DRAFT

LANDFILL GAS AND SOIL CONDITIONS EVALUATION

A Mountain Landfill, Tucson, Arizona

May 29, 2015

Prepared for:

RIO NUEVO MULTIPURPOSE FACILITIES DISTRICT
400 W. Congress, Suite 152
Tucson, Arizona 85701

Contract Number: 662393.1

Prepared by:

HYDRO GEO CHEM, INC.
51 West Wetmore Road, Suite 101
Tucson, Arizona 85705
(520) 293-1500

Project Number: 2014037.00

HYDRO GEO CHEM, INC.
Environmental Science & Technology

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLES

FIGURES

APPENDICES

1. INTRODUCTION

Hydro Geo Chem, Inc. (HGC) was retained by the Rio Nuevo District to provide consulting services to assess conditions at the A Mountain Landfill (AMLF) in Tucson for potential redevelopment approaches. Of particular interest are the potential impacts of landfill gas (LFG) on plantings and the potential methane concentration impacts of structures. Various proposals for redevelopment of the AMLF property have been advanced as part of the Rio Nuevo project. Evaluation of the competing proposals requires an understanding of the nature and current conditions at the site. In particular, one proposal for a Sonoran desert park at the site relies on the viability of plantings on the landfill cover that could be affected by LFG generated by the landfill, as well as by soil conditions. Better definition of the amount and distribution of methane at the AMLF, necessary for this evaluation, was part of the current study.

The specific objectives of this study were to install nested vapor probes in order to measure landfill gas compositions and their distribution across the AMLF; evaluate LFG pressures and landfill properties that might influence LFG flow; and collect and analyze soil samples for agronomic parameters. The resulting information was evaluated in terms of potential impacts to plantings at the landfill.

2. LANDFILL BACKGROUND AND STATUS

The AMLF is located along the Santa Cruz River at the base of A Mountain in Tucson, Arizona (Figure 1). It is a closed solid waste landfill located south of Mission Lane and bounded on the west by Grande Avenue and on the south and east by the Santa Cruz River (Figure 2). The legal description of the AMLF is T14S, R13E, Section 14. The landfill covers a total area of approximately 36 acres.

The AMLF was operated by the City of Tucson (COT) and received primarily residential refuse between 1953 and 1962. There were no site restrictions and so-called “wildcat” dumping of hazardous materials may have occurred (COT-ES, 2011a). The AMLF is a closed solid waste facility exempt from state rules covering solid waste facilities as defined under A.R.S. 49-701 because it was closed prior to 1986. COT Solid Waste Management Department (a predecessor to Environmental Services [ES]) procedures at the time of closure included application of a minimal dirt cover over the refuse, light fencing and storm water controls such as earthen berms (COT-ES, 2011b).

A geophysical survey conducted in 2000 indicated that refuse was prominent over an area of 31.4 acres at thicknesses up to 45 feet (ft) (Zonge, 2001). Refuse over the area was typically most prevalent between 15 and 30 ft below ground surface (bgs), with the deepest and thickest refuse, extending to 30-45 ft bgs, present in the northeast portion of the site and thinner, often discontinuous or absent refuse present in the western portion of the site. A topographic low in the northeast of the site, corresponding to the deepest, thickest refuse, suggested the occurrence of subsidence (Zonge, 2001).

In December 2006, a series of soil borings were conducted at the site in order to characterize soils and refuse as part of the Rio Nuevo Master Plan process (COT-ES, 2008). In May 2007, Kleinfelder completed a geotechnical study of landfills within the Rio Nuevo Master Plan area pertaining to the planned construction of the Tucson Origins Cultural Park. As part of this work, additional soil borings were conducted at the AMLF; detailed logs from these borings are provided in Kleinfelder (2007). Kleinfelder recommended the excavation and removal of refuse to a depth of about 20 ft below the then-current grade at the northeast portion of the site to facilitate construction of a historical replica house (Kleinfelder, 2007). Partial excavation and re-grading of the northern portion of the landfill, including part of the deep northeastern zone, appears to have occurred in early of 2008 (COT-ES, 2008).

Methane has been monitored at the boundary of the AMLF since around 1997 (COT-ES, 2012a), and groundwater elevations and quality have been monitored since 2000 (COT-ES, 2011a). The

AMLF has also been inspected annually in the fourth quarter following the monsoon season as part of the COT Comprehensive Landfill program (COT-ES, 2012b; 2014).

2.1 Methane Monitoring

Quarterly methane monitoring began at twelve shallow probes (AM-1 through AM-8 and AMT-1 through AMT-4) in 2000. Locations of these probes are shown on Figure 2. Nested probes AM-1 through AM-4, AM-6 and AM-7 consisted of probes at both 10 ft bgs and 20 ft bgs. Nested probe AM-5 consisted of probes at 5 ft bgs and 15 ft bgs; nested probe AM-8 consisted of probes at 10 ft bgs, 20 ft bgs and 30 ft bgs. Probes AMT-1 through AMT-4 were set to 5 ft bgs. In its 2011 Comprehensive Landfill Investigation Final Report, COT-ES notes that it monitors 12 permanent perimeter shallow landfill gas probes at the site (COT-ES, 2011a). However, monitoring data provided by COT-ES indicates that only AM-2, AM-3 and AMT-4 have been monitored within the last approximately 5 years, as confirmed by the 2011 and 2012 monitoring reports for the site (COT-ES, 2011c and 2012a). Eight additional measuring points, nested probes ASM-3 through ASM-9 and MS-1, are included in the site methane monitoring data with one data point each. No detectable methane was present at any of the nested probes in ASM-3 through ASM-9 during the March 2012 monitoring event; no detectable methane was present at MS-1 during the July 2010 monitoring event. The nature and location of these probes, which appear to have been temporary installations, is unclear from available information.

Methane concentrations above trace levels have never been detected for any monitoring event in AM-1 through AM-4, nor in AMT-1 through AMT-4. Methane concentrations between 0% and 51% were consistently detected in AM-5 through AM-8 between 2000 and 2005 (Appendix A), when monitoring at these probes ceased. The highest methane concentrations were detected in AM-8 at all depths (Appendix A), and typically ranged between 35% and 50%. Since the second quarter of 2005, probes AM-5 through AM-8 have not been monitored. Notes by COT-ES field personnel indicate that monitoring at AM-5 through AM-8 stopped at this time because these probes were completed in refuse and the City was primarily concerned with monitoring the potential for lateral migration of methane offsite.

During or immediately after the re-grading activities in 2007, methane probes AMT-1 through AMT-3 were noted by COT-ES field personnel conducting monitoring activities to have been destroyed. Monitoring at nested methane probes AM-1 and AM-4 ceased after the second quarter of 2009. Field notes by COT-ES personnel indicate that this is because these probes had been buried.

2.2 Groundwater Monitoring

Three groundwater monitoring wells were installed at the site in the second quarter of 2000: WR-364A, WR-365A and WR-366A (ADWR, 2015). WR-364A and WR-366A are completed in the regional aquifer (total depths of 186 and 168 ft bgs, respectively) and include nested piezometers completed to shallower depths (30 to 55 ft bgs) to monitor potential perched groundwater. Soils at these shallower depths were noted to be damp during drilling. WR-365A was completed to 77 ft bgs where refusal at bedrock occurred. The shallow piezometers and WR-365A are dry; nearby wells showed perched water to be present at elevations between 2,290 ft above mean sea level (amsl) and 2,320 ft amsl in 2011 (COT-ES, 2011c).

Another well present at the site, identified as LM-007A, was completed in 1958 in the regional aquifer to 226.5 ft bgs, and has been monitored since 2007. Video logging of LM-007A was conducted in 2011 because no screened interval information for the well was available. The video log indicated that perched groundwater was seeping into the casing and cascading to the depth of the regional aquifer; subsequent laboratory analyses indicated no significant difference in quality between the perched groundwater and the regional aquifer (COT-ES, 2012a).

COT-ES conducted a groundwater elevation study between 2003 and 2009 in wells along the Santa Cruz River, including those at the AMLF. Overall, water levels were found to be decreasing at an average of 1.2 ft per year (ft/yr) in wells north of A-Mountain and increasing in wells south of A-Mountain at an average of 1.5 ft/yr. WR-364A, located east of the AMLF and approximately 80 ft from the Santa Cruz River, showed the most rapid and largest water level response to precipitation; the maximum groundwater elevation observed in this well following a large storm was still roughly 60 ft below the estimated lowest depth of refuse at the AMLF (COT-ES, 2011a).

Circa 2011, regional groundwater elevations at the site ranged from approximately 2,233 ft amsl at LM-007A to 2,247 ft amsl in WR-364A. The regional groundwater gradient was roughly 0.014 ft/ft to the northwest. This suggests that WR-366A is downgradient of the site, though no currently monitored well is present immediately downgradient of the northeast portion of the site, where the deepest refuse is known to occur. LM-007A is downgradient of the extreme northeast corner of the site. In 2011, COT-ES planned to locate an existing monitor well downgradient of the northeast portion of the site that could be added to the monitoring network. An inventory of private wells near the site was updated in 2011 and indicated that no private or public supply wells are present in the immediate vicinity of the site (COT-ES, 2011c).

Nitrate is routinely reported at concentrations less than the Aquifer Water Quality Standard (AWQS) of 10 mg/L in each regional monitoring well at the site. Tetrachloroethene (PCE) has been reported consistently in WR-364A and WR-366A at concentrations of 1.1 µg/L or lower; the AWQS for PCE is 5 µg/L. Concentrations of 1,4-dichlorobenzene, *cis*-1,2-dichlorethene, methylene chloride and toluene have occasionally been reported near the AMLF at concentrations less than the AWQS (COT-ES, 2012a). Chloroform and total trihalomethanes have also been reported in WR-364A at concentrations less than the AWQS and likely result from recharge of water treated with chlorine for potable use rather than from on-site sources. Regional groundwater concentrations of these compounds are stable or declining near the site. No PCE or other volatile organic compounds have been detected in LM-007A (COT-ES, 2012a).

3. LANDFILL GAS AND BARO-PNEUMATIC EVALUATION

The composition and distribution of LFG generated by the AMLF was determined using nested vapor probes to obtain vertical profiles of LFG component concentrations. LFG pressures in the vapor probes and their response to barometric pressure fluctuations were used to evaluate gas transport within the AMLF.

3.1 Vapor Probe Installation

Nested vapor monitoring probes were installed at ten locations across the landfill (Figure 2). Each nest consists of three vapor probes installed at three different depths. HGC contracted with Cascade Drilling, LP to install the vapor monitoring probes. Drilling was conducted between February 23 and 26, 2015, using a truck mounted CME Model 75 rotary drill rig equipped with 8-inch outside diameter augers to drill to the base of the refuse. The locations were chosen to provide representative characterization of landfill cover materials, thickness of refuse, landfill gas concentrations and vertical permeability.

A series of three nested, 1-inch diameter, Schedule 40, poly vinyl chloride probes, equipped with 1-foot long, 0.05-inch slot screens and a bottom cap and sealed at the top using an airtight J-plug sanitary seal were installed at varying depths at each location. Each screened interval was then sand packed with 8x12 washed silica sand from about 1 foot below the bottom of the screen to 2 feet above the top of the screen. Bentonite chips, 3/8-inch in diameter, were then used to seal between each probe screen and hydrated. The top several feet above each well installation was sealed with Portland cement. At each well location, an 8-inch diameter by 5-foot long steel well housing, equipped with a lockable cap, was installed to protect the probe installations. After well installations were completed, they were left untouched for a period of 48 hours to allow the bentonite seals and Portland cement to cure.

Drilling at the landfill indicated that the cover material is quite variable from location to location and varies in thickness from about 3 to 16 feet above the refuse contact. As a result of this variability, the depth of each nested probe installation was adjusted to yield the best information about the characteristics of the landfill refuse and the cover material at each location. Location and construction information for the probes is summarized in Table 1. An “as built” construction diagram for each nested well installation, along with lithologic descriptions, is provided in Appendix B.

Grab samples of drill cuttings were collected during the drilling process for lithologic descriptions. Additionally, the airspace just above the drill cuttings accumulating at ground surface around the auger were periodically monitored using a Landtec Gem 5000® multi-gas meter (Landtec) to determine concentrations of methane, carbon dioxide and oxygen. All drill cuttings were then removed from each well site and contained in a single 20 cubic yard roll-off bin lined with polyethylene plastic and equipped with a steel cover provided by Environmental Response Incorporated (ERI). At the end of the well installation event, a composite sample of the drill cuttings was collected from the bin and sent to TestAmerica, an Arizona-certified laboratory, for analysis of volatile organic compounds by EPA method 8260B and RCRA metals by EPA methods 6010B and 7471A to provide a profile of the material for shipment to an approved disposal facility.

3.2 Landfill Gas Sampling

Landfill gas composition in each vapor probe was measured using the Landtec. Concentrations of methane, carbon dioxide and oxygen were measured on a percent by volume basis. Additionally, samples from the shallow vapor probe at each nest were collected for laboratory analysis, both to confirm the field measurements and to determine the low concentrations of methane expected to be present in these probes.

3.2.1 Methodology

At least three casing volumes of soil vapor were purged from the vapor probes using a 1-HP rotary vane air purge pump. Prior to purging, the soil vapor probes were equipped with a wellhead assembly constructed of a slip to threaded PVC coupler, a threaded barb fitting, and secured with self-adhesive gas-tight silicon tape. The wellhead assembly was then connected to the decontaminated sampling train. Each sampling train included vinyl tubing and a T-valve. The T-valve connects the vapor probe, the air purge pump, and the laboratory-supplied quick-connect flow controller. The effluent soil vapor was monitored from the purge pump using the Landtec. Field information and Landtec measurements of carbon dioxide, oxygen and methane were recorded during purging (Appendix C).

Landfill gas samples for laboratory analysis were collected from the shallow vapor probes in each nest using 1-liter stainless steel SUMMA® canisters. After purging three casing volumes of soil vapor from each vapor probe and prior to shutting off the purge pump, the T-valve was turned to disconnect the air purge pump and positioned to allow soil vapor flow for sample collection. After verification that the SUMMA® canister had been properly prepared and was under a vacuum of approximately 28.5 inches of Hg, the sample was collected for one minute or until the pressure gauge measured less than four inches Hg.

The SUMMA® canister samples were stored in a cool, secure place prior to shipment to the laboratory. After sample collection, HGC packed and shipped canisters under Chain of Custody to TestAmerica, an Arizona-certified laboratory, for analysis of fixed gases by EPA Method 3C. Each sample was labeled with permanent indelible ink on the waterproof label affixed to the container that included the sample location, date and time of collection, and the analysis requested.

Upon completion of sampling at each vapor probe, the sampling train was separated and disposed of. The flow controller was returned to the laboratory. The wellhead assembly was decontaminated using an Alconox triple rinse process after each use.

3.2.2 Results

LFG constituents were measured on March 16, 2015, in the shallow probes and on March 18, 2015, in all probes. Field measurements for methane, carbon dioxide and oxygen are summarized in Table 2.

The distribution of methane concentrations in the vapor probes is shown in Figure 3. Methane concentrations in the shallow probes ranged from 0.2% to 8.4% for field measurements from both LFG monitoring events, and were 1.1% or less at all probes besides AMVP-1. Field-measured methane concentrations at the middle-depth probes ranged from 0.5% to 31.8%, and were also highest at AMVP-1. At the deep probes, field-measured methane concentrations were between 1.4% and 55.6%, with the highest concentration observed at AMVP-2.

Samples for LFG analysis by EPA Method 3C were collected from each shallow probe on March 16, 2015. Table 3 compares the analytical results with field LFG composition measurements taken prior to sample collection. The analytical laboratory report is provided in Appendix D.

Field methane measurements for the shallow probes generally exceed laboratory results and significantly overestimate methane concentrations below 1% due to instrument limitations at very low methane concentrations. Field methane measurements of 0.5% to 0.6% (5,000 ppmv to 6,000 ppmv) correspond to a range of laboratory methane concentrations between 13 ppmv and 190 ppmv (0.0013% and 0.019%). Field and laboratory results for carbon dioxide and oxygen were in better agreement because concentrations for these constituents were higher. While the field-measured concentrations were lower, they were generally within 30% of laboratory results.

The distribution of carbon dioxide concentrations in the vapor probes is shown in Figure 4. Field measured concentrations of carbon dioxide in the shallow probes ranged from 1.2% to 19% for both sampling events and are spatially heterogeneous. Those for the middle-depth probes are consistently elevated, ranging from 9.8% to 27.6%, as are those for the deep probes that ranged from 16.1% to 35%.

The distribution of oxygen concentrations in the vapor probes is shown in Figure 5. Oxygen concentrations from field measurements in the shallow probes ranged from 3.1% to 19.2%, with the lowest values observed at AMVP-1-S. Field measured oxygen concentrations in the middle-depth probes were uniformly low, ranging from not detected to 0.9%, with the exception of probes AMVP-7-M and AMVP-6-M that displayed anomalously high concentrations at 5.1% and 10.9%, respectively. Oxygen was not detected in the deep probes with the exception of AMVP-6-D, with an anomalous concentration of 4.3%.

3.2.3 Discussion

Due to the imprecision of the Landtec portable instrument at low methane concentrations, methane concentrations measured as 0.2% to 1.0% in the field at the shallow probes likely represent trace concentrations. Based on laboratory gas analyses, field measurements overestimated methane concentrations in the shallow probes by 39% to 100% at locations other than AMVP-1. These overestimates could result from method error at low concentrations or from the presence of other hydrocarbon compounds that inflate field methane readings.

Both methane and carbon dioxide concentrations generally increased with depth at each probe nest location, while oxygen concentration decreased. The highest methane concentrations were measured in vapor probes located at the northeast portion of the landfill (AMVP-1 and AMVP-2), where the refuse is believed to be thickest. The methane concentrations at all depths in AMVP-1 were an order of magnitude greater than those measured at all other probes besides AMVP-2. Higher methane concentrations are expected to coincide with greater refuse thickness due to the greater availability of organic substrates and the potential for the development of anaerobic conditions that facilitate methanogenesis.

The northern portion of the landfill in the areas of AMVP-1 and AMVP-2 is clearly methanogenic, whereas the remainder of vapor probe locations suggests varying conditions ranging from mildly methanogenic to aerobic. The overall pattern of landfill gas constituents is consistent with the occurrence of methane oxidation in the cover soils and the upper part of the refuse with the exception of AMVP-1.

Carbon dioxide concentrations show a positive relationship with methane concentrations, while oxygen concentrations show a negative relationship with both methane and carbon dioxide concentrations. These trends are expected, as oxygen consumption by degradation processes generates carbon dioxide, oxygen facilitates consumption of methane via methane oxidation, and elevated methane concentrations imply the localized presence of anaerobic conditions.

Elevated concentrations of carbon dioxide in the shallow vapor probes (Figure 4) suggest intrusion of carbon dioxide from the waste mass into the overlying cover soils. Carbon dioxide concentrations in excess of 10% were present in four of the shallow vapor probes (AMVP-1-S, AMVP-2-S, AMVP-3-S, AMVP-8-S) and slightly lower concentrations exceeding 5% were present in two additional shallow vapor probes (AMVP-4-S, AMVP-9-S).

3.2.3.1 Landfill Gas Impact to Plants

Many revegetated landfills have poor plant cover, including bare areas where plants do not grow. The major constituents of landfill gas, methane and carbon dioxide, can be detrimental to the growth of plants (Nagendran *et al*., 2006; Trotter and Cooke, 2005; El-Fadel *et al*., 1997; Lan and Wong, 1994; Chan *et al*., 1991; Flower *et al*., 1981). Methane is not itself toxic to plants; however, high concentrations can displace oxygen and indirectly impact plant growth (Flower *et al*., 1981; Lan and Wong, 1994). In contrast, carbon dioxide can be directly toxic to plant roots, with different plant species varying in their susceptibility (Flower *et al*., 1981; Trotter and Cooke, 2005).

El-Fadel *et al*. (1997) found that oxygen deficiency in the root zone due to displacement of oxygen by LFG leads to asphyxia; oxygen deficiency is exacerbated by methane oxidation near the surface; methane oxidation raises soil temperature and the potential for asphyxia; and carbon dioxide within LFG and via methane oxidation can be directly harmful to plant growth. Chan *et al*. (1991) indicate that high carbon dioxide is a more immediate threat than low oxygen; short-term high carbon dioxide exposure can create long-term problems with root development; root growth was inhibited by carbon dioxide exceeding 15%; and taproot growth was inhibited by carbon dioxide exceeding 30%. Flower *et al*. (1981) note that root sensitivity to carbon dioxide is species-dependent and that previous investigators found that carbon dioxide as low as 10% can be directly toxic. Lan and Wong (1994) and Trotter and Cooke (2005) noted that grasses survive better on landfills than trees or shrubs due to their shallow root systems. Trotter and Cooke (2005) found that grass colonization was affected by carbon dioxide and that carbon dioxide intrusion into the root zone is probably the main factor causing vegetative bare spots.

Cacti and succulents appear to be especially susceptible to damage by elevated carbon dioxide in the soil. Nobel (1989) indicates that some species of cacti and succulents (*Agave deserti, Ferocactus acanthodes, and Opuntia ficus-indica*), which have relatively shallow root systems, can be harmed by carbon dioxide concentrations as low as 0.1%, but do not appear to be harmed by lack of oxygen. Nobel and Palta (1989) determined that, although the effects of low oxygen were reversible, carbon dioxide concentrations as low as 2% were fatal to roots of *Opuntia ficus-indica* and *Ferocactus acanthodes* if sustained for more than 6 hours.

Carbon dioxide concentrations at the AMLF range from approximately 1.5% to 19% at shallow depths; from 9.8% to 27.6% at middle depths; and from 16.1% to 35.5% at deeper depths. Based on the research presented above, most desert plants would be expected either to not survive or to be under stress in this setting. Furthermore, because of the relatively dry setting and relatively low expected rate of biodegradation of waste, the factors that are the cause of these concentrations are likely to persist for some time.

Cacti (typically having shallow root systems) are not likely to thrive. All carbon dioxide concentrations measured at the site exceed 0.1%, even at shallow depths, indicating that these plants would at a minimum be under stress. Carbon dioxide concentrations at shallow depths exceed 2%, the concentration considered fatal to root systems, at all locations except AMVP-6S and AMVP-7S. Carbon dioxide concentrations at these locations exceed 1.5% and are likely to exceed 2% under conditions of a sustained drop in barometric pressure accompanying a storm front. Because carbon dioxide concentrations exceeding 2% for more than 6 hours are likely to be fatal, cacti are not likely to survive even at these locations.

Desert trees and shrubs are also likely, at a minimum, to be inhibited by the relatively high carbon dioxide concentrations (exceeding 10%) at middle and deeper depths. The relatively high carbon dioxide concentrations at depth are expected to inhibit the development of or damage the relatively deep root systems of the mesquite and palo verde trees. The potential impact on other desert trees and shrubs is also likely to be negative.

Based on the above research, some grasses are likely to survive better than cacti because of their shallow root systems and apparently higher tolerance to carbon dioxide. However, even grasses may undergo stress in the northeastern portion of the landfill where refuse is thicker and LFG generation more significant.

3.2.3.2 Potential Landfill Gas Impact to Structures

Although measured shallow methane concentrations are generally low, methane concentrations are expected to increase under any buildings constructed on-site because of the transport barrier created by the building foundation slabs. Foundation slabs will restrict the upward transport (escape) of methane and the downward transport of oxygen through the land surface. Wherever upward transport of methane is restricted, concentrations at all depths are expected to increase. Similarly, wherever downward transport of oxygen is restricted, less oxidation of methane will occur, which will increase subsurface methane concentrations especially at shallow depths.

Methane buildup beneath foundation slabs increases the potential for accumulation of methane in any closed structures. Furthermore, unless measures are taken to minimize damage, ongoing land subsidence resulting from biodegradation of refuse may damage foundation slabs and increase the potential for methane buildup in closed structures.

3.3 Gas Pressures and Landfill Gas Production

Downhole logging pressure transducers were deployed to measure pressure fluctuations in the nested probes. The propagation of pressure fronts through landfill materials and the difference between average landfill pressure and average barometric pressure enable estimation of vertical permeabilities in the landfill and an initial estimate of landfill gas production.

3.3.1 Methodology

Each probe was outfitted with an In-Situ® 5-PSI “Level Troll-500” vented relative-pressure transducer equipped with an onboard programmable data logger and sealed inside its respective probe using an airtight wellhead assembly designed for this purpose. Additionally, a barometric pressure transducer was set to log atmospheric pressure changes. All transducers were synchronized to begin logging pressure data at the same time using a one minute logging interval. The test was allowed to run for three consecutive days to collect sufficient data for analysis. At the end of the test the transducer data were downloaded onto a laptop computer for evaluation.

3.3.2 Results

Plots of atmospheric and subsurface pressure data from each measurement location are provided in Appendix E. The atmospheric pressure data are included for purposes of comparison. As shown, all subsurface pressures are slightly less than atmospheric, indicating that the subsurface is under vacuum.

3.3.3 Quantitative Analysis and Results

Vertical gas permeabilities and gas porosities were estimated from the baro-pneumatic data using the numerical finite difference computer code TRACRN (Travis and Birdsell, 1988). TRACRN was developed at Los Alamos National Laboratories and is capable of simulating gas and liquid flow, and solute transport in three dimensions, within variably saturated porous media.

One-dimensional (1-D) models were developed for the three monitored locations having subsurface pressure curves that exhibited measurable lags and attenuations compared to the atmospheric pressure curve. These locations were AMVP2, AMVP7 and AMVP8. Locations AMVP2 and AMVP7 had relatively thick cover which makes them more amenable to quantitative analysis of cover permeability. Subsurface pressure curves at other locations were sufficiently similar to the atmospheric pressure curve so that a quantitative analysis of permeability and porosity was impractical.

Because subsurface pressures were lower than atmospheric, LFG generation rates were not estimated. In performing the analyses, the measured vacuums were subtracted from the subsurface pressures. This is appropriate because permeability and porosity affect only the shape (rather than the 'height') of the curve. Subtracting out the impact of subsurface vacuum (or pressure) essentially reduces the baro-pneumatic analysis to the method of Weeks (1978) for analyzing subsurface pressure data for vadose zone air permeability.

3.3.3.1 Model Construction

Each 1-D numerical model contained 36 layers and was constructed to represent the conditions reported during drilling and to be consistent with site geophysical and depth to water data. Each model extended from the land surface to the water table (which represents a no-flow boundary to gas) and had layer thicknesses that were varied to accurately represent cover thicknesses and monitoring probe depths. The total thickness of refuse represented in each model was based on geophysical estimates of refuse thickness and information from the probe installation drilling.

3.3.3.1.1 Material Distribution

Material types represented in the 1-D models included refuse, cover materials, and underlying vadose soils. In general, the uppermost 4 to 6 model layers represented cover material and the underlying layers represented refuse and vadose soils.

3.3.3.1.2 Boundary Conditions

Because the models were 1-D in the vertical direction, the lateral boundaries were assumed to be no flow. The bottom boundary (coincident with the water table) was also assumed to be no flow. The upper boundary was assigned a varying pressure condition equivalent to the measured atmospheric pressure during the testing.

3.3.3.2 Model Calibration

Each model was calibrated by varying the pneumatic properties (air permeability and porosity) of the cover, refuse, and underlying soil materials until the simulated subsurface pressures were in reasonable agreement with the measured subsurface pressures at each modeled location. As discussed above, each model was calibrated to subsurface pressure data that had the measured vacuums subtracted out. Only a portion of the baro-pneumatic data (between approximately 0.8 and 2.1 days) was analyzed. This portion of the data encompassed large changes in atmospheric pressure that increased the sensitivity of the calibrations and was sufficiently removed from the start of data collection that any potentially lingering effects of transducer installation were minimal.

3.3.3.3 Results

Figures 6 through 8 compare the measured and simulated subsurface pressures from the three locations. The fits achieved between measured and simulated pressures were good at each location. Vertical permeability and porosity estimates are provided in Table 4. Vertical cover permeability estimates are consistently 10 darcies; vertical refuse permeability estimates are consistently 25 darcies; and porosity estimates ranged from 0.2 in the cover to 0.3 in the refuse.

3.3.4 Discussion

In general, the shapes of the subsurface pressure curves are nearly identical to the shape of the atmospheric pressure curve. Peaks and troughs (local maxima and minima) in the subsurface pressure curves have nearly the same magnitudes as those in the atmospheric pressure curve (indicating negligible attenuation), and there appears to be minimal delay in the timing of peaks and troughs in subsurface pressure curves compared to atmospheric (indicating negligible lag). Delay in the timing of peaks and troughs (lag) and reduction in magnitudes of peaks and troughs (attenuation) are expected to increase with an increase in depth, a decrease in permeability, or an increase in gas porosity.

Overall, the data indicate that the cover and refuse have relatively high permeabilities, and that the cover provides a negligible barrier to pressure transmission (and gas flow) between the land surface and the refuse.

Typically, landfills generating LFG are under pressures higher than atmospheric as a result of LFG generation. However, older landfills (especially in dry climates) have sufficiently low LFG generation that outward flow of LFG is insufficient to prevent intrusion of atmospheric oxygen via diffusion and barometric pumping. Oxygen entering the refuse will inhibit anaerobic degradation and induce aerobic degradation of both refuse and methane generated within portions of refuse that remain anaerobic. As discussed in Appendix F, aerobic degradation of refuse and methane is expected to result in a decrease in volume of gas, thus inducing a subsurface vacuum. The induced vacuum further enhances the process by drawing in more oxygen via advection.

Because the cover material has a relatively high permeability, the cover is not expected to inhibit diffusion or advection of oxygen into the refuse, which will enhance aerobic degradation. In addition, the cover is not expected to provide a significant barrier to upward migration of LFG wherever the cover contacts portions of the refuse that remain anaerobic.

Furthermore, carbon dioxide will be produced under both anaerobic and aerobic processes. The combination of aerobic and anaerobic subsurface processes is expected to result in relatively large subsurface carbon dioxide concentrations.

3.3.4.1 Impact of Barometric Pressure on Landfill Gas Emissions

The influences of barometric pressure on landfill methane emissions have been evaluated in a number of studies that show dramatic changes in LFG fluxes over short timeframes (e.g., Christophersen *et al*., 2001; Czpiel *et al*., 2003; Giani *et al*., 2002; Xu *et al*., 2014). Rising barometric pressure suppressed emissions, while falling barometric pressure enhanced emissions – a phenomenon called "barometric pumping" (Xu *et al*., 2014). Barometric pumping results from short-term differences between barometric pressure and subsurface pressure.

Changes in barometric pressure are transmitted to the vadose subsurface but are delayed and attenuated due to resistance to flow and storage in the vadose soils. Consequently, when barometric pressure is rising, the rate of increase in subsurface pressure is lower than the rate of increase in barometric pressure and, when barometric pressure is falling, the rate of decrease in subsurface pressure is lower than the rate of decrease in barometric pressure. As a result, when comparing a time-series of barometric pressure measurements with a similar time series of subsurface pressure measurements, peaks and troughs (local maxima and minima) in the subsurface pressure curves are smaller in magnitude than those in the barometric pressure curve (attenuation), and a delay in the timing of peaks and troughs occurs in the subsurface pressure curves compared to barometric (lag). Delay in the timing of peaks and troughs (lag) and reduction in magnitudes of peaks and troughs (attenuation) are expected to increase with an increase in depth, a decrease in permeability, or an increase in gas porosity. The lag and attenuation result in short term differences between barometric and subsurface pressures, creating a (temporary) flow of air into the subsurface when barometric pressure is rising and a (temporary) flow of soil gas out through the land surface when barometric pressure is falling. In the case of a landfill generating LFG, the average subsurface pressure is typically higher than average barometric pressure, so that changes in barometric pressure tend to modulate outward emissions through the landfill cover. Emissions increase when barometric pressure drops and decrease when barometric pressure rises.

The lag and attenuation measured in the subsurface at the AMLF is small due to the high permeability of the landfill cover and refuse. However, because the permeability is high, small pressure differences can result in significant flow (and barometric pumping). Barometric pressure typically peaks twice in a given 24-hour period and differences between peaks and troughs are typically less than about 0.05 psi. Larger changes in pressure may occur in response to weather fronts. In general, high pressure is associated with calm, sunny weather and dry air, while low pressure occurs on cloudy, rainy days with moist air.

As a consequence of barometric pumping at a typical landfill, during periods of rising barometric pressure, LFG emissions through the cover will be reduced or reversed as outward flow caused by LFG generation is reduced or reversed. If the rate of increase in barometric pressure is sufficient to reverse flow, downward flow into the landfill cover will tend to reduce LFG concentrations in the cover and shallow refuse. During periods of falling barometric pressure, the opposite is expected: LFG emissions will increase as more gas flows upward and out of the cover, and LFG concentrations within the cover and shallow refuse will increase.

At the AMLF, low LFG generation rates and aerobic degradation of refuse and methane have created a slight vacuum. However, rising barometric pressure is expected to result in a decrease in LFG concentrations in the cover and shallow refuse, and falling barometric pressure is expected to result in an increase in LFG concentrations in the cover and shallow refuse. Periods of falling barometric pressure, therefore, are expected to result in conditions that are the most stressful to plants having shallow root systems.

4. SURFACE SOIL CONDITIONS

Soil conditions were characterized by collecting soil samples of surficial cover materials to determine suitability for planting. Samples were analyzed for macro- and micro-nutrients, salts, organic matter, pH, bulk density, and water holding capacity by IAS Laboratories, an agricultural testing laboratory located in Phoenix, Arizona. Samples from 10 locations across the landfill were collected to account for spatial variability (Figure 2).

4.1 Methodology

Surface soil samples were collected near each of the soil vapor probe locations due to their distribution throughout the landfill. The sample site at each of the vapor probes was selected near surrounding vegetation. The top inch of soil was removed prior to sample collection.

The samples were collected using a clean AMS slide hammer attached to a stainless steel split spoon core sampler. The split spoon was placed over the sample location and was driven into the soil by sliding the hammer along the shaft. Once the end of the split spoon core sampler was near land surface, it was removed. The sample was placed in a one gallon brown paper bag, per laboratory direction. The stainless steel split spoon core sampler was removed from the slide hammer and decontaminated using an Alconox triple rinse process after each use.

The sample containers were stored in a cool, secure place prior to transport to the laboratory. After sample collection, HGC packed and delivered samples under Chain of Custody to IAS Laboratories for an analysis that included a complete soil test with soil amendment recommendations (consisting of available calcium, magnesium, sodium, potassium, nitrate, phosphate, zinc, iron, manganese, copper, boron, sulfur, salinity, pH, and free lime), as well as bulk density, organic matter, and soil moisture retention. Each sample was labeled with permanent indelible ink on the container. Labels included the sample location, date and time of collection, and the analysis requested.

4.2 Results

Results of the soil testing performed are summarized in Table 5. Laboratory reports are included in Appendix G.

Cover soils are generally well-drained, consistent with their generally coarse-grained nature. Field capacities range from 6.5% to 12.2%. Because the soils are expected to drain relatively rapidly and retain relatively small amounts of water, frequent irrigation would be required unless landscape plants having relatively small moisture requirements were chosen.

Soil pH ranges from 7.5 to 8.8 indicating alkaline conditions. Free lime levels are high. Soil salinities range from 0.8 to 8.2 deci Siemens per meter (dS/m) and average 4.2 dS/m, indicating moderately saline conditions. Concentrations of calcium (5,200-6,000 mg/kg), magnesium (280-670 mg/kg), and copper (1.2-12 mg/kg) are all very high; sodium (230-870 mg/kg), zinc (1.6-8.2 mg/kg), and manganese (3.2-15 mg/kg) are all high to very high; potash (130-460 mg/kg) and iron (3.3-29 mg/kg) range from medium to very high; and nitrate as nitrogen (2.5-220 mg/kg) and sulfur (3.9-570 mg/kg) range from low to very high. Concentrations of phosphorous (2.6-12 mg/kg) are very low to medium; and concentrations of boron (0.2-0.8 mg/kg) are very low to low.

Based on these results, IAS Laboratories recommended soil amendments (Table 6). These include the addition of:

1. phosphate and boron to all locations;
2. iron to locations AMVP-2, AMVP-5, AMVP-8, and AMVP-10 (to balance micro-nutrients such that iron exceeds manganese and zinc);
3. manganese to locations AMVP-3 and AMVP-5 (to balance micro-nutrients such that manganese exceeds zinc and copper);
4. magnesium to location AMVP-4 (to narrow the calcium to magnesium ratio to between 10:1 and 20:1);
5. nitrogen to all locations except AMVP-4, AMVP-6, AMVP-8, and AMVP-10;
6. sulfur to all locations except AMVP-3, AMVP-6, and AMVP-8 (to reduce pH); and
7. zinc to all locations except AMVP-2, AMVP-5, AMVP-8, and AMVP-9 (to balance micro-nutrients such that zinc exceeds copper, but cautions against over-application).

IAS Laboratories also recommends extra irrigation with water to flush salts out of the root zone at all locations except AMVP-1, AMVP-2, AVP-5, and AMVP-9.

4.3 Discussion

The overall pattern of concentrations of the major cations and anions indicate that the soil is moderately saline, and that most of the sampled locations should be flushed with water to leach excess salts from the root zone. The generally coarse-grained, well-drained nature of the cover soils also indicates that water retention will be minimal and that frequent irrigation of typical landscape plants would be needed.

The potential need for flushing to reduce salts and the likely frequent irrigation needs of landscape plants may be problematic considering the site is a closed, unlined landfill. Although there do not appear to be any current groundwater impacts related to the landfill, water application for flushing, and the ongoing frequent water application to sustain landscape plants, may potentially result in leachate generation leading to undesirable future groundwater quality impacts. Furthermore, increasing the moisture content of the refuse through frequent water application to the overlying cover is expected to increase degradation rates, leading to greater rates of land subsidence in areas receiving water.

Reducing the need for water application by choosing landscape plants having low moisture requirements (such as cacti) would reduce the potential for leachate generation and ground subsidence. However, use of cacti is problematic because of their low tolerance to carbon dioxide that exists at toxic levels at most shallow soil locations and is expected to remain at toxic levels for some time into the future as discussed in Section 3.3.4. Furthermore, the salinities of the majority of the site cover soils are higher than most Sonoran desert surface soils in the Tucson area which typically range from 0.5-2.0 dS/m (USDA, 2014a; 2014b). Six out of the ten sampled locations have salinities that exceed 2.0 dS/m. This suggests that, independent of the carbon dioxide issue, site soils may need to be flushed to reduce salinity before desert plants (including cacti) could thrive.

An alternative to typical landscape plants or desert plants such as cacti would be grasses because of their shallow root systems and greater carbon dioxide tolerance compared to cacti. Selecting grasses that require low moisture and that have moderate salt tolerance should reduce the need for water application and the potential consequences of leachate generation and land subsidence at the site.

5. CONCLUSIONS AND RECOMMENDATIONS

Based upon the available information, conditions in the AMLF range from methanogenic in the northern portion (where refuse is thicker) to weakly methanogenic or aerobic elsewhere. Methane generation rates at the site are relatively low, consistent with the age of the refuse and the relatively dry conditions that limit refuse degradation rates. Methane oxidation supported by oxygen transport into the subsurface appears to be occurring in most areas and is likely contributing to relatively high carbon dioxide concentrations.

No substantive impacts to groundwater appear to be associated with the AMLF under current conditions. Additionally, the results of methane monitoring around the perimeter of the AMLF do not indicate any significant lateral migration of methane from the landfill. The apparent absence of lateral migration likely results from a combination of primarily upward migration of methane through the permeable cover soils and perimeter methane oxidation. This condition would likely change if the site were ever covered with relatively impermeable material. Blocking upward migration of methane and downward transport of oxygen is expected to increase subsurface methane concentrations and promote lateral and downward migration of methane into perimeter and underlying soils.

Based on the results of the investigation, the following conclusions can be drawn:

1. Shallow cover soil methane concentrations are likely to increase beneath buildings constructed on the site due to the transport barrier created by the foundation slabs. Building foundation slabs will also restrict oxygen transport into the shallow soils and reduce methane oxidation, further increasing methane concentrations beneath buildings.
2. Although methane generation rates at the site are low due to low refuse degradation rates, they are likely to persist for some time, prolonging the potential for methane hazards and for high carbon dioxide concentrations.
3. Landscape plants are unlikely to thrive over most of the site without flushing of cover soils with water to reduce salts and without adding amendments to the soils.
4. The coarse-grained, well-drained nature of the cover soils indicates that water retention will be small and that frequent watering of any landscape plants would be needed. Frequent water application may increase biodegradation rates in refuse underlying cover soils receiving water, thereby increasing subsidence and increasing the potential for leachate generation and future groundwater quality impacts. Even in the absence of water application, ongoing land subsidence resulting from refuse degradation must be considered in assessing any future use of the site.
5. High carbon dioxide concentrations in cover soils and underlying refuse will stress trees and/or shrubs planted at the site. Cacti and other succulents having low carbon dioxide tolerance are unlikely to survive.

6. Grasses having tolerance to carbon dioxide and to relatively saline soils are likely to perform better than typical landscape plants or cacti.

Because of the likely persistence of methane hazards and potential buildup of methane beneath any buildings constructed on-site, ongoing ground subsidence resulting from refuse degradation, potentially increased subsidence and leachate generation resulting from water application for landscaping, the need to improve cover soil chemistry to support landscape plants, and carbon dioxide levels that are likely to stress or be fatal to most landscape plants and/or desert trees, shrubs, and cacti, development options will be limited without significant modifications to the site. Under present conditions, potential uses of the site would, at a minimum, need to account for the potential methane hazards and ongoing ground subsidence, which would affect the feasibility of closed structures, and present difficulties even for public walkways, hiking or biking trails, etc.

Hazards would be minimized by maintaining the site primarily as open ground, with open structures built to withstand subsidence conditions, landscaping limited to suitable grasses and/or potted plants, and public access limited to certain times of the year. During periods when the site is not in public use, the site could be inspected and prepared for the next use. Any areas undergoing unacceptable subsidence could be leveled, any open subsidence cracks repaired, public trails and walkways inspected for any offsets and repaired, and landscaping revised or repaired as needed.

Eventually the hazards related to refuse degradation will be reduced to the extent that other options for site use will be more acceptable.

6. REFERENCES

Arizona Department of Water Resources (ADWR). 2015. Well Registry Database. Accessed online January 2015.

Chan, G.Y.S., M.H. Wong and B.A. Whitton (1991). Effects of Landfill Gas on Subtropical Woody Plants. Environmental Management 15(3): 411-431.

Christophersen, M., Kjeldsen, P., Holst, H., and Chanton, J. (2001). Lateral gas transport in soil adjacent to an old landfill: factors governing emissions and methane oxidiation. Waste Management & Research 19(6): 595-612.

City of Tucson Environmental Services (COT-ES). 2008. Letter to Arizona Department of Environmental Quality *Re: City of Tucson A-Mountain Landfill Development Activities Notification*. March 6, 2008.

COT-ES. 2011a. *Comprehensive Landfill Investigation Final Report.* March 2011.

COT-ES. 2011b. *Closed Landfills Inspection and Maintenance Reporting and Procedures*. March 2011.

COT-ES. 2011c. *2011 Groundwater Monitoring Results and July 2010-June 2011 Landfill Gas Monitoring Results, A-Mountain Landfill, Tucson, AZ.* October 7, 2011.

COT-ES. 2012a. *A-Mountain, Congress and Nearmont Landfills, 2012 Annual Monitoring Report.* December 4, 2012.

COT-ES. 2012b. *2012 Annual Landfill Inspection Report*. December 6, 2012.

COT-ES. 2014. *2013 Annual Non-Regulated Closed Landfill Inspection and Reporting, December 2013*. January 28, 2014.

Czepiel, P.M., Shorter, J.H., Mosher, B., Allwine, E., McManus, J.B., Harriss, R.C., Kolb, C.E., Lamb, B.K. (2003). The influence of atmospheric pressure on landfill methane emissions. Waste Management 23(7): 593-598.

El-Fadel, M., A.N. Findikakis and J.O. Leckie (1997). Environmental Impacts of Solid Waste Landfilling. Journal of Environmental Management 50: 1-25.

Flower, F.B., E.F. Gilman and I.A. Leone. (1981). Landfill gas, what it does to trees and how its injurious effects may be prevented. Journal of Arboriculture 7(2): 43-52.

Giani, L., J. Bredenkamp, and Eden, I. (2002). Temporal and spatial variability of the CH_4 dynamics of landfill cover soils. J. Plant Nutr. Soil Sci., 165(2): 205-210.

Kleinfelder. 2007. *Geotechnical Study Report, Tucson Origins Cultural Park, Tucson, Arizona*. May 2007.

Lan, C. and M. Wong (1994). Environmental factors affecting growth of grasses, herbs and woody plants on a sanitary landfill. Journal of Environmental Sciences, 6(4): 504-513.

Nagendran, R., A. Selvam, K. Joseph and C. Chiemchaisri (2006). Phytoremediation and rehabilitation of municipal solid waste landfills and dumpsites: A brief review. Waste Management 26 (2006): 1357-1369.

Nobel, P.S. (1989). A nutrient index quantifying productivity of agaves and cacti. Journal of Applied Ecology 26(2):635-645.

Nobel, P.S., and Palta, J.A. (1989). Soil O_2 and CO_2 effects on root respiration of cacti. Plant and Soil 120(2): 263-271.

Travis, B. J., and K. H. Birdsell. 1988. TRACRN 1.0: A Model of Flow and Transport in Porous Media for the Yucca Mountain Project - Model Description and User's Manual. Los Alamos National Laboratories. TW5-ESS-5/10-88-08.

Trotter, D.H., and Cooke, J.A. (2005). Influence of landfill gas on the microdistribution of grass establishment through natural colonization. Environmental Management 35(3): 303-310.

USDA 2014a. USDA Natural Resources Conservation Service, 2014. Soil Surveys for Pima County, Arizona, Eastern Part (AZ669). Updated September 20, 2014.USDA 2014b. USDA Natural Resources Conservation Service, 2014. Soil Surveys for Tucson-Avra Valley Area, Arizona (AZ668). Updated September 14, 2014.

Weeks, E.P., 1978. Field Determination of Vertical Permeability to Air in the Unsaturated Zone. U.S. Geological Survey Professional Paper 1051.

Xu, L., Lin, X., Amen, J., Welding, K., and McDermit, D. (2014). Impact of changes in barometric pressure on landfill methane emission. Global Biogeochemical Cycles 28 (7): 679-695.

Zonge Engineering & Research Organization, Inc. 2001. *Final Report: IP/Resistivity Survey, A-Mountain Landfill*. Submitted to City of Tucson Environmental Management Division, April 23, 2001.

7. LIMITATIONS

The information and any opinions, recommendation, and/or conclusions presented in this report are based upon the scope of services and information obtained through the performance of the services, as agreed upon by HGC and the party for whom this report was originally prepared. Results of any investigations, tests, or findings presented in this report apply solely to conditions existing at the time HGC's investigative work was performed and are inherently based on and limited to the available data and the extent of the investigation activities. No representation, warranty, or guarantee, express or implied, is intended or given. HGC makes no representation as to the accuracy or completeness of any information provided by other parties not under contract to HGC to the extent that HGC relied upon that information. This report is expressly for the sole and exclusive use of the party for whom this report was originally prepared and the particular purpose for which it was intended. Reuse of this report, or any portion thereof, for other than its intended purpose, or if modified, or if used by third parties, shall be at the sole risk of the user.

TABLES

TABLE 1
Vapor Probe Nest Locations and Construction
A Mountain Landfill

Vapor Probe Nest ID	Latitude (degree)	Longitude (degree)	Screened Intervals (ft bls)
AMVP-1	32.2133333	-110.9852778	5-6
			15-16
			34-35
AMVP-2	32.2127778	-110.9844444	5-6
			12-13
			34-35
AMVP-3	32.2125000	-110.9855556	6-7
			12-13
			24-25
AMVP-4	32.2116667	-110.9852778	5-6
			11-12
			24-25
AMVP-5	32.2119444	-110.9866667	5-6
			12-13
			24-25
AMVP-6	32.2122222	-110.9875000	5-6
			11-12
			19-20
AMVP-7	32.2111111	-110.9875000	5-6
			10-11
			24-25
AMVP-8	32.2111111	-110.9866667	5-6
			12-13
			24-25
AMVP-9	32.2105556	-110.9858333	4-5
			13-14
			24-25
AMVP-10	32.2100000	-110.9872222	7-8
			16-17
			24-25

Notes:
ft bls = feet below land surface

TABLE 2
Landfill Gas Monitoring Results
A Mountain Landfill

Probe	Date and Time	Methane CH_4 (%)	Carbon Dioxide CO_2 (%)	Oxygen O_2 (%)
AMVP-1-S	3/16/2015 14:36	8.4	17.4	4.0
	3/18/2015 13:28	7	19	3.1
AMVP-1-M	3/18/2015 13:31	31.8	27.6	0
AMVP-1-D	3/18/2015 13:36	24.2	25.5	0
AMVP-2-S	3/16/2015 15:17	1.1	12.3	5.9
	3/18/2015 13:52	0.8	13.6	5.7
AMVP-2-M	3/18/2015 13:55	7.3	20.5	0.4
AMVP-2-D	3/18/2015 13:58	55.6	35.5	0
AMVP-3-S	3/16/2015 14:50	1	10.9	9
	3/18/2015 13:42	0.7	11.7	9.3
AMVP-3-M	3/18/2015 13:45	4.3	21.6	0
AMVP-3-D	3/18/2015 13:48	7	23.4	0
AMVP-4-S	3/16/2015 15:05	0.6	7.2	12.3
	3/18/2015 14:01	0.2	8.3	12.5
AMVP-4-M	3/18/2015 14:04	7.4	21.1	0
AMVP-4-D	3/18/2015 14:07	12.7	23.9	0
AMVP-5-S	3/16/2015 15:57	0.5	3.1	16
	3/18/2015 14:47	0.2	3.5	16.9
AMVP-5-M	3/18/2015 14:50	3.3	19.9	0.9
AMVP-5-D	3/18/2015 14:53	6	22.8	0
AMVP-6-S	3/16/2015 16:04	0.5	1.3	17.6
	3/18/2015 14:56	0.2	1.6	18.9
AMVP-6-M	3/18/2015 14:59	0.5	9.8	10.9
AMVP-6-D	3/18/2015 15:02	1.4	16.1	4.3
AMVP-7-S	3/16/2015 15:42	0.5	1.2	17.6
	3/18/2015 14:29	0.2	1.5	19.2
AMVP-7-M	3/18/2015 14:32	0.6	15.9	5.1
AMVP-7-D	3/18/2015 14:35	2.1	21.2	0
AMVP-8-S	3/16/2015 15:50	1	14.3	5.5
	3/18/2015 14:38	0.8	14.4	6
AMVP-8-M	3/18/2015 14:41	7.3	23	0
AMVP-8-D	3/18/2015 14:44	9.3	24	0
AMVP-9-S	3/16/2015 15:28	0.6	7.4	11.3
	3/18/2015 14:09	0.2	8.4	12.1
AMVP-9-M	3/18/2015 14:14	1.7	21	0
AMVP-9-D	3/18/2015 14:17	8.1	23.7	0
AMVP-10-S	3/16/2015 15:35	0.5	3.8	15.2
	3/18/2015 14:20	0.2	4.5	16
AMVP-10-M	3/18/2015 14:23	1.7	20.4	0
AMVP-10-D	3/18/2015 14:26	2.8	22.2	0

TABLE 3
Lab and Field Results

Probe	Date and Time	Field Measurements: Methane CH_4	Field Measurements: Carbon Dioxide CO_2	Field Measurements: Oxygen O_2	Lab Results: Methane CH_4	Lab Results: Carbon Dioxide CO_2	Lab Results: Oxygen O_2
AMVP-1-S	3/16/2015 14:36	84,000	174,000	40,000	82,000	190,000	45,000
AMVP-2-S	3/16/2015 15:17	11,000	123,000	59,000	6,500	140,000	71,000
AMVP-3-S	3/16/2015 14:50	10,000	109,000	90,000	6,100	120,000	100,000
AMVP-4-S	3/16/2015 15:05	6,000	72,000	123,000	190	81,000	140,000
AMVP-5-S	3/16/2015 15:57	5,000	31,000	160,000	51	37,000	180,000
AMVP-6-S	3/16/2015 16:04	5,000	13,000	176,000	54	17,000	200,000
AMVP-7-S	3/16/2015 15:42	5,000	12,000	176,000	18	16,000	200,000
AMVP-8-S	3/16/2015 15:50	10,000	143,000	55,000	4,500	150,000	70,000
AMVP-9-S	3/16/2015 15:28	6,000	74,000	113,000	38	87,000	130,000
AMVP-10-S	3/16/2015 15:35	5,000	38,000	152,000	13	45,000	170,000

Notes:

Concentrations reported as parts per million

TABLE 4
Pneumatic Parameter Estimates Based on Baro-Pneumatic Analysis
A-Mountain Landfill

Location	k_v	k_{cov}	ϕ_1	ϕ_2
AMVP-2	25	10	0.3	0.2
AMVP-7	25	10	0.3	0.2
AMVP-8	25	10	0.3	0.2

Notes:
k_v = *Vertical gas permeability (darcies)*
k_{cov} = *Cover gas permeability (darcies)*
ϕ_1 = *Gas porosity (refuse)*
ϕ_2 = *Gas porosity (cover)*

TABLE 5
Surface Soil Analytical Results
A-Mountain Landfill

Sender ID	IAS Lab No.	*Water Holding Capacity Moisture %			**Organic Matter %	***Bulk Density		pH	Mineralization (mg/kg)												Computed % Sodium (ESP)	Salinity (dS/m)	Free Lime Level
		1/3 Bar	15 Bar	Field Capacity		g/cc	lb/cu. Yd.		Ca	Mg	Na	Potash	Fe	Zn	Mn	Cu	NO_3-N	P	B	S			
AMVP-1	428	20	9	10.9	3.2	1.16	1947	8.8	5,900	530	230	280	11	3.1	4.6	3.7	13	6.6	0.17	3.9	2.8	0.8	High
AMVP-3	429	14.4	6.8	7.6	3.3	1.24	2095	7.7	5,600	470	440	320	12	7.3	9.7	12	3.1	9.9	0.65	180	5.5	7.2	High
AMVP-4	430	13.3	6.8	6.5	1.9	1.32	2220	8.6	5,800	280	230	190	4.4	2.4	3.4	2.7	220	5.2	0.33	8.9	3	6	High
AMVP-2	431	14.3	7.2	7.1	1.8	1.23	2073	8.4	5,700	300	230	130	3.3	2.7	3.7	1.2	3.5	2.6	0.81	83	3.1	1.8	High
AMVP-9	432	16.3	7.9	8.4	2.2	1.23	2065	8.3	6,000	300	230	240	5.6	2.7	3.2	2.7	12	10	0.38	93	2.9	1.5	High
AMVP-10	433	22	9.8	12.2	2.8	1.2	2023	8.3	6,000	670	870	280	4.1	1.6	4.7	3	70	3.9	0.76	570	9.4	8.2	High
AMVP-7	434	17.6	8.4	9.2	2.5	1.22	2058	8.6	5,600	410	400	260	16	2.7	6.6	5.8	10	8.6	0.5	61	5.1	2.1	High
AMVP-8	435	16.3	7.3	8.9	2.7	1.23	2072	7.8	5,600	440	540	460	5.5	8	9.5	4.3	2.5	12	0.6	140	6.7	8	High
AMVP-5	436	16.3	7.6	8.7	3	1.23	2071	8.6	5,600	400	230	250	7	8.2	3.9	4.8	17	6.9	0.33	9	3	0.9	High
AMVP-6	437	18.9	8.9	10.1	3	1.18	1982	7.5	5,200	420	270	230	29	1.9	15	6.2	200	11	0.4	230	3.8	5.8	High

Notes:
**Analysis modified ASTM D3152 and ASTM D2325*
***AASHTO:T267-86*
****The Nature and Properties of Soils Brady , Nyle. 8th Ed. Ch.3.7 p. 50-51*

TABLE 6
Surface Soil Fertility Recommendations
A-Mountain Landfill

Sender ID	Crop	Amendments (lb/1000 ft²)											Leaching of Excess Salts[i]
		Nitrogen N[a]	Phosphate P2O5[b]	Potas[h] K2O	Magnesium Mg[c]	Sulfur S	Iron Fe[d]	Zinc Zn[e]	Manganese Mn[f]	Copper Cu	Boron B[g]	Elemental Sulfur[h]	
AMVP-1	Landscape	1	2	-	-	-	-	0.05	-	-	0.02	20	-
AMVP-3	Landscape	2.5	2	-	-	-	-	0.1	0.1	-	0.02	-	Yes
AMVP-4	Landscape	-	2	-	0.5	-	-	0.05	-	-	0.02	15	Yes
AMVP-2	Landscape	2.5	2.5	-	-	-	0.1	-	-	-	0.02	10	-
AMVP-9	Landscape	1	2	-	-	-	-	-	-	-	0.02	10	-
AMVP-10	Landscape	-	2.5	-	-	-	0.1	0.1	-	-	0.02	10	Yes
AMVP-7	Landscape	2	2	-	-	-	-	0.1	-	-	0.02	15	Yes
AMVP-8	Landscape	-	1	-	-	-	0.2	-	-	-	0.02	-	Yes
AMVP-5	Landscape	1	2	-	-	-	0.1	-	0.05	-	0.02	15	-
AMVP-6	Landscape	-	2	-	-	-	-	0.2	-	-	0.02	-	Yes

Notes:

[a] *Broadcast nitrogen and water into soil. Apply the nitrogen after leaching the excess salts out of the root zone.*

[b] *Broadcast phosphate and till into soil where possible.*

[c] *Apply magnesium to narrow the calcium to magnesium ratio. Landscape plants grow best with a calcium to magnesium ratio of 10:1 to 20:1.*

[d] *Apply iron to balance micronutrients. There should be more iron than manganese and zinc available in the soil.*

[e] *Apply zinc to balance micronutrients. There should be more zinc than copper available in the soil. Do no over apply.*

[f] *Apply manganese to balance micronutrients. There should be more manganese available in the soil than zinc and copper.*

[g] *Apply boron by dissolving it in water and then spray it over the soil. If a boron fertilizer cannot be found use 20 Mule Team Borax Natural Laundry Booster. If using Borax, mix 1 tablespoon per 5 gal water. Then apply 2 gal solution per 1000 ft2.*

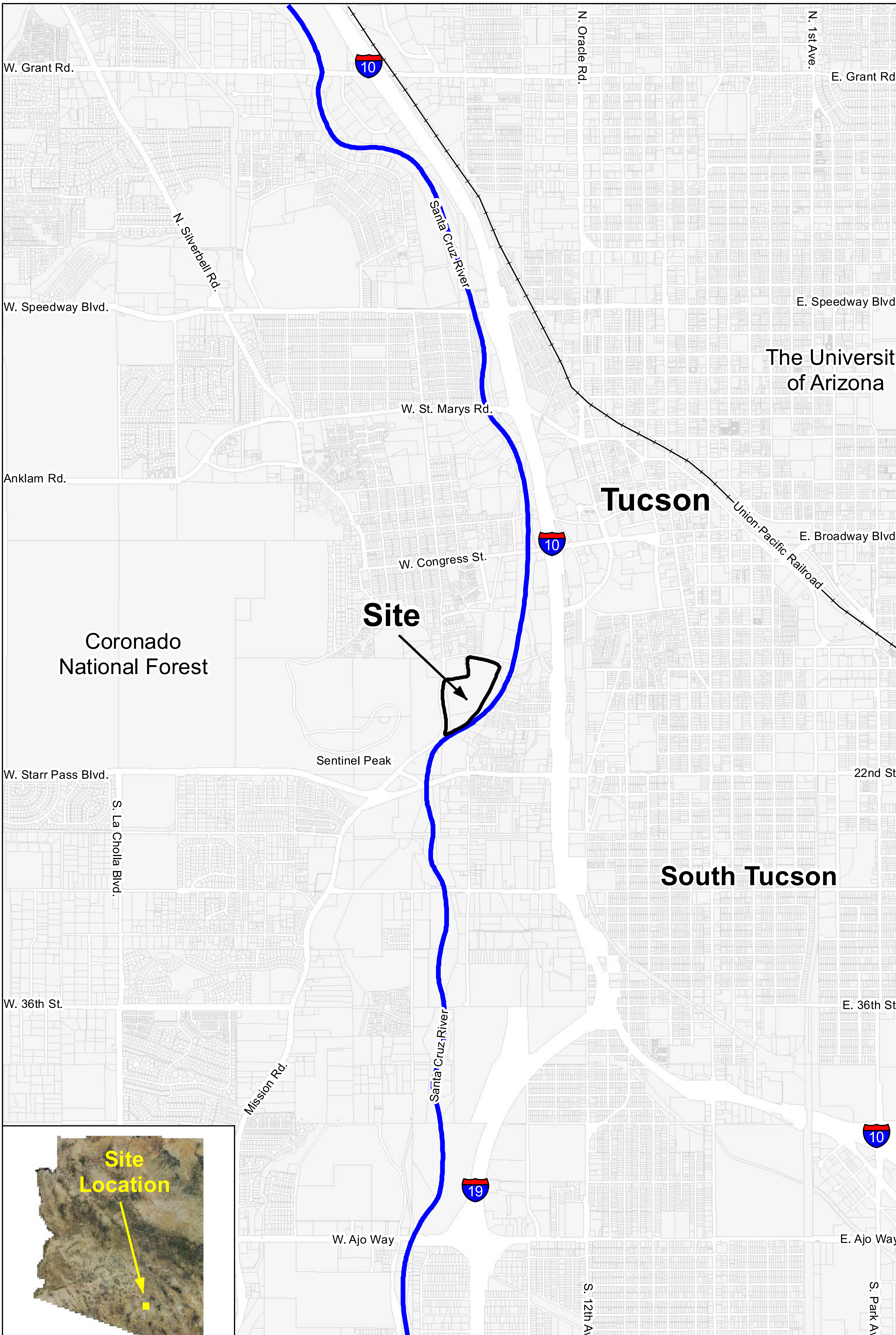
[h] *Till sulfur into the soil to reduce pH. Disper/sul or SSP are sulfur products that should dissolve and can be used if tilling is not possible.*

[i] *Irrigate with extra water to flush salts from root zone. Landscape plants grow best with sodium below 300 ppm and salinity below 3 dS/m. Leaching will also help reduce the nitrate-nitrogen concentration. Nitrogen values above 80 ppm can cause plant burn.*

lb = pound

ft^2 = feet squared

FIGURES



Spatial Reference: NAD 1983 UTM Zone 12N

0 0.5 1

APPROXIMATE SCALE IN MILES

N

HYDRO GEO CHEM, INC.

SITE LOCATION MAP
A-MOUNTAIN LANDFILL, MAY 2015

Approved	Date	File	Figure
MJB	03/17/15	2014037004G	1

Imagery: Pima County Pictometry, 2012

0 250 500

APPROXIMATE SCALE IN FEET

N

HYDRO GEO CHEM, INC.

NESTED LANDFILL GAS MONITORING PROBES
AND OLDER GAS MONITORING WELLS
A-MOUNTAIN LANDFILL, MAY 2015

Approved	Date	File	Figure
MJB	03/17/15	2014037004G	2

Imagery: Pima County Pictometry, 2012

0 250 500

APPROXIMATE SCALE IN FEET

N

HYDRO GEO CHEM, INC.

METHANE MONITORING RESULTS
NESTED LANDFILL GAS MONITORING PROBES
A-MOUNTAIN LANDFILL, MARCH 18, 2015

Approved	Date	File	Figure
MJB	03/17/15	2014037004G	3

Imagery: Pima County Pictometry, 2012

0 250 500
APPROXIMATE SCALE IN FEET

N

HYDRO GEO CHEM, INC.

CARBON DIOXIDE MONITORING RESULTS
NESTED LANDFILL GAS MONITORING PROBES
A-MOUNTAIN LANDFILL, MARCH 18, 2015

Approved	Date	File	Figure
MJB	03/17/15	2014037005G	4

Imagery: Pima County Pictometry, 2012

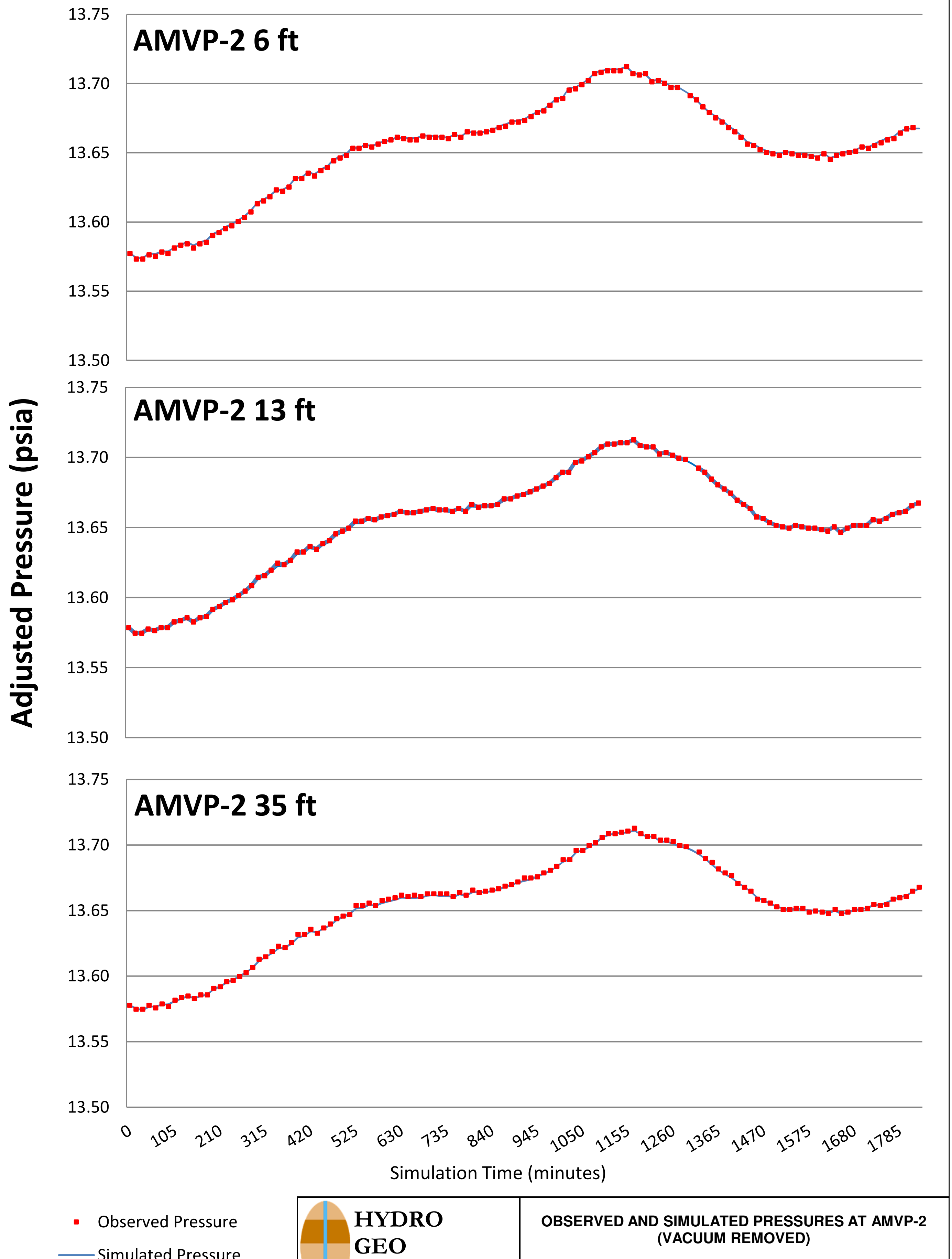
0 250 500
APPROXIMATE SCALE IN FEET

N

HYDRO GEO CHEM, INC.

OXYGEN MONITORING RESULTS
NESTED LANDFILL GAS MONITORING PROBES
A-MOUNTAIN LANDFILL, MARCH 18, 2015

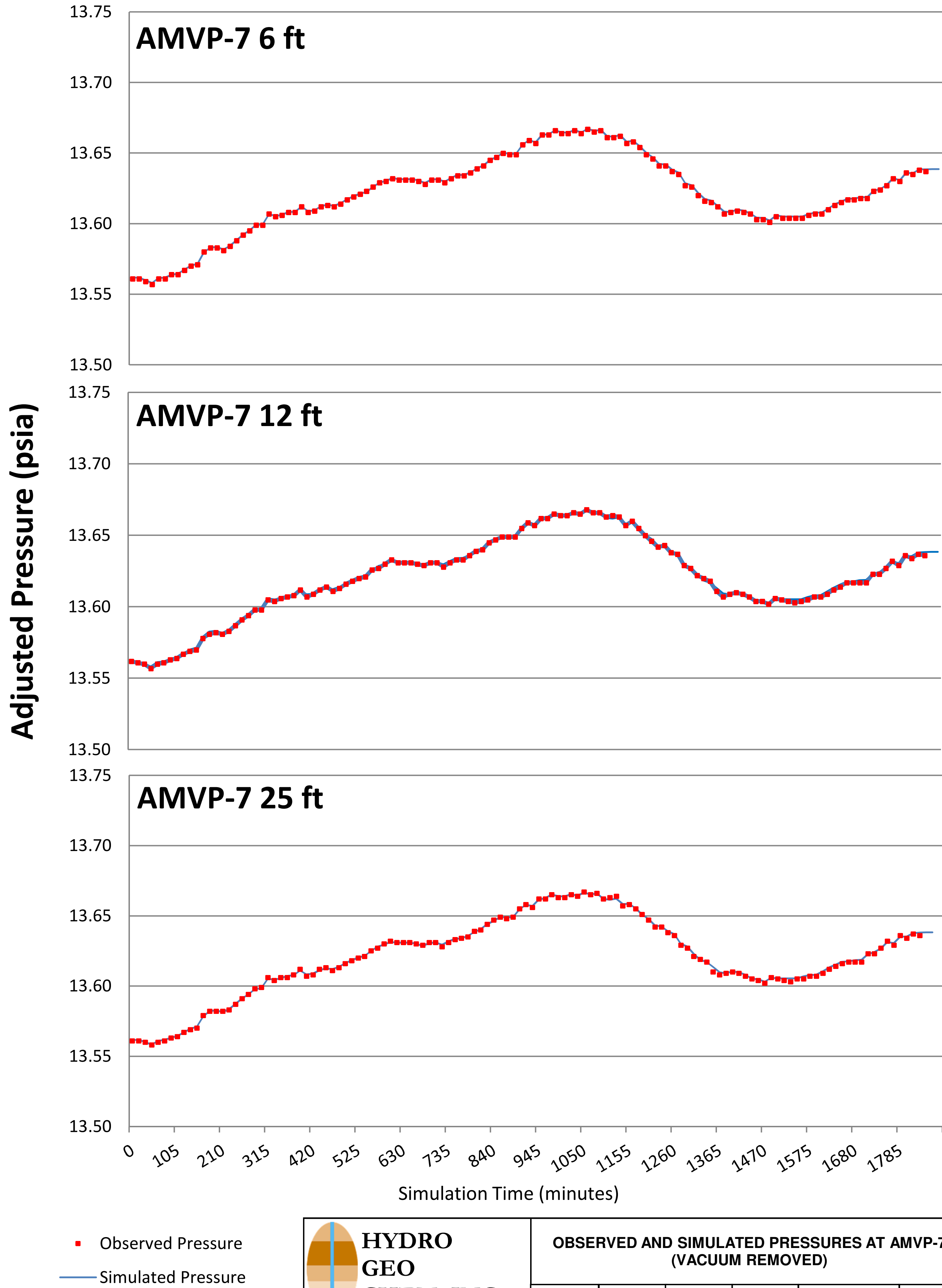
Approved	Date	File	Figure
MJB	03/17/15	2014037006G	5



HYDRO GEO CHEM, INC.

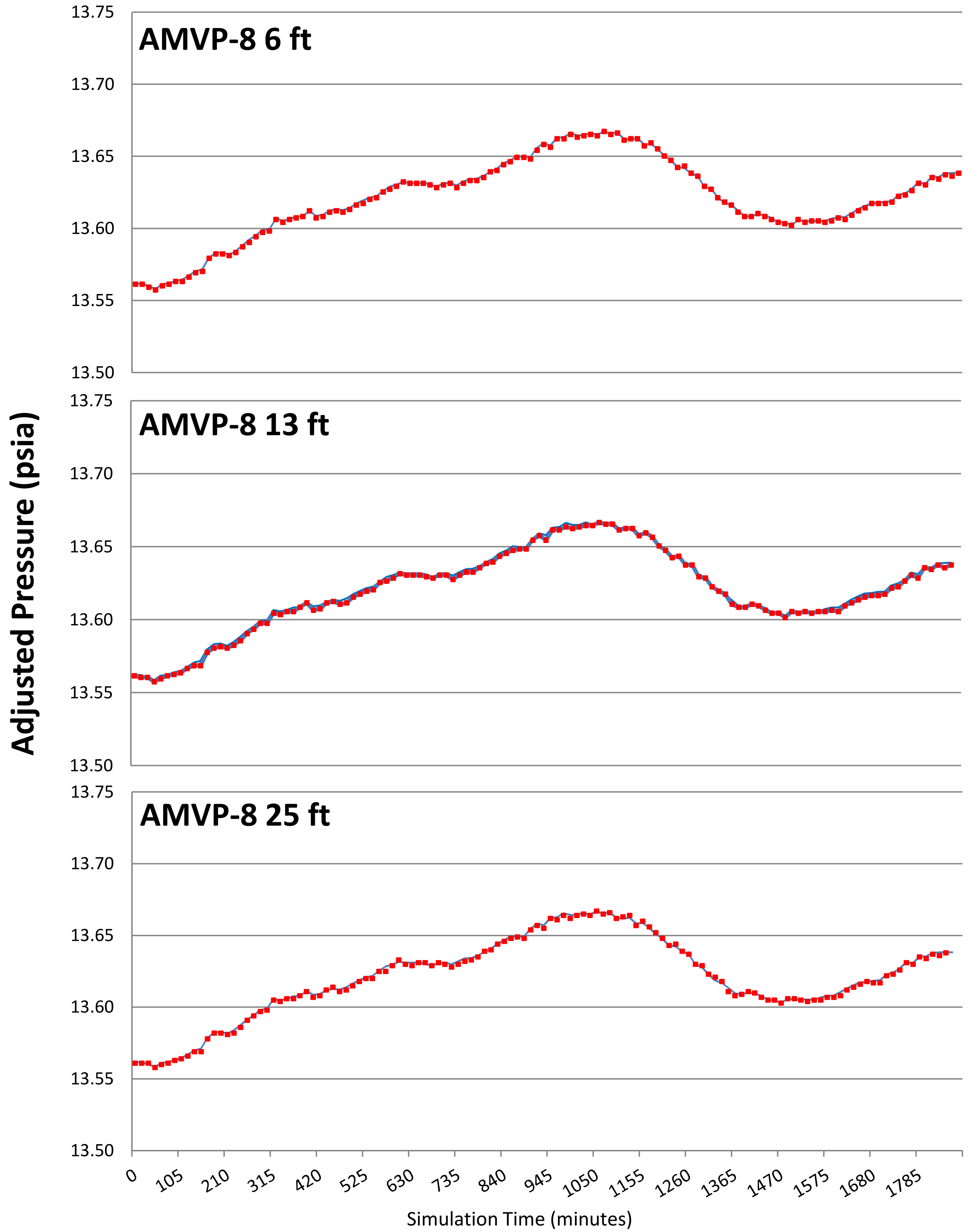
OBSERVED AND SIMULATED PRESSURES AT AMVP-2 (VACUUM REMOVED)

Approved	Date	Author	Date	File Name	Figure
MJB		GEM	5/18/15	201403705E	6



HYDRO GEO CHEM, INC.

OBSERVED AND SIMULATED PRESSURES AT AMVP-7 (VACUUM REMOVED)					
Approved MJB	Date	Author GEM	Date 5/18/15	File Name 201403705E	Figure 7



HYDRO GEO CHEM, INC.

OBSERVED AND SIMULATED PRESSURES AT AMVP-8 (VACUUM REMOVED)

Approved	Date	Author	Date	File Name	Figure
MJB		GEM	5/18/15	201403705E	8