ENGINEERING FOR A BETTER WORLD
FEEZOR ENGINEERING, INC.

BRIDGETON LANDFILL

ASSESMENT OF CORRECTIVE MEASURES REPORT ADDENDUM

BRIDGETON, MISSOURI

Prepared For:

Bridgeton Landfill, LLC

February 2016

Prepared By:
Feezor Engineering, Inc.
406 East Walnut Street
Chatham, Illinois 62629

Engineering for a Better World
FEEZOR
ENGINEERING, INC.

February 19, 2016

Ms. Charlene Fitch
Missouri Department of Natural Resources
Division of Environmental Quality
1730 East Elm Street
Jefferson City, Missouri 65101

RE: Bridgeton Landfill
Assessment of Corrective Measures Report Addendum

Dear Ms. Fitch:

On behalf of Bridgeton Landfill, LLC, Feezor Engineering, Inc. (FEI) is submitting the enclosed Assessment of Corrective Measures (ACM) Report Addendum for the Bridgeton Landfill.

Should you have any questions or comment, please contact Mr. Brian Power with the Bridgeton Landfill at 618-410-0157.

Sincerely,

Andrew Wyatt
Residuals Management Team Member

Attachment: Assessment of Corrective Measures Report Addendum

Cc: Erin Fanning - Bridgeton Landfill
Bob Lambrechts and Jessie Merrigan - Lathrop & Gage
Victoria Warren – Republic Services (emailed PDF)

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Project BT-107

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1 INTRODUCTION

On behalf of Bridgeton Landfill, LLC, Feezor Engineering, Inc. (FEI) has prepared this Assessment of Corrective Measures (ACM) Report Addendum for the Bridgeton Landfill.

1.1 Assessment Monitoring Plan

On December 17, 2013, the Bridgeton Landfill submitted an *Assessment Monitoring Plan* (AMP) to the Missouri Department of Natural Resources' (MDNR) Solid Waste Management Program (SWMP). The *AMP* was prepared in response to groundwater impacts that have been identified at upgradient detection monitoring wells PZ-104-SS and PZ-104-SD, which are located along the southeastern side of the South Quarry portion of the landfill. (See the well location map presented in **Figure 1**.) In accordance with Title 10 of the Code of State Regulations (CSR) 80-3.010(11)(C)6.C, the *AMP* outlined a groundwater assessment monitoring program to characterize the nature and extent of the impacts.

In an April 1, 2013 email, Ms. Connie Rozycki with the SWMP had instructed the facility to begin assessment monitoring only after the SWMP's review and approval of an *AMP*. The SWMP approved the *AMP* with modifications in a July 30, 2014 comment letter, and instructed the facility to begin assessment monitoring during the next scheduled quarterly groundwater sampling event in September 2014. In its letter, the SWMP also instructed the facility initiate a ACM in accordance with 10 CSR 80-3.010(12)(A), prior to the more complete characterization of the impacts based on assessment monitoring. The SWMP specified that the ACM was to begin and proceed concurrently with assessment monitoring. The SWMP further directed the facility to submit a report describing the ACM by October 28, 2014 (90 days from the July 30, 2014 letter), in accordance with 10 CSR 80-3.010(12)(A)(1).

1.2 Assessment of Corrective Measures Report

On October 27, 2014, the Bridgeton Landfill submitted the *ACM Report* to the SWMP. The report evaluated then-current groundwater conditions and discussed interim corrective measures. Significant interim corrective measures had been implemented beginning in mid-2013 in order to address the impacts at wells PZ-104-SS and -SD through source control. As the *ACM Report* described, these and similar measures would continue to be implemented during assessment monitoring. These measures had been and would continue to be focused on the eastern side of the South Quarry (Quarry Quad 3), in the general vicinity of the PZ-104-SS and -SD wells. As noted in the *ACM Report*, the impacts appeared to be associated in part with the subsurface reaction (SSR) that had been identified in the South Quarry, given the proximity of the impacts to the SSR in time and location.

As described in the *ACM Report*, an ACM is typically initiated after an assessment monitoring period in which the nature and extent of groundwater impacts have been investigated. This enables the final corrective measure options to be designed such that they specifically target the constituents and areas associated with the characterized groundwater impact.

Given that the first assessment monitoring event was performed in September 2014, the *ACM Report* proposed that interim corrective measures continue and that the evaluation of the final corrective measures options specified by 10 CSR 80-3.010(12)(A)3 be deferred until after the submission of the facility's first *Annual Assessment Monitoring Report* (AAMR). This deferment was intended to provide adequate time to conduct up to four assessment monitoring events, which would in turn permit a more complete characterization of the nature and extent of groundwater impacts at PZ-104-SS and -SD. The results of these assessment monitoring events could also be utilized to evaluate the effects of the significant interim corrective measures that had been and would continue to be implemented, and to assess and identify potential additional corrective measures to address any remaining groundwater impacts. The *ACM Report* proposed that an ACM Report Addendum be submitted following the first *AAMR* in order to address these components of the ACM.

1.3 Interim Corrective Measures

During assessment monitoring, in accordance with the *ACM Report*, the facility continued to implement aggressive interim corrective measures in order to mitigate leachate and/or landfill gas sources that might potentially be contributing to the groundwater impacts. The interim corrective measures were implemented beginning in mid-2013 and to date have included:

- August 2013: A multi-layer EVOH (ethyl vinyl alcohol) geomembrane cap was installed over the South Quarry. The primary purpose of this cap is to mitigate odors, but it also acts to minimize infiltration and leachate generation.
- September 2013: A Blackhawk reciprocating piston pump was installed in leachate collection sump LCS-3D to improve leachate extraction at this point.
- December 2013: Completed the installation of the Eastern Lift Station to handle liquids in the eastern side of the South Quarry. These improvement reduced backpressure on the leachate management system and enabled it to operate more efficiently.
- December 2013: The new 4-in. × 8-in. leachate collection system forcemain was brought on line.

- January 2014: The new 4-in. × 8-in. forcemain for the Eastern Lift Station was brought on line.
- February 2014: The Blackhawk pump at LCS-3D was replaced with a progressive cavity pump (PCP) to further improve leachate extraction at this point.
- May 2014: Construction was completed on 6-in. × 10-in. perimeter forcemain and associated lateral piping designed to convey all South Quarry liquids to the facility's treatment facility.
- June 2014: A grit chamber was installed above the Eastern Lift Station in order to further segregate solids from the leachate collection system and influent in the eastern side of the South Quarry.
- October 2014: Condensate trap CT-18 was installed on the crest of the South Quarry in order to increase condensate collection for the main landfill gas headers and improve available vacuum.
- October 2014: Construction was completed on South Quarry stormwater management improvements, including:
    - An EVOH geomembrane liner was installed in the eastern stormwater ditch.
    - Maintenance was completed on eastern stormwater ditch infrastructure, including improved pipe boots through the EVOH liner.
- December 2015: Installation was completed on two additional landfill gas extraction wells in the eastern side of the South Quarry (GEW-150 and GW-152).
- January 2015: Installation was completed on four additional landfill gas extraction wells in the eastern side of the South Quarry (GW-143, GW-144, GW-145, and GW-156).
- August 2015: Condensate trap CT-30 was installed near the former East Flare area in order to increase condensation collection and improve available vacuum in the eastern side of the South Quarry.
- September 2015: The Eastern Fill project was completed to fill in an area in the eastern side of the South Quarry in which notable settling had occurred. This filling included the raising of gas management infrastructure to increase condensate collection. The filling also increased the effective thickness of the cap, thereby minimizing infiltration and leachate generation.
- September 2015: (Approximate) Phase C of the 18-in. eastern perimeter landfill gas header was installed. This improvement provided the facility with the ability to provide additional vacuum and thereby enhance gas extraction.

- December 2015: Installation was completed on two additional landfill gas extraction wells and associated pumping systems in the eastern side of the South Quarry (GW-157 and GW-158).
- December 2015: Condensate traps CT-31 (replacing CT-1) and CT-32 (replacing CT-2) and a new landfill gas header lateral system from CT-31 to CT-32 to CT-30 were installed in order to increase condensate collection and improved available vacuum along the northern and eastern side of the South Quarry.
- December 2015: (Approximate) Phase D of the 18-in. eastern perimeter landfill gas header was installed.

1.4 Annual Assessment Monitoring Report

Assessment monitoring events were performed at the Bridgeton Landfill on a quarterly basis in September 2014, November 2014, February 2015, and May 2015. In accordance with the *AMP* and the SWMP's July 30, 2014 comments, the facility submitted the *2015 AAMR* to the SWMP on August 28, 2015. The *AAMR* summarized the first four quarters of assessment monitoring results, compared the results to the established groundwater protection standards (GWPSs) and background concentrations, and provided an updated evaluation of the concentrations, extents, and migration rates (where applicable) of the assessment constituents.

The facility submitted a *2015 AAMR Addendum* to the SWMP on November 24, 2015. The *Addendum* evaluated the results of background sampling conducted at the facility in November 2014, February 2015, May 2015, and August 2015, and utilized the results to develop background concentrations and updated GWPSs for select inorganic constituents. The *Addendum* also provided an updated evaluation of the concentrations, extents, and migration rates (where applicable) of inorganic assessment constituents based on any exceedances of the newly established GWPSs.

Given that four quarters of assessment monitoring and background monitoring had been completed as of August 2015, the *2015 AAMR Addendum* recommended that the facility prepare and submit the ACM Report Addendum previously proposed in the October 2014 *ACM Report*. Accordingly, the facility has prepared this ACM Report Addendum in order to supplement the *ACM Report* and fulfill the requirements specified in 10 CSR 80-3.010(12)(A).

2 ASSESSMENT MONITORING RESULTS

As noted in **Section 1** above, the ACM addressed in this report was initiated in response to groundwater impacts that have been identified at upgradient detection monitoring wells PZ-104-SS and PZ-104-SD. The assessment monitoring program implemented in September 2014 was designed to characterize the nature and extent of these impacts. This section summarizes the results of the assessment monitoring to date.

In accordance with the *AMP*, assessment monitoring at the Bridgeton Landfill includes detection monitoring wells PZ-104-SS and -SD, piezometer PZ-104-KS, and the six investigative monitoring wells installed in the vicinity of PZ-104-SS and -SD in November 2013: PZ-209-SS, PZ-209-SD, PZ-210-SS, PZ-210-SD, PZ-211-SS, and PZ-211-SD. (See **Figure 1**.) These six wells were installed by the facility while the SWMP's approval to submit the *AMP* was pending, in order to assist in the characterization of the nature and extent of the groundwater impacts, and for eventual incorporation into the assessment monitoring program. After the SWMP approved the *AMP* in July 2014, these six wells were incorporated into the assessment monitoring program.

Assessment monitoring was conducted quarterly at the facility between September 2014 and May 2015. These results of these quarterly monitoring events were originally described and evaluated in detail the *2015 AAMR* and are summarized in this section. Following the fourth quarterly assessment event in May 2015, the facility reverted to semi-annual assessment monitoring, in accordance with 10 CSR 80-3.010(11)(C)6.I(III). This section also summarizes the results of the semi-annual assessment event conducted in November 2015, updating the conclusions of the *2015 AAMR* where applicable.

2.1 Assessment Wells and Constituents

As noted above, the following nine groundwater monitoring constitute the facility's assessment wells, and have been sampled as a part of the assessment monitoring program beginning in September 2014:

- PZ-104-SS
- PZ-104-SD
- PZ-104-KS
- PZ-209-SS
- PZ-209-SD
- PZ-210-SS
- PZ-210-SD
- PZ-211-SS
- PZ-211-SD

The locations of the facility's assessment monitoring wells are illustrated on **Figure 1**.

The facility's assessment monitoring constituent list includes 32 constituents. Fifteen of these constituents were specified based on groundwater detection monitoring results at PZ-104-SS and -SD from the May 2012, November 2012, and April 2013 detection monitoring events:

- Arsenic, Total
- Barium, Total
- Chromium, Total

- Cobalt, Total
- Nickel, Total
- Vanadium, Total
- 1,2-Dichloroethane
- 4-Methyl-2-pentanone
- Acetone
- Benzene
- Ethylbenzene
- Methyl Ethyl Ketone
- p-Dichlorobenzene
- Toluene
- Xylenes, Total

During the first assessment event in September 2014, the assessment wells were sampled for the constituents listed in 10 CSR 80-3 Appendix II (hereafter, App II). Six of the App II constituents that were detected in PZ-104-SS and/or -SD in September 2014 had not previously been detected in May 2012, November 2012, and/or April 2013. These six constituents were thereafter added to the assessment constituent list:

- Beryllium, Total
- Cadmium, Total
- Copper, Total
- Lead, Total
- Selenium, Total
- Zinc, Total

Four of the App II constituents that were detected in PZ-104-SS and/or -SD in September 2014 had not previously been analyzed in PZ-104-SS or -SD in May 2012, November 2012, or April 2013. These four constituents were thereafter also added to the assessment constituent list:

- Sulfide
- p-Cresol
- Phenol
- Polychlorinated Biphenyl Aroclor 1221

Seven additional constituents are not included in 10 CSR 80-3, but were specified by the SWMP in its July 30, 2014 letter to be included in the Bridgeton Landfill assessment monitoring program based on the results of SWMP split sampling of PZ-104-SD in November 2012:

- 1,2,4-Trimethylbenzene
- 1,3,5-Trimethylbenzene
- 1-Chlorobutane
- Isopropylbenzene
- Methyl-tert-butyl Ether
- p-Isopropyltoluene
- Tetrahydrofuran

2.2 Constituent Concentrations

In general, concentrations of assessment and SWMP-specified constituents have exhibited reductions or stability between September 2014 and November 2015. The majority of constituents that were not detected in September 2014 remain below laboratory reporting limits (RLs) as of November 2015. The majority of constituents that were detected above laboratory RLs in September 2014 have decreased in concentration, in many cases to below the RLs, as of November 2015.

Five assessment constituents that exhibited exceedances of GWPSs in September 2014 do not exhibit exceedances as of November 2015, indicating improvement with respect to these constituents since the beginning of assessment monitoring.

- Beryllium, Total
- Lead, Total
- Sulfide
- Acetone
- Phenol

In addition, seven other assessment constituents that were detected in September 2014 are not detected as of November 2015:

- Cadmium, Total
- Copper, Total
- Selenium, Total
- Vanadium, Total
- Zinc, Total
- p-Dichlorobenzene
- PCB-1221

Two SWMP-specified constituents that exhibited GWPS exceedances in September 2014 are not detected as of November 2015, indicating improvement with respect to these constituents since the beginning of assessment monitoring.

- 1,2,4-Trimethylbenzene
- p-Isopropyltoluene

As of November 2015, there are only two GWPS exceedances for inorganic constituents at the assessment wells:

- Total arsenic at PZ-104-SD (14.2 ug/L; GWPS 10 ug/L [MCL / Background])
- Total nickel at PZ-104-SD (64.0 ug/L; GWPS 23 ug/L [MCL])

However, total arsenic concentrations at PZ-104-SD have decreased slightly since assessment monitoring began, from 15 ug/L in September 2014 to 14.2 ug/L in November 2015. Total nickel concentrations at PZ-104-SD exhibit a net increase since assessment monitoring began, from 55 ug/L in September 2014 to 64.0 ug/L in November 2015. However, this represents a change is less than the laboratory RL of 10 ug/L.

As of November 2015, the only GWPS exceedances for organic assessment constituents at assessment wells are as follows:

- Benzene at PZ-104-SS (469 ug/L; GWPS 5 ug/L [MCL])
- Benzene at PZ-104-SD (640 ug/L; GWPS 5 ug/L [MCL])
- p-Cresol at PZ-104-SD (67.6 ug/L; GWPS 10 ug/L [RL])

However, benzene concentrations at PZ-104-SS have decreased approximately 69% since assessment monitoring began, from 1,500 ug/L in September 2014 to 469 ug/L as of November 2015. Benzene concentrations at PZ-104-SD have decreased approximately 47% since assessment monitoring began, from 1,200 ug/L in September 2014 to 640 ug/L as of November 2015. p-Cresol concentrations at PZ-104-SD exhibit a net increase since assessment monitoring began, from 21 ug/L in September 2014 to 67.6 ug/L as of November 2015.

As of November 2015, there are only two GWPS exceedances for SWMP-specified constituents at the assessment wells:

- Methyl-tert-butyl Ether at PZ-104-SD (5.4 ug/L; GWPS 5.0 ug/L [RL])
- Tetrahydrofuran at PZ-104-SD (1,560 ug/L; GWPS 1,000 ug/L [RL])

Of the six constituents of concern that exhibit GWPS exceedances as of November 2015, benzene exhibits the highest concentrations (469 ug/L and 640 ug/L) relative to its GWPS (5 ug/L), and is generally regarded as the primary constituent of concern. **Figure 2** presents a graph of benzene concentrations at wells PZ-104-SS and -SD over time. As illustrated on the figure, since benzene was initially detected at these wells in 2012, concentrations of the constituent generally increased to historic maximums in April 2013 (PZ-104-SS) and May 2014 (-SD), but concentrations have since decreased and continue to decrease as of November 2015.

In both wells, concentrations began to decrease prior to the initiation of assessment monitoring. When evaluated from the historical maximum concentrations to the present rather than from the beginning of assessment monitoring, the reductions in benzene concentrations are even more substantial at PZ-104-SS and -SD. Benzene concentrations at PZ-104-SS have decreased approximately 80% since a high of 2,400 ug/L in April 2013, and concentrations at PZ-104-SD have decreased approximately 50% since a high of 1,300 ug/L in May 2014. **Figure 2** indicates the implementation or completion dates of individual interim corrective measures components in relation to benzene concentrations at PZ-104-SS and -SD. As the figure illustrates, the implementation of interim corrective measures appears to correspond in time to the period of decreasing benzene concentrations at PZ-104-SS and -SD. As discussed in **Section 2.5** below, these decreases are believed to be attributable to the aggressive pursuit of interim corrective measures focused on source control, supplemented by natural attenuation processes.

2.3 Constituent Extents

In general, the extents of the exceedances of assessment and SWMP-specified constituents have exhibited contraction or stability since the beginning of assessment monitoring. For the majority of constituents that exhibited GWPS exceedances in September 2014, the extents of their exceeding areas have contracted as of November 2015. There are no constituents that exhibited an overall expansion of their exceeding area extents since the beginning of assessment monitoring.

As noted in **Section 2.1.2** above, five assessment constituents that exhibited areas of GWPS exceedances in September 2014 do not exhibit such exceeding areas as of November 2015:

- Beryllium, Total
- Lead, Total
- Sulfide
- Acetone
- Phenol

Two SWMP-specified constituents that exhibited area of GWPS exceedances in September 2014 do not exhibit such exceeding areas as of November 2015:

- 1,2,4-Trimethylbenzene
- p-Isopropyltoluene

As noted in **Section 2.1.2** above, only four assessment constituents exhibit GWPS exceedances as of November 2015: total arsenic, total nickel, benzene, and p-cresol. The extents of the total arsenic, total nickel, and p-cresol exceedances remain unchanged since the beginning of assessment monitoring. The extent of the benzene exceedances has contracted since the beginning of monitoring, such that as of November 2015, the exceeding area no longer encompasses wells PZ-210-SS and PZ-210-SD. As of November 2015, the exceeding area encompasses only wells PZ-104-SS and PZ-104-SD.

Only two SWMP-specified constituents exhibit GWPS exceedances as of November 2015: methyl-tert-butyl ether and tetrahydrofuran. Methyl-tert-butyl ether was detected above the RL (i.e., a GWPS exceedance) at one well, PZ-104-SD, in November 2015, but has not previously been detected at this well. The November 2015 detection will be confirmed during the next assessment monitoring event. Since the beginning of assessment monitoring, the extent of tetrahydrofuran GWPS exceedances has changed such that it no longer encompasses the St. Louis / Upper Salem Zone in the vicinity of PZ-104-SS.

As discussed in **Section 2.5** below, the contractions and stability observed in the extents of exceeding areas are believed to be attributable to the aggressive pursuit of interim corrective measures focused on source control, supplemented by natural attenuation processes.

2.4 Constituent Migration Rates

The majority of assessment and SWMP-specified constituents either do not exhibit GWPS exceedances as of November 2015, or exhibit exceedance extents that have not changed since the beginning of assessment monitoring. Accordingly, rates of expansion/contraction in exceeding extents ("migration rates") for these constituents cannot be evaluated at the present time due to the absence of such expansion/contraction.

Only two constituents exhibit both:

- Exceedances of GWPSs in both September 2014 and November 2015; and
- An expansion or contraction of the extent of exceedances between September 2014 and November 2015.

These constituents are benzene and tetrahydrofuran. Extent contraction rates for these constituents are summarized in the sub-sections below. In general, because the assessment well area has historically been regarded as hydrogeologically upgradient of the

Bridgeton Landfill, migration of constituents via advective-dispersive transport away from the waste mass and towards the assessment monitoring wells is not believed to be likely.

2.4.1 Benzene

The extent of benzene GWPS exceedances has contracted since the beginning of assessment monitoring, such that it no longer encompasses wells PZ-210-SS and PZ-210-SD. In the St. Louis / Upper Salem Zone, benzene exceedances contracted approximately 206 feet from PZ-210-SS to PZ-104-SS between September 2014 and November 2014, indicating a horizontal extent contraction rate of approximately 3.7 ft/day (206 ft / 55 days) during this period, roughly parallel to the landfill. In the Deep Salem Zone, benzene exceedances contracted approximately 200 feet from PZ-210-SD to PZ-104-SD between the February 2015 and May 2015 sampling events, indicating a horizontal extent contraction rate of approximately 2.0 ft/day (200 ft / 99 days) during this period, roughly parallel to the landfill.

2.4.2 Tetrahydrofuran (SWMP-Specified Constituent)

The extent of tetrahydrofuran GWPS exceedances has contracted since the beginning of assessment monitoring, such that it no longer encompasses well PZ-104-SS. Based on the as-built construction drawings for wells PZ-104-SS and PZ-104-SD, their screened intervals are at elevations of 347.1 - 337.3 ft/msl and 246.9 - 237.1 ft/msl, respectively. The midpoints of the PZ-104-SS and PZ-104-SD screens are therefore at elevations of 342.2 ft/msl and 242.0 ft/msl, respectively, indicating 100.2 ft of vertical separation between the screen midpoints. Tetrahydrofuran exceedances contracted across this distance between the September 2014 and November 2104 sampling events, indicating a vertical extent contraction rate of approximately 1.8 ft/day (100.2 ft / 57 days) during this period.

2.5 Summary

In general, the reductions in concentrations and exceeding area extents that have been observed since the beginning of assessment monitoring are believed to be attributable to the aggressive pursuit of interim corrective measures focused on source control, supplemented by natural attenuation processes. As described in **Section 1**, the facility implemented interim corrective measures beginning in mid-2013 in order to mitigate leachate and landfill gas sources that might potentially be contributing to the groundwater impacts, and the implementation of interim corrective measures has continued during assessment monitoring. The interim corrective measures implemented to date are described in **Section 1.3** and include numerous, significant improvements designed to mitigate leachate and/or landfill gas sources that might potentially be contributing to the groundwater impacts. As illustrated on **Figure 2**, the implementation of interim corrective measures appear to correspond in time to the period of decreasing benzene concentrations at PZ-104-SS and -SD.

3 CONSTIUENTS OF CONCERN AND IMPACTED AREA

As described in the *2015 AAMR* and in **Section 2.1** above, there are six groundwater assessment and SWMP-specified constituents that exhibited GWPS exceedances as of the November 2015 semi-annual assessment monitoring event:

- Arsenic, Total
- Nickel, Total
- Benzene
- Methyl-tert-butyl Ether
- p-Cresol
- Tetrahydrofuran

Of the facility's groundwater assessment monitoring wells, only two exhibited GWPS exceedances for any of the six constituents identified above:

- *PZ-104-SS:* Benzene
- *PZ-104-SD:* Total arsenic, total nickel, benzene, p-cresol, methyl-tert-butyl ether, and tetrahydrofuran

PZ-104-SS and -SD are companion wells in the same well cluster. As of November 2015, the impacted area is therefore limited horizontally to the area immediately surrounding the PZ-104 well cluster, and limited vertically to the St. Louis / Upper Salem Zone (PZ-104-SS) and Deep Salem Zone (PZ-104-SD). (See **Figure 1**.)

The corrective measures options evaluated as a part of the ACM should, if practicable, be designed to address the six constituents of concern identified above within the area encompassing wells PZ-104-SS and -SD.

In general, the risks to human health and the environment presented by the groundwater impacts are anticipated to be relatively low, due to the low likelihood of potential exposure. The spatially limited, hydrogeologically upgradient character of the impacted area mitigates such exposure, given the lack of downgradient receptors relative to the impacted area, the lack of private or municipal use of groundwater from the impacted area, and the extent of downgradient monitoring data confirming the lack of movement of the impact away from the landfill.

4 OBJECTIVES OF ASSESSMENT OF CORRECTIVE MEASURES

The objective of the ACM is to identify a remedy that will mitigate the GWPS exceedances observed at the facility. 10 SR 80-3.010(12)(B)(2) specifies that a selected remedy shall:

- "Be protective of public health and the environment"; a remedy should reduce the current potential risk to human and environmental receptors posed by the groundwater exceedances for the constituents of concern.

- "Attain the groundwater protection standard"; as detailed in the *AMP*, the GWPSs for the constituents of concern are as follows:

    - Arsenic, Total: 10 ug/L [Maximum Contaminant Level, or MCL]
    - Nickel, Total: 10 ug/L [Background Concentration]
    - Benzene: 5 ug/L [MCL)]
    - Methyl-tert-butyl Ether: 5 ug/L [RL]
    - p-Cresol: 10 ug/L [RL]
    - Tetrahydrofuran: 100 ug/L [RL]

- "Control the source(s) of releases so as to reduce or eliminate, the maximum extent practicable, further releases [...] into the environment that may pose a threat to human health or the environment"; if practicable, a remedy should include source control measures that will reduce any potential risk posed by a future release of additional quantities of the identified constituents of concern (or other potential constituents of concern) to groundwater.

- "Comply with standards for management of waste"; if applicable, a remedy should include procedures for handling and disposal of any waste generated from implementation of that remedy.

Remedies are generally evaluated qualitatively with respect to the above criteria, in comparison to current conditions and other remedies.

5 REMEDIAL ALTERNATIVES

Appendix A presents a report prepared for Bridgeton Landfill, LLC by Geosyntec Consultants, entitled *Assessment of Corrective Measures for Monitoring Well PZ-104-SS/SD*. This report describes potential remedial alternatives to address the GWPS exceedances at the Bridgeton Landfill. The report first presents a screening of various remedial technologies to determine their viability for inclusion in the potential alternatives. The report then describes, compares, and contrasts four potential remedial alternatives based on those technologies that were deemed viable.

This section briefly summarizes the four remedial alternatives which are presented in more detail in the report in **Appendix A**.

5.1 Alternative A – Source Control

The source control alternative would entail the implementation of both continued leachate extraction and continued landfill gas extraction, acting in concert with the previously implemented interim corrective measures described in **Section 1.3**. This alternative would constitute a continuation of the aggressive source control measures implemented to date at the facility. Leachate extraction promotes additional hydraulic containment, thereby enhancing the capture of constituents of concern in the vicinity of wells PZ-104-SS and -SD, as well as reducing the potential for leachate to act as a source of groundwater impacts. Landfill gas extraction, including liquid removal and well tuning, enhances the vadose zone within the waste mass, increases gas extraction, and reduces the overall pressure within the landfill, thereby reducing the potential for landfill gas to act as a source of groundwater impacts.

This alternative includes:

- An evaluation of the current instrumentation and pumping at leachate collection sumps LCS-3C and LCS-3D, which are in the vicinity of PZ-104-SS and -SD, including the potential implementation of level-control pumping;

- The potential installation of an additional leachate extraction well within the waste mass in the vicinity of PZ-104-SS and -SD, if needed; and

- Continued liquid removal from the landfill gas extraction wells in the vicinity of PZ-104-SS and -SD, including the potential installation of additional liquid removal pumps as needed. This liquid removal would be combined with the application of vacuum at the gas extraction wells, providing continued reduction and control of the source.

The source control alternative would also include groundwater monitoring to evaluate remedial progress and track the effects of individual adjustments to the leachate extraction and landfill gas extraction systems.

Alternative A is described in more detail in Section 2.2.1 of the report in **Appendix A**.

5.2 Alternative B – In Situ Sorption

The in situ sorption alternative entails the application of a commercial product to the groundwater aquifer in order limit or halt the movement of some constituents of concern. Application of such a sorbent—e.g., PlumeStop® activated carbon—would be achieved through a one-time injection of the product slurry into the aquifer via a series of 52 wells (26 pairs) installed between the facility boundary and the PZ-104-SS and -SD monitoring wells. This alternative would immobilize the organic constituents of concern such as benzene, but would not remove or treat those constituents. In addition, this alternative would not affect the inorganic constituents of concern. The in situ sorption alternative would also include groundwater monitoring to evaluate remedial progress as in Alternative A.

Alternative B is described in more detail in Section 2.2.2 of the report in **Appendix A**.

5.3 Alternative C – Aerobic Bioremediation

The aerobic bioremediation alternative entails the amendment of the groundwater aquifer with oxygen in order to enhance the degradation of some constituents of concern by naturally-occurring aerobic microbes. This would be achieved through continual injection of oxygenated water into the aquifer via a series of 26 wells (13 pairs) installed between the facility boundary and the PZ-104-SS and –SD monitoring wells. This alternative would affect benzene and potentially p-cresol, but would not affect other constituents of concern. The aerobic bioremediation alternative would also include groundwater monitoring to evaluate remedial progress as in Alternative A.

Alternative C is described in more detail in Section 2.2.3 of the report in **Appendix A**.

5.4 Alternative D – In Situ Chemical Oxidation

The in situ chemical oxidation (ISCO) alternative entails the amendment of the groundwater aquifer with an oxidant in order to enhance the degradation of some constituents of concern by chemical oxidation processes. This would be achieved through multiple, discrete injections of a commercial oxidant and catalyst—e.g., persulfate with chelated iron—via a series of 26 wells (13 pairs) installed between the facility boundary and the PZ-104-SS and -SD monitoring wells. This alternative assumes three discrete applications of the oxidant. This alternative would affect benzene and potentially other constituents, but may not affect all constituents of concern. The ISCO alternative would also include groundwater monitoring to evaluate remedial progress as in Alternative A.

Alternative D is described in more detail in Section 2.2.4 of the report in **Appendix A**.

6 ANALYSIS OF REMEDIAL ALTERNATIVES

This section presents a comparative, qualitative analysis of the remedial alternatives presented in **Section 5** above. The analysis is intended to present sufficient information such that a final remedy can be proposed for selection. In completing this portion of the CMA, each remedial alternative is evaluated against the criteria described in 10 CSR 80-3.010(12)(A)3.

As noted in **Section 4**, this analysis reviews the relative ability of each remedial alternative to meet the objectives specified in 10 CSR 80-3.010(12)(A)2:

- Will the alternative provide adequate protection to human health and the environment?
- Will the alternative provide for compliance with GWPSs?
- Will the alternative provide source control?
- Will wastes be managed appropriately to comply with applicable standards?

The judgment regarding the ability of the remedial alternatives to respond to these questions affirmatively is largely qualitative, and the discussions pertaining to the noted questions are likewise qualitative.

As noted in **Section 3**, the risks to human health the environment presented by the groundwater impacts are anticipated to be relatively low, due to the low likelihood of potential exposure by the spatially limited, hydrogeologically upgradient impacted area. In additional to a final remedial alternative, facility may also implement typical engineering and institutional controls that are included as a part of the closure and long-term stewardship of solid waste disposal facilities. Examples of potential engineering controls that might be utilized include capping, fencing, and signage. Examples of potential institutional controls that might be utilized include easements, restrictive covenants, zoning, and deed notices. Such controls would act to further reduce the likelihood of potential exposure.

6.1 Alternative A –Source Control

This section evaluates the use of source control measures to address the identified groundwater impacts at the facility.

6.1.1 Long- and Short-Term Effectiveness and Protectiveness

The components included in Alternative A are proven, standard methods for mitigating groundwater impacts through source control. Moreover, as described in **Section 2**, the reductions in concentrations and extents that have occurred to date are believed to be attributable to the aggressive pursuit of interim corrective measures focused on source control. For example, benzene concentrations at PZ-104-SS have decreased 80%, from

2,400 ug/L in April 2013 to 469 ug/L in November 2015. Benzene concentrations at PZ-104-SD have decreased 50%, from 1,300 ug/L in May 2014 to 640 ug/L in November 2015. Accordingly, it is anticipated that Alternative A, which constitutes a continuation and potential enhancement of such measures, would act to reduce existing risks by reducing concentrations of constituents of concern currently present in groundwater. Although it is challenging to estimate the effectiveness of any individual source control measure in reducing risks, Alternative A is advantageous in that its components would address both leachate- and gas-related potential sources of groundwater impacts, as well as promote hydraulic capture of impacted groundwater. [10 CSR 80-3.010(12)(A)3.A(I)] Given that it entails source control, Alternative A also has the potential to reduce residual risks associated with future impacts to groundwater. Geosyntec estimates Alternative A's overall effectiveness would be "Excellent" and its likelihood of success would be "High" (see **Appendix A**). [10 CSR 80-3.010(12)(A)3.A(II)]

Alternative A would require a minor increase in the long-term management associated with leachate management and landfill gas management, in that any upgraded or replaced infrastructure components would require monitoring, operation, and maintenance. Given that Alternative A primarily utilizes the facility's existing leachate and landfill gas management infrastructure, however, most of the long-term management requirements associated with the alternative are already applicable. Alternative A would otherwise only require the long-term management which is already associated with the facility's ongoing groundwater monitoring programs. [10 CSR 80-3.010(12)(A)3.A(III)]

Alternative A would not pose a substantial potential short-term risk to the community, workers, or the environment. The improvement of pumping and instrumentation at leachate collection sumps and the installation of liquid removal pumps in gas extraction wells would not require significant construction activities, and would therefore pose minimal risks. Construction activities associated with the drilling and installation of a new leachate extraction well—should such a well be needed—could have some moderate potential for such risks, due to the requisite drilling through landfill waste. However, similar drilling has been safely completed at the facility on multiple historical occasions. Such activities would proceed according to approved work plans that incorporate appropriate health, safety, and environmental measures. Geosyntec estimates that Alternative A's safety concerns would be "Low" (see **Appendix A**). [10 CSR 80-3.010(12)(A)3.A(IV)]

Likewise, Alternative A would not pose a substantial potential for the exposure of humans and environmental receptors to remaining wastes. Construction activities associated with the drilling and installation of a new leachate extraction well—should such a well be needed—could have some potential for waste exposure, due to the requisite drilling through landfill waste. However, similar drilling has been completed at the facility on multiple historical occasions without substantially exposing humans or environmental receptors to wastes. Drilling and other construction activities would proceed according to approved work plans that incorporate measures to reduce exposure of the community, workers, and the environment to waste. During construction activities, the facility and is contractors would comply with standards for management of wastes as specified in 10 CSR 80-3.010(12)(C)4. The approved work plans would include procedures for characterization, containment, and disposal of any waste produced during construction activities. [10 CSR 80-3.010(12)(A)3.A(VI)]

Aside from source control, Alternative A would incorporate typical engineering and institutional controls for the impacted area that are included as a part of the closure and long-term stewardship of solid waste disposal facilities. See this section's preface, above, for examples. Alternative A does not fundamentally change the facility's leachate, gas, or groundwater infrastructure, as it is limited to potential upgrades to existing system components and the installation of a single leachate extraction well. Accordingly, the facility's other engineering and institutional controls would likely exhibit long-term reliability comparable to that which is exhibited under existing conditions. [10 CSR 80-3.010(12)(A)3.A(VII)]

The time until Alternative A would result in full remediation (i.e., reduction of constituent of concern concentrations to below the GWPSs) would depend on the effectiveness of the source control measures. Geosyntec estimates that Alternative A would require one to five years to achieve remediation, following immediate implementation (see **Appendix A**). [10 CSR 80-3.010(12)(A)3.A(V)]

As with any remedy, Alternative A could potentially require replacement if it does not meet its remediation goals on the anticipated timeframe. [10 CSR 80-3.010(12)(A)3.A(VIII)]

6.1.2 Effectiveness in Source Control

Alternative A is a source control remedy. Although it is challenging to estimate the effectiveness of any individual source control measure in reducing groundwater impacts, Alternative A is advantageous in that its components would address both leachate- and gas-related potential sources of groundwater impacts. [10 CSR 80-3.010(12)(A)3.B]

6.1.3 Implementability

Implementation of Alternative A would require nominal on-site construction work for improvements to the pumping and instrumentation at leachate collection sumps and for the installation of liquid removal pumps in gas extraction wells, if needed. Should a new leachate extraction well within the waste mass be needed, the installation of that well would require moderate additional construction work. Geosyntec estimates that Alternative A's ease of implementation would be "Easy" and the time to implement would be immediate (see **Appendix A**). [10 CSR 80-3.010(12)(A)3.C]

6.1.4 Community Concerns

In accordance with 10 CSR 80-3.010(12)(A)4, the results of the ACM described herein would be discussed in a public meeting with interested and affected parties prior to the final selection of a remedy. See **Section 7** below. [10 CSR 80-3.010(12)(A)3.D]

6.2 Alternative B – In Situ Sorption

This section evaluates the use of in situ sorption to address the identified groundwater impacts at the facility.

6.2.1 Long- and Short-Term Effectiveness and Protectiveness

In situ sorption is a proven, standard technology for mitigating existing impacts to groundwater. Sorbents such as PlumeStop® activated carbon have been shown to be effective at limiting or halting the movement of some constituents in groundwater. Accordingly, it is anticipated that Alternative B would act to reduce existing risks by limiting or halting the movement of some constituents of concern currently present in groundwater. Although this alternative would immobilize the organic constituents of concern such as benzene, it would not affect the inorganic constituents of concern. Uncertainties associated with the effectiveness of Alternatives B in reducing existing risks would include: the possibility of desorption of constituents of concern from the sorbent; the relative complexity of the bedrock aquifer system, which would affect the distribution of the sorbent within the system; and the technology's unproven status in the facility's particular bedrock setting. In addition, Geosyntec estimates Alternative B's effectiveness would be "Poor" and its likelihood of success would be "Moderate to Low" (see **Appendix A**). [10 CSR 80-3.010(12)(A)3.A(I)]

Alternative B does not include source control measures. Accordingly, its ability to reduce residual risks associated with the future impacts to groundwater would depend on the previously applied sorbent's capacity to immobilize the constituents of concern associated with a new release. [10 CSR 80-3.010(12)(A)3.A(II)]

Alternative B would require a substantial increase in long-term management due to the maintenance of the 52 injection wells. Although it is anticipated that these wells would be utilized for a one-time application of the sorbent, the wells would nonetheless be maintained in good working order in the event that potential future use is required. As with Alternative A, Alternative B would otherwise only require the long-term management which is already associated with the facility's ongoing groundwater monitoring programs. [10 CSR 80-3.010(12)(A)3.A(III)]

Alternative B could potentially pose a moderate short-term risk to the community, workers, or the environment. The installation of the 52 injection wells would entail a relatively significant quantity of drilling through over 200 ft of complex bedrock conditions. This drilling would be conducted adjacent to the solid waste disposal area. Such activities would proceed according to approved work plans that incorporate appropriate health, safety, and environmental measures. Geosyntec estimates that Alternative B's safety concerns would be "Moderate" (see **Appendix A**). [10 CSR 80-3.010(12)(A)3.A(IV)]

Alternative B would not pose a substantial potential for the exposure of humans or environmental receptors to remaining wastes. Drilling and other construction activities would proceed according to approved work plans that incorporate measures to reduce exposure of community, workers, and the environment to waste. During construction activities, the facility and is contractors would comply with standards for management of wastes as specified in 10 CSR 80-3.010(12)(C)4. The approved work plans would include procedures for characterization, containment, and disposal of any waste produced during construction activities. [10 CSR 80-3.010(12)(A)3.A(VI)]

Aside from in situ sorption, Alternative B would incorporate typical engineering and institutional controls that are included as a part of the closure and long-term stewardship of solid waste disposal facilities. See this section's preface, above, for examples. Although Alternative B would include the installation of 52 injection wells, these wells could potentially be incorporated into the existing groundwater infrastructure with only minor revisions to the facility's other engineering and institutional controls. Accordingly, such controls would likely exhibit long-term reliability comparable to that which is exhibited under existing conditions. [10 CSR 80-3.010(12)(A)3.A(VII)]

The time until Alternative B would result in full remediation (i.e., reduction of constituent of concern concentrations to below the GWPSs) would depend on the effectiveness of the sorbent in controlling constituent movement and on whether an ongoing source is present at the facility. Assuming that it can be applied successfully and that there is not an ongoing source, the sorbent is anticipated to act relatively quickly to slow or halt constituent movement. Geosyntec estimates that Alternative B would require one year (or less) to achieve remediation, following 6 to 12 months for implementation (see **Appendix A**). [10 CSR 80-3.010(12)(A)3.A(V)]

As with any remedy, Alternative B could potentially require replacement if it does not meet its remediation goals on the anticipated timeframe. [10 CSR 80-3.010(12)(A)3.A(VIII)]

6.2.2 Effectiveness in Source Control

Alternative B entails limiting or halting the migration of existing (and potentially future) constituents of concern in groundwater. It does not include source control measures. [10 CSR 80-3.010(12)(A)3.B]

6.2.3 Implementability

Alternative B would require significant on-site construction work to install the 52 injection wells estimated for the application of the sorbent to the groundwater aquifer. Local companies and contractors should be able to complete the majority of the work associated with this alternative, although injection of the sorbent will likely require the participation of the product manufacturer or their contractors. Uncertainties associated with the implementation of Alternative B include: the highly variable permeability of the aquifer bedrock, which would affect injection of the sorbent; and the relative complexity of the aquifer system, which would affect the distribution of the sorbent within the system. Geosyntec estimates that Alternative B's ease of implementation would be "Difficult" and the time to implement would be 6 to 12 months (see **Appendix A**). [10 CSR 80-3.010(12)(A)3.C] [10 CSR 80-3.010(12)(A)3.C]

6.2.4 Community Concerns

In accordance with 10 CSR 80-3.010(12)(A)4, the results of the ACM described herein would be discussed in a public meeting with interested and affected parties prior to the final selection of a remedy. See **Section 7** below. [10 CSR 80-3.010(12)(A)3.D]

6.3 Alternative C – Aerobic Bioremediation

This section evaluates the use of aerobic bioremediation to address the identified groundwater impacts at the facility.

6.3.1 Long- and Short-Term Effectiveness and Protectiveness

In situ bioremediation is a standard, proven technology for the mitigation of existing groundwater impacts. Accordingly, it is anticipated that Alternative C would act to reduce existing risks by reducing the concentrations of some constituents of concern currently present in groundwater. The potential magnitude of such risk reduction would depend in part on the toxicological characteristics and the susceptibility to bioremediation of the individual constituents of concern. This alternative could affect benzene and potentially p-cresol, but would not affect other constituents of concern. Uncertainties associated with the effectiveness of Alternatives C in reducing existing risks would include: the challenge of overcoming existing reducing conditions; the potential for iron precipitation, which could result in well fouling and aquifer clogging; and the non-standard character of the application approach. Geosyntec estimates Alternative C's effectiveness would be "Good" and its likelihood of success would be "Moderate" (see **Appendix A**). [10 CSR 80-3.010(12)(A)3.A(I)]

Alternative C does not include source control measures. Accordingly, its ability to reduce residual risks associated with the future impacts to groundwater would depend on the capacity of the continual enhanced bioremediation to attenuate the constituents of concern associated with a new release. [10 CSR 80-3.010(12)(A)3.A(II)]

Alternative C would require a substantial increase in long-term management due to the monitoring, operation, and maintenance of the 26 oxygenated water injection wells and associated pumping, filtration, aeration and piping infrastructure. As with Alternative A, Alternative C would otherwise only require the long-term management which is already associated with the facility's ongoing groundwater monitoring programs. [10 CSR 80-3.010(12)(A)3.A(III)]

Alternative C could potentially pose a moderate short-term risk to the community, workers, or the environment. The installation of the 26 oxygenated water injection wells would entail a relatively significant quantity of drilling through over 200 ft of complex bedrock conditions. This drilling would be conducted adjacent to the solid waste disposal area. Such activities would proceed according to approved work plans that incorporate appropriate health, safety, and environmental measures.

In addition, the injection of a large volume of water into the aquifer could potentially promote the movement of constituents of concern away from the landfill. Geosyntec estimates that Alternative C's safety concerns would be "Moderate" (see **Appendix A**). [10 CSR 80-3.010(12)(A)3.A(IV)]

Alternative C would not pose a substantial potential for the exposure of humans or environmental receptors to remaining wastes. Drilling and other construction activities would proceed according to approved work plans that incorporate measures to reduce exposure of community, workers, and the environment to waste. During construction activities, the facility and is contractors would comply with standards for management of wastes as specified in 10 CSR 80-3.010(12)(C)4. The approved work plans would include procedures for characterization, containment, and disposal of any waste produced during construction activities. [10 CSR 80-3.010(12)(A)3.A(VI)]

Aside from aerobic bioremediation, Alternative C would incorporate typical engineering and institutional controls that are included as a part of the closure and long-term stewardship of solid waste disposal facilities. See this section's preface, above, for examples. Although Alternative C would include the installation of 26 oxygenated water injection wells and associated pumping, filtration, aeration and piping infrastructure, these components could potentially be incorporated into the existing stormwater and groundwater infrastructure with moderate revisions to the facility's other engineering and institutional controls, such as any needed enhancements to site access control. Such controls would likely exhibit long-term reliability comparable to that which is exhibited under existing conditions. [10 CSR 80-3.010(12)(A)3.A(VII)]

The time until Alternative C would result in full remediation (i.e., reduction of constituent of concern concentrations to below the GWPSs) would depend on the effectiveness of the oxygenated water in enhancing aerobic biodegradation, on the speed of the biodegradation processes, and on whether an ongoing source is present at the facility. Geosyntec estimates that Alternative C would require one to five years to achieve remediation, following 6 to 12 months for implementation (see **Appendix A**). [10 CSR 80-3.010(12)(A)3.A(V)]

As with any remedy, Alternative C could potentially require replacement if it does not meet its remediation goals on the anticipated timeframe. [10 CSR 80-3.010(12)(A)3.A(VIII)]

6.3.2 Effectiveness in Source Control

Alternative C entails the enhanced biodegradation of existing (and potentially future) constituents of concern in groundwater. It does not include source control measures. [10 CSR 80-3.010(12)(A)3.B]

6.3.3 Implementability

Alternative C would require moderate to significant on-site construction work to install the 26 oxygenated water injection wells and the pumping, filtration, aeration and piping infrastructure necessary to transport water from the storm water retention basin to the wells. Local companies and contractors can complete the majority of the work associated with this alternative. Uncertainties associated with the implementation of Alternative C include: the highly variable permeability of the aquifer bedrock, which would affect injection of the oxygenated water; the challenge of overcoming existing reducing conditions; and the potential for iron precipitation, which could result in well fouling and aquifer clogging. Geosyntec estimates that Alternative C's ease of implementation would be "Moderate" and the time to implement would be 6 to 12 months (see **Appendix A**). [10 CSR 80-3.010(12)(A)3.C]

6.3.4 Community Concerns

In accordance with 10 CSR 80-3.010(12)(A)4, the results of the ACM described herein would be discussed in a public meeting with interested and affected parties prior to the final selection of a remedy. See **Section 7** below. [10 CSR 80-3.010(12)(A)3.D]

6.4 Alternative D – In Situ Chemical Oxidation

This section evaluates the use of ISCO to address the identified groundwater impacts at the facility.

6.4.1 Long- and Short-Term Effectiveness and Protectiveness

ISCO is a standard, proven technology for the mitigation of existing groundwater impacts. Accordingly, it is anticipated that Alternative D would act to reduce existing risks by reducing the concentrations of some constituents of concern currently present in groundwater. The potential magnitude of such risk reduction would depend in part on the toxicological characteristics and the susceptibility to chemical oxidation of the individual constituents of concern. This alternative would affect benzene and potentially other constituents, but may not affect all constituents of concern. Uncertainties associated with the effectiveness of Alternative D in reducing existing risks would include: the highly variable permeability of the aquifer bedrock, which would affect injection of the oxidant and catalyst; the relative complexity of the aquifer system, which would affect the distribution of the oxidant and catalyst within the system; the challenge of overcoming existing oxidant demand; and the potential for iron precipitation, which could result in well fouling and aquifer clogging. Geosyntec estimates Alternative D's effectiveness would be "Poor" and its likelihood of success would be "Moderate to Low" (see **Appendix A**). [10 CSR 80-3.010(12)(A)3.A(I)]

Alternative D does not include source control measures. Accordingly, its ability to reduce residual risks associated with the future impacts to groundwater would depend on the capacity of previous or additional chemical oxidant applications to attenuate the constituents of concern associated with a new release. [10 CSR 80-3.010(12)(A)3.A(II)]

Alternative D would require a moderate increase in long-term management due to the operation and maintenance of the 26 oxidant injection wells and associated pumping infrastructure. Although it is assumed that these wells would be utilized for three discrete applications of the oxidant, the wells would nonetheless be maintained in good working order in the event that potential future use is required. As with Alternative A, Alternative D would otherwise only require the long-term management which is already associated with the facility's ongoing groundwater monitoring programs. [10 CSR 80-3.010(12)(A)3.A(III)]

Alternative D could potentially pose a relatively high short-term risk to the community, workers, or the environment. The installation of the 26 oxidant injection wells would entail a relatively significant quantity of drilling through over 200 ft of complex bedrock conditions. This drilling would be conducted adjacent to the solid waste disposal area. The handling of fluids with added oxidant entails safety risks to workers, as well as a risk of environmental release. Construction and injection activities would proceed according to approved work plans that incorporate appropriate health, safety, and environmental measures. In addition, the injection of a large volume of water into the aquifer could potentially promote the movement of constituents of concern away from the landfill. Geosyntec estimates that Alternative D's safety concerns would be "High" (see **Appendix A**). [10 CSR 80-3.010(12)(A)3.A(IV)]

Alternative D would not pose a substantial potential for the exposure of humans or environmental receptors to remaining wastes. Drilling and other construction activities would proceed according to approved work plans that incorporate measures to reduce exposure of community, workers, and the environment to waste. During construction activities, the facility and is contractors would comply with standards for management of wastes as specified in 10 CSR 80-3.010(12)(C)4. The approved work plans would include procedures for characterization, containment, and disposal of any waste produced during construction activities. [10 CSR 80-3.010(12)(A)3.A(VI)]

Aside from ISCO, Alternative D would incorporate typical engineering and institutional controls that are included as a part of the closure and long-term stewardship of solid waste disposal facilities. See this section's preface, above, for examples. Although Alternative D would include the installation of 26 oxidant injection wells and associated pumping infrastructure, these components could potentially be incorporated into the existing groundwater infrastructure with only minor revisions to the facility's engineering and institutional controls. Accordingly, such controls would likely exhibit long-term reliability comparable to that which is exhibited under existing conditions. [10 CSR 80-3.010(12)(A)3.A(VII)]

The time until Alternative D would result in full remediation (i.e., reduction of constituent of concern concentrations to below the GWPSs) would depend on the effectiveness of the injected oxidant in enhancing chemical oxidation and on whether an ongoing source is present at the facility. Geosyntec estimates that Alternative D would require one year (or less) to achieve remediation, following over one year for implementation (see **Appendix A**). [10 CSR 80-3.010(12)(A)3.A(V)]

As with any remedy, Alternative D could potentially require replacement if it does not meet its remediation goals on the anticipated timeframe. [10 CSR 80-3.010(12)(A)3.A(VIII)]

6.4.2 Effectiveness in Source Control

Alternative D entails the enhanced chemical oxidation of existing (and potentially future) constituents of concern in groundwater. It does not include source control measures. [10 CSR 80-3.010(12)(A)3.B]

6.4.3 Implementability

Alternative D would require moderate to significant on-site construction work to install the 26 oxidant injection wells and associated pumping infrastructure. Local companies and contractors can complete the majority of the work associated with this alternative. Uncertainties associated with the implementation of Alternative D include: the highly variable permeability of the aquifer bedrock, which would affect injection of the oxidant and catalyst; the relative complexity of the aquifer system, which would affect the distribution of the oxidant and catalyst within the system; the challenge of overcoming existing oxidant demand; and the potential for iron precipitation, which could result in well fouling and aquifer clogging. Geosyntec estimates that Alternative D's ease of implementation would be "Difficult" and the time to implement would be over one year (see **Appendix A**). [10 CSR 80-3.010(12)(A)3.C]

6.4.4 Community Concerns

In accordance with 10 CSR 80-3.010(12)(A)4, the results of the ACM described herein would be discussed in a public meeting with interested and affected parties prior to the final selection of a remedy. See **Section 7** below. [10 CSR 80-3.010(12)(A)3.D]

7 PROPOSED CORRECTIVE MEASURE

In accordance with 10 CSR 80-3.010(12)(A)4, the results of the ACM described herein will be discussed in a public meeting with interested and affected parties prior to the final selection of a remedial alternative. Following the SWMP's review and approval of this ACM Addendum, consideration of comments (if any) made at the public meeting, and a determination as to the degree to which community concerns will be addressed by corrective measures, the facility will select a remedial alternative that meets the requirements of 10 CSR 80-3.010(12)(B)2:

- Be protective of public health and the environment;
- Attain the GWPSs;
- Control the source(s) of releases so as to reduce or eliminate, to the maximum extent practicable, further releases of constituents detected under assessment monitoring into the environment that may pose a threat to human health or the environment; and
- Comply with standards for management of wastes as specified in 10 CSR 80-3.010(12)(C)(4).

Although the final selection of a remedial alternative will occur after the public meeting, a proposed remedial alternative is presented in this ACM Addendum. The following sections describe the rationale for the proposed remedial alternative.

7.1 Protection of Human Health and the Environment

Implementation of a final remedy to address groundwater impacts at the facility should protect human health and the environment to a greater degree than existing conditions. Alternative A would enhance the current level of protection by reducing the concentrations of constituents of concern in groundwater, while also acting to reduce the potential for further releases by addressing the potential leachate and landfill gas sources of the groundwater impacts. Alternatives C and D would likewise reduce constituent of concern concentrations through enhanced in situ aerobic bioremediation (C) and enhanced in situ chemical oxidation (D). Alternative B would also enhance the current level of protection by slowing or halting the movement of concentrations of concern in groundwater. However, these alternatives (B, C, and D) would not include source control and would therefore not directly address the potential for further releases. Moreover, unlike Alternative A, each of the other alternatives would address only some of the constituents of concern, and the success of those measures would be impacted by the existence of any new or continuing source.

7.2 Attainment of Groundwater Quality Standards

Implementation of a final remedy should attain the GWPS on a reasonable timeframe. Geosyntec estimates that Alternatives A and C would require one to five years to achieve remediation, while Alternatives B and D would require one year or less to achieve remediation. However, the time to implementation should also be considered alongside the time from implementation to remediation. Geosyntec estimates that Alternative A could be implemented immediately, Alternatives B and C in 6 to 12 months, and Alternative D in a year or more. Although Alternative is estimated to require one to five years to achieve remediation, it also can be implemented immediately. (See **Appendix A**.) Based on the reductions noted to date (see **Section 2.2** above), it is anticipated that reductions will continue throughout implementation of Alternative A.

7.3 Source Control

Where practicable, implementation of a final remedy should provide additional source controls to reduce or eliminate future impacts. Alternative A includes source control measures. Moreover, the reductions in concentrations and extents that have occurred to date are believed to be attributable to the aggressive pursuit of interim corrective measures focused on source control. Alternative A constitutes a continuation and potential enhancement of such measures. Alternatives B, C, and D do not include source control measures.

7.4 Compliance with Waste Management Standards

Implementation of a final remedy should include plans to achieve compliance with waste management standards, where applicable. Implementation of Alternatives A, B, C, and D would include compliance with standards for management of wastes as specified in 10 CSR 80-3.010(12)(C)4. Approved work plans associated with Alternatives A, B, C, and D would include procedures for characterization, containment, and disposal of any waste produced during construction activities associated with the remedies.

7.5 Proposed Remedy

It is believed that utilization of source control (Alterative A) would be the most appropriate alternative to meet the remedial objectives. Alternative A presents the following advantages:

- The alternative constitutes a long-term continuation of and potential enhancement of the aggressive source control measures that have already been implemented with demonstrated success. The reductions in groundwater concentrations and extents that have been observed to date are believed to be attributable to these measures.

- The alternative would enhance the level of protection of human health and the environment to a greater degree than other alternatives, by acting aggressively to reduce the potential for further releases.

- The alternative could potentially achieve remediation in one to five years, while also being potentially implemented immediately.

- The alternative would result in only a minor increase in the long-term management associated with the leachate management and landfill gas management systems.

- The alternative would not pose a substantial potential short-term risk to the community, workers, or the environment compared to other alternatives.

- The alternative would partially incorporate the existing leachate management and landfill gas management systems, which are routinely modified by experienced personnel from the facility and its contractors.

7.6 Implementation Schedule

Following the SWMP's approval of this ACM Addendum, the occurrence of the public meeting, and the final selection of a remedial alternative, the facility will submit a Corrective Action Plan (CAP) to the SWMP. It is anticipated that this CAP will be submitted within 90 days of the SWMP's review and approval of this ACM Addendum. The CAP will provide design information and work plans for the implementation of the selected remedial alternative. The CAP will also include a groundwater corrective action monitoring plan (CAMP) for the long-term evaluation of remedial progress.

Consistent with Geosyntec's estimations (see **Appendix A**), it is anticipated that Alternative A can be implemented immediately following MDNR approval of the CAP and the receipt of all other applicable permits and approvals.

8 REFERENCES

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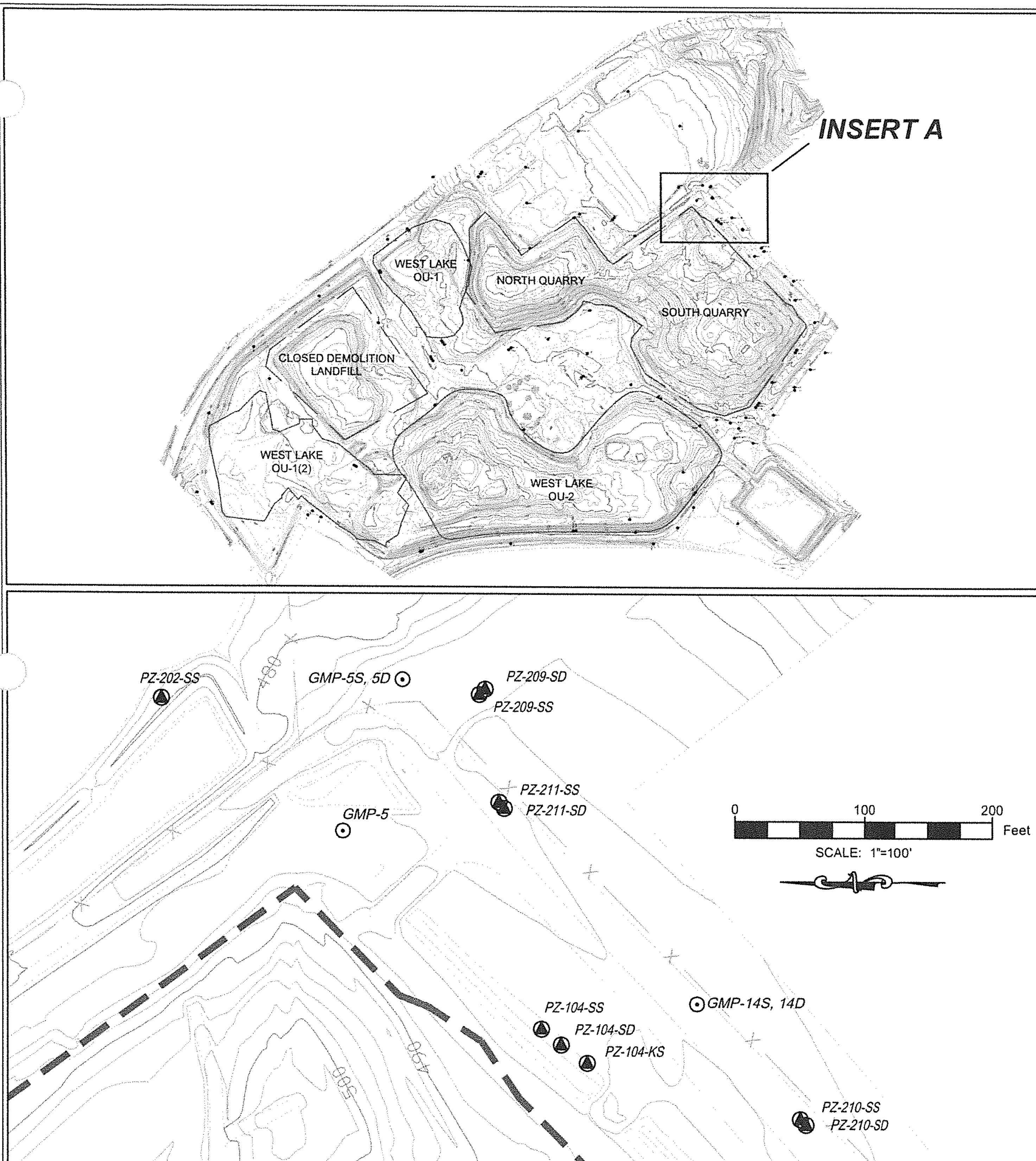
FIGURE 1

ASSESSMENT MONITORING WELLS



INSERT A

LEGEND

- PERMITTED WASTE BOUNDARY
- PERIMETER FENCE
- GROUNDWATER MONITORING WELL
- LANDFILL GAS PROBE

NOTES:

- BASE TOPOGRAPHY IS BASED ON AERIAL SURVEY DATA PROVIDED BY COOPER AERIAL SURVEYS CO.

BRIDGETON LANDFILL, LLC 13570 ST. CHARLES ROCK ROAD BRIDGETON, MISSOURI 63044	BRIDGETON LANDFILL ACM ADDENDUM

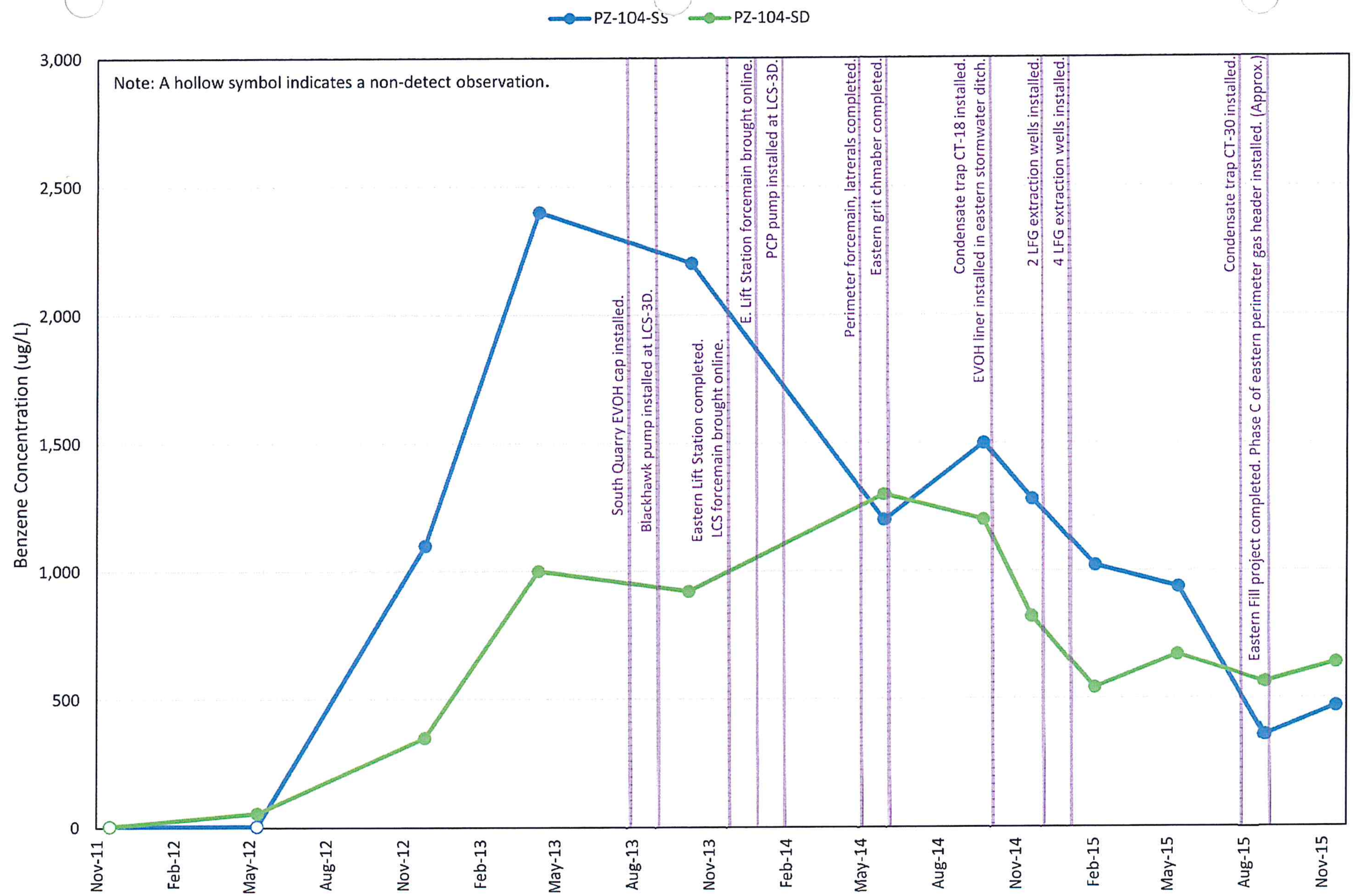
FIGURE 1: ASSESSMENT MONITORING WELLS

PROJECT NUMBER: BT-107	FEBRUARY 2016	DESIGNED BY: AMR	APPROVED BY: AW

Engineering for a Better World
FEEZOR ENGINEERING, INC.

FIGURE 2

BENZENE CONCENTRATIONS IN GROUNDWATER AND INTERIM CORRECTIVE MEASURES TIMELINE



BRIDGETON LANDFILL, LLC 13570 ST. CHARLES ROCK ROAD BRIDGETON, MISSOURI 63044	BRIDGETON LANDFILL ACM ADDENDUM

FIGURE 2: BENZENE CONCENTRATIONS IN GROUNDWATER AND INTERIM CORRECTIVE MEASURES TIMELINE

PROJECT NUMBER: BT-107 | FEBRUARY 2016 | DESIGNED BY: AMR | APPROVED BY: AW

FEEZOR ENGINEERING, INC.
Engineering for a Better World

APPENDIX A

GEOSYNTEC REPORT: ASSESSMENT OF CORRECTIVE MEASURES FOR MONITORING WELL PZ-104-SS/SD

Prepared for:

Bridgeton Landfill, LLC

Assessment of Corrective Measures for Monitoring Well PZ-104-SS/SD

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1. OBJECTIVE

The objective of this assessment of corrective measures (ACM) is to identify a remedy that will mitigate detections of contaminants of concern (COCs) at groundwater monitoring wells PZ-104-SS and PZ-104-SD located adjacent to the south quarry at the Bridgeton Landfill. Constituents listed below exceeded groundwater quality protection standards (GWPS) at these wells in November 2015 and are considered COCs.

PZ-104-SS

Benzene: 469 micrograms/liter µg/L (GWPS = 5 µg/L)

PZ-104-SD

Benzene: 640 µg/L (GWPS = 5 µg/L)
Arsenic, total: 14.2 µg/L (GWPS = 10 µg/L)
Nickel, total: 64.0 µg/L (GWPS = 10 µg/L)
p-Cresol: 67.6 µg/L (GWPS = reporting limit [RL])
Methyl-tert-butyl Ether (MTBE): 5.4 µg/L (GWPS = RL)
Tetrahydrofuran (THF): 1,560 µg/L (GWPS = RL)

Of the COCs detected at PZ-104-SD, the concentration of benzene in groundwater exceeds the GWPS by a greater amount than other COCs. Benzene is also the only COC detected at PZ-104-SS. This ACM considers all site COCs, but because of these factors, this report provides particular consideration of benzene in groundwater at PZ-104-SS and PZ-104-SD during the analysis of remedial alternatives.

Title 10 CSR 80-3.010(12)(B) 2 (the Rule) specifies that the selected remedy shall:

- be protective of the public health and the environment;
- attain the groundwater protection standards as specified pursuant to subparagraph (11)(C)6.E of the Rule;
- control source(s) of releases so as to reduce or eliminate, to the maximum extent practicable, further releases of constituents listed in Appendix II of the Rule into the environment that may pose a threat to human health of the environment; and
- comply with standards for management of wastes as specified in paragraph 12(C)4 of the Rule.

Alternative remedies are evaluated against the above criteria qualitatively and relative to one another using profession judgment and experience. In accordance with subparagraph 12(A)3 of the Rule, this assessment will evaluate the effectiveness (potential performance), reliability, ease of implementation, relative cost, remediation timeframe, institutional requirements, and safety and cross media concerns for each alternative in the context of the above criteria.

2. REMEDIAL ALTERNATIVES

This ACM describes remedial options that have been developed to address COCs in groundwater monitoring wells PZ-104-SS and PZ-104-SD (collectively referred to as PZ-104), a well couplet located on the southeast edge of the south quarry landfill. The goal of this ACM is to rank viable remedies for their expected ability to reduce COC concentrations at PZ-104 and achieve the objectives listed above.

Concentrations of benzene at PZ-104 during the past five years have increased and subsequently decreased, peaking in about 2013/2014. Table 1 presents benzene concentrations at PZ-104-SS and PZ-104-SD since 2008. These data demonstrate an increase in benzene concentrations beginning in 2012. In particular, benzene concentrations increased from non-detectable concentration prior to 2012 to a maximum of 2,400 µg/L at PZ-104-SS in April 2013; the maximum benzene concentration at PZ-104-SD occurred about a year later in May 2014. Since 2013/2014, benzene concentrations at the PZ-wells have been declining; for example, from a high of 2,400 µg/L at PZ-104-SS in April 2013 to a current concentration of 469 µg/L, or an 80% decrease in concentration in about 2.5 years. Similarly, benzene concentrations at PZ-104SD have decreased by approximately 50% in 1.5 years.

Recently, monitoring wells MO 1-SS and MO 1-SD were installed by the Missouri Department of Natural Resources (MDNR) upgradient to the southeast of the PZ-104 wells. Groundwater sampling at this new well couplet revealed non-detectable concentrations of benzene, demonstrating that impacts at PZ-104 wells are limited in extent.

2.1 Technology Screening

The contaminants, geology, and groundwater geochemistry at PZ-104 wells are conducive to some technologies, but incompatible with other technologies. The sections below briefly describe technologies that are considered viable (i.e., screened-in) for the PZ-104 area and technologies that are screened-out.

PZ-104 wells are screened in bedrock and located proximal to the south quarry landfill. Groundwater at PZ-104 wells is reducing and anaerobic; on average, PZ-104-SD contains more than 10 mg/L of dissolved iron whereas PZ-104-SS contains 1 to 3 mg/L of dissolved iron. Technologies that are considered potentially viable for COC remediation at PZ-104 wells are listed below.

- Source Control:

- Hydraulic Control: Leachate extraction from within the landfill is ongoing. Continued pumping and/or adjusting pumping from wells within the landfill is a viable alternative to hydraulically control COC migration at the PZ-104 wells.
- Landfill Gas Control: Benzene has been noted in landfill gas (LFG) and in groundwater at sites where LFG has been known to cause impacts. Also, reducing groundwater conditions (which can be the result of LFG migration) have the potential to mobilize naturally-occurring arsenic and nickel. Landfill gas is currently extracted from the landfill via the existing gas collection and control system (GCCS). Operation of the GCCS may be partially responsible for the decline in benzene concentrations over the past two years.

- In Situ Sorption: Amendments are available to increase the organic carbon concentration of the aquifer to impede organic COC migration via sorption. Given the relatively limited area of the COC plume at PZ-104, this is a viable alternative, although amendment delivery in bedrock is challenging due to high variability of permeability in limestone and dolomite aquifers and the potential for fracture flow in this aquifer. However, sorption is expected to be ineffective for inorganic COCs and potentially less effective for MTBE compared to other organic COCs.

- Aerobic Bioremediation: Benzene readily degrades under aerobic conditions and aerobic biogdegradation has proven effective at other sites. If groundwater geochemistry could be transformed from anaerobic and reducing to aerobic and oxidizing, this technology would be viable. Biodegradation may be less effective for other organic COCs, but creating oxidizing conditions may precipitate arsenic and nickel thereby reducing their mobility in groundwater.

- In Situ Chemical Oxidation (ISCO): Benzene as well as some other COCs can be oxidized by some oxidants such as persulfate, so this technology is viable. However, the effectiveness of ISCO, as with any amendment injection approach, will be contingent on the ability to deliver oxidants to impacted groundwater, which can be difficult in a bedrock aquifer. The effectiveness of ISCO will also depend on natural oxidant demand of the matrix and competing reactions that could occur under the altered geochemical regime, including sufficient oxidant delivery to overcome current reducing conditions. The effectiveness of ISCO for all COCs is unknown. Laboratory testing would be needed to determine which organic COCs can be oxidized and to understand phase changes for the inorganic COCs under strongly oxidizing conditions.

The following are technologies that have been screened-out for the site. Each bullet also provides a brief description of why the technology was screened-out.

- Monitored natural attenuation (MNA): MNA is an alternative whereby groundwater sampling and analysis is performed to observe conditions in groundwater that contribute to the attenuation of COCs under ambient conditions. Natural attenuation processes may be physical such as dilution and dispersion, chemical such as sorption and volatilization, and biological such as aerobic biodegradation. The most convincing evidence of natural attenuation is a decrease in the groundwater concentrations for the COCs over time. Secondary lines of evidence for the efficacy of natural attenuation include data indicative of favorable geochemistry supporting the ongoing attenuation of contaminants. MNA is implemented by performing routine sampling within and around the contaminated area to observe direct attenuation of the contaminants (i.e., changes in concentration) as well as supporting mechanisms for the attenuation of the contaminant such as hydraulic gradients and groundwater geochemistry.

  A number of interim measures have been implemented at the site including measures in the vicinity of the PZ-104 wells. Decreasing COC concentrations at PZ-104 wells coincide with the implementation of these measures, demonstrating their effectiveness and suggesting that they continue. Implementation of a MNA remedy would result in ceasing these interim measures since they would not be part of MNA; this would be ill advised, therefore MNA is screened out as an alternative.

- Thermal Remediation: Thermal technologies are effective for removing benzene from groundwater (by combustion and/or volatilization). Thermal remediation (depending on the temperature) may remove some of the other organic COCs, but will not remove inorganic COCs and may have limited effectiveness for MTBE. Thermal approaches are screened-out for this site given the proximity of the PZ-wells to the landfill waste. Fires are a significant concern for landfills (which are filled with combustible materials); the potential risk of causing a landfill fire makes thermal remediation an unacceptable risk and therefore infeasible for this site.

- Anaerobic Bioremediation: Benzene biodegradation under anaerobic conditions is marginally accepted as a remedial technology, and anaerobic biodegradation of other COCs is not well understood. Research is ongoing at lab-scale to investigate bacteria and proper groundwater conditions that degrade benzene anaerobically, but this research is currently only in the laboratory and has not been demonstrated at field scale. As an unknown and/or unproven technology in the field, anaerobic bioremediation for benzene and other COCs is not considered viable for the site.

- Air Sparging: Benzene volatilizes readily, so air sparging is a viable technology for removing it from groundwater. Air sparging also has the potential to precipitate arsenic and nickel in situ. However, some of the COCs (e.g., MTBE) are less volatile than benzene, so air sparging will not be effective for all COCs. Groundwater at this site also contains dissolved iron. Dissolved iron will precipitate rapidly with the introduction of air and quickly clog air sparge wells and possibly the formation. In addition, air injection at the perimeter of the landfill has a risk of generating greater amounts of landfill gas and/or supporting combustion of landfill material. Potential well and formation clogging from air sparging and risks to landfill operations make this technology impractical for this site.
- Phytoremediation and Excavation: The depth of impacts and matrix (i.e., bedrock) make both of these technologies nonviable.

2.2 Remedial Alternatives Evaluation

Below are conceptual designs for potential remedies (alternatives) for the PZ-104 area of the site that take into consideration viable technologies identified above as well as site-specific limitations. Fundamental mechanisms of COC removal for each alternative are included below along with a brief description of how the alternative might be implemented at the site. Advantages and limitations of the technologies are also discussed. Table 2 provides a relative screening comparison of the technologies based on the criteria in Title 10 CSR 80-3.010(12)(A)3.

All of the alternatives considered below will include a monitoring component to track changes in COC concentrations. For the purpose of costing, monitoring for all remedies is assumed to entail ongoing monitoring at the PZ-104 wells and nearby existing monitoring wells such as PZ-210-SS/SD, PZ-211-SS/SD, and PZ-209-SS/SD on a quarterly frequency for the initial two years and then semiannually for years three through five.

2.2.1 Alternative A: Source Control

Source control for this site is an alternative that combines hydraulic containment by leachate extraction and LFG extraction with monitoring. This alternative is a continuation of and includes possible enhancements to interim corrective measures recently implemented at the site such as improved LFG and leachate removal, and groundwater monitoring. Hydraulic containment is already being performed for the south quarry landfill to capture leachate. Enhancements could entail, if warranted based on future monitoring results, assessment and potential adjustments to the site leachate extraction program as well as ongoing monitoring to track the impact of these adjustments. The goal of adjustment to leachate extraction within the south quarry landfill would be to enhance capture of COCs at PZ-104 wells.

Given that the extent of COC impacts outside the south quarry landfill are limited (i.e., a shorter distance than to the MO 1 well couplet) and general groundwater flow is from MO 1 toward the northwest, hydraulic containment is likely to be able to capture COCs that have migrated to PZ-104 wells. The south quarry landfill already has a leachate extraction system in place which utilizes leachate collection sumps (LCS) and to a lesser extent gas extraction wells (GEW wells), and interim measures that include optimizing the leachate collection system have been beneficial. As a result, continued improvement to hydraulic containment within the PZ-104 area, if warranted based on future monitoring results, may be achievable by adjusting the system that is already operating at the site. Adjustments would be consistent with ongoing interim measures and aim to capture groundwater impacted by COCs at PZ-104 wells and draw it back to the landfill.

LFG extraction is already occurring via the existing GEW wells, including additional GEW wells that have been installed as part of interim corrective measures to increase the density of extraction wells in the area to a level well above the typical extraction well density. The facility will continue to optimize LFG extraction in the south quarry by tuning the well field and lowering liquid levels (as needed) in GEW wells. Along with enhancing capture of groundwater at PZ104-wells, lowering liquid levels is intended to enhance the "vadose zone" in the waste mass, increase gas extraction vacuum, and reduce the overall pressure within the landfill.

For conceptual design and costing, this alternative is conceived to have the components described below.

- Improvements to the instrumentation and pumping for leachate collection sump LCS-3D that would include level-controlled pumping.
    - The level-control system would entail either a small PLC or periodic manual measurements to monitor the hydraulic head in LCS-3D, and compare the levels to changes in the COC concentrations in the PZ-104 wells.

  - The conceptual design of this alternative assumes that the site leachate treatment system will not need any upgrades to accommodate changing extraction from the LCS-3 wells (or other potential leachate extraction points).
  - For costing, one additional leachate collection sump is assumed. The location of, and even the need for, this sump is uncertain, but it is included as a conservative assumption. The new sump would be screened in the landfill and operate similarly to LCS-3D described above. An alternative to installing an additional leachate collection sump is the evaluation and potential rehabilitation of existing sump LCS-3C.

- Improvements to the GEW wells in the vicinity of the PZ-104 area would include additional liquid removal from those wells where liquid levels inhibit optimal extraction of gas. Additional pumps could be installed in wells that do not already have a pump, as needed. The discharge from these pumps would be sent to the on-site leachate treatment system. Reduction of liquid levels in those effected wells may allow them to be adjusted (e.g. application of additional vacuum) for increased gas extraction.

- Monitoring would be performed at PZ-104 wells and nearby monitoring locations as described above to track temporal changes in COC concentrations and groundwater geochemistry, as well as the hydraulic gradient around PZ-104 wells.

The advantage of this alternative is that it relies, to a large extent, on existing infrastructure, which makes it compatible with other operations and maintenance actions being performed at the site and eliminates any delay in implementation. This alternative also is effective for all COCs because it relies on groundwater advection as opposed to in situ chemical or biological reactions, as some of the COCs are not readily mitigated by these reactions. Further, ongoing operational changes to site leachate collection and LFG extraction that are being implemented as interim measures have proven effective, so it is reasonable to expect that the optimization of the existing system can achieve remedial goals. Lastly, this alternative is not expected to alter the south quarry landfill in a way that might contribute to additional environmental or operational problems (i.e., this alternative will "do no harm") since it involves optimization of the currently-effective treatment technology and could be adjusted back to prior conditions if it is found to negatively affect the south quarry.

2.2.2 Alternative B: In Situ Sorption

The mobility of benzene, as well as some other organic COCs, can be reduced by increasing the amount of sorption to aquifer solids for these COCs. Sorption for organic compounds in groundwater occurs when the chemical encounters organic materials that are part of the aquifer matrix (i.e., partitioning from the aqueous to the sorbed phase). Once a chemical sorbs to aquifer solids, it becomes immobile (i.e., aquifer solids do not move) and can degrade. The amount of sorption is a function of the organic carbon fraction of the aquifer matrix as well as characteristics of the organic chemical (e.g., solubility). Aquifers with a higher fraction of organic carbon on solids will sorb more mass than aquifers with a lower fraction of organic carbon. Inorganic chemicals are unlikely to have reduced mobility from sorption to organic carbon in the aquifer matrix, so this technology is not expected to be effective for inorganic COCs.

Commercial products are available that boost the organic carbon concentration for an aquifer matrix. In essence, these materials consist of fine particles of granular activated carbon. The particles are mixed with a carrier fluid to create a slurry that is injected into the aquifer. One such material, PlumeStop® (http://plumestop.com/) is considered a viable alternative for retarding the migration of benzene and other organic COCs[1] in the PZ-104 area. Injecting plume stop in the PZ-104 area is expected to immobilize, to a large extent, organic COCs in bedrock and act as a barrier if they migrate into bedrock in the future. The vendors of PlumeStop® claim that sorbed chemicals on PlumeStop® may degrade, but as mentioned above, anaerobic biodegradation of benzene is unlikely to provide much mass reduction and the pathways for anaerobic biodegradation of other COCs are uncertain. Consequently, this alternative is expected to immobilize organic COCs, but is not expected to remove or treat them and is not expected to immobilize inorganic COCs.

Conceptually, this alternative would entail injecting PlumeStop® into bedrock as a barrier between the PZ-104 wells and the site property line. Bedrock injections would be difficult and require the installation of permanent small-diameter wells. For costing, the conceptual remedy is conceived as a 250-foot long barrier composed of a couplet of 2-inch diameter injection wells every 10 feet (ft), resulting in 26 well couplets. Two wells would be installed in a single boring at each location, with one well screened in the St Louis Formation and one well screened in the Salem Formation; a bentonite seal

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[1] The effectiveness of PlumeStop® is expected to vary among organic COCs based on each compound's affinity to partition onto carbon versus remain in aqueous solution. For example, PlumeStop® is expected to be less effective for MTBE than for benzene.

would be installed between filter packs for the wells. PlumeStop® would be injected into the wells and into bedrock pore spaces along the alignment of the barrier.

An advantage of in situ sorption is that the treatment is passive, so once applied, it can operate for years without any required maintenance. Also, PlumeStop® will provide a barrier if, in the future, benzene or other organic compounds migrate from the south quarry landfill. There is also a possibility that some biodegradation may occur.

One of the disadvantages of PlumeStop® is that it immobilizes the organic COCs as opposed to treating them. As long as organic COCs remain in situ, there will be sorption/desorption between the PlumeStop® and groundwater at a rate that achieves chemical equilibrium between the phases, which means that low-level groundwater impacts may persist. Also, PlumeStop® is not a remedy for metals in groundwater. Secondarily, injecting PlumeStop into bedrock will be difficult. In addition to the high variability of permeability anticipated within this limestone and dolomite bedrock aquifer, potentially clogging of bedrock fractures/pores may also occur. PlumeStop® particles have a diameter of 1-2 micrometers (um), so pore/fractures smaller than this diameter will not be amended, and PlumeStop® particles may clog pores/fractures unless they are much larger than 2 um (i.e., bridging) which may inhibit distribution of the amendments and reduce the hydraulic conductivity of the aquifer. Perhaps the greatest disadvantage of PlumeStop® is that its implementation is irreversible, meaning that once injected into the aquifer PlumeStop® cannot be removed if PlumeStop® has unforeseen negative impacts to the aquifer.

For costing purposes, this alternative is assumed to require installation of 52 wells at 26 locations as described above. PlumeStop® would be injected into the aquifer twice over five years using the transect of wells. Five years of monitoring as described above would also be a component of this alternative.

2.2.3 Alternative C: Aerobic Bioremediation

Benzene (and potentially p-creosol) can be destroyed through aerobic biodegradation when groundwater geochemistry is favorable for naturally occurring aerobic microbes. Typically, aerobic biodegradation rates for benzene in an aquifer are limited by lower concentrations of dissolved oxygen resulting in slower rates of biological activity and therefore slower rates of contaminant destruction. Amending the aquifer with oxygen either through bubbling oxygen into the aquifer or injecting oxygenated water can enhance biological contaminant destruction. Benzene has been shown to be readily biodegradable in aerobic environments (provided other conditions are favorable for biological activity, such as pH). Although effective for benzene and potentially effective for p-creosol, aerobic biodegradation is unlikely to be effective for MTBE and THF or for inorganic COCs; however, adjusting groundwater to an oxidizing state is likely to immobilize arsenic by precipitating iron-arsenic oxides and may precipitate nickel.

As described above, air injection as a means to deliver oxygen to groundwater was screened out due to concerns over well/aquifer clogging from precipitated iron-oxides plus potential impacts of excess gas on landfill operation and safety. However, injection of oxygenated water into the aquifer, although still challenging, could provide a feasible alternative to deliver dissolved oxygen for microbes, thereby enhancing aerobic biodegradation of benzene and p-creosol, and potentially precipitate inorganic COCs.

Conceptually, this alternative would consist of injecting oxygenated water into a row of injection wells screened in bedrock and located along the 250-ft transect parallel to the property line. With water as the amendment, the conceptual design for this alternative assumes a 20-ft lateral well spacing resulting in 13 well locations; wells are assumed to be 4-inches in diameter. Two wells would be installed in a single boring at each location, with one well screened in the St Louis Formation and one well screened in the Salem Formation. A bentonite seal would be installed between filter packs for the wells. Aerated groundwater, sourced from the storm water retention basin located proximal to the target remediation area, would be filtered and then injected under gravity continuously into the aquifer via injection wells. This alternative may require an increase in leachate pumping from wells located within the south quarry landfill in order to compensate for injected water that is expected to flow toward the landfill.

Advantages of this alternative include destruction of the benzene and potentially p-creosol via aerobic biodegradation thereby lowering concentrations in groundwater and removing contaminant mass, and precipitation/immobilization of arsenic and nickel. In addition, this process may be relatively rapid compared to the more passive measures with reduction in benzene concentrations anticipated to occur in one to five years. This approach, like Alternative B, may be effective for all COCs because it enhances advection toward the landfill.

There are several concerns related to this approach that might limit its success. First, iron currently dissolved in groundwater will likely precipitate when exposed to oxygenated water. Iron precipitation may lead to aquifer clogging or injection well fouling. Also, current aquifer conditions are reducing and would need to be overcome by addition of aerated water which will consume oxygen intended for biodegradation. This could increase the remediation timeframe and it might be difficult to alter groundwater redox conditions uniformly throughout the bedrock aquifer leaving potential pockets of undestroyed contaminant mass that could lead to persistent low level concentrations for an extended time. Thirdly, precipitation reactions that immobilize arsenic and nickel are reversible, so if groundwater reverts to reducing conditions in the future, then these metals may dissolve back into groundwater. Finally, this option may increase required pumping from the landfill so the costing for the conceptual design incorporates additional leachate extraction for the landfill. Further, this alternative may result in a local gradient away from the landfill on the back-side of the injection wells due to the addition of water volume being injected.

For costing purposes, this alternative is assumed to require installation of 26 wells at 13 locations as described above. Aerated water would be injected into the aquifer for one year using the transect of wells. Five years of monitoring as described above would also be a component of this alternative.

2.2.4 Alternative D: ISCO

ISCO is an in situ technology for destroying benzene that has been well established as a successful alternative. ISCO destroys chemicals such as benzene through an oxidation reaction, so it requires amending the aquifer with a strong oxidant and sometimes adjusting pH. The effectiveness of ISCO for other COCs is uncertain. Laboratory testing would be necessary to determine if other organic COCs can be oxidized as well as to assess how strongly oxidizing conditions affect the inorganic COCs (e.g., do they become more soluble).

ISCO requires that the oxidant make contact with the contaminants for it to be effective. Complex aquifer systems, such as heterogeneous systems and/or low permeability matrix conditions, can be difficult for injected oxidants to contact contaminant mass or require multiple applications to address back-diffusion of contaminants retained in the aquifer matrix. Oxidants are typically added to an aquifer using pressurized or gravity-feed injection techniques through individual injection wells. Typically, multiple applications of the oxidant are required to meet remedial objectives due to difficulties encountered with amendment distribution coupled with short-lived chemicals.

The oxidant, activated persulfate, has been shown to be effective in destroying benzene in many settings including bedrock aquifers. Commercial availability of persulfate is common as this is a standard oxidant used in ISCO remedies. Persulfate is the oxidant assumed for conceptual design of this alternative.

The ISCO alternative is similar in conceptual design to the aerobic degradation approach described above. The oxidant would be injected into a series of injection wells that are screened in bedrock. These wells would be oriented in a 250-ft transect along the property line. A 20-ft lateral well spacing is assumed resulting in 13 well locations; wells are also assumed to be 4-inches in diameter. Two wells would be installed in a single boring at each location, with one well screened in the St Louis Formation and one well screened in the Salem Formation; a bentonite seal would be installed between filter packs for the wells. Oxidant would be delivered through pressurized injections into each of the injection wells and it is anticipated that multiple injections would be required to reduce benzene concentrations to meet remedial objectives. The amount of oxidant required depends on the natural oxidant demand (NOD) of the aquifer which is typically much greater than the contaminant oxidant demand. Persulfate also requires a catalyst to initiate the reaction; for the conceptual design, natural and/or chelated iron is assumed to be the activator for the persulfate and it is assumed that no pH adjustment will be required. For costing, the conceptual design assumes three persulfate injection events as well as five years of monitoring as described above.

Advantages to the ISCO approach include the potential for complete destruction of the benzene (and potentially other organic COCs) through the oxidation process resulting in lower concentrations and reduction in contaminant mass. This approach would also be relatively rapid compared to many of the other alternatives, with significant reduction in concentrations anticipated within weeks or months and possibly achievement of remedial objectives (or substantial progress) in less than one year.

Due to the need to overcome the NOD as described above and the likelihood that the NOD will be significant, the cost and likelihood of multiple injections are clear disadvantages to this approach. Further, direct contact with the contaminants in the bedrock aquifer will be challenging and isolated areas could remain untreated. This could result in persistent low-level COC concentrations after multiple ISCO injections. It is also unlikely that ISCO will be effective for all COCs, and there is a possibility that it could worsen conditions by changing the valence and consequently the solubility for the inorganic COCs. As noted above, laboratory testing would be needed to assess the impact of ISCO for all COCs.

Finally, there is a potential safety concern from adding significant volumes of oxidant at the perimeter of the landfill. Oxidants are never mixed with fuel sources because combustion can occur. Given that the landfill is filled with potentially combustible materials, substantial risks exist with adding a strong oxidant near the landfill because if the oxidant migrated into the waste mass it could result in a subsurface oxidation reaction in the landfill.

TABLES

Table 1

Benzene Concentration at PZ-104-SS and PZ-104-SD since 2008

Date	PZ-104-SD	Date	PZ-104-SS
5/7/2008	<5	5/7/2008	<5
11/4/2008	<5	11/4/2008	<5
5/8/2009	<5	5/8/2009	<5
11/4/2009	<5	11/4/2009	<5
5/20/2010	<5	5/20/2010	<5
11/10/2010	<5	11/10/2010	<5
5/9/2011	<5	5/9/2011	<5
11/17/2011	<5	11/17/2011	<5
5/11/2012	57	5/11/2012	<5
8/1/2012	120	8/1/2012	470
11/27/2012	330	11/27/2012	1100
11/27/2012	350		
		12/21/2012	1500
4/11/2013	1000	4/11/2013	2000 - 2500
4/11/2013	820	4/11/2013	2400
		4/11/2013	1900
7/11/2013	800	7/11/2013	1800
10/7/2013	920	10/9/2013	2100
10/7/2013	640	10/9/2013	2200
		10/9/2013	2000
5/28/2014	1300	5/28/2014	1200
5/28/2014	1300		
9/24/2014	1200	9/24/2014	1500
9/24/2014	1200		
11/20/2014	825	11/20/2014	1280
11/20/2014	820		
2/3/2015	520	2/3/2015	1020
2/3/2015	542		
5/13/2015	673	5/14/2015	935
5/13/2015	672		
8/25/2015	628	8/25/2015	357
8/25/2015	564		
11/18/2015	569	11/18/2015	469
11/18/2015	640		

Notes:
Blank cells indicate a sample was not collected on the date.
Concentrations are in micrograms per liter (μg/L).

Table 2

Remedial Alternatives Evaluation, PZ-104 Area
Bridgeton Landfill

	Description	Description	Pros and Cons Summary		Evaluation Criteria: Effectiveness (Performance)		Reliability		Feasibility and Ease of Implementation		Safety Concerns and Cross Media Impact Potential		Relative Cost		Estimated Time		Institutional Requirements (Permitting)		Other: Likelihood of Success		
Alternative	**Basis of Technology**	**Proposed Method of Implementation**	**Advantages**	**Limitation**	**Rating**	**Basis**	**Rating**	**Basis**	**Rating**	**Basis**	**Rating**	**Basis**	**Rating**	**Estimated Cost ($MM)**	**To Implement**	**To Site Restoration**	**Rating**	**Basis**	**Rating**	**Basis**	**Total Rating**
Source Control	Control and extraction of leachate with groundwater monitoring	Leachate extraction to capture groundwater at PZ-104 wells; LFG extraction through liquid removal and well field tuning	Utilizes exsiting infrastructure, mitigates concern for off-property migration of COCs, continuation of ongoing interim remedial measures that are effective	Medium timeframe	3	Effective for reducing/eliminating COC releases from landfill; ongoing interim measures are effective; inward gradient should capture plume.	3	Proven standard technology for controlling migration of COC in groundwater. Infrastructure and operations are already in place.	3	Requires current pumping regime to increase control and possibility of additional leachate collection sump installation of type previously installed successfully. Additional pumping should not alter treatment or discharge operations.	3	Limited safety concerns related to sampling of monitoring wells. Medium concerns with drilling through landfill waste. However, this has been safely completed many other times historically at the site. Limited safety concerns related to modifying leachate extraction since this falls under routine operations for the site.	2	1.4	3	2	2.5	Additional pumping, if required, is not anticipated to impact current treatment but may affect discharge operations such that additional permitting is needed (e.g., larger discharge volume). More effluent sampling may be required due to greater volume.	3	Absence of COCs in other landfill perimeter wells suggests that source control is successfully mitigating contaminant migration from the landfill elsewhere. Interim measures implemented over the last year (approximately) have proved effective.	24.5
In Situ Sorption	Sorption of organic COCs using injected activated carbon	Inject activated carbon amendment into fenceline of wells upgradient of PZ-104 with wells at 10-ft spacing	Moderate cost, retention of contaminant, possiblility for biological degradation	Limited or no destruction of CoCs; potential for desorption from carbon. limited sorption capacity; delivery complex in bedrock; reduces porosity/causes clogging, ineffective for inorganic COCs	1	Some organic COCs readily sorb to activated carbon, but limited to no destruction of mass; possibility of desorption; requires contact in complex bedrock aquifer; ineffective for inorganic COCs.	2	Novel approach with limited application in bedrock aquifers to date.	1	Requires significant drilling in bedrock at close spacing and near the landfill. injection of solids into highly variable bedrock permeability, and good distribution in complex aquifer system.	2	Requires significant drilling at depths of over 200 ft in complex bedrock conditions and adjacent to the landfill, and material handling and injection under pressure.	0	6.1	1	3	1.5	May require injection permits (Underground Injection Control Program).	1.5	Approach requires good distribution in a complex aquifer system with variable permability and fracture flow potential. Also, unproven technology, particularly in this (bedrock) setting. Unlikely to be sucessful for inorganic COCs.	13.0
Aerobic Bioremediation	Injection of aerated stormwater to enhance aerobic degradation of some organic COCs and precipitation of inorganic COCs	Inject oxygenated water into fenceline of wells upgradient of PZ-104 wells with wells at 20-ft spacing	Increases biologicial destruction of some COCs and potential immobilization of inorganic COCs, relatively short timeframe for remediation	Oxidation of iron could cause well or aquifer clogging, need to overcome current reducing conditions; likely to increase the required pumping from within the landfill; could create a local gradient away from the landfill	2	Some organic COCs readily degrade under aerobic conditions. Current reducing conditions will need to be overcome and high iron content in aquifer may result in precipitation, potentially leading to well fouling or aquifer clogging; may precipitate/immobilize arsenic and nickel.	3	Proven technology (i.e., biological degradation) for benzene but oxygen delivery by stormwater injection is novel. Reliability for other COCs is uncertian.	2	Requires injection of fluids into highly variable bedrock permeability and overcoming current reducing conditions to condition aquifer for aerobic degradation. Also, potential for iron precipitates due to high iron content resulting in well fouling and aquifer clogging. Same challenges as alternative C relative to drilling.	2	Requires significant drilling at depths of over 200 ft in complex bedrock conditions and adjacent to the landfill. Injection of a large volume of water could "push" COCs located in the aquifer southeast of the property away from the landfill. Fluid handling always has a risk of release (although storm water is uncontaminated).	1	2.4	1	2	1.5	May require injection permits (Underground Injection Control Program).	2	Proven technology for benzene but not for some other COCs. Reliable adjacent source of aerated water (stormwater basin) and conceptually simple system. However, non-standard application approach and there is a need to overcome current reducing conditions for aerobic biodegradation to occur. Also, risk of aquifer clogging/well fouling due to high iron content in aquifer.	16.5
In Situ Chemical Oxidation (ISCO)	Injection of oxidant to chemically oxidize organic COCs	Inject oxidant into fenceline of wells upgradient of PZ-104 wells with wells at 20-ft spacing	Destroys some COCs, realtive short timeframe	Oxidation of iron could cause well or aquifer clogging, need to overcome natural organic demand (higher Fe); likely to require multiple injections; safety concern related to potential for oxidant exposure to landfill waste; could create a local gradient away from the landfill; may not be effective for all organic COCs and unknown reactions with inorganic COCs.	1	Benzene can be destroyed by some oxidants; effectiveness for other COCs is uncertian. Significant natural oxidant demand (NOD) and complex aquifer provide challenges for oxidant contact with contaminant.	3	Proven technology for destruction of benzene in groundwater but uncertian for other COCs. Technology requires contact between oxidant and COC. Distribution of oxidant in bedrock is challenging.	1	Requires injection of fluids into highly variable bedrock permeability, good distribution in a complex aquifer system, overcoming potentially high natural oxidant demand, may have mineral (iron) precipitation; unknown reactions with inorganic COCs. Same challenges as alternative C and D relative to drilling.	1	Requires significant drilling at depths of over 200 ft in complex bedrock conditions and includes adding oxidant to area adjacent to landfill waste known to have potential for combustion Injection of a large volume of water could "push" COCs located in the aquifer southeast of the property away from the landfill Fluid handling always has a risk of release; this risk is significant when oxidant is added to the water. Oxidant handling adds worker risk.	0	3.5	0	3	1	May require injection permits (Underground Injection Control Program). Permitting more intense because chemicals are being injected.	1.5	Approach requires oxidant-COC contact. Uniform distribution of oxidant in a complex aquifer system with variable permeability and fracture flow potential will be difficult. Also significant natural oxidant demand and current reducing conditions to overcome. Impact on inorganic COCs is unknown and effectiveness for all organic COC is uncertain.	11.5

Notes
Evaluation is qualitative based on professional judgement.
Costs are approximate and relative, and based on a conceptual remedy.

Rating																
3 =	excellent		excellent		easy		low		low	<$1MM	immediately	0 - 1 year	minimal		high
2 =	good		good		moderate		moderate		moderate	$1MM - $2MM	0 - 0.5 year	1 - 5 years	moderate		moderate
1 =	poor		poor		difficult		high		high	$2MM - $3MM	0.5 to 1 year	5 - 10 years	significant		low
0 =	NA		NA		NA		very high		very high	>$3MM	>1 year	>10 years	very significant		none