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October 5, 2017

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SITE ASSESSMENT, REMEDIATION & REVITALIZATION

Mr. Greg Cassidy
South Carolina Department of Health and Environmental Control
State Remediation Section
Bureau of Land and Waste Management
2600 Bull Street
Columbia, SC 29201

Subject: Focused Feasibility Study Comments
Spartanburg Pine Street MGP Site
Spartanburg, SC File 56553

Dear Mr. Cassidy:

In accordance with your agency's request dated September 21, 2017, Duke Energy Carolinas, LLC (Duke Energy) has revised Table 6 of the Focused Feasibility Study (FFS) to include a numerical ranking of the evaluation criteria used for each remedial alternative. Please find attached to this cover letter revised hard copies of the table of contents, Section 6.8 and Table 6 as replacement pages to the FFS. Please also find enclosed a CD of the revised FFS.

If you have any questions, please feel free to contact me at 704.497.3627 or at Richard.powell2@duke-energy.com.

Sincerely,

Richard E. Powell

Richard E. Powell, P.G.
Senior Environmental Specialist

cc: Paul Farris, AECOM

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AECOM Environment

Submitted to
Duke Energy
Charlotte, NC

Submitted by
AECOM
Raleigh, NC
Project No. 60544098
July 2017

Focused Feasibility Study

Former Pine Street MGP Site
BLWM File # 56553
684 North Pine Street
Spartanburg, SC

Prepared for:

DUKE ENERGY.
CAROLINAS

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AECOM Environment

Submitted to
Duke Energy
Charlotte, NC

Submitted by
AECOM
Raleigh, NC
Project No. 60544098
July 2017

Focused Feasibility Study

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly re ponsible for gathering the information, the information submitted is, to be the best of my knowledge and belief, true, accurate, and complete. I am aware tl:lat there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Prepared By Jon Kucera, PE

SOUTH CAROLINA LICENSED PROFESSIONAL ENGINEER No. 24110 JONATHAN J. KUCERA JR 7/31/2017

Reviewed By Paul Farris, PG

Reviewed By Matthew J. Zenker, Ph.D., BCEE

Former Pine Street MGP Site
BLWM File# 56553
684 North Pine Street
Spartanburg, SC

SOUTH CAROLINA AECOM TECHNICAL SERVICES, INC. No. 1473 CERTIFICATE OF AUTHORIZATION

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List of Acronyms

AECOM	AECOM Technical Services, Inc.
ARAR	Applicable or Relevant and Appropriate Requirements
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm/sec	Centimeter per Second
CO_2	Carbon dioxide
COC	Constituent of concern
Duke	Duke Energy
EPA	United States Environmental Protection Agency
FFS	Focused Feasibility Study
FS	Feasibility Study
ft bgs	Feet below ground surface
ft msl	Feet above mean sea level
FW	Fresh water
HASP	Health and safety plan
ISCO	In situ chemical oxidation
LDP	Land disturbance permit
LUC	Land use control
MAROS	Monitoring and Remediation Optimization System
MCL	Maximum Contaminant Level
MGP	Manufactured gas plant
MNA	Monitored natural attenuation
PPE	Personal Protective Equipment
PNG	Piedmont Natural Gas
PWR	Partially weathered rock
RAO	Remedial Action Objective
RBSL	Risk-based screening level
RG	Remedial goal
RI	Remedial Investigation
SCDHEC	South Carolina Department of Health and Environmental Control
SVOC	Semi-volatile organic compound
TLM	Tar-like Material
VCP	Voluntary Cleanup Program
VOC	Volatile Organic Compound

Executive Summary

This Focused Feasibility Study (FFS) has been developed for the Former Pine Street manufactured gas plant (MGP) facility located in Spartanburg, SC (the Site). Substantial assessment and remedial action activities have been performed at the Site since 2000, which have significantly decreased the overall site risk. Important aspects of the historical assessment and remedial activities include the following:

- Extensive sampling and analysis of soil and groundwater has been performed since 2000. The primary constituents of concern (COCs) are benzene and naphthalene.
- The removal, thermal destruction, and offsite disposal of approximately 67,596 tons of impacted soil and debris was performed between February 2003 and March 2004.
- Human health and ecological risk assessments were completed and approved by South Carolina Department of Health and Environmental Control (SCDHEC) in 2004. The assessments indicated the need to restrict the use of Site groundwater.
- A Declaration of Covenants and Restrictions was registered in 2006 to limit property use and prohibit groundwater to be used for drinking or irrigation purposes.
- Sampling and analysis has demonstrated that the onsite creek is not impacted by COCs.
- Historical groundwater monitoring (more than 30 events) indicates groundwater COC concentrations are decreasing, with the exception of three localized areas where the groundwater concentration trends are stable.
- The most recent investigation activities, reported in the April 2017 *Focused Feasibility Study Work Plan*, concluded:
    - Tar-like material (TLM) is present within a narrow horizon below the water table. The zones are generally between 1-3 feet thick and located just above or into the uppermost zone of partially weathered rock (PWR). There are up to three individual areas of remaining TLM over an estimated areal extent of 1,000 square feet with an estimated volume of 1,150 cubic yards.
    - Biodegradation of benzene and naphthalene, the primary COCs in groundwater, is occurring. This conclusion is confirmed through evaluating the overall site-wide decreasing COC trends in monitoring wells, geochemical data, and microbial activity and stable isotope analyses.
    - The benzene and naphthalene plumes are shrinking and the risk of COC migration is minimal. The overall decreasing trend of the plumes can be linked to microbial degradation. The areas where COCs have been most persistent in groundwater correlate with the areas where TLM was identified.

Based on the available data and historical information, six remedial alternatives have been selected for evaluation in this FFS. Evaluation methods and criteria follow those published by the US Environmental Protection Agency (EPA). The remedial alternatives are:

1. No action
2. Monitored Natural Attenuation (MNA) and Land Use Controls (LUCs)
3. Targeted excavation with MNA/LUCs
4. In situ encapsulation/stabilization with MNA/LUCs
5. In situ chemical oxidation (ISCO) with MNA/LUCs
6. In situ bioremediation with MNA/LUCs

1 Introduction

1.1 Purpose

On behalf of Duke Energy (Duke), AECOM Technical Services, Inc. (AECOM) has prepared this Focused Feasibility Study (FFS) for submittal to the South Carolina Department of Health and Environmental Control (SCDHEC), Bureau of Land and Waste Management. The purpose of the FFS is to compare viable remedial alternatives that, upon implementation, will sufficiently address residual impacts to groundwater and deep soil resulting from a manufactured gas plant (MGP) that operated between the early-1900s and the mid-1950s at 684 North Pine Street, Spartanburg, South Carolina (the Site). The FFS has been prepared in general accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Remedial Investigation (RI)/Feasibility Study (FS) Guidance document (United States Environmental Protection Agency [EPA], 1988).

Remediation efforts for the Site are regulated by SCDHEC under the Voluntary Cleanup Program (VCP). The most recent document developed for the Site was a FFS work plan, submitted by Duke Energy to SCDHEC in April 2017 (AECOM, 2017). The FFS work plan reported the results of a field investigation and desktop data analysis, which were necessary to help select appropriate alternatives for a FFS. The FFS work plan proposed four remedial alternatives to be evaluated in this FFS. The work plan was approved by SCDHEC on May 12, 2017 (SCDHEC, 2014) with a request that two additional remediation technologies be considered in the FFS evaluation. A copy of the SCDHEC correspondence is provided in as **Appendix A**.

The remedial alternatives being evaluated are:

- Alternative 1: No action
- Alternative 2: Monitored Natural Attenuation (MNA) and Land Use Controls (LUCs)
- Alternative 3: Targeted excavation with MNA/LUCs
- Alternative 4: In situ encapsulation/stabilization with MNA/LUCs
- Alternative 5: In situ chemical oxidation (ISCO) with MNA/LUCs
- Alternative 6: In situ bioremediation with MNA/LUCs

1.2 Report Organization

This FFS is organized as follows:

- **Section 1** describes the documents purpose and organization, and summarizes the Site’s remedial history.
- **Section 2** summarizes the Site characteristics.
- **Section 3** identifies the remedial action objectives (RAOs) and the remedial goals (RGs).
- **Section 4** presents a screening of remedial alternatives.
- **Section 5** provides a description and detailed analysis of remedial alternatives
- **Section 6** provides a comparative analysis of the remedial alternatives.
- **Section 7** provides references.

1.3 Site Setting and Remedial History Summary

The Site is located in a predominately commercial and industrial section of Spartanburg, South Carolina, consisting of approximately 7.4 acres that are bounded by North Pine Street (US Highway 176) to the west, Southern Railway System mainline tracks to the north, additional commercial/industrial property to the east, and Linder Road to the south. The location and general site plan are depicted on **Figures 1** and **2**, respectively.

Soil was extensively characterized by grid sampling for volatile organic compounds (VOCs) and semi- volatile organic compounds (SVOCs) to support remedial excavation in 2003 and 2004. The excavation was performed in three phases, from February 2003 to March 2004, and 67,596 tons of MGP-impacted soil and debris were removed. However, due to constraints not all potentially impacted material was removed from depths greater than 8-13 feet below ground surface (ft bgs).

A groundwater monitoring network was installed following completion of the excavation work, consisting of shallow (water table) wells and deep (shallow bedrock) wells. A routine groundwater monitoring program was implemented to evaluate post-remediation groundwater quality. Groundwater sampling has been performed more than 30 times since 2004, which has provided a statistically relevant dataset to evaluate groundwater conditions. Naphthalene and benzene are the primary constituents of concern (COCs) in groundwater. The COCs are present in localized areas at varying concentrations above their respective United States Environmental Protection Agency (EPA) Maximum Contaminant Levels (MCLs), or the SCDHEC risk-based screening level (RBSL) in the absence of an established MCL. The historical data trends indicate that the plumes are either decreasing in size or remaining stable (AECOM, 2017).

The primary risk is the exposure of humans to these localized areas of groundwater. This risk is administratively mitigated through the Declaration of Covenants and Restrictions that was executed by Piedmont Natural Gas (PNG) in 2006, prohibiting the use of groundwater for drinking or irrigation without the approval of SCDHEC and restricting property use against residential, agricultural, recreational, child care and elderly care facilities, and schools (AMEC, 2012). The potential for human receptors to be in contact with COCs is unlikely based on the depth at which groundwater is present (i.e., greater than 8 feet below ground surface). A *Trespasser Focused Risk Evaluation Report* concluded that conditions do not present unacceptable risks for industrial/commercial use scenarios (Blue Ridge, 2004; CES, 2004).

In 2006, an oxygen diffusion curtain pilot study was initiated in monitoring well MW-13D and subsequently in well MW-13iSOC for treatment of groundwater COCs in bedrock and saprolite zones. The pilot study concluded that the direct delivery of oxygen to groundwater through diffusers resulted in the reduction of benzene and naphthalene in the groundwater locally (ENSR, 2008). The operation of the diffusion units was later discontinued due to persistent inorganic fouling of the delivery system.

A pilot study testing in situ chemical oxidation (ISCO) technology to address COCs in groundwater was performed in 2012 and 2013 in the same area that the oxygen diffusion curtain study was performed in 2006 (i.e., vicinity of wells MW-13iSOC and MW-13S/D). The pilot study consisted of injecting approximately 12,360 gallons of activated persulfate compound into the subsurface (AMEC, 2014). These activities resulted in the initial reduction of dissolved phase concentrations of benzene and naphthalene by approximately 50 to 99 percent (AMEC, 2014). Longer term groundwater monitoring data, however, has indicated that benzene/naphthalene concentrations have rebounded (AECOM, 2016a). ISCO was not implemented at full scale following the pilot study, as the study concluded that oxidant solution volumes of up to 1 million gallons would be required via 40-70 injection events. The ISCO remedial alternative is considered in this FFS; however, the proposed oxidant delivery method differs from that which was used in the pilot study. Additional information about the results of the ISCO pilot study is included in Section 5.1.5.

Based on the chemical oxidant volumes recommended in the ISCO pilot study report (AMEC, 2014), Duke performed additional subsurface investigation work to delineate potential lingering source areas in order to better inform a remedial alternative selection process and maximize the effects of implementing the selected alternative. Investigation work was performed in 2016 and consisted of delineating tar-like material (TLM) not removed during the 2003-2004 excavation, a groundwater plume dynamics evaluation, and a microbial organisms study to quantify microbial populations actively contributing to biodegradation of target COCs (AECOM, 2016a). The investigation results indicated TLM is present within a narrow horizon below the water table and has a narrow areal extent (AECOM, 2017). These narrow zones tend to coincide with areas of dissolved benzene and naphthalene groundwater concentrations that are persistent and stable. The investigation also confirmed that biodegradation of benzene and naphthalene within the underlying groundwater is occurring (AECOM, 2017).

The remedial alternatives presented in this FFS are focused on addressing the remaining TLM not removed by previous excavation and the areas where groundwater is impacted by COCs above the RBSL or MCL.

2 Site Characteristics

PNG, a subsidiary of Duke, presently owns the majority of the former MGP property, and Duke owns an electrical substation situated near the center of the property. There are no occupied structures within the footprint of known impacts to groundwater. Chinquapin Creek originates off-site and generally flows west to east through the center of the Site, eventually converging with Lawson Fork Creek approximately 3,600 feet east of the Site. Extensive surface water sampling of the creek, performed routinely from 2011 to 2015,has demonstrated that it is not impacted by COCs (S&ME, 2011; AMEC, 2015).

2.1 Regional Geology and Hydrogeology

2.1.1 Regional Geology

The Site is located within the Piedmont Geologic Province of South Carolina. The area is characterized by metamorphic crystalline rocks that include mica schist and biotite gneiss of Precambrian age. Locally, granitoids (typically foliated) and pegmatites cut across regional rock units (ENSR, 1999).

Rock that has been exposed at or near the surface has typically undergone chemical weathering, resulting in the formation of saprolite (soil retaining structural features of the rock). Below the saprolite is typically a zone of weathered rock that transitions with depth to more competent bedrock (i.e., having a lesser degree of fracturing and weathering). Near streams there is typically a layer of alluvium, Quaternary in age, on top of the saprolite or in direct contact with partially weathered rock.

2.1.2 Regional Hydrogeology

Regional groundwater underlying the Site is present within the Piedmont bedrock . This bedrock is a fractured crystalline complex of dense igneous and metamorphic rocks. Most public and private water supply wells in the Piedmont of South Carolina are completed within the bedrock unit. Groundwater in bedrock is recharged from the overlying saprolite formation, which is a major storage unit for the underlying bedrock (ENSR, 1999).

The average annual rainfall in the Spartanburg area is approximately 44.9 inches. The driest average month is November, with an average of 3.02 inches of rainfall. The wettest average month is March, with an average of 4.76 inches of rainfall (South Carolina State Climatology Office [SCO], 2017a). Evapotranspiration generally exceeds precipitation during summer months and is less than precipitation in the winter months (SCO, 2017b).

2.1.3 Site Physiography and Surface Water

Land surface elevations range from 695 feet above mean sea level (ft msl) at well MW-17s down to 680 ft msl at Chinquapin Creek. To the north of the Site is a steeply sloping hill to an adjacent railroad bed. Chinquapin Creek cuts through the Site to the south. The majority of the Site is grass-covered and relatively flat with a gentle slope toward Chinquapin Creek. During typical rain events water percolates thorough the pervious surface, although some overland runoff from the Site is discharged directly to Chinquapin Creek, especially during heavy storm events. Chinquapin Creek is the primary discharge location for storm water and groundwater discharge for the local area (**Figure 1**). Chinquapin Creek is a tributary to the North Fork Edisto River. All surface water within this watershed is classified as freshwater (FW) (SCDHEC, 2012). Surface waters classified as FW are suitable for primary and secondary contact recreation, drinking water supply, fishing, survival and propagation of a balanced indigenous aquatic community of fauna and flora, industrial and agricultural uses.

2.1.4 Site Geology

A site assessment, performed by S&ME for Duke in 2004 shortly after the large remedial excavation effort, generated the most detailed site-specific geologic information to date. According to the *Site Assessment Report* (S&ME, 2004) a majority of the Site where MGP operations occurred is covered by fill resulting from the excavation efforts. The fill soils, which extend to depths of approximately 8 to 13 ft bgs, were locally sourced and predominately consist of silty sands. Below the alluvium and saprolite , very dense soil and soft rock, identified as partially weathered rock (PWR), was encountered between approximately 15 to 24 ft bgs. Refusal to mechanical auger advancement was encountered in all deep monitoring wells, designated with a “D” (**Figure 2**), at depths between 18.5 and 24 feet. Bedrock, identified as gneiss, was typically encountered at 24 ft bgs during installation of deep monitoring wells. **Figures 3** and **4** provide an interpretation of the hydrogeologic units in the general area where the selected remedial alternative would be implemented.

2.1.5 Site Hydrogeology

Groundwater occurs within two apparent zones. The first is a shallow unconfined zone within the unconsolidated zone of fill / alluvium / saprolite and within the PWR (i.e., regolith). The second zone, while not completely isolated from the upper zone, occurs within the lower PWR and into the upper bedrock. This zone is where the flow transitions from an equivalent porous media regime into a more fracture-dominated flow regime. In both zones groundwater appears to flow toward the nearest apparent discharge point (Chinquapin Creek). **Figure 5** and **Figure 6** illustrate the shallow and intermediate potentiometric surfaces from the October 2016 sampling event (AECOM, 2016b).

Hydraulic conductivity testing (rising head slug tests) was performed in 2004 after the installation of the monitoring well network. The calculated geometric mean of hydraulic conductivities in the shallow monitoring wells was 6.37×10^{-4} centimeters/second (cm/sec), and the calculated geometric mean of hydraulic conductivities in the deep monitoring wells was 2.34×10^{-5} cm/sec (S&ME, 2004). The average linear velocity in the shallow and deep monitoring wells was estimated at 0.2 and 0.05 feet per day, respectively (S&ME, 2004).

2.2 Current Nature and Extent of COCs

The current nature and extent of COCs was presented in the *Focused Feasibility Study Work Plan* (AECOM, 2017) approved by SCDHEC on May 12, 2017. As illustrated on **Figure 7**, excerpted from the Work Plan, TLM was identified by TarGOST® within a confined area west of the substation. The area coincides with monitoring wells that have exhibited lingering groundwater impacts. The TLM is generally located within a relatively narrow zone (1-3 feet thick) just above or into the uppermost zone of partially weathered rock. Saturated soil samples indicated the TLM contained residual naphthalene and benzene within narrow bands in isolated areas.

The current groundwater plume(s) occurs in two apparently isolated areas and exhibit both benzene and naphthalene above their respective remedial goals. These two areas appear co-located with areas that indicated residual TLM. **Figure 8** and **Figure 9** illustrate the areal extent from the October 2016 groundwater sampling event (AECOM, 2016b).

The trends of benzene and naphthalene in individual wells are either decreasing or stable and the bulk plume mass of benzene and naphthalene is decreasing. The center of mass of these plumes is not migrating downgradient toward Chinquapin Creek, and monitoring data have demonstrated COCs are biodegrading before reaching the creek. Horizontal migration of the plume has not occurred at a significant rate and would not be expected to migrate significantly further horizontally based on historical trends. The benzene and naphthalene plumes are shrinking and the risk of COC migration is minimal. However, the remaining TLM will likely continue to release benzene and naphthalene into the adjacent groundwater for a period beyond 30 years (AECOM, 2017).

3 Identification of Remedial Action Objectives and Remedial Goals

3.1 Constituents of Concern

COCs are media-specific chemicals that are present at concentrations that either exceed an established promulgated standard or present an unacceptable risk of exposure to receptors. COCs for soil, groundwater, and surface water are summarized below:

- **Soil COCs:** Impacted soil in the unsaturated zone has been removed. Existing data indicate there are no soil COCs.
- **Groundwater COCs:** COCs for groundwater are benzene and naphthalene. Benzene and naphthalene were detected above remediation goals (defined in Section 3.3) in 5 of 18 shallow monitoring wells and 3 of 11 PWR wells during the October 2016 groundwater monitoring event. Benzene and naphthalene are the only constituents historically detected above promulgated standards (AECOM, 2016b). The promulgated standard for benzene is the EPA-established MCL. While there is no MCL for naphthalene, the SCDHEC consistently uses the RBSL as its target for naphthalene; therefore, naphthalene is considered a COC. While the FFS investigation detected ethylbenzene, toluene, and xylenes within zones of saturated soil, these analytes have historically been detected infrequently in groundwater and have never been detected above a promulgated standard. Therefore, they are not considered as COCs.
- **Surface Water COCs:** The evaluation of trends and plume dynamics performed using the Monitoring and Remediation Optimization System (MAROS) software and the SourceDK computer-based program indicate COCs in groundwater degrade to concentrations below remediation goals (defined in Section 3.3) before reaching Chinquapin Creek. Additionally, historical surface water sampling performed in conjunction with groundwater monitoring events has demonstrated that COCs are not present above reporting or method detection limits. While there have been trace concentrations of chlorinated VOCs detected in surface water, these analytes originate offsite, as these constituents are present at higher concentrations upstream (north) of the Site.

3.2 Remedial Action Objectives

Remedial action objectives (RAOs) are the end points which, when obtained, will result in appropriate protection of human health and the environment. The Site RAOs are:

- **RAO 1:** Prevent ingestion of groundwater containing COCs in excess of applicable drinking water standards.
- **RAO 2:** Restore groundwater concentrations to applicable remediation goals.
- **RAO 3:** Prevent or confirm that groundwater containing COCs does not impact on-site surface water above South Carolina surface water standards

3.3 Remedial Goals

Remedial goals (RGs) are components of RAOs that are medium and constituent specific numerical values meant to provide an objective metric for when the RAO has been attained. The following RGs are proposed:

- Benzene in groundwater – **MCL of 5 micrograms per liter (μg/L)**
- Naphthalene in groundwater – **RBSL of 25 μg/L**

4 Screening of Technologies and Identification of Remedial Alternatives

In accordance with the CERCLA RI/FS guidance document, this section typically presents the rationale for screening of remedial technologies and identifying remedial alternatives to address impacted media (EPA, 1988). It presents an initial evaluation (i.e., screening) to identify potentially applicable remedial methods (i.e., process options). Remedial methods passing the initial screening process are combined to create potentially feasible remedial alternatives. The remedial alternatives are described in detail for further evaluation as presented in Section 5.

Technology screening was completed during the development of the FFS Work Plan (AECOM, 2017).

Based on the considerations provided above, remedial alternatives were developed to address impacted groundwater in the saprolite and PWR/shallow bedrock zones. These alternatives are as follows:

- Alternative 1: No Action
- Alternative 2: MNA and LUCs
- Alternative 3: Targeted excavation with MNA/LUCs
- Alternative 4: In situ encapsulation/stabilization with MNA/LUCs
- Alternative 5: In situ chemical oxidation with MNA/LUCs
- Alternative 6: In situ bioremediation with MNA/LUCs

Detailed discussion of these alternatives is presented in Section 5. There are existing LUCs (e.g. groundwater use restriction) on the property. It is assumed that the existing LUCs will remain in place until the groundwater RGs are achieved. The underlying assumption for all the alternatives discussed and evaluated is that measures will be implemented until the groundwater RGs are achieved.

5 Description and Detailed Analysis of Groundwater Remedial Alternatives

The CERCLA RI/FS guidance (EPA, 1988) provides nine evaluation criteria for assessing the remedial alternatives within the context of a comprehensive FS. These criteria cover regulatory, technical, cost, institutional, and community considerations.

The two *threshold* criteria are:

- Overall Protection of Human Health and the Environment: Evaluates how the alternative, as a whole, protects and maintains protection of human health and the environment during and after implementation.
- Compliance with Applicable or Relevant and Appropriate Requirements (ARARs): Evaluates how the alternative complies with chemical-specific, location-specific, and action-specific ARARs.

The five *balancing* criteria are:

- Long-term Effectiveness and Permanence: Evaluates the long-term ability of an alternative to protect human health and the environment after remedial goals have been achieved. The primary consideration is the effectiveness of controls that are necessary to manage the risks posed by treated or untreated residuals.
- Reduction of Toxicity, Mobility, or Volume through Treatment: Addresses the EPA's statutory preference for remedial alternatives that (1) permanently reduce the toxicity, mobility, and volume of the compounds of concern and (2) use treatment as a principal element. This criterion focuses on the following factors:
  - The amount of hazardous materials treated or destroyed
  - The degree of reduction in toxicity, mobility, and volume of impacted material
  - The degree to which the treatment method would be irreversible
  - The characteristics and quantity of residual material that would remain
- Short-term Effectiveness: Addresses the effects of each alternative during construction and implementation until RAOs have been met. Specifically, this criterion evaluates the potential impact each alternative would have on workers, the community, and the environment during implementation of the remedial action.
- Implementability: Assesses the technical and administrative feasibility of implementing an alternative. Technical feasibility addresses the difficulties and unknowns associated with a technology, the reliability of a technology, the ease of undertaking future remedial actions, and the ability to monitor the effectiveness of the system. Administrative feasibility refers to the activities required to coordinate with regulatory agencies and the availability of equipment, services, and materials.
- Cost: Evaluates the capital and O&M costs associated with an alternative. Present worth analysis is used to evaluate expenditures that occur over multiple years (maximum 30 years). It should be noted that these costs are for comparison of alternatives and actual costs of implementation may vary (typically around -30 to +50 percent).

The final two criteria that often are evaluated after the initial publication of the FFS are:

- Regulatory Acceptance: Evaluates the technical and administrative issues that the EPA or the State of South Carolina may have regarding each of the alternatives. This analysis would include formal comments from meetings, agency reviews, and the transmittal of comments between agencies.
- Community Acceptance: Incorporates community input (solicited during the public comment period) regarding the selection of remedial alternatives.

Although the Site is under the SCDHEC VCP, at the direction of SCDHEC, the RI/FS Guidance (EPA, 1988) document has been used to develop and analyze the remedial alternatives. The first seven criteria will be evaluated in this FFS. The final two criteria will not be used during the evaluation process for the Site. Preliminary pricing information was solicited from vendors for this FFS. This pricing information was used together with other sources to prepare the cost estimates for the alternatives evaluated.

All the alternatives discussed and evaluated assume that the existing LUCs (e.g., groundwater use restriction) would remain in place until the RAOs are achieved.

5.1 Remedial Alternatives

The groundwater remedial alternatives developed for detailed analysis are listed below. These remedial alternatives are focused on groundwater, as previous remedial activities have removed soil impacts.

- Remedial Alternative 1: No Action
- Remedial Alternative 2: MNA and LUCs
- Remedial Alternative 3: Targeted excavation with MNA/LUCs
- Remedial Alternative 4: In situ encapsulation/stabilization with MNA/LUCs
- Remedial Alternative 5: In situ chemical oxidation with MNA/LUCs
- Remedial Alternative 6: In situ bioremediation with MNA/LUCs

5.1.1 Remedial Alternative 1 – No Action

5.1.1.1 *Description*

The No Action alternative is a baseline alternative included for comparison with the other alternatives. The No Action alternative assumes that no action is taken, no monitoring is performed, and no costs are incurred. This alternative would not achieve the required RAOs.

5.1.1.2 *Overall Protection of Human Health and the Environment*

Alternative 1 would not provide control of exposure or reduction of risk to human health and the environment posed by impacted groundwater at the Site. This alternative would not actively reduce the COC concentrations in groundwater to the RGs and, therefore, would not achieve the RAOs. A decrease in the COC concentrations may occur over time through natural processes. However, such reduction would not be monitored, quantified, or documented.

5.1.1.3 *Compliance with Applicable or Relevant and Appropriate Requirements*

Since no remedial activities are associated with this alternative, compliance with the chemical-specific ARARs for groundwater would not be met until such time that natural attenuation processes have reduced COC concentrations to the RGs. Since no remedial activities would be conducted under this alternative, action-specific ARARs are not applicable. Location-specific ARARs do not apply to this alternative.

5.1.1.4 *Long-term Effectiveness and Permanence*

This alternative would not provide for controls or long-term risk management measures for the untreated COCs. The current and potential future risks are likely to remain the same under this alternative.

5.1.1.5 *Reduction of Toxicity, Mobility, or Volume*

This alternative would not employ active treatment that would reduce the toxicity, mobility, or volume of the COCs in groundwater; therefore, this alternative would not satisfy the statutory preference for treatment. A decrease in the groundwater COC concentrations may occur over time through natural processes, although this would not be quantified because this alternative does not include additional sampling.

5.1.1.6 *Short-term Effectiveness*

Because the No Action alternative would not involve any active remedial measures, no short-term risks to the community, workers or the environment are likely to exist.

5.1.1.7 *Implementability*

There are no technical or administrative limitations to implementing the No Action alternative.

5.1.1.8 *Cost*

There are no costs associated with this alternative.

5.1.2 Alternative 2 – Monitored Natural Attenuation and Land Use Controls

5.1.2.1 *Description*

This alternative proposes to continue implementation of the current MNA program and keep in place the current LUCs. **Figure 2** depicts the locations of the existing monitoring well network. It is assumed that the entire well network would be incorporated within the MNA approach and groundwater samples would be collected for analysis annually for 50 years.

MNA is a passive approach that monitors the natural degradation or reductions of COCs in groundwater. A typical MNA approach centers on monitoring the groundwater geochemistry, and the COC concentrations, to continually evaluate and confirm that the site conditions are supportive of COC degradation. During the implementation phase, a groundwater sampling plan would be developed to monitor remedy performance and to confirm that COC concentrations remain stable or decrease following the implementation of the remedy. Additionally this would also include any implementation of LUCs necessary to protect human health and the environment. LUCs include development restrictions and groundwater use restrictions, which are already in place.

5.1.2.2 *Overall Protection of Human Health and the Environment*

This alternative is expected to be protective of human health and the environment implementing appropriate measures to prevent exposure to COCs from groundwater until it meets the RGs. Historical data indicate current plume stability in on-site areas. Risk reduction and protectiveness is also contingent upon maintaining the current LUCs (e.g., groundwater use restrictions).

5.1.2.3 *Compliance with Applicable or Relevant and Appropriate Requirements*

This alternative is not expected to meet with analyte-specific RGs within a reasonable time frame. Continued use of current LUCs would assist in meeting the action-specific ARARs on-site. There are no location-specific ARARs for this alternative.

5.1.2.4 *Long-term Effectiveness and Permanence*

Magnitude of residual risk: Alternative 2 is a passive remedy. Minimal long-term residuals are expected to persist at the Site while MNA is ongoing. While it is expected that MNA will eventually meet RGs, it will most likely take greater than 50 years to reach this end point.

Adequacy and Reliability of controls: Existing risks in groundwater, currently mitigated through the LUCs, are expected to be low and decline in the future due to the observed natural processes.

5.1.2.5 *Reduction of Toxicity, Mobility, or Volume*

The MNA approach will reduce the volume, mobility, and toxicity of constituents in groundwater as demonstrated by isotope studies (AECOM, 2017).

5.1.2.6 *Short-term Effectiveness*

Implementation of this alternative is not expected to be effective in the short term. Proper use of personal protective equipment (PPE) and adhering to a site-specific health and safety plan (HASP) would minimize or eliminate impacts during groundwater sampling. Implementation of this alternative would not result in adverse environmental impacts and short-term risks are minimal.

5.1.2.7 *Implementability*

- Technical feasibility: This alternative involves continuing the current MNA program with minor changes (i.e., perhaps a reduction in frequency) and is easily implemented.
- Availability of services and materials: No special equipment or specialists other than a licensed driller and a qualified technician are anticipated during implementation.

5.1.2.8 *Cost*

The 50-year present worth (as an opinion of probable costs) for this alternative is approximately $509,000. The present worth cost was calculated using a discount rate of 5 percent. Details of the probable cost and key assumptions are included in **Table 1**.

5.1.3 Remedial Alternative 3 – *Targeted Excavation and MNA*

5.1.3.1 *Description*

Under this scenario, a targeted excavation of TLM would be performed. Then, once the presumed residual source material was removed, non-impacted fill would be used for backfilling. Once the emission of COCs into the groundwater is mitigated, COC biodegradation through the documented natural attenuation processes should treat the dissolved phase concentrations. MNA and LUCs would then be instituted for up to 8 years. The targeted excavation would be performed in several steps and in two apparent areas as shown on **Figure 10**.

First the wells in the area of proposed excavation will be properly abandoned or removed. The unimpacted fill/overburden would be removed from the top approximate 10-ft to expose the potential TLM horizon. This relatively thin horizon varies from between 1-3 ft in thickness (estimated to be 1,150 CY). Once the TLM material is exposed it would be excavated, transported as a non-hazardous waste to a local sanitary landfill for disposal.

Since all of the residual TLM would be below the water table some excavation pit water management can be expected. Due to the relatively low transmissivity of the onsite native material it is expected that generated water could be temporarily stored on-site and then disposed (e.g., in a publicly owned treatment works) following completion of the job. Once the TLM is excavated from the pit, then imported clean backfill would be installed within the excavation.

The backfill material would be mixed with amendments, including oxygen releasing solids, nutrients, and an activated carbon media to act as an attached growth media. The purpose of adding these materials is to “polish” the impacted groundwater that has been in contact with the TLM. Once backfilled, the surface will be restored by planting grass, and the monitoring wells would be re-installed.

Once excavation and backfill are complete, a series of performance monitoring events will be conducted for a year. These will include four quarterly events to track the progress of groundwater concentration reduction. At the same time the current MNA program will also be performed semi-annually for the first year. Two of the performance monitoring events will serve as the MNA events. After the first year, it is anticipated that MNA will continue for another seven years when RGs are expected to be reached.

For the purpose of this evaluation, the project life of this alternative is estimated to be 8 years.

5.1.3.2 *Overall Protection of Human Health and the Environment*

Implementation of Alternative 3 would provide protection to human health and the environment by removing TLM that remains in the subsurface. This would eliminate the emittance of COCs into groundwater, creating a significant reduction in dissolved phase COC mass. MNA would be implemented at the completion of excavation activities to monitor the degradation of COCs remaining in groundwater. LUCs would continue to be implemented to restrict usage of impacted groundwater until RGs are met.

5.1.3.3 *Compliance with Applicable or Relevant and Appropriate Requirements*

Chemical-specific: This alternative is expected to result in COCs in groundwater meeting RGs within 8 years.

Location-specific: No location-specific ARARs were identified for this alternative at the Site.

Action-specific: While the anticipated disturbed area of this alternative would be less than one-acre, it is anticipated that a land disturbance permit (LDP) or at least an erosion control plan consistent with SCDHEC requirements for a LDP be developed to protect Chinquapin Creek and the other on-site tributaries. Although oxygen releasing solids and carbon would be applied within the excavation as a groundwater polishing mechanism, the excavation would be wider than it is deep and would not require an underground injection control (UIC) permit from the SCDHEC UIC Section (i.e., the excavation would not meet the definition of a well in South Carolina).

5.1.3.4 *Long-term Effectiveness and Permanence*

Magnitude of residual risk: Alternative 3 involves a combination of active and passive remedies. Minimal long-term residuals are expected to persist in the active treatment area while MNA is expected to assist in meeting RGs in the untreated areas. Removal of TLM is permanent for the anticipated sorbed mass. Then the documented biodegradation and MNA processes that are occurring should transform the remaining dissolved phase concentrations into innocuous daughter products.

Adequacy and reliability of controls: Existing risks with untreated residuals in groundwater are expected to be low and decline in the future due to physical removal and natural processes.

5.1.3.5 *Reduction of Toxicity, Mobility, or Volume*

This alternative is expected to reduce the toxicity, mobility, and volume of COCs in the groundwater. The excavation of the remaining TLM removes further mass that may be slowly released in the groundwater, thereby reducing the mass/volume of COCs.

5.1.3.6 *Short-term Effectiveness*

Implementation of Alternative 3 would involve a temporary disturbance of the Site. Once the excavated material is removed it is anticipated that groundwater concentrations in the immediate area will start decreasing at a fairly rapid rate. Although it is possible through the temporary disturbance a small spike in groundwater concentrations could occur it is anticipated through the performance monitoring that within the first year significant decreases in the groundwater COC concentrations would be observed.

5.1.3.7 *Implementability*

Technical feasibility: Excavation, transportation and disposal has been successfully used to remediate MGP Sites in similar geologic settings both similar to that of the Site and at the Site itself. The construction activities required to perform the anticipated scope are commonly implemented and there are ample experienced contractors in the area to perform the work. The process of excavating the materials would require the implementation of an approved HASP. The HASP would help to minimize exposure to affected media during the construction and monitoring activities.

Administrative feasibility: Implementation of Alternative 3 requires no excessive coordination with state and local agencies. While it appears that the land disturbance would be less than 1 acre, due to the proximity of Chinquapin Creek, a land disposal permit should be obtained or at least the erosion control features in a LDP should be incorporated. This alternative also requires drillers and construction contractors. No other specialized contractors are anticipated to be needed.

Availability of services and materials: Vendors and contractors are available to supply labor and equipment to implement the targeted excavation program. Availability and scheduling of equipment and supplies would not be anticipated to pose problems.

5.1.3.8 *Cost*

The 8-year present worth (as an opinion of probable costs) for this alternative is approximately $966,000. The present worth cost was calculated using a discount rate of 5 percent. Details of the probable cost and key assumptions are included in **Table 2**.

5.1.4 Remedial Alternative 4 – In Situ Encapsulation/Stabilization and Monitored Natural Attenuation

5.1.4.1 *Description*

Under this scenario, the remaining horizons of TLM would be stabilized in place. The stabilization effort would serve to limit the continued emission of COCs from the sorbed TLM into the groundwater. Once the emission of COCs into the groundwater is mitigated, COC biodegradation through the documented natural attenuation processes should treat the dissolved phase concentrations. MNA and LUCs would then be instituted for up to 8 years. The targeted stabilization effort would be very similar to the excavation effort described in Alternative 3 and would be performed in several steps and in two apparent areas as shown on **Figure 11**.

First the wells in the area of proposed stabilization effort would be properly abandoned or removed. The unimpacted fill/overburden would be removed from the top approximate 10-ft to expose the potential TLM horizon. This relatively thin horizon varies from between 2-5 ft in thickness. Once the TLM is exposed, the TLM would be scraped and loosened within the excavated pit. Then a stabilization amendment usually consisting of cement and/or pozzolan material (fly ash) and/or powdered activated carbon would be added and mixed in place with the excavator. In this alternative, it is anticipated that 10% by weight of cement and 1% by weight of powdered activated carbon will be used as the amendment. Upon completion of the mixing the material would be re-compacted into the bottom of the pit and allowed to cure. The stabilization effort should serve to bind to the TLM effectively retarding the emission of COCs back into the groundwater.

Once the stabilization process is complete, the pit would be backfilled with the stockpiled overburden and the surface will be restored by planting grass. Wells would be installed immediately down gradient and perhaps below the stabilized material. It is anticipated that the stabilized material would be nearly monolithic so there would be no purpose in re-installing wells within that material. The purpose of any wells would be to monitor areas just downgradient (horizontally and vertically) of the stabilized zone.

Once the stabilization effort is complete, a series of performance monitoring events would be conducted for a year. These would include four quarterly events to track the progress of groundwater concentration reductions. At the same time the current MNA program would also be performed semi-annually for the first year. Two of the performance monitoring events would serve as the MNA events. After the first year, it is anticipated that MNA would continue annually for another 7 years when remedial goals should be reached.

For the purpose of this evaluation, the project life of this alternative is estimated to be 8 years.

5.1.4.2 *Overall Protection of Human Health and the Environment*

Implementation of Alternative 4 would provide protection to human health and the environment by causing COCs that remain in the subsurface to become less mobile and less able to emit into adjacent groundwater. A reduction in dissolved phase COC mass is expected with this alternative. MNA would be implemented after stabilization activities were complete to monitor the degradation of COCs. LUCs would continue to be implemented to restrict usage of impacted groundwater until RGs are met.

5.1.4.3 *Compliance with Applicable or Relevant and Appropriate Requirements*

Chemical-specific: This alternative is expected to result in COCs in groundwater meeting RGs within 8 years.

Location-specific: No location-specific ARARs were identified for this alternative.

Action-specific: While the anticipated disturbed area of this alternative would be less than one-acre, it is anticipated that a LDP, or at least an erosion control plan consistent with SCDHEC requirements for a LDP, be developed to protect Chinquapin Creek and the other on-site tributaries. Although stabilization amendments would be applied within the subsurface, the pit would be wider than it is deep and would not require an UIC permit from the SCDHEC UIC Section (i.e., the pit would not meet the definition of a well in South Carolina).

5.1.4.4 *Long-term Effectiveness and Permanence*

Magnitude of residual risk: Alternative 4 involves a combination of active and passive remedies. All TLM would remain bound in the subsurface, minimizing the potential for emittance of COCs to groundwater. MNA is expected to assist in meeting RGs in the untreated areas. While stabilization of TLM is considered permanent, there is risk that sorbed mass could "break free" over time.

Adequacy and reliability of controls: Existing risks with untreated residuals in groundwater are expected to be low and decline in the future due to natural processes.

5.1.4.5 *Reduction of Toxicity, Mobility, or Volume*

This alternative is expected to primarily reduce the toxicity and mobility of COCs in the groundwater. The stabilization/solidification of the remaining TLM reduces the mobility of the remaining mass that may be at the Site.

5.1.4.6 *Short-term Effectiveness*

Implementation of Alternative 4 would involve a temporary disturbance of the Site. Once the stabilized material is in place it is anticipated that groundwater concentrations in the immediate area would start decreasing at a fairly rapid rate. Although it is possible through the temporary disturbance a small spike in groundwater concentrations could occur it is anticipated through the performance monitoring that within the first year significant decreases in the groundwater concentrations would be observed.

5.1.4.7 *Implementability*

Technical feasibility: Stabilization/solidification has been successfully used to remediate MGP sites in similar geologic settings similar to that of the Site. The construction activities required to perform the anticipated scope are fairly common and there are some experienced contractors in the region to perform the work. The process of stabilizing the materials would require the implementation of an approved HASP. The HASP would help to minimize exposure to affected media and to minimize dust generation during the construction and monitoring activities.

Administrative feasibility: Implementation of Alternative 4 requires no excessive coordination with state and local agencies. While it appears that the land disturbance would be less than 1 acre, due to the proximity of Chinquapin Creek, a land disposal permit should be obtained or at least the erosion control features in a LDP should be incorporated. This alternative also needs drillers and construction contractors. No specialized contractors are anticipated to be needed.

Availability of services and materials: Vendors and contractors are available to supply stabilization services. Availability and scheduling of equipment and supplies would not be anticipated to pose problems.

5.1.4.8 *Cost*

The present worth (as an opinion of probable costs) for this alternative is approximately $884,000. The present worth cost was calculated using a discount rate of 5 percent. Details of the probable cost and key assumptions are included in **Table 3**.

5.1.5 Remedial Alternative 5 – In Situ Chemical Oxidation and MNA

5.1.5.1 *Description*

ISCO is a process that reduces the mass of organic COCs through the direct injection or direct mixing of a strong oxidizing agent into the subsurface. Nearly all organic COCs can be oxidized to non-hazardous end products (e.g., carbon dioxide [CO_2] and water). Several chemical oxidants are available for remediation of benzene and naphthalene. They include, in order of strength from strongest to weakest oxidation potential: Fenton's reagent, activated persulfate, ozone, sodium persulfate, hydrogen peroxide, and potassium permanganate. Each oxidant has relative strengths and weaknesses that depend on capital cost, reaction rate, and the site-specific geochemical environment.

A pilot ISCO test was conducted from December 2012 to January 2013 with sodium hydroxide/persulfate. These activities resulted in the initial reduction of dissolved phase concentrations of benzene and naphthalene by approximately 50 to over 99 percent (AMEC, 2014). Longer term groundwater monitoring data, however, has indicated that benzene/naphthalene concentrations have rebounded (AECOM, 2016a). The pilot study used the direct injection ISCO method, which had marginal success delivering the oxidant to the subsurface due to low permeability conditions (AMEC, 2014).

Based on the marginal results during the pilot study for delivering the oxidant by injection, the conceptual delivery process for any future implementation of the ISCO would involve direct application and mixing of an oxidant/activator solution with the impacted material in the subsurface in an open pit using heavy equipment designed for this purpose. To be successful, chemical oxidants must achieve contact with the targeted remediation material. Therefore, a direct-mixing delivery method was selected over an injection delivery method to increase the probability of contact between the oxidant and the targeted remediation material. It is assumed that oxidants would be applied by the open pit direct-mixing method in two separate locations encompassing approximately 15,600 square feet, as shown on **Figure 12**. These areas were selected due to exhibiting elevated groundwater concentrations and residual TLM, as measured by TarGOST® (AECOM, 2017).

The ISCO direct-mixing delivery method assumes the addition of approximately 25,000 to 50,000 gallons of oxidant/activator solution, which includes between 75,000 to 90,000 pounds of hydrogen peroxide (48 tons). Previous estimates, which are listed in the pilot study results report, concluded that approximately 1.5 million pounds of oxidant (750 tons) would be required, and the oxidant would be delivered by injecting approximately 500,000 to 1,000,000 gallons of solution (AMEC, 2014). The significant discrepancy in dosing mass and volume is largely due to the additional subsurface information collected by TarGOST® in 2016, which quantified smaller targeted treatment areas and horizons (AECOM, 2017).

Wells in the area of mixing would be properly abandoned or removed prior to breaking ground. The unimpacted fill would be removed from the top approximate 10-ft to expose the potential TLM horizon. This relatively thin horizon varies from between 2-5 ft in thickness. Once the TLM material is exposed, the TLM material would be scraped and loosened within the excavated pit. Then an oxidation/activator amendment would be added and mixed in place with an excavator equipped with a soil mixing head. Modified Fenton's reagent (hydrogen peroxide with an iron-based catalyst) was assumed, as it offers some advantages over other oxidants: hydrogen peroxide has a much lower stoichiometric oxidant demand for the target constituents, has a lower cost per unit mass compared with other oxidants, and has a relatively short reaction time (hours) allowing soil confirmation samples to be collected within days after treatment to evaluate if soil mixing treatment goals have been achieved. Once the oxidant mixing process is complete, the pit would be backfilled with the stockpiled overburden and the surface would be restored by planting grass. Monitoring wells would be installed within the treated areas and immediately down gradient to monitoring groundwater COC concentrations.

Natural attenuation would be used to address the residual constituents in areas beyond the influence of chemical oxidation. As part of post-application monitoring and MNA, groundwater monitoring would be performed to evaluate if natural processes are enhancing attenuation of the residual dissolved COCs. For the purpose of costing, it is estimated that 30 monitoring wells would be sampled quarterly in year one and annually from years two through eight for VOCs. Eight wells would be sampled for various geochemical parameters (e.g., dissolved gases, electron acceptors, etc.) at each event. In addition, field parameters such as DO, ORP, pH, temperature, and conductivity would be measured at each sampled well during the monitoring events. The exact number and locations of monitoring wells would be revised during the remedial design and remedial action phases.

After the first year, it is anticipated that MNA would continue annually for another 7 years when remedial goals should be reached. For the purpose of this evaluation, the project life of this alternative is estimated to be 8 years.

5.1.5.2 *Overall Protection of Human Health and the Environment*

Alternative 5 is expected to be protective of human health and the environment. Chemical oxidation in the treatment area is expected to reduce benzene and naphthalene. Natural attenuation processes are expected to remediate any remaining untreated (residual) impacts in groundwater. LUCs will continue to be implemented to restrict usage of impacted groundwater until RGs are met.

5.1.5.3 *Compliance with Applicable or Relevant and Appropriate Requirements*

Chemical-specific: This alternative is expected to result in COCs in groundwater meeting RGs within 8 years.

Location-specific: No location-specific ARARs were identified for this alternative.

Action-specific: While the anticipated disturbed area of this alternative would be less than one-acre, it is anticipated that a LDP, or at least an erosion control plan consistent with SCDHEC requirements for a LDP, be developed to protect Chinquapin Creek and the other on-site tributaries. Although oxidants would be applied within the subsurface, the pit would be wider than it is deep and would not require an UIC permit from the SCDHEC UIC Section (i.e., the pit would not meet the definition of a well in South Carolina).

5.1.5.4 *Long-term Effectiveness and Permanence*

Magnitude of Residual Risk: Alternative 5 involves a combination of active and passive remedies. Naturally occurring oxidant demand in the subsurface will determine the quantities of oxidant required for the treatment. The untreated residual COCs in groundwater are expected to attenuate through natural biotic processes. ISCO technology has been demonstrated in a pilot study to be effective in treating benzene and naphthalene.

Adequacy and reliability of controls: Treatment of impacted groundwater with chemical oxidation would be an effective method of treating constituents in groundwater and reducing impacts to the environment. Existing risks associated with untreated residuals in groundwater are expected to decline in the future due to natural attenuation processes. LUCs would be required until the groundwater RGs are achieved.

5.1.5.5 *Reduction of Toxicity, Mobility, or Volume*

Chemical oxidation is expected to reduce toxicity, mobility, and volume of constituents in groundwater. In this process, organics are oxidized to CO_2 and water. Further, natural attenuation processes are expected to assist in reducing toxicity, mobility, and volume of constituents in groundwater. While chemical oxidation processes can temporarily reduce the concentration and activity of heterotrophic bacteria, this effect is typically limited to a few months after oxidant application, after which microbial activity is restored (Siegrist and others, 2011).

5.1.5.6 *Short-term Effectiveness*

Implementation of Alternative 5 would involve routine groundwater sampling to monitor effectiveness. The areas proposed for chemical oxidation treatment in this alternative are easily accessible. Chemical oxidation involves handling of corrosive chemicals (hydrogen peroxide). Use of proper PPE and adhering to a site-specific HASP would provide adequate protection. This alternative would not impact the community or result in adverse environmental impacts. As observed in the pilot study, some rebounding of groundwater concentrations will likely following oxidant application and mixing. Eight years of post-application monitoring are anticipated to meet the groundwater remedial goals. Due to the application of an aqueous amendment, monitoring of surface water may be necessary to ensure amendments do not impact Chinquapin Creek or other on-site tributaries.

5.1.5.7 *Implementability*

Technical feasibility: To be successful, chemical oxidants must achieve contact with the targeted remediation material. This requirement is often difficult to achieve in low permeability subsurface conditions, such as dense silts and saprolite, which are present at the Site. Therefore, delivery of the oxidant via direct-mixing (instead of injection) would be performed in order to increase contact of the oxidant with the targeted remediation material. The open pit direct-mixing method has been successfully used to remediate organic chemicals in groundwater in geologic settings similar to those present at the Site. The construction activities required to perform soil mixing and to apply chemicals are easily implemented. The process of applying the chemicals via soil mixing would require the implementation of a HASP. Implementation of the HASP would prevent exposure to chemicals during the application.

Administrative feasibility: Implementation of Alternative 5 requires no excessive coordination with state and local agencies. While it appears that the land disturbance would be less than 1 acre, due to the proximity of Chinquapin Creek, a land disposal permit should be obtained or at least the erosion control features in a LDP should be incorporated. This alternative also needs drillers and construction contractors. No specialized contractors are anticipated to be needed.

Availability of services and materials: Vendors and contractors for chemical oxidation are available to supply treatment chemicals and implementation of chemical oxidation process. Availability and scheduling of equipment and supplies would not be anticipated to pose problems.

5.1.5.8 *Cost*

The present worth (as an opinion of probable costs) for this alternative is approximately $1,267,000. The present worth cost was calculated using a discount rate of 5 percent. Details of the probable cost and key assumptions are included in **Table 4.**

5.1.6 Remedial Alternative 6 – In Situ Bioremediation and MNA

5.1.6.1 *Description*

In situ bioremediation involves the amplification of biological processes within the subsurface for the removal of target constituents of concern from soil and groundwater. Aerobic biodegradation is particularly effective for benzene and naphthalene, as the biodegradation of these compounds occurs readily by soil bacteria (Cookson, 1995). The site-specific ability of aerobic biodegradation was initially evaluated by the implementation of an oxygen diffusion pilot study (S&ME, 2008). This pilot study concluded that the addition of oxygen resulted in the reduction of benzene and naphthalene within wells that had oxygen diffusers (ENSR, 2008). In addition, microbial analysis at several monitoring wells indicated the presence of genes responsible for aerobic benzene and naphthalene biodegradation (AECOM, 2017).

Application of solid calcium peroxide was selected as the oxygen delivery method for this FFS. This amendment is capable of imparting oxygen to groundwater for up to 12 months. It was assumed that this amendment would be applied in two separate locations encompassing approximately 15,600 square feet as shown on **Figure 13**. This area was selected as it contains elevated groundwater concentrations and residual TLM, as measured by TarGOST® (AECOM, 2017). This amendment would be applied via soil mixing, as described in Alternative 5.

Natural attenuation would be used to address the residual constituents in areas beyond the influence of calcium peroxide application. As part of post-application monitoring and MNA, groundwater monitoring would be performed to evaluate if natural processes are enhancing attenuation of the residual dissolved COCs. For the purpose of costing, it is estimated that 30 monitoring wells would be sampled quarterly in year one and annually from years two through eight for VOCs. Eight wells would sampled for various geochemical parameters (e.g., dissolved gases, electron acceptors, etc.) at each event. In addition, field parameters such as DO, ORP, pH, temperature, and conductivity would be measured at each sampled well during the monitoring events. The exact number and locations of monitoring wells would be revised during the remedial design and remedial action phases.

After the first year, it is anticipated that MNA would continue annually for another 7 years when remedial goals should be reached. For the purpose of this evaluation, the project life of this alternative is estimated to be 8 years.

5.1.6.2 *Overall Protection of Human Health and the Environment*

Alternative 6 is expected to be protective of human health and the environment. Aerobic biodegradation in the treatment area is expected to reduce benzene and naphthalene. Natural attenuation processes are expected to remediate any remaining untreated (residual) impacts in groundwater. Institutional controls will continue to be implemented to restrict usage of impacted groundwater until RGs are met.

5.1.6.3 *Compliance with Applicable or Relevant and Appropriate Requirements*

Chemical-specific: This alternative is expected to result in COCs in groundwater meeting RGs within 8 years.

Location-specific: No location-specific ARARs were identified for this alternative.

Action-specific: While the anticipated disturbed area of this alternative would be less than one-acre, it is anticipated that a LDP, or at least an erosion control plan consistent with SCDHEC requirements for a LDP, be developed to protect Chinquapin Creek and the other on-site tributaries. Although amendments would be applied within the subsurface, the pit would be wider than it is deep and would not require an UIC permit from the SCDHEC UIC Section (i.e., the pit would not meet the definition of a well in South Carolina).

5.1.6.4 *Long-term Effectiveness and Permanence*

Magnitude of residual risk: Alternative 6 involves a combination of active and passive remedies. Areas containing residual COCs in groundwater that are not directly affected by amendment application are expected to attenuate through natural biotic processes. Aerobic bioremediation has been demonstrated in a pilot study and laboratory analyses to be effective in treating benzene and naphthalene (S&ME, 2008).

Adequacy and reliability of controls: Treatment of impacted groundwater with aerobic bioremediation would be an effective method of treating constituents in groundwater and reducing impacts to the environment. Existing risks associated with untreated residuals in groundwater are expected to decline in the future due to natural attenuation processes. Groundwater use restrictions will continue until the groundwater RGs are achieved.

5.1.6.5 *Reduction of Toxicity, Mobility, or Volume*

Aerobic bioremediation is expected to reduce toxicity, mobility, and volume of constituents in groundwater. In this process, organics are biotically and permanently converted into to CO_2 and water. Further, natural attenuation processes are expected to assist in reducing toxicity, mobility, and volume of constituents in groundwater.

5.1.6.6 *Short-term Effectiveness*

Implementation of Alternative 6 would involve routine groundwater sampling to monitor effectiveness. The areas proposed for aerobic bioremediation in this alternative are easily accessible. Aerobic bioremediation involves handling of corrosive chemicals (calcium peroxide). Use of proper PPE and adhering to a site-specific HASP would provide adequate protection. This alternative would not impact the community or result in adverse environmental impacts. Long-term monitoring will be required to meet the groundwater RG.

5.1.6.7 *Implementability*

Technical feasibility: To be successful, biological amendments must achieve contact with the targeted remediation material. This requirement is often difficult to achieve in low permeability subsurface conditions, such as dense silts and saprolite, which are present at the Site. Therefore, delivery of the amendment via direct-mixing (instead of injection) would be performed in order to increase contact of the amendment with the targeted remediation material. The open pit direct-mixing method has been successfully used to remediate organic chemicals in groundwater in geologic settings similar to those present at the Site. The construction activities required to perform soil mixing and to apply chemicals are easily implemented. The process of applying the amendment via soil mixing would require the implementation of a HASP. Implementation of the HASP would prevent exposure to chemicals during the application.

Administrative feasibility: Implementation of Alternative 6 requires no excessive coordination with state and local agencies. While it appears that the land disturbance would be less than 1 acre, due to the proximity of Chinquapin Creek, a land disposal permit should be obtained or at least the erosion control features in a LDP should be incorporated. This alternative also needs drillers and construction contractors. No specialized contractors are anticipated to be needed.

Availability of services and materials: Vendors and contractors for chemical oxidation are available to supply treatment chemicals and implementation of chemical oxidation process. Availability and scheduling of equipment and supplies would not be anticipated to pose problems.

5.1.6.8 *Cost*

The present worth (as an opinion of probable costs) for this alternative is approximately $1,185,000. The present worth cost was calculated using a discount rate of 5 percent. Details of the probable cost and key assumptions are included in **Table 5**.

6 Comparative Evaluation of Remedial Alternatives

This section presents a comparative analysis of the remedial alternatives according to the CERCLA evaluation criteria. This analysis is the second stage of the detailed evaluation process and provides information that forms the basis for selecting a preferred remedy. The analysis of similarities and differences among alternatives is presented to highlight significant differences. A summary of the comparative analysis is presented on **Table 6**.

6.1 Overall Protection of Human Health and the Environment

The six alternatives provide varying levels of human health protection. Alternative 1, no action, does not achieve the RAOs and provides the least protection of all the alternatives; it provides no reduction in risks to human health and the environment because no measures would be implemented to eliminate potential pathways for human exposure to COCs in groundwater.

All five remaining alternatives protect human health and the environment as long as appropriate measures are implemented (i.e., LUCs) to prevent exposure to COCs from groundwater until the RGs are met. Alternative 2 relies upon continued performance of the current MNA program. Alternatives 3 and 4 rely upon physical processes to either remove mass or reduce the mobility of current mass and the propensity of that mass to be emitted into the groundwater. Alternatives 5 and 6 use chemical or biological processes to convert mass of COCs into innocuous compounds.

6.2 Compliance with Applicable of Relevant and Appropriate Requirements

Alternative 1 (No Action) - Does not comply with chemical-specific ARARs for groundwater because no remedial measures would be implemented.

All remaining treatment alternatives (i.e., Alternatives 2-6) are expected to return the groundwater to meet the chemical-specific ARARs although they would require different time frames to achieve the RGs.

Alternative 2 (MNA and LUCs) - Continues the current MNA program and while it is anticipated to take a comparatively long time (i.e., 50 years or more), it will eventually meet the chemical and action-specific ARARs.

Alternative 3 (Targeted Excavation with MNA/LUCs) - Relies upon removal of mass and represents the shortest time to achieve the RAOs.

Alternative 4 (In Situ Encapsulation/Stabilization with MNA/LUCs) - Relies upon the immobilization of any remaining mass to limit or stop the emission of the mass into the groundwater thereby achieving the groundwater RGs.

Alternative 5 (In Situ Chemical Oxidation with MNA/LUCs) and Alternative 6 (In Situ Bioremediation with MNA/LUCs) - Comply with the chemical-specific ARARs for groundwater because they would convert the current existing mass into innocuous compounds and would eventually result in groundwater concentrations to less than RGs.

All of the active treatment alternatives would comply with the location-specific and action-specific ARARs.

6.3 Long-term Effectiveness and Permanence

Alternative 1 would be the least effective and permanent in the long term because no COC removal or treatment would take place and no measures would be implemented to control exposure to risks posed by affected groundwater or the potential for groundwater to migrate to downgradient receptors. Alternative 2 would be slightly more effective than No Action since it provides additional risk mitigation through periodic verification that the assumptions made in the performance of the risk evaluation are still salient.

Residual risk for the remaining active alternatives is expected to be minimal as long as the integrity of institutional and engineered controls is maintained.

Alternatives 3 and 4 exhibit the most permanence and long-term effectiveness of all the alternatives either by removal of COC mass or by the complete immobilization. While stabilization of TLM is considered permanent, there is risk that sorbed mass could “break free” over time.

Alternatives 5 and 6 run recurring risk of COC rebound in groundwater either by ineffective contact with the amendments, COC mass heterogeneities, or through altering of the groundwater geochemistry and mobilizing additional mass. All four active alternatives (Alternatives 3 through 6) would require some level of long-term management until RAOs are achieved.

6.4 Reduction in Toxicity, Mobility, and Volume

Alternative 1 does not employ treatment of groundwater and would not result in a reduction of toxicity, mobility, or volume of COCs, other than that which occurs naturally.

The active alternatives are expected to reduce toxicity, mobility, and volume through removal, immobilization and/or in situ treatment. Alternative 2 provides documentation of reductions in toxicity and volume via continued performance of the current MNA Program.

Alternative 3 provides a reduction of mass volume and through that reduction a reduction in overall toxicity. Alternative 4 provide significant reduction in mobility by binding the remaining mass within the soil. Alternative 5 and 6 reduce both the volume and toxicity of COCs by degrading the COCs to innocuous compounds. However, Alternatives 5 and 6 have a higher likelihood of having elevated COC mass remain after active remediation.

6.5 Short-term Effectiveness

Risk to workers during implementation of the four active groundwater alternatives includes exposure to dissolved phase plume or vapor; however, this risk would be minimized when proper health and safety procedures are used. Each of the alternatives present on site physical risks due to the use of heavy equipment. Proper safety measures are required to ensure potential chemical hazards associated with the use of cement for Alternative 4, sodium persulfate and sodium hydroxide for Alternative 5 and calcium peroxide for Alternative 6. Engineering controls would significantly minimize exposure to COCs. MNA would be required for all active alternatives to demonstrate meeting groundwater RGs.

6.6 Implementability

Administratively, all the action alternatives are implementable.

The four action alternatives (Alternatives 3 through 6) are all technically implementable with varying degrees of difficulty. In the order of increasing difficulty, the Alternatives are ranked: Alternative 3, Alternative 5, Alternative 6, and Alternative 4. Each of the alternatives discussed are common applications, have been historically used in the environmental industry, and have specifically been used at former MGP sites.

6.7 Costs

The following table presents the probable range of costs for each alternative:

Alternative	Low Cost (-30%)	Most Likely Cost	High Cost (+50%)
1. No Action	$0	$0	$0
2. MNA and LUCs	$356,000	$509,000	$763,000
3. Excavation with MNA/LUCs	$676,000	$966,000	$1,449,000
4. Stabilization / Solidification with MNA/LUCs	$619,000	$884,000	$1,326,000
5. ISCO with MNA/LUCs	$887,000	$1,267,000	$1,900,000
6. In-Situ Bioremediation with MNA/LUCs	$830,000	$1,185,000	$1,778,000

6.8 Numerical Evaluation and Alternatives Ranking

Table 6 presents a summary of the comparative analysis. A relative score of 1 through 6, with 6 being the highest score (i.e., excellent) and 1 being the lowest score (i.e., unacceptable) was assigned to rank the evaluation criteria for each alternative, with the exception of cost. The criteria scores were then summed to give a total score for each of the alternatives for ranking purposes.

As shown in **Table 6**, the alternative with the highest ranking is Alternative 3 – Targeted Excavation with MNA/LUCs (Score of 31) followed by Alternative 4 – In Situ Encapsulation with MNA/LUCs (Score of 26). These are followed in order by Alternative 6 – In Situ Bioremediation with MNA/LUCs, Alternative 5 – In Situ Chemical Oxidation with MNA/LUCs, Alternative 2 – MNA and LUCs, and finally Alternative 1– No Action.

7 References

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Tables

Table 1
Alternative 2 Opinion of Probable Costs - Monitored Natural Attenuation and Land Use Controls
Former Pine Street MGP
Spartanburg, South Carolina

			DESCRIPTION	NOTES	UNITS	QUANTITY	UNIT COST ($)	TOTAL COST ($)
I.	**Pre-Implementation Costs**							
	1.	Office Preparation						
		a.	Work Plan		ls	1	$15,000	$15,000
		b.	HASP Update		ls	1	$13,000	$13,000
			Subtotal Services					*$28,000*
			Total Pre-Implementation Costs					**$28,000**
II.	**MNA Costs**							
	1.	MNA Year 1						
		a.	Semi-Annual Sampling Year 1		ea	2	$8,500	$17,000
		b.	Groundwater Reporting (annual)		yr	1	$15,000	$15,000
		c.	Semi-Annual Waste Removal		ea	2	$1,000	$2,000
		d.	Site Maintenance		ea	4	$3,500	$14,000
			Subtotal Year 1 MNA					*$48,000*
	2.	MNA Years 2-50 (Annual Cost)						
		a.	Annual Sampling		ea	1	$8,500	$8,500
		b.	Groundwater Reporting (annual)		yr	1	$10,000	$10,000
		c.	Semi-Annual Waste Removal		ea	1	$1,000	$1,000
		d.	Site Maintenance		ea	2	$2,500	$5,000
			Subtotal Year 2-50 MNA					*$445,134*
			Subtotal prior to services					*$445,134*
	3.	Services						
		a.	Project Management/Coordination	a	ls	1	$35,611	$35,700
			Subtotal Services					*$35,700*
			Total MNA Costs					**$480,834**
			Cost Summary					
		I.	Pre-Implementation Costs					$28,000
		II.	MNA Costs					$480,834
			TOTAL PROBABLE COSTS					**$508,834**
			TOTAL PROBABLE COSTS RANGE (-30%; + 50%)			**$356,184**	**to**	**$763,251**

Notes/Key Assumptions:

a/ Project management/coordination costs based on Table 5-8 from "A guide to developing and documenting cost estimates during the feasibility study" ; Capital costs <100K (10%), 100K-500K (8%); 500K-2M (6%); 2M-10M (5%); >10M (5%)

Operation and maintenance costs are discounted at a rate of 5 percent.

Table 2
Alternative 3 Opinion of Probable Costs - Targeted Excavation with MNA/LUCs
Former Pine Street MGP
Spartanburg, South Carolina

			DESCRIPTION	NOTES	UNITS	QTY	UNIT COST ($)	TOTAL COST ($)
I.	**Pre-Construction Costs**							
	1.	Office Preparation						
		a.	Remedial Action Work Plan		ls	1	$14,500	$14,500
		b.	HASP Update		ls	1	$13,000	$13,000
		c.	Erosion Plan / Land Disturbance Permit		ls	1	$15,000	$15,000
			Subtotal prior to services					*$42,500*
	2.	Services						
		a.	Contingency (20% Pre-Construction Costs)		ls	1	$8,500	$8,500
		b.	Project Management/Coordination	a	ls	1	$4,250	$4,300
			Subtotal Services					*$12,800*
			Total Pre-Construction Costs					**$55,300**
II.	**Construction Costs**							
	1.	Site Preparation						
		a.	Utility Locate and Survey		ls	1	$1,800	$1,800
		b.	Equipment Decontamination Pad		ls	1	$5,500	$5,500
			Subtotal Site Preparation					*$7,300*
	2.	Excavation						
		a.	Mobilization		ls	1	$5,000	$5,000
		b.	Water Management		ls	1	$22,000	$22,000
		c.	Soil Excavation		tons	9,800	$12.20	$119,600
		d.	Soil Transportation and Disposal		tons	2,250	$50.00	$112,500
		e.	Confirmation Sampling		ls	1	$6,500	$6,500
		f.	Granular Activated Carbon		tons	2	$4,000.00	$9,000
		g.	Oxygen Compound		tons	0.7	$8,000.00	$6,000
		h.	Backfill and Compact Onsite Fill		tons	9,800	$7.65	$75,000
		i.	Import Soil and Backfill		tons	3,840	$20.55	$79,000
		j.	Planting of Soil		acre	1	$15,000	$15,000
		k.	Re-install monitoring wells		ea	5	$4,500.00	$22,500
		l.	Investigative derived waste disposal		ls	1	$1,500	$1,500
			Subtotal Excavation					*$473,600*
	3.	Services						
		a.	Contingency (20% Excavation)		ls	1	$94,720	$94,800
		b.	Project Management/Coordination	a	ls	1	$37,888	$37,900
		c.	Construction Management	b	ls	1	$47,360	$47,400
			Subtotal Services					*$180,100*
			Total Construction Costs					**$661,000**

Table 2
Alternative 3 Opinion of Probable Costs - Targeted Excavation with MNA/LUCs
Former Pine Street MGP
Spartanburg, South Carolina

			DESCRIPTION	NOTES	UNITS	QTY	UNIT COST ($)	TOTAL COST ($)
III.	**MNA and Site Maintenance Costs**							
	1.	MNA / Performance Monitoring Year 1						
		a.	Quarterly Groundwater Poerformance Monitoring		ea	2	$4,500	$9,000
		b.	Semi-Annual MNA Sampling		ea	2	$8,500	$17,000
		c.	Semi-Annual Waste Removal		ea	2	$1,000	$2,000
		d.	Site Maintenance		ea	4	$3,500	$14,000
		e.	Groundwater Reporting (annual)		ea	1	$15,000	$15,000
			Subtotal Year 1 MNA					*$57,000*
	2.	MNA Years 2-8 (Annual Cost)						
		a.	Annual Sampling		ea	1	$8,500	$8,500
		b.	Groundwater Reporting (annual)		yr	1	$10,000	$10,000
		c.	Semi-Annual Waste Removal		ea	1	$1,000	$1,000
		d.	Site Maintenance		ea	2	$2,500	$5,000
			Subtotal Year 2-8 MNA					*$141,766.15*
	3.	Services						
		a.	Contingency (20% MNA Monitoring)		ls	1	$39,753	$39,800
		b.	Project Management/Coordination	a	ls	1	$11,341	$11,400
			Subtotal Services					*$51,200*
			Total O&M Costs					**$249,966**
			Cost Summary					
		I.	Pre-Construction Costs					$55,300
		II.	Construction Costs					$661,000
		III.	MNA and Site Maintenance Costs					$249,966
			TOTAL PROBABLE COSTS					**$966,266**
			TOTAL PROBABLE COSTS RANGE (-30%; + 50%)			**$676,386**	**to**	**$1,449,399**

Notes/Key Assumptions:

a/ Project management/coordination costs based on Table 5-8 from "A guide to developing and documenting cost estimates during the feasibility study" ; Capital costs <100K (10%), 100K-500K (8%); 500K-2M (6%); 2M-10M (5%); >10M (5%)

b/ Construction management costs based on Table 5-8 from "A guide to developing and documenting cost estimates during the feasibility study" ; Capital costs <100K (15%), 100K-500K (10%); 500K-2M (8%); 2M-10M (6%); >10M (6%)

Operation and maintenance costs are discounted at a rate of 5 percent.

Table 3
Alternative 4 Opinion of Probable Costs - In Situ Encapsulation/Stabilization with MNA/LUCs
Former Pine Street MGP
Spartanburg, South Carolina

			DESCRIPTION	NOTES	UNITS	QTY	UNIT COST ($)	TOTAL COST ($)
I.	**Pre-Construction Costs**							
	1.	Office Preparation						
		a.	Remedial Action Work Plan		ls	1	$17,500	$17,500
		b.	HASP Update		ls	1	$13,000	$13,000
		c.	Erosion Plan / Land Disturbance Permit		ls	1	$15,000	$15,000
			Subtotal prior to services					*$45,500*
	2.	Services						
		a.	Contingency (20% Pre-Construction Costs)		ls	1	$9,100	$9,100
		b.	Project Management/Coordination	a	ls	1	$4,550	$4,600
			Subtotal Services					*$13,700*
			Total Pre-Construction Costs					**$59,200**
II.	**Construction Costs**							
	1.	Site Preparation						
		a.	Utility Locate and Survey		ls	1	$1,800	$1,800
		b.	Equipment Decontamination Pad		ls	1	$2,500	$2,500
			Subtotal Site Preparation					*$4,300*
	2.	Excavation						
		a.	Mobilization		ls	1	$5,000	$5,000
		b.	Water Management		ls	1	$22,000	$22,000
		c.	Soil Excavation		tons	6,400	$12.20	$78,100
		d.	Soil Mixing (10% cement and 1% PAC)		tons	3,350	$68.00	$227,800
		e.	Backfill and Compact Onsite Fill		tons	6,400	$7.65	$49,000
		f.	Planting of Soil		acre	1	$15,000	$15,000
		g.	Investigative derived waste disposal		ls	1	$1,500	$1,500
			Subtotal Stabilization					*$398,400*
	3.	Services						
		a.	Contingency (20% Stabilization)		ls	1	$79,680	$79,700
		b.	Project Management/Coordination	a	ls	1	$31,872	$31,900
		c.	Construction Management	b	ls	1	$39,840	$39,900
			Subtotal Services					*$151,500*
			Total Construction Costs					**$554,200**

Table 3
Alternative 4 Opinion of Probable Costs - In Situ Encapsulation/Stabilization with MNA/LUCs
Former Pine Street MGP
Spartanburg, South Carolina

			DESCRIPTION	NOTES	UNITS	QTY	UNIT COST ($)	TOTAL COST ($)
III.	**MNA and Site Maintenance Costs**							
	1.	MNA / Performance Monitoring Year 1						
		a.	Quarterly Groundwater Performance Monitoring		ea	2	$4,500	$9,000
		b.	Semi-Annual MNA Sampling		ea	2	$8,500	$17,000
		c.	Semi-Annual Waste Removal		ea	2	$1,000	$2,000
		d.	Site Maintenance		ea	4	$3,500	$14,000
		e.	Groundwater Reporting (annual)		ea	1	$20,000	$20,000
			Subtotal Year 1 MNA					*$62,000*
	2.	MNA Years 2-8 (Annual Cost)						
		a.	Annual Sampling		ea	1	$8,500	$8,500
		b.	Groundwater Reporting (annual)		yr	1	$10,000	$10,000
		c.	Semi-Annual Waste Removal		ea	1	$1,000	$1,000
		d.	Site Maintenance		ea	2	$3,500	$7,000
			Subtotal Year 2-8 MNA					*$153,339*
	3.	Services						
		a.	Contingency (10% MNA Monitoring)		ls	1	$43,068	$43,100
		b.	Project Management/Coordination	a	ls	1	$12,267	$12,300
			Subtotal Services					*$55,400*
			Total O&M Costs					**$270,739**
			Cost Summary					
		I.	Pre-Construction Costs					$59,200
		II.	Construction Costs					$554,200
		III.	MNA and Site Maintenance Costs					$270,739
			TOTAL PROBABLE COSTS					**$884,139**
			TOTAL PROBABLE COSTS RANGE (-30%; + 50%)			**$618,897**	**to**	**$1,326,208**

Notes/Key Assumptions:

a/ Project management/coordination costs based on Table 5-8 from "A guide to developing and documenting cost estimates during the feasibility study" ; Capital costs <100K (10%), 100K-500K (8%); 500K-2M (6%); 2M-10M (5%); >10M (5%)

b/ Construction management costs based on Table 5-8 from "A guide to developing and documenting cost estimates during the feasibility study" ; Capital costs <100K (15%), 100K-500K (10%); 500K-2M (8%); 2M-10M (6%); >10M (6%)

Operation and maintenance costs are discounted at a rate of 5 percent.

Table 4
Alternative 5 Opinion of Probable Costs - In Situ Chemical Oxidation with MNA/LUCs
Former Pine Street MGP
Spartanburg, South Carolina

			DESCRIPTION	NOTES	UNITS	QTY	UNIT COST ($)	TOTAL COST ($)
I.	**Pre-Construction Costs**							
	1.	Office Preparation						
		a.	Remedial Action Work Plan		ls	1	$22,000	$22,000
		b.	HASP Update		ls	1	$13,000	$13,000
		c.	Erosion Plan / Land Disturbance Permit		ls	1	$15,000	$15,000
			Subtotal prior to services					*$50,000*
	2.	Services						
		a.	Contingency (20% Pre-Construction Costs)		ls	1	$10,000	$10,000
		b.	Project Management/Coordination	a	ls	1	$5,000	$5,000
			Subtotal Services					*$15,000*
			Total Pre-Construction Costs					**$65,000**
II.	**Construction Costs**							
	1.	Site Preparation						
		a.	Utility Locate and Survey		ls	1	$1,800	$1,800
		b.	Equipment Decontamination Pad		ls	1	$5,500	$5,500
			Subtotal Site Preparation					*$7,300*
	2.	Excavation						
		a.	Mobilization		ls	1	$5,000	$5,000
		b.	Overburden Excavation		tons	6,400	$12.20	$78,100
		c.	Soil Mixing		ls	1	$330,000.00	$330,000
		d.	Material (H2O2 and Chelated Iron)		tons	48	$3,580.00	$170,100
		e.	Confirmation Sampling		ls	1	$6,500.00	$6,500
		f.	Backfill and Compact Onsite Fill		tons	6,400	$9.50	$60,800
		g.	Planting of Soil		acre	1	$15,000	$15,000
		h.	Investigative derived waste disposal		ls	1	$1,500	$1,500
		i.	Re-install monitoring wells		ea	5	$4,500.00	$22,500
			Subtotal ISCO Soil Blending					*$689,500*
	3.	Services						
		a.	Contingency (20% ISCO)		ls	1	$137,900	$137,900
		b.	Project Management/Coordination	a	ls	1	$41,370	$41,400
		c.	Construction Management	b	ls	1	$55,160	$55,200
			Subtotal Services					*$234,500*
			Total Construction Costs					**$931,300**

Table 4
Alternative 5 Opinion of Probable Costs - In Situ Chemical Oxidation with MNA/LUCs
Former Pine Street MGP
Spartanburg, South Carolina

			DESCRIPTION	NOTES	UNITS	QTY	UNIT COST ($)	TOTAL COST ($)
III.	**MNA and Site Maintenance Costs**							
	1.	MNA / Performance Monitoring Year 1						
		a.	Quarterly Groundwater Poerformance Monitoring		ea	2	$4,500	$9,000
		b.	Semi-Annual MNA Sampling		ea	2	$8,500	$17,000
		c.	Semi-Annual Waste Removal		ea	2	$1,000	$2,000
		d.	Site Maintenance		ea	4	$3,500	$14,000
		e.	Groundwater Reporting (annual)		ea	1	$20,000	$20,000
			Subtotal Year 1 MNA					*$62,000*
	2.	MNA Years 2-8 (Annual Cost)						
		a.	Annual Sampling		ea	1	$8,500	$8,500
		b.	Groundwater Reporting (annual)		yr	1	$10,000	$10,000
		c.	Annual Waste Removal		ea	1	$1,000	$1,000
		d.	Site Maintenance		ea	2	$3,500	$7,000
			Subtotal Year 2-8 MNA					*$153,339*
	3.	Services						
		a.	Contingency (10% MNA Monitoring)		ls	1	$43,068	$43,100
		b.	Project Management/Coordination	a	ls	1	$12,267	$12,300
			Subtotal Services					*$55,400*
			Total O&M Costs					**$270,739**
			Cost Summary					
		I.	Pre-Construction Costs					$65,000
		II.	Construction Costs					$931,300
		III.	MNA and Site Maintenance Costs					$270,739
			TOTAL PROBABLE COSTS					**$1,267,039**
			TOTAL PROBABLE COSTS RANGE (-30%; + 50%)			**$886,927**	**to**	**$1,900,558**

Notes/Key Assumptions:

a/ Project management/coordination costs based on Table 5-8 from "A guide to developing and documenting cost estimates during the feasibility study" ; Capital costs <100K (10%), 100K-500K (8%); 500K-2M (6%); 2M-10M (5%); >10M (5%)

b/ Construction management costs based on Table 5-8 from "A guide to developing and documenting cost estimates during the feasibility study" ; Capital costs <100K (15%), 100K-500K (10%); 500K-2M (8%); 2M-10M (6%); >10M (6%)

Operation and maintenance costs are discounted at a rate of 5 percent.

Table 5
Alternative 6 Opinion of Probable Costs - In Situ Bioremediation with MNA/LUCs
Former Pine Street MGP
Spartanburg, South Carolina

			DESCRIPTION	NOTES	UNITS	QTY	UNIT COST ($)	TOTAL COST ($)
I.	**Pre-Construction Costs**							
	1.	Office Preparation						
		a.	Remedial Action Work Plan		ls	1	$17,500	$17,500
		b.	HASP Update		ls	1	$13,000	$13,000
		c.	Erosion Plan / Land Disturbance Permit		ls	1	$15,000	$15,000
			Subtotal prior to services					*$45,500*
	2.	Services						
		a.	Contingency (20% Pre-Construction Costs)		ls	1	$9,100	$9,100
		b.	Project Management/Coordination	a	ls	1	$4,550	$4,600
			Subtotal Services					*$13,700*
			Total Pre-Construction Costs					**$59,200**
II.	**Construction Costs**							
	1.	Site Preparation						
		a.	Utility Locate and Survey		ls	1	$1,800	$1,800
		b.	Equipment Decontamination Pad		ls	1	$5,500	$5,500
			Subtotal Site Preparation					*$7,300*
	2.	Excavation						
		a.	Mobilization		ls	1	$5,000	$5,000
		c.	Overburden Excavation		tons	6,400	$12.20	$78,100
		e.	ORC Mixing (39000 lbs ORCx)		tons	3,350	$45.00	$150,800
		f.	ORC Material Costs		lbs	39,000	$7.50	$292,500
		f.	Confirmation Sampling		ls	1	$6,500.00	$6,500
		g.	Backfill and Compact Onsite Fill		tons	6,400	$9.50	$60,800
		h.	Planting of Soil		acre	1	$15,000	$15,000
		k.	Investigative derived waste disposal		ls	1	$1,500	$1,500
		l.	Re-install monitoring wells		ea	5	$4,500.00	$22,500
			Subtotal In Situ Bioremediation Blending					*$632,700*
	3.	Services						
		a.	Contingency (20% In Situ Bio)		ls	1	$126,540	$126,600
		b.	Project Management/Coordination	a	ls	1	$37,962	$38,000
		c.	Construction Management	b	ls	1	$50,616	$50,700
			Subtotal Services					*$215,300*
			Total Construction Costs					**$855,300**

Table 5
Alternative 6 Opinion of Probable Costs - In Situ Bioremediation with MNA/LUCs
Former Pine Street MGP
Spartanburg, South Carolina

			DESCRIPTION	NOTES	UNITS	QTY	UNIT COST ($)	TOTAL COST ($)
III.	**MNA and Site Maintenance Costs**							
	1.	MNA / Performance Monitoring Year 1						
		a.	Quarterly Groundwater Poerformance Monitoring		ea	2	$4,500	$9,000
		b.	Semi-Annual MNA Sampling		ea	2	$8,500	$17,000
		c.	Semi-Annual Waste Removal		ea	2	$1,000	$2,000
		d.	Site Maintenance		ea	4	$3,500	$14,000
		e.	Groundwater Reporting (annual)		ea	1	$20,000	$20,000
			Subtotal Year 1 MNA					*$62,000*
	2.	MNA Years 2-8 (Annual Cost)						
		a.	Annual Sampling		ea	1	$8,500	$8,500
		b.	Groundwater Reporting (annual)		yr	1	$10,000	$10,000
		c.	Annual Waste Removal		ea	1	$1,000	$1,000
		d.	Site Maintenance		ea	2	$3,500	$7,000
			Subtotal Year 2-8 MNA					*$153,339*
	3.	Services						
		a.	Contingency (10% MNA Monitoring)		ls	1	$43,068	$43,100
		b.	Project Management/Coordination	a	ls	1	$12,267	$12,300
			Subtotal Services					*$55,400*
			Total O&M Costs					**$270,739**
			Cost Summary					
		I.	Pre-Construction Costs					$59,200
		II.	Construction Costs					$855,300
		III.	MNA and Site Maintenance Costs					$270,739
			TOTAL PROBABLE COSTS					**$1,185,239**
			TOTAL PROBABLE COSTS RANGE (-30%; + 50%)			**$829,667**	**to**	**$1,777,858**

Notes/Key Assumptions:

a/ Project management/coordination costs based on Table 5-8 from "A guide to developing and documenting cost estimates during the feasibility study" ; Capital costs <100K (10%), 100K-500K (8%); 500K-2M (6%); 2M-10M (5%); >10M (5%)

b/ Construction management costs based on Table 5-8 from "A guide to developing and documenting cost estimates during the feasibility study" ; Capital costs <100K (15%), 100K-500K (10%); 500K-2M (8%); 2M-10M (6%); >10M (6%)

Operation and maintenance costs are discounted at a rate of 5 percent.

Table 6
Comparison of Remedial Alternatives to Evaluation Criteria
Former Pine Street MGP
Spartanburg, South Carolina

	Remedial Alternatives					
	Alternative 1	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative 6**
Criterion	**No Action**	**MNA and LUCs**	**Targeted Excavation with MNA/LUCs**	**In Situ Encapsulation with MNA/LUCs**	**ISCO with MNA/LUCs**	**In Situ Bioremediation with MNA/LUCs**
Overall protection of human health and the environment	2	3	5	4	4	4
Compliance with applicable federal, state and local regulations	1	2	5	5	4	4
Long-term effectiveness and permanence	3	3	6	4	3	3
Reduction of toxicity, mobility and volume	2	3	6	5	4	4
Short-term effectiveness	3	3	5	4	4	3
Implementability	6	5	4	4	3	4
Total Score	**17**	**19**	**31**	**26**	**22**	**22**
Cost	$0	$ 509,000	$ 966,000	$ 884,000	$ 1,267,000	$ 1,185,000
State and community acceptance	--	--	--	--	--	--

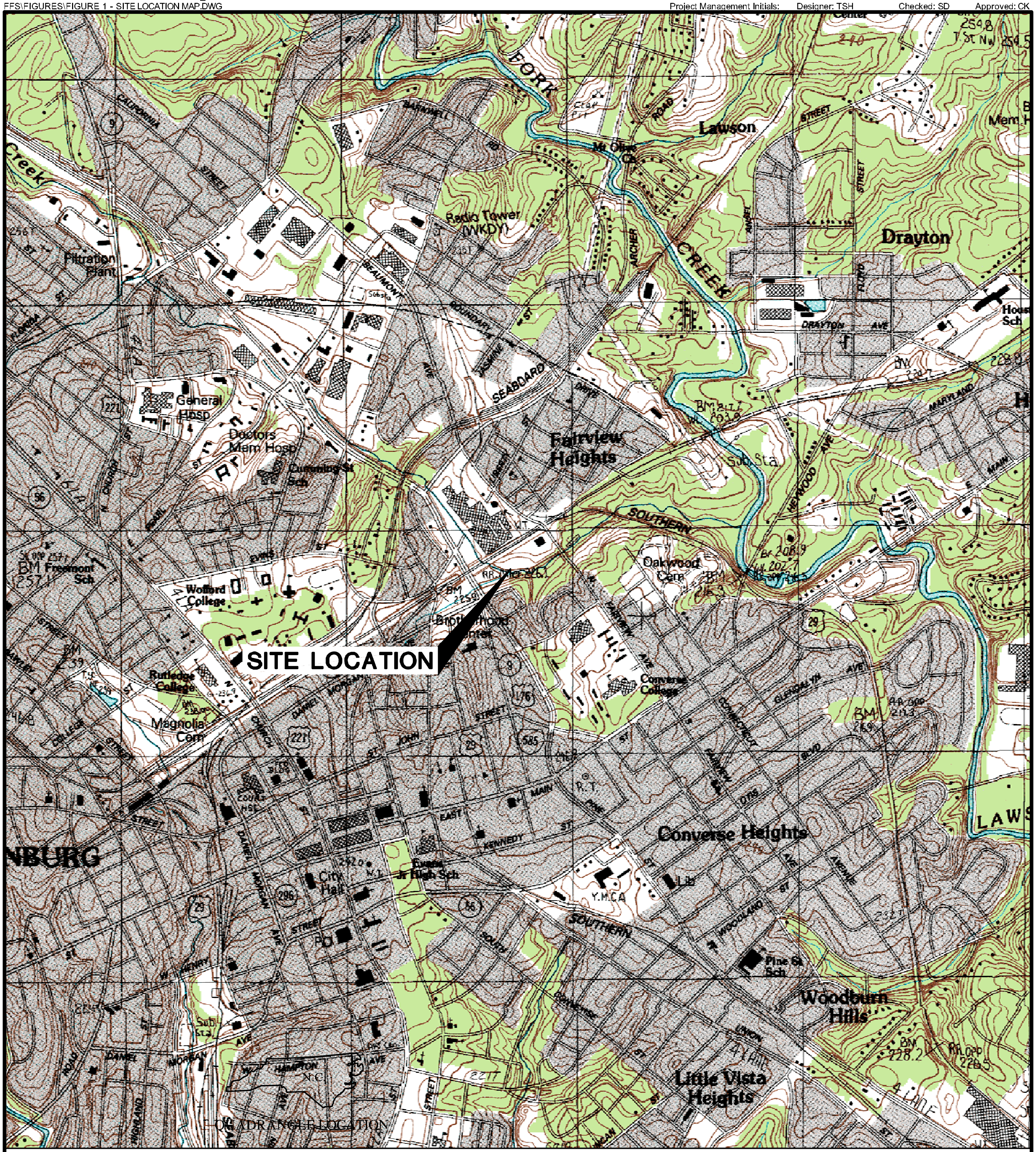
Notes:
ISCO - In Situ Chemical Oxidation
MNA - Monitored Natural Attenuation
LUCs - Land Use Controls
-- Not Ranked. State and community acceptance will be evaluated following approval.

Scoring:
1 = Unacceptable, does not meet the minimum requirements
2 = Alternative is on the **Low** end of the alternative criteria
3 = Alternative is **Fair** with respect to meeting the alternative criteria
4 = Alternative is **Good** with respect to meeting the alternative criteria
5 = Alternative is **Very Good** with respect to meeting the alternative criteria
6 = Alternative is **Excellent** with respect to meeting the alternative criteria

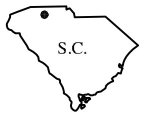
Figures

Filename: M:\DCS\PROJECTS\L-URS\COMMON_PROJECTS\DUKE ENERGY\SPARTANBURG\60544098 - FFS 2017\DRAFT FFS\FIGURES\FIGURE 1 - SITE LOCATION MAP.DWG

Project Management Initials: Designer: TSH Checked: SD Approved: CK



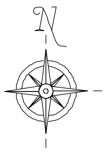
SPARTANBURG, SC – USGS TOPOGRAPHIC QUADRANGLE



QUADRANGLE LOCATION

SCALE IN FEET

0 2000

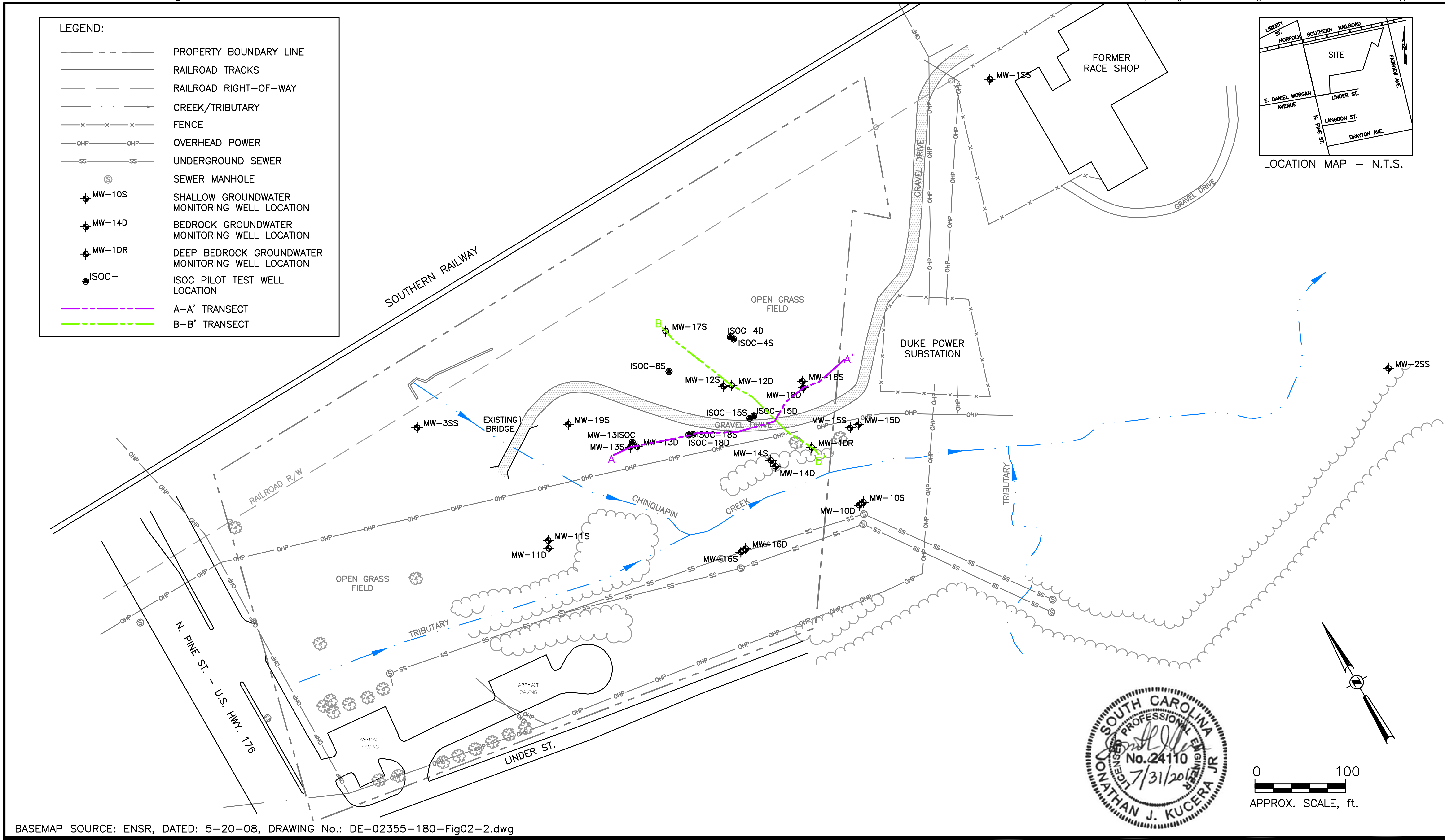


FOCUSED FEASIBILITY STUDY
DUKE ENERGY CORPORATION-FORMER MGP SITE
SPARTANBURG, SOUTH CAROLINA
Project No.: 60544098 Date: 2017-06-22

SITE LOCATION MAP

AECOM

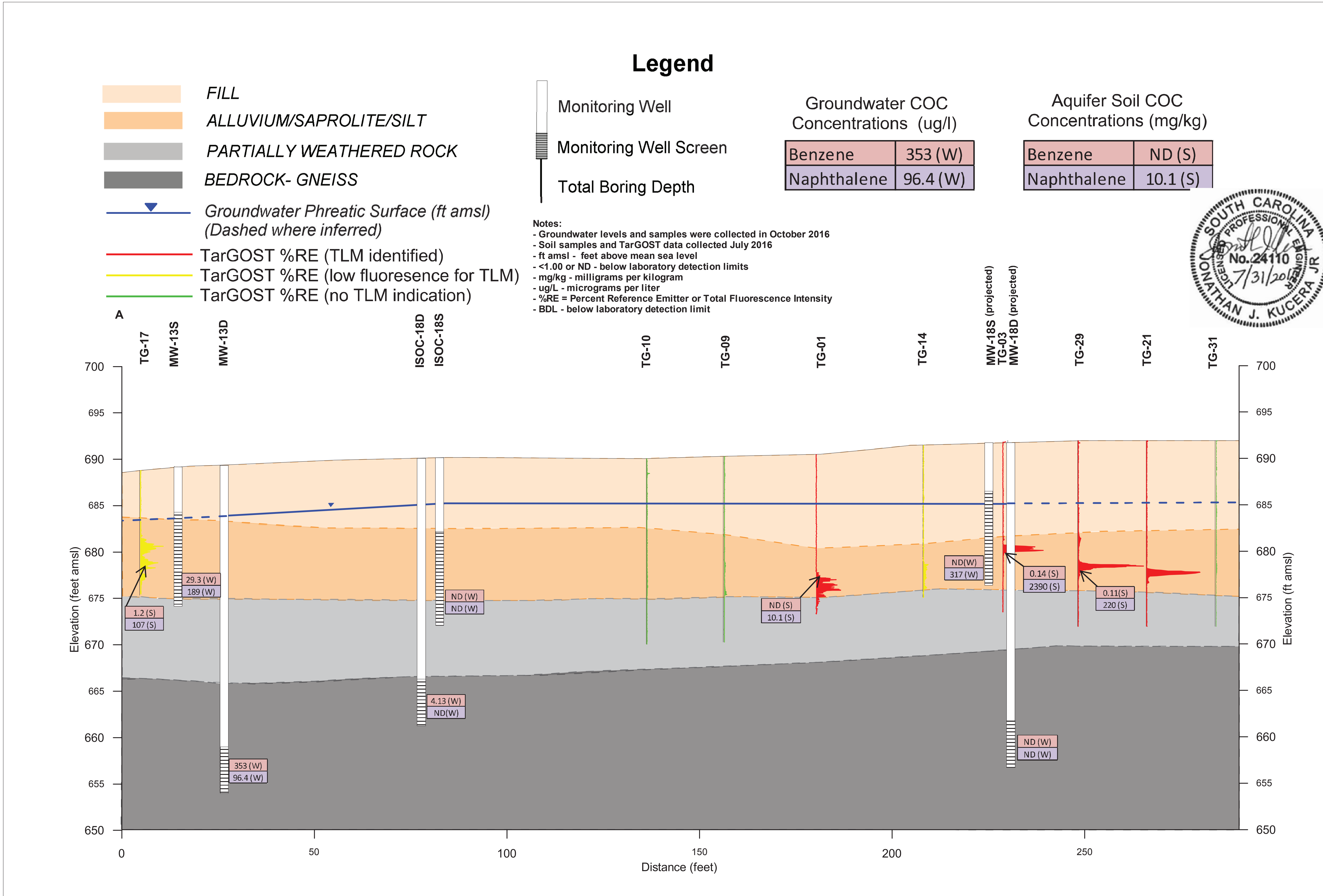
Figure: 1



FOCUSED FEASIBILITY STUDY
DUKE ENERGY CORPORATION-FORMER MGP SITE
SPARTANBURG, SOUTH CAROLINA
Project No.: 60544098 Date: 2017-06-22

SITE PLAN

AECOM
Figure: 2



AECOM

Figure 3

Cross-Section A-A'

Focused Feasibility Study
Spartanburg MGP
Spartanburg, SC
Project No.: 60544098 Date: 2017-06-30

Legend

Symbol	Description
	FILL
	ALLUVIUM/SAPROLITE/SILT
	PARTIALLY WEATHERED ROCK
	BEDROCK- GNEISS
	Groundwater Phreatic Surface (ft amsl) (Dashed where inferred)
	TarGOST %RE (TLM identified)
	TarGOST %RE (low fluoresence for TLM)
	TarGOST %RE (no TLM indication)
	Monitoring Well
	Monitoring Well Screen
	Total Boring Depth

Groundwater COC Concentrations (ug/l)

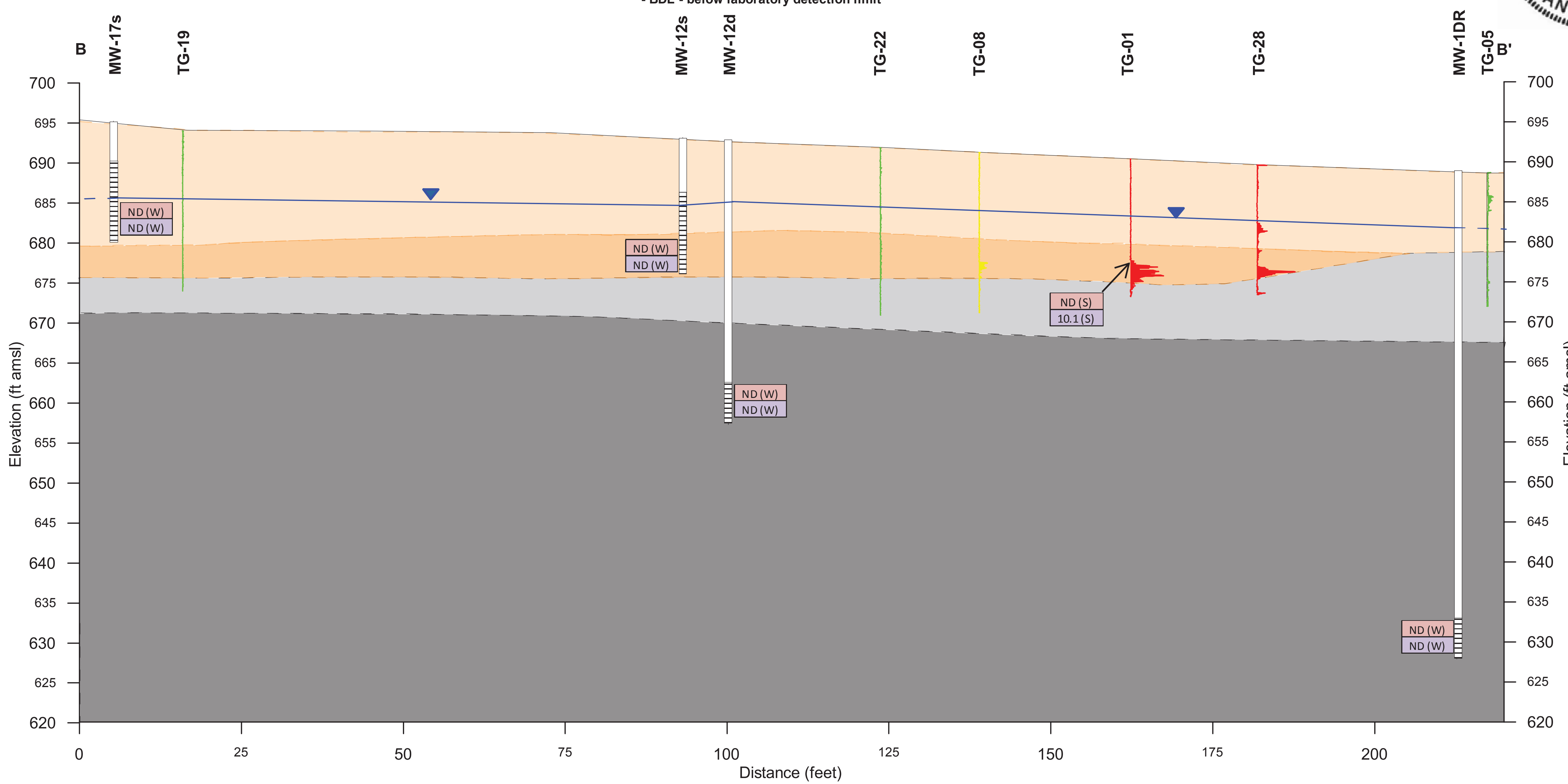
Benzene	ND (W)
Naphthalene	ND (W)

Aquifer Soil COC Concentrations (mg/kg)

Benzene	ND (S)
Naphthalene	10.1 (S)

Notes:
- Groundwater levels and samples were collected in October 2016
- Soil samples and TarGOST data collected July 2016
- ft amsl - feet above mean sea level
- <1.00 or ND - below laboratory detection limits
- mg/kg - milligrams per kilogram
- ug/L - micrograms per liter
- %RE = Percent Reference Emitter or Total Fluorescence Intensity
- BDL - below laboratory detection limit

SOUTH CAROLINA PROFESSIONAL ENGINEER No. 24110 JONATHAN J. KUCERA JR LICENSED 7/31/2017



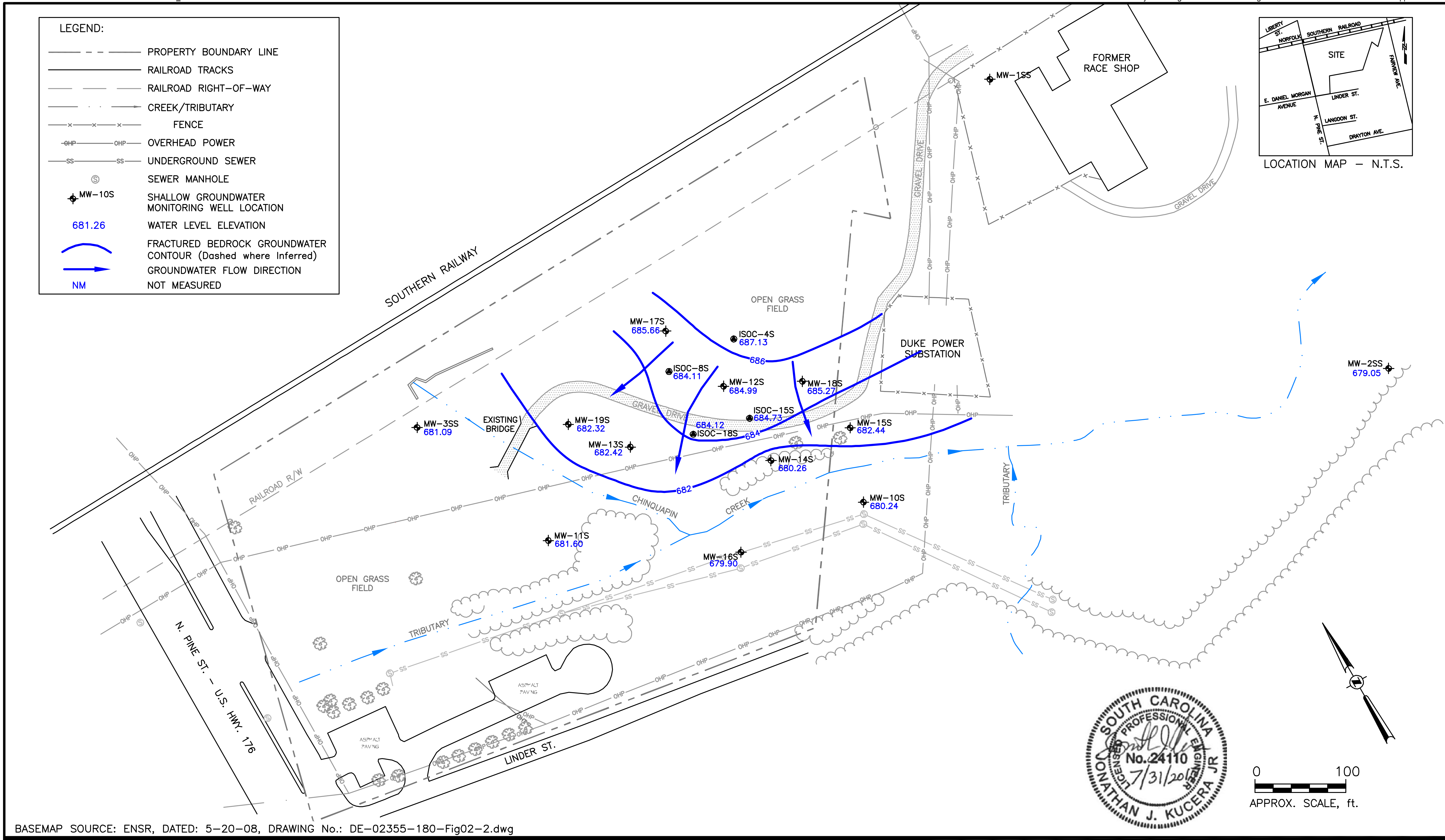
AECOM

Figure 4

Cross-Section B-B'

Focused Feasibility Study
Spartanburg MGP
Spartanburg, SC
Project No.: 60544098 Date: 2017-06-30

Filename: M:\DCS\PROJECTS\L-URS\COMMON_PROJECTS\DUKE ENERGY\SPARTANBURG\60544098 - FFS 2017\DRAFT FFS\FIGURES\FIGURES 5.6 - GROUNDWATER CONTOURS.DWG   Project Management Initials: Designer: TSH Checked: JK Approved: PF

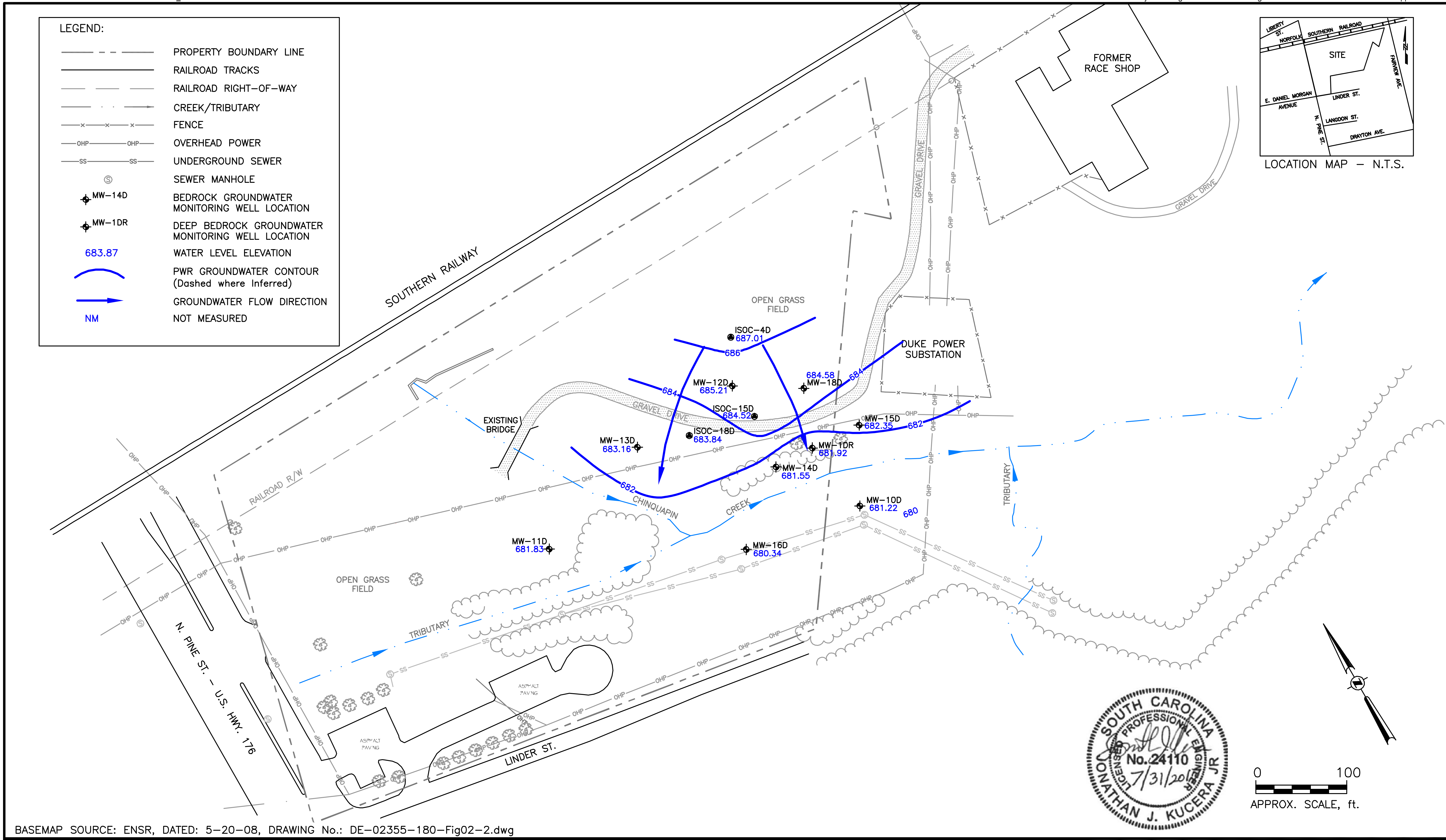


FOCUSED FEASIBILITY STUDY
DUKE ENERGY CORPORATION-FORMER MGP SITE
SPARTANBURG, SOUTH CAROLINA
Project No.: 60544098 Date: 2017-06-22

GROUNDWATER ELEVATIONS IN SAPROLITE WELLS - 10/17/2016

AECOM
Figure: 5

Filename: M:\DCS\PROJECTS\L-URS\COMMON_PROJECTS\DUKE ENERGY\SPARTANBURG\60544098 - FFS 2017\DRAFT FFS\FIGURES\FIGURES 5.6 - GROUNDWATER CONTOURS.DWG Project Management Initials: Designer: TSH Checked: JK Approved: PF

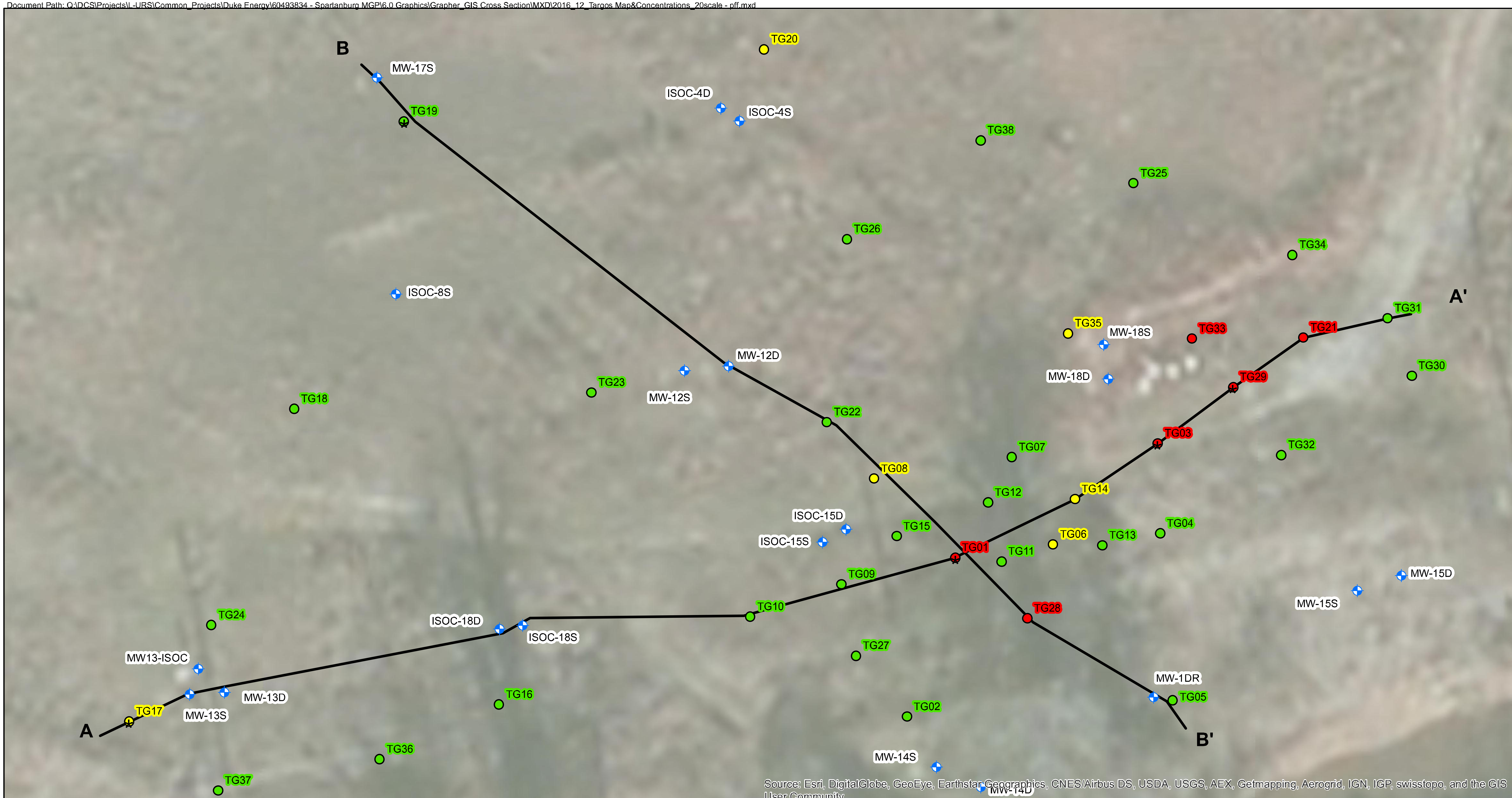


FOCUSED FEASIBILITY STUDY
DUKE ENERGY CORPORATION-FORMER MGP SITE
SPARTANBURG, SOUTH CAROLINA
Project No.: 60544098 Date: 2017-06-22

GROUNDWATER ELEVATIONS IN PWR AND FRACTURED ROCK WELLS - 10/17/2016

AECOM
Figure: 6

Document Path: Q:\DCS\Projects\I_-URS\Common_Projects\Duke Energy\60493834 - Spartanburg MGP\6.0 Graphics\Grapher_GIS Cross Section\MXD\2016_12_Targos Map&Concentrations_20scale - pff.mxd



Legend

- Monitoring Well
- TarGOST Boring (TLM identified)
- TarGOST Boring (low fluorescent response)
- TarGOST Boring (fluorescent resopnse not consistent with TLM)
- Soil Sample Collected
- Cross-Section Location

N

TarGOST Boring Location Map

Duke Energy Corporation- Former MGP Site
Spartanburg, South Carolina

1 inch = 20 feet

0 25 50 100 Feet

January 2017
60493834

SOUTH CAROLINA PROFESSIONAL ENGINEER LICENSED No. 24110 JONATHAN J. KUCERA JR 7/31/2017

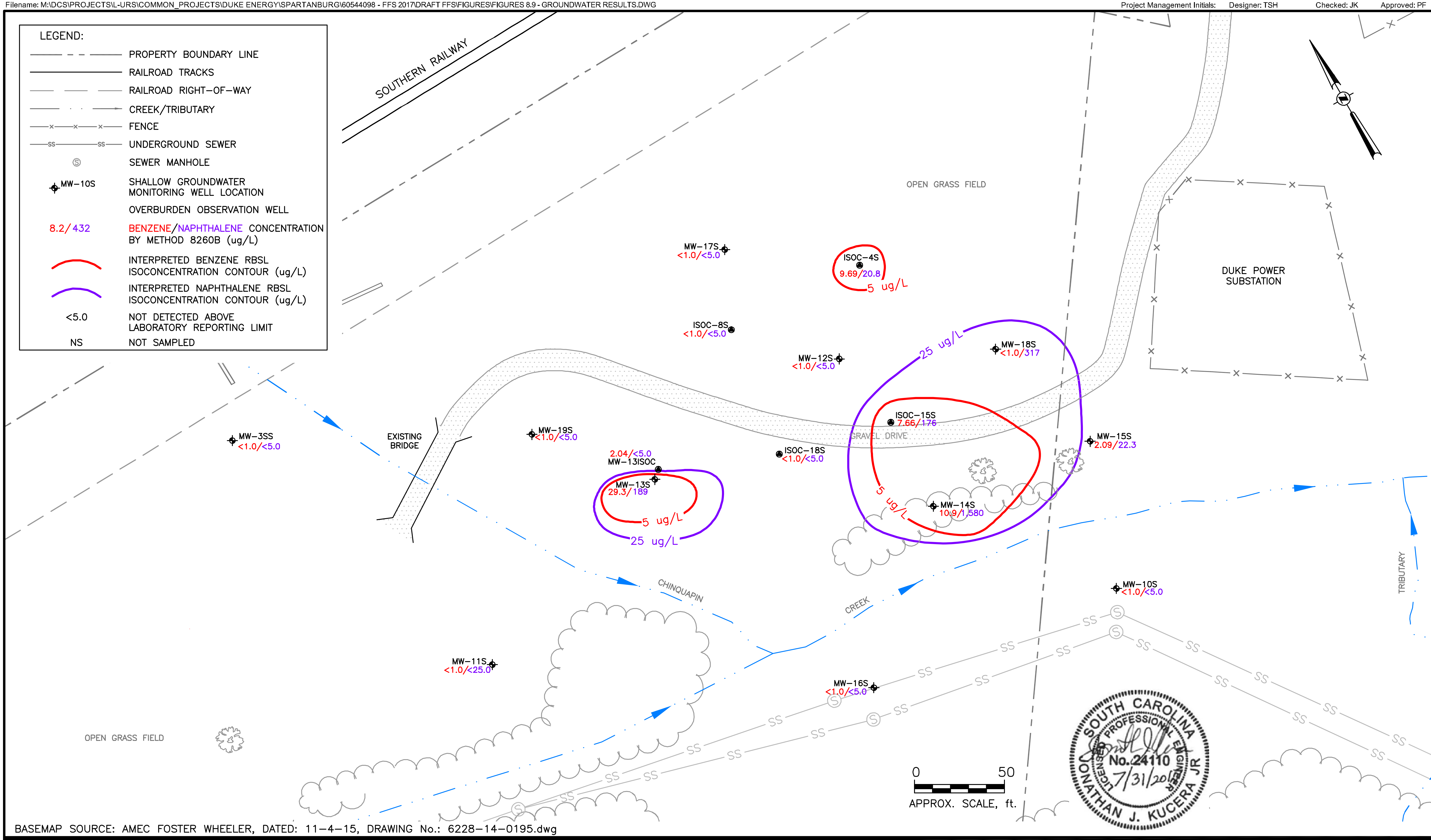
Figure 7

AECOM

1600 Perimeter Park Drive, Suite 400
Morrisville, NC 27560
tel: (919) 461-1100
fax: (919) 461-1415
web: www.AECOM.com

Filename: M:\DCS\PROJECTS\L-URS\COMMON_PROJECTS\DUKE ENERGY\SPARTANBURG\60544098 - FFS 2017\DRAFT FFS\FIGURES\FIGURES 8.9 - GROUNDWATER RESULTS.DWG

Project Management Initials: Designer: TSH Checked: JK Approved: PF



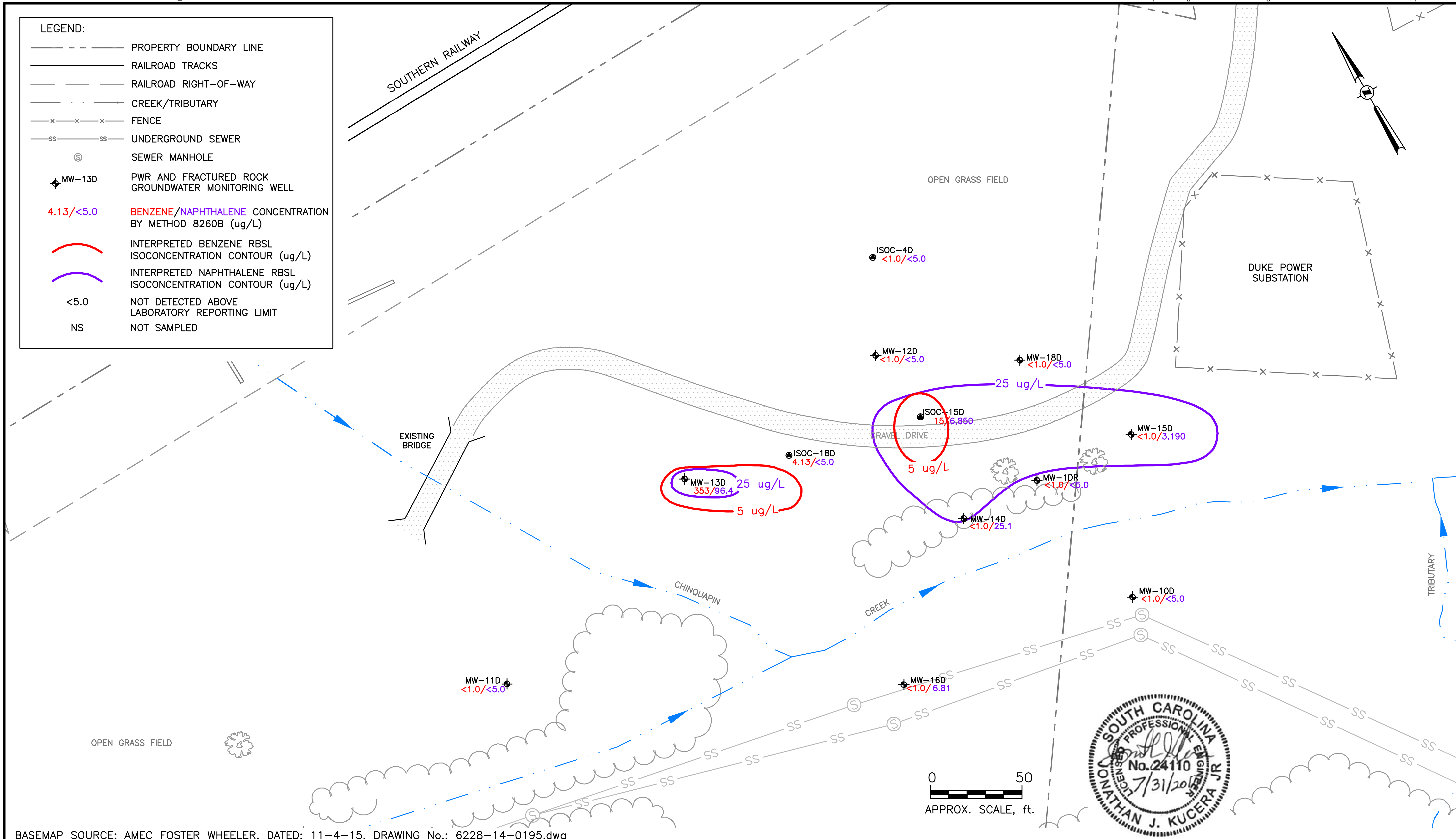
FOCUSED FEASIBILITY STUDY
DUKE ENERGY CORPORATION-FORMER MGP SITE
SPARTANBURG, SOUTH CAROLINA
Project No.: 60544098 Date: 2017-06-22

BENZENE/NAPHTHALENE CONCENTRATIONS IN SAPROLITE WELLS - OCTOBER 2016

AECOM
Figure: 8

Filename: M:\DCS\PROJECTS\L-URS\COMMON_PROJECTS\DUKE ENERGY\SPARTANBURG\60544098 - FFS 2017\DRAFT FFS\FIGURES\FIGURES 8.9 - GROUNDWATER RESULTS.DWG

Project Management Initials: Designer: TSH Checked: JK Approved: PF



BASEMAP SOURCE: AMEC FOSTER WHEELER, DATED: 11-4-15, DRAWING No.: 6228-14-0195.dwg

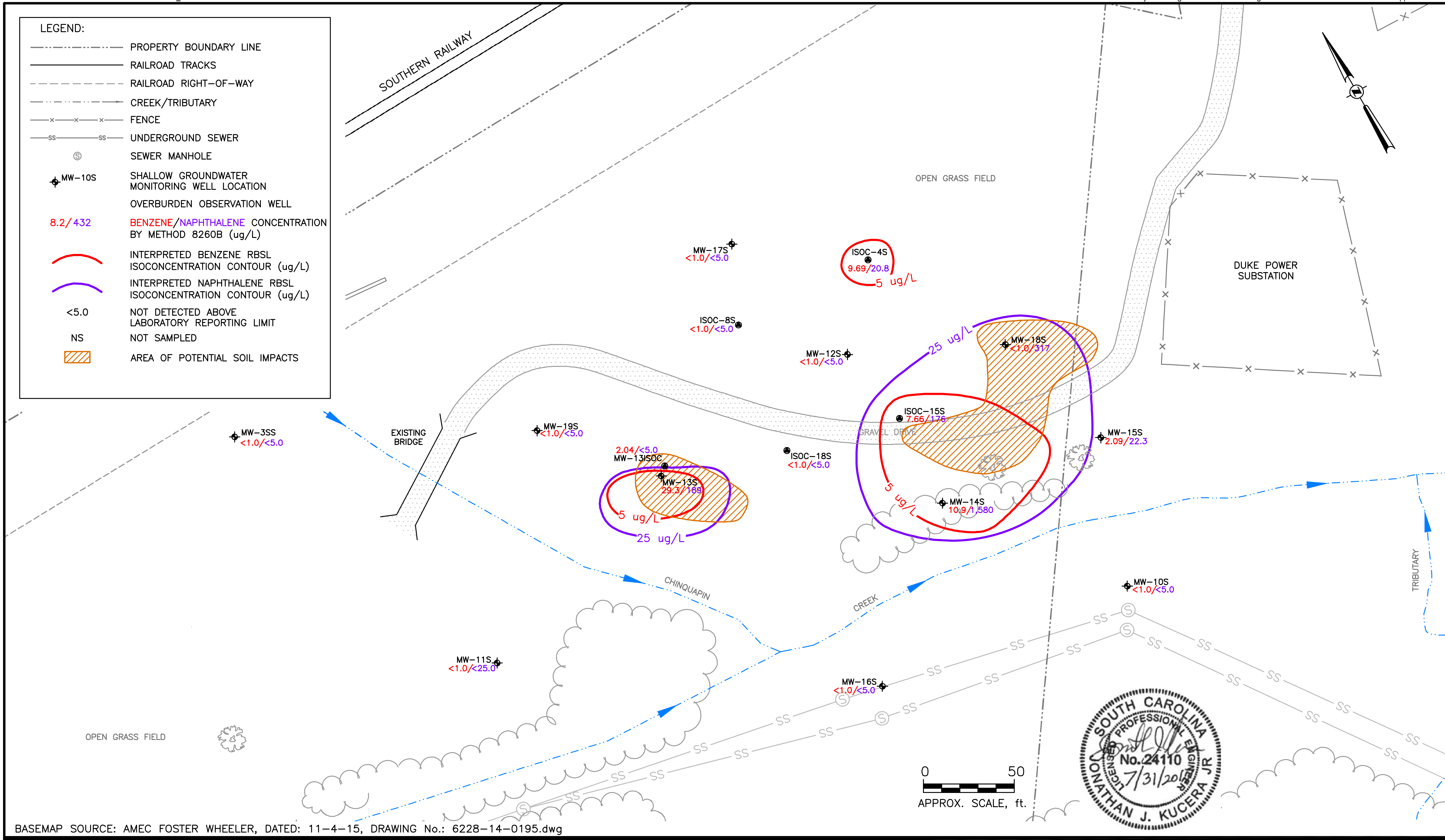
FOCUSED FEASIBILITY STUDY
DUKE ENERGY CORPORATION-FORMER MGP SITE
SPARTANBURG, SOUTH CAROLINA
Project No.: 60544098 Date: 2017-06-22

BENZENE/NAPHTHALENE CONCENTRATIONS IN PWR & FRACTURED ROCK WELLS - OCTOBER 2016

AECOM
Figure: 9

Filename: M:\DCS\PROJECTS\L-URS\COMMON_PROJECTS\DUKE ENERGY\SPARTANBURG\60544098 - FFS 2017\DRAFT FFS\FIGURES\FIGURE 10 - ALTERNATIVE 3.DWG

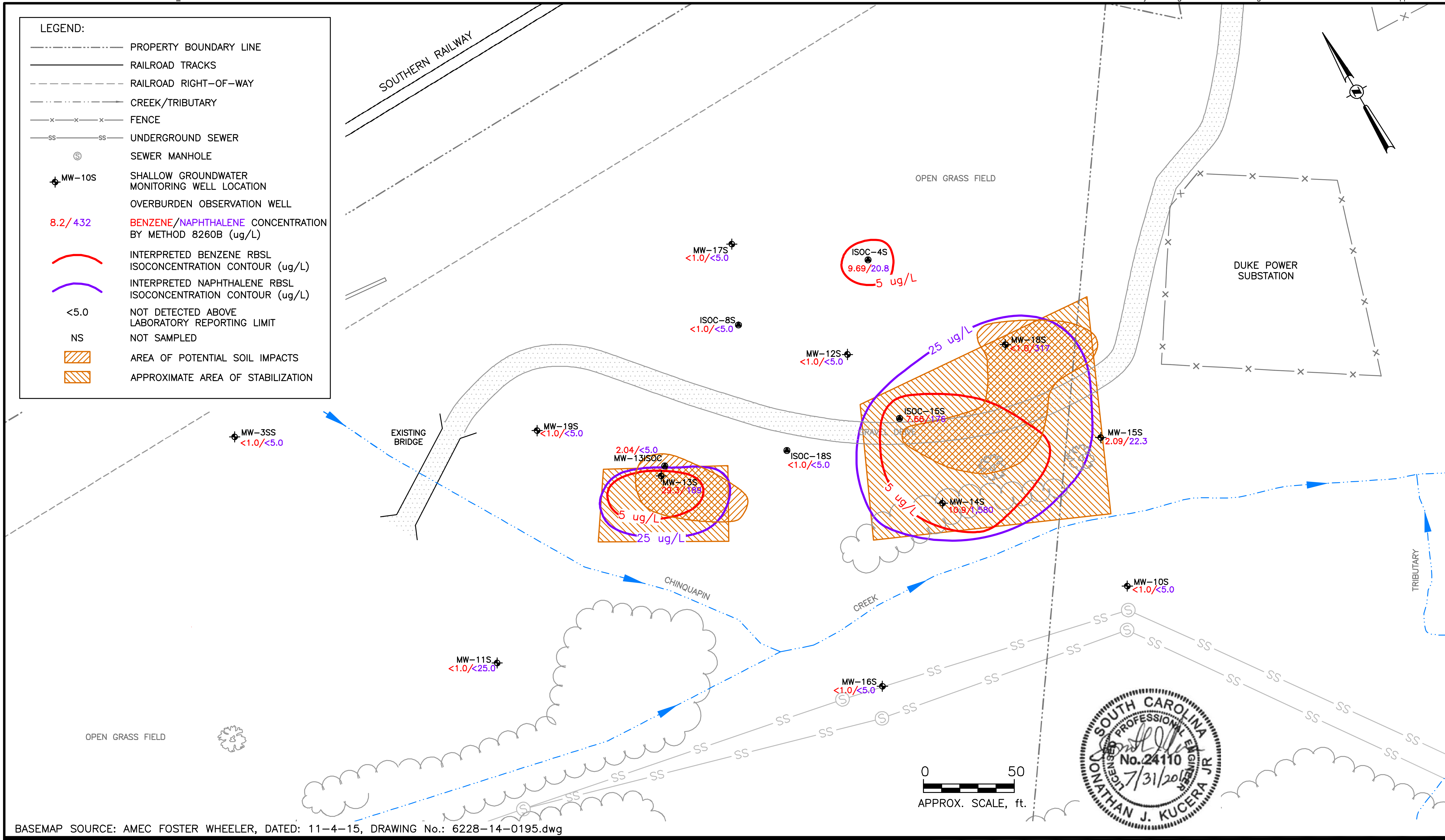
Project Management Initials: Designer: TSH Checked: JK Approved: PF



FOCUSED FEASIBILITY STUDY
DUKE ENERGY CORPORATION-FORMER MGP SITE
SPARTANBURG, SOUTH CAROLINA
Project No.: 60544098 Date: 2017-06-22

ALTERNATIVE 3
TARGETED EXCAVATION AND MNA

AECOM
Figure: 10



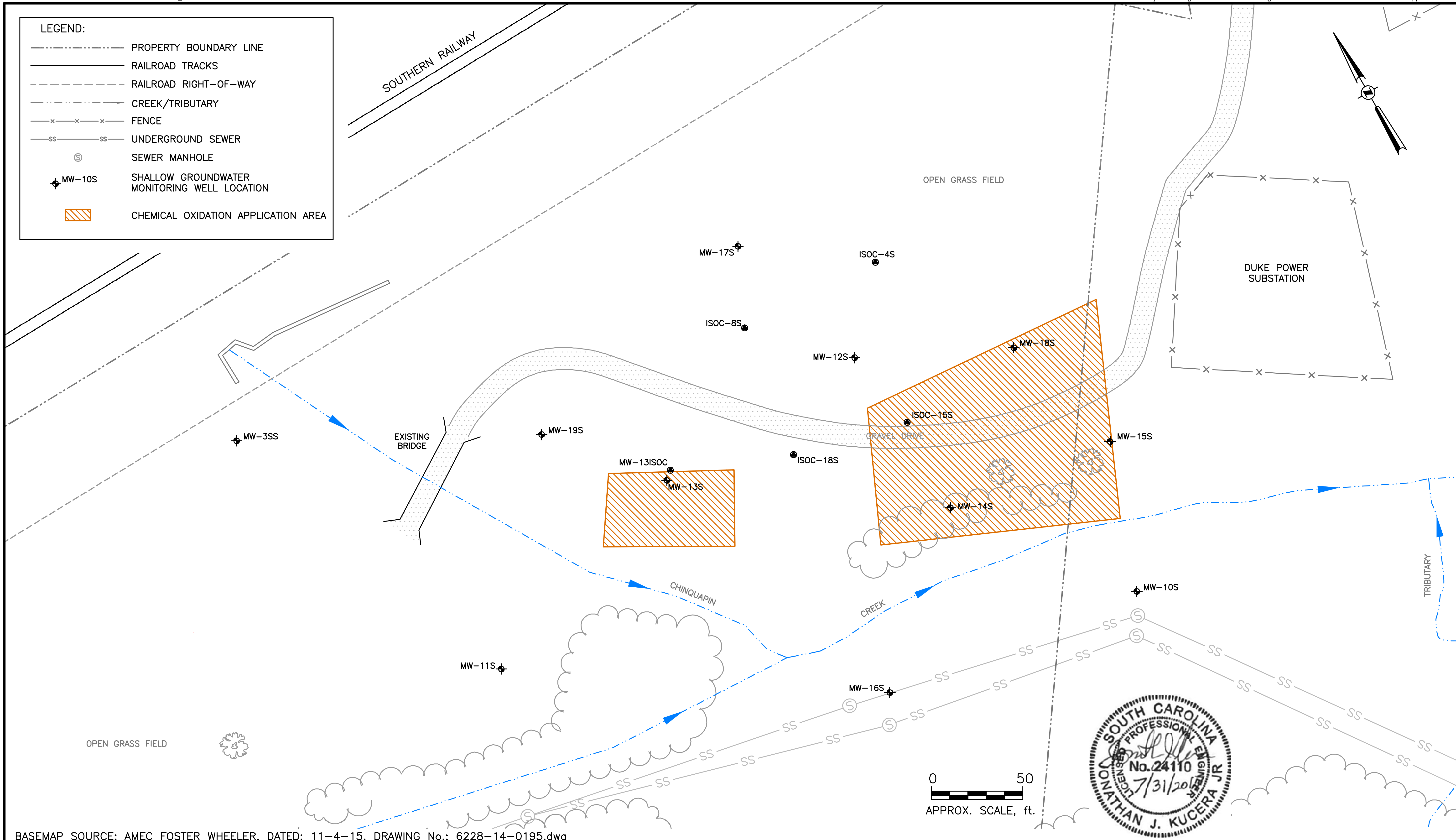
FOCUSED FEASIBILITY STUDY
DUKE ENERGY CORPORATION-FORMER MGP SITE
SPARTANBURG, SOUTH CAROLINA
Project No.: 60544098 Date: 2017-06-22

ALTERNATIVE 4
SOIL STABILIZATION/SOLIDIFICATION AND MNA

AECOM
Figure: 11

Filename: M:\DCS\PROJECTS\L-URS\COMMON_PROJECTS\DUKE ENERGY\SPARTANBURG\60544098 - FFS 2017\DRAFT FFS\FIGURES\FIGURE 10 - ALTERNATIVE 3.DWG

Project Management Initials: Designer: TSH Checked: JK Approved: PF



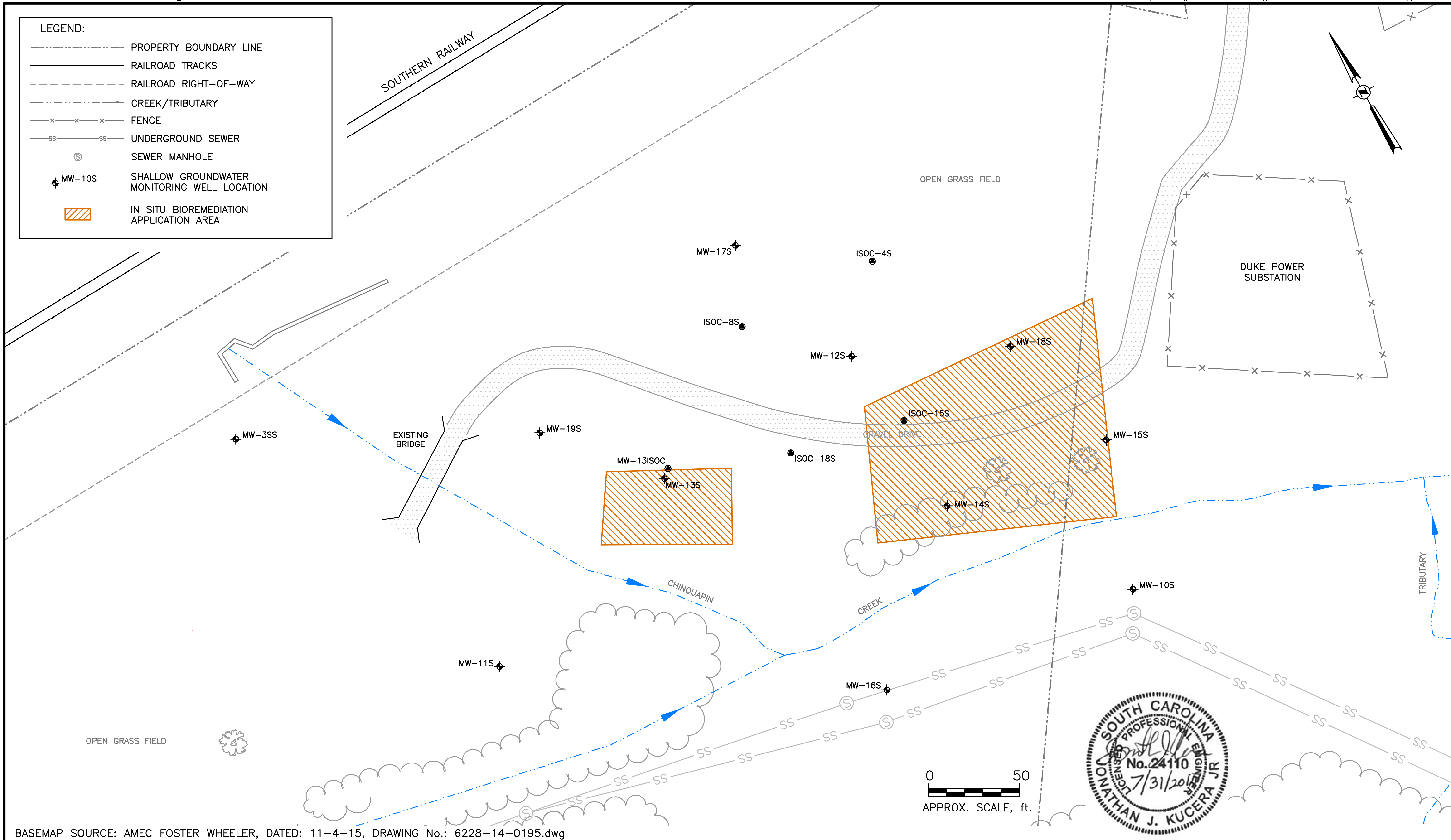
BASEMAP SOURCE: AMEC FOSTER WHEELER, DATED: 11-4-15, DRAWING No.: 6228-14-0195.dwg

FOCUSED FEASIBILITY STUDY
DUKE ENERGY CORPORATION-FORMER MGP SITE
SPARTANBURG, SOUTH CAROLINA
Project No.: 60544098 Date: 2017-06-22

ALTERNATIVE 5
IN SITU CHEMICAL OXIDATION AND MNA

AECOM
Figure: 12

Filename: M:\DCS\PROJECTS\L-URS\COMMON_PROJECTS\DUKE ENERGY\SPARTANBURG\60544098 - FFS 2017\DRAFT FFS\FIGURES\FIGURE 10 - ALTERNATIVE 3.DWG   Project Management Initials: Designer: TSH   Checked: JK   Approved: PF



FOCUSED FEASIBILITY STUDY
DUKE ENERGY CORPORATION-FORMER MGP SITE
SPARTANBURG, SOUTH CAROLINA
Project No.: 60544098   Date: 2017-06-22

ALTERNATIVE 6
IN SITU BIOREMEDIATION AND MNA

AECOM
Figure: 13

Appendix A.
SCDHEC CORRESPONDENCE

Healthy People. Healthy Communities.

May 12, 2017

Richard E. Powell, P.G.
Senior Environmental Specialist
526 South Church Street
Mail Code EC13K
Charlotte, NC 28202

RE: Focused Feasibility Study Work Plan
Duke Power Spartanburg MGP Site
Spartanburg, South Carolina
BLWM File # 56553

Dear Mr Powell:

The State Voluntary Cleanup Program of the Division of Site Assessment, Remediation, and Revitalization has reviewed the Focused Feasibility Study Work Plan submitted by AECOM for the Duke Power Spartanburg MGP Site in Spartanburg, South Carolina on May 1, 2017. The Department approves of the Focused Feasibility Study Work Plan and would like Duke to move forward with the Focused Feasibility Study with the following change. The Department would like in situ chemical oxidation and in situ biological remediation technologies to be subjected to detailed analysis within the Focused Feasibility Study.

The Department requests that a Draft Focused Feasibility Study be submitted by August 1, 2017. If you have any questions, please contact me at (803) 898-0910 or by email at cassidga@dhec.sc.gov.

Sincerely,

Greg Cassidy

Greg Cassidy
State Remediation Section
Div. of Site Assessment, Remediation & Revitalization
Bureau of Land and Waste Management

cc: Lucas Berresford BLWM
Jon Kucera, Jr, PE, AECOM
Natalie Kirkpatrick, Upstate EA