2×10^{-12} to 1×10^{-11}	3×10^{-12} to 1×10^{-10}
Porosity (%)	6.1 to 7.1	1.5 to 2.0	1.5 to 20	3 to 43

Average values of porosity, effective diffusion coefficients and permeability are presented in Table 14 to facilitate comparison of the mass transport properties of Queenston shale and Cobourg limestone. It should be noted that the results from one sample of Cobourg limestone (43.8 m and parallel to bedding) are significantly different from the other samples, and produce high standard deviations for average diffusion parameter values calculated for Cobourg limestone. The permeability results from the shale samples taken from the Bruce Nuclear site were not included in this table.

Mercury intrusion porosimetry indicated that the shale and limestone have similar average pore sizes, although the shale has a slightly smaller pore space. Taken by itself this may suggest similar diffusion properties. The average iodide effective diffusion coefficients for shale and limestone were similar, although if the high diffusivity limestone sample parallel to bedding is excluded the average iodide diffusion coefficient in limestone would be a factor 4.6 lower. The average tritium diffusion coefficient was a factor 2.8 lower in limestone, although this would increase to a factor 5.0 if the high diffusivity sample was excluded. The limestone had values of water immersion porosity, iodide rock capacity and tritium rock capacity that were smaller by factors of 3.9, 3.5 and 3.8, respectively, than those measured for Queenston shale. This indicates that to a large degree, the difference in diffusion properties can be explained by the differences in the porosities of Queenston shale and Cobourg limestone. (Note that this latter comparison excluded consideration of the high diffusivity sample, because water immersion data was not available for this sample.)

Effective diffusion coefficients for tritium were about an order of magnitude higher than values for iodide. This is explained by the tritium free water diffusion coefficient being a factor 5 higher than the iodide free water diffusion coefficient, and by the ability of tritium to use a larger portion of the pore space for diffusive mass transport.

Pore geometry also plays a role in determining effective diffusion coefficients. The parameters commonly used to approximate the effects of pore geometry are constrictivity and geometric tortuosity (Eq. 7). These terms can be combined into a single term, referred to as the effective tortuosity (Eq. 12). The calculated iodide and tritium effective tortuosities of the limestone were larger than those of shale. Although the shale had a smaller average pore size, its porosity was less tortuous and constrictive to diffusion. The effective tortuosities of tritium were smaller than those of iodide, indicating that in both rock types, the porosity used by tritium was less tortuous and less constricted than that of iodide.

The permeability of limestone was a factor 4.8 less than that of shale. This is also consistent with the limestone’s lower porosity and higher effective tortuosity. Although diffusivity and permeability are affected by porosity and pore geometry to a similar degree, the effects are not exactly the same. This is not entirely surprising because the physical processes that control resistance to chemical diffusion are different than those that determine resistance to water flowing under a hydraulic gradient.

Table 14: Average Parameter Values Affecting Mass Transport

	Queenston Shale	Cobourg Limestone
MIC Porosity (%)	3.7 ± 0.5	1.26 ± 0.09
MIC Derived Pore Size (nm)	6.2 ± 0.9	7.7 ± 1.6
Water Immersion Porosity (%)	6.63 ± 0.48	1.71 ± 0.27
Iodide Rock Capacity (%)	3.4 ± 1.1	2.3 ± 3.3
Tritium Rock Capacity (%)	9.6 ± 4.3	2.7 ± 2.3
Iodide Effective Tortuosity	10.7 ± 1.3	11. ± 5.6
Tritium Effective Tortuosity	7.6 ± 0.9	9.1 ± 4.6
Iodide De (m^2/s)	$(1.2 \pm 0.3) \times 10^{-12}$	$(1.2 \pm 3.9) \times 10^{-12}$
Tritium De (m^2/s)	$(1.1 \pm 0.3) \times 10^{-11}$	$(3.9 \pm 4.8) \times 10^{-12}$
Permeability (m^2)	$(4.5 \pm 5) \times 10^{-21}$	$(9.4 \pm 7.0) \times 10^{-22}$

Reported errors are standard deviations

In Table 14 the errors reported for average parameter values are standard deviations, which provide a sense of variability. A comparison of these standard deviations shows that, with the exception of tritium rock capacity, diffusion parameters have greater variability in limestone compared to shale. This suggests that further research should emphasize additional quantification of the variability in the diffusive properties of the limestone formations.

In the Queenston shale samples, there appears to be a factor 1.3 to 1.5 decrease in iodide and tritium diffusion coefficients with sample depth, suggesting that greater burial depth has reduced the diffusive properties of shale. In the limestone, the iodide and tritium diffusion coefficients were higher by a factor 2.7 to 3.3 in samples taken from the two greater depths. This could result from heterogeneities within the limestone as due to differences in lithology, or as a result of greater sample alteration in rocks removed from greater depths. The alteration would take the form of micro cracks caused by stress relief. The number of measurements is insufficient to establish the actual reason for this variation.

In shale, the iodide and tritium effective diffusion coefficients measured perpendicular to bedding were identical (within sample variability) with values measured parallel to bedding, indicating that diffusion in Queenston shales is isotropic. However, permeability measured perpendicular to bedding was a factor 4 higher than measured parallel to bedding. The permeability perpendicular to bedding was probably higher because the Queenston formation contains irregular parting planes that cross cut bedding and may be related to digenetic processes. These parting planes may explain the increase in permeability measured perpendicular to bedding. However, these parting planes apparently did not have an effect on the diffusivity because diffusion coefficients measured parallel and perpendicular to bedding planes were identical within experimental error.

In Cobourg limestone, the average iodide and tritium effective diffusion coefficients were approximately an order of magnitude higher when measured parallel to bedding, compared to perpendicular to bedding, mainly because of high diffusivity in one sample. Only two samples were used for estimating diffusion parallel to bedding, and the difference in the diffusion coefficient values between these two samples was approximately one order of magnitude. This indicates that diffusivity parallel to bedding in Cobourg limestone is highly variable. Although permeability in Cobourg limestone is low parallel to bedding, $(1.1 \pm 0.7) \times 10^{-21}$ m^2, the permeability perpendicular to bedding appears to be an order of magnitude lower, $(1.9 \pm 1.2) \times 10^{-22}$. Therefore, in the Cobourg limestone, sample orientation appears to have the same effect on both diffusivity and permeability. However, more data points are required to establish a statistically significant database to support any conclusions regarding the effect of sample orientation on diffusivity and permeability.

The archived core samples used in this study were not drilled for the specific purpose of characterizing mass transport properties or pore water composition. No precautions were taken to prevent evaporation; the rock samples had been stored in a dried condition without any attempt to control temperature. Sample drying had the greatest impact on Queenston shale, which is known to spall when rewetted. However, adjusting experimental procedures to ensure that samples are properly constrained before being wetted was found to minimize the impact of spalling. Proper preservation of the moisture content of samples of this shale immediately after drilling may reduce or eliminate this tendency. The permeability measured with fresh Queenston shale samples also showed a significantly lower value parallel to bedding compared to perpendicular to bedding. However, on average the permeability estimated with these samples was a factor 6 higher than determined with archived samples. Given the difference in geographic location, possible rock variability, and the sample thickness of the new core was less than that of archived core, the significance of this difference has not been established.

Drying did not appear to have an effect on the integrity of Cobourg limestone samples. Drying experiments with resaturated limestone samples indicated that a significant fraction of the pore fluids would evaporate within 10 to 20 days of air-drying. A similar experiment was not performed with Queenston shale because unconfined coupons, which had been re-saturated with water, tended to break apart when exposed to air. When pore fluids evaporate, volatile elements and stable isotopes are lost. However, soluble salts are left behind. In the current study, leaching experiments were used to extract, and quantify these salts, and used to estimate pore fluid major element concentrations using measured rock porosities.

The results of leaching experiments indicated that Lower Silurian and Upper Ordovician sediments of southern Ontario have saline pore waters with TDS values ranging from 176 to 270 g/L, and corresponding ionic strengths between 3.6 and 6.0 mol/L. The average pore water element concentrations estimated for Lower Silurian Whirlpool sandstone and Upper Ordovician Queenston shale and Cobourg limestone using the leach experiments are compared to groundwater compositions from the Trenton Group (Upper Ordovician shales) and the Blue Mountain Formation (Middle to Upper Ordovician limestones) reported by McNutt et al. (1987), which are given in Table 15. As a first approximation, the high salinity pore fluids appear to be similar to the high salinity groundwaters sampled from hydrocarbon reservoirs in comparable stratigraphic horizons.

Comparing the Queenston shale pore fluids with groundwater from the Blue Mountain formation, the chloride and bromide concentrations are similar. The estimated pore fluid composition has higher sodium and potassium concentrations, and slightly higher strontium.

However, calcium and magnesium are lower in the pore fluid. The measured sulfate concentration was significantly higher in the pore fluid, possibly due to the dissolution of gypsum or the oxidation of sulfides during the leaching process. Anhydrite/gypsum nodules are visible in hand specimens of Queenston shale.

The Cobourg limestone (Michigan basin) pore fluid has similar concentrations of sodium and chloride to groundwater from the Trenton Group (Appalacian basin). The pore fluid had slightly higher concentrations of potassium, magnesium and strontium, and slightly lower calcium. Bromide was significantly lower in the pore fluid. Sulfate was again very high in the pore fluid. Because calcium concentrations are not high enough to balance the measured sulfate concentrations, another possible source for sulfate is the oxidation of sulfide. The leach experiments were conducted under atmospheric conditions, which may have resulted in the oxidation of sulfide minerals to sulfate.

In summary, the estimated pore water solutions from the leach experiments conducted as part of this study suggest the presence of high salinity water in the rock matrix. These estimated pore fluid compositions are similar to groundwater compositions sampled from oil and gas wells from formations of the same age, but different geographic locations.

Table 15: Compare Pore Water Compositions with Groundwater Compositions

	Cl g/L	**Br g/L**	**SO_4 g/L**	**Na g/L**	**K g/L**	**Ca g/L**	**Mg g/L**	**Sr g/L**
			Pore Water - This Study					
mean sandstone	69	0.49	52	22	0.7	29	2.5	0.37
mean shale	115	0.99	7.74	60	5.4	15	1.9	0.29
mean limestone	121	0.21	23.3	46	3.4	26	9.3	1.20
			Ground Water – McNutt et al. (1987)					
Blue Mountain (sh)	118	1.08	0.12	22	0.4	39	4.5	0.70
Trenton Group (lim)	150	1.19	0.34	50	2.1	33	6.0	0.62

The diffusion experiments using synthetic pore water solutions suggest that the diffusion coefficients determined using the standard 17 g/L solutions could be a factor 2 to 4 lower than if measurements were performed using real pore water chemistry. In shale the total porosities used by iodide and tritium were not affected by changing pore water chemistry, suggesting that the shale porosity was not altered by the 17 g/L solutions during the experimental time frame. Also the higher ionic strength of the synthetic pore waters did not change any anion exclusion effects that could have affected iodide diffusion. In limestone the iodide and tritium rock capacities appear to be slightly higher when synthetic pore waters are used (although the differences were close to experimental variation). Since the tritium rock capacity is not influenced by anion exclusion and therefore, is not expected to be affected by salinity, the apparent increase in tritium rock capacity could be attributed to an increase in porosity.

In shale the iodide and tritium De values were a factor 1.9 higher in synthetic pore water, despite the observation that the porosity used by diffusion had not changed. Ruling out a change in porosity, one could consider several explanations for higher diffusion coefficients determined using synthetic pore waters that include (1) a higher iodide concentration in the synthetic pore waters, (2) a change in pore geometry, and (3) an experimental artefact due to differences in the tracer and eluant solutions. The higher iodide concentration in the tracer should not be a factor because the tritium concentration was the same in both sets of experiments. A change in pore geometry also does not seem likely given that there were no apparent changes in total porosity used by diffusion. Although the ionic strengths of the tracer and eluant solutions were similar, the TDS of the tracer solution was a factor 1.7 higher. Perhaps the difference in the TDS values could have affected De values in shale.

In limestone the iodide and tritium De values determined with synthetic pore water were a factor 4 and 2.7 higher, respectively. The higher diffusion porosities could account for a portion of the differences in De values. If there was a change in diffusion porosity it is also conceivable that there was a change in pore geometry, resulting in a reduced effective tortuosity. The difference in the TDS values of tracer solution and eluant could also have played a role, as proposed for shale.

This study has focused on improving the understanding of mass transport processes on the scale of 1 to 3 cm. Samples were selected to be free of fractures at the macroscopic scale. Therefore, the results of this study represent a preliminary database which can be applied to improve our understanding of mass transport in the unfractured rock matrix of these two formations. One example where a fracture or a bedding plane had created a preferential transport pathway is the sample of Cobourg limestone that was cut to measure diffusion parallel to bedding (Table 8). In this sample the effective diffusion coefficients were about an order of magnitude higher than in all of the other Cobourg limestone samples, and the porosities available for diffusion had increased by factors of 7 and 2 for iodide and tritium, respectively.

Although the number of samples examined in this study was limited, the results from different sample depths suggested that in the Queenston shale, alteration by stress release during drilling did not change the diffusion parameters by more than a factor of about 3. However, it is not clear whether the same could be said regarding the sample of Cobourg limestone cut to measure diffusion parallel to bedding. Under a litho static load, would the fracture or parting responsible for the high diffusivity have been open to the same degree as in the distressed rock sample? When the confining pressure on samples of shale and limestone was increased to about 15 MPa, the permeability was reduced by a factor 3 to 5. A comparison of laboratory and in-situ measurements with granite samples removed from high stress environments showed that laboratory estimated diffusion coefficients were a factor 1 to 15 higher than in-situ values, while laboratory derived permeabilities were a factor 2 to 100 higher than in-situ values (Vilks et al. 2004). This implies that any effects of sample alteration during drilling have a more significant effect on laboratory derived permeability values, compared to effective diffusion coefficients. Furthermore, the very low laboratory derived permeability values in this study suggest that the samples were not subjected to significant alteration and therefore the derived diffusion coefficients may provide a good first approximation of matrix diffusion under in-situ conditions. This conclusion could be tested by measuring diffusion and permeability on fresh core samples taken from a broad range of depths.

4.2 SUGGESTIONS FOR FUTURE WORK

Twenty diffusion cell experiments were performed in this study to develop protocols for measuring the diffusive properties of sedimentary rocks, and to initiate a database of diffusion parameters for Ordovician sedimentary rocks of southern Ontario. Additional diffusion measurements should be performed on other Ordovician shale and limestone samples to increase the number of measurements in the database to a statistically significant number. The enhanced database could be used to improve the understanding of the effects of burial depth, orientation with respect to bedding planes, sample alteration, and heterogeneity produced by changes in lithology with geography and with stratagraphic depth.

The results presented in this report were obtained from archived samples, which had been subjected to drying. Fresh samples, which had been sealed at the time of drilling to prevent evaporation, might provide more representative results for diffusion parameters and pore water compositions.

To resolve the question of experimental artefacts caused by pore water chemistry, it would be useful to perform a series of diffusion experiments using a range of synthetic or real pore waters. Tritium would be used as the tracer because it does not impact the ionic strength and TDS. That way the tracer and eluant solutions could have the same basic chemistry, ruling out density or osmotic effects.

The understanding of mass transport would benefit from a program of comparative laboratory and in-situ experiments. The in-situ experiments would account for the effects of natural pore water chemistry, natural stress conditions, and would not be affected by sample alteration during drilling. A comparison of in-situ results with comparative experiments could be used to validate laboratory measurements used with sedimentary rocks. In-situ experiments could also be used to evaluate the effects of sample scale on mass transport driven by diffusion or by a hydraulic gradient.

This study has focused mainly on non-sorbing tracers because of practical time constraints, and due to the fact that significantly longer experimental times that would be required to study the diffusion of sorbing tracers. At present, the understanding of contaminant sorption on shales and limestones in very saline water is limited. In addition to having knowledge of sorption reactions and sorption coefficients, the ability to use sorption to predict retardation during mass transport in a rock matrix requires an understanding of sorption/desorption kinetics and of the specific surface area available to sorption. This understanding can be obtained from mass transport experiments that use either diffusion or a hydraulic gradient. The HPRM may be of particular interest to study mass transport of sorbing tracers at different confining pressures. By modifying the confining pressure, one might be able to vary the porosity available for transport and perhaps the specific surface area available to sorption.

5. CONCLUSIONS

Experimental protocols to measure the diffusive properties of sedimentary rocks have been developed in this study. An experimental program was undertaken with archived core samples of Ordovician shale and limestone to test these protocols (water immersion porosity, mercury intrusion porosimetry, diffusion cell experiments, porosity, and pore water chemistry) for characterizing the diffusive and mass transport properties of rock matrix. The results showed that Queenston shale had an average porosity of 0.0663 ± 0.0048, and average iodide and tritium diffusion coefficients of $(1.2 \pm 0.3) \times 10^{-12}$ and $(1.1 \pm 0.2) \times 10^{-11}$ (m^2/s). These numbers are consistent with values reported for shales in the literature. The Cobourg limestone had an average porosity of 0.0171 ± 0.0027, and average iodide and tritium diffusion coefficients of

$(1.2 \pm 3.9) \times 10^{-12}$ and $(3.9 \pm 4.8) \times 10^{-12}$ (m^2/s), respectively. These values are low compared to typical values reported for limestone in the literature. The matrix permeability of these samples was also very low, with average values of $(4.5 \pm 5) \times 10^{-21}$ (m^2) for Queenston shale and $(9.4 \pm 7.0) \times 10^{-22}$ (m^2) for Cobourg limestone.

Porosity and pore geometry determine diffusivity and permeability. Although average pore sizes are similar in Queenston shale (6.6 ± 0.5 nm) and Cobourg limestone (7.7 ± 1.6 nm), the differences in total porosity and pore geometry (as characterized by effective tortuosity) produced significant differences in diffusivity, particularly for tritium. The rock features, such as parting planes related to diagenetic processes (Queenston shale) and bedding planes (Cobourg limestone) may affect permeability and in some cases diffusion.

The present study did not show evidence of significant sample alteration as a result of stress relief during drilling, which may suggest that the reported diffusion coefficients and permeability values can be used to provide a reasonable approximation of mass transport under in-situ conditions. However, a detailed study of the diffusive properties over a greater range of depths for the sedimentary formations from southern Ontario would be required to verify this finding.

Leaching experiments to extract soluble salts indicated that the pore waters in Ordovician sediments are highly saline, with TDS values ranging from 180 to 270 g/L. As a first approximation, the high salinity pore fluids appear similar to the high salinity groundwaters sampled from producing hydrocarbon wells in comparable stratigraphic horizons.

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APPENDIX A: LEACH DATA TO DETERMINE PORE WATER COMPOSITION

CONTENTS

LIST OF TABLES

A.1 CALCULATION OF PORE WATER COMPOSITIONS FROM LEACHATE SOLUTIONS

Crushed rock samples were suspended in deionized water (25 mL for Queenston shale and 20 mL for Cobourg limestone) and stored in centrifuge tubes. The samples were periodically shaken to homogenize the leachate composition. The samples were allowed to leach for at least 30 days, after which they are centrifuged. The supernatant was then removed and analyzed for anions and cations. Blank solutions with deionized water and no rock sample were included to check for contamination.

The concentrations of anions and cations determined in the leachates were converted to pore water concentrations using Eq. 17, which included the sample weight, the 20 to 25 mL volume of the leaching solutions, the rock density, and the estimated sample porosity. The rock density was determined from porosity measurements, which gave average values of 2.66 for shale and 2.65 for limestone. The leached sample weights, the porosity values used, and the anion and cation concentrations determined for leach solutions are given in Table A.1 for shale and Table A.2 for limestone. The calculated pore water compositions are given in Tables 11 and 12, in the main body of the report.

$$[M]_P = \frac{[M]_L V_L \rho_{rock}}{W_S \varepsilon_c} \qquad (17)$$

where:

$[M]_L$ ion concentration in leachate solution (mg/L)
$[M]_P$ ion concentration in pore water (mg/L)
V_L volume of leachate (L)
ρ_{rock} rock density (g/cm^3)
W_S weight of leached sample (kg)
ε_c rock porosity

Table A.1: Concentrations of Anions and Cations Leached from Queenston Shale

Sample Depth (m)	Porosity	Sample Weight g	Cl mg/L	Br mg/L	SO_4 mg/L	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	Sr mg/L
blank	-	0	<0.5	<0.5	<0.5	0.021	0.015	<0.08	<0.03	<0.004
73.584	0.060	27.7391	3590	< 3	13	1730	143	400	59	7.5
84.04	0.060	26.4946	2720	15.5	35.7	1520	121	280	39	5.8
84.064	0.060	17.8353	2100	25.1	123	1040	92	300	39	5.8
90.221	0.060	28.3232	3120	6.8	183	1590	117	380	50	8.3
101.719	0.060	23.7156	2280	24.2	240	1240	118	310	37	6.2
101.72	0.060	18.1211	1760	24.4	168	950	94	220	27	4.5
101.721	0.060	18.1442	1700	24.7	166	910	94	220	27	4.5
104.83	0.060	18.0555	1540	21	220	810	80	220	29	4.3

The volume of the leach solutions was 0.025 L.

Table A.2: Concentrations of Anions and Cations Leached from Cobourg Limestone

Sample Depth (m)	Porosity	Sample Weight g	Cl mg/L	Br mg/L	SO_4 mg/L	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	Sr mg/L
blank	-	0	0.0012	0.001	<0.001	0.004	<0.0001	<0.001	<0.001	<0.0001
36.5	0.015	15.1054	657	1.22	110	210	15.8	116	41	5.3
36.5	0.015	15.6319	541	1.1	100	240	18.6	138	52	6.4
36.5	0.020	15.7683	688	1.23	139	260	18.1	138	52	7.5
36.5	0.019	15.1486	510	0.5	119	200	15.2	115	40	4.8

The volume of the leach solutions was 0.020 L.

ATTACHMENT B-10
UNLV FINAL REPORT OF CELL DIFFUSION EVALUATION AT THE ATHENS ROAD WELL FIELD

Diffusion Evaluation at the Athens Road Well Field, (NERT) site, Henderson, Nevada.

HOWARD R. HUGHES College of ENGINEERING
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Final Report

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Las Vegas, NV
Dec 13, 2019

Diffusion Evaluation at the Athens Road Well Field, (NERT) site, Henderson, Nevada.

BACKGROUND AND OBJECTIVES

The contaminated groundwater at the Nevada Environmental Response Trust (NERT) is extracted and treated ex-situ by the Groundwater Extraction and Treatment System (GWETS). In its 2015/2016 Annual Remediation Reports, the Nevada Division of Environmental Protection (NDEP) noted increased perchlorate concentrations in wells located downgradient from the Athens Road Well Field (AWF), part of the GWETS. The site consists of alluvial deposits (QAL) under-laid by a very low hydraulic conductivity silt/clay layer (UMCf). There is a significant amount of perchlorate contamination at the top of the UMCf layer.

Hydrogeologists who work at the site have postulated that an upward groundwater flow exists caused by a natural vertical gradient that travels from the UMCf to the QAL. It has been postulated that the observed higher perchlorate concentrations downgradient from the AWF is the result of contaminant diffusion from the UMCf into the QAL.

The objective of this study is to investigate the hypothesis that perchlorate contained in the UMCf can diffuse into the QAL. Both diffusion and advection tests were performed in this study. The parameters determined in this laboratory investigation will be used to assist with the modeling of the diffusion of perchlorate and other ions from the UMCf to the QAL at the NERT site.

EXPERIMENTAL APPROACH

Six acrylic diffusion chambers were designed and built for the diffusion tests, which used soil cores taken from the NERT site. Two large California Tubes (2.5 inches diameter and 30 inches long) from the PZ-1M location, five small California Tubes (2.5 inches diameter and 6 inches long), from the PZ-1S location, and four additional small California Tubes, from the PZ-2M location, were used in the research. In addition, groundwater from the PZ-1M and PZ-2M wells were used in this study.

The diffusion chambers were composed of three chambers. The first chamber stored the tracer solution (tracer chamber), the second the soil sample (soil chamber), and the third the elution solution (elution chamber). The sample holding chamber had an opening that is 2.5 inches in diameter and 1.0-inch-thick to accommodate the soil ring from the California tubes. Four long screws were fitted to the first chamber to hold all of the parts together when joined at the center. Diluted groundwater from the site was used in the tracer and eluent chambers. The contaminated soil rings, from the California tubes, were held in place using a fine stainless-steel screen and sealed around the edges with a concrete adhesive.

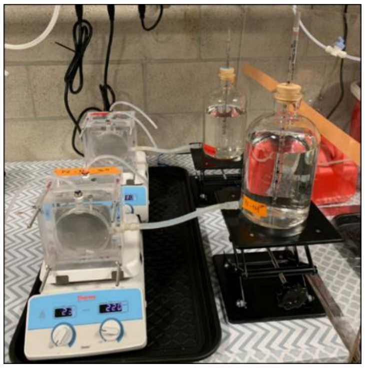


Figure ES1- Set up for Diffusion Tests.

The entire chamber assembly was placed on top of a magnetic stirring base. Magnetic stirring bars were used to mix the contents of the chamber constantly.

A filling reservoir glass bottle (Mariotte Bottle) was attached to the elution chamber (third chamber) through silicone tubing so that a constant flow of elution groundwater was delivered when samples were taken. The bottle was placed on an adjustable screw-jack so that water levels could be regulated during the diffusion tests to achieve the desired gradient, depending on the test scenario.

For advection testing, the set-up was modified. The tests used a hydraulic head gradient to generate a flow from the tracer to the elution chamber; however, the side port in the third chamber (elution chamber) was closed. In addition, a V-notch weir chamber was added to the set-up in order to assist with maintaining the desired gradients as constant during the experiments. The V-notch weir chamber was fitted with a gray plastic square chamber, as well as a PVC slotted well casing to distribute the flow evenly, and an aluminum V-notch weir attached to the square chamber wall to assure constant water level in the chamber.

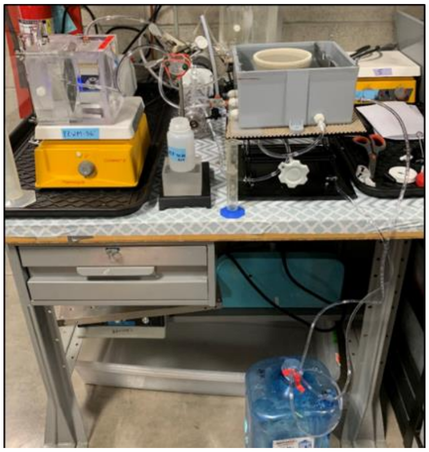


Figure ES2- Set up for Advection Tests.

Part of the soil sample cores were used for soil property determination along with evaluation of the amount of contaminants present in the cores. The properties measured were wet bulk density, dry bulk density, porosity, moisture content, percent saturation, and specific gravity. Triple extraction of the soil samples with high quality deionized water was performed to determine the amount of contaminants present in the soil. The ions evaluated included perchlorate, chlorate, nitrate, sulfate, and chlorate.

MAJOR FINDINGS

Soil characteristics

- ✓ Soil investigations reveals that the PZ-1M soil is composed of fine gray clay, while the PZ-2M soil has fine gray clay, brown sand, and gravel. The specific gravity is around 2.7 g/cm3 for all locations and boreholes.
- ✓ The PZ-1M soil shows a higher porosity (i.e. 72.25%) than the tested samples for the PZ-2M location (48.64 % and 61.99 %). Consequently, the bulk density for PZ-1M is 91.25 lb./ft3, and is thus, lower than the bulk density for the PZ-2M samples (119.76 and 103.28 lb./ft3).

Contaminant Concentrations of Soils

- ✓ The PZ-2M soil is more contaminated with perchlorate and chlorate than the PZ-1M soil. All of the constituents (perchlorate, chlorate, sulfate, chloride, and nitrate) have higher concentrations at the PZ-2M location for all of the boreholes tested.
- ✓ For PZ-1M, sulfate and chloride are at the highest concentrations, with 0.40 mg/g of wet soil and 0.23 mg/g of wet soil, respectively. The perchlorate concentration in PZ-1M is 0.57 ug/g of wet soil, and higher than the chlorate

concentration (0.07 ug/g of wet soil). However, for PZ-2M the perchlorate concentrations are lower (0.63-5.54 ug/g wet soil) than the chlorate concentrations (0.64 - 11.71 ug/g of wet soil).

Groundwater Contaminant Concentrations

- ✓ The PZ-2M groundwater is more contaminated than the PZ-1M. The chlorate concentrations are about 40 times higher in PZ-2M groundwater (i.e. 14,000 ug/L) than in PZ-1M groundwater (i.e. 340 ug/L). The perchlorate concentrations also differ significantly, at 3,100 ug/L for the PZ-2M groundwater and 380 ug/L for PZ-1M groundwater.
- ✓ The sulfate concentration is only 1.4 times higher for the PZ-2M groundwater (1,200 mg/L) than the PZ-1M groundwater (i.e. 840 mg/L). The chloride concentrations are similar, varying only 80 mg/L between PZ-1M (410 mg/L) and PZ-2M (490 mg/L).

Diffusion Tests

- ✓ The first diffusion test performed using soil samples and groundwater from the PZ-1M and PZ-2M locations revealed an increase in chloride and sulfate levels in the elution chamber for the first samples collected. Perchlorate, chlorate, and nitrate were not sufficiently high enough to be detected under the reporting limit of the analytical method.
- ✓ For PZ-1M, concentrations of sulfate increased from 88 mg/L to 150 mg/l, and then decreased steadily to reach 85 mg/L within 33 days, and 44 mg/L after 122 days of elution. The chloride diffusion showed a very similar trend to that of sulfate. Chloride concentrations increased from 44 mg/L to 75 mg/L, and then within 20 days, chloride decreased to 44 mg/L.
- ✓ The test with the PZ-2M sample showed a similar elution trend; however, the elution was much slower. It took about 90 days for the sulfate concentrations to decrease from 73 to 23 mg/L. Chloride concentrations stabilized faster, after 60 days. Slower elution was expected from PZ-2M because it has smaller porosity (48.64%), as compared to PZ-1M (72.25%).
- ✓ Sampling from the tracer chamber in the second diffusion test provided different results, as compared to the first diffusion test, in which sampling was performed from the elution chamber. For both PZ-1M and PZ-2M soil samples, there were increased concentrations of the ions of interest with time. This may be explained considering that the smaller elution chamber (300 ml) allowed for a faster increase in concentration; however, because the sample was taken from the same chamber where fresh diluted water was added, the impact of dilution was observed.
- ✓ Concentrations of sulfate in the second elution test increased from 8 mg/L to about 25 mg/l within 7.5 days, and then stabilized. Chloride concentrations increased from about 5 mg/L to above 10 mg/L within two days. A similar pattern was observed for sample PZ-2M. Some sporadic peaks of chloride and sulfate were also observed.
- ✓ Chlorate and perchlorate diffusion were observed in this test for PZ-2M, but the data are highly variable. The data show chlorate levels increasing from 200 ug/L to 300 ug/L within 2.5 days. After 10 days, the levels dropped to100 ug/L. A similar variation was seen for perchlorate, except that it stayed stable at 60 mg/L up to day 10, and then started

increasing, reaching 200 ug/L after day 10.

Advection Tests

- ✓ For the first advection test performed with a gradient of 2.0, sulfate and chloride concentrations were easily detected in the elution effluent, and perchlorate and chlorate showed detectable values. The concentrations of t chloride and sulfate increased within the first 72 hours, but then decreased and stayed about that of the groundwater; however, after 650 hours, the concentrations of both increased to the highest observed levels. Higher chlorate and perchlorate levels observed in the effluent indicate elution of these contaminants from the soil. It took about 400 hours to observe significant elution of perchlorate and chlorate under a gradient of 2.0.
- ✓ For the advection test performed with a gradient of 0.2 and sample PZ-2M with 56-feet of depth, screen clogging was observed after 5 hours of testing. However, under a 0.6 gradient, all ions were observed in the effluent chamber. For the 0.2 gradient, the chloride concentration increased to about 60 mg/L, and the sulfate concentrations also increased to 140 mg/L within four hours.
- ✓ After the gradient was increased to 0.6, sulfate concentrations increased further to 160 mg/L, and then decreased back to 140 mg/l after 37 hours. The results show that under a gradient of 0.2 and within about 10 hours, the concentrations of chlorate and perchlorate increased considerably. With an increased gradient of 0.6, the concentrations of both decreased steadily and reached lower levels after 3,000 ml of groundwater were passed through the soil. The decrease was more drastic for chlorate than for perchlorate. A similar behavior was observed for nitrate. The results demonstrate the flushing of ions with higher gradients applied to the soil samples.
- ✓ For the second advection test with PZ-2M, performed with a gradient of 7.4, both sulfate and chloride concentrations in the effluent chamber increased within the first 50 hours of the experiment. After 50 hours, sulfate concentrations decreased and reached the level of the diluted groundwater. Chloride concentrations also decreased after 50 hours, but the decrease was much slower, and after almost 300 hours, the chloride concentration was still 53 mg/l.
- ✓ Perchlorate and chlorate showed similar behaviors, with significant increases in concentrations within 50 hours, and then significant decreases to low levels with the processing of more groundwater. The decreases for perchlorate and chlorate concentrations were more prominent than those for sulfate and chloride.
- ✓ The third advection test with the PZ-2M 56-feet deep soil sample was performed with a gradient of 0.6. This sample was less compacted than the soil used with a gradient of 7.4. For sulfate and chloride, only small increases in concentration levels were observed initially. The ion concentrations stabilized at concentrations found in the groundwater used in the test. Higher chlorate concentrations were observed during 10 hours of the experiment, while higher perchlorate concentrations were only observed during 5 hours.

Table of Contents

List of Figures

List of Tables

1 Background & Objectives

Currently, contamination at the NERT site is prevented from reaching the Las Vegas Wash and the Colorado River by a system of intercepting wells including the Interceptor Well Field (IWF), the Athens Road Well Field (AWF), and the Seep Well Field (SWF). The contaminated groundwater is extracted and treated ex-situ by the Groundwater Extraction and Treatment System (GWETS). In Its 2015/2016 Annual Remediation Reports, the Nevada Division of Environmental Protection (NDEP) noted increased perchlorate concentrations in wells located downgradient from the AWF. Geologically, the site consists of alluvial deposits with gravel and sand (QAL) underlaid by a very low hydraulic conductivity silt/clay layer (UMCf). Groundwater contained in both the QAL and UMCf is contaminated. However, there is a significant amount of perchlorate contamination at the top of the UMCf caused by the low hydraulic conductivity of this formation, which acts as a barrier to perchlorate and co-contaminant migration deeper into the aquifer. Hydrogeologists who work at the site have postulated that there exists an upward groundwater flow caused by a natural vertical gradient that travels from the UMCf to the QAL. It is hypothesized that the observed higher perchlorate concentrations downgradient from the AWF is the result of contaminant diffusion from the UMCf into the QAL. It is thought that as the QAL groundwater is pumped and treated and with the natural upward gradient, perchlorate contained in the UMCf migrates into the QAL, causing perchlorate concentrations to increase in the QAL.

The objective of this study is to investigate the hypothesis that perchlorate contained in the UMCf can diffuse into QAL. The parameters determined in this laboratory investigation will be used to assist with modeling of diffusion of perchlorate and other ions from the UMCf to QAL at the NERT site.

2 Methodology

2.1 Soil Characterization

2.1.1 Soil Sample Collection

The soil samples were provided by Ramboll, and were extracted from the Nevada Environmental Response Trust (NERT) site. Two large California Tubes (2.5 inches diameter and 30 inches long) from the PZ-1M location were provided. Five small California Tubes (2.5 inches diameter and 6 inches long), from the PZ-1S location, and four additional small California Tubes, from the PZ-2M location, were also provided. All of the small California Tubes had six one-inch metal rings inside, while the large California Tubes did not have rings. All of the soil samples collected at varying depths for the study are shown in Table 1. Samples were kept refrigerated and packed tightly into plastic bags to avoid loss of moisture.

Table 1 – Soil samples collected for the diffusion investigation study at UNLV.

Sample ID	Tube Type	Code	Top Depth	Bottom Depth	Length
PZ – 1S	Small California Tube	0820	45.0 ft.	45.5 ft.	0.5 ft./ 6”
PZ – 1S	Small California Tube	0820	45.5 ft.	46.0 ft.	0.5 ft./ 6”
PZ – 1S	Small California Tube	0820	46.0 ft.	46.5 ft.	0.5 ft./ 6”
PZ – 1S	Small California Tube	0905	55.5 ft.	56.0 ft.	0.5 ft./ 6”
PZ – 1S	Small California Tube	0905	56.0 ft.	56.5 ft.	0.5 ft./ 6”
PZ – 2M	Small California Tube	1050	55.5 ft.	56.0 ft.	0.5 ft./ 6”
PZ – 2M	Small California Tube	1050	56.0 ft.	56.5 ft.	0.5 ft./ 6”
PZ – 2M	Small California Tube	1050	65.5 ft.	66.0 ft.	0.5 ft./ 6”
PZ – 2M	Small California Tube	1050	66.5 ft.	67.0 ft.	0.5 ft./ 6”
PZ – 1M	Large California Tube	0835	35.0 ft.	37.5 ft.	2.5 ft./ 30”
PZ – 1M	Large California Tube	1030	46.5 ft.	49.0 ft.	2.5 ft./ 30”

For the six-inch California Tubes, extraction of the soil rings was performed using a soil weight- pusher (2.4 inch diameter) (Figure 1), while for the 30-inch tubes, a California Tube extrusion apparatus was used.

Figure 1 - Soil weight pusher with 2.4 inches diameter used to extrude samples from the small California Tubes.

It was necessary to cut the ends of the casing housing the 30-in tube using a saw because it was damaged. The soil sample was carefully extruded and placed into metal forms to form rings to be used in the diffusion tests. Several inches of the soil core were intact, and it was possible to form a soil cake using metal rings. The cakes were packed tightly with plastic wrap and placed into an empty California Tube to avoid loss of moisture. The portions of the core that were not intact were used to determine physical soil properties. Figure 2 shows the extracted core for the large California Tube.

Figure 2 - Extracted 30-inch core sample after extrusion with the California Tube extrusion apparatus.

2.1.2 Physical Properties of Soil

The soil samples listed in Table 1 were used for the diffusion studies and soil physical properties characterization. The physical properties of the soil were determined from the soil contained in the California sample tubes. The properties measured were wet bulk density dry bulk density, porosity, moisture content, percent saturation (ASTM D-2116), and specific gravity (ASTM D-854). Table 2 shows the major soil properties determined and Figures 3 – 6 shows part of the tests performed in the laboratory. A detailed soil report is presented in Appendix A and testing was performed by the UNLV soil laboratory manager Dr. Kazem Jadidirendi.

Table 2 - Major soil properties determined by physical testing.

	Units	PZ-1M 46.5’	PZ-2M 55.5’	PZ-2M 66.0’
Moisture Content (dry basis)	%	93.07	34.90	58.65
Specific Gravity	g/cm^3	2.729	2.770	2.745
Porosity	%	72.25	48.64	61.99
Degree of saturation	-	97.58	103.42	99.19
Wet Bulk Density	lb./ft^3	91.25	119.76	103.28
Dry Bulk Density	lb./ft^3	47.26	88.77	65.10

Figure 3 - De-airing process required for the determination of soil specific gravity.

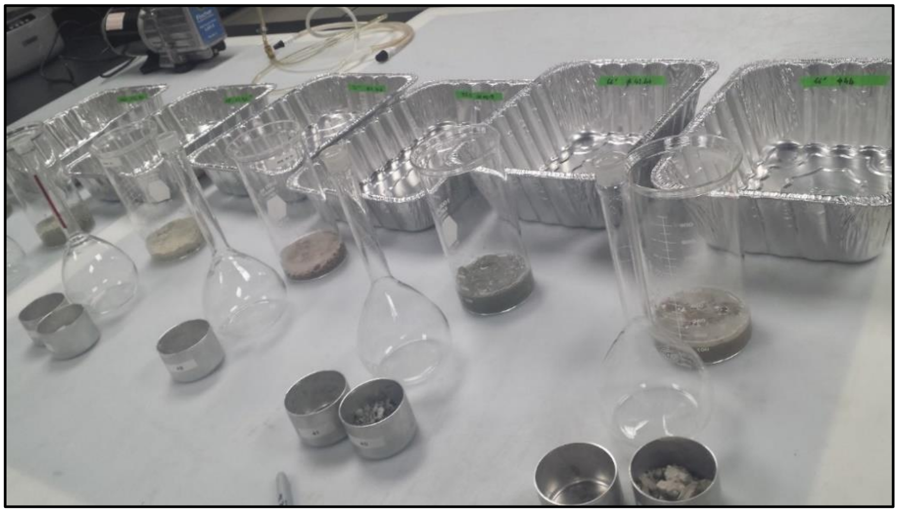


Figure 4 - Weighted soil specimens ready for soil property testing.

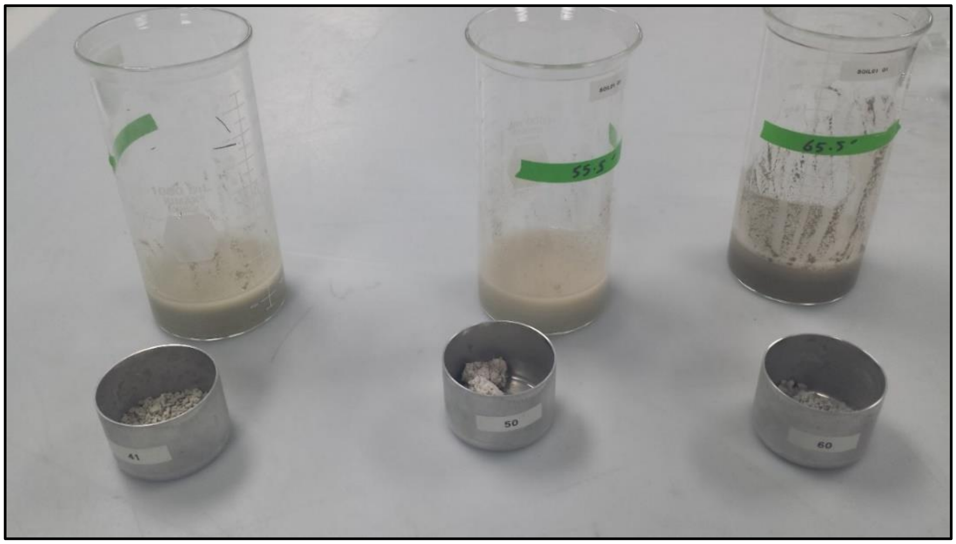


Figure 5 –Soil specimens prepared for hydrometer testing.

Figure 6 – Extruded soil rings for bulk density determination.

2.1.3 Chemical Composition of Soil Extracts

2.1.3.1 Determination of Moisture Content of Soils at Various Depths

Soil moisture for the soil rings used in the diffusion tests was measured in rings of the same California Tube used for the diffusion testing. The ASTM D2216-19 method was used for soil moisture determination and all samples were tested in duplicates. For the test, a wet soil sample was placed in an aluminum dish and weighed. Next the dish containing the sample was placed in the oven at 105°C for 24 hours. After 24 hours, the dried soil was weighed, and the moisture content was calculated using Equation 1 for wet soil basis and Equation 2 for dry soil basis expressions.

Equation 1 – Moisture content determination formula in wet basis.

$$Moisture\ content\ (\%) = \frac{Mass\ of\ wet\ soil - Mass\ of\ Dry\ Soil}{Mass\ of\ Wet\ Soil} \times 100$$

Equation 2 – Moisture content determination formula in dry basis.

$$Moisture\ content\ (\%) = \frac{Mass\ of\ wet\ soil - Mass\ of\ Dry\ Soil}{Mass\ of\ Dry\ Soil} \times 100$$

2.1.3.2 Determination of Chemical Constituents of Soil Using Soil Extraction

Extraction of the soil samples with high quality deionized water was performed to determine the amount of contaminants present in the soil. It has been established by past research that perchlorate and chlorate are highly soluble ions and can be extracted by multiple rinsing with deionized water. The same extraction procedure was applied for all of the test samples. Sometimes the amount of soil and water used in the extraction was changed to accommodate expected higher concentrations of contaminants (Table 3). In the test, the wet sample was weighed and transferred to a 250 ml plastic centrifuge bottle. Deionized (DI) water was added to the centrifuge bottle and the contents of the bottles were mixed well until a solution was formed. After mixing, the tubes were centrifuged at 3,500 rpm for 30 minutes at 24 °C. Following centrifugation, the liquid phase was decanted and filtered, and its volume was measured. The soil phase (i.e. soil pellet) remained at the bottom of the centrifuge tube. The extraction procedure was repeated two more times by adding deionized water to the remaining soil pellet, mixing, and centrifuging it again. Therefore, in total, most soil samples were extracted with deionized water three times. The filtered extracts were analyzed for the contaminants of concern. The combined analysis of all extracts was used, along with the volume decanted, to compute the total mass of contaminants present in each soil ring. Table 3 shows all of the samples that were extracted, as well as their masses, and volume of deionized water used.

Table 3 – Weighed soil mass duplicates and DI water volume used for soil extraction for each type of soil tested.

Sample Type/ Depth	Duplicate	Soil mass (g)	DI water added (mL)
PZ-1M/ 46.5’	D1	50.1210	100
	D2	50.1347	100
PZ-2M/ 55.5’	D1	50.4959	100
	D2	50.3372	100
PZ-2M/ 56’	D1	25.2939	25
	D2	25.3564	25
PZ-2M/ 65’	D1	25.3842	25
	D2	25.329	25
PZ-2M/ 66.5’	D1	50.2754	100
	D2	50.0074	100

2.2 Groundwater Sample Composition

Groundwater from the PZ-1M and PZ-2M locations in the NERT site were used in this study and provided by Ramboll. Both water samples were tested for sulfate (SO_4^{-2}), chloride (Cl^-), perchlorate (ClO_4^-), chlorate (ClO_3^-) and nitrate (NO_3^-). Advection and diffusion tests were performed with the correspondent water for each soil sample tested.

2.3 Diffusion Tests

2.3.1 Diffusion Chamber Design

Six diffusion chambers were designed and built for the diffusion tests. The design followed that used by Vilks and Miller (2007) for diffusion through rocks (Figure 7).

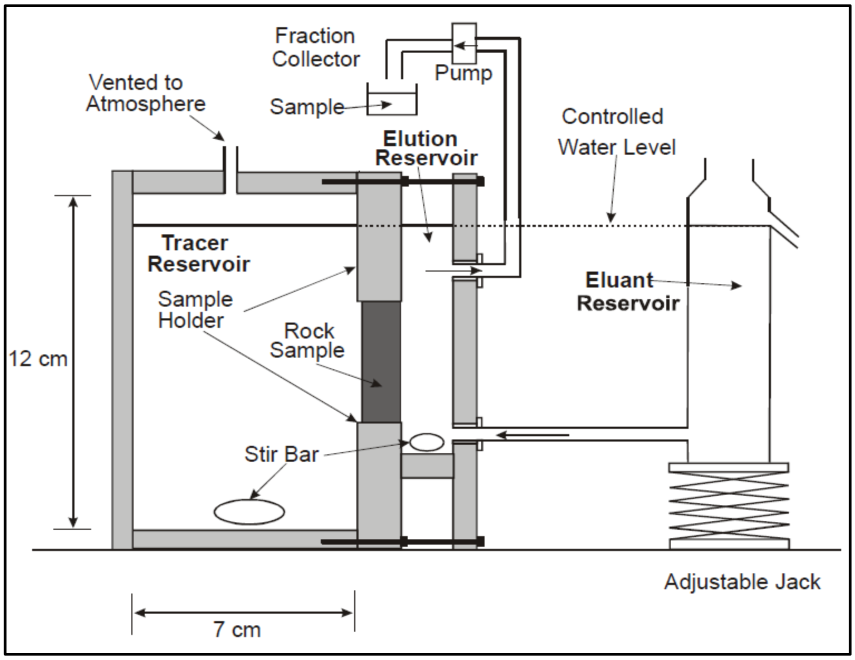


Figure 7 – Diffusion chamber's schematic drawing proposed by Vilks and Miller (2007), showing the division and measures for each chamber and setup arrangement.

The diffusion chambers were built in acrylic and were composed of three chambers (Figure 8). The first chamber stores the tracer solution (tracer chamber), the second the soil sample (soil chamber), and the third the elution solution (elution chamber). The sample holding chamber has an opening that is 2.5 inches in diameter and 1.0-inch-thick to accommodate the soil ring from the California tubes; all chambers have the same length and height, at 5.7 inches for both measures. The width of the first chamber is of 3.3 inches, and that of the third chamber is 1.5 inches. Four long screws are fitted to the first chamber to hold all of parts together when joined at the center (Figure 9). The volumes of the tracer and elution chambers are 1.0 and 0.3 liters, respectively. The soil sample holding chamber has a volume of 0.06 liters and holds a soil sample that is 2.5 inches in diameter and 1.0 inch thick.

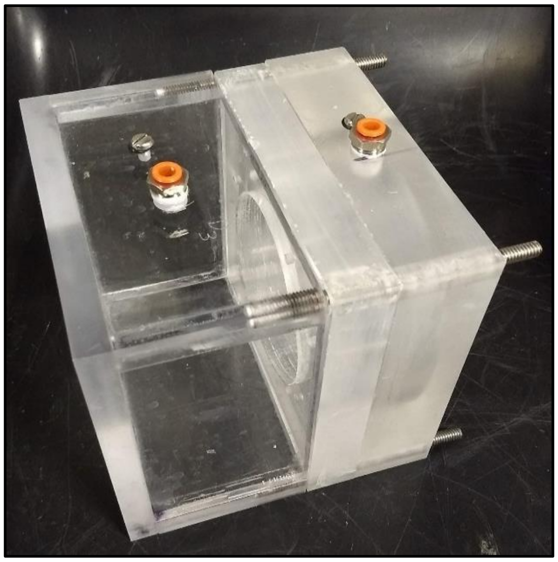


Figure 8 - Picture of all three empty acrylic chambers placed together connected by four screws.

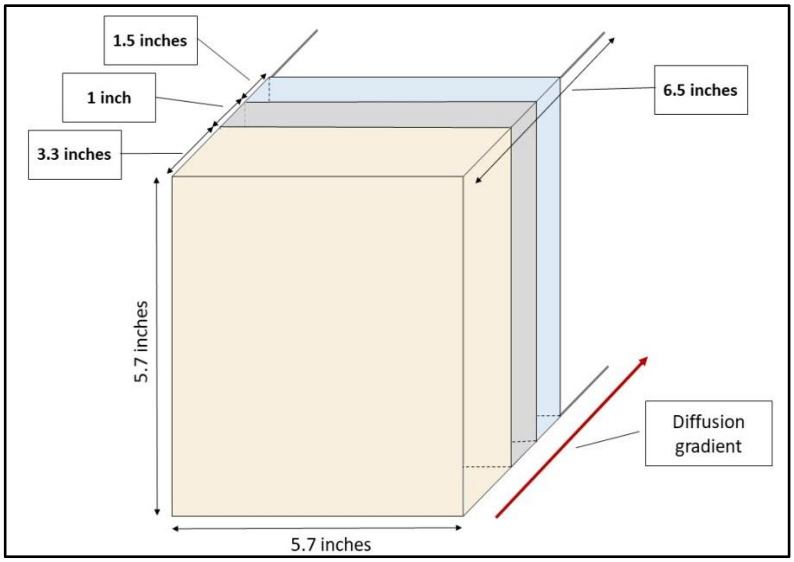


Figure 9 – three chamber diffusion cells showing the divisions for each chamber, their dimensions and the direction of the diffusion gradient.

Chamber 1: Tracer Solution Chamber

The first chamber, as illustrated in Figures 10 and 11, is the one responsible for the storage of the tracer solution (contaminated groundwater for this study). The chamber storage capacity, when attached to the other chambers, is approximately one liter. The chamber has two orifices at its top, one with a hose connector, and a small one to release the air while filling.

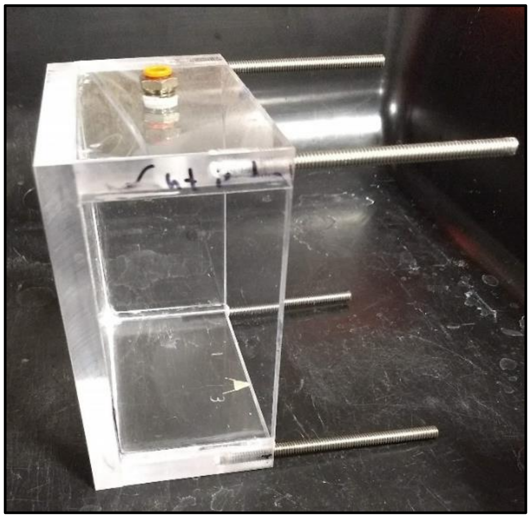


Figure 10 - Tracer solution chamber built in acrylic with four long screws to hold the other parts of the set up together.

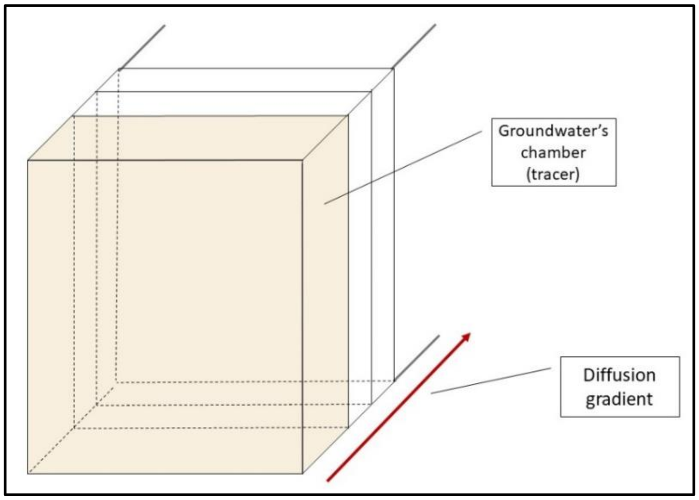


Figure 11 – Diffusion chamber set up with the tracer solution chamber and the direction of the diffusion gradient shown.

Chamber 2: Soil Sample holder

The second chamber (Figure 12) was machined to hold the soil ring sample. The chamber is composed of an acrylic block with a circular cavity in its center. This block stays positioned in the middle of the other two chambers (Figure 13). The groundwater from the first chamber, through the diffusion gradient, reaches the soil sample placed in the acrylic block. The diffusion happens through the soil, and the groundwater is responsible for the transport of major ions. If the ions contained in the soil ring are soluble in water, like perchlorate and chlorate, they will be transported to the elution chamber.

In the case of the chamber built by Vilks and Miller (2007) and used as reference for this study, the tracer elements are contained in the solution placed in the tracer chamber; in the case of this study, the source of tracer is the soil sample itself. By using diluted groundwater of the site in the tracer and eluent chambers, one expects the concentration of ions to increase in in the chambers because of diffusion of ions from the soil into the solution phase.

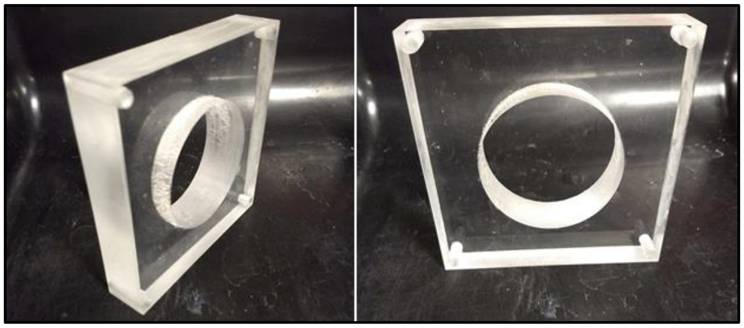


Figure 12 – Acrylic block machined to hold the soil ring sample in its center; soil chamber is attached between the tracer and elution chambers.

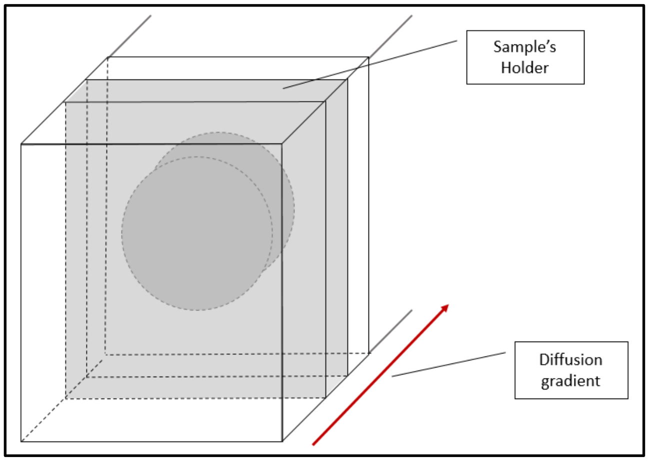


Figure 13 – Diffusion chamber setup showing the position of the sample holder in the diffusion apparatus.

Chamber 3: Elution Chamber

Figure 14 illustrates the third chamber that stores the eluted solution. A circular opening was machined inside the acrylic block. The circular opening, with 4 inches diameter, had to be larger than the sample size to assure all of the water flowing through the sample is collected. The elution chamber storage capacity is approximately 0.3 liters. Similar to the first chamber, the third chamber also has the two ports on its top. On the side, there is one port to which tubing can be connected in order to attach the chamber to the eluent reservoir to fill the chamber when samples are collected (Figure 15). Such a connection maintains the water level, and therefore, the gradient stays the same in both chambers, when samples are collected.

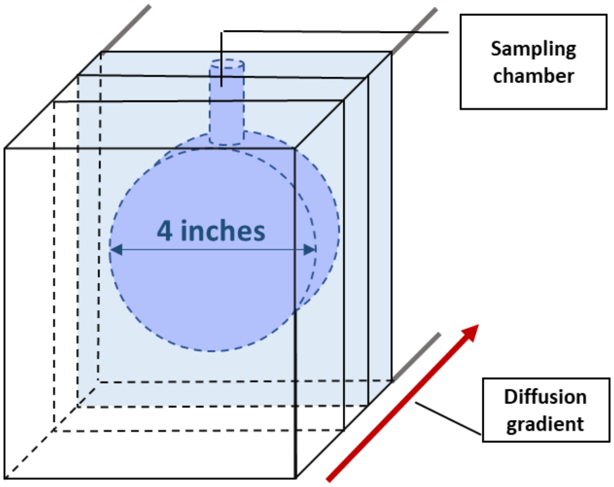


Figure 14 – Diffusion chamber setup showing the position of the eluent sampling chamber in the apparatus.

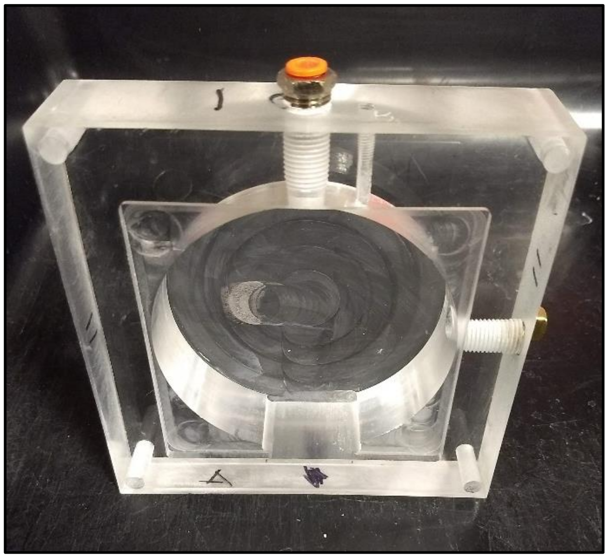


Figure 15 – Picture of the eluent chamber built in acrylic, showing the interior circular sampling chamber and the magnetic stirring bar in the compartment.

Within the third chamber on the bottom, there is a small compartment to hold a magnetic stirring bar to mix the contents of the chamber constantly. A stirring bar is also present in the first chamber. It is important that all of the solutions inside the chamber are mixing continuously in order to provide homogeneous concentrations. For the tests, the entire set-up is placed on top of a magnetic stirring base to promote mixing (Figure 16).

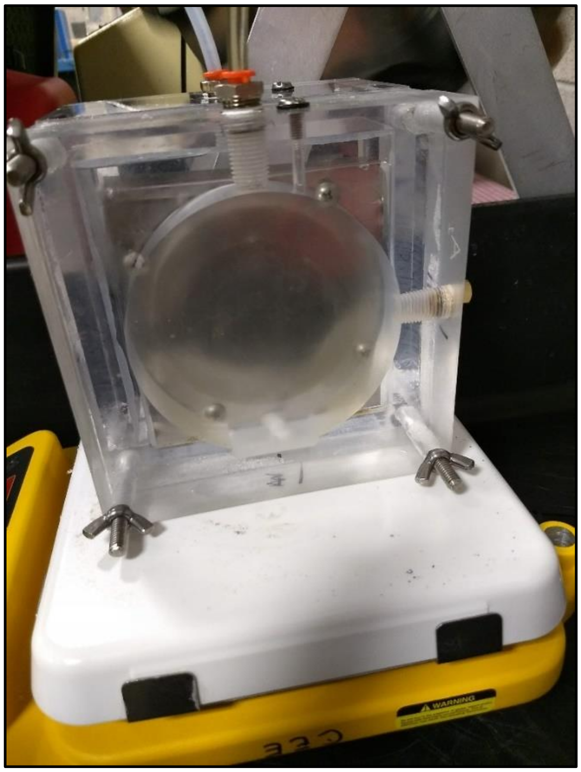


Figure 16 – Diffusion apparatus placed on a magnetic stirring plate with magnetic stirring bars inside the chamber.

Eluent Chamber

A filling reservoir glass bottle (Mariotte Bottle) is attached to the elution chamber (third chamber) through silicone tubing (Figure 17). The bottle is closed by a rubber stopper and fitted with a pipet to allow the entrance of air, so that a constant flow of elution groundwater is delivered when samples are taken. The bottle is placed on an adjustable screw-jack so that water levels can be regulated during the diffusion tests to achieve the desired gradient, depending on the desired test scenario.

Figure 17 – Final diffusion chamber setup for the diffusion test, using a Mariotte Bottle to fill the eluent reservoir.

2.3.2 Attachment of Soil Sample to the Chamber

To attach the sample to the acrylic block, it was necessary to apply glue between the soil sample and the block (Figure 18) to avoid water from percolating around the sample. .

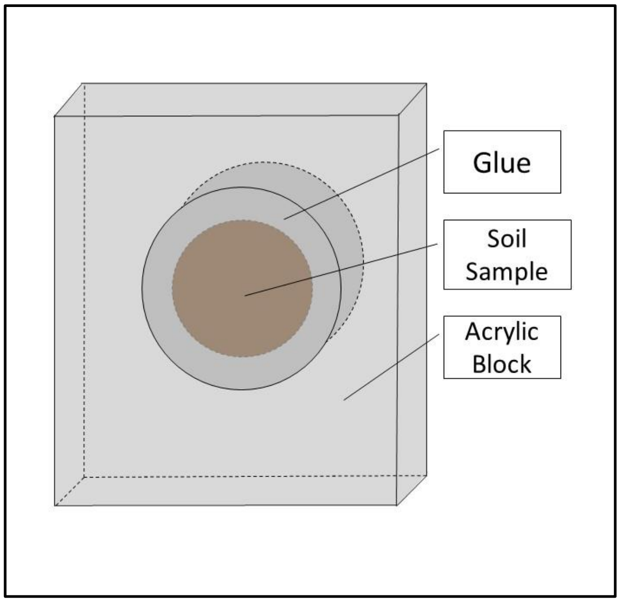


Figure 18 – Sample holder filled with the soil sample attached by the silicone glue.

Figure 19 – Specifications of the silicone glue used to attach the soil to the acrylic block.

Figure 19 shows the first silicone glue type selected to glue the soil sample to the chamber. Compared to the study of Vilks and Miller 92007) that used hard rocks, in this study the samples are silty-clayey soils that do not have the mechanical stability of a hard rock sample. Therefore, to hold samples in place, a final metal screen grid was used. The first soil attachment trial was to evaluate if the soil sample could be glued to the chamber without leaving space for water transport, except through the surface of the soil sample. The tested glue was effective in holding the sample, but ineffective in promoting good sealing, since bubbles and empty spaces were present around the sample (Figure 20).

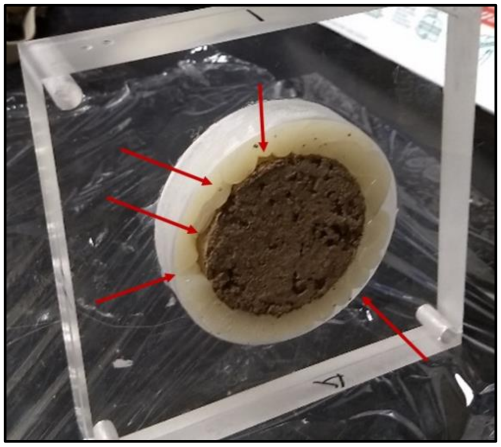


Figure 20 – Soil sample attached to the acrylic structure showing empty spaces in the silicone glue layer.

Another trial was performed with the silicone glue applying it in layers and spreading each layer with a metal spatula. The attachment was better than the first one, but small bubbles and small empty spaces were present in the silicone layer (Figure 21). After the glue was applied to the sample it was necessary to wrap the acrylic block with plastic film to avoid drying. It took 24 hours to completely dry.

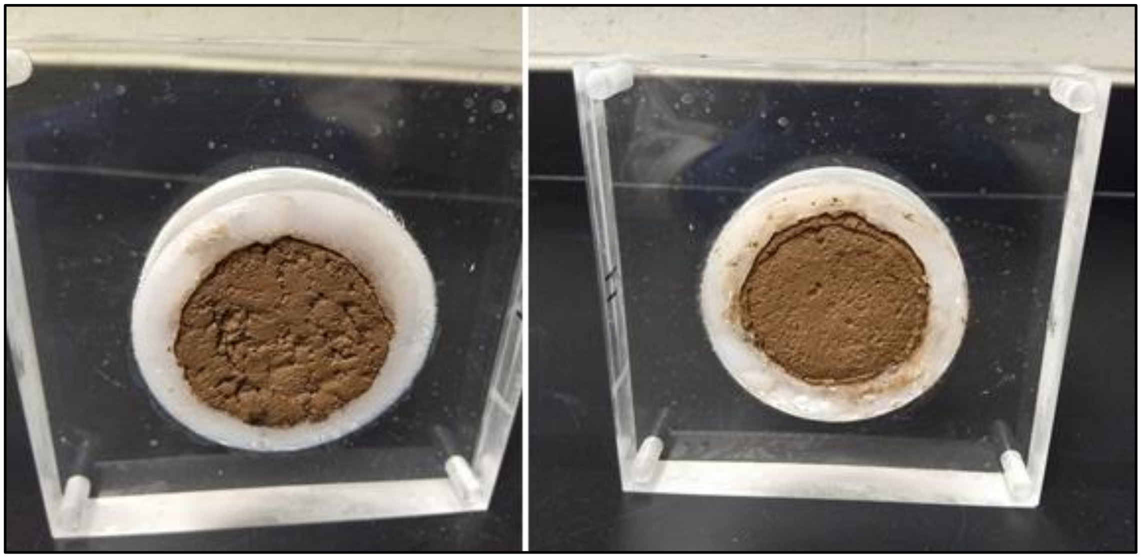


Figure 21 - Second test of soil sample attachment using silicone glue; attachment still shows some empty spaces between the soil and the acrylic block.

Another trial was performed using concrete caulk glue (Figure 22) to attach the soil ring to the diffusion apparatus. This adhesive has the advantage of being very spreadable and does not require additional attention to settle.

Figure 22 – Specifications of the concrete & masonry adhesive used to attach the soil samples to the diffusion chamber.

Soil sample attachment with the concrete adhesive was very efficient. Figure 23 shows the attachment with no bubbles or empty spaces between the sample and the chamber. This method was used to attach the soil samples for all advection and diffusion tests reported here.

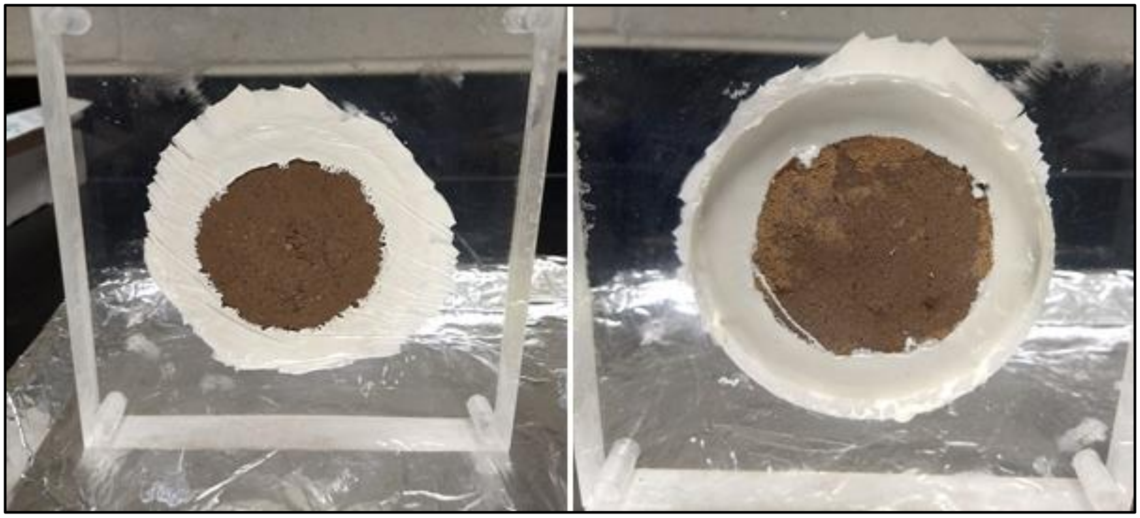


Figure 23 – Soil sample attachment to the sample holder using concrete caulk adhesive.

The drying time was the only concern regarding the concrete adhesive, as it dries more efficiently when in contact with the air. However, when exposed to the atmosphere, the adhesive dries and shrinks damaging the seal (Figure 23-right side). To solve this issue, a slightly wetted sponge was placed on top of the soil sample and the holder was then covered with plastic film (Figure 24). It required about three days to dry the concrete adhesive. The sponge was efficient to maintain the original moisture of the sample and to help the adhesive to dry faster. It took about one day to dry using this method.

Figure 24 – Soil sample attached to the support protected by the damp sponge and wrapped in a plastic film during the drying period.

After some trials, it was noticed that some of the glue was being deposited on the other side of the soil sample, reducing its surface area. To avoid this issue, a hybrid approach was used with both glue types. In the bottom of the empty space, between the sample and the block, the silicone glue was applied until half of the space was filled. The sponge was placed on top of the sample while the silicone layer was drying (around 30 minutes). After the silicone was almost dry, the concrete adhesive was applied to fill the remaining space of the block. The sponge was kept on the top of the sample, and the entire block was wrapped in plastic film. To ensure complete drying, the block was left to dry for about 24 hours. After drying the blocks with the sample were ready to be used.

To ensure that no sample fragment was released from the support, it was decided to use a perforated stainless-steel screen (McMaster-Carr). The screen used has a hole diameter of 0.006” and a 27% opening; it was fixed on both sides of the acrylic block and, held by four screws on each side (Figures 25 and 26).

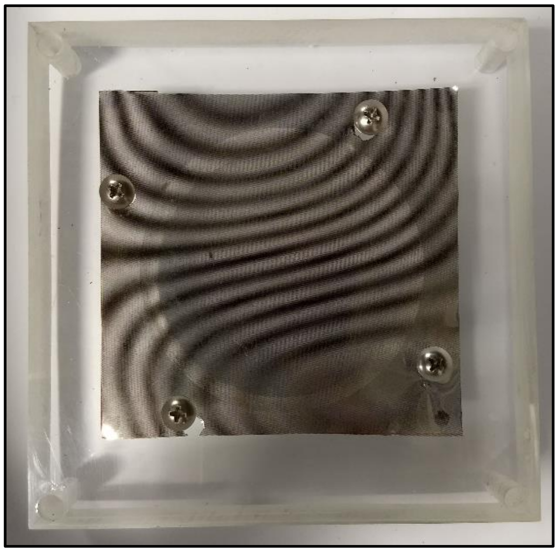


Figure 25 - Stainless steel screen (McMaster Carr) with a diameter of 0.006” and a 27% opening used to avoid any fragment release.

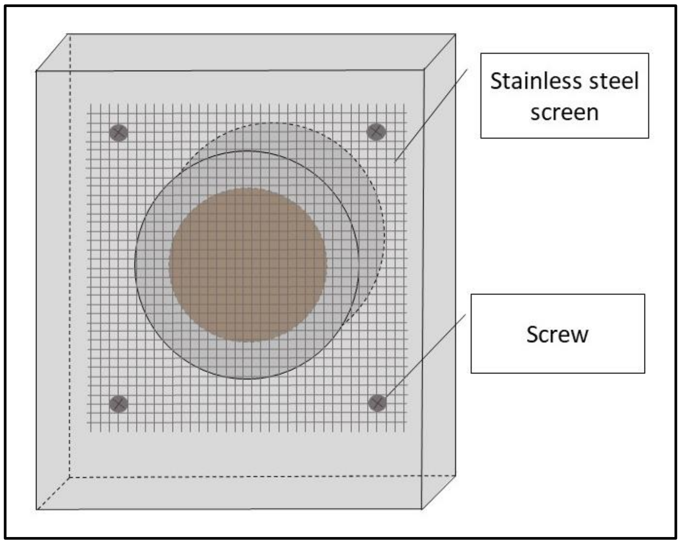


Figure 26 - Drawing of the sample holder with the screen on to protect the soil sample.

2.3.3 Diffusion Tests

For the diffusion tests, soil rings from the California Tubes were attached to the chamber as described under 2.2. After covering the samples with a screen, the soil sample block chamber was attached to the other chambers using screws. Both chambers were filled with diluted groundwater. It was necessary to dilute the groundwater because the concentration of the contaminants of interest in the soil was not very high. The goal was to be able to document an increase in contaminant concentration due to the diffusion of ions from the soil into the elution chamber.

The Mariotte Bottle was attached to the elution chamber and contained the diluted groundwater. The same water level between the two chambers was established using the Jack-screw table with the Mariotte Bottle. At pre-determined time intervals, 20 ml samples were collected from the elution chamber and the Mariotte bottle replaced that volume in order to assure that the gradient remained the same. A total of four diffusion tests were performed following all of the previously described steps. For all of the tests the collected sample volumes were 20 mL. The parameters that were changed in each test are described in Table 4.

Table 4 – Parameters used for diffusion tests performed.

Test Performed	Sample type/ Depth	Sample Mass(g)	Groundwater/ Dilution Factor	Sampling Chamber	Start date	End Date
First Diffusion Test	PZ-1M/ 46.5’	117.94	PZ-1M/ 10x	Elution	12/06/19	Still running
	PZ-2M/ 56’	144.70	PZ-2M/ 1000x	Elution	12/06/19	Still running
Second Diffusion Test	PZ-1M/ 46.5’	115.15	PZ-1M/ 1000x	Tracer	03/04/19	Still running
	PZ-2M/ 56’	122.00	PZ-2M/ 1000x	Tracer	03/04/19	Still running

2.4 <u>Advection Tests</u>

2.4.1 Advection Test Setup

The advection tests used a hydraulic head gradient to generate a flow from the tracer to the elution chamber. The vertical gradient target for the diffusion test was 0.1 and it was given to UNLV by Ramboll as a value measured at the NERT site in the area of the study. The soil rings from the California Tube are one-inch thick (2.54 cm), therefore, the target difference in water level between the tracer and elution chamber would be 2.54 *0.1= 0.254 cm. The chamber set-up was maintained in the same way as the diffusion test; however, the side port in the third chamber (elution chamber) was closed. In addition, a V-notch weir chamber was added to the set-up in order to assist with maintaining the desired gradients constant during the experiments. The V-notch weir chamber is fitted with a gray plastic square chamber, as well as, PVC slotted well casing to distribute the flow evenly, and an aluminum V-notch weir attached to the square chamber wall to assure constant water level in the chamber. The soil sample attachment was performed the same way as previously described for the diffusion tests.

As described earlier, a stable water level reservoir was used to create the desired gradient (Figure 27). The reservoir contains an overflow system to keep the water level constant and a recirculation loop where the overflow water returns to the storage container (Figure 28). The reservoir was placed on an adjustable jack to adjust the desired head. The first chamber (tracer chamber) was attached to the stable water level reservoir with plastic tubing. Tubing was also attached to the connector on the top of the third chamber (elution chamber) for the flow exit.

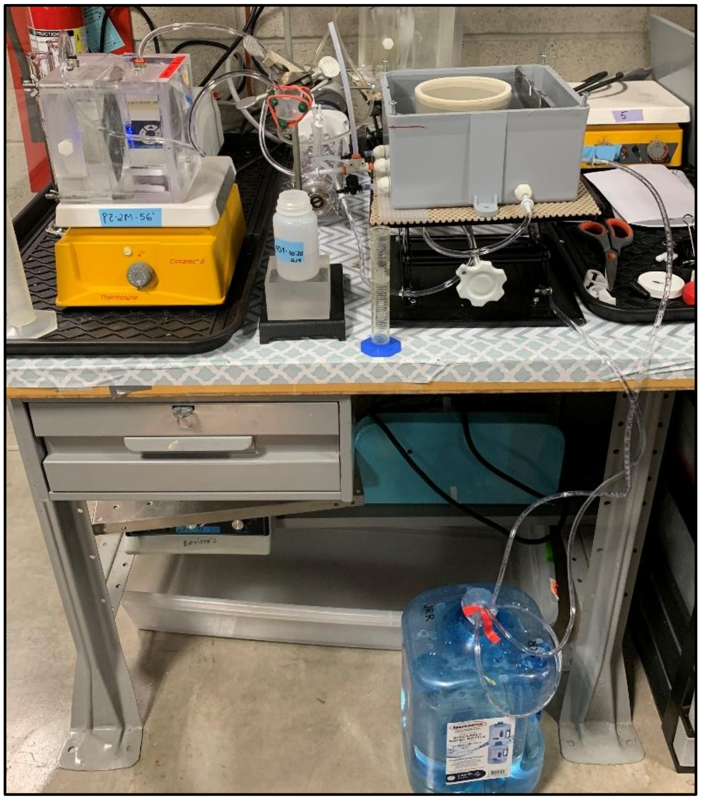


Figure 27 – Final advection test setup using the stable water level box connected to the chamber's arrangement.

Figure 28 – Stable water level reservoir used to create the gradient applied to the soil sample and its recirculation system.

Figure 29 shows the distance between the water level in the reservoir and the outlet flow; both measures were used to calculate the gradient using Equation 3. To hold the outlet tubing at a stable level, a plastic syringe was adapted and held by a clamp attached to a support.

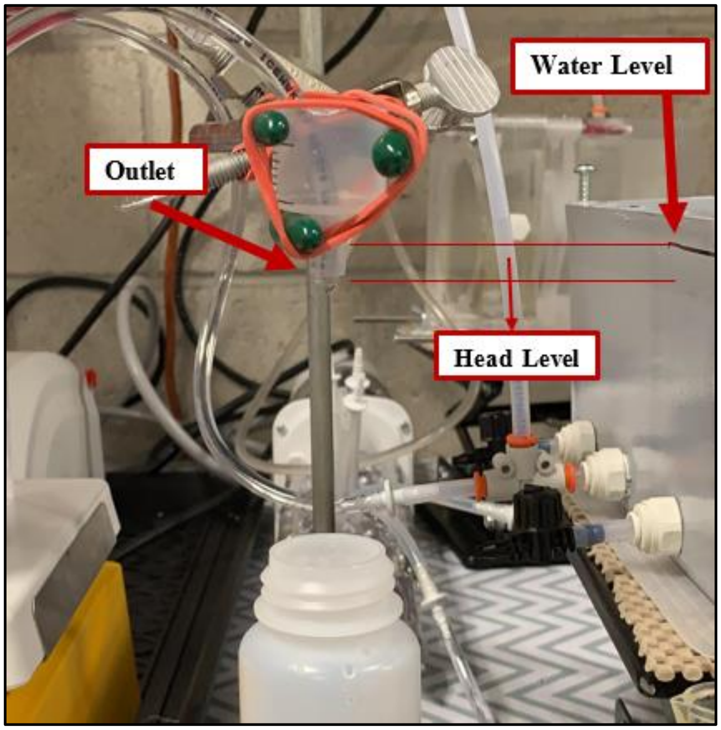


Figure 29 – Illustration of the head level determination using the distance between the water level and the outlet height.

Equation 3 – Gradient determination formula using the heal level over the soil thickness.

$$Gradient = \frac{Head\ Level\ (mm)}{Soil\ ring\ thickness\ (mm)}$$

2.4.2 Advection Tests Performed

For the advection tests, soil rings from the California Tubes were attached to the chamber as described under section 2.2. After covering the samples with a screen, the soil sample block chamber was attached to the other chambers using screws. Diluted groundwater was then filled into both chambers. It was necessary to dilute the groundwater because the concentrations of the contaminants of interest in the soil were not very high. In addition, it was necessary to assure that the concentrations of contaminants after diffusion were high enough to be detected by the analytical methods used. The goal was to be able to document a diffusivity of contaminants from the soil into the elution chamber. Because of the gradient applied in the diffusion chamber, it was expected that contaminants would move faster from the soil to the elution chamber.

A total of four advection tests were performed following all the previously described steps. The parameters that were used in each test are described in Table 5.

Table 5 –Parameters used for advection tests performed.

Test Performed	Sample type/ Depth	Sample Mass(g)	Groundwater/ Dilution Factor	Gradient	Start date	End Date
Advection Test	PZ-1M/ 46.5’	108.20	PZ-1M/ 2x	1.0	02/16/19	03/22/19
First Advection Test	PZ-2M/ 56’	125.10	PZ-2M/ 10x	0.2	02/09/19	02/14/19
Second Advection Test	PZ-2M/ 56’	133.00	PZ-2M/ 10x	7.4	03/19/19	04/03/19
Third Advection Test	PZ-2M/ 56’	134.00	PZ-2M/ 10x	0.6	03/25/19	03/26/2019

3 Results

3.1 Soil Characterization

3.1.1 Chemical and Physical Properties of Soil

3.1.1.1 Moisture Content

Table 6 shows the moisture content for the soils tested. Moisture contents shown in Table 6 were determined for California Tube from which soil rings were taken for the diffusion and advection tests. Sample PZ-1M has about 44% moisture. The moisture content of borehole samples PZ-2M is smaller varying from about 23% to 32.7% and, in general, it decreases slightly with depth, except for the 56' horizon.

Table 6 - Moisture content determination expressed on wet basis.

Sample type/ Depth	Duplicate	Aluminum dish (g)	Wet soil mass (g)	Dry soil mass (g)	Moisture content in wet soil basis (%)	Average Moisture (%)
PZ-1M/ 46.5'	D1	4.0447	30.1741	16.8757	44.07	43.91
	D2	4.0298	30.1659	16.9709	43.74	
PZ-2M/ 55.5'	D1	4.0263	30.3963	22.1032	27.28	27.43
	D2	4.0505	30.4823	22.079	27.57	
PZ-2M/ 56'	D1	1.7570	23.5418	15.7882	32.94	32.73
	D2	1.7234	29.0551	19.6067	32.52	
PZ-2M/ 65'	D1	1.7405	44.2138	34.259	22.52	23.41
	D2	1.7308	48.1775	36.464	24.31	
PZ-2M/ 66.5'	D1	3.9966	30.1323	22.1329	26.55	26.62
	D2	4.0603	30.1039	22.0692	26.69	

The moisture content, showed in Table 6, was calculated in the Environmental Engineering Laboratory of UNLV and expressed on a wet basis using the Equation 4.

Equation 4 – Moisture content determination in wet basis.

$$Moisture\ content = \frac{Mass\ of\ water}{Mass\ of\ wet\ soil} * 100$$

The moisture content was also quantified by the Soils Engineering Laboratory, as shown in the soils report (Appendix A), using the mass of water divided by the dry soil (Equation 5): and expressed on a dry basis.

Equation 5 – Moisture content determination in dry basis.

$$Moisture\ content = \frac{Mass\ of\ water}{Mass\ of\ dry\ soil} * 100$$

The moisture content calculated in the Environmental Engineering Laboratory was also converted into a dry basis and the comparison is shown in Table 7.

Table 7 - Moisture content of soils measured in various samples by two different laboratories.

	Environmental Engineering Laboratory % moisture		**Soils Engineering Laboratory % moisture**
	Wet soils basis	**Dry soil basis**	**Dry soil basis**
PZ-1M 46.5’	43.91	78.28	93.07
PZ-2M 55.5’	27.43	37.79	34.90
PZ-2M 66.0’	26.62	36.27	58.65

The soil from borehole PZ-1M showed the highest variation between the moisture content results on a dry basis. The samples of PZ-IM were taken from a thirty-inch long California Tube and the wax used to seal this tube did not work well and some drying was observed on the ends of the tube. The tube was cut using a saw to eliminate the dried ends, but still uneven quality was observed after extrusion. It is believed that contributed to the difference in moisture content observed in whole core.

For the PZ-2M borehole samples the difference in moisture content is not as drastic; however, some significant difference was observed for the 66’ horizon.

3.1.1.2 Chemical Composition of Soil Extracts

To determine the concentration of several contaminants of concern in the soil, three soil extractions were performed following the procedures described in Section 2.1.3. The volumes of liquid obtained for each extraction test are shown in Table 8.

Table 8 – Rinse volumes collected from triple soil extractions. All extractions were performed in duplicate samples (D1 and D2).

Sample type/ Depth	Duplicate	Extraction 1 (mL)	Extraction 2 (mL)	Extraction 3 (mL)
PZ-1M/ 46.5’	D1	86	98	98
	D2	86	98	98
PZ - 2M/ 55.5’	D1	92	100	100
	D2	94	99	99
PZ - 2M/ 56’	D1	28	28	28
	D2	27	27	28
PZ - 2M/ 65’	D1	22	28	28
	D2	22	28	28
PZ - 2M/ 66.5’	D1	90	96	100
	D2	90	97	99

Table 9 shows the concentrations of major targeted ions (i.e. sulfate, chloride, perchlorate, chlorate, and nitrate concentrations obtained from the soil extractions. The results revealed that PZ-2M samples are more contaminated with chlorate and perchlorate than PZ-1M samples; perchlorate and chlorate concentrations in PZ-2M are approximately 20 times and 300 times higher, respectively. The perchlorate and chlorate contamination is greatest between the 55.5’ – 65’ horizons.

As expected, the concentration of all the ions monitored decreased with the number of extractions, with the highest concentrations found in the first extract and the smallest concentrations found in the third extract. Nitrate concentrations for all samples were relatively low and below 1 mg N/L. The highest sulfate and chloride concentrations in the first extracts were about 275 mg/L and 102 mg/L, respectively.

Table 9 – Target contaminant concentrations found in soil extracts.

Sample type/ Depth	Extraction	Sulfate	Chloride	Perchlorate	Chlorate	Nitrate as N
Units	**-**	**mg/L**	**mg/L**	**ug/L**	**ug/L**	**mg/L**
PZ-1M/ 46.5’	1	159.00	82.50	81.00	14.50	0.19
	2	52.40	28.30	120.00	10.90	0.14
	3	13.85	15.55	100.00	11.50	0.14
PZ - 2M/ 55.5’	1	154.30	102.40	2,100.00	4,350.00	0.65
	2	63.00	29.85	705.00	1,500.00	0.22
	3	25.10	7.80	137.00	370.00	0.08
PZ - 2M/ 56’	1	275.70	102.00	100.00	3,400.00	0.44
	2	168.80	29.90	85.00	1,600.00	2.50
	3	35.80	9.10	420.00	300.00	2.50
PZ - 2M/ 65’	1	275.00	86.60	1,600.00	2,400.00	0.56
	2	144.70	35.60	480.00	780.00	0.36
	3	37.50	9.50	96.00	180.00	0.26
PZ - 2M/ 66.5’	1	266.65	50.30	135.00	210.00	0.36
	2	135.30	19.90	100.00	101.00	0.09
	3	61.90	7.55	100.00	36.00	0.11

The total mass of contaminants (Equation 6) was calculated multiplying the volume of the extracts obtained (Table 8) times the concentration of the contaminants (Table 9).

Equation 6 – Total mass of contaminants obtained from the performed soil extractions.

$$Total\ mass\ of\ contaminants = Concentration\ of\ contaminant \times volume$$

The overall mass of contaminant extracted was computed by adding the masses of all three extractions. The same procedure was applied to the replicate samples. Table 10 shows the values for the calculated masses of contaminants and Table 11 depicts the concentration of contaminants per gram of soil extracted, computed using Equation 7.

Table 10 - Total mass of contaminants extracted from soil samples of PZ-1M and PZ-2M and soil mass present in each soil cake (California Tube rings) tested.

Sample ID	Contaminant	Total mass of contaminants			Soil sample mass (g)	
-	-	**Replicate 1**	**Replicate 2**	**Units**	**Replicate 1**	**Replicate 2**
PZ-1M-46.5'	Perchlorate	24.93	32.12	ug	50.12	50.13
	Chlorate	3.28	3.60	ug	50.12	50.13
	Nitrate as N	0.04	0.04	mg	50.12	50.13
	Nitrate as NO3	0.20	0.19	mg	50.12	50.13
	Sulfate	20.17	20.16	mg	50.12	50.13
	Chloride	11.39	11.40	mg	50.12	50.13
PZ-2M-55'	Perchlorate	270.60	287.49	ug	50.50	50.34
	Chlorate	603.20	577.46	ug	50.50	50.34
	Nitrate as N	0.09	0.09	mg	50.50	50.34
	Nitrate as NO3	0.42	0.38	mg	50.50	50.34
	Sulfate	23.18	23.02	mg	50.50	50.34
	Chloride	13.33	13.19	mg	50.50	50.34
PZ-2M-56'	Perchlorate	16.94	0.00	ug	25.29	NA*
	Chlorate	148.40	0.00	ug	25.29	NA
	Nitrate as N	0.15	0.00	mg	25.29	NA
	Sulfate	13.45	0.00	mg	25.29	NA
	Chloride	3.95	0.00	mg	25.29	NA
PZ-2M-65'	Perchlorate	51.33	0.00	ug	25.38	NA
	Chlorate	79.68	0.00	ug	25.38	NA
	Nitrate as N	0.03	0.00	mg	25.38	NA
	Sulfate	11.15	0.00	mg	25.38	NA
	Chloride	3.17	0.00	mg	25.38	NA
PZ-2M-66'	Perchlorate	32.20	31.30	ug	50.28	50.01
	Chlorate	31.23	33.23	ug	50.28	50.01
	Nitrate as N	0.06	0.04	mg	50.28	50.01
	Nitrate as NO3	0.16	0.15	mg	50.28	50.01
	Sulfate	42.25	44.17	mg	50.28	50.01
	Chloride	7.07	7.32	mg	50.28	50.01

*NA = not available (duplicates not performed).

Equation 7 – Mass concentration formula used to quantify the soil contaminants expressed in mass of contaminants per mass of wet soil.

$$Mass\ concentration\ of\ contaminants = \frac{Total\ mass\ of\ contaminant}{mass\ of\ wet\ soil}$$

Table 11 - Contaminants mass concentration, expressed as mass of contaminant per mass of soil for three extractions with deionized water.

Sample type/ Depth	Sulfate	Chloride	Perchlorate	Chlorate	Nitrate as N
Units	**mg/g of wet soil**	**mg/g of wet soil**	**ug/g of wet soil**	**ug/g of wet soil**	**mg/g of wet soil**
PZ-1M/ 46.5’	0.40	0.23	0.57	0.07	0.0009
PZ - 2M/ 55.5’	0.46	0.26	5.54	11.71	0.0018
PZ - 2M/ 56’	0.53	0.16	0.67	5.87	0.0060
PZ - 2M/ 65’	0.44	0.12	2.02	3.14	0.0012
PZ - 2M/ 66.5’	0.86	0.14	0.63	0.64	0.0010

Figures 30 and 31 compare the concentrations of contaminants in the various horizons of PZ-1m and PZ-2M soil samples. Detailed computations are show in in Appendix B.

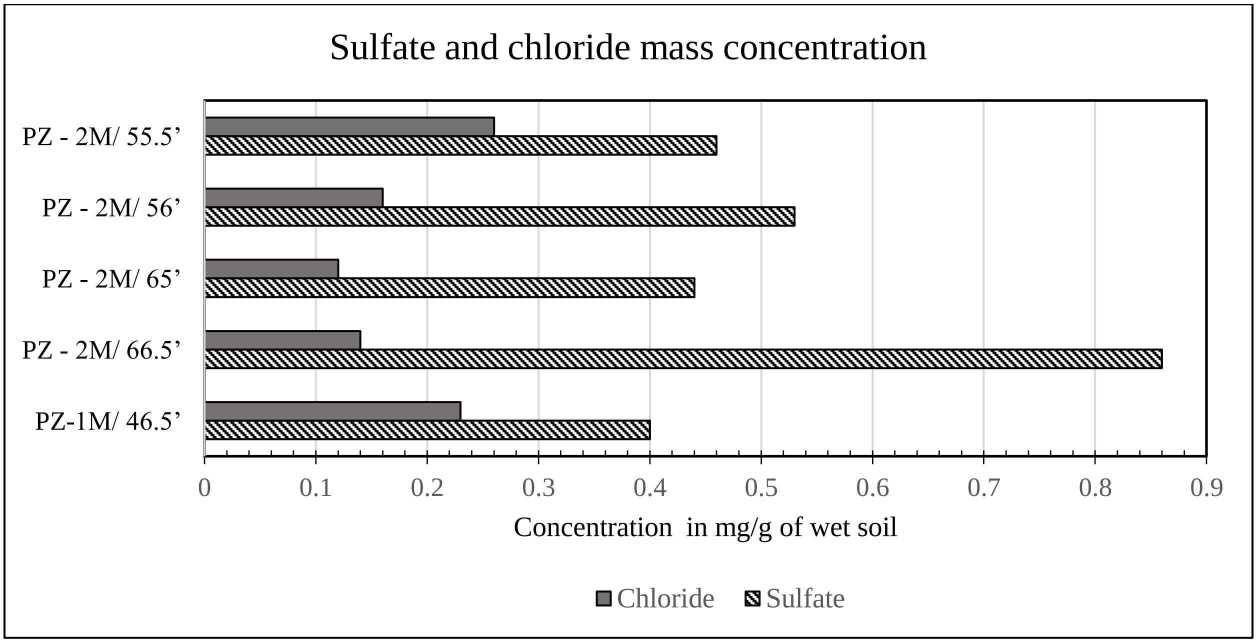


Figure 30 - Sulfate and chloride mass concentration at different soil horizons for PZ-1M and PZ-2M soils.

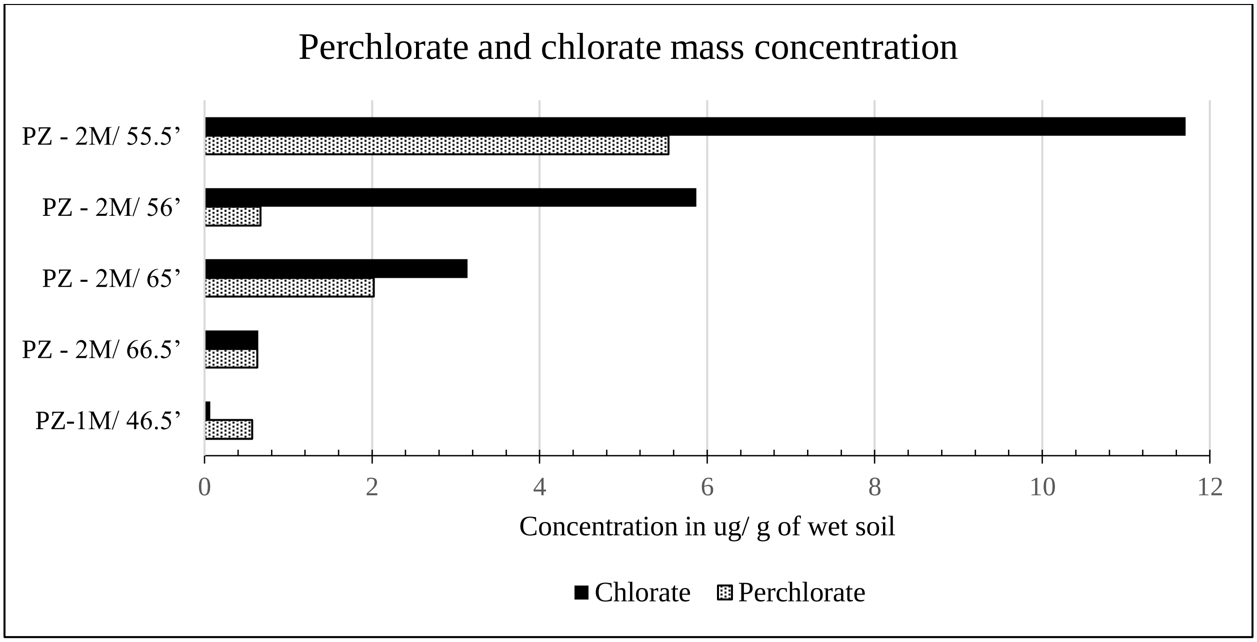


Figure 31 - Perchlorate and chlorate mass concentration at different soil horizons for PZ-1M and PZ-2M soils.

Chloride content varies from 0.12-0.26 mg/g wet soil with highest levels found at PZ-1M and PZ-2 M 55.5’ horizon. Sulfate levels vary from 0.4-0.86 mg/g wet soil and the level decrease with depth for PZ-2M soils. The highest levels are found at PZ-1M. Perchlorate and chlorate levels are highest at PZ-2M and about 10 times higher than the levels found in PZ-1M. Perchlorate and chlorate levels in PZ-2 M decreases with depth with the highest levels found at PZ-2 M 55’ and 65’ horizons.

For all horizons of PZ-2M, higher levels of chlorate than perchlorate were found. Nitrate levels are very low in all tested soil samples.

For the diffusion and advection tests, it was necessary to calculate the expected contaminant concentrations in the elution chamber, if all contaminants present in the soil were eluted; these calculations were made only for the soil samples used in the tests (PZ-1M 46.5-feet deep and PZ-2M 56-feet deep). The results are shown in detail in Appendix B.

3.2 Chemical Composition of Groundwater

The measured contaminant concentrations for the raw groundwater and for all the prepared dilutions for the performed tests are shown in Table 12. Notice that analysis of nitrate, sulfate and chloride reflect very well the dilutions performed. However, for low levels of chlorate and perchlorate, the method detection limit plays a role, since it is reported as < 100 ug/L. As it will be discussed later, this fact impacts accurate measurements of diffusion for soil samples containing low levels of chlorate and perchlorate. That is, when the small amount of chlorate and perchlorate is released, the increase in concentration in the elution chamber may not be significant enough to overcome the decrease in sensitivity in the ion chromatography method used to measure chlorate and perchlorate.

Table 12 – Measured concentration of contaminants in the raw and diluted groundwater used in the diffusion tests.

Test	Groundwater type	Dilution Factor	Sulfate	Chloride	Perchlorate	Chlorate	Nitrate as N	Nitrate as NO_3
	Units	**-**	**mg/L**	**mg/L**	**ug/L**	**ug/L**	**mg/L**	**mg/L**
Raw	PZ-1M	Raw	840	410	380	340	0.15	0.67
Raw	PZ-2M	Raw	1,200	490	3,100	14,000	1.6	6.90
1st Diffusion Test	PZ-1M	10	88	44	< 100	52	< 0.11	< 0.5
	PZ-2M	1,000	1.3	0.60	< 100	15	< 0.11	< 0.5
2nd Diffusion Test	PZ-1M	1,000	1.9	0.75	< 100	< 100	< 0.11	< 0.5
	PZ-2M	1,000	4.4	1.3	< 100	26	< 0.11	< 0.5
Advection Test	PZ-1M	2	440	220	170	170	0.098	0.43
1st Advection Test	PZ-2M	10	110	45	330	1,400	0.16	0.70
2nd Advection Test	PZ-2M	10	120	49	300	1,400	0.12	0.55
3rd Advection Test	PZ-2M	10	120	50	330	1,500	0.19	0.83

The data reveal that the PZ-2M raw groundwater has a higher concentration of contaminants than that of PZ-1M and these findings correlate well with the soil extraction results. Perchlorate and chlorate concentrations in PZ-2M are about 10 times and 40 times higher, respectively. Sulfate levels were only 1.5 times higher in PZ-2M compared to PZ-1M. Chloride and nitrate levels in both wells were low.

3.3 **Diffusion Test Results**

3.3.1 First Diffusion Test

The first diffusion test was performed with two samples, PZ-1M 46.5-feet deep and PZ-2M 56-feet deep. The samples have similar contaminants levels, except that PZ-2M has higher chlorate (Table 10). The complete results for the first diffusion test are shown in Appendix C. All samples collected in the elution chamber were tested for sulfate, chloride, perchlorate and chlorate. Nitrate concentrations were analyzed only for PZ-2M sample because of the presence of higher concentration of nitrate in this sample.

The contaminant concentrations in the elution chamber for the two samples were similar. All chlorate and perchlorate readings were below the 100 ug/L detection limit, as already expected from the diluted groundwater results (Table 12). Figures 32 and 33 and 34 and 35 depict the sulfate and chloride concentrations in the tested soil with time and with cumulative sample volume taken.

Notice that the total volume of sample collected was 360 ml (PZ-1M) and 340 ml (PZ-2 M) which are about 26.2% and 26.1% of the total chamber volume. Computations were performed (Appendix D) to determine if the addition of fresh diluted groundwater, every time 20ml sample was taken, had an impact on the concentrations measured. The results will be discussed later in this report.

For PZ-1M, concentrations of sulfate increased from an initial 88 mg/L in the diluted groundwater to 150 mg/l within a few hours and then it started decreasing steadily to reach 85 mg/L within 33 days. After 33 days, the decrease was very slow and the concentration reached 44 mg/L after 122 days elution. The chloride diffusion showed very similar trend, even the sporadic peak at day 113. Chloride concentrations increased from 44 mg/L in the diluted groundwater to 75 mg/L within a few hours. Within 20 days chloride decreased to 44 mg/L and it remained at this level until the end of the test.

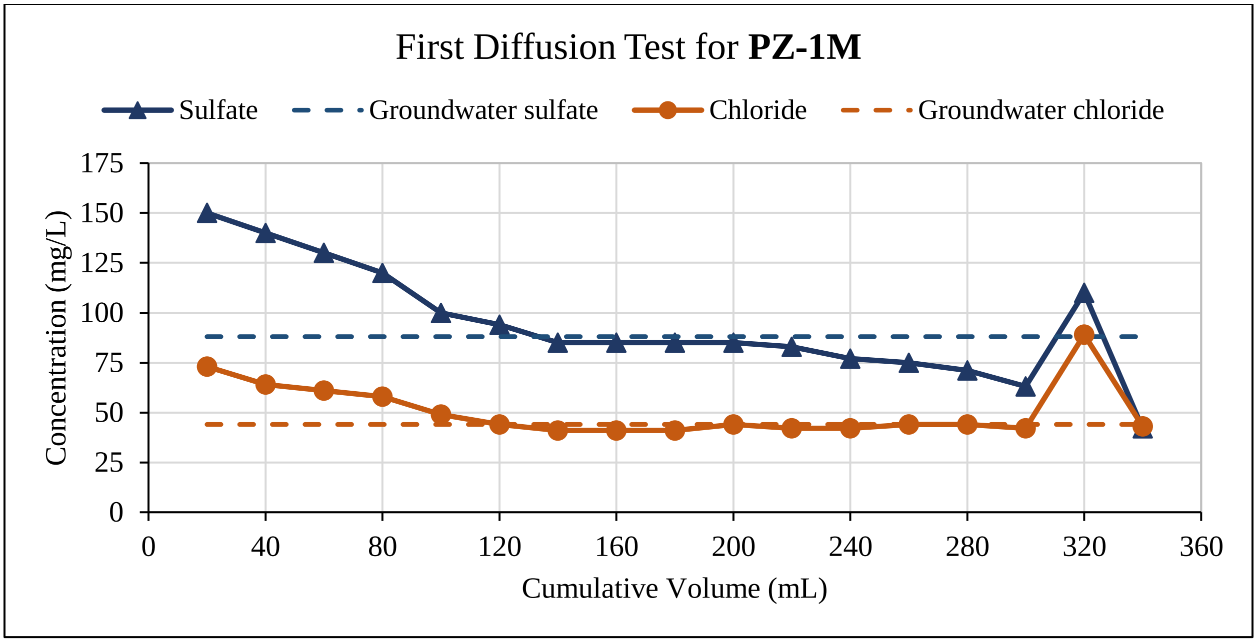


Figure 32 - Sulfate and chloride concentration versus sample volume for the first diffusion test performed using PZ-1M 46.5 feet deep sample.

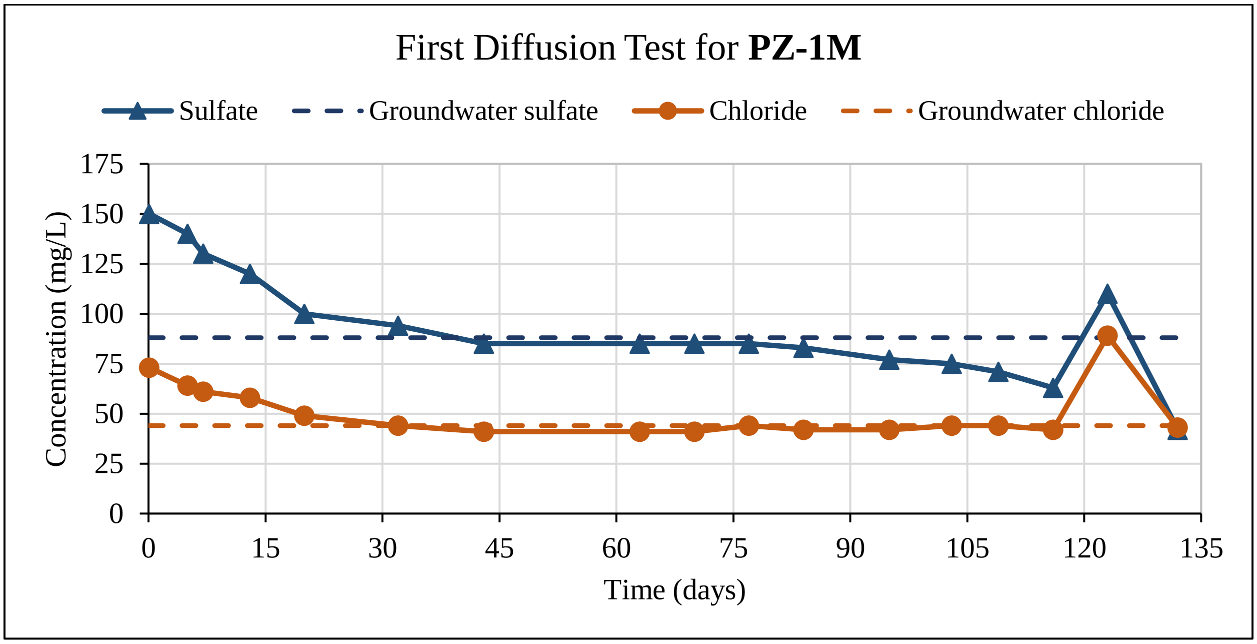


Figure 33 - Sulfate and chloride concentration over time for the first diffusion test performed using PZ-1M 46.5 feet deep sample.

For PZ-2M, a similar elution trend was observed for chloride and sulfate, as compared to PZ-1M. However, the elution was much slower. It took about 90 days for the sulfate concentrations to decrease from 73 to 23 mg/L and then stabilize. Chloride concentrations stabilized faster, after

60 days. Slower elution was expected from PZ-2M because it has smaller porosity (48.64%), as compared to PZ-1M (72.25%) (Table 2).

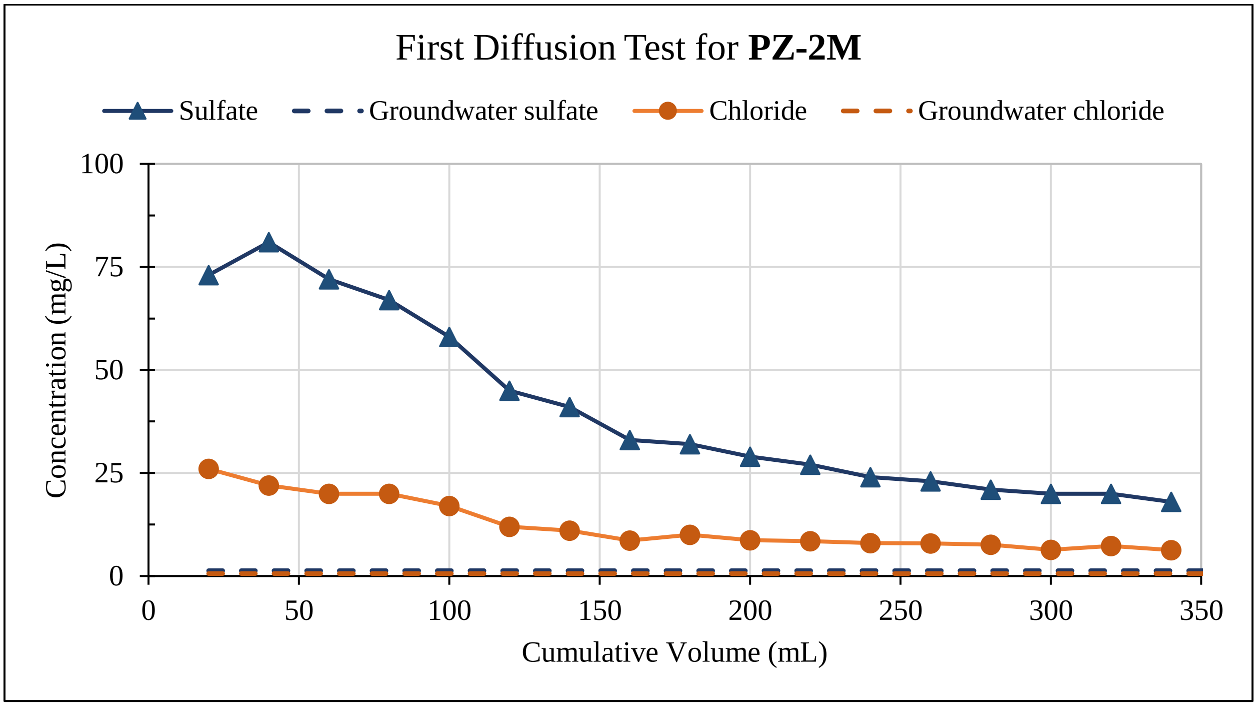


Figure 34 - Sulfate and chloride concentration versus sample volume for the first diffusion test performed using PZ-2M 56 feet deep sample.

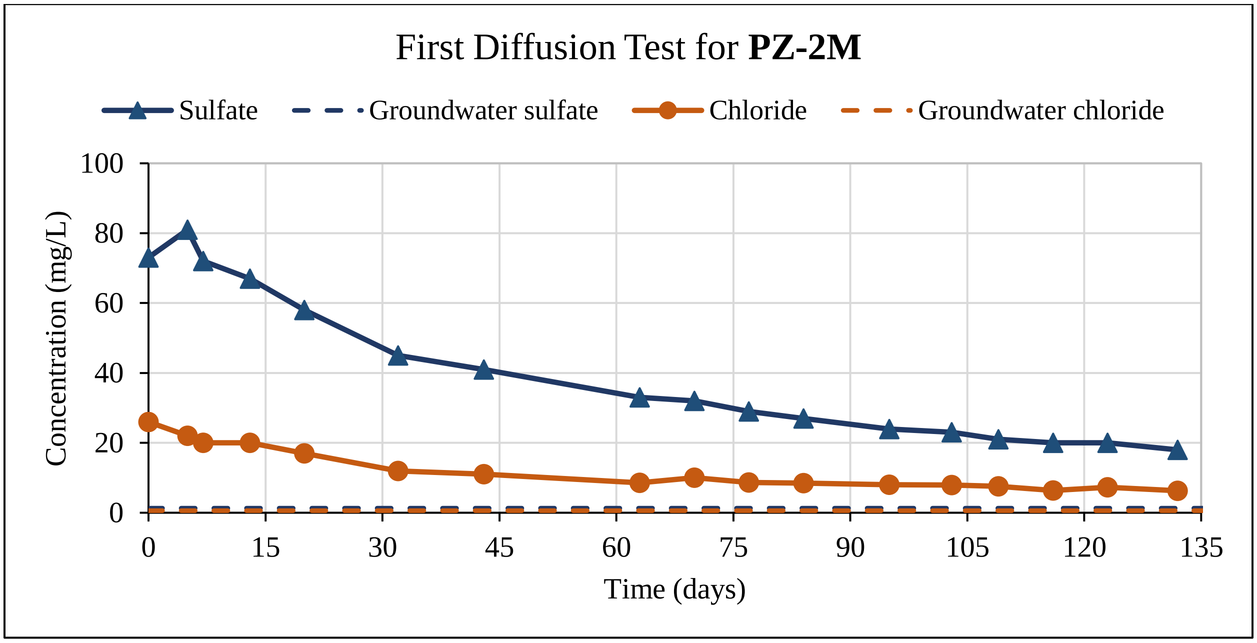


Figure 35 - Sulfate and chloride concentration over time for the first diffusion test performed using PZ-2M 56 feet deep sample.

The data also revealed that the leak that occurred during the sample collection of PZ-1M 12-26-2018 did not impact the results, as the values post-incident did not change much.

Chlorate and perchlorate concentrations were not sufficiently high enough to be detected in the first diffusion test. However, it was possible to measure the chloride and sulfate levels and their elution with time. For PZ-1M, the elution of these ions occurred instantly, and it took about 15 days for the concentrations to stabilize. For the PZ-2M samples, which have much less porosity, elution occurred at a much smaller rate, and it took 90 days and 60 days to stabilize the concentrations of sulfate and chloride, respectively.

Taking the contaminant masses reported in Table 10 and assuming all contaminants would be released into the 1.3 L chamber, it could be seen that the concentrations measured were higher than expected (Appendix B). However, one must keep in mind that the samples used in the diffusion test and the extraction tests (Table 10) were from the same California Tube, but not exactly the same sample; therefore, some variation was expected. After completing the diffusion tests, the soil cake was also extracted to determine the amount of contaminants remaining. Analyses are currently being performed, and the data will be added in the final version of this report.

3.3.2 Second Diffusion Test

The second diffusion test also used samples PZ-1M 46.5 feet deep and PZ-2M 56 feet deep. The procedures used were maintained the same, but the groundwater was diluted 1000X for both tests. For this test, as previously mentioned in Section 2.3.3, the samples were collected from the Tracer Reservoir, which does not have a connection with the Eluent Reservoir for filling. Considering this adaptation, every time that the 20 mL samples were collected, 20 mL of the same diluted groundwater was added to the Tracer Reservoir.

Appendix E shows the results obtained for both samples assessed in this test. Nitrate concentrations were not included because the values were not detected at the reporting limit (0.5 mg/L) for any of the tested samples.

Due to the low content of perchlorate and chlorate, the PZ-1M sample did not provide high enough concentrations of chlorate and perchlorate, and therefore, only sulfate and chloride

(Figures 34 and 35) are reported. Figures 36 and 37 show these concentrations with time, and with the cumulative volume of the sample taken for the PZ-1M samples.

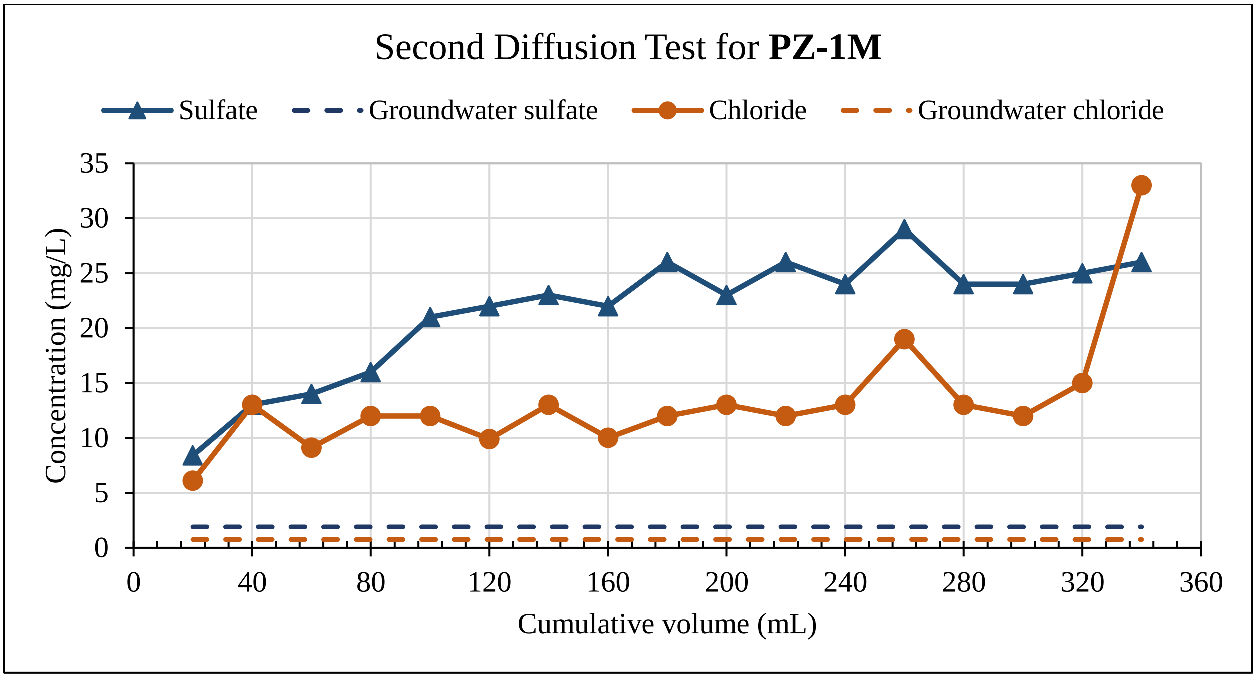


Figure 36 - Sulfate and chloride concentration versus sample volume for the second diffusion test performed using PZ-1M 46.5 feet deep sample.

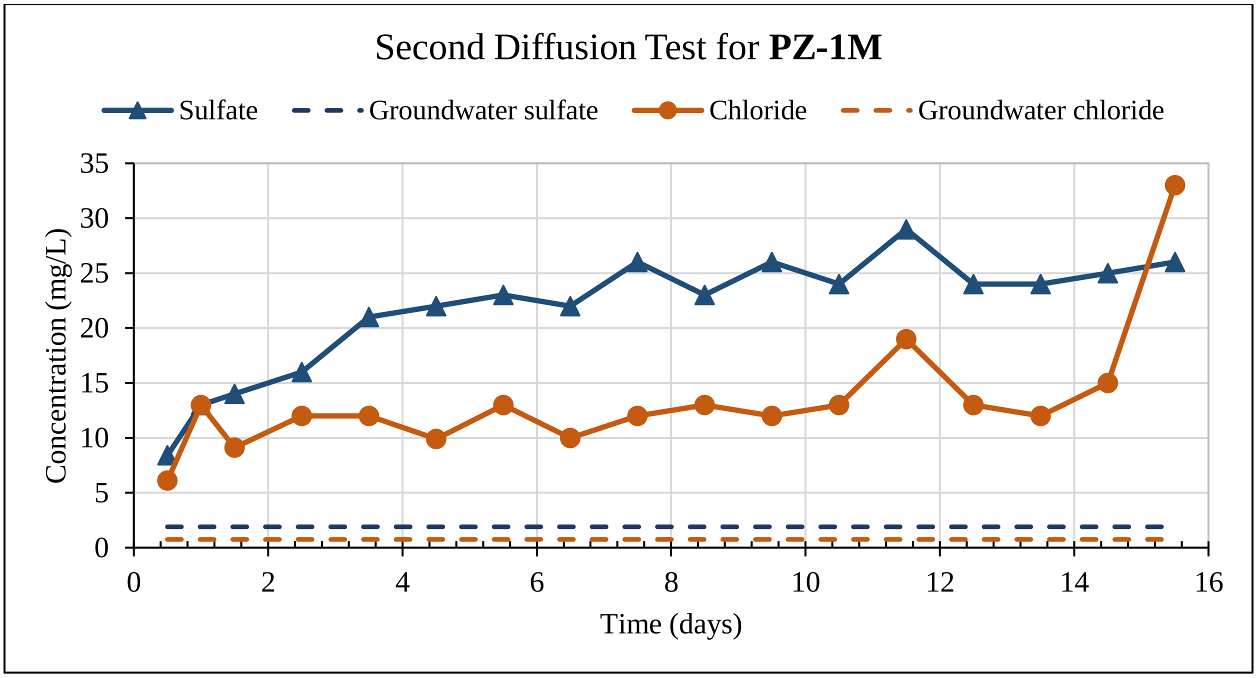


Figure 37 - Sulfate and chloride concentration over time for the second diffusion test performed using PZ-1M 46.5 feet deep sample.

Sampling from the Tracer chamber resulted in increased in concentrations with time. This behavior was the opposite of what was observed in the first diffusion test. A potential explanation is that the smaller (300 ml) elution chamber allowed for a faster increase in concentration; however, because the sample was taken from the same chamber where fresh diluted water was added, the impact of dilution was observed. Concentrations of sulfate in the second elution test increased from 8 mg/L to about 25 mg/l within 7.5 days, and then stabilized. Chloride concentrations increased from about 5 mg/L to above 10 mg/L within 2 days. This stayed stable for some days, and then had some significant variations between days 10 and 13. Then a large peak was observed on day 16. No disturbance of the experimental set-up occurred within this period, and therefore, we cannot explain the reason for this large peak. It seems that sulfate elution is faster than that of chloride. On a mass basis, there was about double the mass of sulfate in the sample than chloride.

A Similar pattern was observed for sample PZ-2M, except that the sulfate concentrations were somewhat larger (Figures 38 and 39). For this sample, sporadic peaks of chloride were also observed. Perhaps some chloride was diffusing back from the Elution Chamber into the Tracer Chamber.

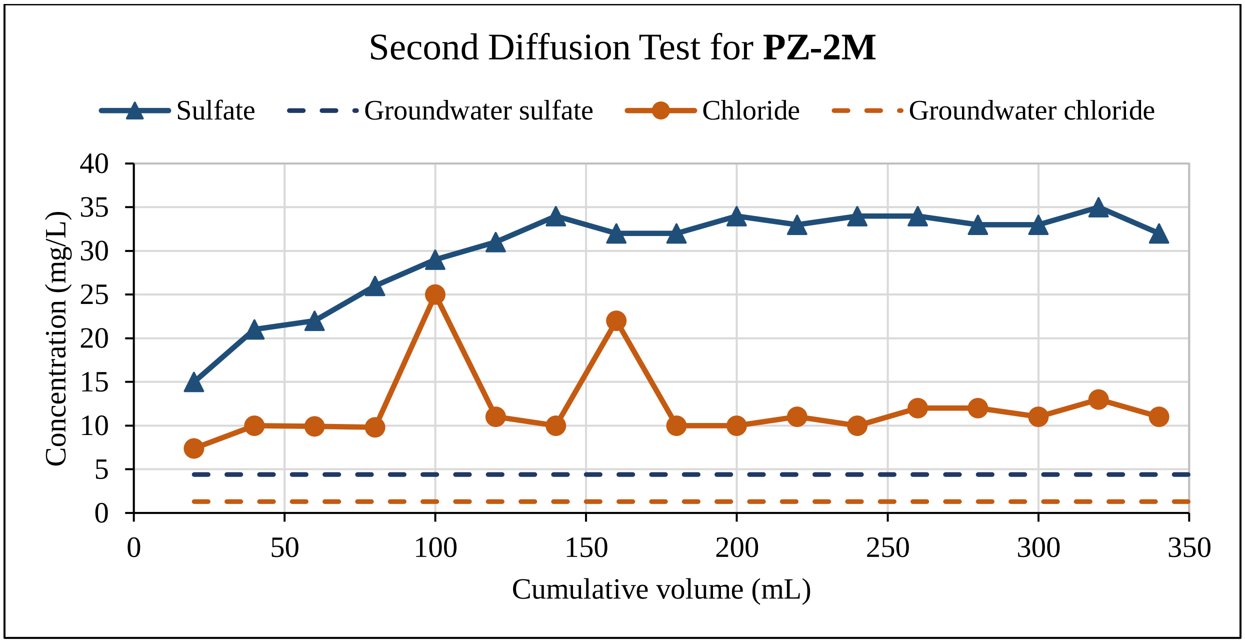


Figure 38 - Sulfate and chloride concentration versus sample volume for the second diffusion test performed using PZ-2M 56 feet deep sample.

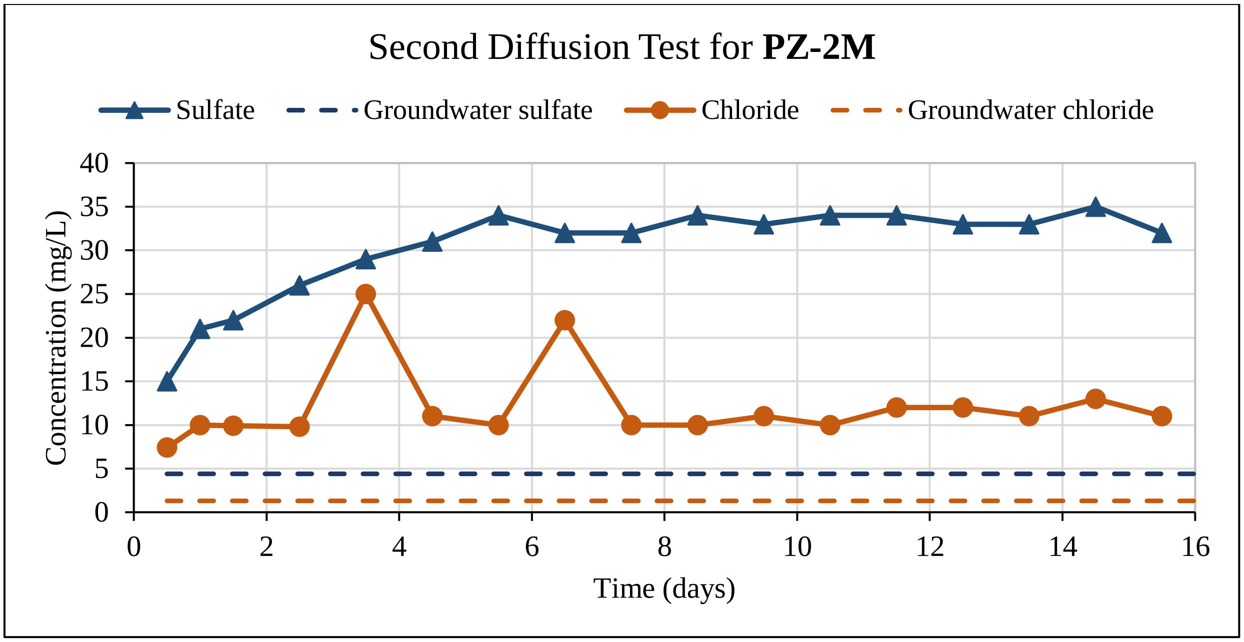


Figure 39 - Sulfate and chloride concentration over time for the second diffusion test performed using PZ-2M 56 feet deep sample.

Chlorate and perchlorate diffusion were observed in this test for the PZ-2M sample (Figures 40 and 41). The data are highly variable owing to the difficulty of accurately measuring the lower levels of chlorate and perchlorate in this matrix. Notwithstanding, the data show chlorate levels increased from 200 ug/L to 300 ug/L within 2.5 days. After 10 days, the levels dropped to 100 ug/L. A similar variation was seen for perchlorate, except that it decreased initially, stayed stable at 60 mg/L up to day 10, and then started increasing, reaching 200 ug/L after day 10, and staying at this level until day 16.

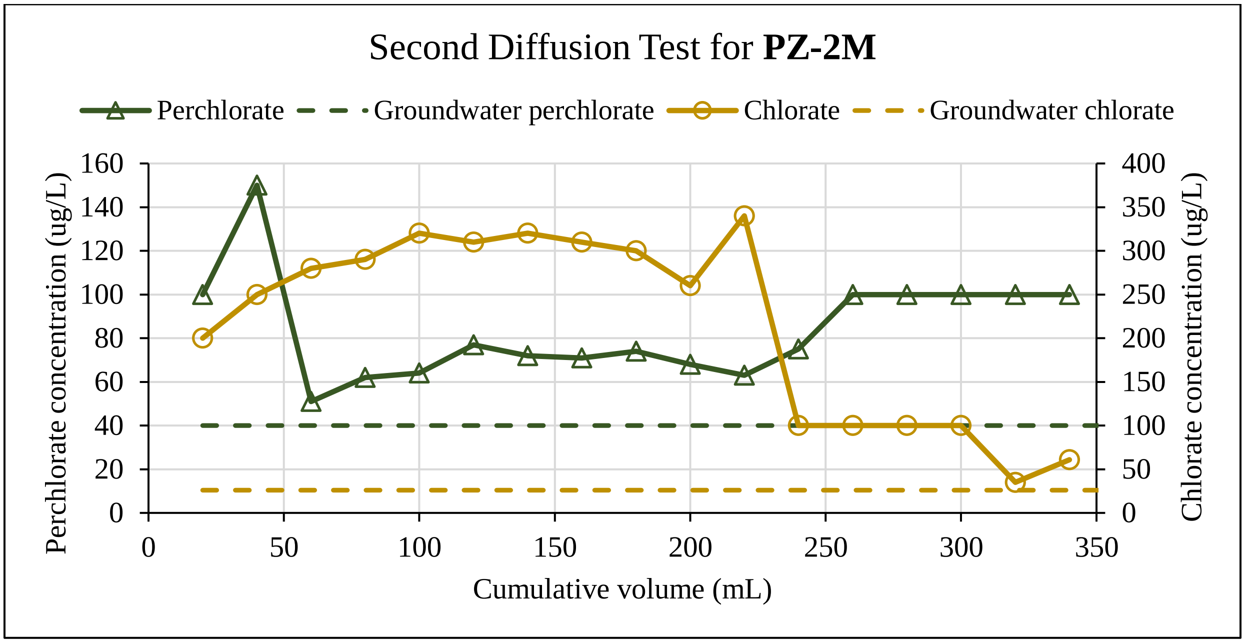


Figure 40 - Perchlorate and chlorate concentration versus sample volume for the second diffusion test performed using PZ-2M 56 feet deep sample.

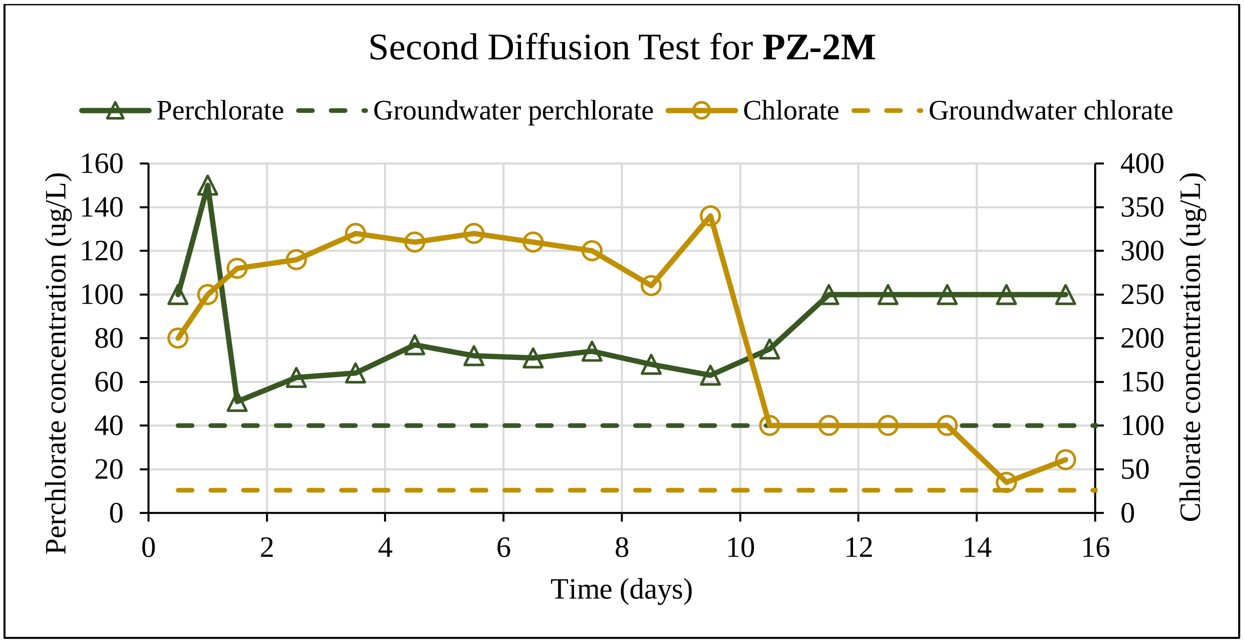


Figure 41 – Perchlorate and chlorate concentration over time for the second diffusion test performed using PZ-2M 56 feet deep sample.

3.4 <u>Advection Test</u>

3.4.1 Advection Test for PZ-1M

The sample PZ-1M with 46.5-feet of depth was tested under a gradient of two, calculated as previously described in Section 2.4. The initial flow for the applied gradient was 0.03 mL/min. The collected samples were analyzed for sulfate, chloride, perchlorate, and chlorate concentrations, and the complete test results are shown in Appendix F.

Sulfate and chloride concentrations were easily detected in the Elution effluent. In addition, perchlorate and chlorate showed detectable values. Figures 42 and 43 show the ion concentrations with time, and with cumulative groundwater volume passed through the sample chamber. The initial concentrations of sulfate and chloride in the diluted wastewater were 440 mg/l and 200 mg/L. The concentrations of the chloride and sulfate increased within the first 72 hours, but then decreased and stayed at about that of the groundwater; however, after 650 hours, the concentrations of both increased to the highest observed levels.

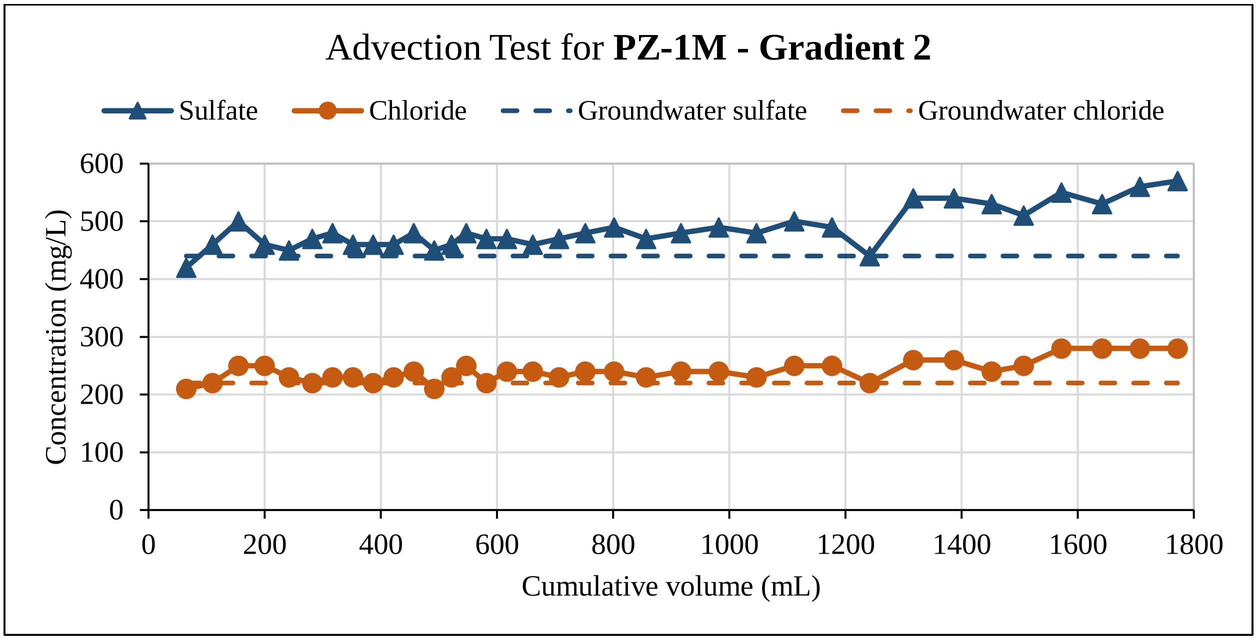


Figure 42 – Sulfate and chloride concentration versus sample volume for the advection test performed using PZ-1M 46.5 feet deep sample.

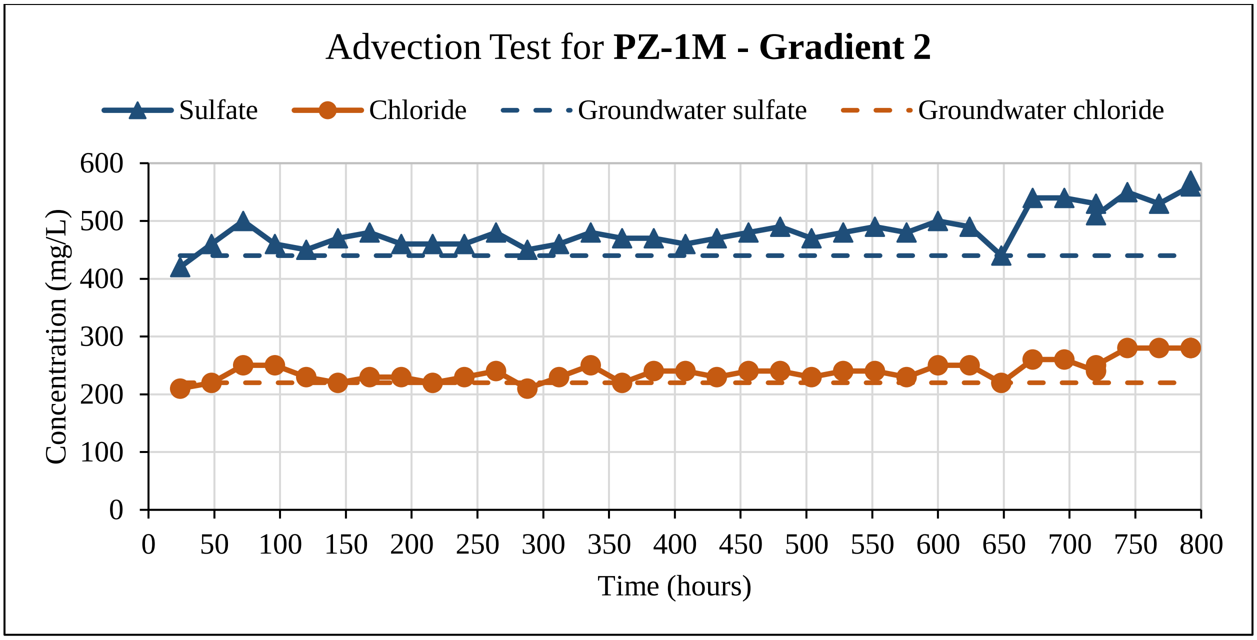


Figure 43 - Sulfate and chloride concentration over time for the advection test performed using PZ-1M 46.5 feet deep sample.

Chlorate and perchlorate concentrations in the diluted groundwater used in this test were 170 ug/L; however, much higher concentrations of chlorate and perchlorate were observed in the test, indicating elution (Figures 44 and 45). The peak concentrations detected for perchlorate and chlorate are very likely indicative of diffusion, given that the values are high, and much above the method detection limit for this groundwater matrix. Initially, the perchlorate concentrations were low and about the same as in the diluted groundwater. However, after about 400 hours, much higher concentrations were observed. For chlorate, the concentrations observed were lower. These results are consistent with the extractions, as PZ-1M contains almost eight times more perchlorate than chlorate.

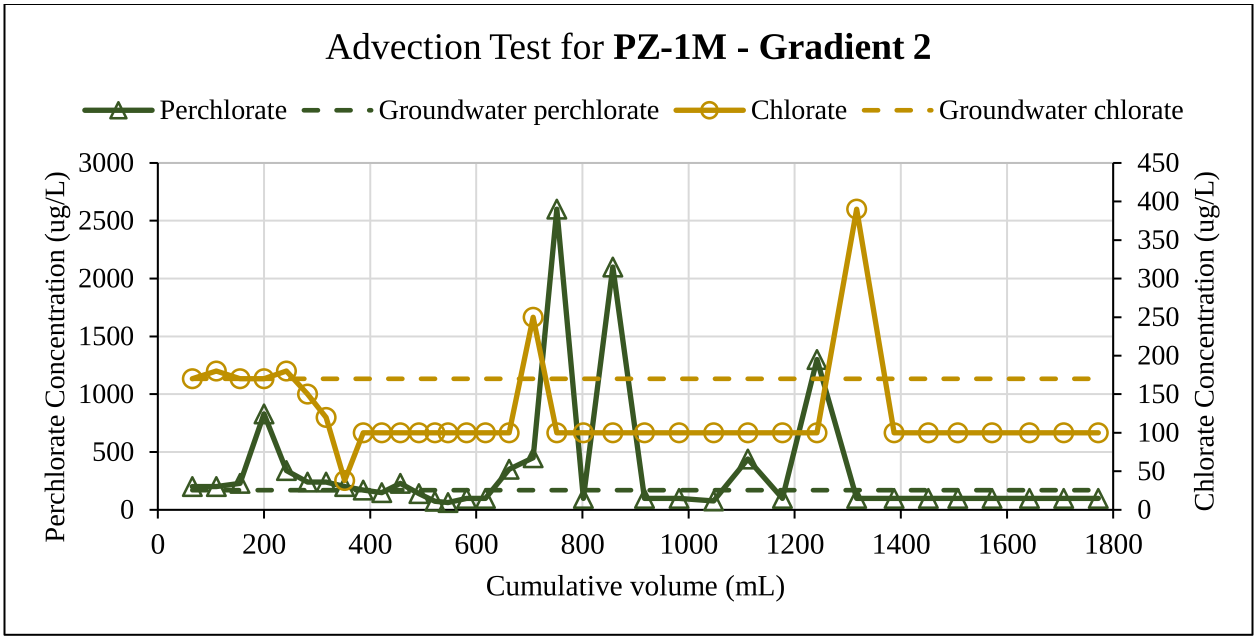


Figure 44 - Perchlorate and chlorate concentration versus sample volume for the advection test performed using PZ-1M 46.5 feet deep sample.

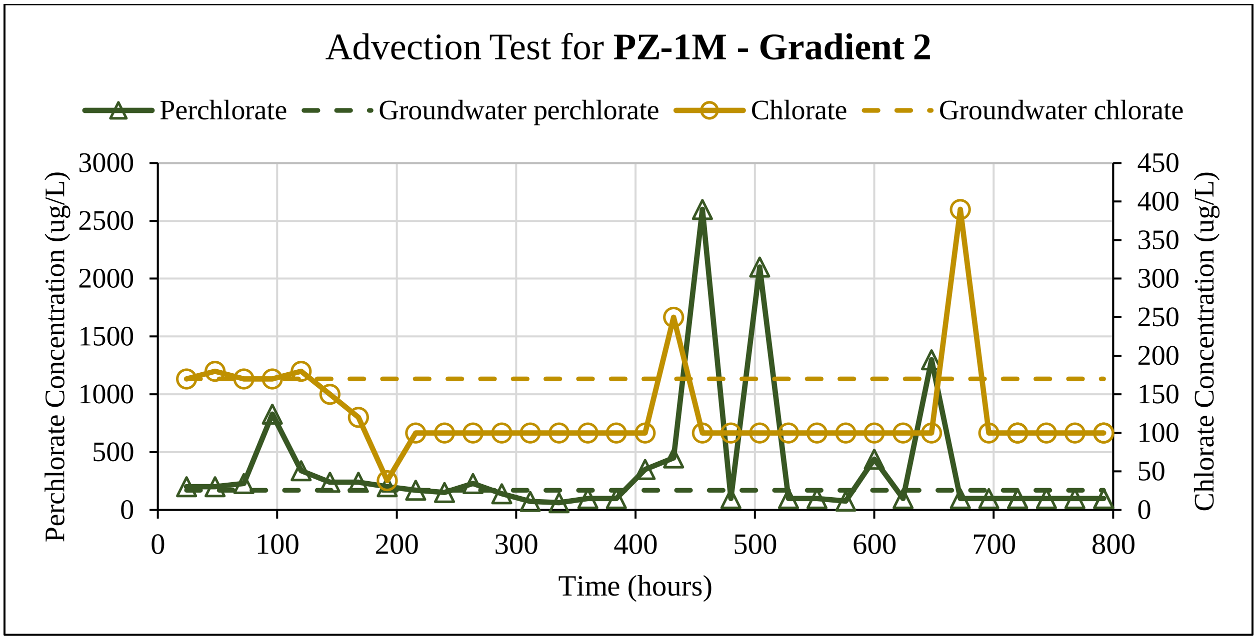


Figure 45 – Perchlorate and chlorate concentration over time for the advection test performed using PZ-1M 46.5 feet deep sample.

3.4.2 First Advection Test for PZ-2M 56-feet deep

A gradient of 0.2 was applied in the advection test for sample PZ-2M with 56-feet of depth. The initial flow was 0.71 mL/min; however, after five hours of testing, the screen clogged and the flow stopped. The head was then increased, and a new gradient of 0.6 was applied until the end of the test. The complete results of the test are shown in Appendix G. For this test, it was possible to detect all of the ions of interest. Figures 46, 47, 48, 49, 50, and 51 show the concentrations of perchlorate, chlorate, sulfate, chloride, and nitrate over time, and with flow processed through the sample chamber. Initial concentrations of sulfate, chlorite, chlorate, and perchlorate in the diluted groundwater were 110 mg/L, 45 mg/l. 1,400 ug/l, and 330 ug/L, respectively.

For the 0.2 gradient, the chloride concentration increased to about 60 mg/L, and the sulfate concentrations also increased to 140 mg/L within four hours. After the gradient was increased to 0.6, sulfate concentrations increased further to 160 mg/L, and then decreased back to 140 mg/l after 37 hours. On a volume basis, the concentration of chloride and sulfate started decreasing after 1,000 mL groundwater was processed through the soil sample.

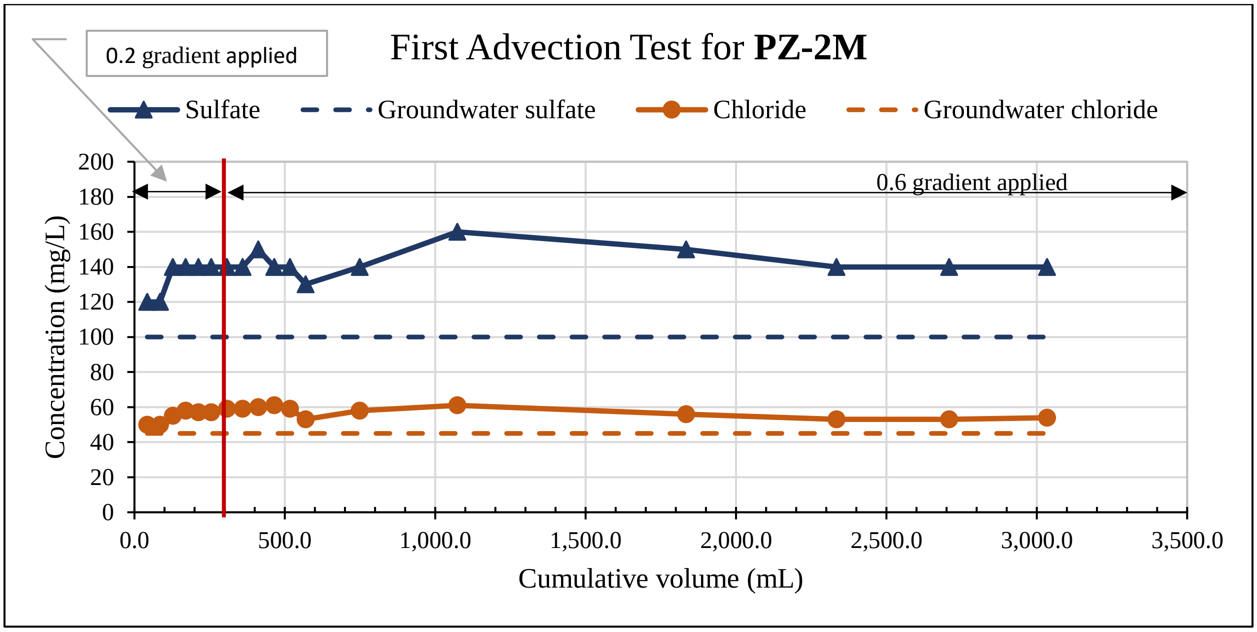


Figure 46 - Sulfate and chloride concentration versus sample volume for the first advection test performed using PZ-2M 56 feet deep sample.

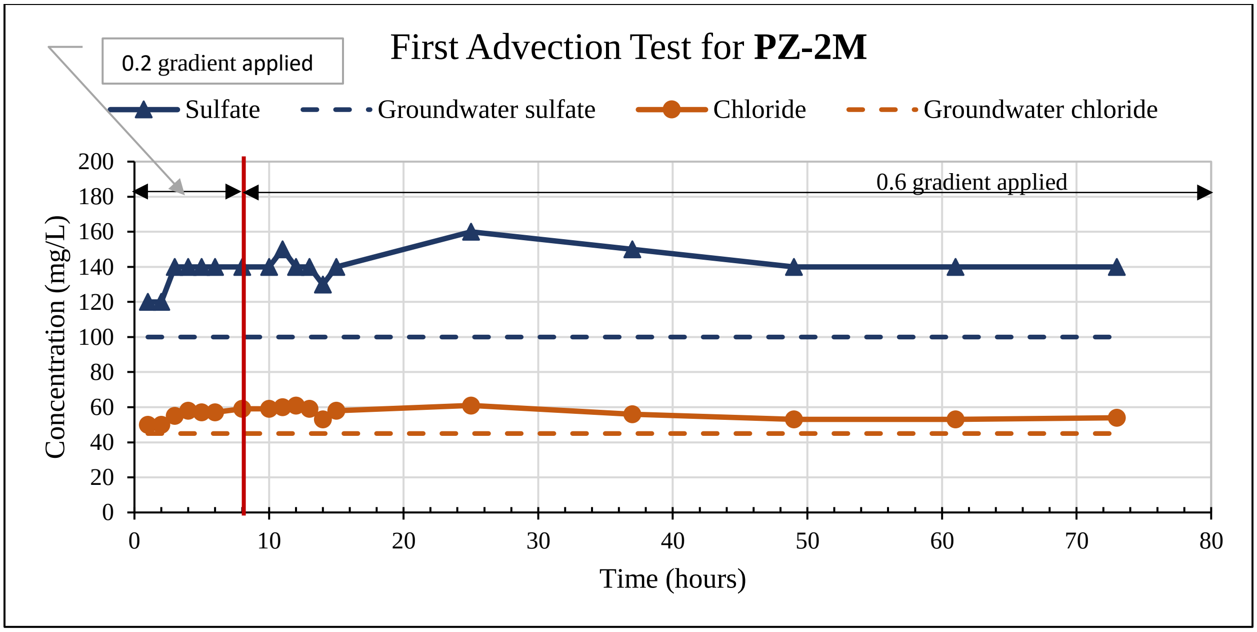


Figure 47 - Sulfate and chloride concentration over time for the first advection test performed using PZ-2M 56 feet deep sample.

The results show (Figures 48 and 49) that under a gradient of 0.2 and within about 10 hours, corresponding to 500 ml of groundwater processed, the concentrations of chlorate and perchlorate increased considerably. With an increased gradient of 0.6, the concentrations of both decreased steadily, and reached lower levels after 3,000 ml of groundwater were passed through the soil chamber. The decrease was more drastic for chlorate than for perchlorate. A similar behavior was observed for nitrate (Figures 50 and 51). As a whole, the results demonstrate the flushing of the ions with higher gradients applied to the soil samples.

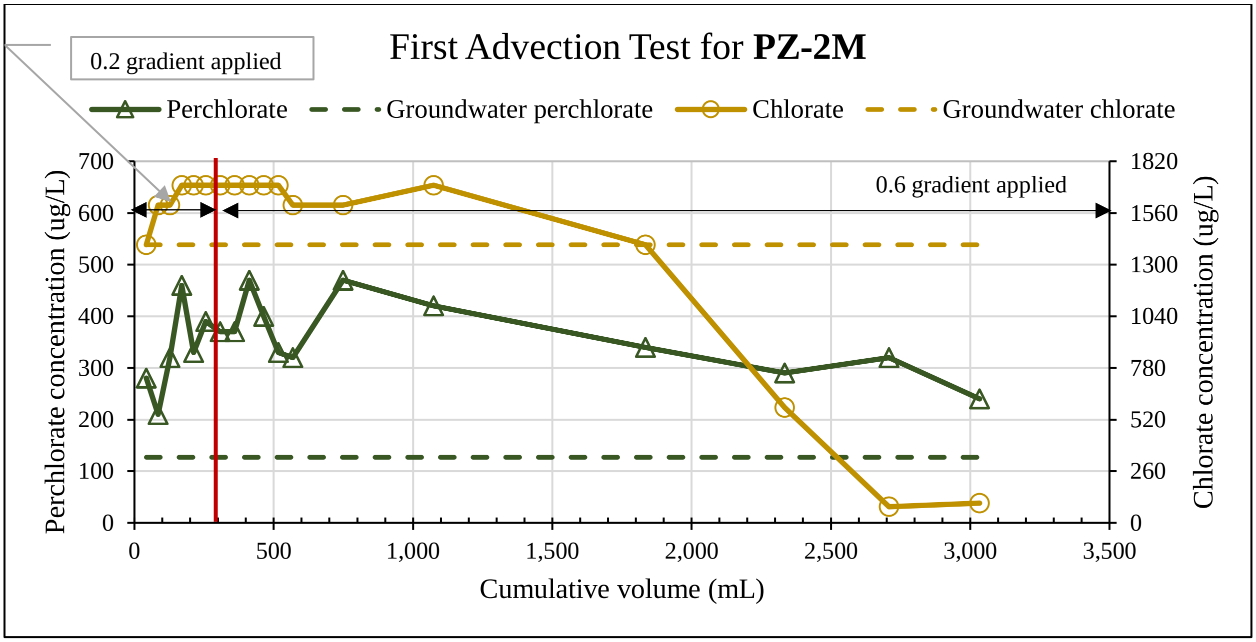


Figure 48 – Perchlorate and chlorate concentration versus sample volume for the first advection test performed using PZ-2M 56 feet deep sample.

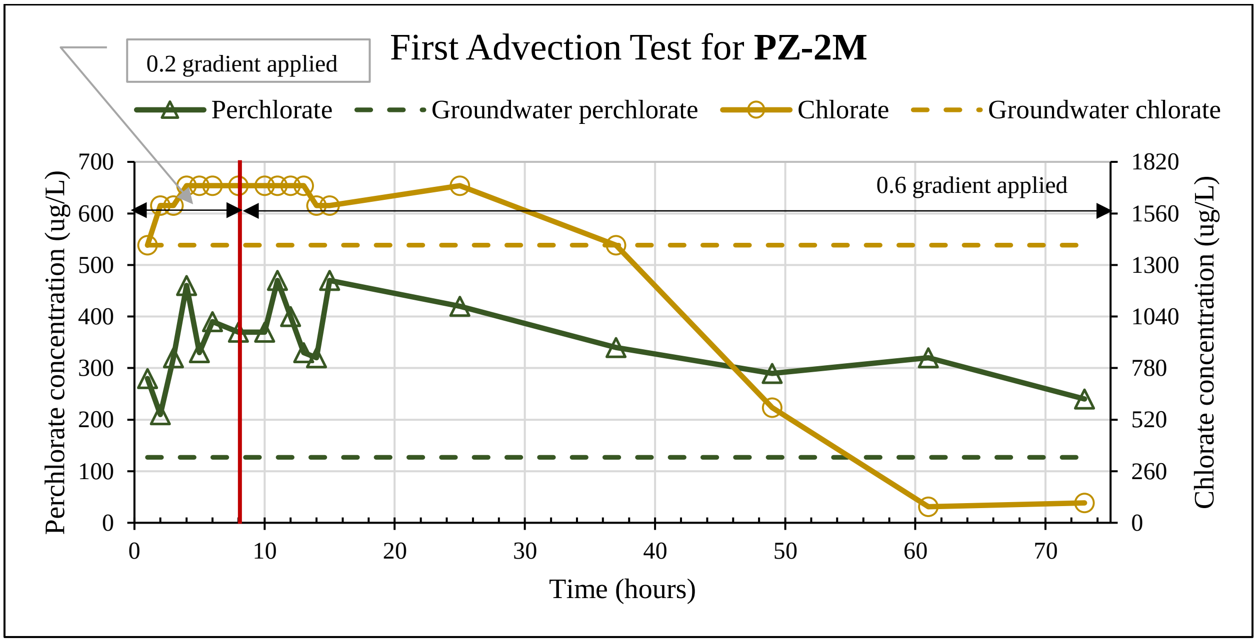


Figure 49 – Perchlorate and chlorate concentration over time for the first advection test performed using PZ-2M 56 feet deep sample.

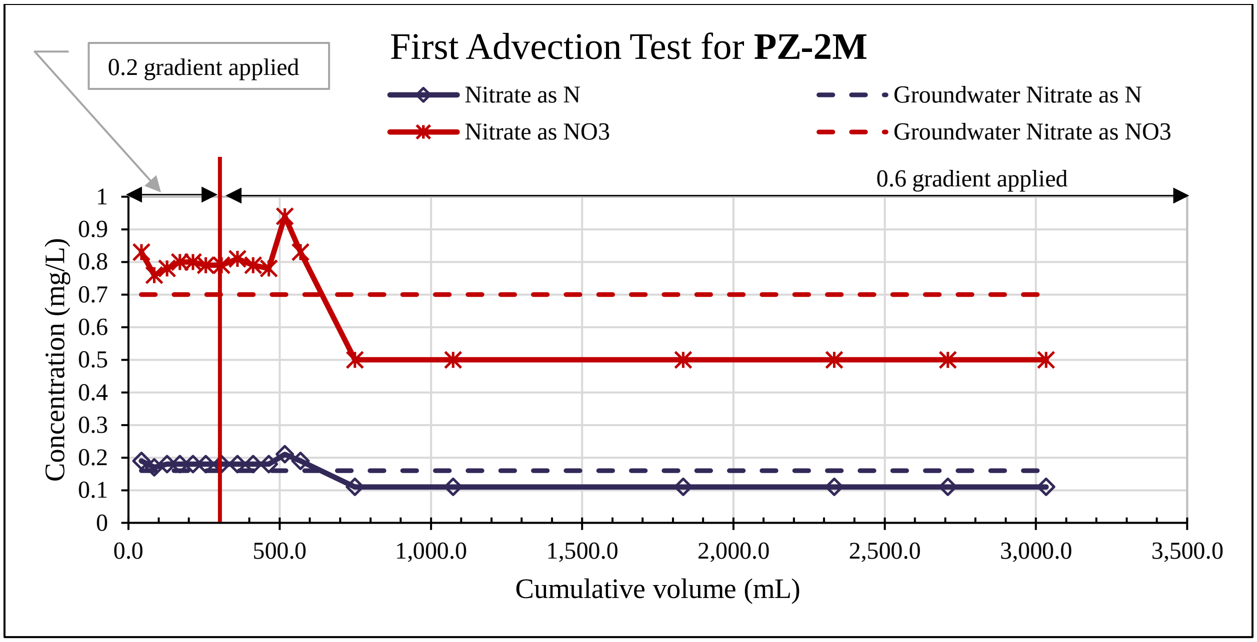


Figure 50 - Nitrate as N and nitrate as NO_3 concentration versus sample volume for the first advection test performed using PZ-2M 56 feet deep sample.

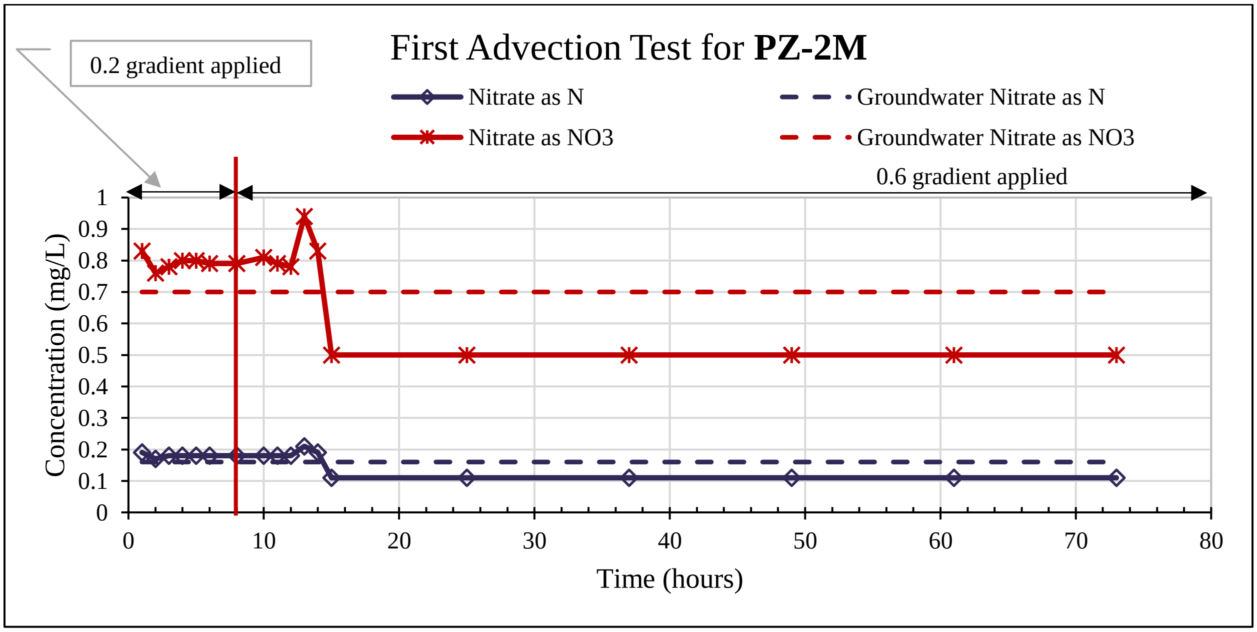


Figure 51 – Nitrate as N and NO_3 concentration over time for the first advection test performed using PZ-2M 56 feet deep sample.

3.4.3 Second Advection Test for PZ-2M 56-feet deep

For the second advection test, it was previously determined that the head level would not be changed in order to keep the gradient constant. The initial gradient, applied to sample PZ-2M 56-feet deep, was set for 7.4, with a flow of 0.3 mL/min. Compared to the previous advection tests, this experiment used a higher gradient. This was because of the different porosity values for each sample. Even when taken from the same depth, each soil cake studied in this investigation had a different porosity and texture. These factors dictated whether the sample could be processed with a higher or lower gradient. The results of this advection test are shown in Appendix H and plotted in Figures 52 and 53.

Both sulfate and chloride concentrations in the effluent chamber increased within the first 50 hours of the experiment, or about 800 ml groundwater processed. After 50 hours, sulfate concentrations decreased and reached the levels of the diluted groundwater. Chloride concentrations also decreased after 50 hours, but the decrease was much slower, and after almost 300 hours (2600 ml groundwater processed), the chloride concentration was still 53 mg/l.

Perchlorate and chlorate showed similar behaviors, with significant increases in concentration within 50 hours, and then significant decreases to low levels with the processing of 2600 ml of groundwater (Figures 54 and 55). In this test, the decreases for perchlorate and chlorate concentrations were more prominent than those for sulfate and chloride.

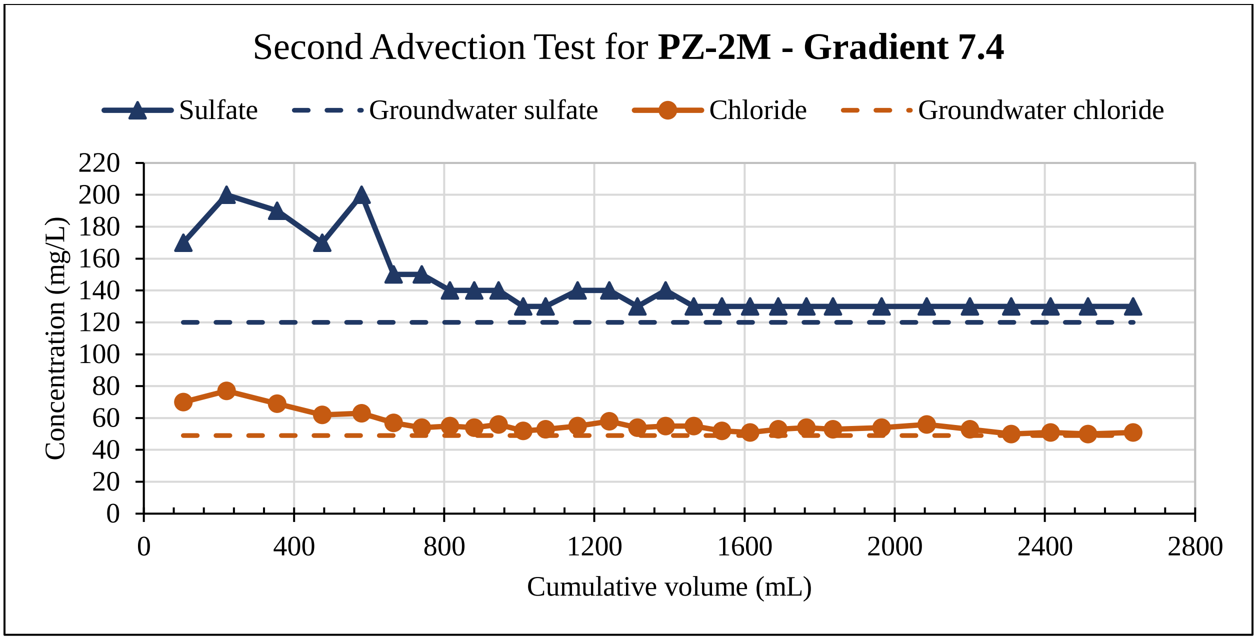


Figure 52 - Sulfate and chloride concentration versus sample volume for the second advection test performed using PZ-2M 56 feet deep sample.

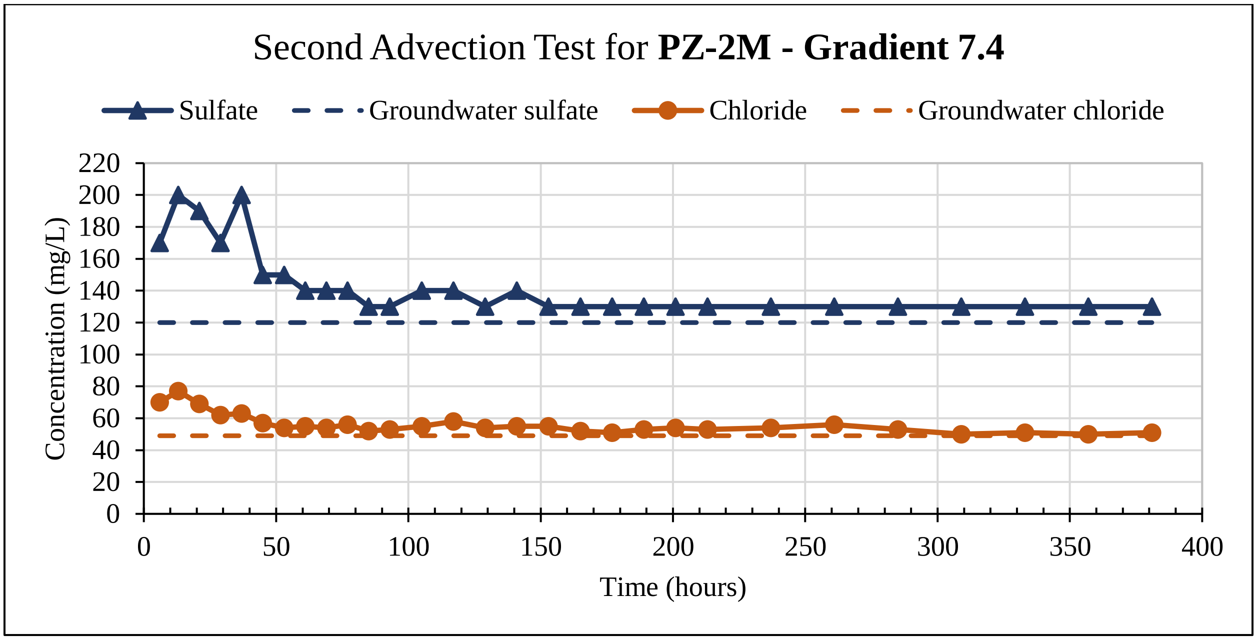


Figure 53 - Sulfate and chloride concentration over time for the second advection test performed using PZ-2M 56 feet deep sample.

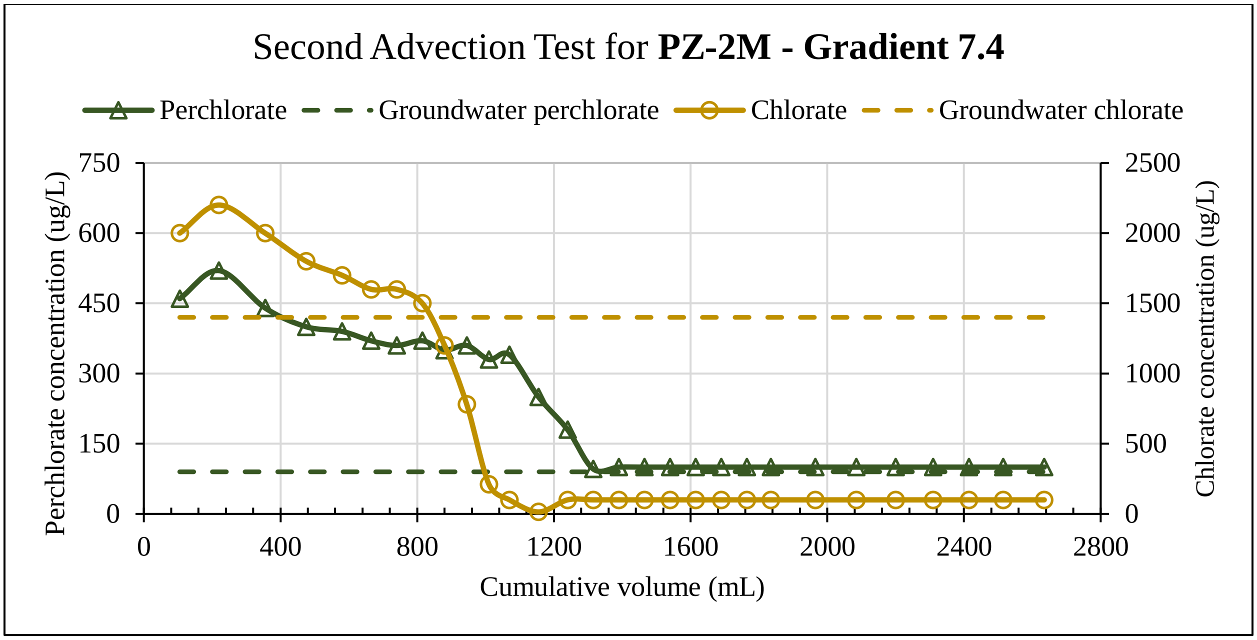


Figure 54 – Perchlorate and chlorate concentration versus sample volume for the second advection test performed using PZ-2M 56 feet deep sample.

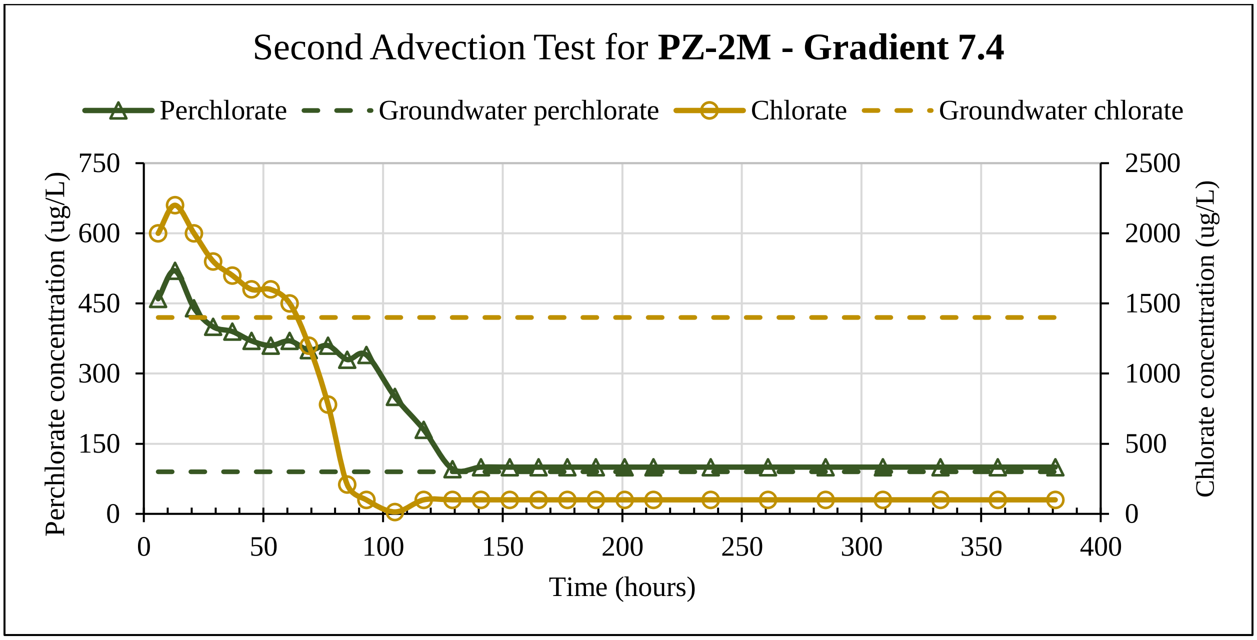


Figure 55 - Perchlorate and chlorate concentration over time for the second advection test performed using PZ-2M 56 feet deep sample.

3.4.4 Third Advection Test for PZ-2M 56-feet deep

An initial gradient of 0.6 was applied to the sample PZ-2M with 56 feet of depth, and the initial flow was 2.1 mL/min. Different from the soil sample used in the second advection test performed, this soil sample was less compacted, permitting the water to flow faster. The results of this experiment are shown in Appendix I and summarized in Figures 56, 57, 58, and 59. For sulfate and chloride, only small increases in concentration levels were observed initially, and then the ion concentrations stabilized at concentrations found in the groundwater used in the test. Higher chlorate concentrations were observed for the first 10 hours, while higher perchlorate concentrations were only observed for the first five hours of the experiment.

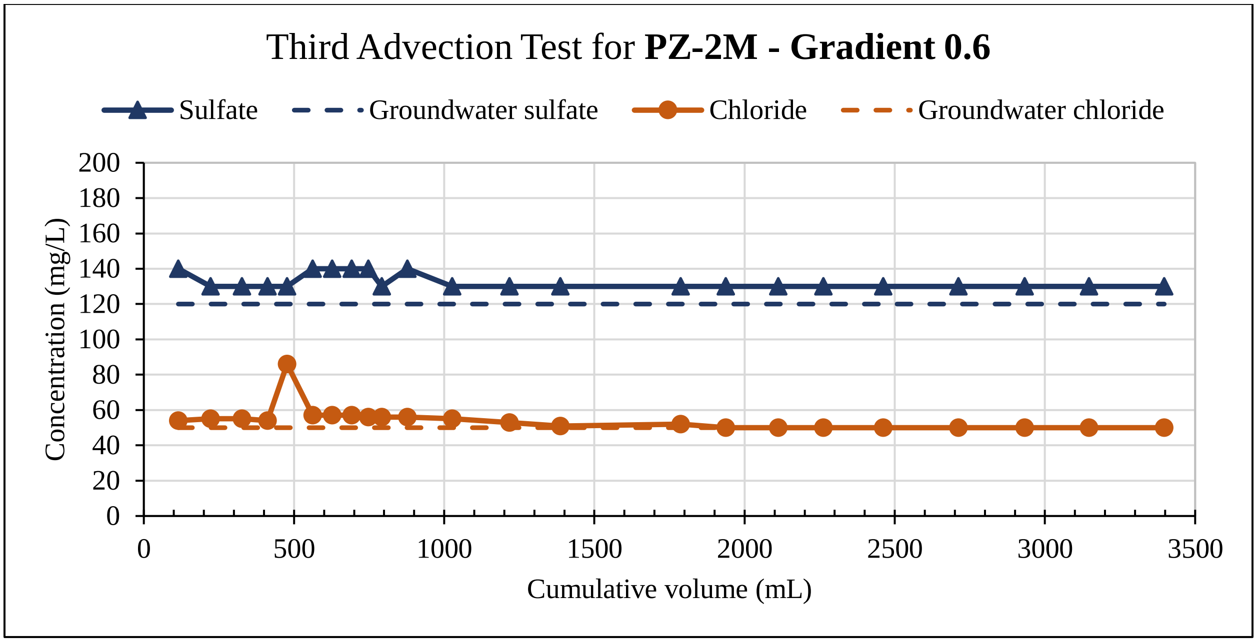


Figure 56 – Sulfate and chloride concentration versus sample volume for the third advection test performed using PZ-2M 56 feet deep sample.

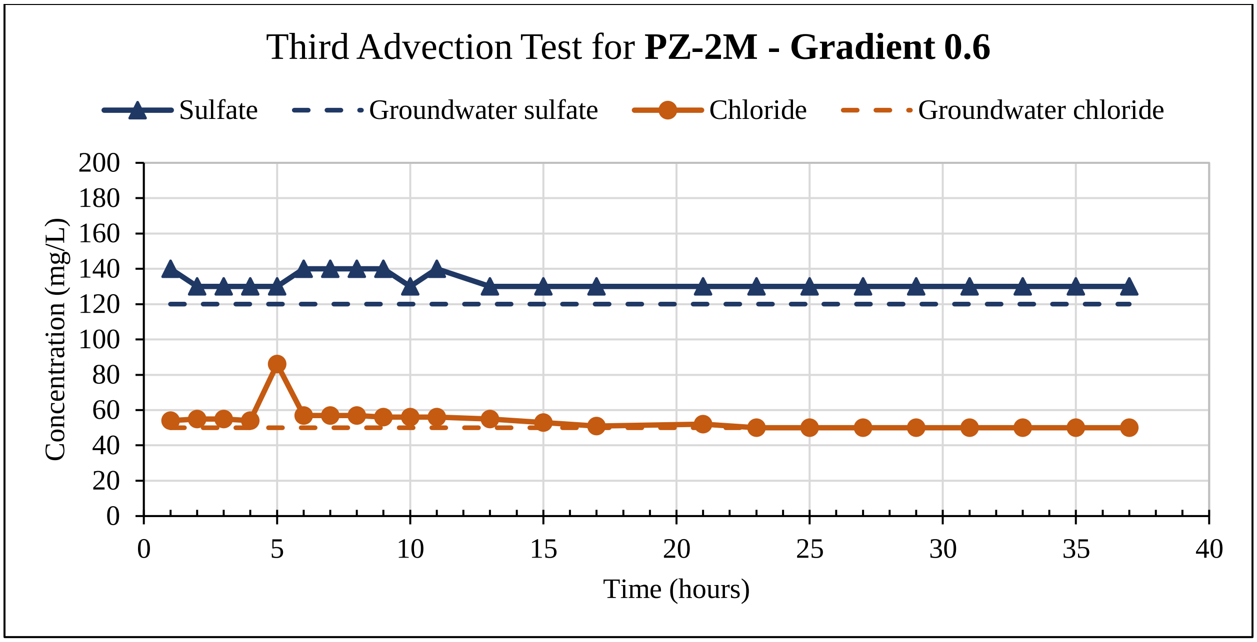


Figure 57 - Sulfate and chloride concentration over time for the third advection test performed using PZ-2M 56 feet deep sample.

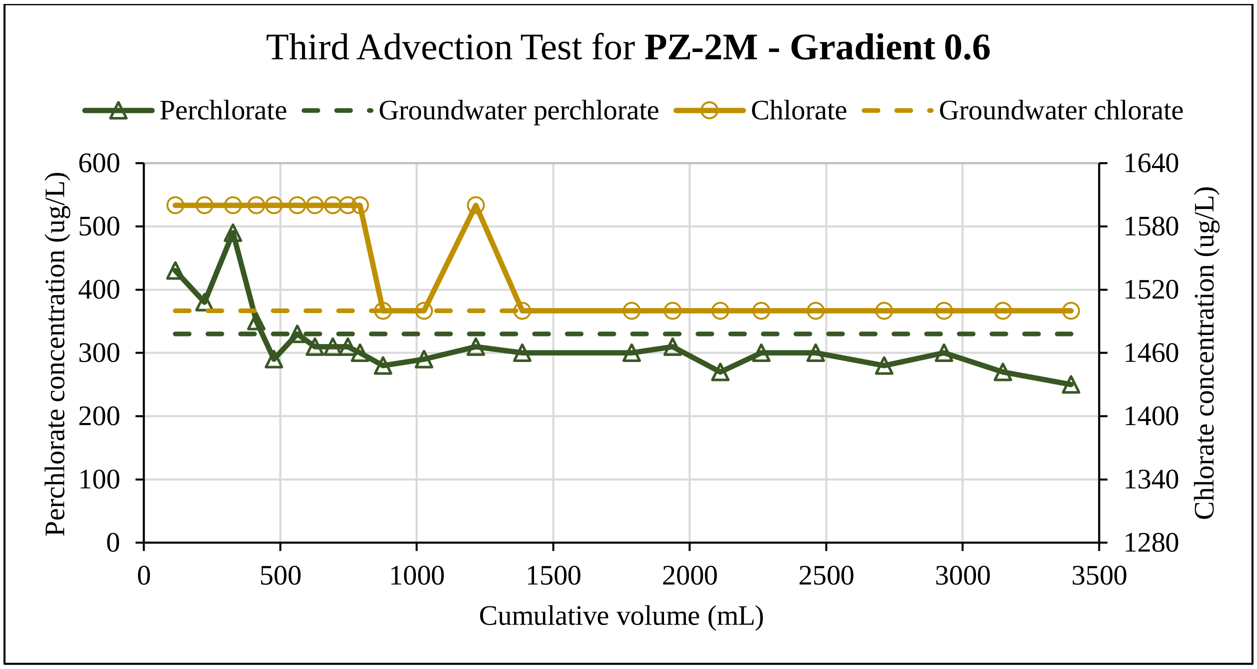


Figure 58 – Perchlorate and chlorate concentration versus sample volume for the third advection test performed using PZ-2M 56 feet deep sample.

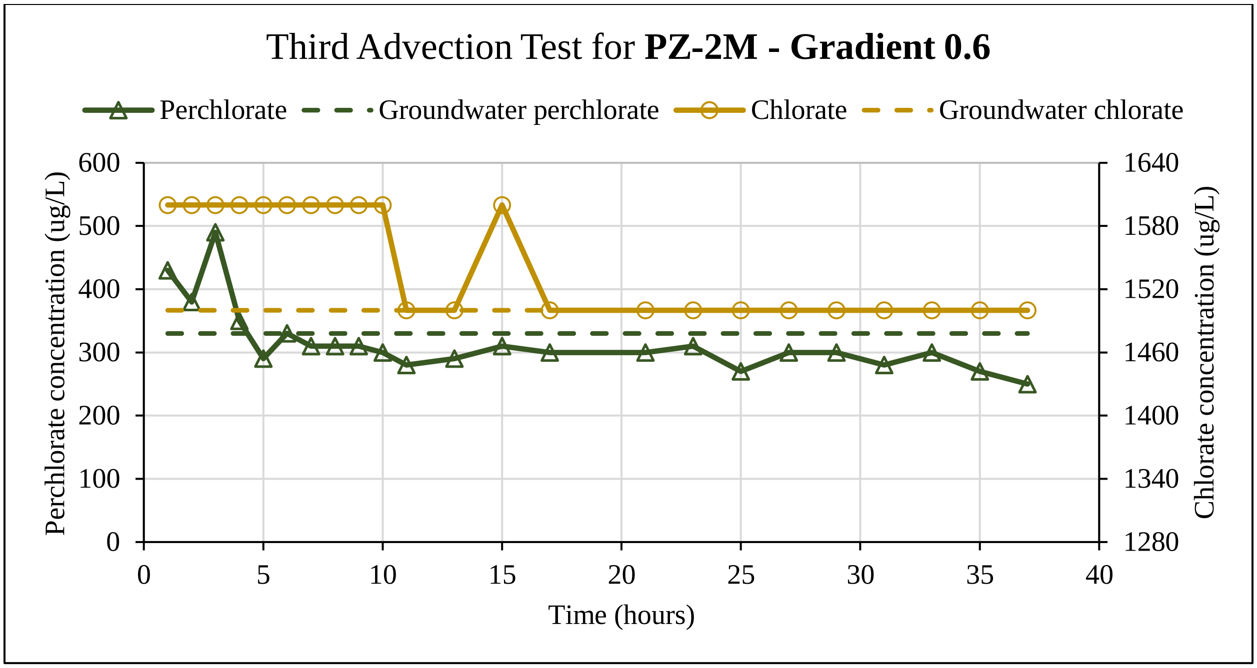


Figure 59 - Perchlorate and chlorate concentration over time for the third advection test performed using PZ-2M 56 feet deep sample.

4 Major Findings

1. The soil investigations show that the PZ-1M soil is composed of fine gray clay, while the PZ-2M soil has fine gray clay, brown sand, and gravel. The specific gravity is around 2.7 g/cm^3 for all locations and boreholes. The PZ-1M soil shows a higher porosity (i.e. 72.25%) than the tested samples for the PZ-2M location (48.64 % and 61.99 %). Consequently, the bulk density for PZ-1M is 91.25 lb./ft^3, and is thus, lower than the bulk density for PZ-2M samples (119.76 and 103.28 lb./ft^3).

2. The PZ-2M soil is more contaminated with perchlorate and chlorate than the PZ-1M soil. All the constituents (perchlorate, chlorate, sulfate, chloride, and nitrate) have higher concentrations at the PZ-2M location for all of the boreholes tested. For PZ-1M, sulfate and chloride are at the highest concentrations, with 0.40 mg/g of wet soil and 0.23 mg/g of wet soil, respectively. The perchlorate concentration in PZ-1M is 0.57 ug/g of wet soil, and higher than the chlorate concentration (0.07 ug/g of wet soil). However, for PZ-2M the perchlorate concentrations are lower (0.63-5.54 ug/g wet soil) than the chlorate concentrations (0.64 - 11.71 ug/g of wet soil).

3. The PZ-2M groundwater is more contaminated than the PZ-1M. The chlorate concentrations are about 40 times higher in PZ-2M groundwater (i.e. 14,000 ug/L) than in PZ-1M groundwater (i.e. 340 ug/L). The perchlorate concentrations also differ significantly, at 3,100 ug/L for the PZ-2M groundwater and 380 ug/L for PZ-1M groundwater. The sulfate concentration is only 1.4 times higher for the PZ-2M groundwater (1,200 mg/L) than the PZ-1M groundwater (i.e. 840 mg/L). The chloride concentrations are similar, varying only 80 mg/L between PZ-1M (410 mg/L) and PZ-2M (490 mg/L).

4. The first diffusion test performed using soil samples and groundwater from the PZ-1M and PZ-2M locations revealed an increase in chloride and sulfate levels in the elution chamber for the first samples collected. Perchlorate, chlorate, and nitrate were not sufficiently high enough to be detected under the reporting limit of the analytical method. For PZ-1M, concentrations of sulfate increased from 88 mg/L to 150 mg/l, and then decreased steadily to reach 85 mg/L within 33 days, and 44 mg/L after 122 days of elution. The chloride diffusion showed a very similar trend to that of sulfate. Chloride concentrations increased from 44 mg/L to 75 mg/L, and then within 20 days, chloride decreased to 44 mg/L. The test with the PZ-2M sample showed a similar elution trend; however, the elution was much slower. It took about 90 days for the sulfate concentrations to decrease from 73 to 23 mg/L. Chloride concentrations stabilized faster, after 60 days. Slower elution was expected from PZ-2M because it has smaller porosity (48.64%), as compared to PZ-1M (72.25%).

5. Sampling from the tracer chamber in the second diffusion test provided different results, as compared to the first diffusion test, in which sampling was performed from the elution chamber. For both PZ-1M and PZ-2M soil samples, there were increased concentrations of the ions of interest with time. This may be explained considering that the smaller elution chamber (300 ml) allowed for a faster increase in concentration; however, because the sample was taken from the same chamber where fresh diluted water was added, the impact of dilution was observed.

Concentrations of sulfate in the second elution test increased from 8 mg/L to about 25 mg/l within 7.5 days, and then stabilized. Chloride concentrations increased from about 5 mg/L to above 10 mg/L within two days. A similar pattern was observed for sample PZ-2M. Some sporadic peaks of chloride and sulfate were also observed; this might indicate that some back diffusion from the elution chamber into the tracer chamber was occurring. Chlorate and perchlorate diffusion were observed in this test for PZ-2M, but the data are highly variable. The data show chlorate levels increasing from 200 ug/L to 300 ug/L within 2.5 days. After 10 days, the levels dropped to100 ug/L. A similar variation was seen for perchlorate, except that it stayed stable at 60 mg/L up to day 10, and then started increasing, reaching 200 ug/L after day 10.

6. For the first advection test performed with a gradient of 2.0, sulfate and chloride concentrations were easily detected in the elution effluent, and perchlorate and chlorate showed detectable values. The concentrations of the chloride and sulfate increased within the first 72 hours, but then decreased and stayed about that of the groundwater; however, after 650 hours, the concentrations of both increased to the highest observed levels. Higher chlorate and perchlorate levels observed in the effluent indicate elution of these contaminants from the soil. It took about 400 hours to observe significant elution of perchlorate and chlorate under a gradient of 2.0.

7. For the advection test performed with a gradient of 0.2 and sample PZ-2M with 56-feet of depth, screen clogging was observed after five hours of testing. A higher gradient of 0.6 was then applied. Under a 0.6 gradient, all ions were observed in the effluent chamber. For the 0.2 gradient, the chloride concentration increased to about 60 mg/L, and the sulfate concentrations also increased to 140 mg/L within four hours. After the gradient was increased to 0.6, sulfate concentrations increased further to 160 mg/L, and then decreased back to 140 mg/l after 37 hours. The results show that under a gradient of 0.2 and within about 10 hours, corresponding to 500 ml of groundwater processed, the concentrations of chlorate and perchlorate increased considerably. With an increased gradient of 0.6, the concentrations of both decreased steadily and reached lower levels after 3,000 ml of groundwater were passed through the soil chamber. The decrease was more drastic for chlorate than for perchlorate. A similar behavior was observed for nitrate. The results demonstrate the flushing of the ions with higher gradients applied to the soil samples.

8. For the second advection test with PZ-2M, performed with a gradient of 7.4, both sulfate and chloride concentrations in the effluent chamber increased within the first 50 hours of the experiment. After 50 hours, sulfate concentrations decreased and reached the level of the diluted groundwater. Chloride concentrations also decreased after 50 hours, but the decrease was much slower, and after almost 300 hours (2600 ml groundwater processed) the chloride concentration was still 53 mg/l. Perchlorate and chlorate showed similar behaviors, with significant increases in

concentrations within 50 hours, and then significant decreases to low levels with the processing of 2600 ml of groundwater. The decreases for perchlorate and chlorate concentrations were more prominent than those for sulfate and chloride.

9. The third advection test with the PZ-2M 56-feet deep soil sample was performed with a gradient of 0.6. This sample was less compacted than the soil used with a gradient of 7.4. For sulfate and chloride, only small increases in concentration levels were observed initially, and then the ion concentrations stabilized at concentrations found in the groundwater used in the test. Higher chlorate concentrations were observed during 10 hours of the experiment, while higher perchlorate concentrations were only observed during five hours.

5 References

Rowe, R.K., Caers, C.J, and Barone, F., 1988. Laboratory determination of diffusion and distribution coefficients of contaminates using undisturbed clayey soil. Canadian Geotechnical Journal, 25(1), pp. 108-118.

Vilks, P. and N. H. Miller. Evaluation of Experimental Protocols for Characterizing Diffusion in Sedimentary Rock. Atomic Energy of Canada, NWMO TR-2007-11, Dec, 2007.

APPENDIX A – Physical Characterization Soil Testing Report

A1 – Bulk Density and Moisture Content

Bulk Density and Moisture Content							
Name: Kazem	Date: 11/23/2018		**Boring Depth: 46.5 feet**				
Sample number:	**PZ-1M** **1050-3**						
Sample description: The soil in the core was gray color fine silt or clay							
Tare NO.			50	51	52	53	54
Mass in grams	Tare + Wet soil		96.21	100.81	113.49	100.84	97.77
	Tare + Dry soil		64.09	66.2	74.02	67.19	65.49
	Water	Mw	32.12	34.61	39.47	33.65	32.28
	Tare		30.31	30.39	30.41	30.19	30.46
	Dry Soil	Md	33.78	35.81	43.61	37	35.03
Water Content (I eliminated can #1, it was from top of core, seems dried during handling)		W	95.09	96.65	90.51	90.95	92.15
		Average		93.07			
Weight-Volume Relations							
Sample or Specimen No.			Replicate 1	Replicate 2			
Cylinder No.							
Centimeters	Height of Cylinder	H	6.68	6.1		**Average**	
	Inside Diameter of Cylinder	D	7.276	7.275			
Mass in grams	Wet soil and tare		409.72	367.18			
	Tare		0	0			
	Wet soil	Mt	409.72	367.18			
	Dry soil	Md	212.22	190.18			
Specific Gravity of soil (avg. of 3 tests)		Gs	2.729	2.729		2.729	
Volume in CC	Wet Soil (Volume of Cylinder)	V	277.61	253.43			
	Dry soil (Md/Gs)	Vs	77.763	69.689			
LBS per CU FT	Wet Unit Weight (Mt/V)*62.4	Ym	92.096	90.406		91.25	
	Dry Unit Weight (Md/V)*62.4	Yd	47.701	46.826		47.26	
Void Ratio (V-Vs)/Vs		e	2.5699	2.6366			
Porosity % [((V-Vs)/V]*100		n	71.99	72.50		72.25	
Weight of water		Mw	197.50	177.00			
Volume of water in metric		Vw	197.5	177			
Degree of Saturation [Vw/(V-Vs)]*100		S	98.829	96.328		97.58	

Bulk Density and Moisture Content

Name: Kazem Date: 11/2/2018 **Boring Depth: 55.5 - 56.0 feet**

Sample number: **PZ-2M** **1050-3**

Sample description: The soil in the core contained half gray color fine silt or clay and the top half was brown sand and gravel

Tare NO.			45	45	47	48	49
Mass in grams	Tare + Wet soil		120.94	132.71	120.41	148.79	173.58
	Tare + Dry soil		89.5	96.2	99.84	128.15	154.68
	Water	Mw	31.44	36.51	20.57	20.64	18.9
	Tare		30.31	30.39	30.41	30.19	30.46
	Dry Soil	Md	59.19	65.81	69.43	97.96	124.22
Water Content (eliminated can #1, it was from top of core, seems dried during handling)		W	53.12	55.48	29.63	21.07	15.21
		Average		34.90			
Weight-Volume Relations							
Sample or Specimen No.			Replicate 1	Replicate 2			
Cylinder No.							
Centimeters	Height of Cylinder	H	7.62	7.62		**Average**	
	Inside Diameter of Cylinder	D	6.096	6.096			
Mass in grams	Wet soil and tare		596.05	484.6			
	Tare		136.46	90.97			
	Wet soil	Mt	459.59	393.63			
	Dry soil	Md	340.69	291.79			
Specific Gravity of soil (ave. of 3 tests)		Gs	2.770	2.770		2.770	
Volume in CC	Wet Soil (Volume of Cylinder)	V	222.29	222.29			
	Dry soil (Md/Gs)	Vs	122.99	105.34			
LBS per CU FT	Wet Unit Weight (Mt/V)*62.4	Ym	129.02	110.5		119.76	
	Dry Unit Weight (Md/V)*62.4	Yd	95.637	81.911		88.77	
Void Ratio (V-Vs)/Vs		e	0.8073	1.1101			
Porosity % [((V-Vs)/V]*100		n	44.67	52.61		48.64	
Weight of water		Mw	118.90	101.84			
Volume of water in metric		Vw	118.9	101.84			
Degree of Saturation [Vw/(V-Vs)]*100		S	119.75	87.083		103.42	

Bulk Density and Moisture Content							
Name: Kazem	Date: 11/2/2018		**Boring Depth: 66.0 - 66.5 feet**				
Sample number:	**PZ-2M 1050-1**						
Sample description: The soil contained gray color fine silt or sand							
Tare NO.			40	41	42	43	44
Mass in grams	Tare + Wet soil		102.14	114.38	99.88	112.4	111.92
	Tare + Dry soil		74.4	81.95	70.97	85.7	85.55
	Water	Mw	27.74	32.43	28.91	26.7	26.37
	Tare		30.42	30.39	30.37	30.4	30.38
	Dry Soil	Md	43.98	51.56	40.6	55.3	55.17
Water Content (eliminated can #6, it was from top of core, seems it dried during handling)		W	63.07	62.90	71.21	48.28	47.80
		Average		58.65			
Weight-Volume Relations							
Sample or Specimen No.							
Cylinder No.							
Centimeters	Height of Cylinder	H	7.62	7.62		**Average**	
	Inside Diameter of Cylinder	D	6.096	6.096			
Mass in grams	Wet soil and tare		467.77	519			
	Tare		125.45	125.48			
	Wet soil	Mt	342.32	393.52			
	Dry soil	Md	215.77	248.04			
Specific Gravity of soil (avg. 3 tests)		Gs	2.745	2.745		2.745	
Volume in CC	Wet Soil (Volume of Cylinder)	V	222.287	222.29			
	Dry soil (Md/Gs)	Vs	78.6182	90.377			
LBS per CU FT	Wet Unit Weight (Mt/V)*62.4	Ym	96.0953	110.47		103.28	
	Dry Unit Weight (Md/V)*62.4	Yd	60.57	69.629		65.10	
Void Ratio (V-Vs)/Vs		e	1.82743	1.4596			
Porosity % [((V-Vs)/V]*100		n	64.63	59.34		61.99	
Weight of water		Mw	126.55	145.48			
Volume of water in metric		Vw	126.552	145.48			
Degree of Saturation [Vw/(V-Vs)]*100		S	88.0856	110.29		99.19	

A2 – Specific Gravity

Name: Kazem		Date: 12/26/2018	Boring Depth: 46.5 '	
Sample number:	PZ-1M			
Sample description: very fine soil. This test is done based on Method A on wet soil and then dried to find dry mass				
		First try	Second try	Dry method
Mass in grams	Pycnometers Mp	163.61	162.00	
	Oven dry soil (passing # 4) Ms	69.80	80.25	
	Nominal pycnometer Volume	500.00	500.00	
	pycnometer + water Mp,w	662.18	660.45	
	pycnometer + water+soil Mp,w,s	705.99	711.76	
	Temperature	20.30	20.70	
	Specific gravity at T	2.686	2.773	
	Specific Gravity at 20 c	2.685	2.773	
	Average Specific Gravity at 20 c	**2.729**		

Name: Kazem		Date: 12/26/2018	Boring Depth: 55.5 - 56 '	
Sample number:	PZ-2M			
Sample description: White color very fine soil was on top of the tube and brown sandy soil was in the bottom half of the tube.				
		First try	Second try	Dry method
Mass in grams	pycnometer Mp	169.08	157.74	
	Oven dry soil (passing # 4) Ms	78.06	121.10	
	Nominal pycnometer Volume	500.00	500.00	
	pycnometer + water Mp,w	668.05	656.92	
	pycnometer + water+soil Mp,w,s	718.64	733.15	
	Temperature	20.80	20.40	
	Specific gravity at T	2.842	2.699	
	Specific Gravity at 20 c	2.841	2.699	
	Average Specific Gravity at 20 c	**2.770**		

Name: Kazem	Date: 12/26/2018		Boring Depth: 65 - 66.5 '	
Sample number:	PZ-2M			
Sample description: soil was gray color and very fine				
		First try	Second try	Dry method
Mass in grams	pycnometer Mp	163.56	163.58	
	Oven dry soil (passing # 4) Ms	81.23	81.19	
	Nominal pycnometer Volume	500.00	500.00	
	pycnometer + water Mp,w	662.03	662.28	
	pycnometer + water+soil Mp,w,s	714.13	713.42	
	Temperature	21.50	20.80	
	Specific gravity at T	2.789	2.702	
	Specific Gravity at 20 c	2.788	2.701	
	Average Specific Gravity at 20 c	**2.745**		
	* Mp,w = Mp + (Vp*pws) Vp = (Mp.w - Mp)/pw			

A3 – Hydrometry Analysis

Reading data

Hydrometry Analysis							
Name: Kazem			Date:	12/27/2018			
Sample number:		PZ - 1M	Boring Depth:	46.5 - 47.0 '			
Sample description:							
Tare NO.					41	glass	
Mass in grams	Tare + Wet soil				50.7		
	Tare + Dry soil				50.05		
	Water			Mw	0.65		
	Tare				30.39		
	Wet soil			Mm	20.31	65.51	
	Dry Soil			Md	19.66		
Hygroscopic Moisture Correction				Hy	0.968		

Hydrometer Type	152 H	Mass of dry soil (Ms)	63.41
Temperature	20.8	Percent out of total sample	100
Meniscus Correction (Fm)	6	Zero Correction (Fz)	
Specific Gravity	2.729	Correction Factor ASTM D422 Table 1(a)	0.985

Hydrometer Reading and Data

Time (minute)	R	Rc	Percent Finer	temperature	L	K	D (mm)
2	30	24	37.28	20.6	13.2	0.013	0.0334
5	23	17	26.41	20.6	13.8	0.013	0.0216
15	18	12	18.64	20.5	14.3	0.013	0.0127
30	15	9	13.98	20.5	14.7	0.01303	0.0091
60	13	7	10.87	20.4	15	0.01311	0.0066
250	11	5	7.77	20	15.3	0.01318	0.0033
1440	10	4	6.21	19.4	15.8	0.01322	0.0014

Sample number:	PZ - 2M		Boring Depth:	55.5 - 56.0 '		
Sample description:						
Tare NO.				50	glass	retained
Mass in grams	Tare + Wet soil			59.56		
	Tare + Dry soil			59.26		
	Water		Mw	0.3		
	Tare			30.57		
	Wet soil		Mm	28.99	70.35	10
	Dry Soil		Md	28.69		
Water Content			W	0.990		

Hydrometer Type	152 H	Mass of dry soil (Ms)	69.62
Temperature	20.8	Percent out of total sample	85.79
Meniscus Correction (Fm)	5	Zero Correction (Fz)	
Specific Gravity	2.770	Correction Factor ASTM D422 Table 1(a)	0.986

Hydrometer Reading and Data

Time	R	Rc	Percent Finer	Temperature	L	K	D (mm)
2	35	30	42.49	20.6	7.1	0.0131	0.0247
5	30	25	35.41	20.6	8.1	0.01313	0.0167
15	24	19	26.91	20.5	8.8	0.01315	0.0101
30	19	14	19.83	20.4	9.5	0.01315	0.0074
60	15	10	14.16	20.3	10.1	0.01318	0.0054
250	9	4	5.66	19.9	11.1	0.01324	0.0028
1440	7	2	2.83	19.3	13.2	0.01322	0.0013

Hydrometry Analysis							
Name: Kazem			Date:	12/27/2018			
Sample number:		PZ - 2M		Boring Depth:	66.0 - 66.5 '		
Sample description: Gray sample with slow sedimentation. First reading was high which shows the particles are fine. Added 3 more reading.							
Tare NO.					60	glass	
Mass in grams	Tare + Wet soil				49.14		
	Tare + Dry soil				48.44		
	Water			Mw	0.7		
	Tare				30.38		
	Wet soil			Mm	18.76	62.71	
	Dry Soil			Md	18.06		
Water Content				W	0.963		

Hydrometer Type	152 H	Mass of dry soil (Ms)	60.37
Temperature	20.5	Percent out of total sample	100
Meniscus Correction (Fm)	6	Zero Correction (Fz)	
Specific Gravity	2.745	Correction Factor ASTM D422 Table 1(a)	0.99

Hydrometer Reading and Data

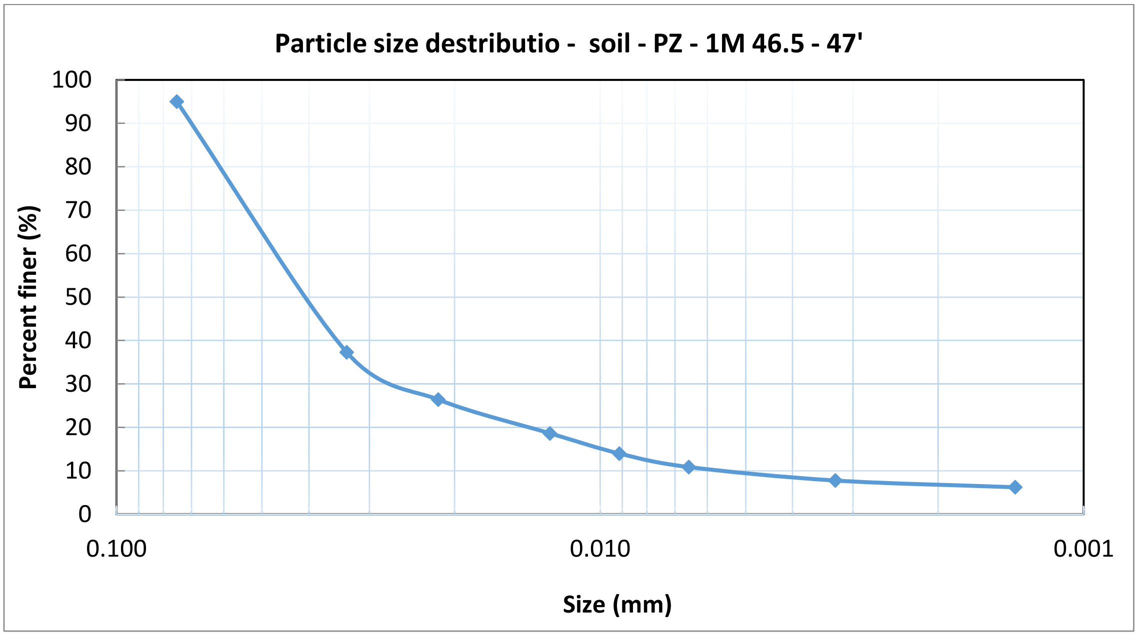
Time (minute)	R	Rc	Percent Finer	Temperature	L	K	D (mm)
2	30	24	39.36	20.5	7.6	0.01314	0.0256
5	25	19	31.16	20.5	9.1	0.01314	0.0177
15	20	14	22.96	20.5	10.1	0.01316	0.0108
30	16	10	16.40	20.4	10.7	0.01317	0.0079
60	14	8	13.12	20.3	11.4	0.0132	0.0058
250	11	5	8.20	19.9	12.1	0.01322	0.0029
1440	10	4	6.56	19.5	12.7	0.01322	0.0012

Sieve and Hydrometry Results

Sieve and hydrometry results (PZ 1M 46.5 - 47 feet)			
Sieving stage	Sieve number	Size (mm)	Percent passing
Retain on sieve #10 (Gravel)	2 in	50.8	100.00
	1 1/2 in	38.1	
	1 in	25.4	
	3/4 in	19.05	
	3/8 in	9.5	
	No 4	4.75	
Passing #10 on washed hydrometry sample (Sand)	NO 10	2	
	NO 20	0.85	
	NO 40	0.425	
	NO 60	0.25	
	NO 140	0.106	
	NO 200	0.075	95.00
Hydro-metry		0.0334	37.28
		0.0216	26.41
		0.0127	18.64
		0.0091	13.98
		0.0066	10.87
		0.0033	7.77
		0.0014	6.21

SG	**2.729**
Moisture	**34.90**

Soil type
Silt or Clay (very fine)

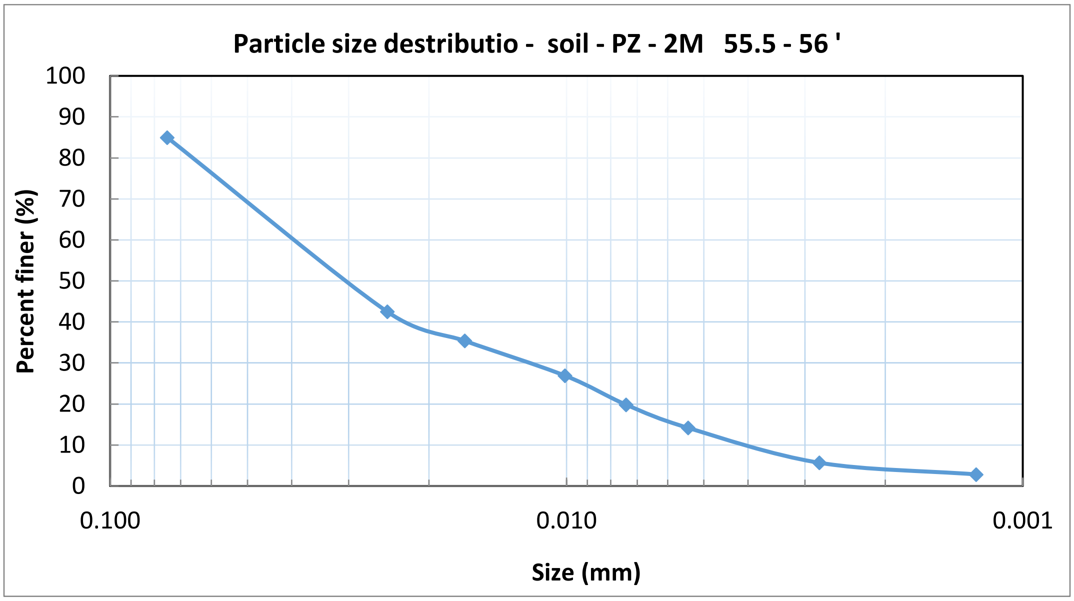


Sieve and hydrometry results (PZ 2M 55.5 - 56 feet)

Sieving stage	Sieve number	Size (mm)	Percent passing
Retain on sieve #10	2 in	50.8	100
	1 1/2 in	38.1	
	1 in	25.4	
	3/4 in	19.05	
	3/8 in	9.5	
	No 4	4.75	
Passing #10 on washed hydrometry sample	NO 10	2	
	NO 20	0.85	
	NO 40	0.425	
	NO 60	0.25	
	NO 140	0.106	
	NO 200	0.075	85.00
Hydro-metry		0.0247	42.49
		0.0167	35.41
		0.0101	26.91
		0.0074	19.83
		0.0054	14.16
		0.0028	5.66
		0.0013	2.83

SG	**2.770**
Moisture	**93.07**

Soil type
Silt or Clay and half was brown sand

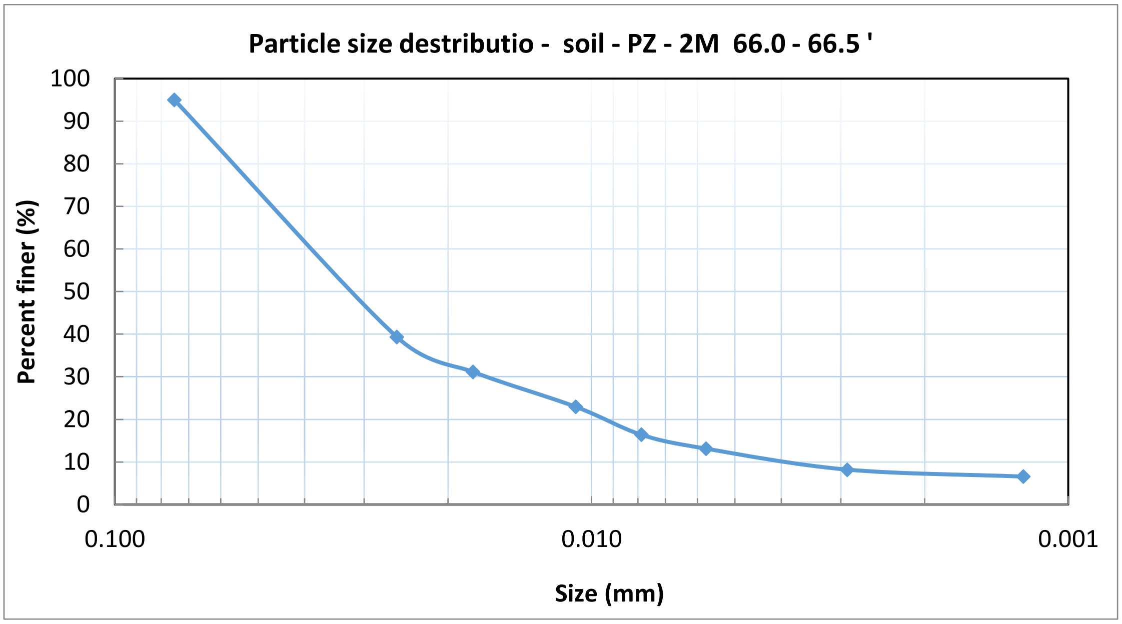


Sieve and hydrometry results (PZ - 2M 65.0 - 66.5')

Sieving stage	Sieve number	Size (mm)	Percent passing
Retain on sieve #10	2 in	50.8	100
	1 1/2 in	38.1	
	1 in	25.4	
	3/4 in	19.05	
	3/8 in	9.5	
	No 4	4.75	
Passing #10 on washed hydrometry sample	NO 10	2	
	NO 20	0.85	
	NO 40	0.425	
	NO 60	0.25	
	NO 140	0.106	
	NO 200	0.075	95.00
Hydro-metry		0.0256	39.36
		0.0177	31.16
		0.0108	22.96
		0.0079	16.40
		0.0058	13.12
		0.0029	8.20
		0.0012	6.56
		0.0000	0.00
		0.0000	0.00

SG	**2.745**
Moisture	**58.65**

Soil type
Silt or Clay



APPENDIX B – Computation of contaminant mass concentration.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Sample ID	Contaminant	Contaminants concentration from extraction rinses												
-	-	Extraction 1				Extraction 2				Extraction 3				Units
-	-	Replicate 1		Replicate 2		Replicate 1		Replicate 2		Replicate 1		Replicate 2		-
-	-		-		-		-		-		-		-	-
PZ-1M-46.5'	Perchlorate		62.00	<	100.00	<	100.00		140.00	<	100.00	<	100.00	ug/L
	Chlorate		19.00		10.00		6.80		15.00		10.00		13.00	ug/L
	Nitrate as N		0.21		0.16		0.13		0.14		0.14		0.15	mg/L
	Nitrate as NO3		0.95		0.72		0.58		0.64		0.62		0.66	mg/L
	Sulfate		160.90		157.10		50.20		54.60		14.40		13.30	mg/L
	Chloride		83.20		81.80		27.70		28.90		15.50		15.60	mg/L
PZ-2M-55'	Perchlorate		2100.00		2100.00		680.00		730.00		94.00		180.00	ug/L
	Chlorate		4600.00		4100.00		1500.00		1500.00		300.00		440.00	ug/L
	Nitrate as N		0.68		0.62		0.21		0.23	<	0.11		0.06	mg/L
	Nitrate as NO3		3.00		2.70		0.93		1.00	<	0.50		0.27	mg/L
	Sulfate		162.50		146.00		60.20		65.80		22.10		28.10	mg/L
	Chloride		106.00		98.70		28.50		31.20		7.30		8.30	mg/L
PZ-2M-56'	Perchlorate	<	100.00		-		85.00		-		420.00		-	ug/L
	Chlorate		3400.00		-		1600.00		-		300.00		-	ug/L
	Nitrate as N		0.44		-	<	2.50		-	<	2.50		-	mg/L
	Sulfate		275.70		-		168.80		-		35.80		-	mg/L
	Chloride		102.00		-		29.90		-		9.10		-	mg/L
PZ-2M-65'	Perchlorate		1600.00		-		480.00		-		96.00		-	ug/L
	Chlorate		2400.00		-		780.00		-		180.00		-	ug/L
	Nitrate as N		0.56		-		0.36		-		0.26		-	mg/L
	Sulfate		275.00		-		144.70		-		37.50		-	mg/L
	Chloride		86.60		-		35.60		-		9.50		-	mg/L
PZ-2M-66'	Perchlorate		140.00		130.00	<	100.00	<	100.00	<	100.00	<	100.00	ug/L
	Chlorate		210.00		210.00		92.00		110.00		35.00		37.00	ug/L
	Nitrate as N		0.40		0.31	<	0.11		0.06	<	0.11	<	0.11	mg/L
	Nitrate as NO3		0.73		0.87	<	0.50		0.26	<	0.50	<	0.50	mg/L
	Sulfate		263.40		269.90		131.90		138.60		58.80		65.00	mg/L
	Chloride		49.90		50.70		19.10		20.70		7.50		7.60	mg/L

CONTINUATION OF APPENDIX B (Calculation of contaminant mass concentrations)

A	B	P	Q	R	S	T	U
Sample ID	Contaminant	Volume of rinses for each extraction replicates (L)					
-	-	Extraction 1		Extraction 2		Extraction 3	
-	-	Replicate 1	Replicate 2	Replicate 1	Replicate 2	Replicate 1	Replicate 2
-	-	-	-	-	-	-	-
PZ-1M-46.5'	Perchlorate	0.086	0.086	0.098	0.098	0.098	0.098
	Chlorate	0.086	0.086	0.098	0.098	0.098	0.098
	Nitrate as N	0.086	0.086	0.098	0.098	0.098	0.098
	Nitrate as NO3	0.086	0.086	0.098	0.098	0.098	0.098
	Sulfate	0.086	0.086	0.098	0.098	0.098	0.098
	Chloride	0.086	0.086	0.098	0.098	0.098	0.098
PZ-2M-55'	Perchlorate	0.092	0.094	0.100	0.099	0.100	0.099
	Chlorate	0.092	0.094	0.100	0.099	0.100	0.099
	Nitrate as N	0.092	0.094	0.100	0.099	0.100	0.099
	Nitrate as NO3	0.092	0.094	0.100	0.099	0.100	0.099
	Sulfate	0.092	0.094	0.100	0.099	0.100	0.099
	Chloride	0.092	0.094	0.100	0.099	0.100	0.099
PZ-2M-56'	Perchlorate	0.028	0.027	0.028	0.027	0.028	0.028
	Chlorate	0.028	0.027	0.028	0.027	0.028	0.028
	Nitrate as N	0.028	0.027	0.028	0.027	0.028	0.028
	Sulfate	0.028	0.027	0.028	0.027	0.028	0.028
	Chloride	0.028	0.027	0.028	0.027	0.028	0.028
PZ-2M-65'	Perchlorate	0.022	0.022	0.028	0.028	0.028	0.028
	Chlorate	0.022	0.022	0.028	0.028	0.028	0.028
	Nitrate as N	0.022	0.022	0.028	0.028	0.028	0.028
	Sulfate	0.022	0.022	0.028	0.028	0.028	0.028
	Chloride	0.022	0.022	0.028	0.028	0.028	0.028
PZ-2M-66'	Perchlorate	0.090	0.090	0.096	0.097	0.100	0.099
	Chlorate	0.090	0.090	0.096	0.097	0.100	0.099
	Nitrate as N	0.090	0.090	0.096	0.097	0.100	0.099
	Nitrate as NO3	0.090	0.090	0.096	0.097	0.100	0.099
	Sulfate	0.090	0.090	0.096	0.097	0.100	0.099
	Chloride	0.090	0.090	0.096	0.097	0.100	0.099

CONTINUATION OF APPENDIX B (Calculation of contaminant mass concentrations)

A	B	V	W	X	Y	Z	AA	AB
Sample ID	Contaminant	Mass of contaminants in extraction rinses						
-	-	Extraction 1		Extraction 2		Extraction 3		Units
-	-	Replicate 1	Replicate 2	Replicate 1	Replicate 2	Replicate 1	Replicate 2	-
-	-	(D*P)	(F*Q)	(H*R)	(J*S)	(L*T)	(N*U)	-
PZ-1M-46.5'	Perchlorate	5.33	8.60	9.80	13.72	9.80	9.80	ug
	Chlorate	1.63	0.86	0.67	1.47	0.98	1.27	ug
	Nitrate as N	0.02	0.01	0.01	0.01	0.01	0.01	mg
	Nitrate as NO3	0.08	0.06	0.06	0.06	0.06	0.06	mg
	Sulfate	13.84	13.51	4.92	5.35	1.41	1.30	mg
	Chloride	7.16	7.03	2.71	2.83	1.52	1.53	mg
PZ-2M-55'	Perchlorate	193.20	197.40	68.00	72.27	9.40	17.82	ug
	Chlorate	423.20	385.40	150.00	148.50	30.00	43.56	ug
	Nitrate as N	0.06	0.06	0.02	0.02	0.01	0.01	mg
	Nitrate as NO3	0.28	0.25	0.09	0.10	0.05	0.03	mg
	Sulfate	14.95	13.72	6.02	6.51	2.21	2.78	mg
	Chloride	9.75	9.28	2.85	3.09	0.73	0.82	mg
PZ-2M-56'	Perchlorate	2.80	-	2.38	-	11.76	-	ug
	Chlorate	95.20	-	44.80	-	8.40	-	ug
	Nitrate as N	0.01	-	0.07	-	0.07	-	mg
	Sulfate	7.72	-	4.73	-	1.00	-	mg
	Chloride	2.86	-	0.84	-	0.25	-	mg
PZ-2M-65'	Perchlorate	35.20	-	13.44	-	2.69	-	ug
	Chlorate	52.80	-	21.84	-	5.04	-	ug
	Nitrate as N	0.01	-	0.01	-	0.01	-	mg
	Sulfate	6.05	-	4.05	-	1.05	-	mg
	Chloride	1.91	-	1.00	-	0.27	-	mg
PZ-2M-66'	Perchlorate	12.60	11.70	9.60	9.70	10.00	9.90	ug
	Chlorate	18.90	18.90	8.83	10.67	3.50	3.66	ug
	Nitrate as N	0.04	0.03	0.01	0.01	0.01	0.01	mg
	Nitrate as NO3	0.07	0.08	0.05	0.03	0.05	0.05	mg
	Sulfate	23.71	24.29	12.66	13.44	5.88	6.44	mg
	Chloride	4.49	4.56	1.83	2.01	0.75	0.75	mg

CONTINUATION OF APPENDIX B (Calculation of contaminant mass concentrations)

A	B	AC	AD	AE	AF	AG
Sample ID	Contaminant	Total Mass of Contaminants			Soil sample Mass (g)	
-	-	-	-	Units	-	-
-	-	Replicate 1	Replicate 2	-	Replicate 1	Replicate 2
-	-	(V+X+Z)	(W+Y+AA)	-	-	-
PZ-1M-46.5'	Perchlorate	24.93	32.12	ug	50.12	50.13
	Chlorate	3.28	3.60	ug	50.12	50.13
	Nitrate as N	0.04	0.04	mg	50.12	50.13
	Nitrate as NO3	0.20	0.19	mg	50.12	50.13
	Sulfate	20.17	20.16	mg	50.12	50.13
	Chloride	11.39	11.40	mg	50.12	50.13
PZ-2M-55'	Perchlorate	270.60	287.49	ug	50.50	50.34
	Chlorate	603.20	577.46	ug	50.50	50.34
	Nitrate as N	0.09	0.09	mg	50.50	50.34
	Nitrate as NO3	0.42	0.38	mg	50.50	50.34
	Sulfate	23.18	23.02	mg	50.50	50.34
	Chloride	13.33	13.19	mg	50.50	50.34
PZ-2M-56'	Perchlorate	16.94	0.00	ug	25.29	-
	Chlorate	148.40	0.00	ug	25.29	-
	Nitrate as N	0.15	0.00	mg	25.29	-
	Sulfate	13.45	0.00	mg	25.29	-
	Chloride	3.95	0.00	mg	25.29	-
PZ-2M-65'	Perchlorate	51.33	0.00	ug	25.38	-
	Chlorate	79.68	0.00	ug	25.38	-
	Nitrate as N	0.03	0.00	mg	25.38	-
	Sulfate	11.15	0.00	mg	25.38	-
	Chloride	3.17	0.00	mg	25.38	-
PZ-2M-66'	Perchlorate	32.20	31.30	ug	50.28	50.01
	Chlorate	31.23	33.23	ug	50.28	50.01
	Nitrate as N	0.06	0.04	mg	50.28	50.01
	Nitrate as NO3	0.16	0.15	mg	50.28	50.01
	Sulfate	42.25	44.17	mg	50.28	50.01
	Chloride	7.07	7.32	mg	50.28	50.01

CONTINUATION OF APPENDIX B (Calculation of contaminant mass concentrations)

A	B	AH	AI	AJ	AK
Sample ID	**Contaminant**	**Mass of contaminants per grams of wet soil**			
-	-	-		-	**Units**
-	-	**Replicate 1**	**Replicate 2**	**Average**	-
-	-	**(AC/AF)**	**(AD/AG)**	**(AH+AI/2)**	-
PZ-1M-46.5'	Perchlorate	0.50	0.64	0.57	ug/g of wet soil
	Chlorate	0.07	0.07	0.07	ug/g of wet soil
	Nitrate as N	0.00	0.00	0.00	mg/g of wet soil
	Nitrate as NO3	0.00	0.00	0.00	mg/g of wet soil
	Sulfate	0.40	0.40	0.40	mg/g of wet soil
	Chloride	0.23	0.23	0.23	mg/g of wet soil
PZ-2M-55'	Perchlorate	5.36	5.71	5.54	ug/g of wet soil
	Chlorate	11.95	11.47	11.71	ug/g of wet soil
	Nitrate as N	0.00	0.00	0.00	mg/g of wet soil
	Nitrate as NO3	0.01	0.01	0.01	mg/g of wet soil
	Sulfate	0.46	0.46	0.46	mg/g of wet soil
	Chloride	0.26	0.26	0.26	mg/g of wet soil
PZ-2M-56'	Perchlorate	0.67	-	0.67	ug/g of wet soil
	Chlorate	5.87	-	5.87	ug/g of wet soil
	Nitrate as N	0.01	-	0.01	mg/g of wet soil
	Sulfate	0.53	-	0.53	mg/g of wet soil
	Chloride	0.16	-	0.16	mg/g of wet soil
PZ-2M-65'	Perchlorate	2.02	-	2.02	ug/g of wet soil
	Chlorate	3.14	-	3.14	ug/g of wet soil
	Nitrate as N	0.00	-	0.00	mg/g of wet soil
	Sulfate	0.44	-	0.44	mg/g of wet soil
	Chloride	0.12	-	0.12	mg/g of wet soil
PZ-2M-66'	Perchlorate	0.64	0.63	0.63	ug/g of wet soil
	Chlorate	0.62	0.66	0.64	ug/g of wet soil
	Nitrate as N	0.00	0.00	0.00	mg/g of wet soil
	Nitrate as NO3	0.00	0.00	0.00	mg/g of wet soil
	Sulfate	0.84	0.88	0.86	mg/g of wet soil
	Chloride	0.14	0.15	0.14	mg/g of wet soil

CONTINUATION OF APPENDIX B (Calculation of contaminant mass concentrations)

A	B	AL	AM	AN
Sample ID	**Contaminant**	**Moisture Content (%)**	**Mass of contaminants in dry basis**	
-	-	-		**Units**
-	-	-	**Total**	-
-	-	-	**(AJ/(1-AL))**	-
PZ-1M-46.5'	Perchlorate	43.91	0.01	ug/g of dry soil
	Chlorate	43.91	0.00	ug/g of dry soil
	Nitrate as N	43.91	0.00	mg/g of dry soil
	Nitrate as NO3	43.91	0.00	mg/g of dry soil
	Sulfate	43.91	0.01	mg/g of dry soil
	Chloride	43.91	0.00	mg/g of dry soil
PZ-2M-55'	Perchlorate	27.43	0.08	ug/g of dry soil
	Chlorate	27.43	0.16	ug/g of dry soil
	Nitrate as N	27.43	0.00	mg/g of dry soil
	Nitrate as NO3	27.43	0.00	mg/g of dry soil
	Sulfate	27.43	0.01	mg/g of dry soil
	Chloride	27.43	0.00	mg/g of dry soil
PZ-2M-56'	Perchlorate	32.73	0.01	ug/g of dry soil
	Chlorate	32.73	0.09	ug/g of dry soil
	Nitrate as N	32.73	0.00	mg/g of dry soil
	Sulfate	32.73	0.01	mg/g of dry soil
	Chloride	32.73	0.00	mg/g of dry soil
PZ-2M-65'	Perchlorate	23.41	0.03	ug/g of dry soil
	Chlorate	23.41	0.04	ug/g of dry soil
	Nitrate as N	23.41	0.00	mg/g of dry soil
	Sulfate	23.41	0.01	mg/g of dry soil
	Chloride	23.41	0.00	mg/g of dry soil
PZ-2M-66'	Perchlorate	26.62	0.01	ug/g of dry soil
	Chlorate	26.62	0.01	ug/g of dry soil
	Nitrate as N	26.62	0.00	mg/g of dry soil
	Nitrate as NO3	26.62	0.00	mg/g of dry soil
	Sulfate	26.62	0.01	mg/g of dry soil
	Chloride	26.62	0.00	mg/g of dry soil

Expected contaminant concentrations in elution chamber

A	B	C	D	E
Sample type Units	Performed test -	Contaminant -	Contaminant Concentration	Units
PZ-1M 46.5	First Diffusion Test	Perchlorate	0.569	ug/g of wet soil
		Chlorate	0.069	ug/g of wet soil
		Nitrate as N	0.001	mg/g of wet soil
		Nitrate as NO3	0.004	mg/g of wet soil
		Sulfate	0.402	mg/g of wet soil
		Chloride	0.227	mg/g of wet soil
PZ-2M 56	First Diffusion Test	Perchlorate	0.670	ug/g of wet soil
		Chlorate	5.867	ug/g of wet soil
		Nitrate as N	0.006	mg/g of wet soil
		Sulfate	0.532	mg/g of wet soil
		Chloride	0.156	mg/g of wet soil
PZ-1M 46.5	Second Diffusion Test	Perchlorate	0.569	ug/g of wet soil
		Chlorate	0.069	ug/g of wet soil
		Nitrate as N	0.001	mg/g of wet soil
		Nitrate as NO3	0.004	mg/g of wet soil
		Sulfate	0.402	mg/g of wet soil
		Chloride	0.227	mg/g of wet soil
PZ-2M 56	Second Diffusion Test	Perchlorate	0.670	ug/g of wet soil
		Chlorate	5.867	ug/g of wet soil
		Nitrate as N	0.006	mg/g of wet soil
		Sulfate	0.532	mg/g of wet soil
		Chloride	0.156	mg/g of wet soil
PZ-1M 46.5	Advection Test	Perchlorate	0.569	ug/g of wet soil
		Chlorate	0.069	ug/g of wet soil
		Nitrate as N	0.001	mg/g of wet soil
		Nitrate as NO3	0.004	mg/g of wet soil
		Sulfate	0.402	mg/g of wet soil
		Chloride	0.227	mg/g of wet soil
PZ-2M 56	First Advection Test	Perchlorate	0.670	ug/g of wet soil
		Chlorate	5.867	ug/g of wet soil
		Nitrate as N	0.006	mg/g of wet soil
		Sulfate	0.532	mg/g of wet soil
		Chloride	0.156	mg/g of wet soil
PZ-2M 56	Second Advection Test	Perchlorate	0.670	ug/g of wet soil
		Chlorate	5.867	ug/g of wet soil
		Nitrate as N	0.006	mg/g of wet soil
		Sulfate	0.532	mg/g of wet soil
		Chloride	0.156	mg/g of wet soil
PZ-2M 56	Third Advection Test	Perchlorate	0.670	ug/g of wet soil
		Chlorate	5.867	ug/g of wet soil
		Nitrate as N	0.006	mg/g of wet soil
		Sulfate	0.532	mg/g of wet soil
		Chloride	0.156	mg/g of wet soil

A	B	C	F	G	H
				(D*F)	
Sample type	Performed test	Contaminant	Soil cake mass (g)	Expected [ ] in soil	
Units	-	-			Units
PZ-1M 46.5	First Diffusion Test	Perchlorate	117.94	67.11	ug
		Chlorate	117.94	8.10	ug
		Nitrate as N	117.94	0.10	mg
		Nitrate as NO3	117.94	0.46	mg
		Sulfate	117.94	47.45	mg
		Chloride	117.94	26.80	mg
PZ-2M 56	First Diffusion Test	Perchlorate	144.70	96.91	ug
		Chlorate	144.70	848.96	ug
		Nitrate as N	144.70	0.87	mg
		Sulfate	144.70	76.93	mg
		Chloride	144.70	22.59	mg
PZ-1M 46.5	Second Diffusion Test	Perchlorate	115.15	65.53	ug
		Chlorate	115.15	7.91	ug
		Nitrate as N	115.15	0.10	mg
		Nitrate as NO3	115.15	0.45	mg
		Sulfate	115.15	46.32	mg
		Chloride	115.15	26.17	mg
PZ-2M 56	Second Diffusion Test	Perchlorate	122.00	81.71	ug
		Chlorate	122.00	715.78	ug
		Nitrate as N	122.00	0.73	mg
		Sulfate	122.00	64.87	mg
		Chloride	122.00	19.04	mg
PZ-1M 46.5	Advection Test	Perchlorate	108.20	61.57	ug
		Chlorate	108.20	7.43	ug
		Nitrate as N	108.20	0.09	mg
		Nitrate as NO3	108.20	0.42	mg
		Sulfate	108.20	43.53	mg
		Chloride	108.20	24.59	mg
PZ-2M 56	First Advection Test	Perchlorate	125.10	83.78	ug
		Chlorate	125.10	733.97	ug
		Nitrate as N	125.10	0.75	mg
		Sulfate	125.10	66.51	mg
		Chloride	125.10	19.53	mg
PZ-2M 56	Second Advection Test	Perchlorate	133.00	89.07	ug
		Chlorate	133.00	780.31	ug
		Nitrate as N	133.00	0.80	mg
		Sulfate	133.00	70.71	mg
		Chloride	133.00	20.76	mg
PZ-2M 56	Third Advection Test	Perchlorate	134.00	89.74	ug
		Chlorate	134.00	786.18	ug
		Nitrate as N	134.00	0.81	mg
		Sulfate	134.00	71.25	mg
		Chloride	134.00	20.92	mg

A	B	C	I	J	K
				(G*I)	
Sample type Units	Performed test -	Contaminant -	Chamber Volume (L)	Expected [ ] in chamber	Units
PZ-1M 46.5	First Diffusion Test	Perchlorate	1.3	51.63	ug/L
		Chlorate	1.3	6.23	ug/L
		Nitrate as N	1.3	0.08	mg/L
		Nitrate as NO3	1.3	0.35	mg/L
		Sulfate	1.3	36.50	mg/L
		Chloride	1.3	20.62	mg/L
PZ-2M 56	First Diffusion Test	Perchlorate	1.3	74.55	ug/L
		Chlorate	1.3	653.05	ug/L
		Nitrate as N	1.3	0.67	mg/L
		Sulfate	1.3	59.18	mg/L
		Chloride	1.3	17.37	mg/L
PZ-1M 46.5	Second Diffusion Test	Perchlorate	1.3	50.41	ug/L
		Chlorate	1.3	6.08	ug/L
		Nitrate as N	1.3	0.08	mg/L
		Nitrate as NO3	1.3	0.34	mg/L
		Sulfate	1.3	35.63	mg/L
		Chloride	1.3	20.13	mg/L
PZ-2M 56	Second Diffusion Test	Perchlorate	1.3	62.85	ug/L
		Chlorate	1.3	550.60	ug/L
		Nitrate as N	1.3	0.57	mg/L
		Sulfate	1.3	49.90	mg/L
		Chloride	1.3	14.65	mg/L
PZ-1M 46.5	Advection Test	Perchlorate	1.3	47.36	ug/L
		Chlorate	1.3	5.72	ug/L
		Nitrate as N	1.3	0.07	mg/L
		Nitrate as NO3	1.3	0.32	mg/L
		Sulfate	1.3	33.48	mg/L
		Chloride	1.3	18.92	mg/L
PZ-2M 56	First Advection Test	Perchlorate	1.3	64.45	ug/L
		Chlorate	1.3	564.59	ug/L
		Nitrate as N	1.3	0.58	mg/L
		Sulfate	1.3	51.16	mg/L
		Chloride	1.3	15.02	mg/L
PZ-2M 56	Second Advection Test	Perchlorate	1.3	68.52	ug/L
		Chlorate	1.3	600.24	ug/L
		Nitrate as N	1.3	0.62	mg/L
		Sulfate	1.3	54.40	mg/L
		Chloride	1.3	15.97	mg/L
PZ-2M 56	Third Advection Test	Perchlorate	1.3	69.03	ug/L
		Chlorate	1.3	604.76	ug/L
		Nitrate as N	1.3	0.62	mg/L
		Sulfate	1.3	54.80	mg/L
		Chloride	1.3	16.09	mg/L

A	B	C	L	M	N	O
						(J+M)
Sample type **Units**	**Performed test** **-**	**Contaminant** **-**	**Groundwater [ ]**		**Units**	**Final expected concentration in water**
PZ-1M 46.5	First Diffusion Test	Perchlorate	<	100.00	ug/L	151.63
		Chlorate		52.00	ug/L	58.23
		Nitrate as N	<	0.11	mg/L	0.19
		Nitrate as NO3	<	0.50	mg/L	0.85
		Sulfate		88.00	mg/L	124.50
		Chloride		44.00	mg/L	64.62
PZ-2M 56	First Diffusion Test	Perchlorate	<	100.00	ug/L	174.55
		Chlorate		15.00	ug/L	668.05
		Nitrate as N	<	0.11	mg/L	0.78
		Sulfate		1.30	mg/L	60.48
		Chloride		0.60	mg/L	17.97
PZ-1M 46.5	Second Diffusion Test	Perchlorate	<	100	ug/L	150.41
		Chlorate	<	100	ug/L	106.08
		Nitrate as N	<	0.11	mg/L	0.19
		Nitrate as NO3	<	0.55	mg/L	0.89
		Sulfate		1.9	mg/L	37.53
		Chloride		0.75	mg/L	20.88
PZ-2M 56	Second Diffusion Test	Perchlorate	<	100	ug/L	162.85
		Chlorate		26	ug/L	576.60
		Nitrate as N	<	0.11	mg/L	0.68
		Sulfate		4.4	mg/L	54.30
		Chloride		1.3	mg/L	15.95
PZ-1M 46.5	Advection Test	Perchlorate		170.00	ug/L	217.36
		Chlorate		170.00	ug/L	175.72
		Nitrate as N		0.10	mg/L	0.17
		Nitrate as NO3		0.43	mg/L	0.75
		Sulfate		440.00	mg/L	473.48
		Chloride		220.00	mg/L	238.92
PZ-2M 56	First Advection Test	Perchlorate		330.00	ug/L	394.45
		Chlorate		1400.00	ug/L	1964.59
		Nitrate as N		0.16	mg/L	0.74
		Sulfate		110.00	mg/L	161.16
		Chloride		45.00	mg/L	60.02
PZ-2M 56	Second Advection Test	Perchlorate		300.00	ug/L	368.52
		Chlorate		1400.00	ug/L	2000.24
		Nitrate as N		0.12	mg/L	0.74
		Sulfate		120.00	mg/L	174.40
		Chloride		49.00	mg/L	64.97
`PZ-2M 56	Third Advection Test	Perchlorate		330.00	ug/L	399.03
		Chlorate		1500.00	ug/L	2104.76
		Nitrate as N		0.19	mg/L	0.81
		Sulfate		120.00	mg/L	174.80
		Chloride		50.00	mg/L	66.09

APPENDIX C – Contaminant concentration for the first diffusion test.

PZ-1M/ 46.5' depth					
Sample ID	**Date**	**Chloride**	**Sulfate**	**Chlorate**	**Perchlorate**
Units	**-**	**mg/L**	**mg/L**	**ug/L**	**ug/L**
PZ-1M Groundwater	12/6/2018	44	88	52	< 100
PZ-1M 12-06-2018	12/6/2018	73	150	< 200	< 100
PZ-1M 12-11-2018	12/11/2018	64	140	< 200	< 100
PZ-1M 12-13-2018	12/13/2018	61	130	< 200	< 100
PZ-1M 12-19-2018	12/19/2018	58	120	< 200	< 100
PZ-1M 12-26-2018	12/26/2018	49	100	< 200	< 100
PZ-1M 12-26-2018[1]	12/26/2018	44	93	< 200	< 100
PZ-1M 01-07-2019	01/07/2019	44	94	< 100	< 100
PZ-1M 01-18-2019	01/08/2019	41	85	54	< 100
PZ-1M 01-28-2019	01/28/2019	41	85	< 100	< 100
PZ-1M 02-04-2019	02/04/2019	41	85	< 100	< 100
PZ-1M 02-11-2019	02/11/2019	44	85	< 100	< 100
PZ-1M 02-18-2019	02/18/2019	42	83	< 100	< 100
PZ-1M 03-01-2019	03/01/2019	42	77	< 100	< 100
PZ-1M 03-09-2019	03/09/2019	44	75	< 100	< 100
PZ-1M 03-15-2019	03/15/2019	44	71	< 100	< 100
PZ-1M 03-22-2019	03/22/2019	44	71	< 100	< 100
PZ-1M 03-29-2019	03/29/2019	42	63	< 100	< 100
Expected concentration	-	64.62	124.50	58.23	151.63

[1] New feed was applied because of a leak in the setup.

PZ-2M/ 56' Depth

Sample ID	Date	Chloride	Nitrate as N	Nitrate as NO_3	Sulfate	Chlorate	Perchlorate
Units	**-**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**ug/L**	**ug/L**
PZ-2M Groundwater	12/6/2018	0.6	< 0.11	< 0.5	1.3	15	< 100
PZ-2M 12-06-2018	12/6/2018	26	< 2.2	< 10	73	603	110
PZ-2M 12-11-2018	12/11/2018	22	< 2.2	< 10	81	< 200	< 100
PZ-2M 12-13-2018	12/13/2018	20	< 2.2	< 10	72	< 200	< 100
PZ-2M 12-19-2018	12/19/2018	20	< 2.2	< 10	67	< 200	< 100
PZ-2M 12-26-2018	12/26/2018	17	< 2.2	< 10	58	< 200	< 100
PZ-2M 01-07-2019	01/07/2019	12	< 0.11	< 0.5	45	< 100	< 100
PZ-2M 01-18-2019	01/08/2019	11	< 0.11	< 0.5	41	< 100	< 100
PZ-2M 01-28-2019	01/28/2019	8.6	< 0.11	< 0.5	33	< 100	< 100
PZ-2M 02-04-2019	02/04/2019	10	0.097	0.43	32	< 100	< 100
PZ-2M 02-11-2019	02/11/2019	8.7	< 0.11	<0.5	29	< 100	< 100
PZ-2M 02-18-2019	02/18/2019	8.5	< 0.11	<0.5	27	22	< 100
PZ-2M 03-01-2019	03/01/2019	8	< 0.11	<0.5	24	< 100	< 100
PZ-2M 03-09-2019	03/09/2019	7.9	< 0.11	<0.5	23	< 100	< 100
PZ-2M 03-15-2019	03/15/2019	7.6	< 0.11	<0.5	21	< 100	< 100
PZ-2M 03-22-2019	03/22/2019	6.4	< 0.11	<0.5	20	< 100	< 100
PZ-1M 03-29-2019	03/29/2019	7.3	< 0.11	<0.5	20	< 100	< 100
Expected concentration		17.97	0.78	-	60.48	668.05	174.55

APPENDIX D – Corrected contaminant concentrations for the first diffusion test performed.

		Date	Initial Concentration (mg/L)	Total Volume (Liters)	Mass measured (mg)	GW concentration (mg/L)	Mass added (mg)	Volume of sample taken (Liters)	Mass taken (mg)	Corrected concentration (mg/L)
Sulfate	**PZ - 1M**	12/02/2018	86.76	1.3	112.79	86.76	-	-	-	86.76
		12/06/2018	150.00	1.3	195.00	86.76	-	0.02	-	150.00
		12/11/2018	140.00	1.3	182.00	86.76	1.74	0.02	3.00	139.03
		12/13/2018	130.00	1.3	169.00	86.76	1.74	0.02	2.78	129.20
		12/19/2018	120.00	1.3	156.00	86.76	1.74	0.02	2.58	119.35
		12/26/2018	100.00	1.3	130.00	86.76	1.74	0.02	2.39	99.50
		12/26/2018 [1]	93.00	1.3	120.90	86.76	1.74	0.02	1.99	92.80
	PZ - 2M	12/02/2018	1.23	1.3	1.60	1.23	-	-	-	1.23
		12/06/2018	73.00	1.3	94.90	1.23	-	0.02	-	73.00
		12/11/2018	81.00	1.3	105.30	1.23	0.02	0.02	1.46	79.90
		12/13/2018	72.00	1.3	93.60	1.23	0.02	0.02	1.60	70.79
		12/19/2018	67.00	1.3	87.10	1.23	0.02	0.02	1.42	65.93
		12/26/2018	58.00	1.3	75.40	1.23	0.02	0.02	1.32	57.00
Chloride	**PZ - 1M**	12/02/2018	46.10	1.3	59.93	46.10	-	-	-	46.10
		12/06/2018	73.00	1.3	94.90	46.10	-	0.02	-	73.00
		12/11/2018	64.00	1.3	83.20	46.10	0.92	0.02	1.46	63.59
		12/13/2018	61.00	1.3	79.30	46.10	0.92	0.02	1.27	60.73
		12/19/2018	58.00	1.3	75.40	46.10	0.92	0.02	1.21	57.77
		12/26/2018	49.00	1.3	63.70	46.10	0.92	0.02	1.16	48.82
		12/26/2018 [1]	44.00	1.3	57.20	46.10	0.92	0.02	0.98	43.96
	PZ - 2M	12/02/2019	0.55	1.3	0.71	0.55	-	-	-	0.55
		12/06/2018	26.00	1.3	33.80	0.55	-	0.02	-	26.00
		12/11/2018	22.00	1.3	28.60	0.55	0.01	0.02	0.52	21.61
		12/13/2018	20.00	1.3	26.00	0.55	0.01	0.02	0.43	19.68
		12/19/2018	20.00	1.3	26.00	0.55	0.01	0.02	0.39	19.71
		12/26/2018	17.00	1.3	22.10	0.55	0.01	0.02	0.39	16.71

[1] New feed was applied because of a leak in the setup.

APPENDIX E – Contaminant concentrations for the second diffusion test.

		PZ-1M-46.5'			
Sample ID	**Date**	**Sulfate**	**Chloride**	**Perchlorate**	**Chlorate**
Units	**-**	**mg/L**	**mg/L**	**ug/L**	**ug/L**
Groundwater	03/04/2019				
Diffusion 1	03/04/2019	8.4	6.1	< 100	13
Diffusion 2	03/05/2019	13	13	260	< 100
Diffusion 3	03/05/2019	14	9.1	< 100	< 100
Diffusion 4	03/06/2019	16	12	< 100	< 100
Diffusion 5	03/07/2019	21	12	< 100	< 100
Diffusion 6	03/08/2019	22	9.9	< 100	< 100
Diffusion 7	03/09/2019	23	13	< 100	12
Diffusion 8	03/10/2019	22	10	< 100	14
Diffusion 9	03/11/2019	26	12	< 100	< 100
Diffusion 10	03/13/2019	23	13	< 100	18
Diffusion 11	03/15/2019	26	12	< 100	20
Diffusion 12	03/17/2019	24	13	< 100	20
Diffusion 13	03/19/2019	29	19	< 100	20
Diffusion 14	03/21/2019	24	13	< 100	22
Diffusion 15	03/23/2019	24	12	< 100	23
Diffusion 16	03/30/2019	25	15	< 100	35
Diffusion 17	04/07/2019	26	33	< 100	22
Expected concentration		35.63	20.13	50.41	6.08

		PZ-2M-56'			
Sample ID	**Date**	**Sulfate**	**Chloride**	**Perchlorate**	**Chlorate**
Units	**-**	**mg/L**	**mg/L**	**ug/L**	**ug/L**
Groundwater	03/04/2019				
Diffusion 1	03/04/2019	15	7.4	100	200
Diffusion 2	03/05/2019	21	10	150	250
Diffusion 3	03/05/2019	26	9.8	62	290
Diffusion 4	03/06/2019	29	25	64	320
Diffusion 5	03/07/2019	31	11	77	310
Diffusion 6	03/08/2019	34	10	72	320
Diffusion 7	03/09/2019	32	22	71	310
Diffusion 8	03/10/2019	32	10	74	300
Diffusion 9	03/11/2019	34	10	68	260
Diffusion 10	03/13/2019	33	11	63	340
Diffusion 11	03/15/2019	34	10	75	100
Diffusion 12	03/17/2019	34	12	<100	<100
Diffusion 13	03/19/2019	33	12	<100	<100
Diffusion 14	03/21/2019	33	11	<100	<100
Diffusion 15	03/23/2019	33	11	<100	<100
Diffusion 16	03/30/2019	35	13	<100	35
Diffusion 17	04/07/2019	32	11	<100	61
Expected concentration		49.90	14.65	62.85	550.60

APPENDIX F – Contaminant concentrations for the advection test performed using PZ-1M 46.5-feet deep sample.

PZ-1M 46.5' Depth						
Sample ID	**Date**	**Flow**	**Sulfate**	**Chloride**	**Perchlorate**	**Chlorate**
Units	**-**	**mL/min**	**mg/L**	**mg/L**	**ug/L**	**ug/L**
Groundwater	2/16/2019	-	440	220	170	170
Expected concentration	-	-	473.48	238.92	217.26	175.72
AD 1	2/16/2019	0.05	420	210	200	170
AD 2	2/17/2019	0.03	460	220	200	180
AD 3	2/18/2019	0.03	500	250	230	170
AD 4	2/19/2019	0.03	460	250	830	170
AD 5	2/20/2019	0.03	450	230	340	180
AD 6	2/21/2019	0.03	470	220	240	150
AD 7	2/22/2019	0.02	480	230	240	120
AD 8[1]	2/23/2019	0.02	460	230	200	38
AD 9	2/24/2019	0.02	460	220	170	< 0.1
AD 10	2/25/2019	0.02	460	230	150	< 0.1
AD 11	2/26/2019	0.02	480	240	230	< 0.1
AD 12	2/27/2019	0.02	450	210	140	< 0.1
AD 13	2/28/2019	0.02	460	230	73	< 0.1
AD 14	3/1/2019	0.02	480	250	63	< 0.1
AD 15	3/2/2019	0.02	470	220	< 0.1	< 0.1
AD 16	3/3/2019	0.02	470	240	< 0.1	< 0.1
AD 17	3/4/2019	0.03	460	240	350	< 0.1
AD 18	3/5/2019	0.03	470	230	450	250
AD 19	3/6/2019	0.03	480	240	2,600	< 0.1
AD 20	3/7/2019	0.03	490	240	< 0.1	< 0.1
AD 21	3/8/2019	0.04	470	230	2,100	< 0.1
AD 22	3/9/2019	0.04	480	240	< 0.1	< 0.1
AD 23	3/10/2019	0.05	490	240	< 0.1	< 0.1
AD 24	3/11/2019	0.05	480	230	76	< 0.1
AD 25	3/12/2019	0.05	500	250	440	< 0.1
AD 26	3/13/2019	0.05	490	250	< 0.1	< 0.1
AD 27	3/14/2019	0.05	440	220	1,300	<0.1
AD 28	3/15/2019	0.05	540	260	< 0.1	390
AD 29	3/16/2019	0.05	540	260	< 0.1	< 0.1
AD 30	3/17/2019	0.05	530	240	< 0.1	< 0.1

[1] New feed was applied because of a leak in the pump's tubing.

APPENDIX G – Contaminant concentrations for the first advection test performed using PZ-2M 56 feet deep sample.

PZ-2M 56'									
Sample ID	**Time**	**Date**	**Flow**	**Sulfate**	**Chloride**	**Perchlorate**	**Chlorate**	**Nitrate as NO_3**	**Nitrate as N**
Units	**Hour**	**-**	**mL/min**	**mg/L**	**mg/L**	**ug/L**	**ug/L**	**mg/L**	**mg/L**
Groundwater	10:20 AM	2/9/2019	0.71	110	45	330	1400	-	0.16
Expected Concentration	-	-	-	161.16	60.02	394.45	1965	-	0.74
AD 1	10:20 AM	2/9/2019	0.71	120	50	280	1400	0.83	0.19
AD 2	11:20 AM	2/9/2019	0.71	120	50	210	1600	0.76	0.17
AD 3	12:20 PM	2/9/2019	0.71	140	55	320	1600	0.78	0.18
AD 4	1:20 PM	2/9/2019	0.71	140	58	460	1700	0.80	0.18
AD 5	2:20 PM	2/9/2019	0.71	140	57	330	1700	0.80	0.18
AD 6	3:20 PM	2/9/2019	0.71	140	57	390	1700	0.79	0.18
AD 7 [1]	5:20 PM	2/9/2019	0.87	140	59	370	1700	0.79	0.18
AD 8	7:20 PM	2/9/2019	0.87	140	59	370	1700	0.81	0.18
AD 9	8:20 PM	2/9/2019	0.87	150	60	470	1700	0.79	0.18
AD 10	9:20 PM	2/9/2019	0.87	140	61	400	1700	0.78	0.18
AD 11	10:20 PM	2/9/2019	0.87	140	59	330	1700	0.94	0.21
AD 12	11:20 PM	2/9/2019	0.87	130	53	320	1600	0.83	0.19
AD 13 [2]	12:20 AM	2/10/2019	0.30	140	58	470	1600	< 0.5	<0.11
AD 14	10:20 AM	2/10/2019	0.45	160	61	420	1700	< 0.5	<0.11
AD 15	10:20 AM	2/11/2019	1.06	150	56	340	1400	< 0.5	<0.11
AD 16 [3]	10:20 AM	2/12/2019	0.69	140	53	290	580	< 0.5	<0.11
AD 17	10:20 AM	2/13/2019	0.52	140	53	320	80	< 0.5	<0.11
AD 18	10:20 AM	2/14/2019	0.45	140	54	240	<100	< 0.5	<0.11

[1] There was no flow in the outlet, the gradient was increased to 0.6 (minimal flow possible).

[2] The volume of the samples increased due to the increased time between the collected samples.

[3] New feed was applied because of a leak caused by the recirculation system.

APPENDIX H – Contaminant concentrations for the second advection test performed using PZ-2M 56-feet deep sample.

PZ-2M 56'									
Sample ID	**Time**	**Date**	**Flow**	**Sulfate**	**Chloride**	**Perchlorate**	**Chlorate**	**Nitrate as NO_3**	**Nitrate as N**
Units	**Hour**	**-**	**mL/min**	**mg/L**	**mg/L**	**ug/L**	**ug/L**	**mg/L**	**mg/L**
Groundwater	11:00 AM	3/19/19	-	120	49	300	1,400		0.12
Expected concentration	-	-		174.40	65	368.52	2,000	-	0.74
AD-2M-1	11:00 AM	3/19/19	0.29	170	70	460	2,000	1.2	0.27
AD-2M-2	5:00 PM	3/19/19	0.27	200	77	520	2,200	-	-
AD-2M-3	12:00 AM	3/20/19	0.28	190	69	440	2,000	-	-
AD-2M-4	8:00 AM	3/20/19	0.25	170	62	400	1,800	0.26	0.058
AD-2M-5	4:00 PM	3/20/19	0.22	200	63	390	1,700	-	-
AD-2M-6	12:00 AM	3/21/19	0.18	150	57	370	1,600	-	-
AD-2M-7	8:00 AM	3/21/19	0.16	150	54	360	1,600	<0.5	<0.11
AD-2M-8	4:00 PM	3/21/19	0.16	140	55	370	1,500	-	-
AD-2M-9	12:00 AM	3/22/19	0.14	140	54	350	1,200	-	-
AD-2M-10	8:00 AM	3/22/19	0.14	140	56	360	780	<0.5	<0.11
AD-2M-11	4:00 PM	3/22/19	0.14	130	52	330	210	-	-
AD-2M-12	12:00 AM	3/23/19	0.13	130	53	340	<100	-	-
AD-2M-13	8:00 AM	3/23/19	0.12	140	55	250	14	<0.5	<0.11
AD-2M-14	8:00 PM	3/23/19	0.12	140	58	180	<100	-	-
AD-2M-15	8:00 AM	3/24/19	0.10	130	54	96	<100	-	-
AD-2M-16	8:00 PM	3/24/19	0.10	140	55	<100	<100	<0.5	<0.11
AD-2M-17	8:00 AM	3/25/19	0.10	130	55	<100	<100	<0.5	<0.11
AD-2M-18	8:00 PM	3/25/19	0.10	130	52	<100	<100	<0.5	<0.11
AD-2M-19	8:00 AM	3/26/19	0.10	130	51	<100	<100	<0.5	<0.11
AD-2M-20	8:00 PM	3/26/19	0.10	130	53	<100	<100	<0.5	<0.11
AD-2M-21	8:00 AM	3/27/19	0.10	130	54	<100	<100	<0.5	<0.11
AD-2M-22	8:00 PM	3/27/19	0.10	130	53	<100	<100	<0.5	<0.11
AD-2M-23	8:00 AM	3/28/19	0.18	130	54	<100	<100	<0.5	<0.11
AD-2M-24	8:00 AM	3/29/19	0.17	130	56	<100	<100	<0.5	<0.11
AD-2M-25	8:00 AM	3/30/19	0.16	130	53	<100	<100	<0.5	<0.11
AD-2M-26	8:00 AM	3/31/19	0.15	130	50	<100	<100	-	-
AD-2M-27	8:00 AM	4/1/19	0.15	130	51	<100	<100	<0.5	<0.11
AD-2M-28	8:00 AM	4/2/19	0.14	130	50	<100	<100	-	-
AD-2M-29	8:00 AM	4/3/2019	0.17	130	51	<100	<100	<0.5	<0.11

APPENDIX I - Contaminant concentrations for the third advection test performed using PZ-2M 56-feet deep sample.

PZ-2M 56'									
Sample ID	**Time**	**Date**	**Flow**	**Sulfate**	**Chloride**	**Perchlorate**	**Chlorate**	**Nitrate as NO_3**	**Nitrate as N**
Units	**Hour**	**-**	**mL/min**	**mg/L**	**mg/L**	**ug/L**	**ug/L**	**mg/L**	**mg/L**
Groundwater	9:00 AM	3/25/2019		120	50	330	1,500.00		0.19
Expected concentration		-		175	66	399.03	2104.76	-	0.81
AD3 - 1	9:00 AM	3/25/2019	1.92	140	54	430	1600.00	0.84	0.19
AD3 - 2	10:00 AM	3/25/2019	1.78	130	55	380	1600.00	-	-
AD3 - 3	11:00 AM	3/25/2019	1.75	130	55	490	1600.00	-	-
AD3 - 4	12:00 PM	3/25/2019	1.42	130	54	350	1600.00	0.79	0.18
AD3 - 5	1:00 PM	3/25/2019	1.08	130	86	290	1600.00	-	-
AD3 - 6	2:00 PM	3/25/2019	1.42	140	57	330	1600.00	-	-
AD3 - 7	3:00 PM	3/25/2019	1.08	140	57	310	1600.00	0.63	0.14
AD3 - 8	4:00 PM	3/25/2019	1.08	140	57	310	1600.00	-	-
AD3 - 9	5:00 PM	3/25/2019	0.92	140	56	310	1600.00	-	-
AD3 - 10	6:00 PM	3/25/2019	0.75	130	56	300	1600.00	0.47	0.11
AD3 - 11	7:00 PM	3/25/2019	1.42	140	56	280	1500.00	-	-
AD3 - 12	8:00 PM	3/25/2019	2.50	130	55	290	1500.00	-	-
AD3 - 13	10:00 PM	3/25/2019	1.58	130	53	310	1600.00	0.33	0.076
AD3 - 14	12:00 AM	3/26/2019	1.42	130	51	300	1500.00	-	-
AD3 - 15	2:00 AM	3/26/2019	1.67	130	52	300	1500.00	-	-
AD3 - 16	6:00 AM	3/26/2019	1.25	130	50	310	1500.00	<0.5	<0.11
AD3 - 17	8:00 AM	3/26/2019	1.46	130	50	270	1500.00	-	-
AD3 - 18	10:00 AM	3/26/2019	1.25	130	50	300	1500.00	-	-
AD3 - 19	12:00 PM	3/26/2019	1.67	130	50	300	1500.00		
AD3 - 20	2:00 PM	3/26/2019	2.08	130	50	280	1500.00	-	-
AD3 - 21	4:00 PM	3/26/2019	1.83	130	50	300	1500.00	-	-
AD3 - 22	6:00 PM	3/26/2019	1.79	130	50	270	1500.00	<0.5	<0.11
AD3 - 23	8:00 PM	3/26/2019	2.08	130	50	250	1500.00	<0.5	<0.11

APPENDIX J – Diffusion coefficient for the contaminants of interest in water.

Wilke-Chang method for diffusion coefficient in water:

$$D = \frac{5.06 \times 10^{-7} \times T}{\mu \times V^{0.6}}$$

D= diffusion coefficient (cm^2/ sec)

T = temperature (K)

μ = viscosity of water (centipoise, cP)

V = molal volume of contaminant (cm^3/mol)

The temperature adopted for the calculations was 293.15°K and the viscosity of water 0.890 cP. The molal volume was obtained from the table below, estimated from the methods of LeBas.

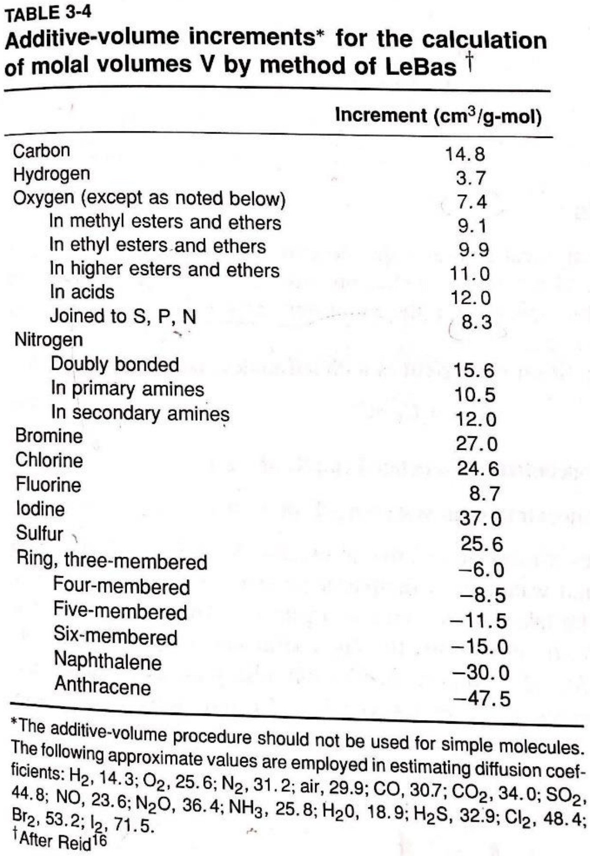


TABLE 3-4

Additive-volume increments* for the calculation of molal volumes V by method of LeBas †

	Increment (cm^3/g-mol)
Carbon	14.8
Hydrogen	3.7
Oxygen (except as noted below)	7.4
In methyl esters and ethers	9.1
In ethyl esters and ethers	9.9
In higher esters and ethers	11.0
In acids	12.0
Joined to S, P, N	8.3
Nitrogen	
Doubly bonded	15.6
In primary amines	10.5
In secondary amines	12.0
Bromine	27.0
Chlorine	24.6
Fluorine	8.7
Iodine	37.0
Sulfur	25.6
Ring, three-membered	−6.0
Four-membered	−8.5
Five-membered	−11.5
Six-membered	−15.0
Naphthalene	−30.0
Anthracene	−47.5

*The additive-volume procedure should not be used for simple molecules. The following approximate values are employed in estimating diffusion coefficients: H_2, 14.3; O_2, 25.6; N_2, 31.2; air, 29.9; CO, 30.7; CO_2, 34.0; SO_2, 44.8; NO, 23.6; N_2O, 36.4; NH_3, 25.8; H_20, 18.9; H_2S, 32.9; Cl_2, 48.4; Br_2, 53.2; I_2, 71.5.

†After Reid[16]

Perchlorate (ClO_4^-)

$$V = 24.6 + (7.4 \times 4)$$

$$V = 54.2\,\frac{cm^3}{g - mol}$$

$$D = \frac{5.06 \ \times 10^{-7} \ \times 293.15}{0.89 \times 54.2^{0.6}}$$

$$D = 1.52 \times 10^{-5}\ cm^2/sec$$

Chlorate (ClO_3^-)

$$V = 24.6 + (7.4 \times 3)$$

$$V = 46.8\,\frac{cm^3}{g - mol}$$

$$D = \frac{5.06 \ \times 10^{-7} \ \times 293.15}{0.89 \times 46.8^{0.6}}$$

$$D = 1.65 \times 10^{-5}\ cm^2/sec$$

Chloride (Cl^-)

$$V = 24.6\,\frac{cm^3}{g - mol}$$

$$D = \frac{5.06 \ \times 10^{-7} \ \times 293.15}{0.89 \times 24.6^{0.6}}$$

$$D = 2.44 \times 10^{-5}\ cm^2/sec$$

Nitrate (NO_3^-)

$$V = 15.6 + (7.4 \times 3)$$

$$V = 37.8\,\frac{cm^3}{g - mol}$$

$$D = \frac{5.06 \ \times 10^{-7} \ \times 293.15}{0.89 \times 37.8^{0.6}}$$

$$D = 1.89 \times 10^{-5}\ cm^2/sec$$

Sulfate (SO_4^{-2})

$$V = 25.6 + (7.4 \times 4)$$

$$V = 55.2\,\frac{cm^3}{g - mol}$$

$$D = \frac{5.06\ \times 10^{-7}\ \times 293.15}{0.89 \times 55.2^{0.6}}$$

$$D = 1.50 \times 10^{-5}\ cm^2/sec$$