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Nevada Environmental Response Trust
Henderson, Nevada

Prepared by
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RI STUDY AREA MASS ESTIMATE AND EXPANDED PERFORMANCE METRICS TECHNICAL APPROACH

NEVADA ENVIRONMENTAL RESPONSE TRUST SITE
HENDERSON, NEVADA

RAMBOLL ENVIRON

RI Study Area Mass Estimate and Expanded Performance Metrics Technical Approach

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

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

Office of the Nevada Environmental Response Trust

Le Petomane XXVII, Inc., not individually, but solely in its representative capacity as the Nevada Environmental Response Trust Trustee not individually, but solely as Pres. Int

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Date: 9/29/17

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Responsible Certified Environmental Manager (CEM) for this project

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

___________________________________ ____10/5/17______________________________

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CONTENTS

FIGURES

ACRONYMS AND ABBREVIATIONS

1D	one-dimensional
3D	three-dimensional
AMPAC/Endeavour	American Pacific Corporation/Endeavour LLC
AOC3	Settlement Agreement and Administrative Order on Consent, BMI Common Areas, Phase 3 (NDEP 2006)
AWF	Athens Road Well Field
bgs	below ground surface
BMI	Black Mountain Industrial
BRC	Basic Remediation Company LLC
CEM	Certified Environmental Manager
cg	Coarse Grain
COPC	chemical of potential concern
ENSR	ENSR Corporation
fg	Fine Grain
FS	Feasibility Study
ft/ft	feet per foot
GWETS	groundwater extraction and treatment system
ITRC	Interstate Technology and Regulatory Council
IWF	Interceptor Well Field
NDEP	Nevada Division of Environmental Protection
NERT	Nevada Environmental Response Trust
OSSM	Olin/Stauffer/Syngenta/Montrose
OU	Operable Unit
Qal	Quaternary alluvium
Ramboll Environ	Ramboll Environ US Corporation
RAO	remedial action objective
RI/FS	Remedial Investigation and Feasibility Study
Site	Nevada Environmental Response Trust Site
SWF	Seep Well Field
Tetra Tech	Tetra Tech, Inc.
TIMET	Titanium Metals Corporation
Tronox	Tronox LLC

Trust	Nevada Environmental Response Trust
UMCf	Upper Muddy Creek Formation
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
xMCf	Transitional Muddy Creek Formation

1. INTRODUCTION

This technical memorandum, prepared by Ramboll Environ US Corporation (Ramboll Environ) on behalf of the Nevada Environmental Response Trust (the Trust or NERT), describes an updated framework for estimating contaminant mass and evaluating remedial performance metrics for the primary NERT chemicals of potential concern, perchlorate and chromium (as applicable), in the subsurface. The NERT Site, which was formerly owned and operated by Tronox LLC (Tronox), comprises approximately 346 acres located within the Black Mountain Industrial (BMI) Complex in unincorporated Clark County and is surrounded by the City of Henderson, Nevada (see Figure 1).

The Trust owns and operates a groundwater extraction and treatment system (GWETS).[1] The GWETS consists of the on-site Interceptor Well Field (IWF), the off-site Athens Road Well Field (AWF)[2], the off-site Seep Well Field (SWF), and related conveyance and treatment systems. On behalf of the Trust, Ramboll Environ prepares Annual Remedial Performance Reports (annual reports) for submittal to the Nevada Division of Environmental Protection (NDEP) in accordance with the Interim Consent Agreement between the Trust and NDEP dated February 14, 2011. In addition to documenting regional groundwater conditions, contaminant distributions, performance of the GWETS, and major site activities, the annual reports include:

- Estimates of the remaining mass of the Site's primary contaminants of concern (perchlorate and chromium); and
- Evaluations of performance metrics other than remaining mass, which were developed as part of the 2013 GWETS Optimization Work Plan (ENVIRON 2013), approved by NDEP on December 3, 2013 (NDEP 2013).

The mass estimates and other performance metrics provided in the annual reports through 2016 were evaluated within the NERT Site and the NERT Off-Site Study Area shown on Figure 1. At NDEP's request, the scope of the NERT RI was expanded to include the Downgradient Study Area and the Eastside Study Area in 2015 and 2016, respectively. As a result, the NERT RI Study Area increased from 1,430 acres to 5,860 acres. The scope of the RI has also expanded vertically based on recently collected data indicating that the vertical extent of chemical impacts extends to greater depths than was previously understood. The methodology for calculating mass estimates and other performance metrics will be modified to account for the increase in the size of the NERT RI Study Area, with the changes to the metrics phased in as additional data becomes available.

[1] Herein "GWETS" will be used to refer to the entirety of all systems and components of the groundwater extraction and treatment systems owned by the Trust, both on-site and off-site, including extraction well fields, treatment facilities, and groundwater conveyance systems.

[2] Although Athens Road has been renamed Galleria Drive, the Athens Road designation has been retained for the well field to maintain consistency with past reports.

Recently, the NERT RI Study Area was divided into Operable Units (OUs), as follows:

- OU-1: NERT Site
- OU-2: NERT Off-Site Study Area south of Galleria Drive and the Eastside Sub-Area (within the Eastside Study Area)
- OU-3: NERT Off-Site Study Area north of Galleria Drive, the Downgradient Study Area, and the Northeast Sub-Area (within the Eastside Study Area)

The boundaries to be used for the mass estimates are shown with the study area boundaries in Figure 2a and with the OU boundaries in Figure 2b. For the sole purpose of the mass estimate, the boundary of the NERT Site (OU-1) will be extended to include adjacent areas where perchlorate and chromium originating from the NERT Site may have migrated. Ultimately, the mass estimate and other performance metrics for perchlorate will be expanded to include the entire NERT RI Study Area (including two areas adjacent to the NERT Site). Performance metrics for chromium, however, will be modified only to add the Mass Estimate Extension Area since the potential presence of hexavalent chromium and chromium in groundwater within and migrating from the Eastside Sub-Area will be investigated and remediated by Basic Remediation Company LLC (BRC), if necessary, pursuant to the terms of the Settlement Agreement and Administrative Order on Consent, BMI Common Areas, Phase 3, with NDEP (AOC3) (NDEP 2006).

This report describes the updated methodologies that will be used to develop mass estimates and the expanded performance metrics for perchlorate and chromium within the NERT RI Study Area (including two areas adjacent to the NERT Site). The new mass estimate methodology will include contaminant mass estimates in both the vadose and saturated zones, and will provide more accurate estimates of mass in deeper groundwater. These estimates are an essential component of the conceptual site model being developed in the RI that will form the basis of evaluating remedial alternatives in the Feasibility Study (FS).

This new framework has been devised by the Trust as part of a comprehensive multi-year program that will be implemented in a phased manner pending the receipt of data from ongoing and planned field investigations being conducted throughout the NERT RI Study Area. The major investigations currently being conducted include the Phase 2 RI, the Phase 3 RI[3], and the Downgradient Study Area Investigation. The schedule for implementing the revised approach for mass estimates and performance metrics is presented in Section 5.

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[3] The work plan describing the Phase 3 RI will be submitted in October 2017.

2. BACKGROUND

2.1 Regional Geology

The Site is located within the Las Vegas Valley, which occupies a topographic and structural basin trending northwest-southeast and extending approximately 55 miles from near Indian Springs on the north to Railroad Pass on the south. The valley is bounded by the Las Vegas Range, Sheep Range, and Desert Range to the north; by Frenchman and Sunrise Mountains to the east; by the McCullough Range and River Mountains to the south and southeast; and the Spring Mountains to the west. The mountain ranges bounding the east, north, and west sides of the valley consist primarily of Paleozoic and Mesozoic sedimentary rocks (limestones, sandstones, siltstones, and fanglomerates), whereas the mountains on the south and southeast consist primarily of Tertiary volcanic rocks (basalts, rhyolites, andesites, and related rocks) that overlie Precambrian metamorphic and granitic rocks (ENSR 2007).

In the Las Vegas Valley, eroded Tertiary and Quaternary sedimentary and volcanic rocks comprise the unconsolidated basin deposits, which can be up to 13,000 feet thick (ENSR 2007). The valley floor consists of fluvial, paludal (swamp), playa, and lacustrine deposits surrounded by more steeply sloping alluvial fan aprons derived from erosion of the surrounding mountains. Generally, the deposits grade finer with increasing distance from their source and with decreasing elevation. The structure within the Quaternary and Tertiary-aged basin fill is characterized by a series of generally north-south trending fault scarps.

The local geology and hydrogeology are defined by data collected from more than 3,500 borings and wells that have been installed in the area. Hydrostratigraphic units are shown on a north-to-south cross-section shown in Figures 3a and 3b. The following descriptions are summarized from the RI/FS Work Plan (ENVIRON 2014).

2.2 Local Geology

Alluvium. The Site is located on Quaternary alluvial deposits (Qal) that slope north toward Las Vegas Wash. The alluvium consists of a reddish-brown heterogeneous mixture of well-graded sand and gravel with lesser amounts of silt, clay, and caliche. Clasts within the alluvium are primarily composed of volcanic material. Boulders and cobbles are common. Due to the mode of deposition, no distinct beds or units are continuous over the area.

A major feature of the alluvial deposits is the stream-deposited sands and gravels that were laid down within paleochannels eroded into the surface of the Muddy Creek Formation during infrequent flood runoff periods. These deposits vary in thickness and are narrow and generally linear. These generally uniform sand and gravel deposits exhibit higher permeability than the adjacent, well-graded deposits. In general, these paleochannels trend northeastward.

The thickness of the alluvial deposits ranges from less than 1 foot to more than 70 feet beneath the Site. Soil types identified in on-site soil borings include poorly sorted gravel, silty gravel, poorly sorted sand, well sorted sand, and silty sand.

Transitional (or reworked) Muddy Creek Formation. Where present, Transitional Muddy Creek Formation (xMCf) is encountered at the base of the alluvium. The

Transitional Muddy Creek Formation consists of reworked sediments derived from the Muddy Creek Formation, which is described below. Therefore, the xMCf appears similar to the Muddy Creek Formation, but it consists of reworked, less consolidated and indurated sediments.

Muddy Creek Formation. The Upper Muddy Creek Formation (UMCf) of Pleistocene age occurs in the Las Vegas Valley as valley-fill deposits that are coarse-grained near mountain fronts and become progressively finer-grained toward the center of the valley. Where encountered beneath the Site, the Muddy Creek Formation is composed of at least two thicker units of fine-grained sediments of clay and silt (the first and second fine-grained facies) interbedded with at least two thinner units of coarse-grained sediments of sand, silt, and gravel (the first and second coarse-grained facies). As shown on Figures 3a and 3b, except for the southernmost 1,000 feet adjacent to Lake Mead Parkway, the first fine-grained facies (UMCf-fg1) separates the first coarse-grained facies (UMCf-cg1) from the overlying Quaternary alluvium at the Site. Within the southern 1,000 feet of the Site, the Muddy Creek Formation's UMCf-fg1 pinches out along a roughly west-northwesterly trending line. South of this line, the UMCf-cg1 directly underlies the Quaternary alluvium.

Locally, the Muddy Creek Formation represents deposition in an alluvial apron environment from the Spring Mountains to the west, grading into fluvial, paludal (swamp), playa, and lacustrine environments further out into the valley center (Ramboll Environ 2016a). On the Site, the Muddy Creek does not crop out but instead subcrops beneath a veneer of Quaternary alluvium. Since the Site is located closer to the mountains, the upper portion of the UMCf-fg1 unit tends to have zones of sandy silt/silty fine sand as well as a greater number of thin, discontinuous layers of silty sand than in the downgradient plume area, which is farther from the mountains and more toward the interior of the depositional basin.

In on-site borings, the contact between the Quaternary alluvium and the Muddy Creek Formation (UMCf-fg1) is typically marked by the appearance of a well-compacted, moderate brown silt-to-sandy silt or stiff clay-to-sandy clay, whereas near the Las Vegas Wash, the contact is marked by gray-green to yellow-green gypsiferous clays and silts. Often, a layer of calichified sediments is observed at the contact.

2.3 Local Hydrogeology

The depth to groundwater in the NERT RI Study Area ranges from about 20 to 70 ft bgs and is generally deepest in the southernmost portion of the NERT Site, becoming shallower as it approaches the Las Vegas Wash to the north (Ramboll Environ 2016a). North of the Site, beyond Boulder Highway, shallow groundwater is generally encountered between four and 30 feet bgs, becoming shallower as it approaches the Las Vegas Wash. The groundwater gradient averages 0.015 to 0.02 ft/ft south of the Athens Road well field (AWF), flattening to 0.007 to 0.010 ft/ft north of the well field. The groundwater flow direction at the Site is generally north to north-northwesterly, whereas north of the Site the direction changes slightly to the north-northeast. This generally uniform flow pattern may be modified locally by subsurface alluvial channels cut into the underlying UMCf (paleochannels), the on-site bentonite-slurry groundwater barrier wall, localized areas of recharge from on-site storm water retention basins, on- and off-site artificial groundwater highs or "mounds" created around the former on-site recharge trenches when they were in use and City of Henderson Water Reclamation Facility Bird

Viewing Preserve Ponds, by depressions created by the groundwater extraction wells at the three groundwater extraction well fields, and nearby groundwater extraction conducted by Olin/Stauffer/Syngenta/Montrose (OSSM), Titanium Metals Corporation (TIMET), and American Pacific Corporation/Endeavour LLC (AMPAC/Endeavour).

3. MASS ESTIMATE METHODOLOGY

This section describes the proposed methodology for developing comprehensive mass estimates of perchlorate and chromium within the NERT RI Study Area (including two areas adjacent to the NERT Site).

3.1 Objectives

As stated previously, the objective of the approach described herein is to develop a comprehensive multi-year program to estimate perchlorate and chromium mass to support the NERT RI/FS. After the approval of the technical approach presented in this memorandum, the new mass estimates (and other performance metrics described in Section 4) will be phased into NERT's remedial performance reporting as the required data becomes available. The anticipated schedule is provided in Section 5.

As shown on Figures 2a and 2b, mass estimates for perchlorate and chromium will be developed within the Perchlorate Mass Estimate Area and the Chromium Mass Estimate Area, respectively. The boundary of the NERT Site/OU-1 for the purpose of the mass estimates will be extended to include adjacent areas where perchlorate and chromium originating from the NERT Site have migrated, with the entire area referred to as the Mass Estimate Extension Area. Vertically, the new mass estimates will include all depths known to be impacted by perchlorate or chromium from the NERT Site, including the vadose zone and impacted intervals of the alluvium and UMCf.

3.2 Current Methodology

Mass estimates have been presented in the Annual Remedial Performance Reports since 2013. The current mass estimate boundary includes the NERT Site and NERT Off-Site Study Area, with the mass reported for each of the three subareas shown on Figure 4. Vertically, the current methodology includes the saturated alluvium and the saturated UMCf to a maximum depth of 50 feet below the contact with the alluvium. The current methodology does not include the vadose zone or deeper impacts within the UMCf that have been discovered during recent investigations.

The mass is currently estimated by interpolating the groundwater concentrations of perchlorate and chromium onto a regular grid based on both the isoconcentration contours and the concentrations at well locations. The grid is composed of square grid cells that all have the same area. At each grid cell, the mass is calculated by multiplying the cell area, the saturated thickness, the interpolated groundwater concentration, and the porosity. The alluvium saturated thickness is estimated as the difference between the interpolated water table elevation and the UMCf contact elevation. The UMCf thickness is assumed to be 50 feet in the on-site area, 15 feet in the area between the site and the AWF, and 0 feet north of the AWF. The assumed depth of perchlorate contamination in the UMCf was established in 2013 based on the understanding of the plume at the time, and this assumption has continued to be used to maintain consistency from year to year. Porosities of 0.37 and 0.54 are assumed for the Qal and UMCf, respectively.

3.3 Conceptual Approach for Proposed Methodology

The current methodology is being refined in order to provide a more complete mass estimate that accounts for the recently expanded NERT RI Study Area (including two areas adjacent to the NERT Site) and the greater vertical extent of impacted groundwater discovered during recent investigations. Mass estimate areas for perchlorate and chromium are shown on Figures 2a and 2b. The revised mass estimate will use available relevant data, including data collected for the RI (in all three OUs), pilot tests, treatability studies, and investigations by other parties (AMPAC/Endeavour, OSSM, TIMET, BRC). Many of these investigations include collection of significant amounts of soil data within the saturated zone. In order to take advantage of the detailed vertical delineation provided by soil data, the new mass estimate methodology will incorporate the soil data into the analysis by converting soil concentrations into equivalent pore water concentrations. To provide more accurate mass estimates in areas where data are sparse, the proposed methodology will supplement soil and groundwater point data with additional information based on the conceptual model (e.g., plume contours).

Soil and equivalent pore water concentrations can be related by the following equation:

$$C_s = C_w\left(K_d + \frac{\theta_w}{\rho_b}\right)$$

where C_s is the soil concentration [mg/kg], C_w is the equivalent pore water concentration [mg/L], K_d is the distribution coefficient [L/kg], θ_w is the total porosity [-], and ρ_b is the dry soil bulk density [kg/L]. The distribution coefficient for perchlorate is equal to zero as perchlorate does not adsorb onto soil mineral surfaces. The distribution coefficient for chromium is an empirical parameter that is a function of soil and groundwater chemistry (USEPA 1999). Representative values for the parameters in the above equation will be selected based on field measurements and verified by comparing the results from the equation with the measured concentrations at sample locations with both soil and groundwater data.

Similar to the current approach, mass estimates for each OU and geologic unit in the saturated zone will be calculated over a regular grid. A mass estimate will also be calculated for the vadose zone that in some cases will include different geologic units. Separate identically sized grids will be used for different depths within geologic units. Specifically, to account for the greater data density and potential for variability, a finer grid will be used in OU-1 (~100x100 feet) than in OU-2 and OU-3 (~400x400 feet). Following general ITRC Guidance on Geospatial Analysis (ITRC 2016), standard geospatial interpolation methods such as kriging will be used to combine all data sources to produce a mass estimate over each grid. Mass estimates in grid cells will be summed to obtain the total mass estimate for each OU and vadose zone/geologic unit.

3.4 Proposed Methodology: OU-1

Perchlorate and chromium mass estimates will be developed for OU-1 and the Mass Estimate Extension Area (see Figures 2a and 2b). As shown on the cross-section in Figure 3a, the main geologic units within OU-1 include: alluvium, UMCf-cg1, and UMCf-fg. There is no indication that the UMCF-cg2 is significantly impacted, so this unit will not be included in the mass estimate. The mass estimation methodology for the vadose zone and each geologic unit in the saturated zone is described below.

3.4.1 Vadose Zone

The vadose zone in OU-1 includes portions of the alluvium, UMCf-cg1, and UMCf-fg. Figure 5 shows the density of currently available vadose zone data. It does not include

Phase 2 RI or other recent data collected in 2017. Under the proposed mass estimate methodology, mass in the vadose zone will be estimated by interpolating the available soil data onto a grid, calculating the chemical mass contained in each grid cell, and summing the cell mass within OU-1 and the Mass Estimate Extension Area. Since there is sufficient vertical data density, the vadose zone will be divided into 10-foot depth slices for interpolation and total mass for each depth slice will be vertically summed.

3.4.2 Saturated Alluvium

Mass in the saturated alluvium will be estimated using the current methodology; however, the mass estimate area will be extended to include the area adjacent to OU-1. The current method interpolates concentrations throughout the grid by combining interpreted isoconcentration contours and point measurements at wells. A conceptual example of the grid within OU-1 and the Mass Estimate Extension Area is shown in Figure 6. The interpolated concentrations will be used to calculate mass in each grid cell by multiplying concentration, saturated cell volume, and porosity in each cell, and then summing cell masses within the region of interest. The saturated cell volume will be obtained by multiplying the cell area and saturated thickness derived from the three-dimensional (3D) geologic model to be developed as part of Phase 6 groundwater model refinement.

3.4.3 Saturated UMCf-cg1

In the southern part of the NERT Site, the UMCf-cg1 is the uppermost saturated unit (see Figures 3a and 3b). The thickness and extent of the UMCf-cg1 based on Phase 1 RI data is shown on Figure 7. As shown on the figure, the UMCf-cg1 thins and pinches out to the north. Recent soil and groundwater data from the Unit Building Investigation (Tetra Tech 2017) and the Phase 2 RI (in progress) indicate that perchlorate impacts extend beyond the base of the UMCf-cg1. However, the presence of fine-grained UMCf-fg beneath the coarse-grained unit (UMCf-cg1) appears to constrain the migration of perchlorate. To estimate mass in the UMCf-cg1, the concentrations will be interpolated using a 3D interpolation method throughout the extent of the unit. The 3D geologic model developed as part of the groundwater modeling task will be used to define the UMCf-cg1 extent and thickness. New boring data collected during the Phase 2 RI and other investigations will be used to update the 3D geologic model.

3.4.4 Saturated UMCf-fg

Under the current conceptual model, perchlorate mass within the UMCf-fg resulted from downward transport from the overlying coarser-grained unit (either alluvium or UMCf-cg1 depending on location). Consistent with this conceptual model, available vertical profile data shows consistent patterns of perchlorate concentration with depth into the UMCf-fg. In general, the concentration within the UMCf-fg drops off fairly rapidly with increasing depth below the contact with the overlying coarser-grained unit (see Figure 8). Depending on mass loading history in the overlying unit, this vertical concentration profile has a peak at or just below the UMCf-fg contact, with an exponential-type decay below the peak.

A relatively simple one-dimensional (1D) transport model can be used to simulate this behavior. This was demonstrated using groundwater data as part of the Phase 5 Groundwater Model development, in which a 1D vertical transport model was developed to evaluate the vertical mass transport at a representative location within the NERT model area (Ramboll Environ 2016d). The location selected was on the NERT Site at monitoring wells M-71, M-162, M-163, and M-164, as shown on Figure 9. By changing the boundary conditions and model parameters, the same model was used to simulate soil concentration data from other locations on the NERT Site (see Figure 10). There is a good match between the model results and the measured data, indicating that this simple model can be used to help estimate the vertical extent of perchlorate and chromium impacts in the UMCf-fg by interpolating the shape of the vertical profiles in between locations with data.

At each location where measured data is available (soil or groundwater concentration data), a transport model will be fit to the data. Estimated model parameters (e.g., concentration in the overlying unit, vertical mass transfer rate) will be individually interpolated onto a grid covering OU-1 and the Mass Estimate Extension Area. Using these parameters, a vertical concentration profile will be simulated for every grid cell. The mass in each vertical profile will be integrated to obtain the total mass within each grid cell, and then the total mass within the UMCf-fg in OU-1 and the Mass Estimate Extension Area will be calculated by summing the masses in the grid cells. If significant laterally continuous lenses or stringers of coarser-grained sediments are identified within the UMCf-fg where the vertical transport model does not adequately capture the distribution of contaminant mass, an alternative approach will be used to estimate mass within the coarser-grained areas, such as the 3D interpolation approach being used for the UMCf-cg unit.

3.5 Proposed Methodology: OU-2 and OU-3

Perchlorate and chromium mass estimates for OU-2 and OU-3 will be developed for the Perchlorate and Chromium Mass Estimate Areas shown on Figures 2a and 2b. Due to the lower data density and lower variability in concentration distribution, a coarser grid will be used for interpolation in OU-2 and OU-3. Since the UMCf-cg1 unit pinches out before reaching OU-2, the mass estimate for OU-2 and OU-3 will be developed for the vadose zone, the saturated alluvium, and the UMCf-fg. Although the proposed methodology for OU-2 and OU-3 is generally the same, separate mass estimates will be provided for each OU.

3.5.1 Vadose Zone

The vadose zone within the former ponds of the Eastside Sub-Area (within OU-2) has been densely sampled, as shown on Figure 11. Other areas within OU-2 and OU-3 have limited vadose zone data, but are expected to be less impacted because they were not used as disposal areas. In the densely sampled areas, the proposed method for estimating contaminant mass is to interpolate vertically averaged vadose zone soil data onto a grid. Based on the interpolated concentrations, the chemical mass contained in each grid cell will be calculated and then the cell masses summed to find the total mass within each OU.

In areas with a lower sampling density, a different approach has been developed that uses information from the conceptual site model to supplement the limited data. Historical data indicates that the water table was higher on average in the past (Malmberg 1965; Harill 1976; Plume 1989); therefore, it is expected that concentrations in the vadose zone immediately above the current water table will be elevated in areas with impacted shallow groundwater. To estimate the residual contaminant mass in the vadose zone in these areas, the historical change in water table elevation will be used to estimate the average thickness of the vadose zone that was previously below the higher water table. Shallow groundwater data will be compared with soil sample data collected within this previously saturated area to derive a relationship between shallow groundwater concentrations and residual concentrations in the vadose zone. This relationship will be applied to shallow groundwater throughout the sparsely sampled portions of OU-2 and OU-3 to predict concentrations in the deep vadose zone in these areas.

3.5.2 Saturated Alluvium

The existing mass estimate approach will be used for saturated alluvium within OU-2 and OU-3. Groundwater concentrations will be interpolated onto the grid shown in Figure 12 from interpreted isoconcentration contours and point measurements. The grid does not cover areas of the plume that originated from the AMPAC/Endeavour site since the mass estimate is focused on mass originating from the NERT Site. The grid for the chromium mass estimate will be limited to the NERT Off-Site Study Area.

In the new mass estimate methodology, soil data may also be incorporated in the mass estimate by calculating equivalent groundwater concentrations.

3.5.3 UMCf-fg

Available soil data suggests that vertical mass transport between the alluvium and UMCf-fg in OU-2 and OU-3 is similar to what has been observed in OU-1 (Figure 13). Thus, the same methodology proposed for estimating the UMCf-fg mass in OU-1 is also proposed for OU-2 and OU-3.

3.6 Soil Physical Properties

Soil physical properties are important parameters in mass estimate calculations in all three OUs. Porosity values are used to calculate the available pore space for contaminant mass to be stored and transported. Soil bulk density is required to convert between equivalent soil and groundwater concentrations.

In the current mass estimate approach, soil physical properties used are based on very limited available data from the Phase 1 RI. In this proposed methodology, soil physical property data to be collected in the Phase 2 RI, Phase 3 RI, and the pilot tests near Las Vegas Wash will be combined with existing data to produce a more robust physical property data set. The locations where new physical properties samples are to be collected are shown on Figure 14. The physical property data will be screened for outliers and any data outside the reasonable range from the literature will be excluded from the analysis. A statistical analysis will be performed and the results summarized for each OU and geological unit. The statistical analysis will assess the degree of variability and spatial correlation. Based on the results of statistical analysis, appropriate methods will be selected for interpolation and further calculations.

4. PERFORMANCE METRICS

GWETS performance metrics are discrete measures of performance reported in the Trust's Annual Remedial Performance Report and Semi-Annual Remedial Performance Technical Memorandum that are used to understand and adjust GWETS performance over time. These metrics were initially developed as part of the 2013 GWETS Optimization Work Plan (ENVIRON 2013), approved by NDEP on December 3, 2013 (NDEP 2013) and is described in the 2016 Annual Remedial Performance Report (Ramboll Environ 2016b).

At the direction of NDEP, the following metrics will be revised and expanded (NDEP 2016a,b):

- Perchlorate and chromium mass
- Perchlorate and chromium mass flux
- Perchlorate mass loading to Las Vegas Wash

Significant changes are proposed to the methodology for calculating perchlorate and chromium mass, as described in Section 3. Additionally, minor changes are proposed for the mass flux and mass loading metrics, which are described below.

4.1 Mass Flux

The capture efficiencies of the NERT well fields are currently evaluated by estimating the perchlorate mass flux at transects located just upgradient of the IWF, AWF, and SWF. These transect lines were established in 2014 and are shown on Figure 15a. At NDEP's request, additional mass flux transect locations were established in 2016 to estimate capture efficiency within the NERT Site and the NERT Off-Site Study Area (NDEP 2016b). These 2016 transects are also shown on Figure 15a and were defined by NDEP as follows:

- Transect along wells WMW6.55S, COH2B, WMW5.5S, WMW4.9S, LNDMW1, and WMW3.5S;
- Transect along wells PC-68, PC-62, PC-59, PC-60, PC-56, PC-58, MCF-18A, and HM-2;
- Transect along wells PC-103, PC-98R, MW-K5, PC-53, PC-2, PC-1, PC-4, and HSW-2;
- Transect along wells PC-152, PC-153, PC-132, PC-131, PC-130, PC-129, PC-128, PC-127, PC-126, and PC-124;
- Northern boundary of NERT Site;
- Eastern boundary of NERT Site; and
- Transect along wells M-123, M-128, M-32, M-33, and M-148A.

Mass flux across the transects established in 2014 and 2016 will be reported in the upcoming Annual Remedial Performance Report that will be submitted to NDEP in October 2017. In addition, and as requested by NDEP, estimated mass flux for chromium at these transects will also be calculated and included in the report.

Since the remedial action objectives (RAOs) are defined based on boundaries of the OUs, ultimately the mass flux transects will be modified to align with the OU boundaries. Proposed transects consistent with the OU boundaries that extend across the entire NERT RI Study Area are shown in Figure 15b. Calculation of perchlorate mass flux at the proposed extended transects will begin once data to be collected as part of the Phase 3 RI is available in mid-2018. Subject to NDEP approval, perchlorate mass flux across the proposed transects will be reported in the Annual Remedial Performance Report to be submitted to NDEP in October 2018.

Initially, the mass flux at all transect locations will be evaluated using a method similar to the one used currently that is described in the Annual Remedial Performance Reports. Mass flux will be calculated using groundwater velocities simulated by the groundwater model and interpolated concentrations. For each grid cell on the transect, the mass flux will be calculated as the product of the interpolated concentration, simulated groundwater velocity, cell width, and saturated thickness of the alluvium and impacted portion of the UMCf. Since the Phase 6 groundwater model (to be completed by mid-2018) will include contaminant transport capabilities, the groundwater model can be used to directly simulate perchlorate mass flux beginning with the 2018 Annual Remedial Performance Report.

4.2 Vertical Mass Flux

In addition to the horizontal mass flux across transects described above, NDEP has requested that vertical mass flux also be evaluated (NDEP 2016b). Accordingly, the Trust proposes to initially evaluate vertical mass flux in three zones: on-site, off-site to the AWF, and from the AWF to the Wash, as shown on Figure 16. The vertical mass flux will be estimated in these three areas based on the vertical groundwater flux from the groundwater flow model and the chemical concentrations from the interpolated Shallow Water Bearing Zone plume maps presented in the Annual Remedial Performance Report. The calculation of vertical mass flux will be done in each grid cell of the groundwater model by multiplying the vertical groundwater flux generated from the model, the area of the model grid cell, and the interpolated chemical concentration in the model grid cell. The total mass flux in each zone will be calculated by summing the calculated mass flux from the grid cells within each zone. The Phase 5 Groundwater Model (Ramboll Environ 2016c) run in steady-state mode using current pumping rates will be used to estimate the vertical groundwater flux. Vertical mass flux will be calculated for perchlorate and chromium.

The NERT groundwater model continues to be refined based on the additional vertical gradient data being collected as part of the Phase 2 and Phase 3 RI. The next version of the model (Phase 6 Model), expected to be available in mid-2018, will include simulation of contaminant transport. Thus, once the Phase 6 Model is available estimates of vertical mass flux can be generated directly from the model. The mass flux values from the model grid cells will be summed over each OU. In addition, vertical mass flux estimates for perchlorate will be calculated for each OU over the entire NERT RI Study Area as shown in Figure 16 after the Phase 6 Model is completed.

4.3 Mass Loading in Las Vegas Wash

In Annual Remedial Performance Reports since 2014, perchlorate mass loading in Las Vegas Wash has been calculated at the following three locations: Las Vegas Wasteway

(LW8.85), Pabco Road (LW6.05), and Northshore Road (LW0.55). These locations are shown on Figure 6. Previously, mass loading estimates have been calculated from measured perchlorate concentrations in surface water and the corresponding stream flow rate at the time of surface water sampling. Stream flows are from co-located United States Geological Survey (USGS) gaging stations.

In June 2017, NERT began collecting monthly surface water samples and testing for perchlorate at the following recently installed USGS gage locations: Duck Creek Confluence Weir (LVW7.2), Bostic Weir (LVW5.3), Homestead Weir (LVW4.2), and Three Kids (LVW3.5). These locations are shown on Figure 17. While NERT will be expanding the number of locations to be evaluated for this metric, the methodology for doing so will remain unchanged. Mass Loading to the Las Vegas Wash will only be calculated for perchlorate since elevated concentrations of chromium in groundwater have not been detected in this area.

5. IMPLEMENTATION SCHEDULE

The expanded performance metrics presented in this memorandum will be implemented in a phased manner pending the receipt of data from several ongoing and planned field investigations including the Phase 2 RI, which is in progress and expected to be completed by November 2017, and the Phase 3 RI, which is to be conducted between November 2017 and April 2018. In addition, several metrics are dependent upon the Phase 6 Groundwater Model refinement, which is expected to be completed in third quarter 2018.

The next Annual Remedial Performance Report will be submitted to NDEP in October 2017 with data through June 2017. Although the 2017 Annual Remedial Performance Report will include plume maps covering the expanded NERT RI Study Area, the mass estimates will cover only the NERT Site and NERT Off-Site Study Area. New performance metrics presented for the first time in this report will include horizontal mass flux at additional transects requested by NDEP and vertical mass flux between the alluvium and UMCf within the NERT Site and NERT Off-Site Study Area. The 2017 Annual Remedial Performance Report will also include analytical results from surface water samples collected in June 2017 from the expanded set of USGS gaging stations in Las Vegas Wash.

The next Semi-Annual Remedial Performance Technical Memorandum will be submitted to NDEP in April 2018 with data through December 2017. It will include for the first time the evaluation of surface water mass discharge in Las Vegas Wash at new stream gages.

The 2018 Annual Remedial Performance Report, to be submitted to NDEP in October 2018, will contain data through June 2018 and will include all mass estimates and performance metrics as described in this document.

The schedule for implementing the updated performance metrics described herein is subject to change, based on data availability. The following table summarizes the current anticipated schedule and includes additional details on data requirements:

Performance Metric	Data Requirement	First Reporting Date
Mass flux at transects established in 2014 and 2016 Vertical mass flux between alluvium and UMCf (OU-1 and OU-2 / OU-3 west of Pabco Road)	Data available through June 2017 Phase 5 Groundwater Model	2017 Annual Remedial Performance Report (October 2017)
Mass loading in Las Vegas Wash (additional 4 locations)	Perchlorate sampling at new USGS gaging stations (Began June 2017)	Semi-Annual Remedial Performance Technical Memorandum (April 2018)

Performance Metric	Data Requirement	First Reporting Date
NERT RI Study Area (including two areas adjacent to the NERT Site) perchlorate mass estimate Mass flux of perchlorate at OU transects across entire NERT RI Study Area Vertical mass flux of perchlorate between alluvium and UMCf across entire NERT RI Study Area	Phase 2 RI data collection (completed by November 2017) Phase 3 RI data collection (November 2017 – April 2018) Phase 6 Groundwater Model refinement (Third Quarter 2018)	2018 Annual Remedial Performance Report (October 2018)

6. REFERENCES

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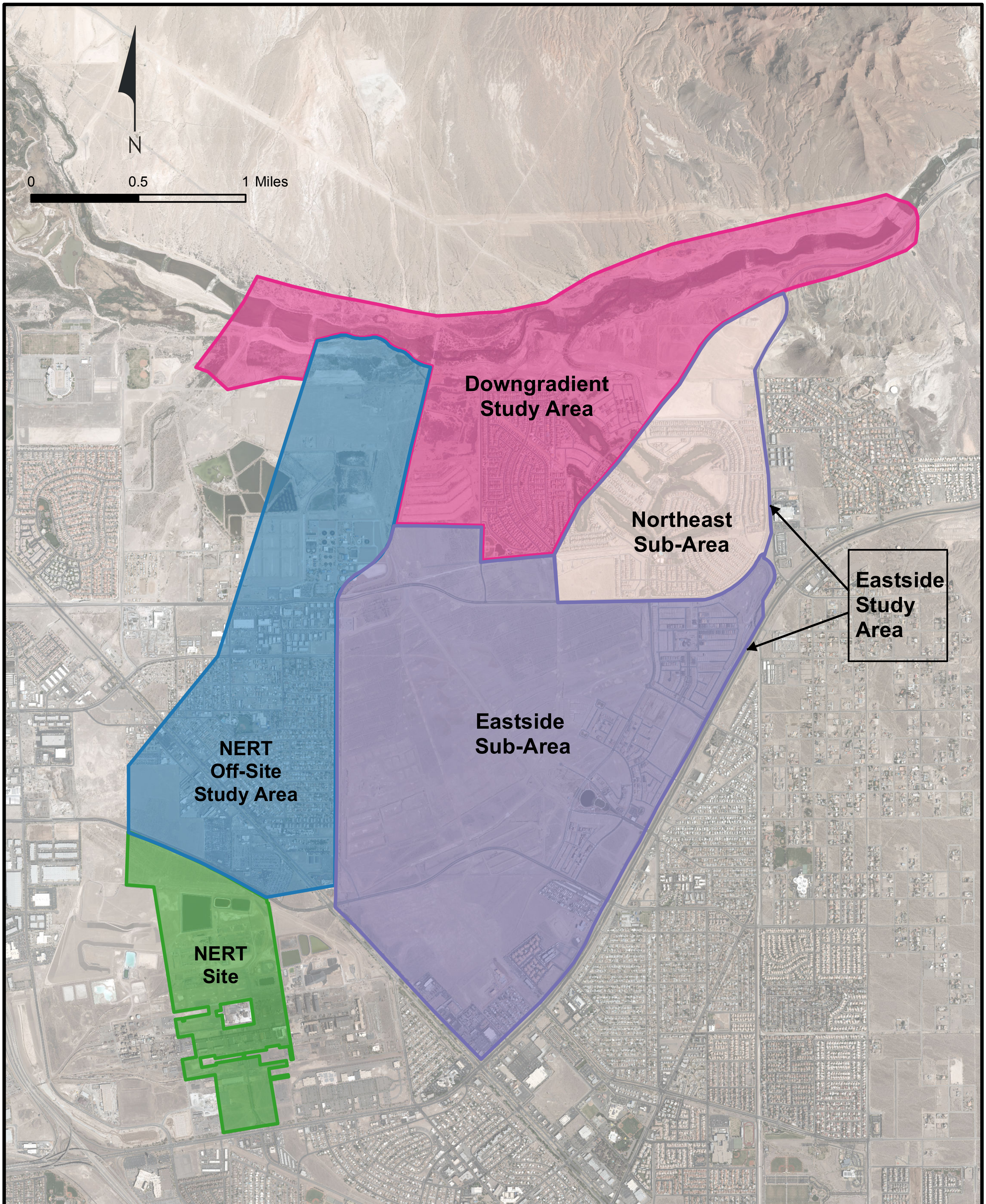
FIGURES



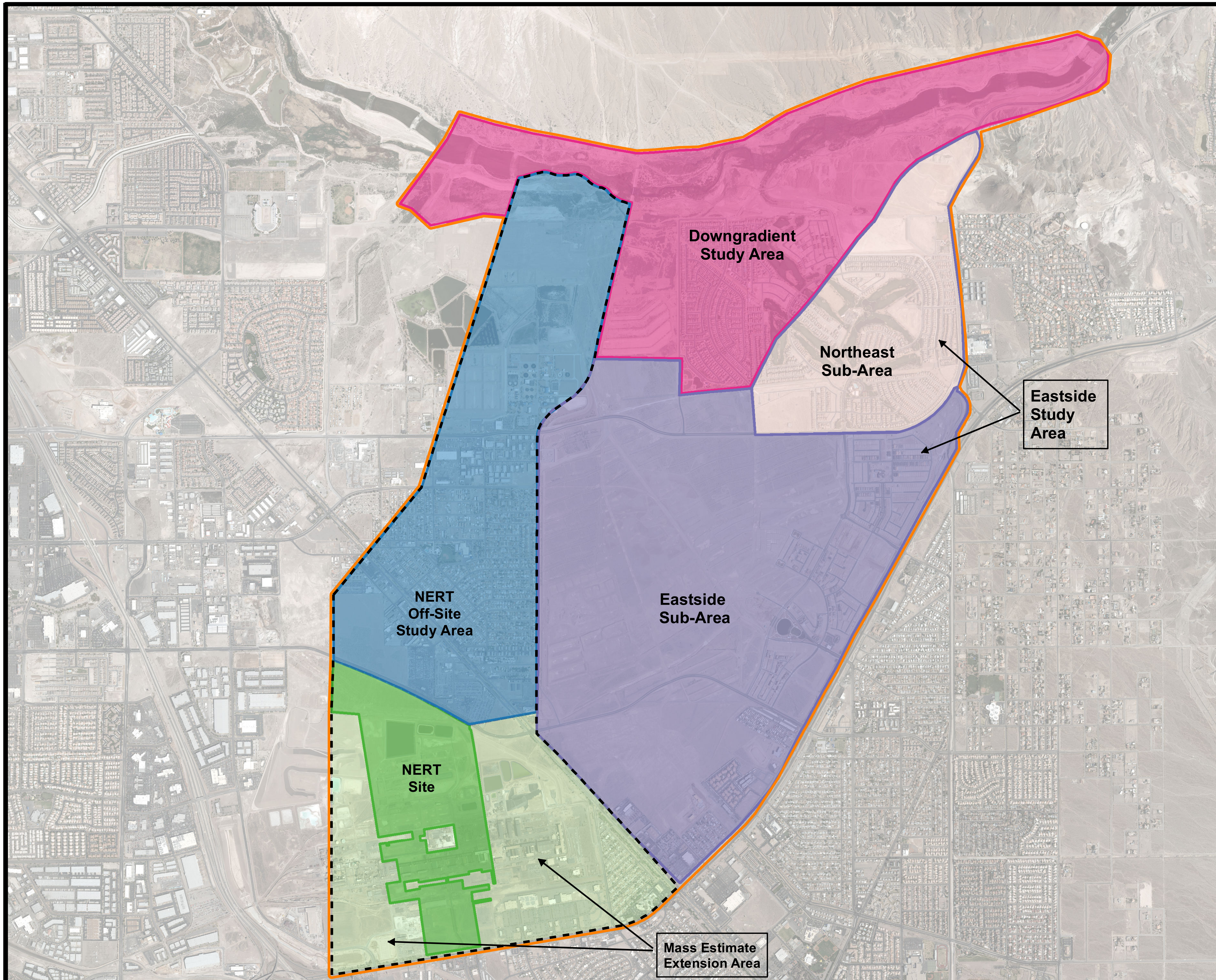
RAMBOLL ENVIRON

Remedial Investigation Study Area Overview
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
1

Drafter: RS | Date: 10/4/2017 | Contract Number: 21-41400C | Approved: | Revised:

Path: H:\LePetomane\NERT\Modeling\MassEstimate2017\Memo\Figures\Figure 1 RI_Phase3_Study Area Overview.mxd



Legend

Mass Estimate Boundaries

Perchlorate Mass Estimate Area

Chromium Mass Estimate Area

N

0 0.5 1 Miles

RAMBOLL ENVIRON

NERT RI Study Area and Mass Estimate Areas

Nevada Environmental Response Trust Site

Henderson, Nevada

Date: 10/4/2017	Contract Number: 21-41400C		Figure 2a
Drafter: LAT	Approved:	Revised:	

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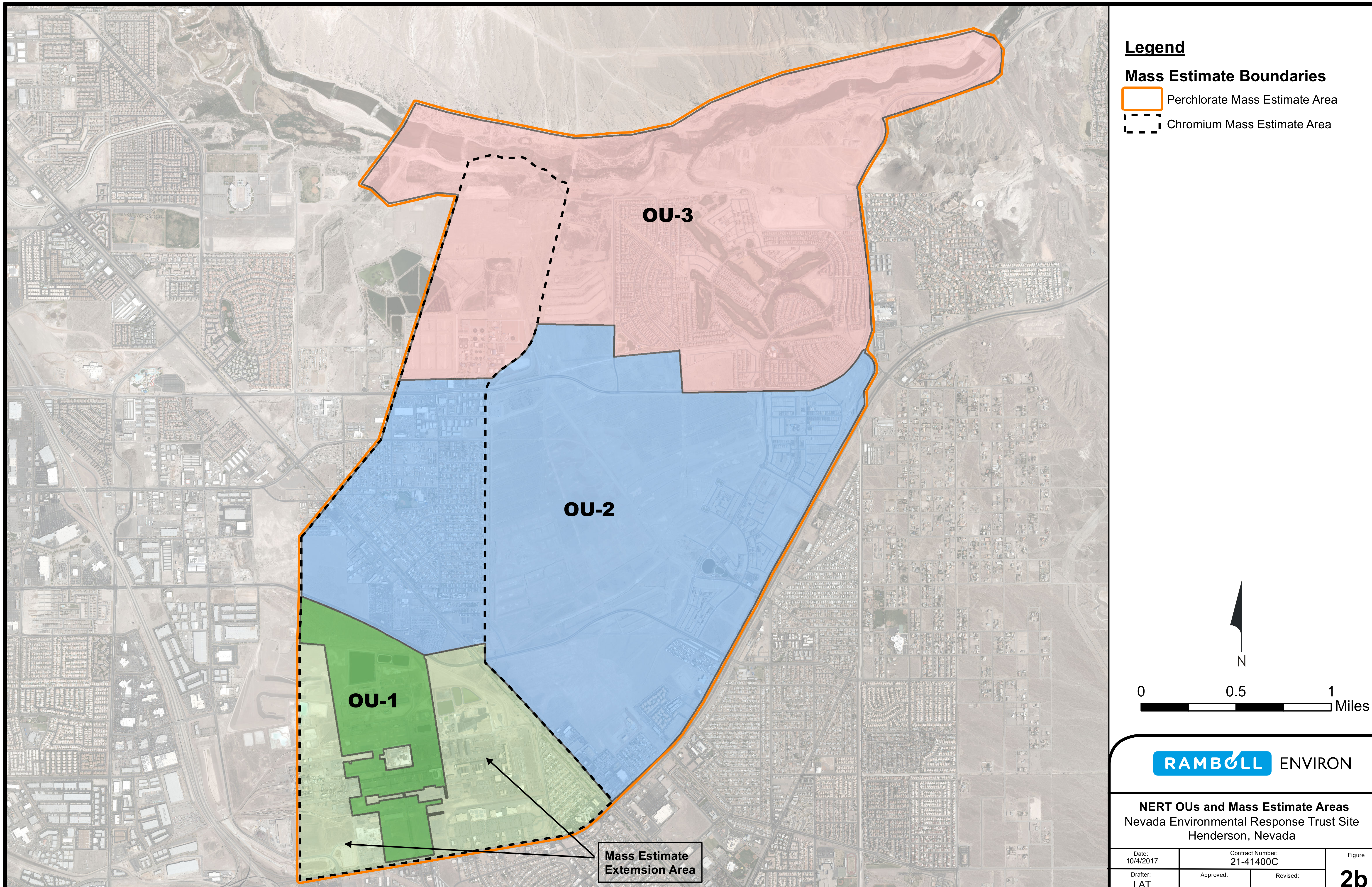
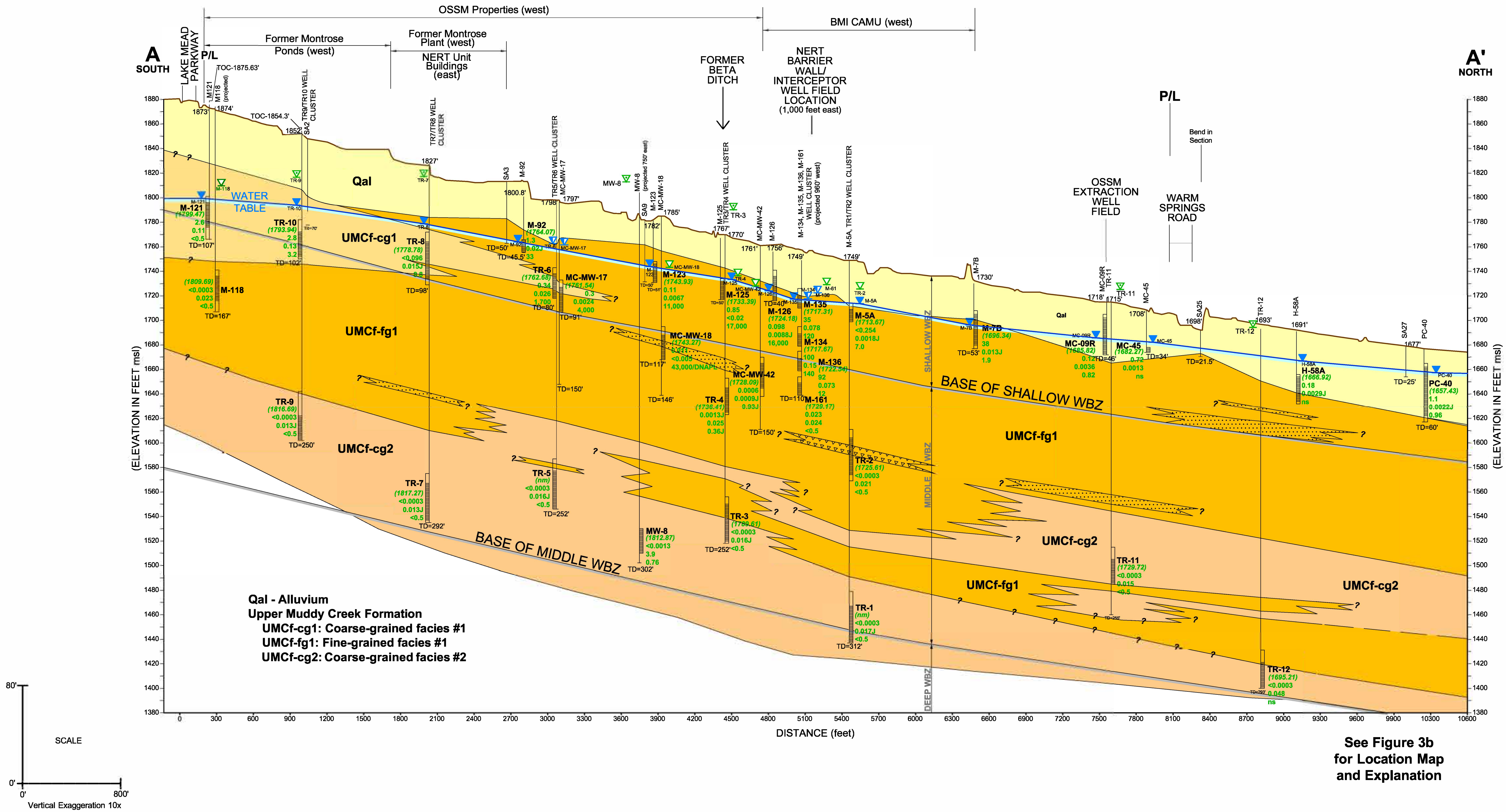


RAMBOLL ENVIRON

NERT OUs and Mass Estimate Areas
Nevada Environmental Response Trust Site
Henderson, Nevada

Date: 10/4/2017	Contract Number: 21-41400C		Figure
Drafter: LAT	Approved:	Revised:	2b

Path: H:\LePetomane\NERT\Modeling\MassEstimate2017\Memo\Figures\Figure 2b - Investigation Boundaries OU.mxd



See Figure 3b for Location Map and Explanation

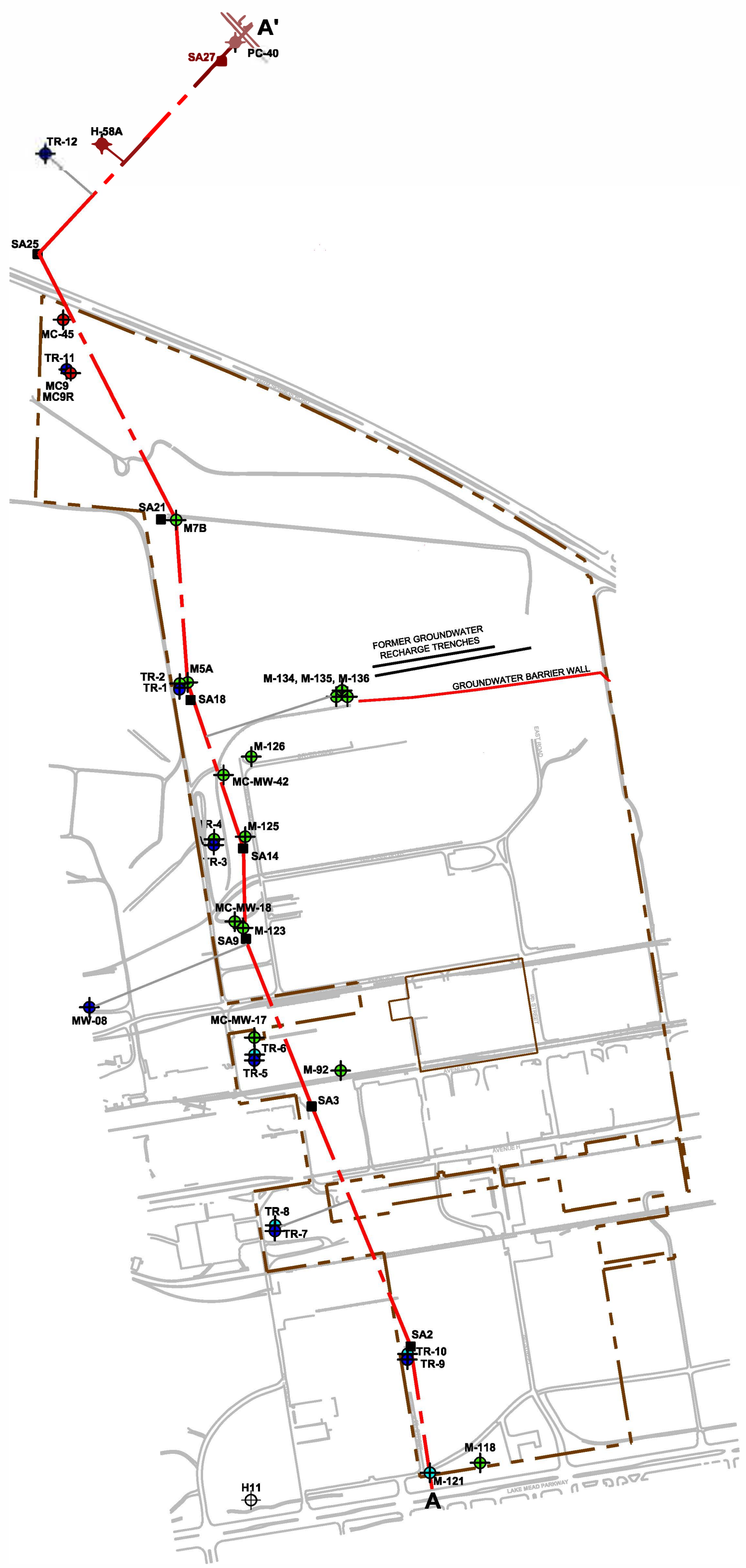
RAMBOLL ENVIRON

Drafter: RS Date: 6/22/15 Contract Number: 21-38800C

Approved: Revised:

Subsurface Cross-Section A-A' Illustrating Site Hydrostratigraphic Units
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
3a



INDEX MAP

0 600 1,200
Scale (Feet)

GROUNDWATER ELEVATIONS

(feet, mean sea level datum)

Shallow Water-Bearing Zone (0-90 ft)

- Water Table Zone Well
- Deeper Shallow WBZ Well

Middle Water-Bearing Zone (90-300 ft)

- Upper Muddy Creek Formation, First Fine-Grained Unit (UMCf-fg1)
- Upper Muddy Creek Formation, Second Coarse-Grained Unit (UMCf-cg2)

A—A' LINE OF GEOLOGIC SECTION

NERT PROPERTY BOUNDARY

MONITORING WELL WITH SCREEN IN THE ALLUVIAL AQUIFER (Qal)

MONITORING WELL WITH SCREEN IN THE MUDDY CREEK FINE GRAINED FACIES (UMCf-fg1)

MONITORING WELL WITH SCREEN IN THE MUDDY CREEK COARSE GRAINED FACIES 1 (UMCf-cg1)

MONITORING WELL WITH SCREEN IN THE MUDDY CREEK COARSE GRAINED FACIES 2 (UMCf-cg2)

LEGEND

Qal QUATERNARY ALLUVIUM

UMCf-fg1 MUDDY CREEK FORMATION FINE-GRAINED FACIES #1

MUDDY CREEK FORMATION FINE-GRAINED FACIES #1 SILTY SAND AND SANDY BED

MUDDY CREEK FORMATION FINE-GRAINED FACIES #1 VOLCANIC ASH DEPOSIT

UMCf-cg1 MUDDY CREEK FORMATION COARSE-GRAINED FACIES #1

UMCf-cg2 MUDDY CREEK FORMATION COARSE-GRAINED FACIES #2

TR-1 — EXISTING BORING/WELL IDENTIFICATION

1797' — GROUND SURFACE ELEVATION (ft, msl)

— FILTER PACK

— SCREEN INTERVAL

TR-1 — WELL (SCREEN) IDENTIFICATION

TD=40' — TOTAL DEPTH OF BORING/WELL

EXPLANATION:

(1799.47) GROUNDWATER ELEVATION (April/May 2012)

2.6 PERCHLORATE CONCENTRATION (May 2012) in milligrams/liter (mg/L).

0.11 TOTAL CHROMIUM CONCENTRATION (May 2012) in milligrams/liter (mg/L).

10.1 CHLOROFORM (January 2015) in micrograms/liter (μg/L).

NOTES:

"<"	NOT REPORTED AT THE PRACTICAL QUANTITATION LIMIT SHOWN
(nm)	NO WATER LEVEL
ND	NOT DETECTED
NS	NOT SAMPLED
WBZ	WATER-BEARING ZONE

1. Chloroform data for wells MC-MW-17, MC-MW-18, MC-MW-42, and MW-8 are from May 2013.

REFERENCES:

APPENDIX A - ANNUAL REMEDIAL PERFORMANCE REPORT FOR CHROMIUM AND PERCHLORATE, JULY 2011 THROUGH JUNE 2012 [NEVADA ENVIRONMENTAL RESPONSE TRUST, HENDERSON, NEVADA] (AUGUST 2012)

BMI COMPLEX DATABASE

ADAPTED FROM FIGURE 4-1, PHASE A SOURCE AREA INVESTIGATION, TRONOX FACILITY, HENDERSON, NEVADA (ENSR/AECOM 2008)

HYDROSTRATIGRAPHIC NOMENCLATURE FOLLOWS UNIFIED HYDROGEOLOGIC NOMENCLATURE PROPOSED BY NDEP IN JANUARY 6, 2009 LETTER

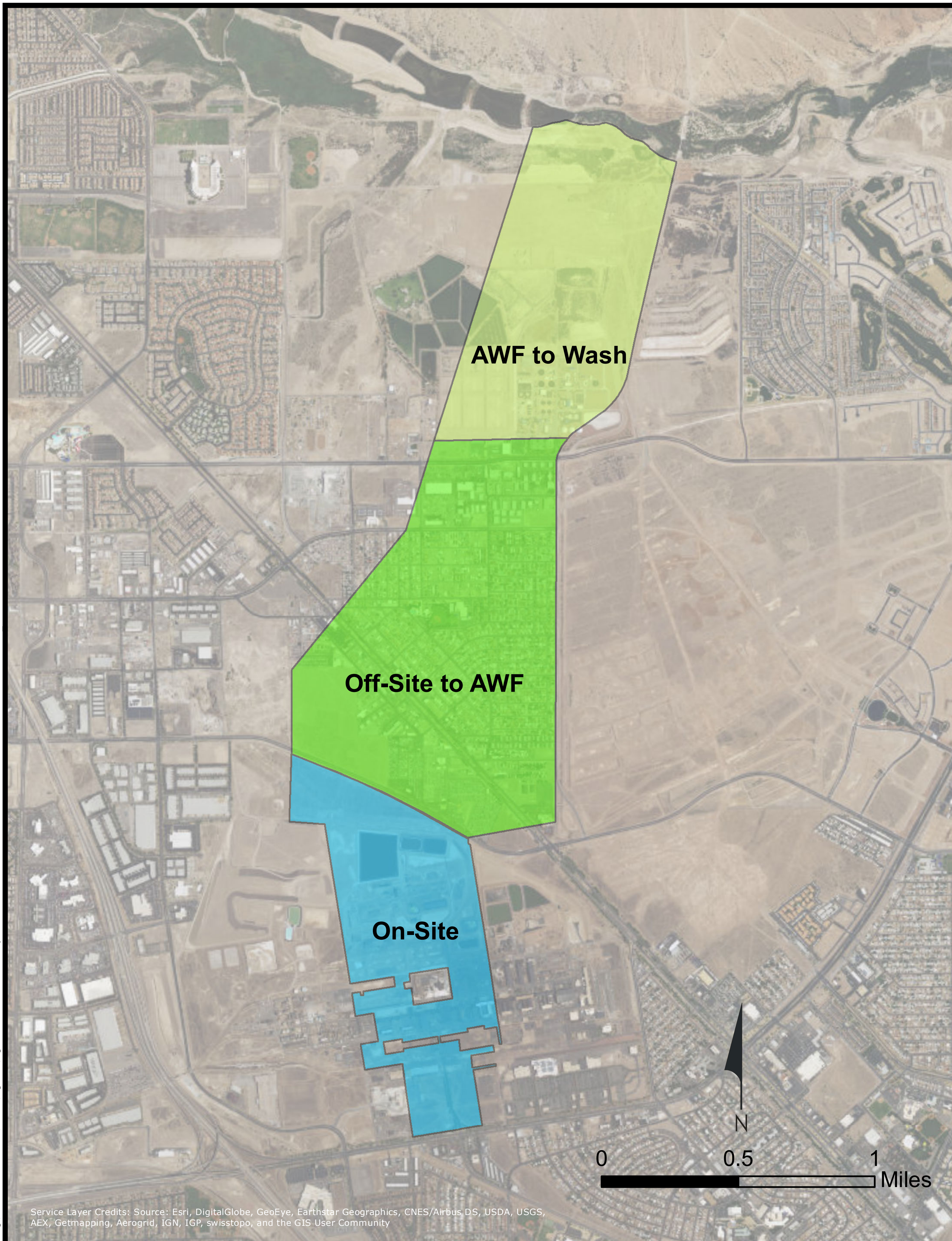
RAMBOLL ENVIRON

Drafter: RS Date: 6/22/15 Contract Number: 21-38800C

Approved: Revised:

Subsurface Cross-Section A-A' - Location Map and Explanation
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
3b



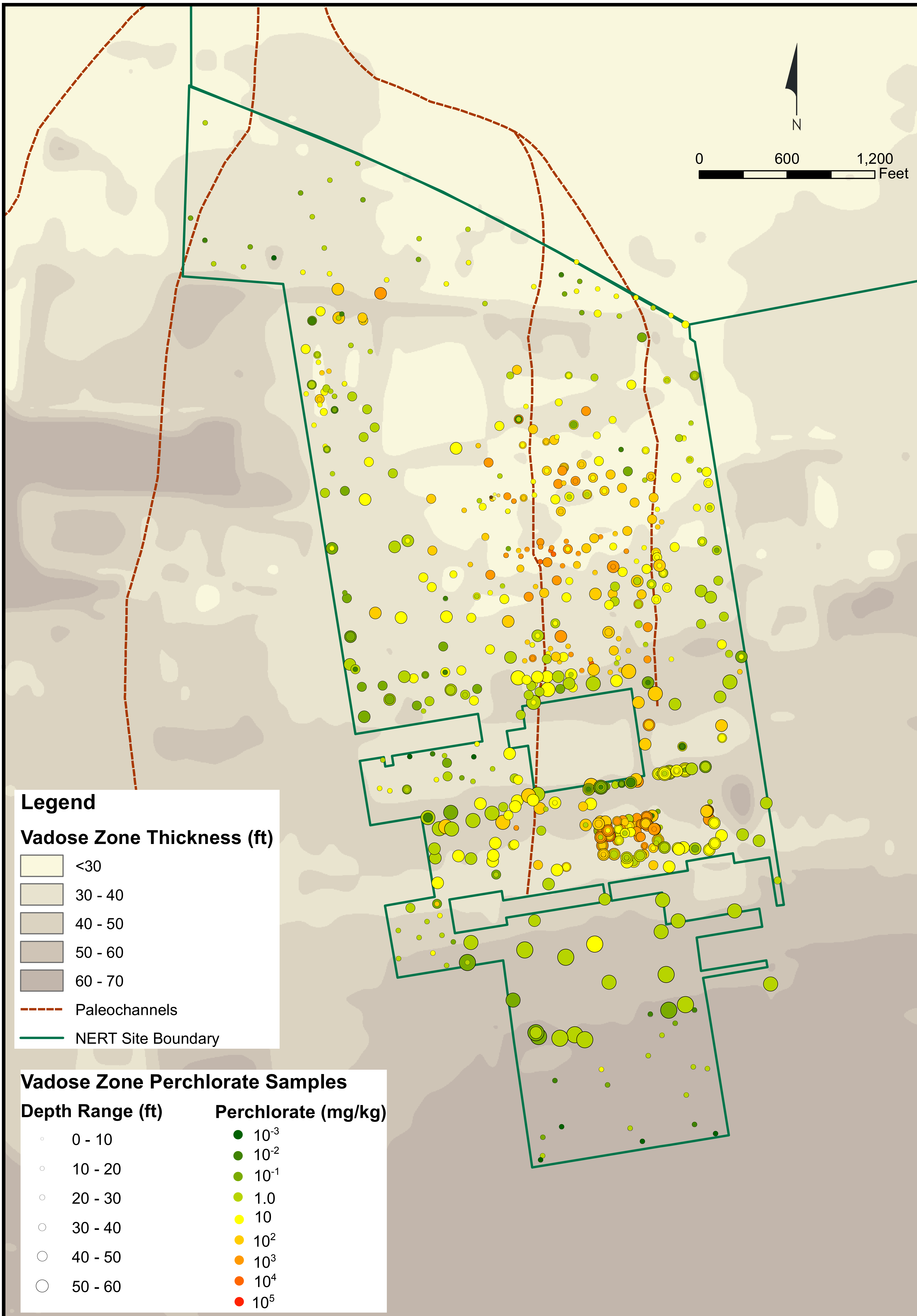
RAMBOLL ENVIRON

Current Mass Estimate Boundary
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
4

DRAFTED BY: AS | DATE: 10/4/2017 | 21-41400C

H:\LePetomane\NERT\Modeling\MassEstimate2017\Memo\Figures\Figure 4 - Current ME Bdry.mxd

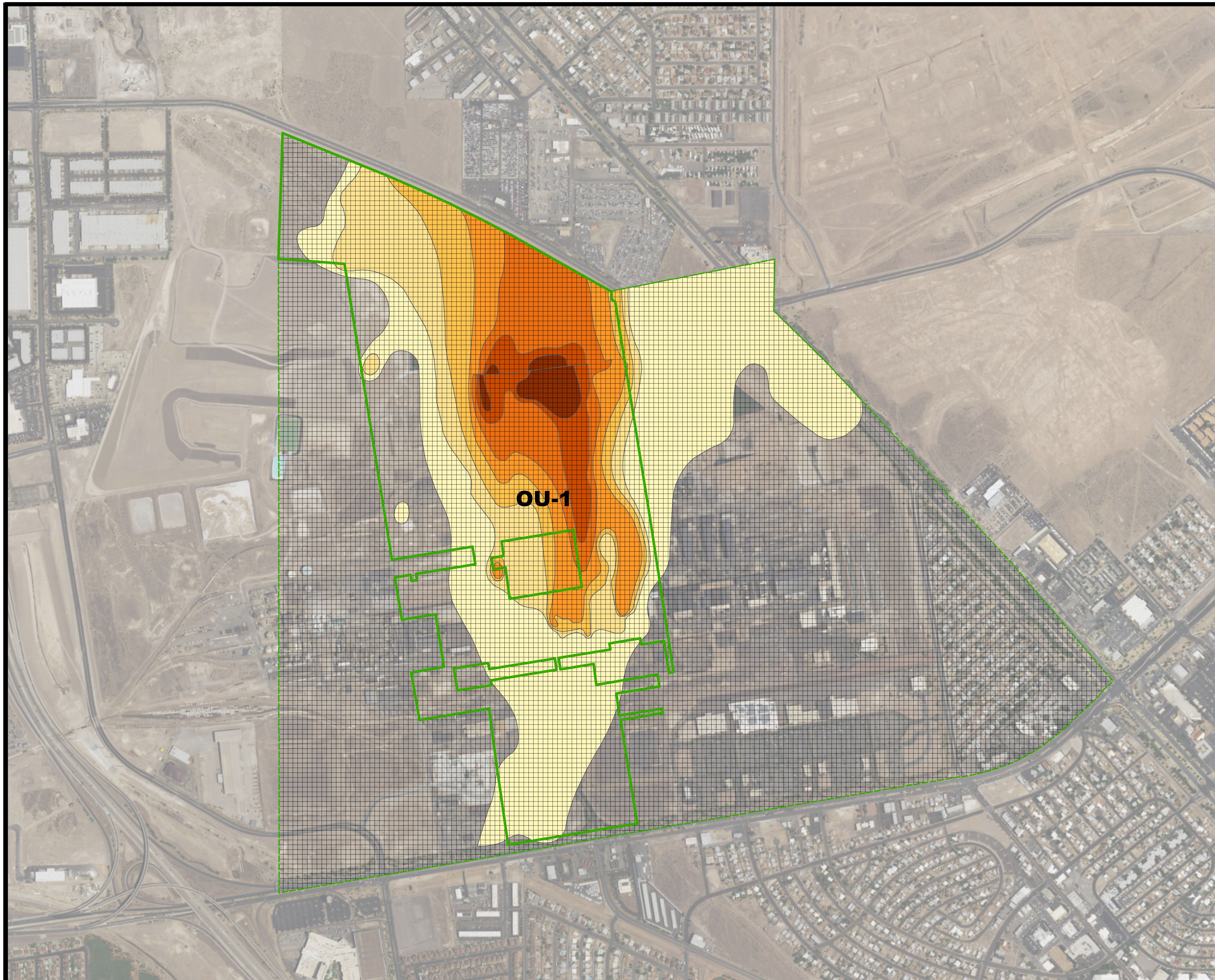


RAMBOLL ENVIRON

OU-1 Vadose Zone Soil Sample Density
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
5

DRAFTED BY: AS | DATE:10/4/2017 | PROJECT



RAMBOLL ENVIRON

OU-1 Saturated Alluvium
Nevada Environmental Response Trust Site
Henderson, Nevada

Date: 10/4/2017	Contract Number: 21-41400C		Figure
Drafter: LAT	Approved:	Revised:	6

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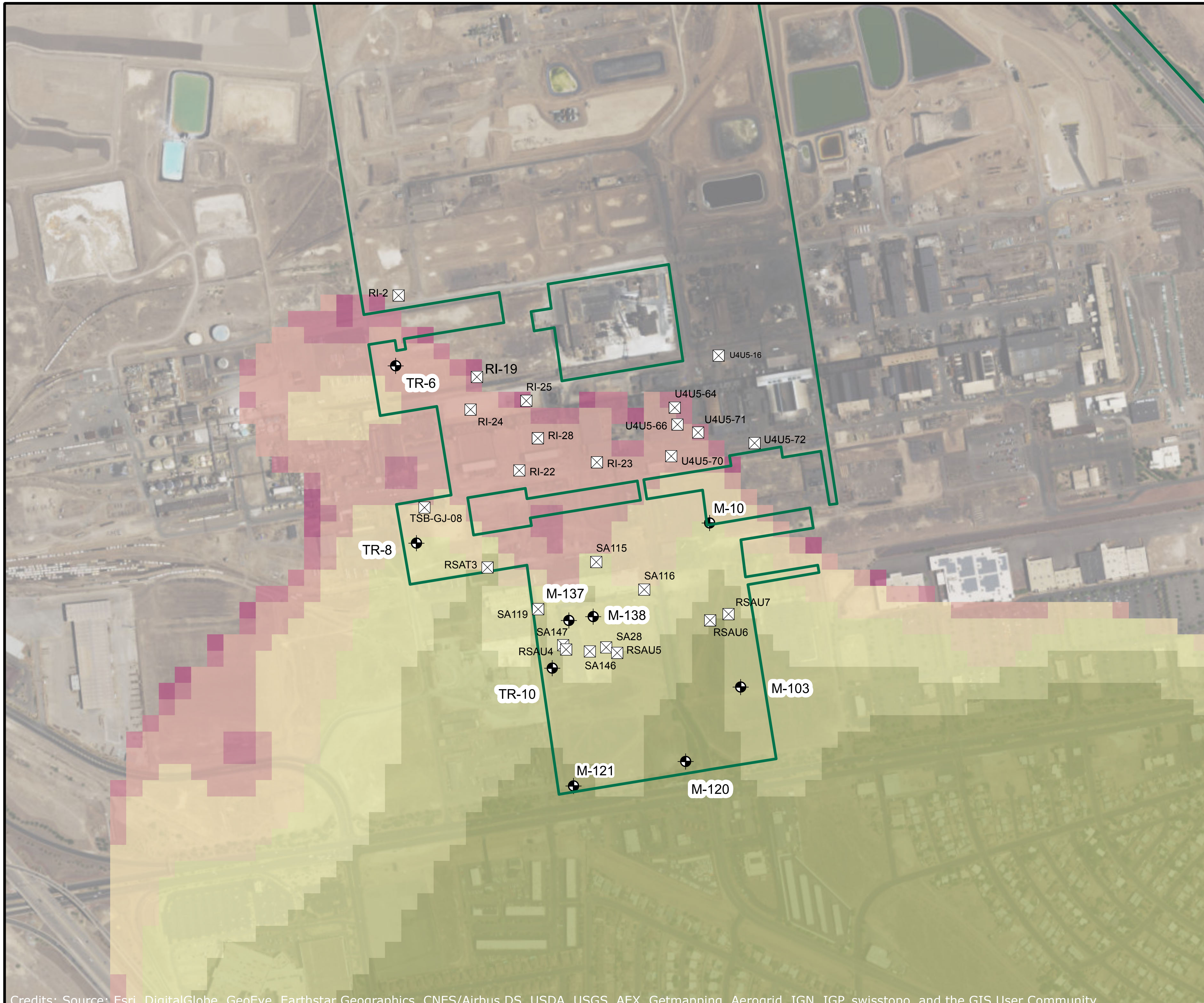


Legend

Sample Data

- Monitoring Well Screened in UMCf-cg1
- Soil Samples From UMCf-cg1 [a]

UMCf-cg1 Thickness [b]

- 0 - 0.1
- 0.2 - 5
- 5.1 - 10
- 10.1 - 20
- 20.1 - 40
- 40.1 - 60
- 60.1 - 80
- 80.1 - 391.7

NOTES:
[a] Additional soil samples to be collected as part of Phase II RI Investigation.
[b] Extent of UMCf-cg1 shown is based on data collected prior to 2017 and will be updated with new investigation data.

N

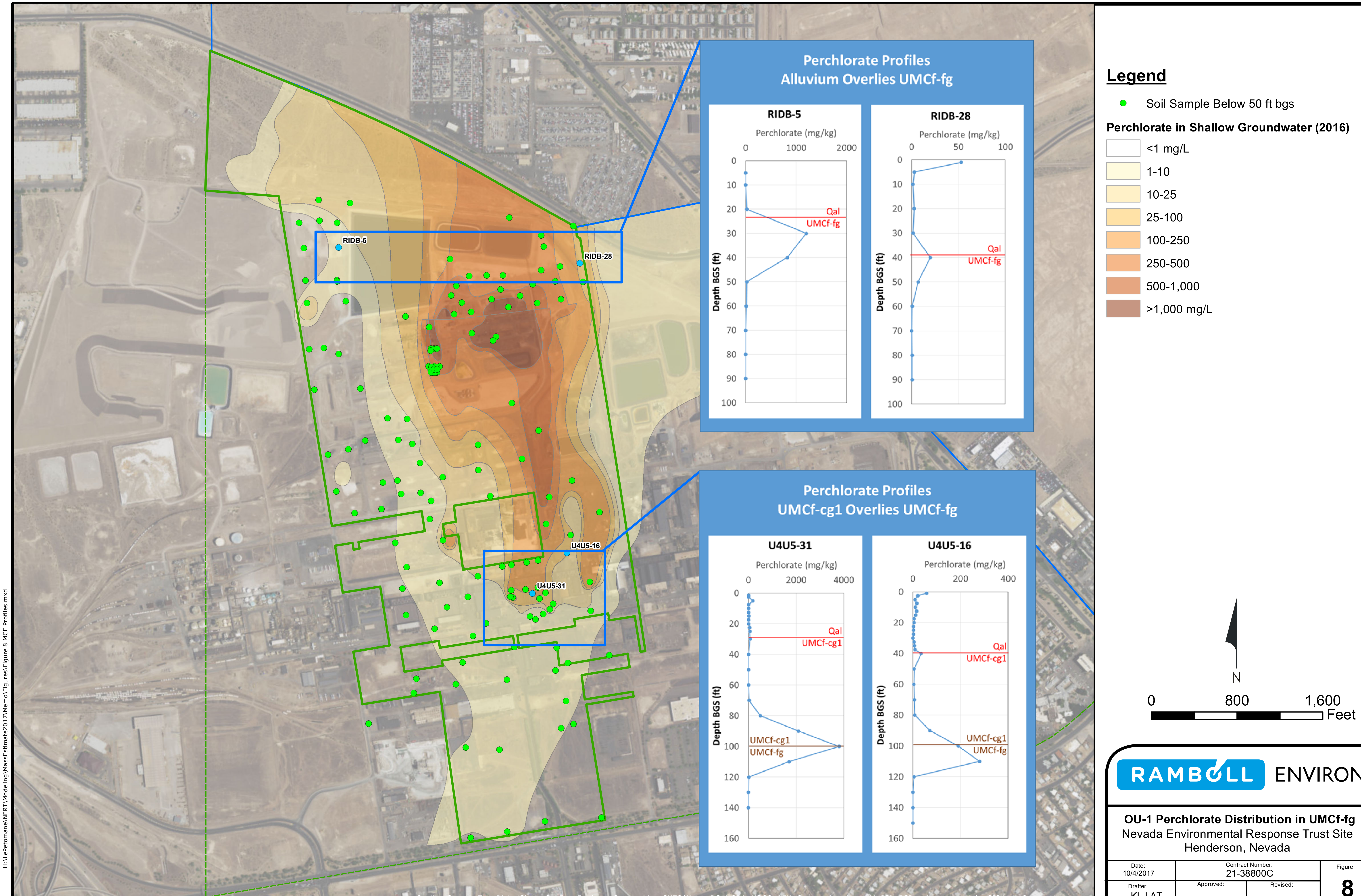
0 400 800
Feet

RAMBOLL ENVIRON

UMCf-cg1 Data Availability
Nevada Environmental Response Trust Site
Henderson, Nevada

Date: 9/28/2017	Contract Number: 21-38800C		Figure 7
Drafter: KL,LAT	Approved:	Revised:	

H:\LePetomane\NERT\Modeling\MassEstimate2017\Memo\Figures\Figure 7 UMCf-cg1_Thickness_v2.mxd



RIDB-5
RIDB-28
U4U5-16
U4U5-31
Perchlorate Profiles
Alluvium Overlies UMCf-fg
RIDB-5
Perchlorate (mg/kg)
0 1000 2000
Depth BGS (ft)
0 10 20 30 40 50 60 70 80 90 100
Qal
UMCf-fg
RIDB-28
Perchlorate (mg/kg)
0 50 100
Depth BGS (ft)
0 10 20 30 40 50 60 70 80 90 100
Qal
UMCf-fg
Perchlorate Profiles
UMCf-cg1 Overlies UMCf-fg
U4U5-31
Perchlorate (mg/kg)
0 2000 4000
Depth BGS (ft)
0 20 40 60 80 100 120 140 160
Qal
UMCf-cg1
UMCf-cg1
UMCf-fg
U4U5-16
Perchlorate (mg/kg)
0 200 400
Depth BGS (ft)
0 20 40 60 80 100 120 140 160
Qal
UMCf-cg1
UMCf-cg1
UMCf-fg
Legend
Soil Sample Below 50 ft bgs
Perchlorate in Shallow Groundwater (2016)
<1 mg/L
1-10
10-25
25-100
100-250
250-500
500-1,000
>1,000 mg/L
N
0 800 1,600
Feet
RAMBOLL ENVIRON
OU-1 Perchlorate Distribution in UMCf-fg
Nevada Environmental Response Trust Site
Henderson, Nevada
Date: 10/4/2017
Contract Number: 21-38800C
Figure 8
Drafter: KL,LAT
Approved:
Revised:
Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community
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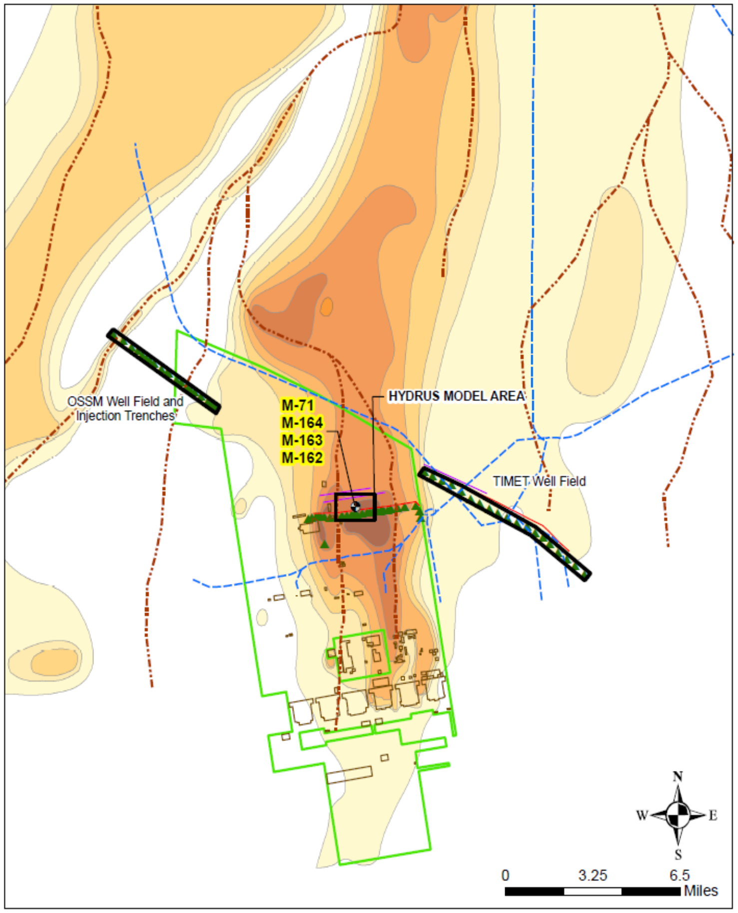
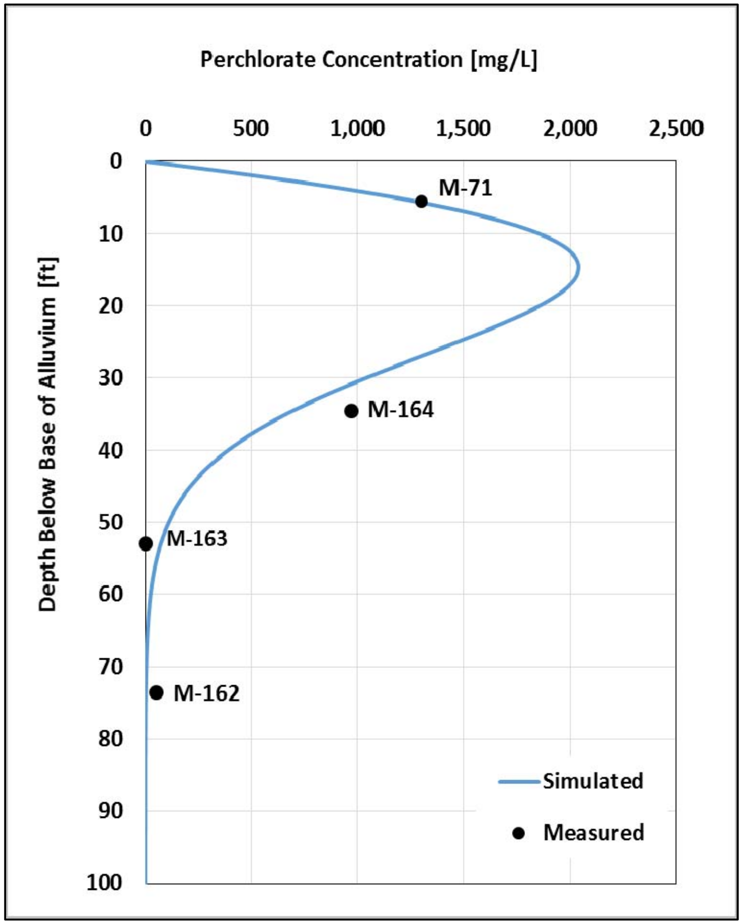
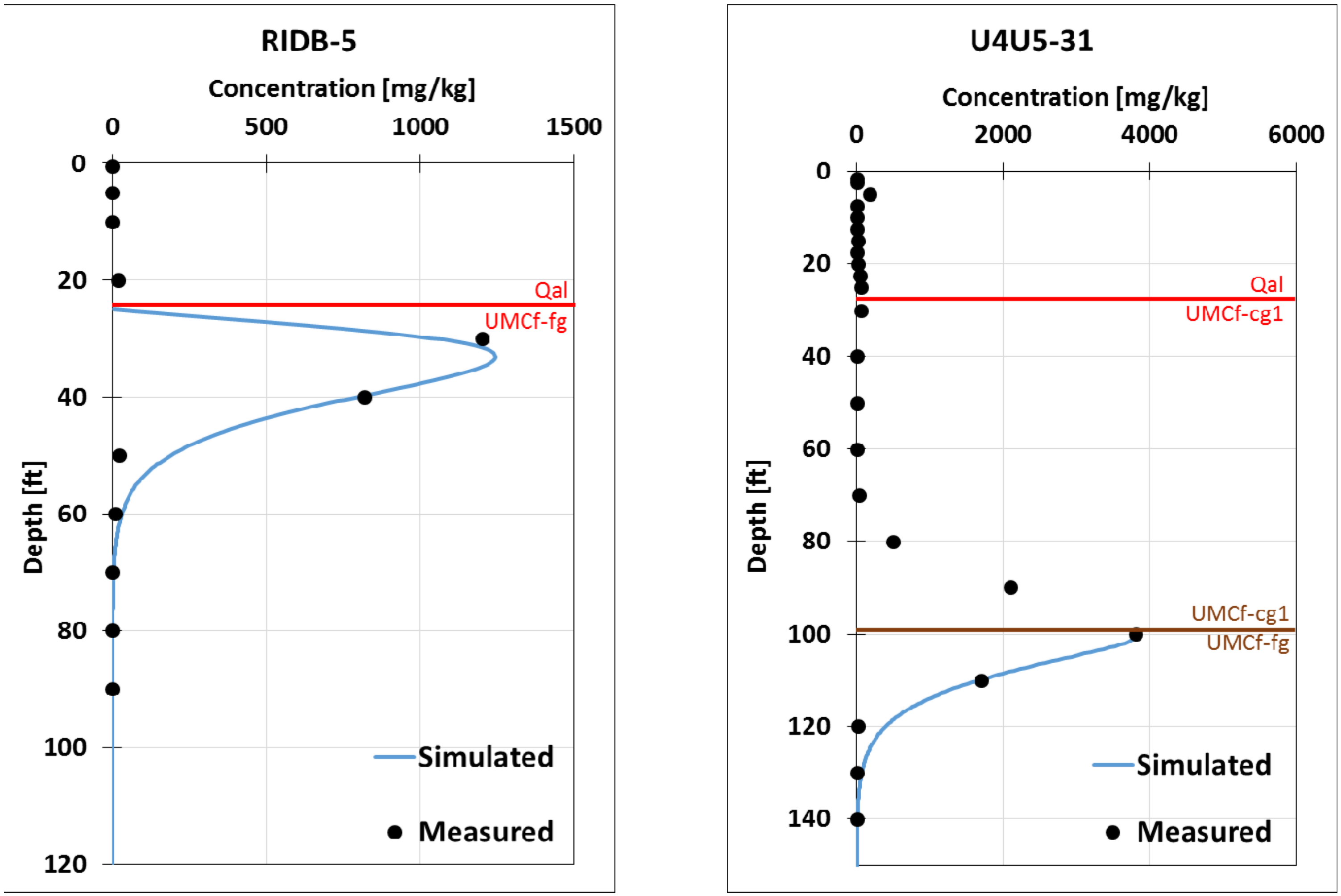




RAMBOLL ENVIRON

Example UMCf-fg Vertical Profile Simulation Using Groundwater Data
Nevada Environmental Response Trust Site
Henderson, Nevada

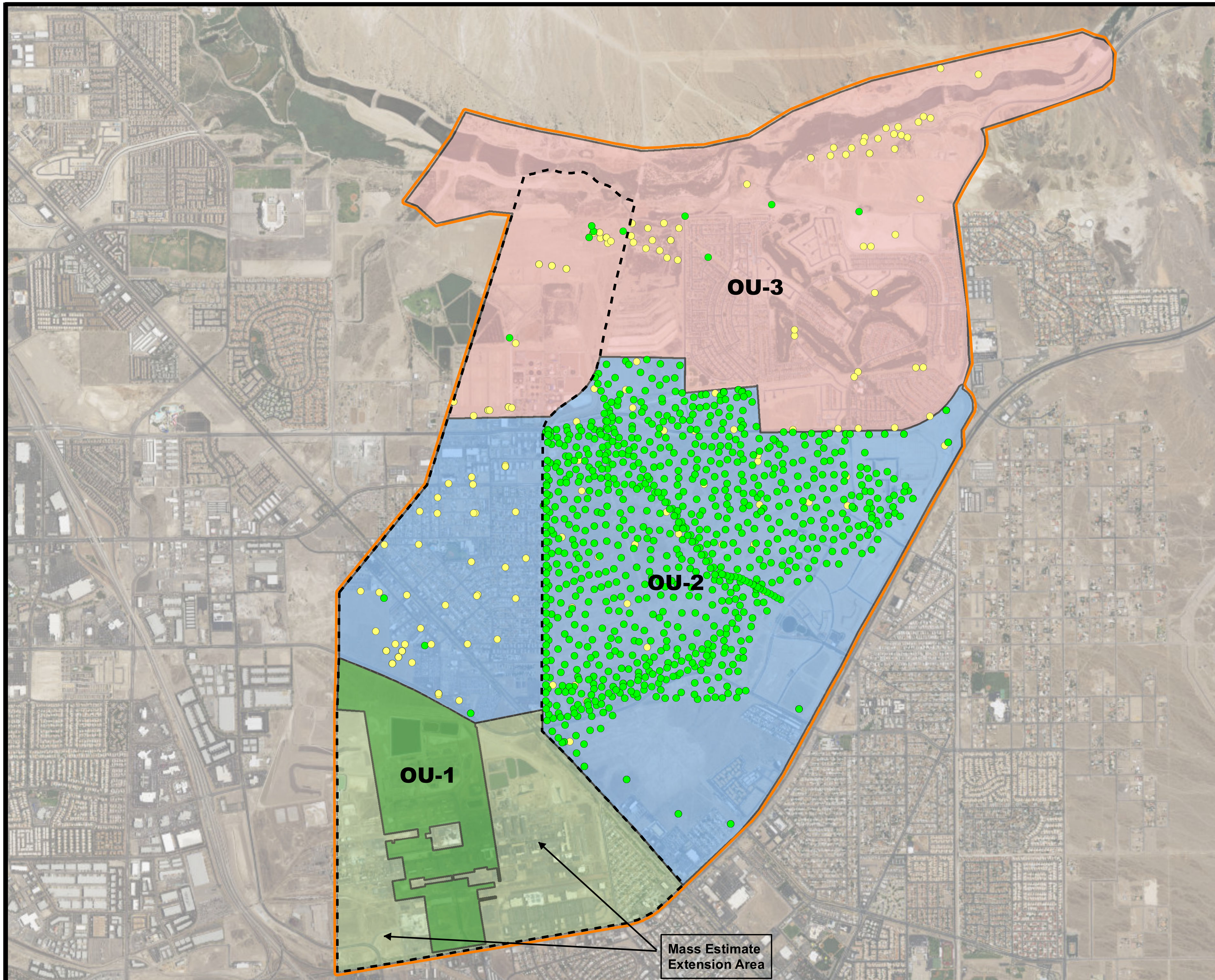
Figure
9



RAMBOLL ENVIRON

Example UMCf-fg Vertical Profile Simulations Using Soil Data
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
10



Legend

- Proposed Sample Locations
- Perchlorate Vadose Zone Samples

Mass Estimate Boundaries

- Perchlorate Mass Estimate Area
- Chromium Mass Estimate Area

N

0 0.5 1 Miles

RAMBOLL ENVIRON

OU-2 and OU-3 Vadose Zone Sample Density
Nevada Environmental Response Trust Site
Henderson, Nevada

Date: 10/4/2017	Contract Number: 21-41400C		Figure
Drafter: LAT	Approved:	Revised:	11

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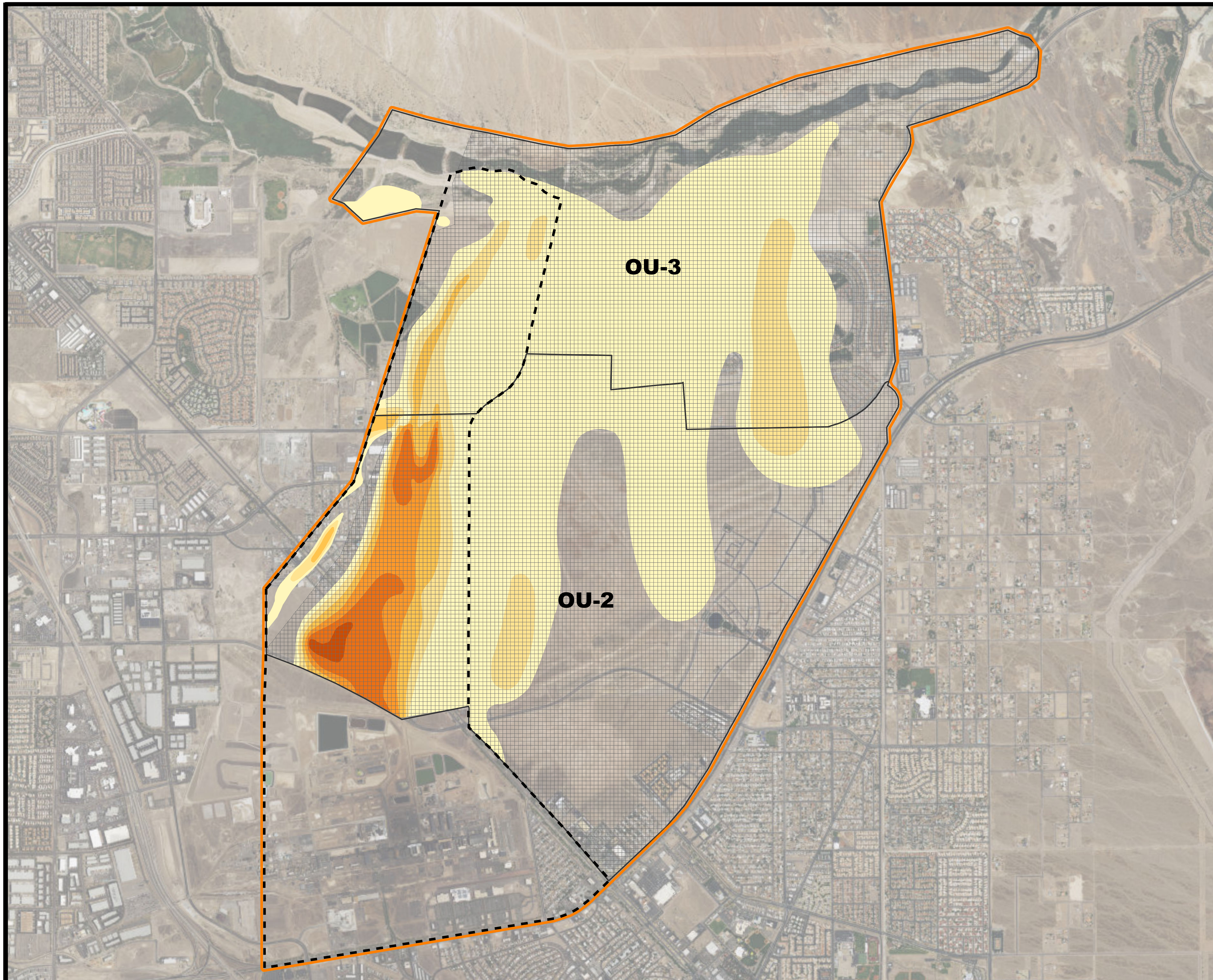


Legend

Interpolation Grid

Perchlorate Isoconcentration (2016)

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

Perchlorate Mass Estimate Area
Chromium Mass Estimate Area

N

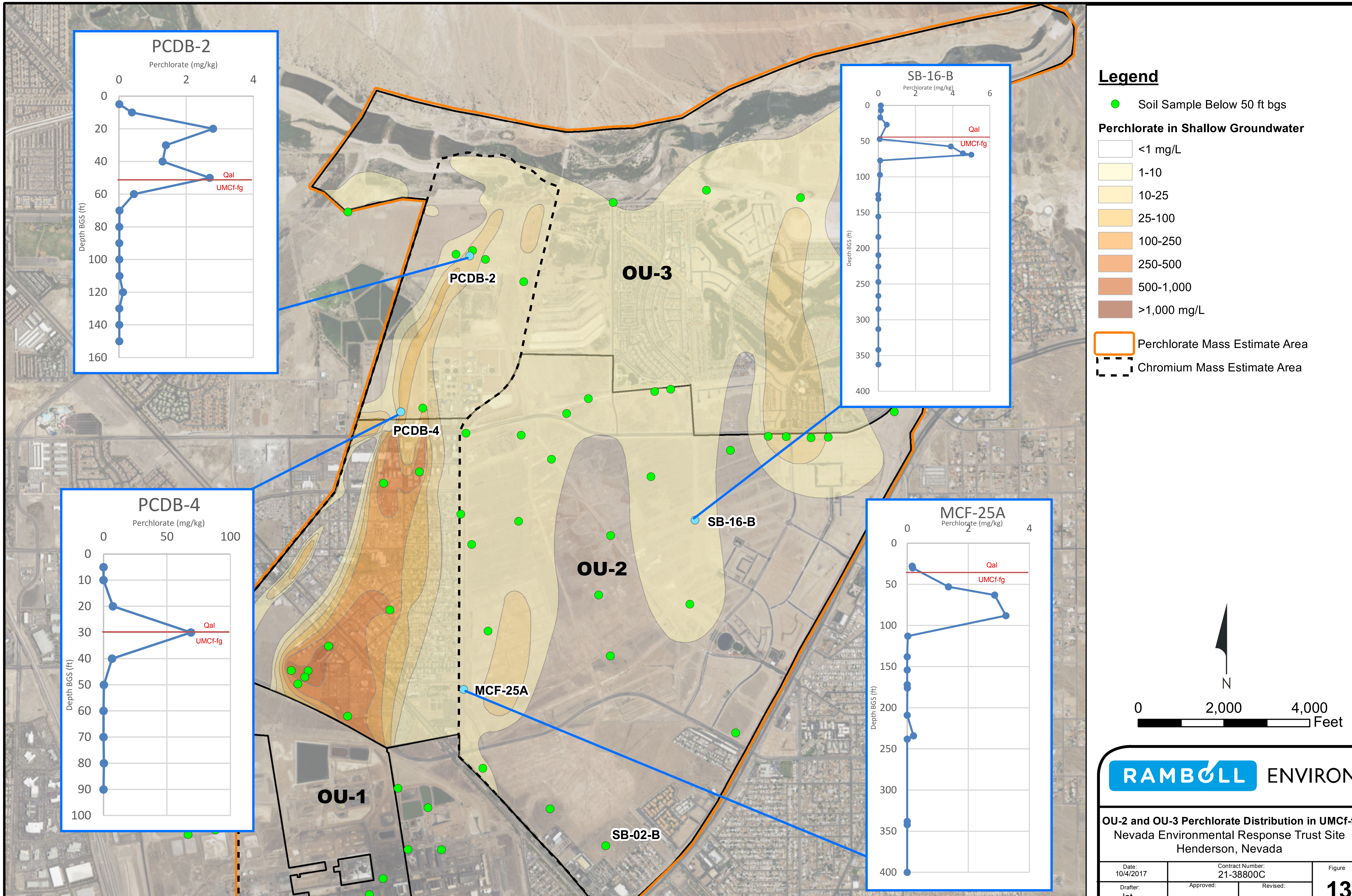
0 0.5 1 Miles

RAMBOLL ENVIRON

OU-2 and OU-3 Saturated Alluvium
Nevada Environmental Response Trust Site
Henderson, Nevada

Date: 10/4/2017	Contract Number: 21-41400C		Figure 12
Drafter: LAT	Approved:	Revised:	

Path: H:\LePetomane\NERT\Modeling\MassEstimate2017\Memo\Figures\Figure 12 OU2-3 Qal Grid 10-4.mxd



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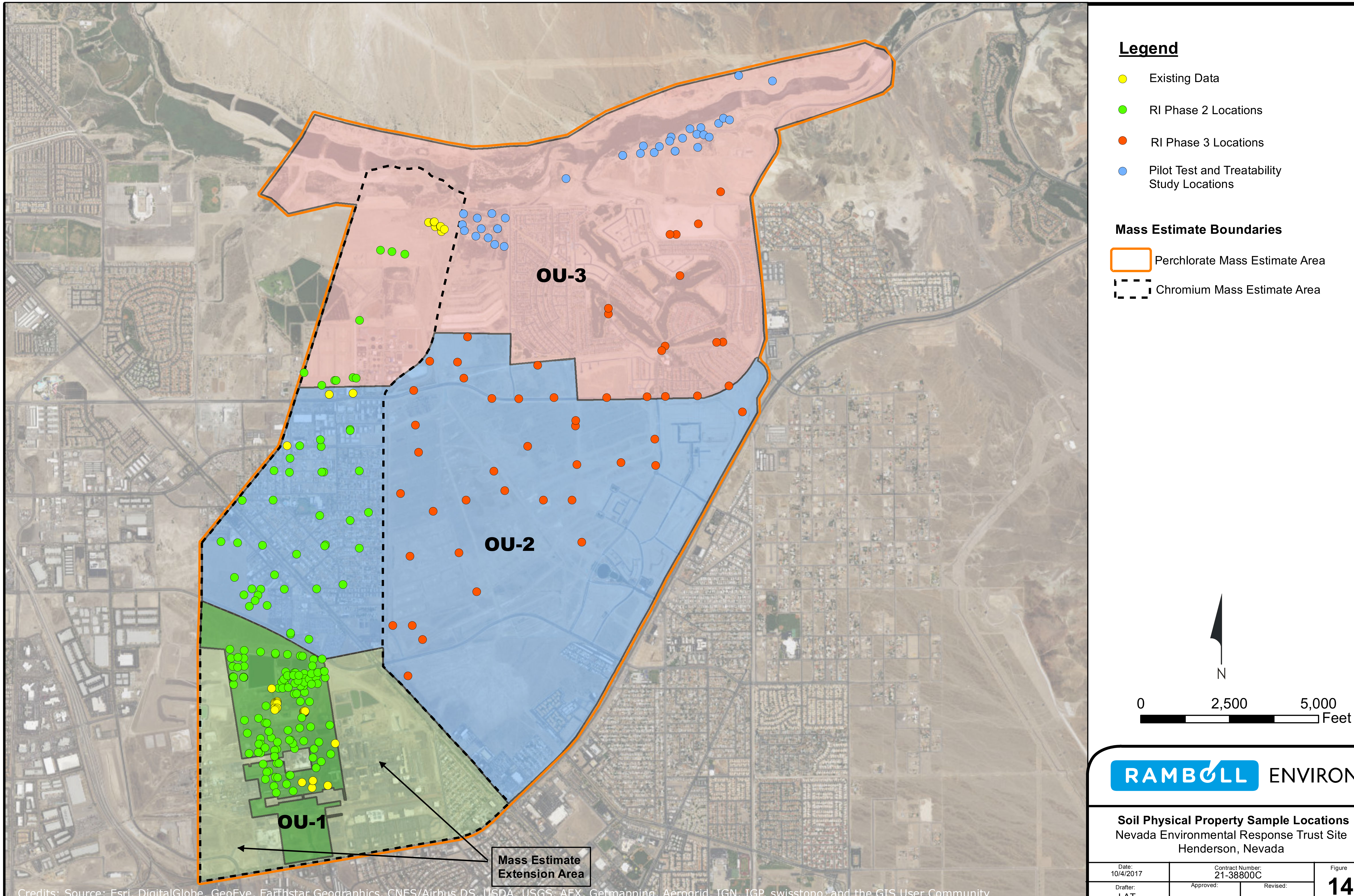
RAMBOLL ENVIRON

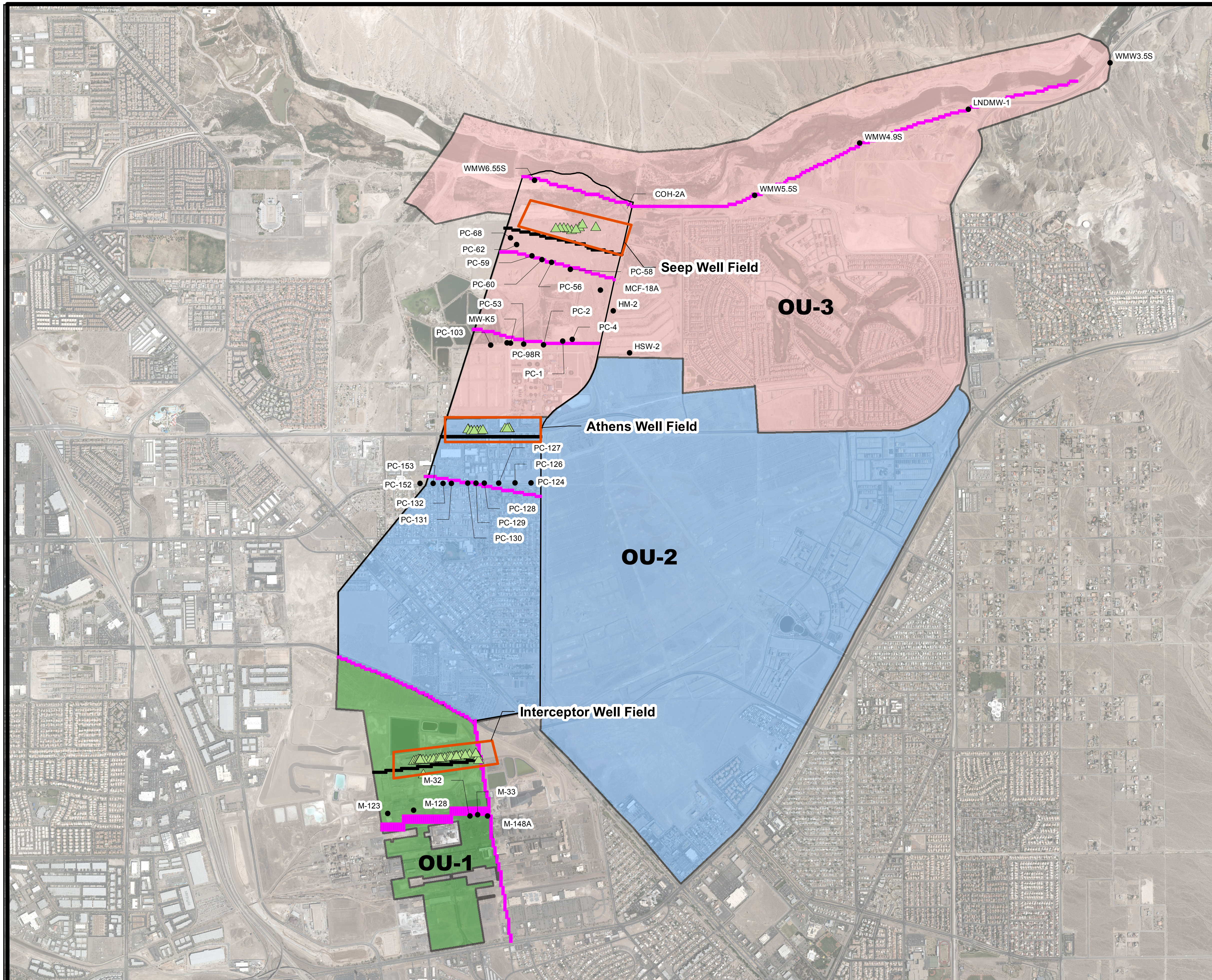
OU-2 and OU-3 Perchlorate Distribution in UMCf-fg
Nevada Environmental Response Trust Site
Henderson, Nevada

Date:	Contract Number:		Figure
10/4/2017	21-38800C		13
Drafter: lat	Approved:	Revised:	



Soil Physical Property Sample Locations
Nevada Environmental Response Trust Site
Henderson, Nevada

Date: 10/4/2017	Contract Number: 21-38800C		Figure
Drafter: LAT	Approved:	Revised:	14



RAMBOLL ENVIRON

Established Mass Flux Transect Locations
Nevada Environmental Response Trust Site
Henderson, Nevada

Date: 10/4/2017	Contract Number: 21-41400C		Figure
Drafter: AS	Approved:	Revised:	15a

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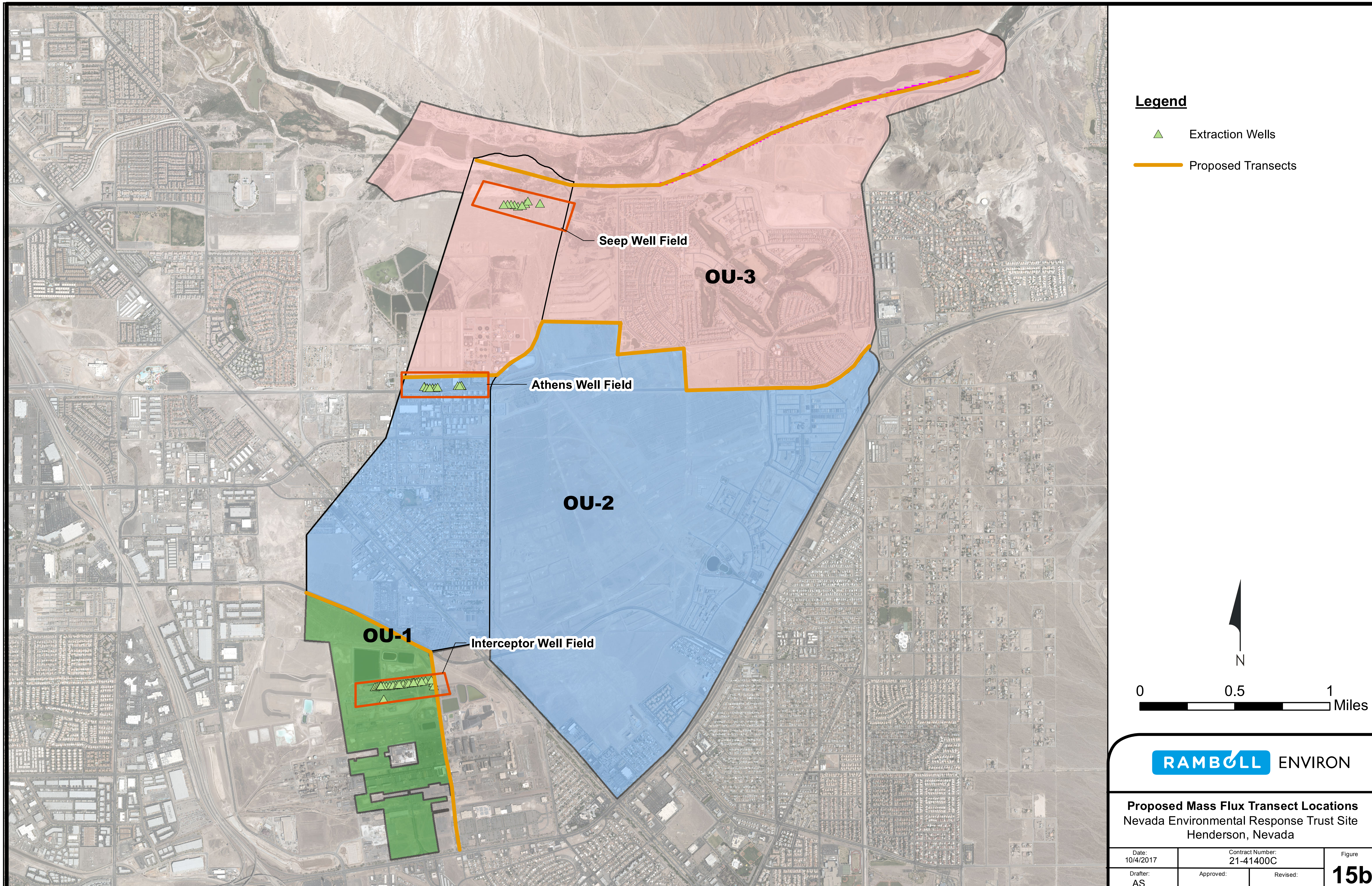
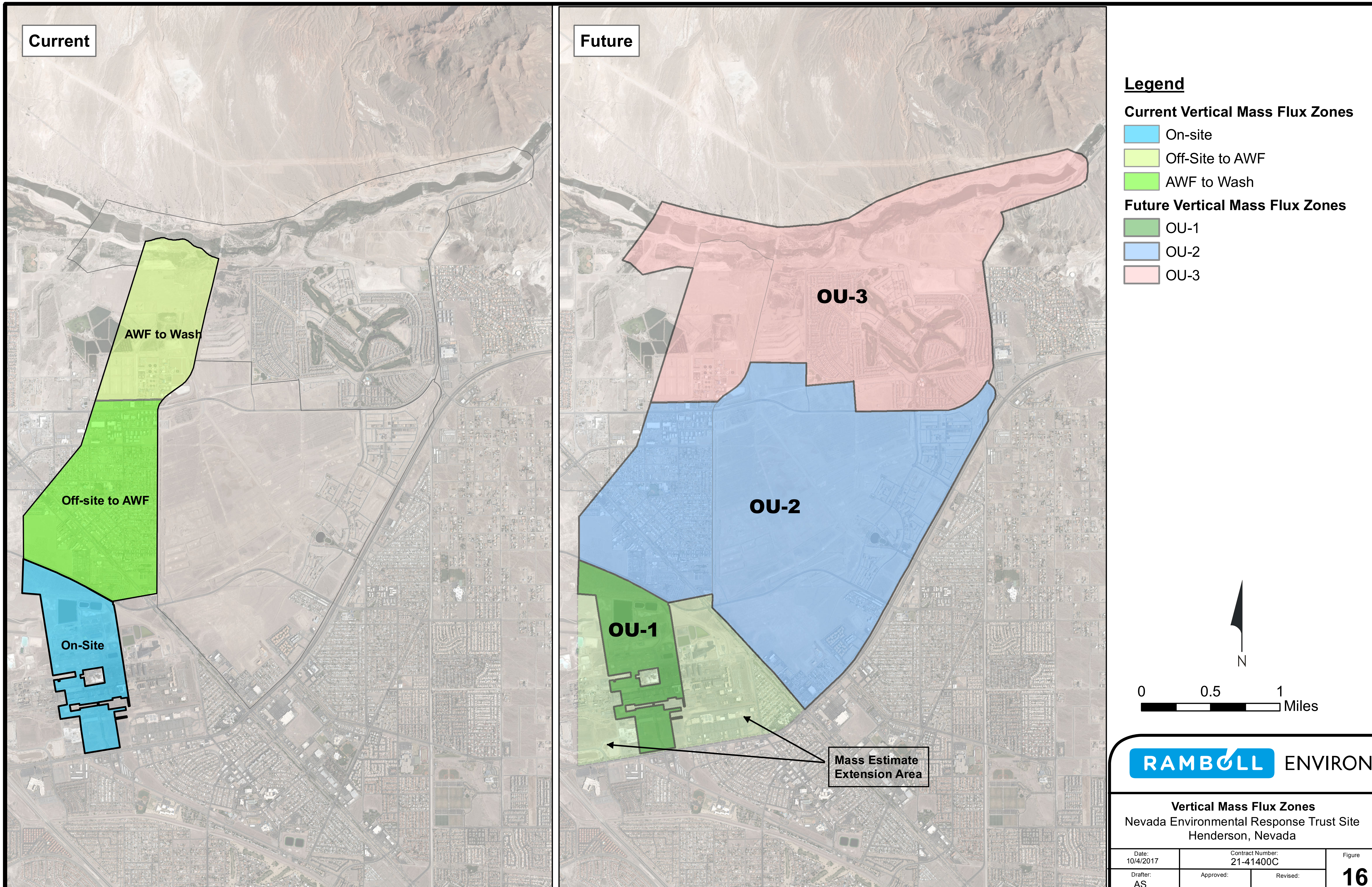


RAMBOLL ENVIRON

Proposed Mass Flux Transect Locations
Nevada Environmental Response Trust Site
Henderson, Nevada

Date: 10/4/2017	Contract Number: 21-41400C		Figure
Drafter: AS	Approved:	Revised:	15b

Path: H:\LePetomane\NERT\Modeling\MassEstimate2017\Memo\Figures\Figure 15b - Transect Location_v2b.mxd

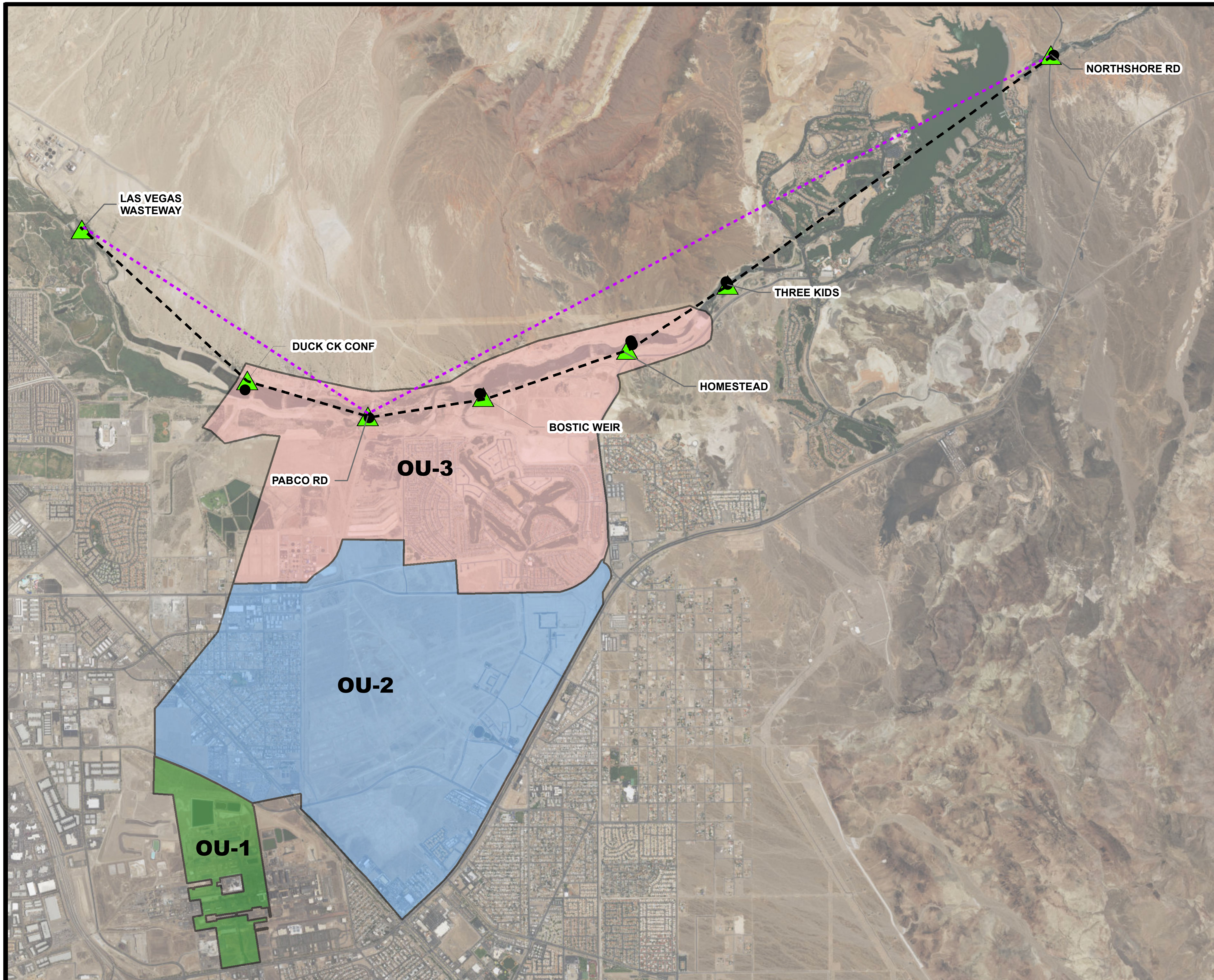


RAMBOLL ENVIRON

Vertical Mass Flux Zones
Nevada Environmental Response Trust Site
Henderson, Nevada

Date: 10/4/2017	Contract Number: 21-41400C		Figure
Drafter: AS	Approved:	Revised:	16

Path: H:\LePetomane\NERT\Modeling\MassEstimate2017\Memo\Figures\Figure 16 - VerticalFluxZones_Revised.mxd



Legend

- USGS Continuous Gaging Station
- NERT Transect Sampling Location
- Current Location
- Future Location

N

0 0.5 1 Miles

RAMBOLL ENVIRON

Mass Loading in the Las Vegas Wash
Nevada Environmental Response Trust Site
Henderson, Nevada

Date: 10/4/2017	Contract Number: 21-41400C		Figure
Drafter: AS	Approved:	Revised:	17

Path: H:\LePetomane\NERT\Modeling\MassEstimate2017\Memo\Figures\Figure 17 - Mass Loading Locations at the Wash.mxd