Gude Landfill
Assessment of Corrective Measures
Montgomery County, Maryland

Prepared for:

Department of Environmental Protection
Division of Solid Waste Services
Montgomery County, Maryland

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LIST OF ACRONYMS AND ABBREVIATIONS

ACL	Alternate Concentration Limit
ACM	Assessment of Corrective Measures
AFCEE	Air Force Center for Environmental Excellence
ANL	Argonne National Laboratory
ATC	Anticipated Typical Concentration
ARARs	Applicable or Relevant and Appropriate Requirements
bgs	Below Ground Surface
BMP	Best Management Practice
CFR	Code of Federal Regulations
CMA	Corrective Measure Alternative
COMAR	Code of Maryland Regulations
COPC	Constituent of Potential Concern
cVOC	Chlorinated Volatile Organic Compound
DCE	Dichloroethene
DEP	Department of Environmental Protection
EA	EA Engineering, Science, and Technology, Inc.
EPA	U.S. Environmental Protection Agency
FRTR	Federal Remediation Technologies Roundtable
ft	Foot or Feet
GLCC	Gude Landfill Concerned Citizens
GRAs	General Response Actions
HPAH	High Molecular Weight Polycyclic Aromatic Hydrocarbon
HQ	Hazard Quotient
in.	Inch(es)
J&E	Johnson and Ettinger
LEL	Lower Explosive Limit
LFGE	Landfill Gas-to-Energy
MCL	Maximum Contaminant Level
MDE	Maryland Department of the Environment
mg/L	Milligram(s) Per Liter (equivalent to parts per million, ppm)
mM	Millimoles Per Liter

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

MNA	Monitored Natural Attenuation
M-NCPPC	Maryland-National Capital Park and Planning Commission
NAVFAC	Naval Facilities Engineering Command
NMOC	Non-Methane Organic Compounds
NCP	National Contingency Plan
NES	Nature and Extent Study
NPDES	National Pollutant Discharge Elimination System
O&M	Operation and Maintenance
ORC®	Oxygen Release Compound
P&T	Pump and Treat
PCB	Polychlorinated Biphenyl
PCE	Tetrachloroethene
ppb	Parts Per Billion
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act
RRF	Resource Recovery Facility
SWPPP	Stormwater Pollution Prevention Plan
TCE	Trichloroethene
VC	Vinyl Chloride
VOC	Volatile Organic Compound
WSSC	Washington Suburban Sanitary Commission
ZVI	Zerovalent Iron
µg/L	Microgram(s) Per Liter (equivalent to parts per billion, ppb)

EXECUTIVE SUMMARY

The Montgomery County (County) Department of Environmental Protection (DEP) has prepared an Assessment of Corrective Measures (ACM) for the Gude Landfill (the Landfill), in compliance with the consent order for the Landfill, and in accordance with specific requirements set forth under Title 40 Code of Federal Regulations (CFR) § 258.56 and the general requirements of the Maryland Department of the Environment (MDE) for regulating solid waste disposal facilities under the Code of Maryland Regulations (COMAR).

The purpose of the ACM is to assess the available technologies and processes that may assist the County with achieving the remedial action objectives (RAOs) at the Landfill, and to recommend the Corrective Measure Alternative (CMA) that the County determines to be most feasible and effective for meeting regulatory compliance requirements at the Landfill.

The consent order for the Landfill (MDE and the County 2013) establishes the following long-term RAOs for the Landfill:

- No exceedances of maximum contaminant levels (MCLs), established by the U.S. Environmental Protection Agency (EPA) as limits for drinking water, in the groundwater at the Landfill property boundary or between the Landfill and adjacent streams.

- No lower explosive limit (LEL) exceedances for methane gas at the Landfill property boundary.

- No non-stormwater discharges to the waters of the State.

The 2010 Nature and Extent Study (NES) and the 2011 NES Amendment No. 1 that were prepared by the County and accepted by MDE described the nature and extent of impacts to environmental media and regulatory exceedances that have been identified during ongoing environmental monitoring at the Landfill. Potential landfill-associated impacts to groundwater that were identified in the NES Amendment No. 1 include MCL exceedances at the Landfill property boundary for the following constituents: 1,1-dichloroethene (DCE), 1,2-dibromoethane, 1,2-dichloropropane, benzene, cadmium (dissolved), cis-1,2-DCE, methylene chloride, nitrate, tetrachloroethene (PCE), trichloroethene (TCE), and vinyl chloride (VC). Of these, the inorganic species (cadmium and nitrate) were determined not to be a focus for remediation at the Landfill based on assessment of their distribution and concentrations in monitoring wells at the Landfill. A supplemental sampling event to assess the causes of metals exceedances at the Landfill was

performed in conjunction with the ACM in September 2013, and further supported the determination that metals are not a focus of remediation.

Other landfill-related regulatory exceedances have also been identified on an intermittent basis at the Landfill, which included LEL exceedances for landfill gas at the Landfill property boundary and non-stormwater discharges (e.g., leachate seeps) on the Landfill property boundary. The risk evaluation performed as part of the NES did not identify concerns for human health or the environment with respect to constituents in groundwater, soil, or surface water, based on the exposure pathways that are currently present and complete at the Landfill.

Seven (7) General Response Actions (GRAs), or broad categories of actions, were identified as potential options for achieving the RAOs at the Landfill. The GRAs are:

- *In Situ* Groundwater Treatment
- *Ex Situ* Groundwater Treatment
- Physical Control of Flow
- Cover System Improvements
- Capping
- Waste Excavation
- No Action

The GRAs were then utilized to identify potential Remedial Technologies, which were screened according to their effectiveness, implementability, and cost of implementation at the Landfill. Case studies describing the implementation of each Remedial Technology at other similar sites were also identified and reviewed as part of the screening process. At the conclusion of the screening process, the following seven (7) out of twelve (12) Remedial Technologies were retained as Corrective Measure Technologies:

- Monitored Natural Attenuation (MNA)
- Enhanced Bioremediation
- Groundwater Pump and Treat (P&T)
- Landfill Gas Collection
- Cover System Improvements
- Partial Capping
- Selective or Extensive Waste Excavation

Five (5) Remediation Areas at the Landfill were identified based on the locations of reported MCL exceedances in groundwater, LEL gas exceedances, and/or non-stormwater discharges.

These areas include the Northwest, West, Southwest, South, and Southeast Areas of the Landfill. Each Area was matched with potentially feasible and effective Corrective Measure Technologies, based on the media of concern, constituents present, concentrations, risk/exposure potential, and implementability in the given Area. These pairings of Remediation Areas and Corrective Measure Technologies were used to assemble the following CMAs, each of which would address the RAOs for each medium of concern (i.e., groundwater, landfill gas, and non-stormwater discharges) in each of the five (5) Areas, the Northwest, West, Southwest, South, and Southeast Areas. The proposed CMAs for the Landfill are the following:

- Alternative 1 – Selective Waste Excavation with Off-Site Disposal and Enhanced Bioremediation
- Alternative 2 – Selective Waste Excavation with On-Site Placement and Enhanced Bioremediation
- Alternative 3 – Extensive Waste Excavation With Monitored Natural Attenuation
- Alternative 4 – Additional Landfill Gas Collection and Cover System Improvements With Groundwater P&T
- Alternative 5 – Additional Landfill Gas Collection and Cover System Improvements With Enhanced Bioremediation

Note that in addition to the remedial technologies included in each alternative, it is anticipated that approximately seven (7) new groundwater monitoring wells would also be installed along the property boundary, outside the network of existing groundwater and landfill gas monitoring wells, to fill in gaps along areas of the property boundary and enable additional monitoring of groundwater impacts during remediation.

Detailed analysis of the five (5) CMAs was conducted using nine (9) criteria, pursuant to guidance from the EPA (EPA 1991):

1) Compliance with Applicable or Relevant and Appropriate Requirements (ARARs) and RAOs
2) Short-Term Effectiveness

3) Long-Term Effectiveness and Permanence

4) Implementability of Alternative

5) Protection of Human and Ecological Health

6) Source Treatment and Reduction of Toxicity, Mobility, and Volume

7) Cost

8) Regulatory Acceptance

9) Community or Stakeholder Acceptance

Based on the detailed analysis using these criteria, the highest-ranked CMA for the Landfill is Alternative 5, Additional Landfill Gas Collection and Cover System Improvements With Enhanced Bioremediation. A work plan for Alternative 5 is provided in Appendix G, with descriptions, schedules, and contingency measures for the recommended technologies.

1. BACKGROUND

EA Engineering, Science, and Technology, Inc. (EA), in conjunction with the Montgomery County (County) Department of Environmental Protection (DEP), has prepared this Assessment of Corrective Measures (ACM) Report for the Gude Landfill ("the Landfill") to address:

- Reported concentrations exceeding maximum contaminant levels (MCLs), established by the U.S. Environmental Protection Agency (EPA) as limits for drinking water, for volatile organic compounds (VOCs) and other groundwater impacts at and beyond the Landfill property boundary per the Code of Maryland Regulations (COMAR) 26.08.02. The constituents identified in the Nature and Extent Study (NES) Amendment No. 1 for the Landfill (EA 2011a) as groundwater impacts, based on MCL exceedances in 2011, include cadmium (dissolved), 1,1-dichloroethene (DCE), cis-1,2-DCE, 1,2-dibromoethane, 1,2-dichloropropane, benzene, methylene chloride, tetrachloroethene (PCE), trichloroethene (TCE), vinyl chloride (VC), and nitrate. (Note that inorganic constituents, including cadmium and nitrate, are not considered in this ACM as focuses of remediation at the Landfill, as described in Section 2.4.1.)

- Intermittent exceedances of the lower explosive limit (LEL) for methane gas at the Landfill property boundary (per COMAR 26.04.07.03B(9)).

- Occurrences of non-stormwater discharges (e.g., leachate seeps) at the Landfill property boundary (per COMAR 26.08.04.08).

This ACM Report was prepared in compliance with the consent order for the Landfill (MDE and the County 2013), and in accordance with the specific requirements set forth under Title 40 Code of Federal Regulations (CFR) § 258.56 and the general requirements of the Maryland Department of the Environment (MDE) for regulating solid waste disposal facilities under COMAR.

1.1 SITE DESCRIPTION

1.1.1 Site Location and Overview

The Landfill is located at 600 East Gude Drive, Rockville, Maryland 20850. The site has road access at two (2) locations: East Gude Drive and Southlawn Lane. A site location map is included as **Figure 1-1**.

The Landfill is currently owned and maintained by the County DEP. The Landfill was used for the disposal of municipal solid waste and incinerator residues from 1964 to 1982. The Landfill property encompasses approximately one hundred sixty-two (162) acres, of which approximately one hundred forty (140) acres were used for waste disposal. An additional seventeen (17) acres of waste disposal area was delineated in 2009 on Maryland-National Capital Park and Planning Commission (M-NCPPC) property, beyond the northeastern property boundary of the Landfill. A land exchange is currently in process between the County and M-NCPPC that will transfer ownership of this additional waste disposal area to the County in exchange for a similar area of land without waste to be transferred to M-NCPPC.

1.1.2 Site and Surrounding Area Land Use

The typical ground cover across the Landfill site is open grassy fields with patches of brushy vegetation and trees on most side slopes and along the perimeter borders of the Landfill. The existing landfill gas collection system, including the gas extraction system well heads and gas conveyance piping, is situated above-grade on the Landfill's ground surface. The site also has a limited area on the top of the Landfill that is currently designated for flying model air planes and a concrete pad near the Southlawn Lane facility entrance road that is used for managing storm-related debris.

The surrounding area and properties adjacent to the Landfill have mixed uses including parkland, industrial property and residential development. Specifically, the adjacent land areas consist of:

- M-NCPPC land and Crabbs Branch Stream (north by northeast).
- Asphalt and cement production facilities, equipment storage yards, scrap metal recycling facilities, and Southlawn Lane (east by southeast).
- East Gude Drive, Washington Suburban Sanitary Commission (WSSC) property and Southlawn Branch Stream (southwest by south by southeast).
- Transcontinental (Williams Gas)/Columbia Gas natural gas pipeline right-of-way and the community of Derwood Station residential development (west by northwest).

1.1.3 Site History

As presented in the NES (Section 1.2 – Landfill History) (EA 2010a), the Landfill was initially permitted by the County in 1963. The Landfill was subsequently operated and closed under several facility names and refuse disposal permits from 1964 to 1982. The facility name of the Gude-Southlawn Landfill was modified by reference to the Gude Landfill. There is no current refuse disposal permit that is applicable to the Landfill.

The Landfill was constructed and operated prior to modern solid waste management disposal and facility design and closure standards that were implemented by EPA, under the Resource Conservation and Recovery Act (RCRA). Therefore, the Landfill was not originally constructed with a geosynthetic liner or compacted clay bottom liner, a leachate collection system, a landfill gas collection system, or a stormwater management system. Reportedly, soil was used as daily cover during waste filling, and a two (2) foot (ft) (minimum) final layer of soil was reportedly placed over the waste mass during closure of the Landfill (in 1982) to support the vegetative cover.

Since 1982, the County has voluntarily, or through regulatory mandates, implemented and maintained Best Management Practices (BMPs) for pre-regulatory era landfills to ensure compliance with COMAR requirements. These BMPs include: soil and vegetative cover system installation, cover system maintenance, leachate seep repairs, landfill gas collection system installation and maintenance, water quality and landfill gas monitoring, and stormwater infrastructure improvements. The County currently maintains an active landfill gas collection system including: flares, a gas-to-energy system, over one hundred (100) gas extraction wells, and horizontal gas conveyance piping. A network of on-site and off-site groundwater monitoring wells; a network of on-site landfill gas monitoring wells; environmental monitoring programs for groundwater, surface water, and landfill gas; and stormwater management infrastructure are also maintained at and for the Landfill site.

1.2 SITE ENVIRONMENTAL SETTING

1.2.1 Topography

The site topography of the Landfill is plateau-like and consists of gentle relief (i.e., slope) along the top of the waste-mass and sharp relief along the perimeter property boundary. The elevation along the top of the plateau gently slopes to the south, with localized mounds and depressions throughout. The side-slope falls sharply from the top of the waste-mass to elevations ranging from fifty-five (55) to ninety (90) ft below the plateau.

A general summary of approximate topographic elevations across the Landfill measured to the toe of slope of the waste mass and/or drainage areas as applicable (including the property with waste encroachment that is owned by M-NCPPC) are provided below:

- Plateau – elevation range four hundred seventy (470) to four hundred fifty (450) ft (top of landfill).
- Northwest – elevation range four hundred twenty-five (425) to four hundred ten (410) ft (toe of slope along the gas pipeline right-of-way).
- North – elevation range three hundred eighty-five (385) to three hundred sixty-five (365) ft (toe of slope along Crabbs Branch stream).
- Northeast – elevation range three hundred eighty-five (385) to three hundred seventy-five (375) ft (toe of slope along M-NCPPC land).
- Southeast – elevation range three hundred seventy (370) to three hundred forty (340) ft (toe of slope along M-NCPPC land and Southlawn Branch stream).
- South – elevation range four hundred twenty-five (425) to three hundred sixty (360) ft (toe of slope along WSSC land and Southlawn Branch stream).
- Southwest – elevation range four hundred twenty-five (425) to four hundred ten (410) ft (toe of slope along County land and gas pipeline right-of-way).

A topographic map (based on the 2009 Survey) of the Landfill that presents ten (10) ft interval contours and the above referenced site features and conditions is presented in **Figure 1-2**.

1.2.2 Geology

The Landfill is located in central Montgomery County, Maryland, within the upland section of the Piedmont Plateau physiographic province (Maryland Geological Society 1968, Trapp and Horn 1997). The geology in the upland section of the Piedmont Plateau physiographic province primarily consists of metamorphic and igneous rock formations of Paleozoic and Precambrian age. The Piedmont Plateau is underlain by an assortment of phyllite, slate, marble, schist, gneiss, and gabbro formations. Unconsolidated material overlying bedrock is present at the surface in the vicinity of the Landfill site and extends twenty (20) to sixty (60) ft below ground surface (bgs). Based on available groundwater monitoring well construction logs from ATEC Associates Inc. (1988) and more recent boring logs (EA 2010a and 2011a), the unconsolidated material consists primarily of silt and clay.

1.2.3 Hydrogeologic Setting

The uplands section of the Piedmont is underlain by three (3) principle types of bedrock aquifers: crystalline-rock and undifferentiated sedimentary-rock aquifers, aquifers in early Mesozoic basins, and carbonate-rock aquifers (Trapp and Horn 1997). The Landfill is underlain by the crystalline rock aquifer that extends over approximately eighty-six (86) percent of the Piedmont Plateau Physiographic Province. At the Landfill, the crystalline rock that comprises the regional aquifer is overlain by unconsolidated material consisting of interbedded silts and clays and saprolite. Recorded logs from on-site and off-site borings for the groundwater monitoring wells correlated well with these general geological descriptions.

Based on information from site boring logs and well gauging, groundwater is present in the unconsolidated material, as well as the bedrock at the Landfill site. The groundwater table is typically present in the unconsolidated material along the perimeter of the Landfill and under the Derwood Station development, at depths ranging from approximately three (3) to sixty (60) ft bgs. Groundwater recharge at the Landfill is variable and is primarily determined by precipitation and runoff. Topographic relief, unconsolidated material, and surface recharge variations created by the Landfill may significantly affect the groundwater flow.

Groundwater flow is highly dependent on the composition and grain size of the sediments, and therefore water likely moves more readily in the unconsolidated material than in the underlying bedrock. Groundwater in the bedrock (typically twenty [20] to sixty [60] ft below grade) is stored in, and moves through, fractures. No documentation of the degree of fracturing or orientation of bedrock fractures at the Landfill is available.

The site topography and the natural cover system (grassy surface and soil layer) of the Landfill make surface water infiltration likely. Some of the infiltrating water likely moves vertically into the bedrock, while a portion also moves laterally along the boundary between the unconsolidated material and the surface of the bedrock and discharges to nearby streams and surface depressions.

Geologic cross-sections of the Landfill area, showing the subsurface geology and the relative depths of unconsolidated material, bedrock, and groundwater, are presented in **Figures 1-3 and 1-4**.

1.2.4 Groundwater Flow

Based on the data collected from new and existing groundwater monitoring wells, including temporary groundwater monitoring wells, and the stream gauge locations (from the NES Amendment No. 1 [EA 2011a]), the groundwater flow direction was inferred. The data indicated that groundwater flows in an easterly flow direction across the Landfill site, with minor northerly, northeasterly, and southeasterly flow components. The stream gauge data of surface water elevations were consistent with groundwater table elevations from adjacent groundwater monitoring wells and locations, indicating a hydraulic connection between groundwater and surface water. The above referenced data collection locations and the inferred groundwater flow contours have been overlain on the site topographic map, and are presented in **Figure 1-5**.

1.2.5 Surface Water Hydrology

The NES and the NES Amendment No. 1 (EA 2010a and 2011a) provided a discussion regarding surface water hydrology on and around the Landfill site. This included the ways in which the Landfill's topography and its existing stormwater drainage structures minimize standing water (i.e., ponding) and infiltration into the waste mass by collecting and conveying surface water runoff from the Landfill's surface to adjacent land and streams. A brief summary of this information is provided below.

Site Topography and Site Improvements

As described in Section 1.2.1, the site topography of the Landfill is plateau-like and consists of gentle relief (i.e., slope) along the top of the waste-mass and sharp relief along the Landfill boundary. Along with the natural contours of the Landfill site, the County has maintained and improved the Landfill's cover system and drainage network since 1984 to actively divert clean stormwater runoff from the Landfill surface. As part of the NES (EA 2010a), an inventory of existing swales, berms, inlet structures, outlet structures, culverts, detention ponds, and sediment basins at the Landfill was performed in 2010 and is presented in **Figure 1-6**. A total of one hundred three (103) stormwater structures were located and assessed in the field. These stormwater drainage structures aid in minimizing standing water on the Landfill.

County DEP has also implemented BMPs for post-closure care with the repair of areas experiencing leachate seeps and standing water at the Landfill. These site management practices and infrastructure improvements have helped to minimize the infiltration of surface water into the Landfill and to minimize the potential for non-stormwater discharges off of the Landfill site.

These practices have, in turn, protected the adjacent receiving surface water bodies of Crabbs Branch Stream and Southlawn Branch Stream and a downstream surface water body, Middle Rock Creek Stream.

Stormwater Drainage and Diversion

With the above referenced improvements to the Landfill's cover system and drainage network, County DEP in conjunction with its Operations Contractors have been actively diverting stormwater off of the Landfill surface from 1984 to present. A drainage area map that correlates the current topography, as-built documents, surveyed stormwater infrastructure and surface runoff (e.g., stormwater) catchment areas and flow directions across the Landfill is provided as **Figure 1-7**. The drainage area boundaries were delineated based upon the contours and surface features collected in the 2009 topographic survey. Drainage areas were also delineated to stormwater structures where contours indicated flow concentrations. Some drainage areas on the cover system are captured and conveyed by storm drains that then discharge further down-gradient at the Landfill perimeter or into another drainage area. Areas where runoff is conveyed by stormwater infrastructure are indicated by a bold arrow.

To complement **Figure 1-7**, a general summary of the directional flow of surface water runoff from the Landfill site is provided below:

- Plateau – flow oriented to the south/south east.
- Northwest – flow oriented to Gas Right-of-Way.
- North – flow oriented to Crabbs Branch stream.
- Northeast – flow oriented to M-NCPPC land.
- Southeast – flow oriented towards M-NCCPC land and Southlawn Branch stream.
- South – flow oriented towards WSSC land and Southlawn Branch stream.
- Southwest – flow oriented towards Pond No. 1.

Overall, the Stormwater Structure Location and Drainage Area Maps provide documentation to support County DEP's implementation of active stormwater diversion techniques and BMPs for a pre-regulatory era (RCRA) landfill. For further information, refer to NES Report, Appendix A, Attachment 3 – Technical Memorandum, Stormwater Infrastructure Review (EA 2010a).

Adjacent Surface Water Bodies

The Landfill is partially bordered by two (2) surface water bodies: Crabbs Branch Stream (north by northeast) and Southlawn Branch Stream (south by southeast). Aside from the lands adjacent to the Landfill, these streams receive the majority of the surface water runoff that is diverted from the Landfill's surface. Middle Rock Creek Stream, a small tributary of Rock Creek (east), may receive surface water runoff from the Landfill at a point downstream, but does not border the Landfill.

Relationship of Surface Water Hydrology and Groundwater

With respect to the relationship of surface water hydrology to groundwater along the northern and southern Landfill boundaries of the Landfill site, the County evaluated stream and groundwater elevation data during the NES Amendment No. 1 (EA 2011a). Stream elevation and groundwater elevation data collected in August 2011 from stream gauge locations (SG-1 through SG-15) and temporary groundwater monitoring wells (TGW-1 through TGW-10) demonstrated a close relationship between stream and groundwater and elevations along Crabbs Branch and Southlawn Branch streams. This close relationship indicates that the shallow groundwater and bordering streams are likely interconnected and that the streams are gaining some amount of water from the shallow groundwater. Deeper groundwater flow paths may be influenced by the streams, but it is not known to what degree, if any, deeper groundwater is captured by the streams.

1.3 EXISTING SITE ENVIRONMENTAL MONITORING NETWORK

1.3.1 Groundwater Monitoring

The existing groundwater monitoring network for the Landfill consists of thirty-nine (39) groundwater monitoring wells. The locations of these wells are presented on **Figure 1-8**. The groundwater monitoring wells were installed from 1984 to 2011, as identified below:

- Groundwater Monitoring Wells (1984-1988) – OB01, OB02, OB02A, OB03, OB03A, OB4, OB04A, OB06, OB07, OB07A, OB08, OB08A, OB10, OB11, OB11A, OB12, OB015, OB025, OB102 and OB105.

- Groundwater Monitoring Wells (2010) – MW-1, MW-2A, MW-2B, MW-3A, MW-3B, MW-4, MW-6, MW-7, MW-8, MW-9, MW-10, MW-11A, MW-11B, MW-12, MW-13A and MW-13B.

- Groundwater Monitoring Wells (2011) – MW-14A, MW-14B and MW-15.

Samples have been regularly collected and analyzed from these groundwater monitoring wells, along with the surface water monitoring locations (refer to Section 1.3.2). The sampling occurred as part of DEP's Water Quality Monitoring Program, from 1984 to 2009, and under the MDE-approved Groundwater and Surface Water Monitoring Plan (DEP 2009a) from 2009 to present. A summary of construction data for the Landfill's groundwater monitoring wells is presented in **Tables 1-1, 1-2 and 1-3**. Boring logs, construction diagrams, well completion logs, and development logs for the groundwater monitoring wells installed in 2010 and 2011 are included in Appendix C of the NES (EA 2010a) and Appendix B of the NES Amendment No. 1 (EA 2011a).

In addition, as part of the NES Amendment No. 1 (EA 2011a), the County installed and collected samples from ten (10) temporary groundwater monitoring wells (TGW-1 through TGW-10) to further delineate the nature and extent of potential groundwater impacts in the vicinity of the Landfill. The construction data for these temporary wells are also included in **Table 1-3**. Following groundwater sampling and laboratory analyses, the temporary wells were abandoned after a period of approximately thirty (30) days in accordance with the requirements of the County's Department of Permitting Services for temporary groundwater wells. Although not part of the County's groundwater monitoring network, the locations of the temporary groundwater monitoring wells are also presented for informational purposes on **Figure 1-8**.

1.3.2 Surface Water Monitoring

The existing surface water monitoring network for the Landfill consists of five (5) locations along Crabbs Branch Stream, Southlawn Branch Stream, and Middle Rock Creek Stream, which are presented in **Figure 1-9**. The surface water monitoring locations are identified below:

- <u>Surface Water Monitoring Locations</u> – ST120, ST065, ST015, ST70, and ST80.

Samples have been regularly collected and analyzed from these surface water monitoring locations, along with the groundwater monitoring wells (refer to Section 1.3.1, above). The sampling occurred as part of DEP's Water Quality Monitoring Program, from 1984 to 2009, and under the MDE-approved Groundwater and Surface Water Monitoring Plan from 2009 to present.

In addition, as part of the NES Amendment No. 1 (EA 2011a), the County installed and surveyed fifteen (15) stream gauge survey locations (SG-1 through SG-15) to illustrate the relationship between surface water elevations in adjacent streams and groundwater table elevations, for purposes of groundwater flow contours. Although not part of the County's surface water monitoring network, the stream gauge locations are presented for informational purposes on **Figure 1-9**.

1.3.3 Landfill Gas Monitoring

The existing landfill gas monitoring network for the Landfill consists of seventeen (17) locations along the perimeter boundaries of the site, which are presented in **Figure 1-10**. The landfill gas monitoring locations are identified below:

- Landfill Gas Monitoring Wells (2005) – W-03, W-04, W-05, W-06, W-07, W-08 and W-09.

- Landfill Gas Monitoring Wells (2010) – W-01, W-02, W-10, W-11, W-25, W-26, W-27, W-28, W-29 and W-30.

- Landfill Gas Monitoring Wells (Future) – Twelve (12) additional landfill gas monitoring wells are currently planned for installation along the eastern border of the Landfill upon completion of the land exchange with M-NCPPC.

These landfill gas monitoring wells have been monitored by DEP from 2005 to 2009 and under the MDE-approved Landfill Gas Monitoring Plan (DEP 2009b) from 2009 to present. Note that portions of the Landfill that are bordered by surface water bodies (e.g., streams) were determined not to require landfill gas monitoring wells, as the streams act as hydraulic barriers to prevent the migration of gas.

Although not part of the landfill gas monitoring network, the County maintains an active gas collection and management system at the Landfill, consisting of over one hundred (100) vertical extraction wells, five (5) dewatering sumps, two (2) enclosed ground flares, and a gas-to-energy facility, which is presented in **Figure 1-10**. A summary of construction data for the landfill gas extraction wells and dewatering sumps is presented in **Table 1-4**. The gas collection and management system is operated and maintained on a continuous basis by the County's Operations Contractor.

1.3.4 Stormwater Management

As indicated and described in Section 1.2.5, the Landfill has a network of one hundred three (103) stormwater structures to capture and divert clean stormwater runoff off of the Landfill's cover system. This infrastructure is presented on **Figures 1-6 and 1-7**.

Currently, there are no monitoring requirements at the Landfill for stormwater. Visual inspections of the site conditions and stormwater discharges (if present) are conducted quarterly and annually under the Landfill's Stormwater Pollution Prevention Plan (SWPPP) for the primary swales, inlets/outlets, and ponds of the stormwater management system. The Landfill's primary areas of post-closure care operations such as the flare station, the landfill gas-to-energy facility, the former power plant storage building and the emergency storm debris management areas are also reviewed for housekeeping activities (e.g., street sweeping and spill prevention, as applicable) to prevent the potential for non-stormwater discharges.

1.4 PRE-REMEDIATION SITE ACTIVITIES

Since 2008, the County has initiated a series of pre-remediation site activities at the Landfill. These activities include formalizing environmental monitoring plans and performing environmental investigations. These activities are categorized into site management, site characterization, and site evaluation elements to more accurately define the existing site conditions at the Landfill. A brief description of these activities is provided below, and associated timelines of performance are provided in **Table 1-5**. The activities were performed at the advisement and direction of MDE, as well as through commitments to the Derwood Station Community and M-NCPPC. In addition, the County performs routine and annual site inspections and implements site improvements to improve landfill gas collection stormwater drainage.

1.4.1 County and MDE Pre-Remediation Activities

- Formalize the Landfill Gas Monitoring Plan – Landfill gas has been actively collected for use in gas-to-energy applications and flaring by the County and its Operations Contractors from 1985 to present. The County and its Operations Contractors have also monitored landfill gas at the Landfill site within a groundwater monitoring well and the landfill gas monitoring wells from 2005 to present. MDE directed the County to formalize the landfill gas monitoring and reporting procedures for the Landfill. The County prepared and submitted an updated landfill gas monitoring plan to MDE. MDE subsequently approved the monitoring plan in April 2009.

- Formalize the Groundwater and Surface Water Monitoring Plan – The County has monitored groundwater and surface water at the Landfill site from 1984 to present. MDE directed the County to formalize the groundwater and surface water monitoring and reporting procedures for the Landfill. The County prepared and submitted an updated monitoring plan to MDE. MDE subsequently approved the groundwater and surface water monitoring plan in May 2009.

- Remediation Approach Work Plan – MDE directed the County to prepare a remedial action plan for the Landfill to address MCL exceedances in groundwater, intermittent LEL exceedances for methane gas, and the occurrence of non-stormwater discharges. The County prepared and submitted a remediation approach work plan to MDE that outlined the scope of work for the initial site characterization activities at the Landfill, which included the aerial/field survey, the Waste Delineation Study, and the NES. MDE subsequently approved the remediation work plan in May 2009.

- Waste Delineation Study (included in Appendix A of the NES [EA 2010a]) – MDE advised the County that in order to properly remediate the Landfill site in the future, the County should manage the entire waste disposal area of the Landfill. Following the aerial/field survey work, the County conducted a field investigation to evaluate the approximate horizontal extent of waste placement around the perimeter of the landfill. The investigation indicated approximately seventeen (17) acres of waste encroachment that extended beyond the northeastern property boundary of the Landfill onto land owned by M-NCPPC. The County prepared and submitted a report of its findings to MDE. MDE subsequently accepted the findings of the study in March 2012.

- Nature and Extent Study (EA 2010a) – As part of the Remediation Approach, the County performed site investigations and analyses to characterize the nature and extent of potential impacts from the Landfill and any potential adverse impacts to public health and the environment. The County prepared and submitted a report presenting the findings of this study to MDE. MDE subsequently provided comments to the County on the study in February 2011.

- NES Amendment No. 1 (EA 2011a) – Based on discussions from a joint review meeting between the County and MDE, the County prepared a response document to address MDE's comments on the original NES (EA 2010a). MDE approved the response document and the County's approach. The County performed additional site investigations and analyses to more fully characterize the nature and extent of potential impacts from the Landfill and any potential adverse impacts to public health and the environment. The County submitted its findings to MDE in the form of an Amendment to the NES. MDE subsequently accepted the findings of the study amendment in March 2012.

- ACM Work Plan – MDE directed the County to prepare a work plan for assessing the available technologies and processes that may assist the County with achieving the RAOs at the Landfill. The County prepared and submitted the work plan to MDE. MDE subsequently approved the work plan in June 2012. The County will ultimately provide a preferred recommendation within the ACM Report identifying the most feasible and effective corrective measure alternative to be implemented at the Landfill to meet regulatory compliance requirements.

- Consent Order – A consent order documenting historical and existing site conditions at the Landfill was signed in May 2013. The consent order commits the County to complete the pre-remediation site characterization and evaluation activities described above, as well as the eventual remediation of the Landfill site.

- County and MDE Meeting Regarding Status of the ACM (6 August 2013) – During this meeting, MDE representatives indicated that they would consider and evaluate alternatives that include drilling vertically through the Landfill waste mass to install injection wells for enhanced bioremediation. MDE representatives also indicated that they would allow waste excavated from the Landfill as part of the remedial activities to be placed on-site, provided that the placement is conducted in accordance with modern landfill engineering controls to control potential odors and vectors. They indicated that placement of an engineered landfill cap would not be required for this activity. MDE also indicated that perimeter/compliance monitoring wells are typically required to be spaced at three hundred (300) ft around the down-gradient perimeter of a site, and that MCL exceedances for metals will need to be considered as part of the ACM.

1.4.2 County and Other Stakeholder Pre-Remediation Activities

- Remediation Feasibility Memorandum (EA 2011b) – At the request of the Gude Landfill Concerned Citizens (GLCC), the County performed a cursory evaluation of potentially feasible technologies and processes that may assist the County with achieving the RAOs at the Landfill. The feasibility memorandum was presented to the GLCC and provided to MDE in January 2011.

- Exchange of Land with M-NCPPC – Based on the results of the Waste Delineation Study, the County initiated a land disposition process with M-NCPPC to obtain and exchange land parcels of approximately equal acreage (seventeen [17] acres). The County would receive the land parcel containing waste and M-NCPPC would receive waste-free land (from within the Landfill property parcel) that borders existing M-NCPPC property along Crabbs Branch Stream and Southlawn Branch Stream. The land exchange through the County land disposition process, which requires County Council approval, is ongoing.

- Remediation Project Meetings with Community – From June 2009 to present, representatives of County DEP, GLCC, and the County's technical support consultant (EA) have held monthly meetings at the Shady Grove Transfer Station located at 16101 Frederick Road in Derwood, Maryland. Discussion topics include ongoing operational and post-closure care maintenance activities at the Landfill, and progress, findings, analyses, reports, potential remedial alternatives, and land reuse. Land reuse is also a recurring topic at the monthly meetings. Meetings are typically held the second Thursday of each month from 7:30 to 9:00 p.m. and are open to the public. The County has also held milestone meetings with larger community groups regarding the initiation and completion of site investigations and environmental studies. The County's primary contacts for the Remediation Project are included in **Table 1-6**.

- Remediation Project Webpage – To facilitate the sharing of information related to the Landfill's Remediation Project with residents and other interested parties, the County created a website forum to present meeting minutes, analyses, reports, and other information regarding the Landfill and associated remediation efforts. The documents can be viewed and/or downloaded. The remediation webpage will continue to be updated during the Remediation Project, and the web address is included in **Table 1-6**.

The information and findings obtained from the above referenced activities were used in part as the basis to develop the content of Sections 2 and 3.

2. CONCEPTUAL SITE MODEL

This section summarizes the Conceptual Site Model for the Landfill that was developed as part of the NES (EA 2010a) and the NES Amendment No. 1 (EA 2011a). This information has been updated as appropriate, based on recent findings obtained through continued environmental monitoring.

The Conceptual Site Model describes the potential human health and ecological receptors for groundwater, soil, and surface water at the Landfill, summarizes the risk evaluations that were performed as part of the NES and updated in the NES Amendment No. 1 (EA 2011a), outlines the regulatory requirements governing the Landfill, and describes the nature and extent of potential groundwater impacts that have been identified during ongoing environmental monitoring. Together, these factors are expected to provide the basis for remedial actions at the Landfill.

2.1 IDENTIFICATION OF POTENTIAL RECEPTORS AND EXPOSURE PATHWAYS

Potential human health and ecological receptors of constituents present in environmental media (groundwater, soil, and surface water) at the Landfill were identified as the first step in the risk evaluation performed as part of the NES (EA 2010a). Groundwater, surface and subsurface soil, and surface water were identified as the environmental media to be evaluated, based on available constituent concentration data. Potential receptors of constituents in these media were identified based on the current use of the Landfill property and adjacent properties, as well as the potential migration pathways (EA 2010a) for constituents within and between the media identified for evaluation. The investigations conducted as part of the NES Amendment No. 1 (EA 2011a) did not change the identified receptors relative to those identified in the NES.

2.1.1 Human Health Receptors and Exposure Pathways

Potential receptors of groundwater, soil, and/or surface water at the Landfill include recreational users, County employees or contractors who maintain the Landfill, residents of the County Coalition for the Homeless, Men’s Emergency Shelter (Men’s Shelter), and residents living in the adjacent Derwood Station residential development. The evaluation of groundwater included both direct contact with tap water and inhalation of VOCs that migrate from groundwater to indoor air, in a process known as vapor intrusion.

Exposure to landfill gas was not evaluated in the risk evaluation because, while methane can be an explosive hazard at concentrations above the LEL, it does not pose a human health risk related to exposure to the chemical itself. Note that as a precaution related to the potential explosive hazard, the County has offered to install methane gas detectors in homes adjacent to the Landfill, and as of June 2013, has installed detectors in nine (9) homes. Potential contact with leachate and waste was also not evaluated as part of the risk evaluation. The exposure media for which potentially complete exposure pathways exist, as identified in the NES and NES Amendment No. 1 (EA 2011a) for each potential receptor group, are summarized below:

Potential Exposure Medium	Recreational Users	County employees/ contractors	Men's Shelter Residents	Derwood Station Residents
Surface soil	X	X	X	X (1)
Subsurface soil		X		X (1)
Surface water	X			X
Groundwater				
- **Tap Water**				(2)
- **Vapor Intrusion**				X

Notes:
(1) Potentially complete pathway for residents as recreational users
(2) Pathway is currently incomplete because groundwater is not currently used as a tap water source.

Note that although direct contact with groundwater was identified as a potential exposure pathway for the residents of the Derwood Station residential development, groundwater is not used as a potable water supply in the area, as a result of WSSC public water service connections. Therefore, the residential use of groundwater as a tap water source is not currently a complete exposure pathway. Thus, vapor intrusion of VOCs from groundwater into indoor air was identified in the NES Report (EA 2010a) as the only complete exposure pathway for groundwater.

The Human Health Conceptual Site Model for the Landfill is provided in **Figure 2-1**.

2.1.2 Ecological Receptors and Exposure Pathways

Ecological receptors are potentially exposed to surface soil and surface water. Terrestrial plants, terrestrial invertebrates (e.g., earthworms), birds, and mammals are in contact with surface soil. Aquatic organisms, birds, and mammals are exposed to constituents in surface water. For both

surface soil and surface water, the most important of the potentially complete exposure pathways is expected to be ingestion. Ingestion of prey/vegetation as part of the food chain is also a potentially complete exposure pathway for birds and mammals. Note that exposure to landfill gas and leachate was not evaluated as part of the risk evaluation.
The Ecological Conceptual Site Model for the Landfill is provided in **Figure 2-2.**

2.2 SUMMARY OF THE RISK EVALUATIONS

Following the identification of potentially complete pathways through which the potential receptors may be exposed to the exposure media, the potential risk associated with known constituents in the exposure media was evaluated, given certain conservative assumptions about the extent and duration of exposure by the receptors. The purpose of the human health and ecological risk evaluations performed as part of the NES (EA 2010a) and updated as part of the NES Amendment No. 1 (EA 2011a) was to provide information regarding the risk-based chemicals of potential concern (COPCs) at the Landfill, and to evaluate whether further risk assessment is warranted.

Using the potentially complete pathways and conservative exposure assumptions, the evaluations identified risk-based COPCs, but concluded that no further assessment was warranted, as none of the COPCs were found to pose a concern for human health or the environment. The results of the evaluations are summarized in Sections 2.2.1 and 2.2.2.

2.2.1 Human Health Risk Evaluation

The Human Health Conceptual Site Model for the Landfill is provided in **Figure 2-1**.

Soil

Ingestion of, dermal contact with, and inhalation of particulates from surface soil at the Landfill site were identified as potentially complete exposure pathways for recreational users, County employees and contractors, residents of the Men's Shelter, and Derwood Station residents (as recreational users).

Ingestion of, dermal contact with, and inhalation of particulates from subsurface soil are potentially complete exposure pathways for Derwood Station residents and for County employees and contractors.

The following constituents were identified as risk-based COPCs for soil, based on comparison of reported soil concentrations to MDE cleanup standards (EA 2010a):

- Arsenic
- Chromium
- Cobalt
- Vanadium
- Polychlorinated biphenyl (PCB) Aroclor 1254
- PCB Aroclor 1260

MDE residential cleanup standards were used to evaluate risk to Derwood Station residents, other recreational users, and Men's Shelter residents, consistent with a relatively higher frequency and longer duration of exposure by these groups. Use of residential cleanup standards was a conservative screening approach, as these receptors are not expected to have typical residential-level exposure to the soil on the Landfill. MDE non-residential cleanup standards were used to evaluate risks to County employees and contractors, as they are expected to have only brief exposures to the Landfill soil.

The maximum detected concentrations of the metals in surface and subsurface soil were comparable to the Maryland Anticipated Typical Concentrations (ATCs) and within an order of magnitude of the MDE cleanup standards. Therefore, the metals were concluded to be primarily naturally occurring and to not pose a concern for human health (EA 2010a).

Two (2) PCB Aroclors were detected in soil (one [1] in surface, one [1] in subsurface). Because the PCBs were detected at low concentrations and only once in surface soil and once in subsurface soil, the NES Report concluded that they were not likely a side-wide concern, and that they did not represent a concern for human health (EA 2010a).

Thus, no COPCs in soil were found to pose a concern for human health, and no further assessment of human health risk related to exposure to soil is needed (EA 2010a, 2011a).

Groundwater

The following constituents were identified as risk-based COPCs for Gude Landfill, based on exceedances of MDE groundwater standards during one (1) or both groundwater sampling events in 2010 (EA 2010a):

- Arsenic
- Beryllium
- Cadmium
- Chromium
- Cobalt
- Lead
- Mercury
- Nickel
- Vanadium
- 1,2-dichloropropane
- Benzene
- Cis-1,2-DCE,
- Hexachlorobutadiene
- Methylene chloride
- Naphthalene
- PCE
- TCE
- VC

Note that this list of COPCs presented as part of the risk evaluation differs from the list of constituents exceeding MCLs presented in the NES Amendment No. 1 (EA 2011a) and in Section 2.4.1 of this ACM, as that list presents constituents with exceedances from two (2) 2011 groundwater sampling events. This list of COPCs based on the 2010 data also includes exceedances based on total (unfiltered) metals concentrations, which were found during the NES Amendment No. 1 (EA 2011a) to be elevated (further discussion of total versus dissolved metals is included in Section 2.4.1).

The use of groundwater standards is a conservative measure, because these standards assume that the water source is used as a primary potable water supply for drinking, bathing, and cooking a total of three hundred fifty (350) days per year for thirty (30) years. However, as noted in Section 2.1.1, the only identified complete exposure pathway for groundwater was potential vapor intrusion of VOCs from groundwater into indoor air. Direct contact with, and ingestion of, groundwater are not complete pathways because local groundwater aquifers near the Landfill are not used as a source of potable water for neighboring residential dwellings and commercial businesses. Public water service is supplied through WSSC. There are no active private water supply wells adjacent to or in immediate proximity to the Landfill. Therefore, the use of MDE groundwater standards does not represent concerns for human health under current conditions.

The vapor intrusion pathway was evaluated through the use of the Johnson and Ettinger (J&E) Model for Subsurface Vapor Intrusion into Buildings (EPA 2004a), which indicated that carcinogenic risks and non-carcinogenic hazards were well below levels of concern identified by MDE (EA 2010a).

Thus, no COPCs in groundwater were found to pose a concern for human health, and no further assessment of human health risk related to exposure to groundwater is needed, as long as the pathways for direct exposure to and ingestion of groundwater remain incomplete (EA 2010a, 2011a).

Surface Water

Cobalt was the only COPC identified in surface water, based on comparison to MDE groundwater cleanup levels. As for groundwater, use of these cleanup levels is a conservative measure, as people do not contact surface water to the degree assumed for a primary potable water supply. Cobalt was found not to be a concern for human health based upon the infrequency of human contact with surface water.

Thus, no COPCs in surface water were found to pose a concern for human health, and no further assessment of human health risk related to exposure to surface water is needed (EA 2010a, 2011a).

2.2.2 Ecological Risk Evaluation

The Ecological Conceptual Site Model for the Landfill is provided in **Figure 2-2**.

Soil

Seven (7) metals and high-molecular weight polycyclic aromatic hydrocarbons (HPAHs) were identified as COPCs in surface soil for ecological receptors, based on exceedances of ecological risk screening values, which were chosen to be conservative (EA 2010a):

- Chromium
- Cobalt
- Copper
- Lead
- Nickel
- Vanadium
- Zinc
- HPAHs

It was concluded that metals do not represent a risk to ecological receptors, based on the magnitude and locations of the exceedances of risk screening values. HPAHs also slightly exceeded the ecological risk screening value; however, the NES (EA 2010a) indicated that these concentrations were indicative of background conditions that represent a ubiquitous atmospheric deposition of PAHs, and were not consistent with release from the Landfill site. Therefore, the

NES concluded that HPAHs are unlikely to represent a concern for populations of ecological receptors.

Thus, no COPCs in soil were found to pose a concern for ecological receptors, and no further assessment of ecological risk related to exposure to soil is needed (EA 2010a, 2011a).

Surface Water

Three (3) metals were identified as COPCs in surface water for ecological receptors based on exceedances of ecological risk screening values, which were chosen to be conservative (EA 2010a):

- Barium
- Cobalt
- Nickel.

A surface water location north-northeast of the Landfill had the highest concentrations of these metals, and the only reported MCL exceedances were for cobalt and nickel. Based on the fact that these were the only exceedances, with concentrations only slightly exceeding the risk screening values, it was concluded that populations of ecological receptors were not at risk from exposure to cobalt and nickel. The risk evaluation also concluded that aquatic receptors are not likely to be at risk from exposure to barium in surface water, based on uncertainty regarding the screening value for barium. This uncertainty results from limited toxicity information available to derive the screening value used in the analysis.

Thus, no COPCs in surface water were found to pose a concern for ecological receptors, and no further assessment of ecological risk related to exposure to surface water is needed (EA 2010a, 2011a).

2.3 DISCUSSION OF APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

In accordance with RCRA, national criteria (e.g., standards) for siting, permitting, designing, constructing, operating, and closure and post-closure care of municipal solid waste landfills are set forth under 40 CFR 258. Subpart A of 40 CFR 258.1(c) states that these criteria do not apply to municipal solid waste landfills that did not receive waste after 9 October 1991. The Landfill ceased waste filling operations and closed in May 1982; therefore, it is not governed by RCRA or 40 CFR 258.

Under RCRA, EPA delegates the authority to regulate solid waste management activities to state entities. The Landfill is governed by the state of Maryland under COMAR and as directed by MDE. COMAR Title 26, Subtitle 04, Section 7 (COMAR 26.04.07), provides regulations for solid waste management.

Although the Landfill is not currently an active landfill operating under an active Refuse Disposal Permit in Maryland, MDE has the responsibility and authority to protect the quality of the environment and public health and safety under COMAR 26.04.07.03. The primary applicable regulatory references under COMAR for the Landfill are provided below:

- Post-Closure Monitoring and Maintenance – includes the inspection of the cover system; notation of any surface drainage irregularities or areas experiencing erosion; notation of any surface expressions of leachate; checking the status of the monitoring wells; and associated maintenance of irregularities or problems noted during inspection at a closed landfill under COMAR 26.04.07.22.

- Water Quality Protection – includes the routine monitoring of the quality of waters (groundwater and surface water) around and beneath the Landfill site; MCL limitations at the Landfill site property boundary; monitoring program requirements; and analytical and reporting requirements under COMAR 26.04.07.08B(17) and 26.04.07.09F.

- Explosive Gas Control – includes the collection and monitoring for explosive gases (i.e., landfill gas – methane) at the Landfill. According to COMAR 26.04.07.03B(9), methane concentrations resulting from the presence of landfill gas in on-site structures at the Landfill cannot exceed one and a quarter (1.25) percent by volume, and methane concentrations cannot exceed five (5.00) percent by volume at the landfill property boundary.

- Stormwater Management – includes the management of stormwater with respect to post-closure care maintenance of the cover and drainage systems; collection and management of stormwater discharges on- and off-site; and prevention of potential stormwater pollutant (i.e., non-stormwater) discharges. Post-closure care maintenance responsibilities are referenced under COMAR 26.04.07.22. Stormwater and non-stormwater discharge inspections and requirements are referenced within the 2001 Gude Landfill SWPPP and COMAR 26.08.04.08. The SWPPP is updated annually and is governed under the General Discharge Permit for stormwater discharges associated with industrial activities (Permit No. 02-SW). Future site redevelopment and construction activities at the Landfill will require compliance under the existing General Permit, the County National Pollutant Discharge Elimination System (NPDES) Permit (Permit No. MDR10, State Discharge Permit No. 09GP), and the Maryland Stormwater Management Act of 2007 or other new permits as amended.

Based on existing conditions and historical environmental data from the Landfill, MDE established the following RAOs for the Landfill (MDE 2009) based on applicable or relevant and appropriate requirements (ARARs):

- No exceedances of MCLs, established by the EPA as limits for drinking water, in the groundwater at the Landfill property boundary or between the Landfill and adjacent streams (COMAR 26.08.02).
- No LEL exceedances for methane gas at the Landfill property boundary (COMAR 26.04.07.03B(9)).
- No non-stormwater discharges to the waters of the State (COMAR 26.08.04.08).

2.4 NATURE AND EXTENT OF ENVIRONMENTAL IMPACTS

Because the risk evaluation performed at the Landfill did not identify unacceptable risks to human health or the environment, based on complete exposure pathways (refer to Section 2.2), this ACM focuses on meeting the RAOs established by MDE. The discussion of impacts presented in this section focuses on the media for which the RAOs were defined: groundwater, landfill gas, and non-stormwater discharges.

2.4.1 Groundwater

Reported concentrations of VOCs and metals in groundwater have historically exceeded the MCLs in areas along the perimeter property boundary of the Landfill. As stated in Section 2.3, one of the established RAOs for the Landfill is no MCL exceedances at the property boundary.

An understanding of groundwater flow direction is important for assessing where constituents originating from the Landfill may impact groundwater, for interpreting the potential sources of observed groundwater impacts, and for selecting the placement and orientation of remedial technologies to intercept impacted groundwater. Inferred groundwater flow directions are described in Section 1.2.4 and presented on **Figure 1-5**. (Note that the locations of two [2] wells, OB102 and OB105, were switched on the corresponding figure in the NES Amendment No. 1 [EA 2011a]; correction of this error resulted in slight changes in the interpreted groundwater elevation contours in the northern portion of the property compared to those presented in the NES Amendment No. 1.)

Potential Sources of Groundwater Impacts

Potential sources of impacts to groundwater were evaluated in the NES and NES Amendment No. 1 (EA 2010a and 2011a). The evaluation included on-site and off-site sources. On-site sources of potential impacts to groundwater consist of in-place waste, landfill leachate and landfill gas, which are described below:

- Waste – material in-place within the Landfill has the potential to include waste from industrial sources (aside from municipal solid waste) and as a result, may include chlorinated solvents that have the potential to impact groundwater at the Landfill site.

- Leachate – liquid generated within the Landfill through the natural decomposition of waste and liquid exposed to waste via infiltration are potential sources of leachate impacts to groundwater at the Landfill site. The Landfill was constructed without a bottom liner and leachate collections system; however, it does have a well-vegetated cover system of natural soil and stormwater collection infrastructure to divert unimpacted stormwater off of the Landfill site.

- Landfill Gas – gases are produced through the natural decomposition of organic matter within the waste mass of the Landfill. Although landfill gas is typically composed primarily of methane and carbon dioxide, it can also contain non-methane organic compounds (NMOC), and has therefore been identified as a potential source by which VOCs may be introduced into the groundwater at the Landfill site.

Potential off-site sources of groundwater impacts were also evaluated and include heavy industry and urban environments such as urban roadways, urban residential developments and recreational land use (EA 2011a) that are located in the vicinity of the Landfill. However, the assessment of groundwater quality in the groundwater monitoring wells along the Landfill property boundary has not indicated significant impacts from off-site sources.

Potential Impacts to Groundwater

As requested by MDE, the NES Amendment No. 1 for the Landfill (EA 2011a) defined all current MCL exceedances in groundwater as potential impacts to groundwater. The Amendment evaluated groundwater data from April and September 2011, and reported that concentrations of the following eleven (11) constituents exceeded MCLs:

- 1,1-DCE
- 1,2-Dibromoethane
- 1,2-Dichloropropane
- Benzene

- Cadmium, dissolved
- cis-1,2-DCE
- Methylene Chloride
- Nitrate
- PCE
- TCE
- VC

Note that “cadmium, dissolved” is the only metal included in this list as having an MCL exceedance. This designation indicates that the referenced exceedance was from a field-filtered groundwater sample, as opposed to an unfiltered sample, which would yield a “total” metal concentration. The NES Amendment No. 1 did not include MCL exceedances for total metals in the list of constituents exceeding MCLs, because dissolved metals concentrations were also analyzed during the 2011 sampling events, using field-filtered samples. The results from field-filtered samples indicated that total metals concentrations were elevated due to the presence of suspended sediment, and therefore likely are not representative of groundwater conditions. This conclusion was supported by sampling conducted in September 2013 using low-flow methods to minimize suspended sediments without filtration (see metals discussion below and **Appendix A**).

MCL exceedances for nine (9) of the same potential impacts to groundwater identified in 2011 (all except 1,1-DCE and 1,2-dibromoethane) were also reported during the semi-annual groundwater sampling events of March 2012, September 2012, and March 2013. Dissolved arsenic concentrations slightly exceeding the MCL were also reported during 2012 and 2013.

The paragraphs below discuss in more detail these potential impacts to groundwater, based on MCLs exceedances during the period from 2010 to 2013, and assess their implications for remedial activities at the Landfill.

Metals

Total concentrations (in unfiltered samples) of the following metals exceeded MCLs during groundwater monitoring events conducted in 2010, 2011, 2012, and 2013: arsenic, beryllium, cadmium, chromium, and mercury. Additionally, exceedances of the EPA action level for lead were also reported in unfiltered samples. However, as discussed above, the NES Amendment No. 1 (EA 2011a) included a comparison of dissolved (field-filtered) versus total (unfiltered) metals concentrations and concluded that total metals concentrations were not considered representative of groundwater conditions, due to the presence of suspended sediment in unfiltered groundwater samples. Although the suspended sediment results in MCL exceedances, these exceedances are sporadic and of small magnitude (fewer than ten [10] results for all metals from all wells, between 2002 and 2013, were more than three [3] times the MCL). Furthermore, the NES Amendment No. 1 (EA 2011a) concluded that metals in the groundwater are not indicative of potential impacts from the Landfill.

The impact of suspended sediment on total metals results for groundwater samples was examined further during two (2) supplemental sampling events performed by EA in September 2013. A technical memorandum describing the purpose, methodology, and results of these sampling events is provided in **Appendix A**. Five (5) of the existing monitoring wells at the Landfill were sampled using low-flow sampling methodology, and then sampled again three (3) days later, using three (3) volume well purge methodology. As expected, the low-flow sampling yielded lower turbidity in samples from wells prone to high concentrations of suspended sediments. The results for the three (3) volume well purge samples included one (1) exceedance of the MCL each for arsenic and cadmium, and two (2) exceedances of the action level for lead, whereas the corresponding low-flow samples did not have exceedances for these metals. The only exceedance reported for low-flow samples was one (1) slight exceedance (two and six-tenths [2.6] micrograms per liter [µg/L]) of the MCL for mercury (two [2.0] µg/L). The three (3) volume well purge sample from the same groundwater monitoring well also had a reported mercury exceedance (two and one-tenth [2.1] µg/L). This exceedance is consistent with sporadic, low-level mercury detections in samples from the Landfill groundwater monitoring network, and is considered to be consistent with the conclusion of the NES Amendment No. 1 (EA 2011a) that metals in groundwater are not indicative of potential Landfill impacts. No MCL exceedances of dissolved mercury have been reported any of the groundwater monitoring wells during last three (3) semi-annual groundwater sampling events (March 2012, September 2012, and March 2013). Background mercury concentrations in central Maryland soil have been documented to average fourteen hundredths (0.14) parts per million (MDE 2008).

The results of the September 2013 supplemental sampling events provide further evidence that the sporadic, low-level exceedances of MCLs for metals at the Landfill result primarily from high suspended sediment concentrations in the groundwater samples. This study also indicates that the high turbidity of routine groundwater samples from the Landfill likely results from sampling methodology. For all these reasons, and because COPCs in groundwater were not found to pose a concern for human health (see Section 2.2.1), metals are not considered potential impacts to groundwater that require remediation at the Landfill.

Nitrate

Nitrate is analyzed as a leachate indicator parameter at the Landfill. Detections of nitrate in the groundwater monitoring wells are typically low, with the exception of MW-7 and MW-8, where concentrations exceeded the MCL during at least one (1) sampling event between 2011 and 2013. The reported concentrations of nitrate (from sampling events over the same period of time) in groundwater monitoring wells throughout the Derwood Station residential development (MW-9, MW-10, MW-11A, MW-11B, MW-12, MW-14A, MW-14B and MW-15) were less than the MCL, with no nitrate detections in MW-10. These comparative results indicate that the area of impact and extent of the MCL exceedances for nitrate are limited. Therefore, nitrate is not considered a potential impact to groundwater that requires remediation at the Landfill.

VOCs

The NES Amendment No. 1 (EA 2011a) identified the nine (9) VOCs listed above as potential impacts to groundwater: 1,1-DCE, 1,2-dibromoethane, 1,2-dichloropropane, benzene, cis-1,2-DCE, methylene chloride, PCE, TCE, and VC. Exceedances of these VOCs are believed to represent the primary landfill-related impacts to groundwater. These VOCs will be the targets of remediation, and will be used as the baseline constituents in selecting the remedial technologies for groundwater.

Historical Trends and Seasonal Influences

Historical concentration plots (i.e., trend plots) for potential impacts to groundwater in each groundwater monitoring well since 2001 are presented in **Appendix B**. Historical trends for the constituents analyzed in groundwater were also evaluated from April 2001 (or, for wells installed after 2001, the date of first sampling of each groundwater monitoring well) through September 2012, using a Mann-Kendall statistical test for trend (results are presented in **Appendix C**). The statistical test indicated decreasing trends in the concentrations of several VOCs in one (1) or more groundwater monitoring wells: benzene (OB03, OB03A), methylene chloride (OB11A), PCE (OB03), TCE (OB10), and VC (OB015).

In contrast, the statistical testing indicated increasing trends in groundwater monitoring well OB11, located along the southern boundary of the Landfill, for the following constituents: 1,2-dichloroethane, 1,2-dichloropropane, benzene, cadmium, cis-1,2-DCE, mercury, methylene chloride, PCE, and TCE. The NES Amendment No. 1 (EA 2011a) also identified trends that indicate seasonal fluctuations in concentrations of constituents within the Landfill groundwater monitoring network.

Extent of Groundwater Impacts

Along with previous constituent analyses performed under the NES and NES Amendment No. 1, recent MCL exceedances of Landfill-related VOCs were used to identify the horizontal extent of groundwater impacts along the Landfill boundary. With respect to the vertical extent of impacts, MCL exceedances have been observed in various groundwater monitoring wells (both temporary and permanent wells) ranging in screen depths from two (2) to one hundred fifty-four (154) ft bgs. Data collected between April 2001 (or, for wells installed after 2001, the date of first sampling) and March 2013 was used to assess extent of impacts, with a focus on MCL exceedances reported between 2010 and 2013.

Figure 2-3 presents the extent of MCL exceedances along the current property boundary of the Landfill, as presented in the NES Amendment No. 1 (EA 2011a). **Figure 2-4** presents the approximate areas of the Landfill with MCL exceedances along the future Landfill property boundary following the land exchange with M-NCPPC for use in evaluating the remedial technologies for groundwater. It is noted that no constituent monitoring data are available from within the interior of the Landfill.

General descriptions of impacts to groundwater along the five (5) identified areas of the Landfill site are described below:

- ***Northwest* –** Groundwater along the Northwest portion of the Landfill boundary (in the vicinity of groundwater monitoring wells OB03, OB03A, OB04, OB04A, OB102, MW-8, MW-13A, and MW-13B) is impacted by VOCs. Recent MCL exceedances for VOCs associated with the Landfill (including 1,2-dichloroethane, 1,2-dichloropropane, benzene, cis-1,2-DCE, methylene chloride, PCE, TCE, and VC) have been reported in this area, in groundwater monitoring wells OB03, OB04A, MW-8, MW-13A, and MW-13B. There have been no MCL exceedances on the northern side of Crabbs Branch Stream, which indicates that this surface water body acts as a hydraulic barrier to the migration of groundwater impacts.

- ***West* –** Groundwater along the West portion of the Landfill boundary (in the vicinity of groundwater monitoring wells OB01, OB02, OB02A, MW-6, MW-7, and MW-9) is impacted by VOCs at lower concentrations than the Northwest portion of the Landfill. TCE and VC have each had one (1) reported exceedance on the Landfill property in this area, in groundwater monitoring well MW-7, since this well was installed in 2010.

Exceedances of PCE have also been consistently reported during semi-annual monitoring events since 2010 in groundwater monitoring well MW-9, which is located within several hundred feet of the Landfill, in the Derwood Station residential development. Due to the limited extent and low concentrations of the impacts in this Area, remediation would likely be phased such that more highly impacted areas would be treated first, and then the need for active treatment in this Area would be reevaluated prior to implementation.

- ***Southwest*** **–** Groundwater along in the Southwest portion of the Landfill boundary (in the vicinity of groundwater monitoring wells OB015 and OB12) is impacted by VOCs at concentrations lower than the Northwest portion of the Landfill, but higher than in the West portion. Exceedances of VC were reported in groundwater monitoring well OB015, located on the Landfill property, between 2003 and 2010. Recent MCL exceedances for additional VOCs associated with the Landfill (including 1,2-dichloropropane, methylene chloride, PCE, TCE, and VC) have also been reported in groundwater monitoring well OB12. This monitoring well is located beyond the Landfill property boundary, on WSSC property, north of Southlawn Branch Stream (Landfill side). There were no MCL exceedances on the south side of Southlawn Branch Stream in temporary groundwater monitoring wells sampled during the NES, which indicates that this surface water body acts as a hydraulic barrier to the migration of groundwater impacts.

- ***South*** **–** Groundwater along the South portion of the Landfill boundary (in the vicinity of groundwater monitoring wells OB025, OB11, and OB11A) is impacted by VOCs at concentrations of a magnitude similar to those reported in the Northwest portion of the Landfill. Recent MCL exceedances for VOCs associated with the Landfill (including 1,1-DCE, 1,2-dichloroethane, 1,2-dichloropropane, benzene, cis-1,2-DCE, methylene chloride, PCE, TCE, and VC) have been reported in this area, in groundwater monitoring wells OB11 and OB11A. Additionally, groundwater monitoring well OB025 had sporadic MCL exceedances for VC between 2003 and 2010. As in the Southwest, there were no MCL exceedances on the south side of Southlawn Branch Stream in temporary groundwater monitoring wells sampled during the NES (EA 2010a), which indicates that this surface water body acts as a hydraulic barrier to the migration of groundwater impacts.

- ***Southeast*** **–** Groundwater along the Southeast portion of the Landfill boundary (in the vicinity of groundwater monitoring wells OB08, OB08A, OB10, MW-3A, MW-3B, MW-4) is impacted by VOCs at relatively low concentrations. Recent MCL exceedances of TCE and/or VC have been reported in groundwater monitoring wells OB08, OB08A, OB10, and MW-4. These impacts currently do not extend beyond the current Landfill property boundary to the southeast. However, if the proposed exchange of land with M-NCPPC along this boundary is completed, wells with reported exceedances will be outside the new property boundary. The extent of potential impacts to groundwater from the Landfill to the Southeast is not bounded by the Southlawn Branch Stream; however, the topography of the area indicates that the potential impacts to groundwater are likely localized. Due to the limited extent and low concentrations of the impacts in this Area, remediation would likely be phased such that more highly impacted areas would be treated first, and then the need for active treatment in this Area would be reevaluated prior to implementation.

2.4.2 Landfill Gas

As described briefly in Section 2.4.1, landfill gas is produced by the natural decomposition of organic matter within the waste mass of the Landfill. In addition to its potential impacts on groundwater, landfill gas that migrates through the subsurface into confined spaces is considered an explosive hazard when it reaches concentrations exceeding the methane LEL. Specifically, COMAR 26.04.07.03B(9) states that methane concentrations cannot exceed five (5) percent by volume at the property boundary and MDE established this as one of the RAOs for the Landfill. Landfill gas is collected and monitored at the Landfill in accordance with the COMAR requirement for Explosive Gas Control. Landfill gas exceedances were reported during weekly monitoring events in 2011 and 2012, in eight (8) of the seventeen (17) permanent gas monitoring wells (**Figure 2-5**). Landfill gas monitoring wells with exceedances were primarily located in two (2) discontinuous areas along the Landfill property boundary, the West and Southwest. There were no reported landfill gas exceedances in the Northwest or Southwest Areas of the Landfill. Remedial technologies and corrective measure alternatives intended to improve the collection efficiency of the existing gas collection system are included in this ACM for the Landfill.

2.4.3 Non-Stormwater Discharges

MDE identified the prevention of non-stormwater discharges as an RAO for the Landfill. The primary non-stormwater discharges of concern at the Landfill are leachate seeps. Leachate seeps are generated by liquid within the Landfill or precipitation that infiltrates the Landfill cover system and comes into contact with waste, and then breaches the cover system at the ground surface. Leachate seeps typically occur on the side-slopes of the Landfill where lower permeability layers within the waste inhibit downward migration of the leachate or where the soil depth of the vegetative cover system is shallow (less than two [2] ft). Leachate seep repairs are required to maintain the integrity of the Landfill cover system and to prevent surface runoff of leachate. Stormwater and non-stormwater discharge inspections and requirements for the Landfill are referenced within the 2001 Gude Landfill SWPPP and COMAR 26.08.04.08.

Historically, leachate seeps have been repaired in a manner that redirects the surface expression of leachate back into the waste mass of the Landfill. This procedure allows for natural attenuation of the leachate, since the Landfill does not have a leachate collection system or a bottom liner. The most recent site repairs for leachate seeps occurred in February 2009 and May-June 2010 and March 2013 along the Northwest, North, and West boundaries of the Landfill (**Figure 2-6**). Although leachate seeps can be managed through such repairs, remedial technologies and corrective measure alternatives that would minimize future seeps at the Landfill are discussed in the ACM to address the RAO for non-stormwater discharges.

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3. REMEDIAL ACTION OBJECTIVES AND GENERAL RESPONSE ACTIONS

This section describes the RAOs for the Landfill, and identifies the General Response Actions (GRAs) that will be considered in the process of screening technologies that may be used to achieve these objectives.

3.1 DEVELOPMENT OF REMEDIAL ACTION OBJECTIVES AND GOALS

As described in Section 2.3, MDE has established the following long-term RAOs for the Landfill, based on applicable ARARs (MDE 2009):

- No exceedances of MCLs, established by the EPA as limits for drinking water, in the groundwater at the Landfill property boundary or between the Landfill and adjacent streams (COMAR 26.08.02).
- No LEL exceedances for methane gas at the Landfill property boundary (COMAR 26.04.07.03B(9)).
- No non-stormwater discharges to the waters of the State (COMAR 26.08.04.08).

A related, ongoing RAO is to continue to minimize any potential risks to human and ecological health.

3.2 MEDIA OF CONCERN

As outlined in Section 2 and summarized in the RAOs, three (3) primary media of concern were identified for the Landfill: groundwater, landfill gas and non-stormwater discharges (e.g., leachate seeps).

3.3 GENERAL RESPONSE ACTIONS

GRAs are broad categories of general actions that are identified as potential options for achieving the RAOs. The GRAs were initially selected based on the media of concern at the Landfill and, where applicable, the chemical properties of the constituents present. The seven (7) GRAs identified for implementation to address the impacts present at the Landfill (in no particular order of preference) are as follows:

- *In Situ* Groundwater Treatment

- *Ex Situ* Groundwater Treatment
- Physical Control of Flow
- Cover System Improvements
- Capping
- Waste Excavation
- No Action

By matching appropriate GRAs with the RAOs, a list of preliminary Remedial Technologies was developed. One (1) or more technologies may be considered within each GRA category.

3.3.1 *In Situ* Groundwater Treatment

In situ treatment of groundwater involves the use of chemical or biological mechanisms for reducing the concentrations or bioavailability (i.e., availability for uptake by plants or animals) of groundwater impacts through "in-place" treatment. Thus, treatment is conducted without first removing the impacted medium from its existing location. Mechanisms for *in situ* treatment may include: natural processes (e.g., natural attenuation), the addition of substances to promote natural processes (e.g., carbon substrates that promote microbial degradation of organic constituents), or the addition of substances that promote the destruction or sequestration of the groundwater impacts by chemical means (e.g., chemical oxidation or adsorption onto a solid phase).

This form of treatment may not be able to treat the sources of groundwater impacts, landfill gas, or non-stormwater discharges within the waste mass. However, this treatment may be able to treat impacted groundwater along the Landfill boundary.

3.3.2 *Ex Situ* Groundwater Treatment

Ex situ treatment of groundwater involves the removal of the impacted media followed by the application of treatment technologies to transform, destroy or immobilize the targeted constituents. Groundwater extraction and treatment (i.e., Groundwater P&T) is an example of an *ex situ* treatment technology.

This form of treatment may not be able to treat the sources of groundwater impacts, landfill gas, or non-stormwater discharges within the waste mass. However, this treatment may be able to treat the migration of impacted groundwater along the Landfill boundary.

3.3.3 Physical Control of Flow

Physical control of the flow of impacted media can cause physical isolation and decreased mobility of constituents, or can cause impacted media to flow into a treatment system. Limiting the flow of groundwater and/or landfill gas, for example, could control the migration of groundwater impacts and methane from the waste mass of the Landfill and thus help achieve the RAOs at the property boundary. Control may be achieved through physical barriers or by reversing the hydraulic or pressure gradients that drive mobility of dissolved or gaseous constituents.

This form of treatment would not treat the sources of groundwater impacts, landfill gas, or non-stormwater discharges within the waste mass. However, this technologies that fall under this GRA may be able to limit the extent of, redirect the migration of, and/or allow capture and treatment of impacted groundwater and gas along the Landfill boundary.

3.3.4 Cover System Improvements

The existing landfill cover system consisting of a vegetative soil layer over the waste mass does not provide the same preventative and/or protection measures as an impermeable geosynthetic capping system with respect to landfill gas and non-stormwater discharges (e.g., leachate seeps). For example, limited soil depth or a poorly graded slope over the waste mass may provide a pathway for fugitive gas emissions or a leachate seep if the cover system is compromised.

However, improvement of the soil cover with respect to depth and grade across the Landfill site could help to achieve the RAOs by decreasing the potential leachate seeps and potentially decreasing fugitive gas emissions.

This form of treatment would not treat the sources of groundwater impacts, landfill gas, or non-stormwater discharges within the waste mass. However, this treatment may be able to decrease the potential for the migration of impacts.

3.3.5 Capping

Capping of the ground surface area of a landfill is a common industry practice to limit the exposure of humans and the environment to landfill contents, while reducing mobility of potential impacts by limiting gas migration beyond the waste mass and water infiltration into the waste mass. Capping systems can be constructed of a variety of materials, with variable permeability such as geosynthetic liners or compacted clay, and may be installed over the entire landfill surface (i.e., Full Capping) or only in selected areas (i.e., Partial Capping).

This form of treatment would not treat the sources of the groundwater impacts, landfill gas, or non-stormwater discharges within the landfill. However, this treatment may be able to decrease the potential for the migration of impacts.

3.3.6 Waste Excavation

Waste excavation is a process in which waste is removed from the ground and transported to another on-site or off-site location. Removing waste from part or all of the Landfill would decrease the size of the waste mass. This in turn would decrease the size of the source of potential impacts, and could lessen localized groundwater and landfill gas exceedances, as well as the occurrence of non-stormwater discharges in the areas targeted for excavation. In the case of the Landfill, where the existing limit of waste is in close proximity to the property boundary, the removal of waste would increase the distance between the future limit of waste and the point of compliance.

Waste excavation can be selective (portions of the waste mass) or extensive (the entire waste mass). In either case, waste excavation would occur in designated engineered phases. Environmental control measures for stormwater diversion, landfill gas and leachate management, vectors, noise, etc., would need to be implemented in conjunction with waste excavation.

This form of treatment would remove some or all of the source of groundwater impacts, landfill gas, or non-stormwater discharges through removal of the waste mass, depending on the amount of waste excavated. This treatment would also likely decrease the potential for the migration of impacts.

3.3.7 No Action

The National Contingency Plan (NCP) requires consideration of a “No Action” response. No action serves as a baseline against which the performance of other remedial alternatives can be compared. This response assumes no active remedial measures are implemented.

4. IDENTIFICATION AND SCREENING OF REMEDIAL TECHNOLOGIES TO DEVELOP THE CORRECTIVE MEASURE ALTERNATIVES

Based on the existing site conditions at the Landfill and with respect to the potential environmental impacts of the site on groundwater, landfill gas and non-stormwater discharges, MDE established RAOs for the Landfill. In turn, GRAs were reviewed to identify potential categories of options that may have the ability to achieve the RAOs. Furthermore, in using the GRAs in conjunction with the RAOs, the County identified, reviewed, and screened specific technologies that can be implemented at the Landfill site to achieve the MDE-specified RAOs. These specific technologies are identified and presented in Section 4.

Section 4 also presents the evaluation of these technologies, from identification and case study literature review (as Remedial Technologies) through the screening process (as Corrective Measure Technologies) to an implementation sequence to achieve the RAOs (as Corrective Measure Alternatives [CMAs]).

A description of the overall methodology for evaluating and screening the Remedial Technologies is provided in Section 4.1. Also provided in Section 4.1 is a detailed description of the process for retaining the Corrective Measure Technologies from the initial screening as well a brief introduction into developing of the Corrective Measure Alternatives.

Sections 4.2 through 4.13 present the results of the screening of Remedial Technologies, and Section 4.14 describes the development of the CMAs.

4.1 METHODOLOGY

4.1.1 Identification of Remedial Technologies

Based on the GRAs and the envisioned remedial actions at the Landfill to meet the RAOs, a group of twelve (12) Remedial Technologies was developed for screening. The Remedial Technologies (in no particular order of preference) include:

- Monitored Natural Attenuation
- Enhanced Bioremediation
- Permeable Reactive Barrier
- Chemical Oxidation
- Groundwater Pump and Treat
- Phytoremediation
- Impermeable Barrier
- Landfill Gas Collection
- Cover System Improvements
- Partial or Full Capping
- Selective or Extensive Waste Excavation

The "No Action" screening option was also included because the NCP requires that such an option be screened, for use as a baseline comparison against the other Remedial Technologies.

A general description of each Remedial Technology and its capabilities and applications is provided in Sections 4.2 through 4.13.

4.1.2 Case Study Literature Review

For each Remedial Technology, a literature review was completed to identify sites where the technology has been implemented. Example sites for each Remedial Technology were selected based on their similarity to the Landfill in terms of site type and site conditions (including media of concern, nature of impacts and RAOs and exposure potential). Select case studies of similar sites that have implemented the Remedial Technologies are summarized in the sections below and in **Table 4-1**. The documents referenced during the literature review are included in **Appendix D**.

4.1.3 Screening of Remedial Technologies to Become Corrective Measure Technologies

In conjunction with a review of the general capabilities, applications and associated case studies, each Remedial Technology underwent a screening process. The screening process used specific criteria (refer to Section 4.1.3.1), such as effectiveness, implementability and cost, to assess each Remedial Technology's potential ability to achieve the RAOs at the Landfill. Based on the evaluation of this information, each Remedial Technology was either retained or not retained for further analysis. **Table 4-2** presents a summary of the screening process.

The Remedial Technologies that were retained from the screening process are considered Corrective Measure Technologies. For areas where the Corrective Measure Technologies might be applied at the Landfill based on reported MCL exceedances in groundwater, LEL exceedances of methane gas, and leachate seeps (i.e., non-stormwater discharges), refer to **Figures 2-5, 2-6 and 2-7**.

The resulting areas where the Corrective Measure Technologies may be implemented ("Remediation Areas") are presented on **Figure 4-1**.

4.1.3.1 Screening Criteria

The following criteria were used in the screening process for evaluating Remedial Technologies that would become Corrective Measure Technologies (i.e., retained technologies) for further analysis.

Effectiveness

The effectiveness criterion evaluates the following elements:

- Potential effectiveness of the Remedial Technologies to meet RAOs for groundwater, landfill gas, and leachate seeps (i.e., non-stormwater discharges) at the Landfill, and
- Reliability and proven effectiveness of the Remedial Technology with respect to the constituents and the site-specific conditions present.

Implementability

The implementability criterion includes the technical and institutional (administrative) feasibility of implementing each Remedial Technology. This screening criterion eliminates Remedial Technologies that are clearly not implementable or will result in unacceptable conditions following construction at the Landfill site. The implementability criterion evaluates the following elements:

- Potential for obtaining MDE approval;
- Availability of necessary equipment and skilled workers to implement the Remedial Technology;
- Availability of treatment, storage, and disposal services;
- Time required for implementation;
- Ability to achieve the applicable remediation standards within a reasonable time frame;
- Potential impacts to human health and the environment during the construction and implementation phase; and
- Site condition acceptance (public, property owner, and other involved parties) during and following construction.

Cost

For this screening criterion, a qualitative cost analysis is provided. Approximate costs presented in this Section for each Remedial Technology are generalized estimates, based on professional experience and estimates by EA and County personnel. Some (as cited) are derived from general costing information published by the Federal Remediation Technologies Roundtable (FRTR), which maintains a Screening Matrix and Reference Guide (FRTR 2012) and a Searchable Database of Remediation Technologies (FRTR 2010). Costs within the ranges presented by the FRTR were selected by considering the size and nature of conditions at the Landfill. Total implementation costs for the Remedial Technologies are expected to vary widely depending on specific design parameters, permit requirements and construction sequencing of each technology.

4.1.4 Development of the Corrective Measure Alternatives

Following the screening process, the Corrective Measure Technologies were combined and sequenced into CMAs, as discussed in Section 4.14. The combination and implementation sequence for CMAs was based on the most feasible and effective methods to achieve the RAOs at the Landfill. Preliminary cost estimates are presented for the CMAs as part of the detailed analysis in Section 5.

4.2 MONITORED NATURAL ATTENUATION

4.2.1 Description

Natural attenuation describes a range of natural physical and biological processes that reduce the volumes and concentrations of potential impacts to groundwater. These processes include biodegradation, adsorption, dilution, dispersion and volatilization. Monitored natural attenuation (MNA) is a Remedial Technology that combines these natural processes with a carefully designed groundwater monitoring program to achieve remediation goals.

At many sites, the most significant natural attenuation process for organic compounds is biodegradation. Chlorinated volatile organic compounds (cVOCs), such as those found at the Landfill, are effectively degraded through a process called reductive dechlorination. Under anaerobic conditions (without oxygen present), PCE is degraded to TCE, which is degraded to DCE and finally VC. VC can be degraded to ethene anaerobically in the presence of specific bacteria, which may already be present at the Landfill, or it can be degraded under aerobic conditions (with oxygen present). The final byproducts of VC degradation are considered to be innocuous or harmless substances that do not pose a risk to human health or the environment, and include ethane, carbon dioxide, water and chloride. This overall process of cVOC degradation is referred to as reductive dechlorination, and is depicted below:

C_2Cl_4	→	C_2HCl_3	→	$C_2H_2Cl_2$	→	C_2H_3Cl	→	C_2H_6 + CO_2 + Water + Chloride
(PCE)		(TCE)		(DCE)		(VC)		(ethane)

To determine whether MNA is an appropriate Remedial Technology for a site impacted by cVOCs, it is necessary to (1) determine whether the expected daughter compounds (TCE, DCE and/or VC) are present; (2) assess the geochemical conditions of the aquifer, to determine whether the conditions are conducive to reductive dechlorination; and (3) estimate the timeframe for natural attenuation to achieve RAOs. MNA is typically used for low-concentration VOCs (approximately less than ten [10] times the site RAOs), as the timeframe for attenuation from higher concentrations to the RAOs is often not consistent with site objectives.

4.2.2 Case Studies

Three (3) sites where MNA was implemented, in combination with other remedial technologies, were identified and selected for consideration during the literature review (**Table 4-1**). Two (2) of the sites were landfill Superfund sites (EPA 2006, 2008a, 2005a); the last site was a former railroad maintenance facility (Lacko et al. 2001). It is noted that Gude Landfill is not a Superfund site. All three (3) case study sites had groundwater impacted by VOCs.

At the Onalaska Municipal Landfill Superfund Site (EPA 2006, 2008a), the existing Groundwater Pump and Treat (P&T) system was temporarily shut down to evaluate MNA as a measure for site remediation. After two (2) years of MNA, VOCs and metals remained at concentrations above cleanup goals. The groundwater down-gradient of the landfill was found to be more reducing (i.e., oxygen deficient) than the background (up-gradient) groundwater, which was concluded to be a potential hindrance to degradation of non-chlorinated VOCs that were present in excess of cleanup goals. Based on insufficient data supporting natural attenuation, MNA was not recommended as a remedy at the site. The MNA study completed in 2008 emphasized the importance of developing a relevant and appropriate conceptual site model prior to designing a monitoring program to assess MNA (EPA 2008a).

At the Somersworth landfill site, natural attenuation was observed in the aquifer above the fractured bedrock, and VOC concentrations were observed to be steady or decreasing. Other treatment technologies were implemented to promote attenuation of impacts in the source area. Sampling for natural attenuation parameters indicated that attenuation is ongoing, and MNA remained the primary treatment mechanism down-gradient of the source area (EPA 2005a).

At the railroad facility, cVOCs, including the daughter products of PCE degradation, were present at concentrations similar to those observed at the Landfill, up to one hundred sixty (160) µg/L. The groundwater was found to be reducing, with sufficient anthropogenic (originating in human activity) and native organic carbon to support microbial activity. After the source was removed, the residual VOCs were found to naturally attenuate all the way to ethane and ethene, with a maximum VOC concentration of sixty-four (64) µg/L, four (4) years after source removal.

4.2.3 Screening

Effectiveness

Groundwater: MNA is advantageous because it results in a reduction in the mass of constituents impacting groundwater; organic constituents are transformed to innocuous byproducts. The presence of all constituents in the common dechlorination series discussed in Section 4.2.1 – PCE, TCE, DCE, and VC – suggests that reductive dechlorination is occurring at the Landfill. This indicates the potential for degradation of cVOCs to concentrations less than MCLs in the long term. An evaluation of natural attenuation processes occurring at the Landfill is presented in **Appendix E**. This analysis indicates that natural attenuation is occurring at the Landfill; however, groundwater monitoring data indicate that concentrations of cVOCs impacting groundwater at the Landfill are up to ten (10) times MCLs along some parts of the property boundary, despite current natural attenuation processes. The timeframe for MNA to decrease these concentrations to below MCLs and meet the groundwater RAO at the property line in the presence of the ongoing source of contamination is unknown, due to the unknown volume of the source of groundwater impacts within the Landfill. MNA is therefore considered unlikely to be an acceptable Remedial Technology for groundwater in the presence of ongoing sources of contamination, but would likely be effective if the source of contamination was removed.

Landfill gas: The natural decomposition of waste within the Landfill via biological processes produces landfill gas. The implementation of MNA would not be expected to impact the current generation rate of landfill gas (including methane) within the Landfill.

Non-Stormwater Discharges (e.g., Leachate Seeps): This groundwater treatment technology would not be expected to have an impact on leachate seeps at the Landfill, as the degradation of VOCs would occur in the aquifer, and would not affect the leachate that is present within the Landfill.

<u>*Implementability*</u>

MNA would be highly implementable as a Remedial Technology. MNA is non-intrusive and generally less costly than other remedial technologies. Implementation of MNA would not require the installation of any structures or specialized remediation equipment. MNA does not have negative impacts in the short-term, as it does not result in the generation of significant volume of wastes from remediation processes. MNA also does not require disturbance of the source material (e.g., in-place waste) or the introduction of additional biological/chemical substances into the subsurface.

Gaining MDE approval for MNA, in the presence of an ongoing source of contamination within the waste mass, would require a demonstration that constituent concentrations within the plume of impacted groundwater are stable (not increasing over time), and that MNA could meet the groundwater RAO in a reasonable timeframe. The MNA evaluation for the Landfill (**Appendix E**) concluded that the plume may be stable or decreasing in size and concentrations in some areas around the perimeter of the Landfill, but is on a general increasing trend in other areas, and that the timeframe to meet the RAO cannot be estimated in the presence of the ongoing source of contamination. Thus, MNA is only expected to be implementable in conjunction with removal of the source of contamination.

<u>*Cost*</u>

The County currently performs post-closure care and monitoring activities at the Landfill. These activities include semi-annual monitoring of groundwater and surface water as well as quarterly landfill gas monitoring. Costs associated with MNA, above and beyond the current monitoring at the Landfill, are expected to be minimal, in the range of $25,000 - $50,000 per year. There may be upfront capital installation costs of approximately $10,000 per groundwater monitoring well if additional wells are required.

4.3 ENHANCED BIOREMEDIATION

4.3.1 Description

Enhanced Bioremediation is an *in situ* (in-place) treatment technology that stimulates the biodegradation of organic constituents through underground injection or placement of electron donors (e.g., carbon-based substrates), electron acceptors (e.g., oxygen), or cultures of microorganisms into the soil and/or groundwater. The absence of a suitable substrate can be a limiting factor for natural biological degradation processes. The addition of food-grade carbon substrate (electron donor) such as vegetable oil, sodium lactate or molasses can therefore stimulate biological reactions in the subsurface to degrade organic constituents and thus enhance the natural attenuation processes.

In the case of cVOCs, the addition of an organic carbon substrate would promote the development of anaerobic conditions and thus promote reductive dechlorination of the VOCs (refer to Section 4.2.1 for a description of the dechlorination process). Inorganic substrates such as zerovalent iron (ZVI) can also be added with the organic carbon, to further promote the reductive process. This form of Enhanced Bioremediation can transform organic constituents into innocuous byproducts (i.e., ethane, carbon dioxide, water and chloride). However, in some cases, bacteria that degrade cVOCs all the way to ethene (e.g., *Dehalococcoides*) may not be naturally present. This can be the case even where natural degradation of PCE and TCE to DCE and VC is occurring, and is often indicated by a build-up of VC. In these cases, one option is to inject a culture containing these organisms (known as a “bioaugmentation culture”). Another option is to inject a source of oxygen (an electron acceptor) to promote aerobic processes, which are also known to degrade VC.

Bioremediation can be effective for the treatment of organic constituents impacting groundwater, including the cVOCs and benzene found at the Landfill. In designing a bioremediation program, it would be necessary to evaluate what kinds of natural biodegradation are already occurring at the Landfill, and how these processes could be enhanced.

4.3.2 Case Studies

Six (6) sites with cVOC impacts were selected as examples of cases where injections of electron donors and electron acceptors resulted in significant changes in the geochemistry and decreases in cVOC concentrations (**Table 4-1**) (Ross et al. 2007, United States Department of Defense [USDOD] 2007, EPA 2000a, EPA 2000b, Finn et al. 2003, EA 2010b).

At the Savannah River Site, methane, air and nutrients (nitrous oxide and triethyl phosphate) were injected into one (1) horizontal injection well at a closed landfill, to encourage the complete mineralization of TCE by methane-oxidizing organisms. Air and nutrients were injected into a separate horizontal injection well, to encourage the aerobic degradation and volatilization of VC. Injections were made on a two (2)-week cycle. During the approximately one (1) year-long field demonstration at the site, TCE concentrations in the groundwater, previously ranging from ten (10) to one thousand thirty-one (1,031) µg/L, decreased to five (5) µg/L. PCE concentrations at the site ranged from three (3) to one hundred twenty-four (124) µg/L before the demonstration and decreased to five (5) µg/L by the end of the demonstration (EPA 2000b). Air injection was suspended after about six (6) years because concentrations of cVOCs were less than the alternate concentration limits (ACLs) and levels were expected to continue decreasing (Ross et al. 2007).

At a landfill located at the Kelly Air Force Base, the groundwater was determined to be biologically limited for complete degradation of VOCs. Electron donors methanol and acetate were injected continuously along with a bioaugmentation culture. The total concentration of methanol and acetate in the groundwater after injection was seven and two-tenths (7.2) millimoles per liter (mM). Reductive dechlorination of PCE began occurring after the electron donor injections, but complete dechlorination to ethene only occurred after the bioculture was introduced (USDOD 2007). The percent of the total VOC concentration represented by PCE and TCE decreased from approximately seventy-two (72) percent to four (4) percent and one and six-tenths (1.6) percent to nine-tenths (0.9) percent, respectively, after about two and one-half (2.5) years. Ethene increased from zero (0) percent to approximately forty-five (45) percent of the total VOC concentration. The concentrations of DCE and VC increased for the first ten (10) months and then decreased, as expected because these constituents are degradation products of TCE, which are then degraded themselves. Ethene (a product of the degradation of VC) was detected within seventy-two (72) days of addition of the bioaugmentation culture.

At the Avco Lycoming Superfund Site, former location of various manufacturing operations, molasses injections created anoxic (oxygen-deficient) conditions, promoted reductive dechlorination, and resulted in PCE and TCE concentrations less than cleanup levels after eighteen (18) months (EPA 2000a). Molasses was injected through twenty (20) injection wells twice a day. The amount of molasses added was based on system monitoring and controlled by a programmable logic controller. After eighteen (18) months of monitoring, the concentration of TCE decreased from sixty-seven (67) µg/L to six and seven-tenths (6.7) µg/L. DCE initially increased within the first ten (10) months from seven (7) µg/L to one hundred (100) µg/L and then decreased to nineteen (19) μg/L in the remaining eight (8) months. The VC concentration also initially increased from less than one (1) μg/L to five (5) μg/L within the first ten (10) months of monitoring and then decreased to less than the detection limit by the eighteenth (18^{th}) month of monitoring.

Two (2) different materials were injected to promote different types of bioremediation during a demonstration project at an industrial site in Massachusetts (EPA 2000b). Initially, nutrients and carbon were injected, and drove reductive dechlorination of PCE and TCE. The anaerobic phase lasted approximately eight (8) months and the injections consisted of twenty-five (25) milligrams per liter (mg/L) ammonium chloride and potassium tripolyphosphate, five (5) mg/L yeast extract, varying concentrations of lactic acid (from one hundred [100] to three hundred fifty [350] mg/L), and sodium hydroxide to neutralize the pH. The injection rate was ten (10) mL/min. After eight (8) months, the TCE concentration had reduced from twelve (12) mg/L to less than one (1) mg/L and the VC concentration had increased. When concentrations of PCE and TCE had decreased, and VC had accumulated in the groundwater, Oxygen Release Compound (ORC®) was injected, enabling aerobic degradation of VC as well as DCE. The total mass of VOCs decreased by eighty (80) percent (EPA 2000b).

At the Caldwell Trucking Superfund Site in New Jersey and at Aberdeen Proving Ground in Maryland, carbon substrate was injected along with bacteria known to promote complete degradation of cVOCs to ethene (Finn et al. 2003, EA 2010b). The combination successfully decreased TCE and PCE concentrations, while increasing concentrations of DCE, VC, and ethene. At the Caldwell Trucking Site, fifty (50) to one hundred (100) gallons of a four thousand five hundred (4,500) mg/L carbon substrate mixture was injected into each injection well during each injection event. During the first year, the mixture used consisted of equal parts of methanol, lactate and acetate. This mixture was injected on a monthly basis for the initial three (3) months and on a weekly basis for the next nine (9) months. After the first year, a different mixture, still with a concentration of four thousand five hundred (4,500) mg/L, but consisting of one (1) part methanol to two (2) parts lactate, was injected five (5) times per week Concentrations in one (1) injection well decreased from twenty-seven thousand (27,000) μg/L to two hundred sixty (260) μg/L PCE, and six hundred eighty thousand (680,000) μg/L to one thousand seven hundred (1,700) μg/L TCE. The concentrations of VC and ethene were sustained at two thousand (2,000) μg/L VC and thirty (30) to forty (40) μg/L ethene (Finn et al. 2003).

4.3.3 Screening

Effectiveness

Groundwater: If appropriate enhancements (e.g., carbon substrates or electron donors) are selected and mixed effectively into the groundwater, biodegradation would be expected to efficiently destroy organic constituents, and would likely decrease cVOC and benzene concentrations at the Landfill to less than MCLs over a period of time. Injections of carbon substrate could address elevated concentrations of cVOCs, by promoting reductive dechlorination, and could also promote degradation of benzene. Periodic injections would likely be required to maintain biodegradation until the sources of VOCs within the waste mass of the Landfill are depleted, which may likely take many decades.

The volume of treated groundwater would be constrained primarily by the location and depth of the injection wells. This Remedial Technology could potentially reduce impacts to groundwater in both shallow and deep groundwater if injection wells are installed in both unconsolidated material and bedrock. Although injected substrate or electron donor may not reach the entire impacted volume of the aquifer, especially within the bedrock, natural attenuation would continue within the bedrock, and would likely be promoted by the effects of the injections on the aquifer as a whole. For large Enhanced Bioremediation systems, pilot tests using a small number of injection wells are often conducted to refine the design of the system, including well spacing, amendments to be injected, and the frequency and concentrations of injections. Site investigations to characterize the aquifer may also be required. The ability to use different combinations of wells for each injection event would allow this Remedial Technology to be modified in response to shifting site conditions and constituent concentrations.

Landfill gas: Enhanced Bioremediation using carbon substrate could potentially increase the generation rate of landfill gas (including methane) by stimulating the microbial activity within the shallow groundwater. The potential increase in the rate of gas generation could be managed through the existing landfill gas collection system and other technologies for controlling gas migration.

Non-Stormwater Discharges (e.g., Leachate Seeps): This groundwater treatment technology would not be expected to have an impact on leachate seeps at the Landfill, as the degradation of VOCs would occur in the aquifer, and would not affect the leachate that is present within the Landfill.

Implementability

Enhanced Bioremediation is expected to be highly implementable at the Landfill. Injection wells would be required for introduction of energy sources and electron acceptors into the groundwater aquifer. Injection wells could be installed either around the perimeter of the waste, if sufficient space is available between the limit of waste and the point of compliance, or through the waste mass to the underlying groundwater.

Currently, the limit of waste is very close to the property boundary (within approximately five [5] to twenty [20] ft) in much of the West, Southwest, and South Areas (see **Figure 1-2**). If the proposed exchange of land along the northern and eastern boundaries of the Landfill with M-NCPPC goes forward, the waste will extend within five (5) to twenty (20) ft of the Landfill property boundary in the Northwest and Southeast Areas. Some distance would be required between the injection wells and the landfill boundary (point of compliance), to allow time for biodegradation of the organic constituents. Therefore, if injection wells for Enhanced Bioremediation were to be installed at the Landfill in its current state, the injection wells would most likely need to be installed through the waste mass, which would present challenges that could be mitigated through use of standard industry procedures for drilling in waste. Alternatively, selective waste excavation along the Landfill property boundary could provide space for the installation of injection wells outside the limit of waste, with space for biodegradation to occur between the injection wells and the property boundary.

Food-grade carbon substrates are often selected as an energy source for promoting bioremediation. If VC accumulation is observed following the sequenced biodegradation of other constituents such as PCE and TCE, contingencies for promoting VC degradation could include bioaugmentation with a culture containing *Dehalococcoides*, or injection of Oxygen Release Compound (ORC®) or similar slow-release oxygen material. Bioaugmentation is expected to be more implementable than injection of ORC® at the Landfill site, because this culture allows simultaneous degradation of PCE, TCE, DCE, and VC, rather than sequential anaerobic degradation of PCE and TCE followed by aerobic degradation of VC. A key part of the design process would be to analyze groundwater conditions in order to select the optimal amendments (carbon substrate, bacterial cultures, and/or electron acceptors) for injection. It would also be necessary to design an injection program that achieves sufficient mixing of enhancements into the water contained in the limited permeability bedrock. Enhanced Bioremediation would be expected to have few short-term negative impacts at the Landfill, because it would result in minimal disruption of the site and its existing infrastructure.

Enhanced Bioremediation is an increasingly common and well accepted method for groundwater remediation (FRTR 2010). MDE acceptance would require a careful plan for design and monitoring of the injection system. Factors such as substrate selection, injection methods and injection well locations would have to be demonstrated to be effective at enhancing biodegradation at the Landfill. MDE recently approved treatment of a cVOC plume at a sanitary landfill in Baltimore County, Maryland, using emulsified vegetable oil via a line of injection wells that are located perpendicular to the plume ("passive biobarrier") (EA 2012). At this landfill, biological testing indicated a significant population of *Dehalococcoides* cultures, but the remediation design included possible bioaugmentation with additional cultures as a contingency measure. Initial results, collected up to three (3) months after the injections, indicated that the injections facilitated reducing conditions that are favorable for reductive dechlorination of site contaminants by *Dehalococcoides*. These results also indicated an initial decrease in total cVOC concentrations down-gradient of the biobarrier.

Community acceptance would likely require education about the benefits of bioremediation as compared to more invasive technologies. In addition, further evaluation of this Remedial Technology would be required to assess the compatibility with other remedial technologies as well as potential future land reuse options.

Cost

The costs for implementing Enhanced Bioremediation will vary widely, depending on the treatment area, groundwater volumes, constituent concentrations, the types and amounts of enhancements added, and the infrastructure needed. An Enhanced Bioremediation program at the Landfill is expected to have an initial capital cost of approximately \$1,000,000 to \$3,000,000 for installation of approximately fifty (50) to two hundred (200) injection wells and associated process monitoring equipment. An additional expenditure of approximately \$400,000 to \$2,000,000 per year is estimated for injection events, monitoring, and operations and maintenance (O&M) (FRTR 2010). These costs are based on reported total costs from other sites impacted by cVOCs, where Enhanced Bioremediation systems were successfully implemented.

4.4 PERMEABLE REACTIVE BARRIER

4.4.1 Description

Permeable Reactive Barriers typically contain materials that destroy or retain constituents known to be present in impacted groundwater. These barriers are installed in a manner to intercept plumes of impacted groundwater, such as in excavated trenches or by injection into the subsurface via a series of wells. As the groundwater flows into the barrier, constituents are treated *in situ* (i.e., in-place). Reactive barriers provide active groundwater treatment without groundwater extraction and are a common technology for in-place treatment. Barriers typically cannot be installed in bedrock, and thus a barrier at the Landfill could only intercept the shallow portion of the impacted groundwater.

4.4.2 Case Studies

Three (3) sites that installed Permeable Reactive Barriers to treat VOC impacts in groundwater were identified and selected for consideration during the literature review (**Table 4-1**) (EPA 1998a, USDOD 2008, Air Force Center for Environmental Excellence [AFCEE] 2004).

Leaking storage tanks and waste sumps (receptacles used for collection and temporary storage of liquid waste) at the Moffett Federal Airfield contributed to groundwater impacts by cVOCs (including TCE, PCE, and DCE). During remedial investigations in 1991, the maximum TCE and PCE concentrations were twenty thousand (20,000) µg/L and five hundred (500) µg/L, respectively. A Permeable Reactive Barrier was installed in 1996 to intercept and treat impacted groundwater from a single source. A funnel and gate system directed groundwater through a Permeable Reactive Barrier of one hundred (100) percent reactive iron. During the pilot test, two hundred eighty-four thousand (284,000) gallons of groundwater were treated in a year. In general, VOC concentrations contained in the water passing through the barrier decreased from one thousand (1,000) µg/L in the area directly up-gradient of the barrier to one (1) µg/L TCE and two hundred (200) µg/L to ten (10) µg/L PCE (EPA 1998a).

Offutt Air Force Base installed a five hundred (500)-ft-long mulch barrier filled with coarse sand mixed with mulch. Following a successful pilot test of a one hundred (100)-ft section, the extended barrier was installed in stiff, low plastic, silty clay, where the groundwater was impacted by VOCs including TCE. The average TCE concentration before the pilot test was eight hundred (800) µg/L, with a maximum TCE concentration of eight thousand seven hundred

(8,700) μg/L. TCE concentrations decreased by seventy (70) percent to ninety-five (95) percent, with minimal generation of VC. Ethene and ethane concentrations increased dramatically, indicating dechlorination of the cVOCs. By October 2003, reported concentrations of TCE, DCE and VC were less than their respective drinking water MCLs (AFCEE 2004).

At Altus Air Force Base, groundwater was impacted by cVOCs from a closed unlined landfill. A recirculating bioreactor was constructed by excavating a thirty (30)-ft by thirty (30)-ft by eleven (11)-ft-deep section of the landfill near the source of impacts and backfilling it with organic material and sand. The initial TCE concentrations in untreated groundwater ranged from forty-three (43) to two thousand one hundred seventy-nine (2,179) μg/L, which decreased to a range of one-tenth (0.1) to twenty and two-tenths (20.2) μg/L in treated groundwater following treatment in the bioreactor test cell. The bioreactor removed six and one-half (6.5) pounds of TCE from six hundred ninety thousand (690,000) gallons of groundwater during the demonstration project; however, the objective of reducing cVOC concentrations by ninety (90) percent was not achieved, due to the presence of a continuing up-gradient TCE source and an accumulation of DCE and VC in the groundwater (USDOD 2008).

4.4.3 Screening

Effectiveness

Groundwater: When Permeable Reactive Barriers are placed to intercept the majority of the plume of impacted groundwater, they can be highly effective for the treatment of a variety of constituents. Because their locations are fixed, reactive barriers are not easily manipulated to respond to changing groundwater conditions and therefore work best with well-defined and consistent plumes. Due to the unknown nature of the sources of potential groundwater impacts within the Landfill, the barrier would likely need to be maintained for many decades, until the sources are depleted.

The effectiveness of reactive barriers for achieving the groundwater RAO at the Landfill would be significantly decreased by the fact that barrier installation in bedrock is typically not feasible, preventing treatment of the deeper impacted groundwater within the bedrock. The unconsolidated material overlying the bedrock around the perimeter of the Landfill is approximately ten (10) to fifty (50) ft thick, while the groundwater impacts have been observed at over one hundred (100) ft below the ground surface. Thus, an unknown but potentially substantial volume of impacted groundwater is located within the bedrock, where Permeable Reactive Barriers cannot directly address impacts. Although treating shallow groundwater could cause some indirect decrease in impacts to deep groundwater, it would be difficult to predict whether a reactive barrier could decrease VOC concentrations to below MCLs, and if so, over what timeframe.

Landfill gas: A Permeable Reactive Barrier installed along the perimeter of the Landfill below ground surface elevation could have a minor impact on the potential for landfill gas migration but would not impact the current generation rate of landfill gas (including methane) at the Landfill. Some methane production could occur within the barrier itself, if sufficiently reducing conditions are established; however, this methane is not expected to impact the likelihood of LEL exceedances.

Non-Stormwater Discharges (e.g., Leachate Seeps): A Permeable Reactive Barrier installed along the perimeter of the Landfill below ground surface elevation would not be expected to have an impact on leachate seeps at the Landfill.

<u>*Implementability*</u>

As discussed in Section 4.4.1, the installation of a Permeable Reactive Barrier would likely be implementable in the unconsolidated material below ground surface elevation that contains the shallow groundwater along the perimeter of the Landfill. This Remedial Technology is not recommended for installation in the bedrock, where deeper groundwater impacts occur at the Landfill, due to concerns related to the placement and potential replacement of barrier media. The installation of this type of barrier is also not expected to be feasible within and/or below the waste mass.

For the installation of a Permeable Reactive Barrier to occur in the unconsolidated material located between the ground surface and the bedrock along the perimeter of the Landfill, waste excavation would be required to create a sufficient buffer distance between the edge of waste, barrier and the property boundary (i.e., compliance point). Following waste excavation, the barrier could either be constructed in a trench dug down to bedrock, or the barrier could be injected into the unconsolidated material. Short-term impacts would likely result from the waste excavation and trench construction, which would include increased levels of odor and dust. Mitigation measures would need to be evaluated and implemented. Regular monitoring and maintenance would be required to ensure that the reactive materials in the Permeable Reactive Barrier remain active.

Permeable Reactive Barriers are an accepted and widely used groundwater treatment technology. However, due to difficulty in treating the impacted groundwater within the bedrock, such barriers may not be an acceptable Remedial Technology at the Landfill. If there are areas where only shallow groundwater is impacted, the use of this Remedial Technology may be applicable.

Depending on the location and installation method for the Permeable Reactive Barrier, interim and ongoing modifications to the landfill gas collection system may be required to ensure the optimum collection of landfill gas.

Cost

The costs for designing and installing a Permeable Reactive Barrier are dependent on whether the barrier is injected or installed, on the treatment media selected and on the overall size of the barrier and potential replacement cost. For excavated barriers, the costs are approximately $30 to $40 per cubic foot of barrier. For example, a barrier sized at three thousand (3,000)-ft-long by two (2)-ft-wide barrier by an average depth of thirty (30) ft would cost approximately $5,400,000 to $7,200,000. The costs of maintaining the barriers are another $2 to $4 per cubic foot per year, or approximately $500,000 per year for the barrier parameters described. These costs are estimated from the Cost Analysis provided in the Remediation Technologies Screening Matrix and Reference Guide (FRTR 2012), using unit costs estimated for large sites (defined by FRTR as a site requiring a six hundred (600)-ft-long Permeable Reactive Barrier).

4.5 CHEMICAL OXIDATION

4.5.1 Description

Chemical Oxidation is an *in situ* technology that uses fast-acting oxidants such as catalyzed hydrogen peroxide mixtures or potassium permanganate. When organic compounds come into contact with such oxidants, the organic compounds are oxidized to carbon dioxide and water. To avoid explosion hazards, an oxidant that does not produce significant heat or free oxygen would need to be selected for use at the Landfill. The oxidant would be injected at periodic intervals, and groundwater would be monitored to assess the continued effectiveness of the Chemical Oxidation program for decreasing groundwater impacts.

Because chemical oxidants are short-lived in the subsurface, this technology is typically used where a large mass of constituents can be targeted for destruction over a short timeframe, such as at VOC source areas or in the highly concentrated portions of plumes in cases where the source has been removed. Treatment of a relatively dilute groundwater plume of VOCs with a persistent source, as is present at the Landfill, would require frequent injections of oxidants over the life of the treatment program to mitigate groundwater impacts from the VOC source.

4.5.2 Case Studies

Three (3) sites where *in situ* Chemical Oxidation was used to treat plumes of cVOCs in groundwater were identified during the literature review as examples of this technology (**Table 4-1**) (Naval Facilities Engineering Command [NAVFAC] 1999, Chapelle et al. 2005, Applebaum and Smith 2009, EPA 2009a). Three (3) different chemical oxidants were used at the three (3) sites. At two (2) sites, Chemical Oxidation was combined with other remedial technologies (Enhanced Bioremediation and Groundwater P&T).

At the Old Camden Landfill in Georgia (NAVFAC 1999, Chapelle et al. 2005), a plume of cVOCs, including PCE, TCE, and DCE (approximately four and one-half [4.5] mg/L total concentration) was present in a sandy aquifer, with potential impacts to groundwater within a residential community. Initially, a Groundwater P&T system was installed along the perimeter of the landfill near the community. However, the subsequent identification of discrete sources of PCE around the edges of the landfill enabled direct treatment of the source material. Direct treatment was achieved through the injection of approximately one hundred thousand (100,000) gallons of the chemical oxidant known as Fenton's reagent (fifty [50] percent hydrogen peroxide and ferrous sulfate catalyst). The injections successfully decreased concentrations of the cVOCs in groundwater to below the cleanup objective of one-tenth (0.1) mg/L, allowing the Groundwater P&T system to be shut off (NAVFAC 1999). In the five (5) years following the oxidant injections, cVOC concentration trends in the down-gradient monitoring wells varied, and included a rebound in PCE concentrations in one (1) monitoring well. However, the case study concluded that treatment by Fenton's reagent led to a significant contraction of the cVOC plume (Chappelle et al. 2005).

Chemical Oxidation was used to treat groundwater TCE plumes at two (2) industrial facilities underlain by bedrock (Applebaum and Smith 2009, EPA 2009a). At the Tenneco Automotive Site (EPA 2009a), semi-annual injections of permanganate were performed for multiple years to maintain oxidative capacity and continually destroy TCE within the groundwater plume. Two hundred fifty (250) to five hundred (500) gallons of two (2) percent permanganate solution was injected into eight (8) injection wells during each event. At the unspecified site described by Applebaum and Smith (2009), approximately eight thousand five hundred (8,500) gallons of a solution of percarbonate, carbonate and ferrous sulfate was injected during a one (1) month injection period. In both cases, the resulting chemical oxidations substantially decreased TCE concentrations after each injection. However, at both of these sites, achieving contact between the chemical oxidant and the cVOCs was found to be a limiting factor for the effectiveness of this technology, due to the inability to distribute the oxidant into the groundwater within the bedrock fractures.

At both the Old Camden Landfill and the unspecified facility (Applebaum and Smith 2009, Chapelle et al. 2005), the injection of chemical oxidant was followed by an injection of carbon substrate. The carbon substrates injected consisted of approximately twenty-five thousand (25,000) gallons of emulsified vegetable oil, and two thousand eight hundred (2,800) gallons of a solution containing sodium lactate, soybean oil, and other additives. The carbon substrates served to promote the restoration of biological activity and reducing conditions in the groundwater and/or subsurface and thus also served to support reductive dechlorination.

4.5.3 Screening

Effectiveness

Groundwater: Chemical Oxidation is highly effective for the direct treatment of VOCs, including cVOCs, in groundwater. Where contact with oxidants is achieved, VOCs are almost completely destroyed. However, due to the short lifetime of the chemical oxidants in the subsurface, Chemical Oxidation is typically used to treat VOC source areas or concentrated plumes without persistent sources, which can be treated using a few closely spaced injection events. To treat a plume of VOCs that originates from a persistent source, as exists within the Landfill, would require multiple injection events every year until the source is depleted, likely many decades.

As with Enhanced Bioremediation, which also relies on injections, the volume of treated groundwater would be constrained primarily by the location and depth of the injection wells. However, the persistence of chemical oxidants in the subsurface is expected to be substantially less than that of the organic substrates that promote bioremediation, because the oxidants are destroyed by a variety of reducing materials (e.g., natural organic matter and reduced metals) within the aquifer. The effectiveness of Chemical Oxidation would be highly dependent on the volume of impacted groundwater that comes into direct contact with active oxidant.

Chemical Oxidation could potentially reduce cVOC concentrations in both shallow and deep groundwater if injection wells are installed in both unconsolidated material and bedrock.

However, as described in Section 4.5.2, case studies indicate that the efficient injection of chemical oxidants into bedrock can be difficult to achieve, and can limit the effectiveness of this technology at sites like the Landfill where impacted groundwater is present within bedrock. Because Chemical Oxidation would stop the natural anaerobic processes that are currently destroying cVOCs at the Landfill, concentrations could rebound to levels higher than the current concentrations when the treatment is stopped (e.g., when the oxidant reaction is diminished or between injection events). The injection of carbon substrate to promote biological activity could help counteract this effect.

Landfill gas: Injection of chemical oxidants into the groundwater could oxidize some methane and prevent its further transport, but would not be expected to impact the current generation rate of landfill gas (including methane) at the Landfill.

Non-Stormwater Discharges (e.g., Leachate Seeps): This groundwater treatment technology would not be expected to have an impact on leachate seeps at the Landfill..

Implementability

As with Enhanced Bioremediation, the installation of injection wells through the waste mass to the underlying groundwater is not a preferred option; therefore, the injection wells would most likely need to be installed around the perimeter of the Landfill. As with Enhanced Bioremediation, if injection wells for Chemical Oxidation were to be installed at the Landfill in its current state, the injection wells would most likely need to be installed through the waste mass, which would present challenges that could be mitigated through use of standard industry procedures for drilling in waste. Alternatively, selective waste excavation along the Landfill property boundary could provide space for the installation of injection wells outside the limit of waste, with space for oxidation to occur between the injection wells and the property boundary. As discussed above, as a result of the continuous leaching of cVOCs from the source (i.e., waste mass) within the Landfill, frequent and ongoing reapplication events of the oxidizing agents would be required. This need for the reapplication process would significantly decrease the implementability of this option. The installation of additional injection points could be required if insufficient contact exists between impacted groundwater and the oxidants.

The physical site constraints would require careful design of a Chemical Oxidation system in order to obtain MDE approval and/or public acceptance. This measure may encounter community resistance related to potential impacts on the aesthetics of nearby surface water bodies (e.g., purple coloration of the stream water from the addition of permanganate).

Cost

As with Enhanced Bioremediation, the capital costs for implementing Chemical Oxidation systems vary widely, depending on the number and depth of injection wells required, injected oxidant, and frequency and timeframe of injections. The estimated cost of installation of a Chemical Oxidation system is approximately $100,000 to $400,000 for installation of approximately ten (10) to forty (40) injection wells (FRTR 2012). Annual O&M costs, including quarterly injections, are estimated at $200,000.

4.6 GROUNDWATER PUMP AND TREAT

4.6.1 Description

Groundwater P&T systems extract impacted groundwater from the subsurface via extraction wells and then treat the groundwater using aboveground (*ex situ*, or not in-place) treatment systems. Groundwater P&T is an aggressive technology that is often used to treat groundwater impacted with high VOC concentrations located within unconsolidated material as well as bedrock. In order to completely capture the plume of impacted groundwater, the extraction system should be designed to achieve hydraulic control over groundwater flow. Hydraulic control over the plumes of impacted groundwater present at the Landfill would require careful design, due to the presence of impacted groundwater (deep) within bedrock, which originates from impacts in the overlying unconsolidated materials.

Flow through bedrock is often channeled preferentially through the most permeable fractures within the rock, which allows groundwater impacts to migrate elsewhere within the bedrock. Therefore, mapping of the bedrock fractures and the characterization of the groundwater impacts within such fractures would be necessary to guide the selection of depths for screen placement within the extraction wells. In these situations, extraction wells would likely need to be closely spaced to achieve hydraulic control. Based on the impacts to groundwater identified at the Landfill, groundwater treatment could include adsorption via an activated carbon adsorption medium, air stripping, filtration, or other treatment technologies. Groundwater can also be treated using constructed wetlands (see Section 4.7.1), although this is not expected to be the most feasible groundwater treatment technology for the landfill, due to space and volume constraints. Depending on the specific level of treatment required, the treated groundwater may be reinjected into the aquifer, discharged to a public wastewater treatment facility, discharged to a pond or similar surface water body, or used on-site if an applicable uses exist.

4.6.2 Case Studies

Three (3) Superfund sites that utilized Groundwater P&T systems to remediate groundwater impacted by VOCs were identified and selected for consideration during the literature review (**Table 4-1**) (EPA 2004b, 2006, 2008a, 2009b, 2010a).

At the Skinner Landfill Superfund site, groundwater impacted by VOCs was treated using a groundwater interception system, which utilized an Impermeable Barrier (refer to Section 4.8) coupled with a Groundwater P&T system. Groundwater located up-gradient of the barrier was pumped and discharged into the sewer system to be treated at a public sewage treatment plant. After less than two (2) years of operation, approximately seven and a half (7.5) million gallons of groundwater had been pumped and treated. In addition, VOC concentrations in up-gradient groundwater had declined or remained stable below site trigger levels, and the elevation of the groundwater table had dropped below the bottom of the buried waste (EPA 2004b, 2009b).

At the Onalaska Landfill Superfund site, cVOC concentrations were as high as eight hundred (800) μg/L 1,1-DCA and twenty-seven (27) μg/L DCE. During the remedial investigation, more than two (2) billion gallons of groundwater were treated over a seven (7) year period. The Groundwater P&T system was eventually shut down when cVOC concentrations had decreased below cleanup goals (EPA 2006, 2008a).

Groundwater impacted by VOCs was present in the unconsolidated material and the bedrock at the Solvents Recovery of New England Superfund site. A Groundwater P&T system was installed with fifteen (15) extraction wells, including one (1) in the bedrock. The hydraulic gradient in the unconsolidated material was reversed, which prevented the migration of impacted groundwater. Over a six (6) year period, one hundred ninety-six (196) million gallons of groundwater were extracted and treated, including the removal of sixteen thousand (16,000) pounds of VOCs. A site assessment concluded that the remedy was expected to be protective of human health and the environment (EPA 2010a).

4.6.3 Screening

Effectiveness

Groundwater: A Groundwater P&T system would remove impacted groundwater from the subsurface, treat the impacted groundwater and remove the targeted constituents from the groundwater. The Groundwater P&T system design would include extraction well spacing and pumping rates designed to achieve hydraulic control in the impacted area to prevent the migration of groundwater impacts across the Landfill property boundary. Site investigations and a pilot study would likely be required to support the system design. Pumping from extraction wells around the perimeter of the Landfill would prevent the migration of shallow, and possibly deep impacted groundwater. The presence of impacted groundwater within the bedrock, where hydraulic control can be difficult to achieve, could decrease the overall effectiveness of Groundwater P&T at the Landfill.

Due to the unknown sources of groundwater impacts within the waste mass of the Landfill, long-term maintenance of hydraulic control along the Landfill perimeter would be required, until the source depletion has occurred. If pumping were stopped prior to source depletion, movement of VOCs across the Landfill property boundary would be likely. Generally, carbon adsorption is effective for removing VOCs from groundwater as it is extracted from the aquifer.

Landfill gas: A Groundwater P&T system would not be expected to impact landfill gas migration or the generation rate of landfill gas (including methane) at the Landfill, as it is primarily a groundwater treatment technology.

Non-Stormwater Discharges (e.g., Leachate Seeps): A Groundwater P&T system installed along the perimeter of the Landfill could potentially decrease the incidence of non-stormwater discharges from leachate seeps along the side-slopes, by lowering the elevation of water within and/or beneath the Landfill.

Implementability

The implementation of a Groundwater P&T system at the Landfill would require careful design to achieve the greatest possible extent of hydraulic control within the unconsolidated materials (i.e., shallow impacts) and the bedrock (i.e., deep impacts) where impacted groundwater has been reported. The P&T system would require the construction of shallow and deep extraction wells, a piping system, an on-site treatment system and a reinjection system, unloading station or a conveyance system for handling of the treated water.

Extraction wells would most likely be installed around the perimeter of the Landfill, and could be installed either outside the limit of waste, or through the waste mass if necessary. With respect to the aboveground treatment of extracted groundwater, adsorption via activated carbon is a highly implementable technology. Adsorbents of various sizes and configurations are commercially available. Implementability would be impacted by the level of long-term effort required to maintain the extraction and treatment system as well as the methods for handling the treated water.

Groundwater P&T is a conventional treatment approach that is reasonably well accepted by MDE and the public. Acceptance at the Landfill would likely require a pumping design that is sufficiently aggressive to decrease impacts to shallow and deep groundwater to acceptable levels, despite the ongoing source of impacts within the waste mass of the Landfill.

Cost

As with Enhanced Bioremediation and Chemical Oxidation systems, the capital costs for implementing a Groundwater P&T system vary widely, depending on the number and depth of extraction wells required, pumping rates, treatment technology infrastructure including media, and requirements for handling and disposal of the treated water. The costs of designing and constructing a Groundwater P&T system are estimated to be approximately $500,000 to $5,000,000. Annual O&M costs are estimated at $200,000 to $4,000,000. These cost ranges were developed from case studies for similar sites (FRTR 2010).

4.7 PHYTOREMEDIATION

4.7.1 Description

Phytoremediation relies on the selection of plant species that are capable of intercepting (i.e., up-taking) and either retaining or transpiring targeted constituents, thereby minimizing their migration and/or persistence in the environment as well as their exposure to humans and ecological organisms. Phytoremediation technologies can include a range of plants, each with the ability to treat certain contaminants under certain conditions. Phytoremediation was identified as a potentially applicable Remedial Technology for addressing groundwater impacts at the Landfill because closely spaced trees with deep roots (such as species of poplars) can limit the flow of groundwater impacted by VOCs. In addition, Phytoremediation using deep-rooted trees also has the benefits of enabling volatilization of the VOCs (following uptake) through transpiration. Trees can also promote degradation of the VOCs in the subsurface, by supporting populations of root-associated organisms that degrade VOCs. Such tree plantings typically require multiple acres available for planting, and the effectiveness of Phytoremediation is dependent on the ability of the trees' roots to reach the groundwater. Aside from tree plantings used to intercept impacted groundwater *in situ*, Phytoremediation through the use of trees or wetland species can be used at landfills to treat impacted groundwater that is pumped to the surface.

Specialized deep-rooting technologies can allow the trees to access deeper groundwater (up to thirty [30] or more ft bgs), but are also more resource-intensive. The timeframe for realizing the benefits of Phytoremediation with trees are dependent on the tree species as well as the depth to groundwater, but often take a minimum of five (5) to ten (10) years to show substantial effects. Therefore, Phytoremediation is most effective for low-concentration VOC plumes in aquifers with relatively slow groundwater flow, where sufficient space is available for planting and long-term hydraulic control by trees will provide sufficient protection to down-gradient receptors.

4.7.2 Case Studies

Four (4) demonstration projects using hybrid poplars, willows, and/or cottonwoods were initiated during the late 1990s, with EPA involvement (**Table 4-1**) (EPA 2000c, 2002a, 2002b, 2003, 2005b; Argonne National Laboratory [ANL] 2010). Three (3) of the sites (Edgewood Area J-Field, Edward Sears Properties Site, and 317/319 Area at Argonne National Laboratory-East) used deep-rooting techniques to target groundwater impacts at more than ten (10) ft bgs. Prior to the 1990s, Phytoremediation primarily involved plantings at the ground surface, used to treat shallow soils and groundwater (less than ten [10] to twenty [20] ft bgs). The deep rooting technology involves planting trees at up to ten (10) ft bgs, and can also incorporate impermeable cylinders placed around the tree in the subsurface, to limit access to shallow and vadose zone water and encourage vertical growth of the tree roots. The demonstration sites were on the order of one-third (1/3) to five (5) acres, and between one hundred eighteen (118) and eight hundred nine (809) trees were planted.

The results of the demonstration projects, during the first two (2) to six (6) years after implementation, showed small, but increasing effects of the plantings on the groundwater elevations and quality. The most complete data set, with nine (9) years of data, were provided for Former Carswell Air Force Base, where shallow planting of cottonwoods was used to treat a TCE plume at less than twelve (12) ft bgs (EPA 2005b). At this site, it was observed that transpiration by the trees was the primary mechanism for decreasing the TCE flux during the first three (3) years after planting, but biodegradation associated with anaerobic processes in the root zone became more prevalent six (6) years after planting (EPA 2005b). Promotion of anaerobic biodegradation of cVOCs was also noted at the Edward Sears Properties Site (EPA 2002b). For all the demonstration sites, trees were not expected to achieve their maximum remedial benefits until at least ten (10) years after planting.

4.7.3 Screening

Effectiveness

Groundwater: Phytoremediation using trees is an emerging, but well documented, technology for long-term control of the flow of shallow groundwater impacted with VOCs. At the Landfill, trees would be planted along the perimeter of the Landfill. Groundwater is more than ten (10) ft bgs on most of the Landfill property; therefore, tree planting using deep rooting technologies would likely be required to allow tree roots to draw from groundwater. However, there is significant uncertainty regarding the degree of effectiveness of this Remedial Technology, given uncertainties regarding site-specific variations in plant growth and water uptake rates. The effects of trees used to reduce the flow of impacted groundwater are primarily seen in the long term (starting five [5] to ten [10] years after planting), with minimal effectiveness during the first few years of tree growth.

As noted in Section 4.7.1 pumping/irrigation of impacted groundwater to plantations of trees or wetlands for absorption and transpiration or filtration can also be effective, if the rate of uptake of water by the trees or wetlands meets or exceeds the rate of irrigation with impacted groundwater.

Landfill gas: Phytoremediation would not be expected to impact landfill gas migration or the current generation rate of landfill gas (including methane) at the Landfill.

Non-Stormwater Discharges (e.g., Leachate Seeps): Phytoremediation, through the use of water uptake by trees and other vegetation, could potentially decrease the incidence of leachate seeps along the side-slopes, by lowering the elevation of water within and/or beneath the Landfill (if a deep-rooted system is installed).

Implementability

The use of Phytoremediation for groundwater treatment or leachate seep mitigation may require the planting of a relatively large number of trees or other specialized plants (roughly one hundred [100] to one thousand [1,000]; **Table 4-1**), spaced to allow growth, at a depth sufficient to reach groundwater. Phytoremediation would not be a standalone Remedial Technology, but instead, a potential enhancement to be coupled with other more aggressive technologies. For example, waste excavation along the Landfill perimeter would create room for trees and other plantings on the Landfill property. Trees currently present at the Landfill and not removed through waste excavation may also need to be removed to implement Phytoremediation.

The implementation of Phytoremediation using deep rooting technology, irrigation pumping systems or wetland-type applications would require a substantial planting effort and the potential for a significant level of maintenance within the first year to few years, to ensure the successful establishment of the population due to the potential for natural competition from flora and ingestion of plants by native fauna. Following the initial growth period associated with more frequent monitoring, periodic maintenance of the planting system would be needed to ensure continued health of the plants and replacement of any plants that are unsuccessful; this periodic maintenance would be required for the life of the system. To promote a hydraulic influence, trees planted for Phytoremediation would need to be maintained until the source is depleted through natural dissolution/diffusion processes, which will likely take many decades. However, operation and maintenance of this type of system can be relatively efficient and have few negative environmental impacts.

Cost

The estimated cost to establish a Phytoremediation system is $100 to $1,000 per tree (estimate one hundred [100] trees per acre), depending on the tree species, depth of planting, and local environmental factors affecting initial maintenance requirements to promote tree survival. An additional cost of approximately $10,000–$20,000 is estimated for annual maintenance costs. These estimates are based on the costs reported in the case studies listed in **Table 4-1**.

4.8 IMPERMEABLE BARRIER

4.8.1 Description

In situ Impermeable Barriers can restrict the flow of impacted groundwater or landfill gas. Such barriers can also be used to divert water or gases away from a sensitive area or toward a treatment system. Impermeable Barriers commonly consist of an excavated trench filled with concrete (slurry walls) or interlocking metal sheets inserted vertically into the subsurface (sheet pile walls). Barriers can only be installed in unconsolidated material, and therefore, do not block flow of deeper impacted groundwater within the bedrock. Impermeable Barriers could potentially be used to limit the migration of shallow impacted water and landfill gas toward sensitive areas along the property boundary of the Landfill.

4.8.2 Case Studies

Impermeable Barriers are often used to contain impacted groundwater or other mobile media (e.g., gases) within an impacted area or areas of a site. Five (5) sites where Impermeable Barriers were installed in the subsurface, in combination with other technologies, were identified and selected for consideration during the literature review (**Table 4-1**) (EPA 1998b, 2008b, 2009c). Three (3) of the sites were municipal solid waste/sanitary landfills, one (1) was an unpermitted waste disposal facility, and one (1) was a waste processing facility. At all five (5) sites, the Impermeable Barrier was constructed around the entire site. The selected remedial alternatives included leachate and/or groundwater extraction on-site to create an inward gradient of groundwater flow within the site's boundaries. Site capping was also implemented at four (4) of the five (5) sites in order to decrease surface infiltration of precipitation, decrease leachate generation and support the development of an inward gradient of groundwater flow.

At four (4) of the sites, the Impermeable Barrier was keyed into a natural low-permeability layer (e.g., clay layer) within the subsurface, which created a "bathtub" effect with impermeable layers located on the bottom and the sides of the barrier. At these sites, an inward gradient was developed and maintained with the impacted groundwater successfully being contained on-site (EPA 1998b, 2008b). At the fifth site (EPA 2009c), impacts were present within both the unconsolidated material (eight [8] to fifty-three [53] ft thick) and the underlying bedrock. A slurry wall was constructed in the unconsolidated material that extended to the depth of the top of the fractured bedrock. While the combination of this slurry wall with an engineered cap and Groundwater P&T system was able to prevent migration of groundwater off-site within the unconsolidated material, it was estimated that seven thousand eight hundred (7,800) gallons per day of impacted groundwater flowed off-site through bedrock fractures beneath the slurry wall (EPA 2009c).

Impermeable Barriers can also be used to direct groundwater or landfill gas flow toward an extraction/treatment system or a collection system, respectively. As discussed in Section 4.4, one (1) of the case studies used a funnel and gate system (Impermeable Barrier) to direct groundwater impacted by VOCs toward a Permeable Reactive Barrier containing reactive iron media (EPA 1998c).

4.8.3 Screening

Effectiveness

Groundwater: The installation of an Impermeable Barrier would not decrease the total mass of constituents in groundwater, but it would divert water around or under the barrier. In order to decrease constituent concentrations and meet MCLs, another treatment technology such as Groundwater P&T or a Permeable Reactive Barrier would need to be implemented in addition to the Impermeable Barrier. However, due to the somewhat radial nature of groundwater flow away from the Landfill, the presence of deep groundwater within bedrock, and the limitations on barrier placement along the property boundaries and outside the limit of waste, the use of Impermeable Barriers to funnel water into a treatment system would likely not be highly effective at the Landfill.

Because Impermeable Barriers, like Permeable Reactive Barriers, typically cannot be installed in bedrock, groundwater flow under the barrier would likely continue (EPA 2009c). Thus, it is unlikely that an overall inward gradient could be achieved using a standalone Impermeable Barrier around the Landfill. A barrier in the Northwest and West Areas, for example, could limit migration of shallow impacted groundwater toward the Derwood Station South residential development. However, this may divert a portion of the shallow impacted groundwater downward into the deep bedrock, which may increase the volume of deeper impacted groundwater.

Landfill gas: An Impermeable Barrier installed in the Northwest and West Areas of the Landfill could limit the migration of landfill gas toward the residential development within the shallow unconsolidated materials (e.g., depth of five [5] to thirty [30] ft). However, such a barrier would not impact gas migration within the waste mass or through the top or side-slopes of the Landfill, and would not impact the generation rate of landfill gas (including methane) within the Landfill.

Non-Stormwater Discharges (e.g., Leachate Seeps): Impermeable Barriers would not be expected to impact leachate seeps at the Landfill, as the barriers would need to be installed outside the limit of waste.

Implementability

As with a Permeable Reactive Barrier, the installation of an Impermeable Barrier in the unconsolidated material along the perimeter of the Landfill would likely require relocation of waste in the area selected. Possible short-term negative impacts of Impermeable Barriers include increased levels of odor, dust, and noise related to the disturbance associated with construction activities. Such activities include waste excavation, trench shoring and trench filling. Interim and ongoing modifications to the landfill gas collection system may also be necessary to ensure the collection of the gas diverted by the Impermeable Barrier.

Cost

Impermeable Barriers such as slurry walls typically cost $5 to $10 per square foot of barrier, for a two (2) to four (4) ft-thick barrier. For example, a barrier sized at three thousand (3,000) ft-long by an average depth of thirty (30) ft would cost approximately $450,000 to $900,000 (FRTR 2012). Impermeable Barriers require minimal ongoing maintenance, which may range up to $20,000 per year.

4.9 LANDFILL GAS COLLECTION

4.9.1 Description

Gas collection is a common method for addressing landfill gas migration across landfill property boundaries. Landfill Gas Collection can be passive, utilizing natural pressure gradients to vent gas from the waste mass, or active, using extraction wells with pumps that actively pull gas from the landfill by creating a pressure gradient. Once collected, the gas is commonly combusted.

As stated in Section 1.3.3, an active landfill gas collection and management system is currently present at the Landfill. This system includes over one hundred (100) vertical extraction wells distributed across the Landfill, and connected to a landfill gas-to-energy (LFGE) facility. This gas collection and management system was installed to manage landfill gas (primarily methane) with the goal of maintaining methane concentrations below the LEL, in compliance with COMAR 26.04.07.03B(9). Expansion of this system, through installation of additional landfill gas extraction wells, is a potential Remedial Technology for addressing the intermittent LEL exceedances for methane that occur along the northwest property boundary of the Landfill (**Figure 2-5**).

The first gas collection system at the Landfill was installed in 1985, in conjunction with construction of a gas-to-energy facility at the site, which operated until 2006. A flare station connected to the gas extraction wells was installed in 2005, and the currently operational LFGE facility, which generates electricity in conjunction with the flare station, became operational in

2009. Thirty-two (32) additional gas extraction wells were installed between 2006 and 2008, to address continued LEL exceedances along the northwest property boundary.

4.9.2 Case Studies

Three (3) sites where Landfill Gas Collection was implemented, in combination with other remedial technologies, were identified and selected for consideration during the literature review (**Table 4-1**) (EPA 2005a, 2010c, 2011). All three (3) sites were landfill Superfund sites. It is noted that Gude Landfill is not a Superfund site.

At Somersworth Landfill, a passive venting trench was installed along the perimeter of the landfill. The venting trench prevents landfill gas from migrating off-site and allows gas to escape from the subsurface. The venting trench is fifteen (15) to twenty-seven (27) ft deep and three (3) ft wide. A vertical geomembrane along the outside wall of the trench acts as a barrier to soil gas migration. Methane concentrations measured in soil gas probes before and after the installation of the landfill gas venting system indicate that the system is performing as designed and cutting off the migration of landfill gases out from the landfill (EPA 2005a).

At Colbert Landfill, a Landfill Gas Collection system was installed consisting of trenches, wells inside the landfill and wells along the perimeter of the landfill. The purpose of the landfill gas system was to prevent off-site migration and buildup of gas pressure. The gas is treated prior to discharge to the atmosphere. Over time, the concentration of the landfill gas extracted at the site has decreased. The initial decrease was due to other landfill post-closure systems, such as a landfill cap, that were installed at the site and flushing and mass removal associated with a P&T system at the site. The fourth five (5) year review stated that the current landfill gas management system would prevent a vapor intrusion pathway for indoor air in residences or businesses adjacent to the landfill (EPA 2010c).

At the Coakley Landfill Superfund Site, a passive Landfill Gas Collection and venting system was chosen as a remedy because EPA concluded that it would prevent off-site, sub-surface migration of landfill gases and be protective of human health and the environment. After some sporadic violations of off-site methane gas levels, methane gas alarms were installed in six (6) off-site buildings. From 2006 to 2011 methane was detected above the New Hampshire state standard for methane soil gas sporadically (six [6] above the standard out of a total of ninety-two [92] readings) and no methane was detected in the off-site buildings being monitored. EPA and the New Hampshire Department of Environmental Services recommended continuing the use of the passive landfill gas system and monitoring the landfill gas probes (EPA 2011).

4.9.3 Screening

<u>*Effectiveness*</u>

Groundwater: Landfill Gas Collection would not be expected to have significant groundwater impacts, as transport from the vapor phase to groundwater is not thought to be a primary contaminant migration pathway at the Landfill.

Landfill gas: Installation of additional landfill gas wells would provide direct control over landfill gas migration. Historical data indicate that the existing wells resulted in dramatic decreases in once-frequent LEL exceedances at the property boundary, such that exceedances are now observed sporadically. Based on this, additional Landfill Gas Collection is expected to be highly effective for addressing the remaining exceedances and meeting the RAO for landfill gas.

Non-Stormwater Discharges (i.e., Leachate Seeps): Landfill Gas Collection would not be expected to impact the occurrence of non-stormwater discharges.

<u>*Implementability*</u>

Installation of gas extraction wells within the waste requires use of specialized procedures and precautions, and challenges such as refusal above the desired depth may be encountered. However, overall, installation of additional landfill gas extraction wells in the areas of recent LEL exceedances is expected to be highly implementable, similar to the well installation that has been performed historically, and as recently as 2008, at the Landfill.

<u>*Cost*</u>

The average cost of an additional Landfill Gas Collection well, with site preparation and piping to connect the well with the existing LFGE facility, is estimated at $15,000.

4.10 COVER SYSTEM IMPROVEMENTS

4.10.1 Description

A cover system is a group of materials that are placed above a waste mass on a Landfill to reduce the potential for odors, vectors, erosion and sedimentation, stormwater infiltration, fugitive landfill gas emissions, leachate generation, non-stormwater discharges (e.g., leachate seeps), and exposure to and of the in-place waste, etc. A cover system can consist of natural materials such as soil, along with a vegetative top layer. By the nature of the materials, which are not selected to be impermeable, a cover system allows for some infiltration of stormwater through its materials. Although the purposes of each are similar, a cover system is different than an engineered capping system (refer to Section 4.10, Partial and Full Capping), which is constructed using an impermeable material such as a geosynthetic layer or a natural clay.

Cover System Improvements is a process in which the existing layers of materials (e.g., vegetation, soil, etc.), on top of the waste mass of a Landfill, are regraded or re-contoured to enhance the prevention of odors, vectors, erosion and sedimentation, stormwater infiltration, fugitive landfill gas emissions, leachate generation, leachate seeps, and exposure to and of the in-place waste, etc. In conjunction with regrading and re-contouring (drainage slope decreases), the depth of soil of an existing cover system may be increased to specifically reduce the potential for fugitive landfill gas emissions (thus improving collection efficiency) and leachate seeps along the side-slopes of a Landfill. Because the improved cover system remains permeable to gas and liquid, it decreases landfill gas emissions and leachate seeps primarily by increasing the time required for gas and leachate to migrate through the cover.

The current vegetative soil cover system atop the waste mass of the Landfill consists of two (2) to five (5) ft of soil. In areas of the Landfill, the soil cover on the side-slopes may be less than two (2) ft and the soil cover on the plateau (i.e., top) may be greater than five (5) ft. It is anticipated that Cover System Improvements would be made in conjunction with waste excavation if implemented. If waste excavation is not performed, Cover System Improvements could be made independent of any excavation, to address landfill gas emissions and leachate seeps.

4.10.2 Case Studies

As noted in Section 4.10.1, cover system improvements and partial/full capping via a geosynthetic liner are similar in purpose. Enhancements to cover systems can significantly improve their overall effectiveness for minimizing exposure to and of the in-place waste. Such enhancements may include steeper slopes and more closely spaced stormwater collection infrastructure to improve stormwater diversion as well as an increased depth of soil above the waste mass to reduce fugitive landfill gas emissions and leachate seeps. Therefore, the case studies presented in Section 4.11.2 can be used in general to describe similar type applications of cover systems.

4.10.3 Screening

Effectiveness

Groundwater: As a standalone Remedial Technology, improvements to the existing vegetative soil cover system would not be expected to impact constituent concentrations in groundwater at the Landfill.

Landfill gas: An increase in soil cover depth over certain portions of the Landfill could provide slightly improved control over fugitive emissions of landfill gas.

Non-Stormwater Discharges (i.e., Leachate Seeps): Improvements to the existing vegetative soil cover system, particularly along the side-slopes of the Landfill, would be expected to reduce the potential for and provide some protection against leachate seeps. This would primarily occur though: 1) regrading and re-contouring improvements along the side-slopes and on the top of the landfill to decrease the drainage slope such that leachate is less likely to penetrate the side-slope; and 2) increasing the soil depth of the cover system to provide additional buffer distance and media between the waste mass and the external ground surface.

Implementability

Cover System Improvements along the top and side-slopes of the Landfill are expected to be highly implementable. If Selective Waste Excavation is performed, the necessary regrading and re-contouring work would be accomplished as part of waste excavation efforts with an improved vegetative soil cover system installed over the new edge of the waste mass. If no waste excavation is performed at the Landfill, the improved cover system would likely be placed over the existing cover.

Cost

The cost of cover soil to be used in Cover System Improvements is estimated at approximately $20 per cubic yard. Therefore, placement of a two (2)-ft-thick soil cover on four thousand five hundred (4,500) ft of side-slopes (approximately half the current landfill side-slopes), with an average slope length of one hundred fifty (150) ft, would cost approximately $1,000,000.

4.11 PARTIAL OR FULL CAPPING

4.11.1 Description

Partial or Full Capping could also be conducted to replace the soil cover system at the Landfill, and would entail installation of an engineered cap on all or selected portions of the top and/or side-slopes of the Landfill. Capping of the waste mass is an integral part of the closure and post-closure care system of modern municipal solid waste landfills, which are also lined prior to filling to allow leachate collection and prevent contact with groundwater. Full Capping is also a commonly accepted method for reducing the production of leachate at historical landfills which, like Gude, were constructed before the current closure requirements were enacted. The installation of a uniform and low-permeability capping system on the ground surface of a landfill decreases the amount of precipitation and surface water that has the potential to infiltrate into and contact the waste mass of the landfill. Typically, engineered caps are installed over the entire area of modern municipal solid waste landfills; however, Partial Capping of the landfill surface could also help achieve RAOs at the Landfill.

COMAR 26.04.07.21.B states that closure caps to reduce infiltration into modern landfills may be constructed of natural or synthetic materials. COMAR 26.04.07.21.E. defines minimum design features for engineered caps at municipal landfills, while noting that approved alternates with equivalent performance can be considered. A typical cross-section of an engineered geosynthetic or soil cover capping system consists of (from top to bottom): a vegetative support (final earthen cover) layer (minimum thickness of two [2] ft), a high-permeability protective cover (drainage) layer (minimum thickness of six [6] inches [in.]), a low-permeability (capping) layer (minimum thickness of twenty [20] mil geosynthetic material or twelve [12] in. of natural fine-grained material), and an intermediate cover (separation) layer (typically twelve [12] to eighteen [18] in. to protect the low-permeability layer from puncture).

Full Capping of the Landfill would require extensive site disturbance but could decrease mounding of groundwater within the waste, which is the direct result of infiltration of water through the soil cover. The effectiveness of Full Capping for decreasing impacts to groundwater would be diminished if waste remains in contact with groundwater even after mounding is diminished, as is likely at the Landfill; therefore, even Full Capping might not achieve RAOs for groundwater, due to continued contact between waste and groundwater. Partial Capping would most likely be used to address landfill gas migration and leachate seeps along the side-slopes. The partial cap could be installed along the existing side-slope, or tied in below the current ground surface to provide better control of landfill gas and leachate migration.

4.11.2 Case Studies

Three (3) sites where a landfill cap was implemented in conjunction with other technologies to remediate groundwater impacted by VOCs were identified and selected for consideration during the literature review (**Table 4-1**) (Washington State Department of Ecology [Washington Ecology] 2001 and 2008, EPA 2008c, NAVFAC 1999).

At the Mica Landfill in Washington, a geosynthetic and engineered clay cap was installed along with a leachate collection system. Contamination in the groundwater began to decrease, and VOCs migration off-site was stopped (Washington Ecology 2001, 2008). The capping remedy was also successful at the Coshocton Landfill, where a low permeability cap was installed, and groundwater impacts at the site are now stable at low levels (EPA 2008c).

At the Northend Landfill, which is located near the coast of an island, the lower portion of the landfilled waste was saturated due to the high groundwater table. A cap was placed over the landfill, but monitoring data indicated few significant changes in groundwater quality following the installation of the cap, possibly due to continued infiltration of the waste by groundwater (NAVFAC 1999).

4.11.3 Screening

<u>*Effectiveness*</u>

Groundwater: Full Capping of the surface of the Landfill could represent a method of controlling the source of impacts to groundwater if groundwater does not contact the waste following installation of the low-permeability capping system. Under such a condition, the cap would control the source by decreasing infiltration of water into the waste mass and subsequent leachate production. Due to the permeability of the current soil cover system, stormwater that does not naturally run off the site or enter the stormwater conveyance piping network likely infiltrates into the waste mass, which generates leachate. Combined with natural attenuation processes, this decrease in leachate production could decrease impacts to groundwater. Groundwater quality would be expected to adjust to the capping system gradually, as constituents present in the groundwater degrade or diffuse away from the Landfill.

However, available data indicate that groundwater would likely remain in contact with the waste mass following capping system installation at the Landfill. Groundwater around the perimeter of the Landfill is currently present at depths as shallow as three (3) to ten (10) ft bgs. It is unknown whether waste was placed on the existing land surface, or whether unconsolidated material was removed prior to waste placement, which would have resulted in waste closer to groundwater. The depth of waste at the Landfill is reported to be fifty-five (55) to ninety (90) ft based on site records; however, no depth measurements are available. Although capping would likely decrease the degree to which groundwater mounds beneath the Landfill, some mounding would persist, and it therefore appears likely that waste would likely remain in contact with groundwater. If this is in fact the case, then Full Capping would not achieve the objective of isolating the waste mass from water infiltration and thus would not meet the groundwater RAO.

Partial Capping of the side-slopes of the Landfill would not be expected to affect groundwater impacts, as infiltration of water into waste along the side-slopes is expected to be minimal.

Landfill gas: Full Capping of the Landfill would have the potential to increase the collection efficiency for landfill gas by minimizing fugitive emissions. Reconstruction of the Landfill Gas Collection system, which would be necessary after installation of the capping system, could further increase the efficiency of gas collection.

The side-slopes of the Landfill, which are the primary areas of concern for meeting RAOs related to leachate, would likely be capped as part of either Partial or Full Capping. Installation of an impermeable cap along the side-slopes could prevent lateral migration of landfill gas toward the property boundary. Therefore, either Partial or Full Capping would be expected to be effective for controlling landfill gas migration along the side-slopes. The cap would be expected to provide additional control of landfill gas migration if it were tied in below the current ground surface.

Non-Stormwater discharges (e.g., Leachate Seeps): Installation of an impermeable cap along the side-slopes, as part of Partial or Full Capping, would also prevent formation of leachate seeps in the capped areas.

<u>*Implementability*</u>

Installation of an engineered cap would require disassembling and reassembling the existing Landfill Gas Collection system, which would likely also need to be redesigned to accommodate changes to gas migration patterns caused by capping, especially in the case of Full Capping. The trees and any facilities currently present in the areas where capping is conducted would need to be removed. Full Capping could require regrading of the side-slopes and limited waste excavation, to provide optimal slope for the edges of the cap. In addition, in the case of a capping system with riprap down chutes, waste would need to be excavated along the perimeter to install the anchor trench and stormwater management infrastructure. Significant modifications to the existing stormwater management system, accounting for increased stormwater runoff resulting from capping, would also be required for Full Capping. In the short-term, Full Capping would create significant disturbance of the site, due to surficial construction activities, and this disturbance would likely be associated with increased levels of odor, dust, and noise, along with potential temporary increases in fugitive landfill gas emissions.

Partial Capping along the side-slopes of the Landfill is expected to be highly implementable, although it would require that any trees on the side-slopes be cleared. The cap would also need to be engineered for compatibility with the Landfill Gas Collection system and the stormwater management system.

Partial or Full Capping is a typical remedy for addressing migration of constituents from landfills and is likely to be accepted by MDE and community stakeholders.

Cost

The cost of Full Capping of the Landfill is estimated at approximately $25,000,000 to $34,000,000. This cost range was estimated by the County based on estimated unit costs for land clearing ($20,000 per acre), grading improvements ($3,000,000) and cap installation ($125,000 per acre), as well as new stormwater ($4,000,000), landfill gas ($2,000,000) and other logistical requirements. The cost of Partial Capping of the northwest side-slope of the Landfill (approximately twenty [20] acres) is estimated at $5,500,000.

4.12 SELECTIVE OR EXTENSIVE WASTE EXCAVATION

4.12.1 Description

Selective or Extensive Waste Excavation is a process by which in-place municipal solid waste is removed from a landfill. Removed waste may be transported off-site in leak-proof containers for treatment and disposal, or placed in another area of the same landfill property. The waste removal process typically uses mechanized equipment (e.g., backhoes, excavators, loaders, and tri-axle trucks).

Extensive Waste Excavation would entail removal of waste from most or all of the Landfill and transport of this waste to an off-site facility. Selective Waste Excavation would entail removal of waste from the edges of the Landfill, to increase the distance or buffer area between the limit of waste and the property boundary point of compliance. Waste removed from the Landfill edges could be disposed in other areas of the Landfill, or at an off-site facility. Areas where Selective Waste Excavation is performed would also require regrading and installation of a new cover system, which could be used to decrease the occurrence of leachate seeps along the side-slopes. Selective Waste Excavation could be expanded to Extensive Waste Excavation in the long-term if the County determines that removal of the waste mass is necessary.

During the excavation process, there would be the option to separate recyclable or non-burnable materials (e.g., scrap metal, white goods, tires, and soil). Recyclable materials would be sent to applicable recycling processors. Soil removed during the excavation would likely be left on-site, if allowed by MDE, for regrading of the Landfill soil cover system.

The most likely off-site disposal option for waste excavated from the Landfill would involve consolidation at the County Shady Grove Processing Facility and Transfer Station, followed by incineration at the at the Montgomery County Resource Recovery Facility (RRF). This disposal option would be dependent on available capacity at the County RRF. If off-site disposal is desired and capacity at the County RRF is insufficient, excavated and screened waste could also be transported to other permitted waste acceptance and disposal facilities (landfills, transfer stations, waste-to-energy facilities), which would require disposal contracts. As an alternative, MDE has also indicated that waste excavated from the Landfill could be placed in other areas on-site, provided that the placement is conducted in accordance with modern landfill engineering controls (see Section 1.4.1). On-site placement of waste would most likely occur atop the current landfill surface, and could be utilized to adjust drainage and contours.

4.12.2 Case Studies

As part of the literature review, three (3) landfill sites were identified where waste excavation occurred as part of the selected remedial action (**Table 4-1**) (Florida DEP 2009, Serpa 2008, EPA 2010b). At one (1) demonstration project, two and one-half (2.5) acres of waste were mined at an unlined landfill that was potentially causing groundwater impacts. Site remedial objectives included decreased future liability from groundwater impacts and improving site space constraints. The demonstration project was focused on identification of waste in the landfill and assessing the economic and technical feasibility of various techniques for use in a large-scale project (Florida DEP 2009).

The groundwater at two (2) of the landfill sites was impacted by VOCs caused by the unlined landfill cells. At Clovis Landfill, sorted waste was relocated to a lined portion of the landfill. The groundwater VOC levels at the site steadily decreased as the project progressed (Serpa 2008). At Ionia City Landfill, source removal was accompanied by other remediation technologies. Source removal eliminated the need for future soil remediation, and the VOC concentrations in the groundwater are stable and decreasing (EPA 2010b).

Although the case studies did not specifically address decreases in landfill gas migration or leachate seep occurrences following waste excavation (apparently because these were not existing issues at these landfills), the demonstration project report (Florida DEP 2009) did emphasize the importance of including provisions for gas and leachate management during the excavation process.

4.12.3 Screening

Effectiveness

Waste Excavation is the only Remedial Technology under consideration that could potentially decrease the mass of the source(s) of impacts currently located within the Landfill. Extensive Waste Excavation could remove the majority of the source mass, while the amount of source removed during Selective Waste Excavation would be more difficult to predict.

Landfill gas: Extensive Waste Excavation would remove the source of landfill gas. Selective Waste Excavation could also achieve compliance with the RAO for landfill gas in the areas of excavation along the property boundary. The removal of waste would remove some of the gasproducing material and would also provide more space for dissipation of any fugitive landfill gas emissions prior to the property boundary.

Non-Stormwater Discharges (e.g., Leachate Seeps): Extensive Waste Excavation would remove the source of leachate and eliminate leachate seeps. Selective Waste Excavation could also achieve compliance with RAOs for leachate seeps (i.e., non-stormwater discharges) in the areas of excavation along the property boundary. Regrading and improvements to the soil cover on the side-slopes following excavation would be expected to decrease the occurrence of leachate seeps and improve stormwater management in the areas targeted for excavation.

Groundwater: By removing the source of leachate, Extensive Waste Excavation would also remove the source of Landfill-related contaminants to groundwater. The degree to which the source mass of impacts to groundwater would be removed during a partial excavation is difficult to predict, as the distribution of the source material around the perimeter of the waste mass and toward the center is unknown. Neither Selective nor Extensive Waste Excavation would address impacts that have already migrated from the waste to the groundwater. Therefore, the concentrations of constituents in groundwater would remain elevated unless a groundwater Remedial Technology was implemented in addition to Waste Excavation. Space created between the waste and the Landfill boundary during Selective Waste Excavation could be used for implementation of a groundwater treatment technology, without drilling through the waste mass.

Implementability

Extensive or Selective Waste Excavation with the appropriate controls is expected to be implementable at the Landfill. The volume of waste to be removed and disposed is subject to uncertainty due to the unknown depth of waste within the Landfill. Selective Waste Excavation is expected to be most highly implementable in the Northwest and West Areas (**Figure 4-1**), due to the accessibility of these areas. Excavation in the Southwest, South, and Southeast Areas would likely be more difficult due to the steep slopes of both the Landfill and the adjacent stream valley in these areas. Extensive or Selective Waste Excavation would require removal of trees growing atop the waste. Either off-site disposal or on-site placement is expected to be implementable, although off-site disposal is associated with logistical considerations related to waste transport and the capacity of the receiving facility.

Due to slope stability concerns, once an area has reached a pre-determined elevation during Waste Excavation activities, clean fill/specified fill placement would need to be initiated, thus implementing a remove and replace operation in step sequence. Components of the Landfill Gas Collection system and the stormwater management system would likely need to be disassembled prior to Waste Excavation. In the case of Selective Waste Excavation, these systems would need to be rebuilt in areas of the Landfill where excavation occurs. Each of these concerns could be mitigated with properly designed Operations and Contingency Plans.

Cost

Waste Excavation is estimated to cost approximately $70 to 80 per cubic yard with off-site disposal, or $30 to $40 per cubic yard with on-site placement, based on approximate costs for excavation, transport, and processing of the waste. Total waste in place is estimated at six (6) million cubic yards. Thus, the cost of Extensive Waste Excavation of the entire waste mass, with off-site disposal, would be approximately $450,000,000, although this could be partially offset by segregation of recyclable materials. The estimated cost of Selective Waste Excavation of one (1) million cubic yards of the waste is approximately $75,000,000 with off-site disposal, or $35,000,000 with on-site placement.

4.13 NO ACTION

4.13.1 Description

There are no technologies associated with this response action. This option does not include efforts to contain, remove, treat, or dispose media at the site. Although the pure No Action alternative would not include provisions for monitoring, in reality, semi-annual groundwater monitoring, quarterly landfill gas monitoring, and periodic evaluation of the presence of leachate seeps would continue in accordance with the current monitoring plans.

4.13.2 Case Studies

No literature review was conducted for the No Action alternative, because this response action is included primarily for comparison purposes.

4.13.3 Screening

Effectiveness

The No Action alternative would not be an effective remedy for the areas that are not already at or near compliance, as described below:

Groundwater: While the No Action alternative does not preclude destruction of constituents by natural attenuation at this site, it does not include provisions to monitor or assess the efficacy of natural attenuation. The time to meet RAOs in areas with groundwater impacts that substantially exceed the MCL would be expected to be substantially longer than for scenarios in which technologies are implemented.

Landfill gas: Under a No Action alternative, periodic exceedances of the LEL for landfill gas would be expected to continue indefinitely, until the methane-producing capacity of the landfill is exhausted.

Non-Stormwater Discharges (e.g., Leachate Seeps): Periodic repairs of localized leachate seeps would also be required to continue indefinitely under a No Action alternative.

Implementability

Administrative implementation of this option for any areas that are not already at or near compliance would be difficult due to required MDE approval and potentially unfavorable public opinion. Additionally, the No Action alternative could not be demonstrated to have met applicable remediation standards in a reasonable timeframe.

Cost

No capital or annual O&M costs are associated with the No Action option. The only costs associated with implementing the No Action alternative would be conducting periodic site reviews as required by MDE.

4.14 DEVELOPMENT OF CORRECTIVE MEASURE ALTERNATIVES

The results of the screening of Remedial Technologies, including which technologies were retained for further consideration as Corrective Measure Technologies, are summarized in

Table 4-2. **Figures 4-2** through **4-4** present each medium of concern with its corresponding RAO, and a summary of the screening process for applicable Remedial Technologies to select Corrective Measure Technologies.

The retained Corrective Measure Technologies were assessed for their applicability to each Remediation Area and combined into five (5) CMAs to address all three (3) of the primary media of concern (groundwater, landfill gas, and non-stormwater discharges [e.g., leachate seeps]) (**Figure 4-5**). The Corrective Measure Technologies and Remediation Areas are listed in the potential order of implementation. Detailed analysis of the CMAs is provided in Section 5.

In addition to the Corrective Measure Technologies presented, it is anticipated that approximately seven (7) new groundwater monitoring wells would be installed along the property boundary (as revised following the exchange of land with M-NCPPC), in addition to the thirty-nine (39) groundwater monitoring wells currently present at the Landfill and on adjacent properties. These additional groundwater monitoring wells would be placed to fill in gaps along areas of the property boundary and enable additional monitoring of groundwater impacts during the remediation.

4.14.1 Selection of Corrective Measure Technologies by Remediation Area

In compiling the CMAs, each Remediation Area (**Figure 4-1**) was matched with potentially feasible and effective Corrective Measure Technologies, based on the media of concern, constituents present, concentrations, risk/exposure potential, and the implementability of the Corrective Measure Technologies in each Area. The Corrective Measure Technologies for each Remediation Area were then combined into CMAs that address the areas of noncompliance (**Figures 2-5** through **2-7**) for all three (3) media of concern (groundwater, landfill gas, and non-stormwater discharges, [e.g., leachate seeps]), as described in Section 4.13.2.

Groundwater is a medium of concern, based on reported MCL exceedances in 2011, 2012, and 2013, in part or all of each of the five (5) Remediation Areas (**Figure 2-4**). Landfill gas is a medium of concern, based on reported LEL exceedances in 2011 and 2012, in the West Area and small portions of the Northwest and Southwest Areas (**Figure 2-5**). Non-stormwater discharge is a medium of concern, based on occurrences of leachate seeps between 2007 and 2010, in portions of the Northwest and West Areas (**Figure 2-6**).

The results of the Corrective Measure Technology selection for each Remediation Area, with Corrective Measure Technologies for each medium of concern specified, are presented below in the potential order of implementation for the Landfill.

Note that, in addition to the Corrective Measure Technologies outlined below for each Area, the combination of Extensive Waste Excavation (removal of the entire waste mass) and MNA is considered as an option to treat all three (3) media in all five (5) Remediation Areas.

Northwest Area

Corrective Measure Technologies evaluated to address non-compliance in the media of concern:

	Landfill Gas Collection	**Selective Waste Excavation**	**Cover System Improvements**	**Enhanced Bioremediation**	**P&T**
Groundwater				X	X
Landfill Gas	X	X	X		
Non-Stormwater Discharges		X	X		X

Additional Landfill Gas Collection in the Northwest Area would decrease LEL exceedances by providing better extraction efficiency in addition to the gas collection already occurring. As an alternative, Selective Waste Excavation would also decrease LEL exceedances, by providing a buffer between the source of landfill gas and the property boundary. LEL exceedances were reported in landfill gas monitoring well W-08 in the Northwest Area during monitoring in 2011 and 2012 (**Figure 2-6**). Cover System Improvements along the side-slopes would address non-stormwater discharges, and could also offer additional mitigation of landfill gas exceedances. Selective Waste Excavation followed by regrading could also decrease the occurrence of non-stormwater discharges. Enhanced Bioremediation or Groundwater P&T would address groundwater impacts in this area, where recent exceedances of the MCLs for PCE, TCE, DCE and VC have been reported. Groundwater in this area (including groundwater monitoring wells MW-13A, MW-13B, OB03, and OB03A) has some of the highest reported concentrations of groundwater impacts at the Landfill. If Groundwater P&T achieved sufficient depression of the groundwater table, it could cause some decrease in the volume of leachate present within the waste and thus potentially affect the occurrence of leachate seeps.

West Area

Corrective Measure Technologies evaluated to address non-compliance in the media of concern:

	Landfill Gas Collection	**Selective Waste Excavation**	**Cover System Improvements**	**Enhanced Bioremediation**	**P&T**
Groundwater				X	X
Landfill Gas	X	X	X		
Non-Stormwater Discharges		X	X		X

Additional Landfill Gas Collection in the West Area would decrease LEL exceedances by providing better extraction efficiency in addition to the gas collection already occurring. As an alternative, Selective Waste Excavation in the West Area would also decrease LEL exceedances by providing a buffer between the source of landfill gas and the property boundary. LEL exceedances were reported in landfill gas monitoring wells W-04, W-05, W-06, W-07 and W-28 in the West Area during monitoring in 2011 and 2012 (**Figure 2-6**). Cover System Improvements along the side-slopes would address non-stormwater discharges, and could also offer additional mitigation of landfill gas exceedances. Selective Waste Excavation followed by regrading could also decrease the occurrence of non-stormwater discharges. Enhanced Bioremediation or Groundwater P&T would address groundwater impacts in this area, where recent but inconsistent exceedances of the MCLs for PCE, TCE and VC have been reported (in groundwater monitoring wells MW-7 and MW-9), at concentrations lower than in the Northwest, Southwest, and South Areas.

Southwest Area

Corrective Measure Technologies evaluated to address non-compliance in the media of concern:

	Landfill Gas Collection	**Enhanced Bioremediation**	**Groundwater P&T**
Groundwater		X	X
Landfill Gas	X		

Additional Landfill Gas Collection in the Southwest Area would decrease LEL exceedances by providing better extraction efficiency in addition to the gas collection already occurring. LEL exceedances were reported in landfill gas monitoring wells W-25 and W-26 during monitoring in

2011 and 2012 (**Figure 2-6**). Enhanced Bioremediation or Groundwater P&T would address groundwater impacts in this area, where multiple recent reported exceedances of the MCLs for PCE, TCE, and VC have been reported (in groundwater monitoring wells OB12 and OB015), at concentrations somewhat lower than those reported in the Northwest and South Areas.

South Area

Corrective Measure Technologies evaluated to address non-compliance in the media of concern:

	Enhanced Bioremediation	**Groundwater P&T**
Groundwater	X	X

Groundwater P&T and Enhanced Bioremediation would address groundwater impacts in this area, where multiple recent exceedances of the MCLs for PCE, TCE, DCE, VC, and benzene have been reported (in groundwater monitoring wells OB11 and OB11A). Along with the Northwest Area, the South Area also has some of the highest concentrations of groundwater impacts at the Landfill.

Southeast Area

Corrective Measure Technologies evaluated to address non-compliance in the media of concern:

	Enhanced Bioremediation	**P&T**
Groundwater	X	X

Enhanced Bioremediation or Groundwater P&T would address groundwater impacts in this area (which includes groundwater monitoring wells MW-3A, MW-3B, MW-4, OB08, OB08A and OB10). Exceedances of the MCL for VC have been reported in this area in recent years, and groundwater monitoring well OB10 has a trend of decreasing TCE concentrations greater than the MCL.

4.14.2 Combination Alternatives

The Corrective Measure Technologies under consideration for each Remediation Area were combined into five (5) CMAs that have the potential to meet the RAOs for the site (**Figure 4-5**).

Alternative 1, Selective Waste Excavation with Off-site Disposal and Enhanced Bioremediation

- Selective Waste Excavation and Cover System Improvements in the Northwest and West Areas, with Off-site Disposal of the Excavated Waste.

- Enhanced Bioremediation in the Northwest, West, Southwest, South, and Southeast Areas.

Selective Waste Excavation would be conducted in the Northwest and West Areas, and would be followed by installation of a new, improved soil cover to address landfill gas migration and leachate seeps in these areas. The waste removed would be transported to an off-site facility for disposal. Injection wells for Enhanced Bioremediation would then be installed to allow treatment of the VOCs in groundwater in all five (5) Areas. The depth and placement of the injection wells would be designed to optimize distribution of the injected carbon substrate, bioaugmentation culture, and/or electron acceptor into the impacted portions of the aquifer.

Alternative 2, Selective Waste Excavation with On-site Placement and Enhanced Bioremediation

- Selective Waste Excavation and Cover System Improvements in the Northwest and West Areas, with On-site Placement of the Excavated Waste.

- Enhanced Bioremediation in the Northwest, West, Southwest, South, and Southeast Areas.

Selective Waste Excavation would be conducted first, and would be followed by installation of a new, improved soil cover to address landfill gas migration and leachate seeps in these areas. The waste removed would be placed in another portion of the Landfill. Injection wells for Enhanced Bioremediation would then be installed to allow treatment of the VOCs in groundwater in all five (5) Areas. The depth and placement of the injection wells would be designed to optimize distribution of the injected carbon substrate, bioaugmentation culture, and/or electron acceptor into the impacted portions of the aquifer.

Alternative 3, Extensive Waste Excavation with Monitored Natural Attenuation

- Extensive Waste Excavation, including removal of all waste.

- Monitored Natural Attenuation in all areas with MCL exceedances.

Extensive Waste Excavation would include excavation of the entire waste mass present at the Landfill and off-site disposal of the waste. During and after the Excavation, MNA would be used to assess the progress of natural degradation of groundwater impacts in all areas.

Alternative 4, Additional Landfill Gas Collection and Cover System Improvements with Groundwater Pump and Treat

- Additional Landfill Gas Collection in the Northwest, West, and Southwest Areas.
- Cover System Improvements in the Northwest and West Areas.
- Groundwater P&T in the Northwest, West, Southwest, South, and Southeast Areas.

Additional landfill gas extraction wells would be installed in the Northwest, West, and Southwest Areas, and the soil cover in the Northwest and West Areas would be improved. Groundwater extraction wells and an aboveground treatment system would then be installed to allow extraction and treatment of the VOCs in groundwater in all five (5) Areas. The depth and placement of the extraction wells would be designed to optimize hydraulic control of impacted portions of the aquifer.

Alternative 5, Additional Landfill Gas Collection and Cover System Improvements with Enhanced Bioremediation

- Additional Landfill Gas Collection in the Northwest, West, and Southwest Areas.
- Cover System Improvements in the Northwest and West Areas.
- Enhanced Bioremediation in the Northwest, West, Southwest, South, and Southeast Areas.

Additional landfill gas extraction wells would be installed in the Northwest, West, and Southwest Areas, and the soil cover in the Northwest and West Areas would be improved. Injection wells for Enhanced Bioremediation would be installed to allow treatment of the VOCs in groundwater in all five (5) Areas. The depth and placement of the injection wells would be designed to optimize distribution of the injected carbon substrate, bioaugmentation culture, and/or electron acceptor into the impacted portions of the aquifer.

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5. DETAILED ANALYSIS OF CORRECTIVE MEASURE ALTERNATIVES

In this chapter, the CMAs presented in Section 4 are examined for adherence to nine (9) criteria, pursuant to EPA guidance (EPA 1991)

Compliance With ARARs and RAOs

The CMAs are evaluated to determine whether each can perform its intended function and meet the RAOs, in accordance with the ARARs (compliance with federal, state, and local regulations). This criterion includes site- and waste-specific characteristics.

Short-Term Effectiveness

This criterion includes evaluation of the short-term effectiveness of each preliminary CMA, including the timeframe to meet RAOs and any short-term risks to the community, workers, or the environment resulting from implementation of the remedy.

Long-Term Effectiveness and Permanence

This criterion includes evaluation of the long-term effectiveness and permanence of each CMA. This criterion evaluates the adequacy of the CMA for meeting and maintaining compliance with the RAOs over the long-term.

Implementability of Alternative

This criterion includes evaluation of the technical and institutional feasibility of executing a CMA, including constructability, permits, legal/regulatory requirements, availability of materials, and length of time from implementation to realization of beneficial effects.

Protection of Human and Ecological Health

Potential threats to workers, nearby communities, and the environment during implementation of the CMA selected are taken into consideration. Additionally, the potential for cross-media transfer of impacts must be evaluated. The extent to which each CMA protects human health and meets ARARs must be evaluated. This criterion includes consideration of the classes and concentrations of impacts left on-site, potential exposure routes, and potentially affected populations. Residual impacts are compared to ARARs.

Source Treatment and Reduction of Toxicity, Mobility, and Volume

This criterion includes the ability of a CMA to reduce the toxicity, mobility, and volume of source materials that impact media at the Landfill site. Reductions in source material may lower the potential for and effects of acute exposure, as well as reduce the projected life-cycle of the CMA in achieving the RAOs.

Cost of Alternative

This criterion includes estimation of capital and annual O&M costs for each CMA, as appropriate. Annual O&M costs typically include labor, maintenance, energy, and sampling/analysis. The costs for each CMA include twenty (20) years of O&M, and a twenty (20) percent contingency. The cost estimates are based on conventional cost estimating guides, vendor information, and engineering judgment. Costs in this study should not be considered estimates for execution of actual work, but rather cost estimates compiled solely for comparison purposes. Costing details and assumptions are provided in **Appendix F**.

Regulatory Acceptance of Alternative

Consideration is given as to whether the CMA is likely to be accepted and approved by MDE.

Community or Stakeholder Acceptance of Alternative

Consideration is given as to whether a given CMA is acceptable to the local community and stakeholders involved in the site. This includes potential concerns regarding implementation of the CMA, including duration and volume of associated vehicle traffic and potential for noise, odor, and dust generation, as well as compatibility with the community preferred land reuse options for the Landfill. The following reuse preferences were identified in a survey of residents performed by the Derwood Station Homeowners Associations:

- Running and walking trails
- Bike paths
- Model plane flying areas
- Children’s play areas
- Dog park areas
- Garden plots.

5.1 ALTERNATIVE 1: SELECTIVE WASTE EXCAVATION WITH OFF-SITE DISPOSAL AND ENHANCED BIOREMEDIATION

Alternative 1 includes Selective Waste Excavation and Cover System Improvements in the Northwest and West Areas with Enhanced Bioremediation in all potential remediation areas. Selective Waste Excavation and Cover System Improvements would address landfill gas exceedances and leachate seeps in the Northwest and West Areas. During waste excavation, site investigations and a pilot study for Enhanced Bioremediation would be initiated in the South Area, with injection wells installed through the waste to allow pilot testing and injection of amendments to enhance the bioremediation of groundwater impacts. Assuming positive results, the pilot study would be followed by installation of injection wells in all five (5) Areas, targeting the areas of highest concentrations of groundwater impacts. After the South, Enhanced Bioremediation systems would likely be installed in the Northwest (following excavation) and Southwest Areas, to enhance the bioremediation of the relatively high-concentration groundwater impacts reported in these Areas. In the West and Southeast Areas, where the lowest concentrations of groundwater impacts occur, groundwater would be monitored during the Selective Waste Excavation and implementation of Enhanced Bioremediation in the other areas. The need for Enhanced Bioremediation in these areas would then be reevaluated prior to implementation. Injection wells in the Northwest Area, and in the West Area as applicable, would be installed outside the limit of waste, in the space created by Selective Waste Excavation.

Selective Waste Excavation would involve removal of waste to provide a buffer between the waste disposal footprint and the northwest property boundary, which is the point of compliance for the Landfill. Excavation would provide room for attenuation of impacts to occur between the limit of the waste mass and this portion of the property boundary point of compliance. The area over which waste is removed would be optimized to balance the advantages of a wider buffer with the cost, time, and level of disturbance required for the excavation. There is expected to be uncertainty regarding the volume of waste to be excavated from a given footprint, due to unknown depth of waste in many portions of the Landfill. Due to slope stability concerns, once an area reaches a pre-determined elevation during waste excavation activities, clean fill/specified fill placement would need to be initiated, thus implementing a remove and replace operation in step sequence. Waste would be removed using conventional techniques, and would be screened to separate the waste from the soil and the recyclable materials. The separated soil would be stockpiled, and composite samples from the stockpiles would be analyzed to assess whether the soil is acceptable for reuse on-site. Waste would then be transported to the County Shady Grove Processing Facility and Transfer Station for processing. Consolidated non-recyclable materials would likely be incinerated at the County Resource Recovery Facility. Following Selective Waste Excavation, the new side-slope of the Landfill would be graded and a new, improved soil cover system would be installed to decrease the occurrence of leachate seeps.

As stated above, due to the size of the Enhanced Bioremediation system to be implemented, site investigations and pilot testing would be conducted to determine the optimal parameters for the full-scale system. The pilot test would be conducted using approximately five (5) to ten (10) injection wells. The results of the investigations and the pilot testing would be used to determine design parameters for the bioremediation systems, such as injection well spacing, amendment components and concentrations, frequency and volume of injections, and whether injection of a bioaugmentation culture is necessary to promote complete degradation and prevent accumulation of DCE and/or VC in the groundwater. Following the pilot testing for Enhanced Bioremediation, injection wells would be installed in other areas, targeting the areas of highest concentrations of groundwater impacts.

5.1.1 Compliance With Applicable or Relevant and Appropriate Requirements and Remedial Action Objectives

Selective Waste Excavation in the Northwest and West Areas would increase compliance with RAOs for landfill gas and leachate in these areas. Regrading following excavation and placement of an improved cover would further increase compliance with the RAO for leachate seeps (i.e., non-stormwater discharges) in the areas targeted for excavation. If designed and implemented effectively, Enhanced Bioremediation would decrease groundwater impacts to below MCLs, and thus meet the RAO for groundwater.

5.1.2 Short-Term Effectiveness

Selective Waste Excavation may create the potential for contact with the exposed waste and higher levels of landfill gas, especially by construction workers, in the short term. Waste excavation may also create fugitive emissions of dust, odor, and noise, which would be managed through compliance measures to be developed in an operations plan. Personal Protective Equipment or other precautions would be necessary to prevent human health concerns resulting from this contact with waste and landfill gas. Although contact with waste and landfill gas was not included in the risk evaluation performed as part of the NES for the Landfill (EA 2010b), waste excavation is a common industry practice and protection measures would be addressed in a site-specific Health and Safety Plan completed prior to excavation activities. Alternative 1 would cause fewer short-term impacts associated with waste excavation than would an alternative involving Extensive Waste Excavation (see Alternative 3). Enhanced Bioremediation would be associated with fewer human health concerns than Selective Waste Excavation, with potential hazards including contact with impacted groundwater during well installation, injection events, and groundwater sampling. These concerns would also be addressed in the site-specific Health and Safety Plan.

Landfill gas concentrations at the property boundary would decrease as Selective Waste Excavation proceeded from the limit of waste inward. Leachate would need to be monitored and controlled during excavation, but the occurrence of leachate seeps would be expected to substantially decrease following regrading and installation of a new cover on the excavated areas of the waste boundary. It is estimated that Selective Waste Excavation could begin three (3) years after approval of the ACM (**Figure 5-1**), based on design, permitting, and contracting requirements. With off-site disposal of the waste, which limits the rate of excavation, it is estimated that the Selective Waste Excavation and Cover System Improvements in the Northwest Area and the West Area could be completed in six (6) years, which would end nine (9) years after approval of the ACM, if no unanticipated delays occur. Improved compliance with the RAOs for non-stormwater discharges and landfill gas in these Areas, where leachate seeps and landfill gas exceedances have been observed (**Figures 2-5 and 2-6**), would be expected to occur soon after the excavation is complete and the improved cover is in place.

The timeframe for implementation of the Enhanced Bioremediation systems would be dependent on site investigations and pilot testing activities as well as the phasing of technologies, including timing of the Selective Waste Excavation. It is estimated that the first phase of Enhanced Bioremediation, including site investigations and implementation and monitoring of a small-scale Enhanced Bioremediation system in the South Area, could be initiated approximately one (1) year after approval of this ACM, and would last approximately three (3) years. The second phase, full-scale implementation, could then begin in the South Area, five (5) years after approval of the ACM, and continue in the Northwest and West Areas as selective waste excavation is completed in these areas. It is anticipated that installation of the Enhanced Bioremediation system would be phased to first target the South, Southwest, and Northwest Areas, which have the highest concentrations of groundwater impacts. Groundwater data for the West and Southeast Areas would then be reviewed to assess the need for implementation of systems in these areas, and installation would proceed as necessary. Installation and optimization of the full-scale bioremediation system in each Area is expected to occur over a period of approximately two (2) years. The estimated timeframe for groundwater impacts to decrease after the first amendment injection is approximately six (6) to eighteen (18) months. Thus, the times between approval of the ACM and achievement of the RAO for groundwater would be expected to be approximately nine (9) years in the South Area, and ten (10) years in the Northwest and Southwest Areas. Assuming that the Enhanced Bioremediation systems in the West and Southeast Areas are installed when Selective Waste Excavation is complete in the West Area, the RAO for groundwater would be expected to be met in these areas in approximately twelve (12) years (or less if natural processes accelerate attenuation of the naturally low impacts in these Areas).

5.1.3 Long-Term Effectiveness and Permanence

Selective Waste Excavation would be an effective and permanent method for decreasing the waste mass located adjacent to the property boundary. The excavation, in combination with continued operation of the gas collection system, would permanently decrease the occurrence of landfill gas exceedances at the boundary. Regrading and placement of a new cover is also expected to be an effective, long-term remedy for addressing leachate seeps.

Enhanced Bioremediation systems in all five (5) Remediation Areas, designed based on the results of site investigations and pilot testing, with appropriate enhancements thoroughly mixed into the groundwater aquifer, are expected to be highly effective for maintaining lower concentrations of groundwater impacts both within the unconsolidated material and the bedrock. Installation of wells through the waste in the Southwest, South, and possibly Southeast Areas is not expected to impact the mobility of groundwater impacts, because the wells would not penetrate a liner or an impermeable cap, and the wells would be constructed to prevent preferential vertical flow along the well casings. If the site investigations or pilot testing reveals a deficit of bacteria that degrade DCE and VC to ethene, then a single inoculation with a bioaugmentation culture of *Dehalococcoides* or similar may improve the long-term effectiveness of the systems. The volume of the aquifer in which lower concentrations are achieved would be constrained primarily by the location and depth of the wells used for injection. Regular injections would be necessary to maintain the lower concentrations achieved by Enhanced Bioremediation. The duration over which subsequent injections of bioremediation amendments would need to occur would be dictated by the attenuation of the mass of source material within the waste mass, as well as the amount of naturally occurring oxidant demand within the treatment zone. If injections were stopped prior to depletion of the source material within the waste mass, a rebound in groundwater impacts might occur once the amendments were exhausted. However, the effects of the amendments on groundwater chemistry and the resulting increase in degradation rates would be expected to persist for some period (months to years, to be better defined by pilot testing) after the last injection.

5.1.4 Implementability of Alternative

Selective Waste Excavation is expected to be implementable at the Landfill. As described in the introduction to Section 5.1, the waste would be removed using conventional excavation equipment and processed in existing waste management facilities. However, the effort would disturb existing vegetation and infrastructure currently present at the Landfill. Hundreds of trees would need to be cleared prior to Selective Waste Excavation in the Northwest and West Areas. The portion of the landfill gas extraction system that is located in the Northwest and West Areas (approximately thirty [30] to forty [40] gas extraction wells) would be removed prior to excavation, and installation of new gas extraction wells would be required along the post-excavation side-slope. The existing stormwater features in the West Area would also be removed prior to excavation, and a new stormwater system for this area would need to be designed and installed following excavation. Well logs for the gas extraction wells along the western side of the Landfill indicate water in a portion of the waste up to thirty (30) ft thick. Based on this, it is expected that a dewatering system would be necessary within the excavations, with water likely pumped to a temporary tank while awaiting treatment. Operations and Contingency Plans would be required to mitigate potential problems resulting from disturbance of the waste during excavation, including erosion and sediment control, leachate and stormwater management, landfill gas migration, odor, dust, and noise. A trash fence would likely be required to prevent debris from blowing off-site. The regrading and cover placement following Selective Waste Excavation, and supporting changes to infrastructure, would need to take into account potential future land reuse options.

Injection wells for Enhanced Bioremediation would be installed through the waste mass to the underlying groundwater in the Southwest and South Areas, and, if necessary, the Southeast Area, to allow space between the system and the property boundary for enhanced degradation of groundwater impacts to occur before the groundwater flows off the property. Installation of injection wells on the side-slopes in these areas is likely to be required, and would require extensive clearing and construction of access roads in steep, tree-covered areas. Well installation through the waste would also present challenges, but these could be mitigated through use of standard industry procedures for drilling in waste. The only option for installing wells outside the waste mass in these areas would be to install wells in the narrow (in places less than twenty [20]-ft-wide) space between the waste mass and the property boundary. The Selective Waste Excavation would provide space for installation of the injection wells for Enhanced Bioremediation in the Northwest and West Areas, without drilling through the waste mass. In all areas, placing the injection wells farther from the property boundary would increase the time to meet the groundwater RAO at the property boundary, but would allow the wells to be more widely spaced, as the amendment would have more time and space, up-gradient of the point of compliance, to spread through the aquifer. Therefore, the position of the injection wells would be selected to balance these two (2) considerations.

Proposed injection well numbers and spacing and amendment composition would be determined through site investigations and pilot testing. Challenges to developing effective systems for injection of bioremediation amendments at the Landfill are primarily related to the challenge of achieving effective distribution of amendments through both the unconsolidated material (which is clayey-silty) and the bedrock, which has unknown fracture density and pattern. These challenges would be addressed through site investigations and pilot testing, which would include evaluations of the coverage and persistence of the amendments within the aquifer, packer testing to determine the depths of impacted fractures within the bedrock, and possibly tracer tests to assess transport of injected materials. Achieving effective injection into both unconsolidated material and bedrock could require specialized well construction techniques and injection methods; however, implementation of an effective program for Enhanced Bioremediation is expected to be feasible.

5.1.5 Protection of Human and Ecological Health

Short-term implications of this CMA for human health and the environment are discussed in Section 5.1.2.

In the long term, Selective Waste Excavation, with regrading and Cover System Improvements, would be protective of human and ecological health by reducing landfill gas emissions and leachate seep occurrences along the landfill perimeter.

As described in Section 2.2, the risk evaluations conducted as part of the NES and NES Amendment No. 1 for the Landfill (EA 2010b and 2011a) indicated that use of groundwater as a tap water source is an incomplete exposure pathway for groundwater for the area surrounding the Landfill, and that there were no human health concerns associated with the potentially complete vapor intrusion pathway. The pathway for ecological contact with groundwater is also assumed to be incomplete. Thus, protectiveness of human and ecological health is already achieved with respect to groundwater.

5.1.6 Source Treatment and Reduction of Toxicity, Mobility, and Volume

Selective Waste Excavation would directly decrease the volume of waste present in the Landfill, and thus would decrease the potential volumes of landfill gas and leachate produced within the waste mass. The magnitude of decreases in the sources of groundwater impacts within the waste mass would be dependent on the volume and contents of waste removed (whether waste containing sources of potential groundwater impacts was present in the excavated areas). Cover System Improvements performed after excavation would also decrease the mobility of landfill gas and leachate.

Enhanced Bioremediation would be expected to achieve significant reductions in the volume and concentrations of groundwater impacts. Enhanced Bioremediation destroys groundwater impacts *in situ*, offering a significant advantage in terms of reducing the toxicity and volume of the impacts. The associated reductions in the volume of groundwater impacts could be quantified using the groundwater monitoring data that would be collected as part of the Enhanced Bioremediation programs.

5.1.7 Cost of Alternative

The total estimated cost for implementation of Alternative 1 is approximately $152,000,000 (**Appendix F**) and includes the capital costs of Selective Waste Excavation with off-site disposal and Cover System Improvements; and the capital costs and O&M associated with Enhanced Bioremediation site investigations, pilot testing, and full-scale implementation. The capital costs for Selective Waste Excavation with off-site disposal and Cover System Improvements (approximately $97,000,000, or $81 per cubic yard of material excavated) include excavation, screening, leachate management, waste transport, disposal, management of recovered materials and special wastes, dewatering and disposal of groundwater, and backfill and soil cover. The capital costs of Enhanced Bioremediation (approximately $5,400,000) include well installation (through the waste mass in areas), well geophysical testing as part of the site investigations, and an amendment delivery system. O&M costs for Enhanced Bioremediation (approximately $2,400,000 per year) include well maintenance, annual injection events, and additional groundwater monitoring.

5.1.8 Regulatory Acceptance of Alternative

Selective Waste Excavation is expected to be acceptable to MDE, provided that the Operations and Contingency Plan is sufficient to control the negative short-term impacts of the excavation and ensure that waste is handled and disposed in compliance with regulations.

It is expected that Enhanced Bioremediation would also be an acceptable remedy, given careful design of a system, supported by site investigations and pilot testing. As described in Section 4.3.3, MDE recently approved Enhanced Bioremediation as a remedy for treatment of a cVOC plume at a sanitary landfill in Baltimore County (EA 2012). MDE has also indicated that they would consider and evaluate the possibility of drilling through the waste mass to install the required injection wells (Section 1.4.1).

5.1.9 Community or Stakeholder Acceptance of Alternative

Although Selective Waste Excavation would decrease the occurrence of landfill gas emissions and leachate seeps along the northwestern boundary of the Landfill, which is adjacent to the Derwood Community, the community is expected to have concerns regarding the waste disturbance and associated potential for dust, odors, scavenging animals, and noise, as well as increased truck traffic. The projected eight (8) year timeframe to implement the Selective Waste Excavation and Cover System Improvements may contribute to these concerns, which would need to be addressed prior to community acceptance of a Selective Waste Excavation program.

The community is not expected to have significant concerns regarding Enhanced Bioremediation, as it would cause minimal site disturbance while addressing groundwater impacts.

This CMA is compatible with the community’s recreational reuse preferences for the Landfill, as the top of the Landfill would not experience long-term disturbance. However, limitations on access would be necessary during construction activities, especially those related to waste excavation.

5.2 ALTERNATIVE 2: SELECTIVE WASTE EXCAVATION WITH ON-SITE PLACEMENT AND ENHANCED BIOREMEDIATION

Alternative 2 combines Selective Waste Excavation and Cover System Improvements in the Northwest and West Areas with Enhanced Bioremediation in all potential remediation areas.

The remedial activities under Alternative 2 would be very similar to Alternative 1, with substitution of on-site placement rather than off-site disposal of the excavated waste, which affects the logistics, schedule, and costing of this CMA.

Waste excavation, Cover System Improvements, and implementation of Enhanced Bioremediation would be as described for Alternative 1. Following excavation and separation of any hazardous materials, recyclable metals, and tires, waste would be placed in another portion of the Landfill property, using modern landfill engineering controls. It is anticipated that the excavated waste would be placed in portions of the top of the landfill where subsidence has resulted in depressions, or where waste placement is determined to be favorable based on other site considerations. Any hazardous materials or tires within the excavated waste would be disposed of off-site, in accordance with regulatory requirements.

5.2.1 Compliance With Applicable or Relevant and Appropriate Requirements and Remedial Action Objectives

Selective Waste Excavation in the Northwest and West Areas would increase compliance with RAOs for landfill gas and leachate in these areas. Regrading following excavation and placement of an improved cover would further increase compliance with the RAO for leachate seeps (i.e., non-stormwater discharges) in the areas targeted for excavation. If designed and implemented effectively, Enhanced Bioremediation would decrease groundwater impacts to below MCLs, and thus meet the RAO for groundwater.

5.2.2 Short-Term Effectiveness

Selective Waste Excavation may create the potential for contact with the exposed waste and higher levels of landfill gas, especially by construction workers, in the short term. Waste excavation may also create fugitive emissions of dust, odor and noise, which would be managed through compliance measures to be developed in an operations plan. Personal Protective Equipment or other precautions would be necessary to prevent human health concerns resulting from this contact with waste and landfill gas. Although contact with waste and landfill gas was not included in the risk evaluation performed as part of the NES for the Landfill (EA 2010b), waste excavation is a common industry practice and protection measures would be addressed in a site-specific Health and Safety Plan completed prior to excavation activities. Alternative 2 would cause fewer short-term impacts associated with waste excavation than would an alternative involving Extensive Waste Excavation (see Alternative 3). Management of waste following excavation, and on-site placement activities, would be conducted using modern landfill engineering controls to minimize impacts. Enhanced Bioremediation would be associated with fewer human health concerns than Selective Waste Excavation, with potential hazards including contact with impacted groundwater during well installation, injection events, and groundwater sampling. These concerns would also be addressed in the site-specific Health and Safety Plan.

Landfill gas concentrations at the property boundary would decrease as Selective Waste Excavation proceeded from the limit of waste inward. Leachate would need to be monitored and controlled during excavation, but the occurrence of leachate seeps would be expected to substantially decrease following regrading of and installation of a new cover on the excavated areas of the waste boundary. It is estimated that Selective Waste Excavation could begin three (3) years after approval of the ACM (**Figure 5-1**), based on design, permitting, and contracting requirements. With on-site placement of waste, it is estimated that the Selective Waste Excavation and Cover System Improvements in the Northwest Area and the West Area could be completed in one (1) year, which would end four (4) years after approval of the ACM, if no unanticipated delays occur. Improved compliance with the RAOs for non-stormwater discharges and landfill gas in these Areas, where leachate seeps and landfill gas exceedances have been observed (**Figures 2-5 and 2-6**), would be expected to occur soon after the excavation is complete and the improved cover is in place.

The timeframe for implementation of the Enhanced Bioremediation systems would be dependent on site investigations and pilot testing activities as well as the phasing of technologies, including timing of the Selective Waste Excavation. It is estimated that the first phase of Enhanced Bioremediation, including site investigations and implementation and monitoring of a small-scale Enhanced Bioremediation system in the South Area, could be initiated approximately one (1) year after approval of this ACM, and would last approximately three (3) years. The second phase, full-scale implementation, could then begin in the South Area, five (5) years after approval of the ACM, and continue in the Northwest and West Areas. It is anticipated that installation of the Enhanced Bioremediation system would be phased to first target the South, Southwest, and Northwest Areas, which have the highest concentrations of groundwater impacts. Groundwater data for the West and Southeast Areas would then be reviewed to assess the need for implementation of systems in these areas, and installation would proceed as necessary. Installation and optimization of the full-scale bioremediation system in each Area is expected to occur over a period of approximately two (2) years. The estimated timeframe for groundwater impacts to decrease after the first amendment injection is approximately six (6) to eighteen (18) months. Thus, the times between approval of the ACM and achievement of the RAO for groundwater would be expected to be approximately nine (9) years in the South Area, and ten

(10) years in the Northwest and Southwest Areas. Assuming that the Enhanced Bioremediation systems in the West and Southeast Areas are installed when Selective Waste Excavation is complete in the West Area, the RAO for groundwater would be expected to be met in these areas in approximately twelve (12) years (or less if natural processes accelerate attenuation of the naturally low impacts in these Areas).

5.2.3 Long-Term Effectiveness and Permanence

Selective Waste Excavation would be an effective and permanent method for decreasing the waste mass located adjacent to the property boundary. The excavation, in combination with continued operation of the Landfill Gas Collection system, would permanently decrease the occurrence of landfill gas exceedances at the boundary. Regrading and placement of a new cover is also expected to be a highly effective, long-term remedy for addressing leachate seeps.

Enhanced Bioremediation systems in all five (5) Remediation Areas, designed based on the results of site investigations and pilot testing, with appropriate enhancements thoroughly mixed into the groundwater aquifer, are expected to be highly effective for maintaining lower concentrations of groundwater impacts both within the unconsolidated material and the bedrock. Installation of wells through the waste in the Southwest, South, and possibly Southeast Areas is not expected to impact the mobility of groundwater impacts, because the wells would not penetrate a liner or an impermeable cap, and the wells would be constructed to prevent preferential vertical flow along the well casings. If the site investigations or pilot testing reveals a deficit of bacteria that degrade DCE and VC to ethene, then a single inoculation with a bioaugmentation culture of *Dehalococcoides* or similar may improve the long-term effectiveness of the systems. The volume of the aquifer in which lower concentrations are achieved would be constrained primarily by the location and depth of the wells used for injection. Regular injections would be necessary to maintain the lower concentrations achieved by Enhanced Bioremediation. The duration over which subsequent injections of bioremediation amendments would need to occur would be dictated by the attenuation of the mass of source material within the waste mass, as well as the amount of naturally occurring oxidant demand within the treatment zone. If injections were stopped prior to depletion of the source material within the waste mass, a rebound in groundwater impacts might occur once the amendments were exhausted. However, the effects of the amendments on groundwater chemistry and the resulting increase in degradation rates would be expected to persist for some period (months to years, to be better defined by pilot testing) after the last injection.

5.2.4 Implementability of Alternative

Selective Waste Excavation is expected to be implementable at the Landfill. The waste would be removed using conventional excavation equipment and processed in existing waste management facilities, as described in the introduction to Section 5.1. However, the effort would disturb existing vegetation and infrastructure currently present at the Landfill. Hundreds of trees would need to be cleared prior to Selective Waste Excavation in the Northwest and West Areas. The portion of the landfill gas extraction system that is located in the Northwest and West Areas (approximately thirty [30] to forty [40] gas extraction wells) would be removed prior to excavation, and installation of new gas extraction wells would be required along the post-excavation side-slope. The existing stormwater features in the West Area would also be removed prior to excavation, and a new stormwater system for this area would need to be designed and installed following excavation. Well logs for the gas extraction wells along the western side of the Landfill indicate water in a portion of the waste up to thirty (30) ft thick. Based on this, it is expected that a dewatering system would be necessary within the excavations, with water likely pumped to a temporary tank while awaiting treatment. Operations and Contingency Plans would be required to mitigate potential problems resulting from disturbance of the waste during excavation, including erosion and sediment control, leachate and stormwater management, landfill gas migration, odor, dust, and noise. A trash fence would likely be required to prevent debris from blowing off-site. The regrading and cover placement following Selective Waste Excavation, and supporting changes to infrastructure, would need to take into account potential future land reuse options.

Injection wells for Enhanced Bioremediation would be installed through the waste mass to the underlying groundwater in the Southwest and South Areas, and, if necessary, the Southeast Area, to allow space between the system and the property boundary for enhanced degradation of groundwater impacts to occur before the groundwater flows off the property. Installation of injection wells on the side-slopes in these areas is likely to be required, and would require extensive clearing and construction of access roads in steep, tree-covered areas. Well installation through the waste would also present challenges, but these could be mitigated through use of standard industry procedures for drilling in waste. The only option for installing wells outside the waste mass in these areas would be to install wells in the narrow (in places less than twenty [20]-ft-wide) space between the waste mass and the property boundary. The Selective Waste Excavation would provide space for installation of the injection wells for Enhanced Bioremediation in the Northwest and West Areas, without drilling through the waste mass. In all areas, placing the injection wells farther from the property boundary would increase the time to meet the groundwater RAO at the property boundary, but would allow the wells to be more widely spaced, as the amendment would have more time and space, up-gradient of the point of compliance, to spread through the aquifer. Therefore, the position of the injection wells would be selected to balance these two (2) considerations.

Proposed injection well numbers and spacing and amendment composition would be determined through site investigations and pilot testing. Challenges to developing effective systems for injection of bioremediation amendments at the Landfill are primarily related to the challenge of achieving effective distribution of amendments through both the unconsolidated material (which is clayey-silty) and the bedrock, which has unknown fracture density and pattern. These challenges would be addressed through site investigations and pilot testing, which would include evaluations of the coverage and persistence of the amendments within the aquifer, packer testing to determine the depths of impacted fractures within the bedrock, and possibly tracer tests to assess transport of injected materials. Achieving effective injection into both unconsolidated material and bedrock could require specialized well construction techniques and injection methods; however, implementation of an effective program for Enhanced Bioremediation is expected to be feasible.

5.2.5 Protection of Human and Ecological Health

Short-term implications of this CMA for human health and the environment are discussed in Section 5.2.2.

In the long term, Selective Waste Excavation, with regrading and Cover System Improvements, would be protective of human and ecological health by reducing landfill gas emissions and leachate seep occurrences along the landfill perimeter. On-site placement of the excavated waste is not expected to adversely affect human or ecological health.

As described in Section 2.2, the risk evaluations conducted as part of the NES and NES Amendment No. 1 for the Landfill (EA 2010b and 2011a) indicated that use of groundwater as a tap water source is an incomplete exposure pathway for groundwater for the area surrounding the Landfill, and that there were no human health concerns associated with the potentially complete vapor intrusion pathway. The pathway for ecological contact with groundwater is also assumed to be incomplete. Thus, protectiveness of human and ecological health is already achieved with respect to groundwater.

5.2.6 Source Treatment and Reduction of Toxicity, Mobility, and Volume

Although Selective Waste Excavation with on-site placement would not decrease the volume of waste present in the Landfill (except for any hazardous materials or tires excavated and disposed off-site), it would decrease the mobility of landfill gas and leachate across the property boundary. Decreases in the sources of groundwater impacts within the waste mass could occur, as any hazardous waste obviously containing sources of potential groundwater impacts would be disposed off-site; however, this decrease would likely be minimal. Cover System Improvements performed after excavation would also decrease the mobility of landfill gas and leachate.

Enhanced Bioremediation would be expected to achieve significant reductions in the volume and concentrations of VOCs. Enhanced Bioremediation destroys VOCs *in situ*, offering a significant advantage in terms of reducing the toxicity and volume of the contaminants. The associated reductions in the volume of contaminants could be quantified using the groundwater monitoring data that would be collected as part of the Enhanced Bioremediation programs.

5.2.7 Cost of Alternative

The total estimated cost for implementation of Alternative 2 is approximately $100,000,000 (**Appendix F**) and includes the capital costs of Selective Waste Excavation with on-site placement and Cover System Improvements; and the capital costs and O&M associated with Enhanced Bioremediation site investigations, pilot testing, and full-scale implementation. The capital costs for Selective Waste Excavation with on-site placement and Cover System Improvements (approximately $45,000,000, or $37 per cubic yard of material excavated) include excavation, screening, leachate management, waste transport, disposal, management of recovered materials and special wastes, dewatering and disposal of groundwater, and backfill and soil cover. The capital costs of Enhanced Bioremediation (approximately $5,400,000) include well installation (through the waste mass in areas), well geophysical testing as part of the site investigations, and an amendment delivery system. O&M costs for Enhanced Bioremediation (approximately $2,400,000 per year) include well maintenance, annual injection events, and additional groundwater monitoring.

5.2.8 Regulatory Acceptance of Alternative

Selective Waste Excavation is expected to be acceptable to MDE, provided that the Operations and Contingency Plan is sufficient to control the negative short-term impacts of the excavation and ensure that waste is handled and disposed in compliance with regulations.

It is expected that Enhanced Bioremediation would also be an acceptable remedy, given careful design of a system, supported by site investigations and pilot testing. As described in Section 4.3.3, MDE recently approved Enhanced Bioremediation as a remedy for treatment of a cVOC plume at a sanitary landfill in Baltimore County (EA 2012). MDE has also indicated that they would consider and evaluate the possibility of drilling through the waste mass to install the required injection wells (Section 1.4.1).

5.2.9 Community or Stakeholder Acceptance of Alternative

Although Selective Waste Excavation would decrease the occurrence of landfill gas emissions and leachate seeps along the northwestern boundary of the Landfill, which is adjacent to the Derwood Station residential development, the community is expected to have concerns regarding the waste disturbance and associated potential for dust, odors, scavenging animals, and noise, as well as increased truck traffic. The projected eight (8) year timeframe to implement the Selective Waste Excavation and Cover System Improvements may contribute to these concerns, which would need to be addressed prior to community acceptance of a Selective Waste Excavation program. On-site placement of excavated waste may also cause concern, which would be addressed through careful selection of the placement location, and use of engineering controls to limit short-term site impacts.

The community is not expected to have significant concerns regarding Enhanced Bioremediation, as it would cause minimal site disturbance while addressing groundwater impacts.

This CMA is compatible with the community’s recreational reuse preferences for the Landfill. The elevation of some portion(s) of the top of the Landfill would likely be increased through placement of excavated waste; however, the placement location, thickness, and slopes would be chosen to limit the impact to potential reuse. Limitations on access would also be necessary during construction activities, especially those related to waste excavation.

5.3 ALTERNATIVE 3: EXTENSIVE WASTE EXCAVATION WITH MONITORED NATURAL ATTENUATION

Alternative 3 utilizes Extensive Waste Excavation, in which all waste would be removed from the Landfill. There is some uncertainty regarding the total volume of waste contained within the Landfill due to unknown depth of waste in many portions of the Landfill, as well as unknown soil fraction and decomposition percentage. Waste would be removed using conventional techniques and would be screened to separate the waste from the soil and recyclable materials. The separated soil would be reused on-site to provide smooth grades after excavation. Waste would then be transported to the County Shady Grove Processing Facility and Transfer Station for processing. Consolidated non-recyclable materials would likely be incinerated at the County Resource Recovery Facility to the extent that excess capacity is available.

During the process of waste excavation, an MNA program would be implemented to monitor groundwater impacts along the Landfill boundaries. Analysis of site data and aquifer conditions indicate that natural attenuation is occurring at the Landfill (**Appendix E**). The monitoring program under the MNA remedy for these areas would assess and document whether natural attenuation continues to occur according to expectations. The effectiveness of MNA (stable or decreasing groundwater impacts, lack of risk, etc.) would be reevaluated every five (5) years to assess whether contingency measures are necessary in these areas.

A monitoring and contingency plan, including milestones to be met and contingencies to be implemented if they are not met, would be developed as part of the MNA program. Regular monitoring would be performed and the data would be analyzed to track the progress of groundwater remediation. The monitoring plan would be designed to achieve the following:

- Identify changes in conditions at the Landfill that could reduce the effectiveness of MNA,
- Detect any persistent increase in groundwater impacts that indicate that the impacted area could be expanding, and
- Verify progress toward meeting the groundwater RAO.

The contingency plan would identify criteria or “triggers” that signal unacceptable performance of the MNA remedy and indicate when to implement one (1) or more potential supplemental remedial options. The most likely supplemental remedy would be Enhanced Bioremediation, to increase the rate and completeness of the natural degradation processes.

5.3.1 Compliance With Applicable or Relevant and Appropriate Requirements and Remedial Action Objectives

Extensive Waste Excavation would ultimately remove the source of landfill gas and leachate, and would thus gradually increase compliance with RAOs during the period of excavation.

Implemented in conjunction with Extensive Waste Excavation, MNA would be expected to decrease the concentrations of groundwater impacts to below MCLs at an accelerated rate, compared to the current rate of attenuation, once the source of impacts within the waste mass is removed. If it is found that MNA is not sufficiently effective within an acceptable timeframe, then contingency measures would be taken to ensure that the groundwater RAO is met within an acceptable timeframe.

5.3.2 Short-Term Effectiveness

Extensive Waste Excavation may create the potential for contact with the exposed waste and higher levels of landfill gas, especially by construction workers, in the short term. Waste excavation may also create fugitive emissions of dust, odor and noise, which would be managed through compliance measures to be developed in an operations plan. Personal Protective Equipment or other precautions would be necessary to prevent human health concerns resulting from this contact with waste and landfill gas. Although contact with waste and landfill gas was not included in the risk evaluation performed as part of the NES for the Landfill (EA 2010b), waste excavation is a common industry practice and protection measures would be addressed in a site-specific Health and Safety Plan completed prior to excavation activities. Alternative 3 would cause substantially more short-term impacts associated with the Extensive Waste Excavation than would the other CMAs, including those involving Selective Waste Excavation. Relatively fewer human health concerns would be associated with MNA, but potential hazards include contact with impacted groundwater during well installation and groundwater sampling. These concerns would also be addressed in the site-specific Health and Safety Plan.

Landfill gas concentrations at the property boundary would decrease as Extensive Waste Excavation proceeded from the limit of waste inward. Leachate would need to be monitored and controlled during excavation, but the occurrence of leachate seeps would be expected to substantially decrease following regrading of and installation of a new cover on the excavated areas of the waste boundary. It is estimated that Extensive Waste Excavation could begin three (3) years after approval of the ACM (**Figure 5-1**), based on design, permitting, and contracting requirements. Completion of the waste excavation effort would be anticipated approximately thirty (30) years after the excavation begins. In the Northwest and West Areas, where leachate seeps and landfill gas exceedances have been observed (**Figures 2-6 and 2-7**), improved compliance with the RAOs for non-stormwater discharges and landfill gas could be expected to occur within ten (10) years after approval of the ACM, if excavation is performed in these areas first. Attenuation of groundwater impacts would also be expected to accelerate, compared to the current rate of attenuation, after the source of impacts within the waste mass has been removed by Extensive Waste Excavation.

In the event that the timeframe for MNA to meet RAOs is determined to be unacceptable in the short term, additional remedies such as Enhanced Bioremediation would need to be implemented under the contingency plan for MNA, to improve the short-term effectiveness. If determined to be necessary as a contingency in any areas, well-designed Enhanced Bioremediation systems are expected to be effective for promoting degradation and decreasing the time to meet RAOs in groundwater, both within the unconsolidated material and the bedrock.

5.3.3 Long-Term Effectiveness and Permanence

Extensive Waste Excavation would be an effective and permanent method for removing the waste mass from the Landfill site. It would permanently remove the source of landfill gas and leachate seeps and thus eliminate LEL exceedances and non-stormwater discharges. Extensive Waste Excavation would also remove the source of groundwater impacts at the Landfill, although natural degradation may offer similar long-term effectiveness and permanence, given the long timeframe required for complete excavation.

Recent groundwater monitoring data have indicated exceedances of MCLs at or beyond the property boundary. However, the presence of VC in the groundwater is strong evidence that reductive dechlorination is occurring (refer to **Appendix E** for an evaluation of natural attenuation processes occurring at the Landfill). The naturally occurring attenuation has the advantage of a high degree of permanence, with the natural processes expected to continue to effectively degrade groundwater impacts in the long term, even after MCLs are met.

5.3.4 Implementability of Alternative

Extensive Waste Excavation is expected to be implementable at the Landfill. As described in the introduction to Section 5.3, the waste would be removed using conventional excavation equipment and processed in existing waste management facilities. However, the effort would disturb all existing vegetation and infrastructure currently present at the Landfill. Hundreds of trees would need to be cleared prior to Extensive Waste Excavation. Steep slopes and limited infrastructure may make access difficult initially, especially in the Southwest and South Areas. The landfill gas extraction system and stormwater features would be removed as excavation proceeded across the Landfill. Well logs for the gas extraction wells along the western side of the Landfill indicate water in a portion of the waste up to thirty (30) ft thick. Based on this, it is expected that a dewatering system would be necessary within the excavations, with water likely pumped to a temporary tank while awaiting treatment. Operations and Contingency Plans would be required to mitigate potential problems resulting from disturbance of the waste during excavation, including erosion and sediment control, leachate and stormwater management, landfill gas migration, odor, dust, and noise. Trash fences would likely be required to prevent debris from blowing off-site.

MNA would be highly implementable, requiring regular monitoring and analysis of the degradation of groundwater impacts. If MNA is determined to be insufficient for meeting the groundwater RAO in an acceptable timeframe in any areas, implementation of an effective program for Enhanced Bioremediation, targeted at areas requiring accelerated degradation, is expected to be feasible.

5.3.5 Protection of Human and Ecological Health

Short-term implications of this CMA for human health and the environment are discussed in Section 5.3.2.

In the long term, Extensive Waste Excavation would be protective of human and ecological health by removing the source of landfill gas emissions and leachate seep occurrences along the landfill perimeter.

As described in Section 2.2, the risk evaluations conducted as part of the NES and NES Amendment No. 1 for the Landfill (EA 2010b and 2011a) indicated that use of groundwater as a tap water source is an incomplete exposure pathway for groundwater for the area surrounding the Landfill, and that there were no human health concerns associated with the potentially complete vapor intrusion pathway. The pathway for ecological contact with groundwater is also assumed to be incomplete. Thus, protectiveness of human and ecological health is already achieved with respect to groundwater.

5.3.6 Source Treatment and Reduction of Toxicity, Mobility, and Volume

Extensive Waste Excavation would remove the waste mass from the Landfill site, thereby eliminating the source of landfill gas and leachate, as well as the source of groundwater impacts.

Natural attenuation would continue to degrade groundwater impacts during and after waste excavation. The associated reductions in the volume of groundwater impacts could be quantified using the groundwater monitoring data that would be collected as part of the MNA program. Enhanced Bioremediation would be expected to further promote the reduction in the volume and concentrations of groundwater impacts in any areas where it is determined to be necessary as a contingency measure. Both MNA and Enhanced Bioremediation destroy VOCs *in situ*, offering a significant advantage in terms of reducing the toxicity and volume of the contaminants.

5.3.7 Cost of Alternative

The total estimated cost for implementation of Alternative 3 is approximately $456,000,000 (**Appendix F**) and includes the capital costs of Extensive Waste Excavation and the costs of implementing an MNA program. The capital costs for Extensive Waste Excavation (approximately $454,000,000, or $73 per cubic yard of material excavated) include excavation, screening, leachate management, waste transport, disposal, management of recovered materials and special wastes, dewatering and disposal of groundwater, and backfill and soil cover. The cost of implementing an MNA program is approximately $48,000 per year.

5.3.8 Regulatory Acceptance of Alternative

Extensive Waste Excavation is expected to be acceptable to MDE, provided that the Operations and Contingency Plan is sufficient to control the negative short-term impacts of the excavation and ensure that waste is handled and disposed in compliance with regulations.

MDE acceptance of MNA would depend on acceptance of the Monitoring and Contingency Plan developed in conjunction with this remedy. The plan would need to include sufficient analysis and appropriate triggers to ensure achievement of the groundwater RAOs. It is expected that Enhanced Bioremediation would be an acceptable contingency measure, given careful design of a system. Although the lack of sufficient information to allow estimation of a timeframe for achieving the RAOs through natural attenuation processes may be seen as a deterrent to MNA at the Landfill, the lack of risk from exposure to groundwater impacts could make MNA an acceptable remedy, when paired with an appropriate Contingency Plan.

5.3.9 Community or Stakeholder Acceptance of Alternative

Although Extensive Waste Excavation would remove the source of landfill gas, leachate seeps, and groundwater impacts, the community is expected to have concerns regarding the waste disturbance and associated potential for dust, odors, scavenging animals, and noise, including increased truck traffic. The projected thirty (30) year timeframe to implement the Extensive Waste Excavation would likely contribute to these concerns, which would need to be addressed prior to community acceptance of such and effort.

The community is not expected to have significant concerns regarding MNA (or Enhanced Bioremediation), as it would cause minimal site disturbance while addressing groundwater impacts. Although the community may have some concerns associated with use of MNA rather than a more active treatment technology in areas with MCL exceedances, these would be addressed through implementation of an MDE-approved monitoring and contingency plan.

This CMA is compatible with the community's recreational reuse preferences for the Landfill in the long-term, as the Landfill site could be redeveloped into a recreational facility following the completion of Extensive Waste Excavation. However, the community would likely have minimal access to the property during the period of waste excavation.

5.4 ALTERNATIVE 4: ADDITIONAL LANDFILL GAS COLLECTION AND COVER SYSTEM IMPROVEMENTS WITH GROUNDWATER PUMP AND TREAT

Alternative 4 combines Groundwater P&T in all potential remediation Areas with Cover System Improvements in the Northwest and West Areas, and installation of additional landfill gas extraction wells in the Northwest, West, and Southwest Areas. An improved soil cover system would be installed on the existing side-slopes of the Northwest and West Areas of the Landfill primarily to decrease the occurrence of leachate seeps, with some potential to help attenuate landfill gas. After the improved cover system is in place, approximately fifteen (15) additional landfill gas extraction wells would be installed to provide further control over gas migration along the property boundary. Extraction wells for the Groundwater P&T system would be installed along the property boundary and outside the limit of waste where possible, or through waste where necessary.

Site investigations and a pilot study for Groundwater P&T would likely be conducted in the Northwest Area. Assuming positive results, the pilot study would be followed by installation of extraction wells in all five (5) Areas, targeting the areas of highest concentrations of groundwater impacts. After the Northwest Area, the Groundwater P&T system would likely be expanded to the West, Southwest, and South Areas. In the Southeast Area, where the lowest concentrations of groundwater impacts occur, groundwater would be monitored during implementation of Groundwater P&T in the other areas. The need for P&T in this area would then be reevaluated prior to implementation.

The groundwater extracted by the Groundwater P&T system would be transported through a piping network to an aboveground treatment facility on-site, where the constituents responsible for groundwater impacts would be removed from the water. Based on the groundwater impacts at the site, this evaluation assumes use of activated carbon adsorption for treatment of the groundwater. The effectiveness of groundwater capture by the Groundwater P&T system would be assessed by monitoring drawdown in the extraction wells and groundwater impacts down-gradient of the system. The treated groundwater would likely be discharged to a public sewer system to be treated further at a public wastewater treatment facility. Alternatively, the possibility of surface water discharge could be evaluated during the permitting and design process.

5.4.1 Compliance With Applicable or Relevant and Appropriate Requirements and Remedial Action Objectives

Installation of an improved cover along the side-slopes in the Northwest and West Areas, and installation of additional landfill gas extraction wells in these areas as well as the Southwest Area, would decrease leachate seep occurrences and help control landfill gas migration, and thus increase compliance with RAOs for landfill gas and leachate in these areas.

Groundwater P&T would extract impacted groundwater in the areas of MCL exceedances. The degree to which groundwater impacts decrease would be dependent on the degree of hydraulic control achieved. As discussed in Section 5.4.3, it would likely be difficult to achieve control over groundwater located in the bedrock fractures. Thus, although some decrease in groundwater impacts would be achieved, the ability of Groundwater P&T to meet the RAO for groundwater is uncertain.

5.4.2 Short-Term Effectiveness

Installation of an improved cover and gas extraction wells along the side-slopes would create some potential for human contact with waste and leachate.

Human health concerns associated with Groundwater P&T include contact with impacted groundwater during well installation, groundwater sampling, and system maintenance. If extraction wells are installed through the waste, as may be necessary, the process of drilling through the waste mass would also create additional hazards, including the potential explosion hazard resulting from the combination of landfill gas with sparks created by metal drilling equipment impacting waste material. These concerns would be addressed in the site-specific Health and Safety Plan, using Personal Protective Equipment and other precautions as necessary. Overall, Alternative 4 is expected to produce fewer short-term negative impacts than CMAs that include waste excavation.

Leachate seep occurrences (**Figure 2-6**) would be expected to become less common following installation of an improved cover on the Landfill side-slopes in the Northwest and West Areas. Landfill gas concentrations at the property boundary would be expected to decrease following installation of additional landfill gas extraction wells in the Northwest, West, and Southwest Areas, where LEL exceedances have been observed (**Figure 2-5**). It is estimated that cover system improvements and installation of landfill gas extraction wells could be completed as part of a first phase of remedial activities. This first phase could begin approximately one (1) year after approval of the ACM (**Figure 5-1**), after this phase of the project has been permitted and contracted, and could be completed in approximately three (3) years. Thus, improved compliance with the RAOs for non-stormwater discharges and landfill gas would be expected to occur within approximately four (4) years of ACM approval.

The timeframe for implementation of the Groundwater P&T system would be dependent on site investigations and pilot testing activities as well as the phasing of technologies. It is estimated that the first phase of Groundwater P&T, including site investigations and implementation and monitoring of a small-scale Groundwater P&T system in the Northwest Area, could also be initiated approximately one (1) year after approval of this ACM, and would last approximately three (3) years. The second phase, full-scale implementation, could then begin in the Northwest Area, five (5) years after approval of the ACM. It is anticipated that installation of the Groundwater P&T system would proceed from the Northwest Area to the West Area, and then to the Southwest and South Areas. At this point, the groundwater data for the Southeast Area collected during the pilot testing and implementation of the Groundwater P&T system in other

Areas could be reviewed to assess the need for extension of the system to this area, which would proceed as necessary. Extension and optimization of the full-scale Groundwater P&T system in each Area is expected to occur over a period of approximately one (1) year. The estimated timeframe for attainment of effective hydraulic control is approximately one (1) to five (5) years, depending on the time required for construction and mitigation efforts and the difficulty encountered in establishing an effective pumping regime. Thus, the times between approval of the ACM and achievement of the remedial objective for groundwater would be expected to be approximately eight (8) to twelve (12) years in the Northwest Area, and up to approximately sixteen (16) years for sitewide compliance.

5.4.3 Long-Term Effectiveness and Permanence

Installation of additional landfill gas extraction wells in the Northwest, West, and Southwest Areas would provide further control of landfill gas migration, beyond the control provided by the existing collection system, and would thus decrease the occurrence of landfill gas exceedances at the boundary. Improvements to the cover system in the Northwest and West Areas is expected to be an effective, long-term remedy for decreasing the occurrence of leachate seeps.

Groundwater P&T using activated carbon adsorption treatment is a proven technology for removal of cVOCs from groundwater. At the Landfill, Groundwater P&T would be expected to decrease the migration of groundwater impacts within the unconsolidated material and the bedrock, to a degree dependent on the degree of hydraulic control achieved. Installation of wells through the waste, if necessary, is not expected to impact the mobility of groundwater impacts, because the wells would not penetrate a liner or an impermeable cap, and the wells would be constructed to prevent preferential vertical flow along the well casings. The potential difficulty of achieving control of groundwater located in fractures in the bedrock creates some uncertainty in the overall effectiveness of a Groundwater P&T system at this site. To achieve hydraulic control, the Groundwater P&T system would need to be operated continuously until the source within the waste is depleted, likely many decades. Groundwater impacts in down-gradient groundwater would rebound if pumping were stopped before the source is depleted. Thus, the benefits of a Groundwater P&T system would not extend beyond the lifetime of the system.

5.4.4 Implementability of Alternative

Installation of an improved cover on the side-slopes would require some site disturbance along portions of the Landfill boundary, including disturbance of existing vegetation and infrastructure currently present at the Landfill. Trees currently present on the side-slopes in areas where the cover requires improvement would need to be cleared. Additionally, the piping of the Landfill Gas Collection system would need to be removed and then replaced at approximately two (2) ft higher elevation, above the new cover surface, and the gas extraction wells would need risers to remain above the new cover. Installation of additional gas extraction wells within the waste would require use of specialized, industry-standard procedures and precautions.

Implementation of a Groundwater P&T system would require construction of shallow and deep groundwater extraction wells, as well as a treatment system in a building on-site. Some extraction wells may require installation through the waste mass to the underlying groundwater, due to space limitations associated with the small distance between the limit of waste and the property boundary in areas. If well installation on the side-slopes is necessary, extensive clearing and construction of access roads in steep, tree-covered areas would be required. Installation of injection wells through the waste would also present challenges, but these could be mitigated through use of standard industry procedures for drilling in waste. Recovery and treatment equipment such as air compressors, groundwater extraction pumps, and activated carbon bed vessels are readily available. O&M requirements would likely include backwashing of the groundwater extraction pumps and replacement of the activated carbon. These O&M activities would likely need to be performed frequently, as a result of concentrations of iron, calcium, and magnesium that are two (2) to three (3) orders of magnitude higher than the concentrations of the groundwater impacts.

It is anticipated that an aggressive pumping system, with closely spaced extraction wells and/or high flow rates, would be necessary to optimize hydraulic control of groundwater within both the low-permeability unconsolidated material and the bedrock. Site investigations and pilot testing would be used to design such a system. Deep groundwater flow is likely controlled by the distribution of fractures within the bedrock; therefore, packer testing or similar may be necessary to characterize the distribution of groundwater impacts within the bedrock fractures, and to determine optimal depths and rates of pumping. Complete control of the impacted groundwater may be very difficult to achieve; however, sufficient control to meet MCLs in groundwater monitoring wells located near the point of compliance would likely be attainable. The Groundwater P&T program would need to be maintained until the source of groundwater impacts within the Landfill is depleted, likely many decades.

5.4.5 Protection of Human and Ecological Health

Short-term implications of this CMA for human health and the environment are discussed in Section 5.4.2.

In the long term, Additional Landfill Gas Collection and Cover System Improvements would be expected to decrease the occurrence of leachate seeps and enable further improvements in the performance of the gas collection and control system along the perimeter of the site, and would thus be protective of human health and the environment.

As described in Section 2.2, the risk evaluations conducted as part of the NES and NES Amendment No. 1 for the Landfill (EA 2010b and 2011a) indicated that use of groundwater as a tap water source is an incomplete exposure pathway for groundwater for the area surrounding the Landfill, and that there were no human health concerns associated with the potentially complete vapor intrusion pathway. The pathway for ecological contact with groundwater is also assumed to be incomplete. Thus, protectiveness of human and ecological health is already achieved with respect to groundwater.

5.4.6 Source Treatment and Reduction of Toxicity, Mobility, and Volume

This CMA would not decrease the source mass within the waste. Additional Landfill Gas Collection and Cover System Improvements in the Northwest and West Areas would decrease the mobility of landfill gas and leachate. Groundwater P&T could accelerate the removal of impacted groundwater from the aquifer, and also decrease the mobility of groundwater impacts within the aquifer, if sufficient hydraulic control was achieved. The use of a nontoxic chemical absorbent such as activated carbon would minimize the toxicity associated with the groundwater treatment system. Groundwater P&T would extract both organic and inorganic constituents present in groundwater. However, VOCs, which are the most widespread groundwater impacts at the site, would not be destroyed *in situ*, as they would by Enhanced Bioremediation, but instead would be transferred from the extracted groundwater to the activated carbon.

5.4.7 Cost of Alternative

The total estimated cost for implementation of Alternative 4 is approximately $74,000,000 (**Appendix F**) and includes the capital costs of additional Landfill Gas Collection and Cover System Improvements, and the capital costs and O&M associated with the Groundwater P&T system. The capital cost of installing fifteen (15) additional landfill gas extraction wells is approximately $250,000. The capital cost of Cover System Improvements is approximately $1,300,000. The capital costs of Groundwater P&T (approximately $4,800,000) include well installation, construction of a treatment system, site investigations, and pilot testing. O&M costs for Groundwater P&T (approximately $3,300,000 per year) include sampling of treated water and reporting to WSSC, discharge of treated water to the sewer (WSSC), system maintenance, and electricity.

5.4.8 Regulatory Acceptance of Alternative

Landfill Gas Collection and Cover System Improvements are common tools for limiting the mobility of impacts from landfills and are likely to be accepted by MDE.

Groundwater P&T has historically been a common remedy for sites with groundwater impacts, although it is no longer widely considered to be more effective than *in situ* remediation technologies, especially for sites like the Landfill where impacted groundwater is present in bedrock. If determined to be the most implementable and effective Corrective Measure Technology for groundwater impacts, Groundwater P&T would be expected to achieve MDE acceptance.

5.4.9 Community or Stakeholder Acceptance of Alternative

Community opinion is expected to favor the much smaller extent and shorter duration of substantial disturbance of the Landfill property under this CMA, relative to CMAs that include waste excavation.

Additional Landfill Gas Collection and Cover System Improvements are expected to be favored by the community, as they would provide additional protectiveness against landfill gas and leachate in the portions of the landfill adjacent to the community, with minimal impacts beyond a period of construction along the side-slope.

The primary community and stakeholder concerns related to installation of a Groundwater P&T system would likely be related to the construction and long-term operation of the necessary infrastructure, and its impacts on aesthetics as well as noise levels at the Landfill.

This CMA is compatible with the community’s recreational reuse preferences for the Landfill, as the Landfill would not experience long-term disturbance. Short-term limitations on access would be necessary during construction activities.

5.5 ALTERNATIVE 5: ADDITIONAL LANDFILL GAS COLLECTION AND COVER SYSTEM IMPROVEMENTS WITH ENHANCED BIOREMEDIATION

Alternative 5 combines Enhanced Bioremediation in all potential remediation areas with Cover System Improvements in the Northwest and West Areas, and installation of additional landfill gas extraction wells in the Northwest, West, and Southwest Areas. An improved soil cover system would be installed on the existing side-slopes of the Northwest and West Areas of the Landfill primarily to decrease the occurrence of leachate seeps, with some potential to help attenuate landfill gas. After the improved cover system is in place, approximately fifteen (15) additional landfill gas extraction wells would be installed to provide further control over gas migration along the property boundary. Injection wells for Enhanced Bioremediation would be installed through the existing waste, due to the lack of space between the waste mass and the property boundary point of compliance, and to allow room for degradation to occur up-gradient of the property boundary. Alternative 5 is similar to Alternative 4, but with Enhanced Bioremediation rather than Groundwater P&T for groundwater treatment.

Due to the size of the Enhanced Bioremediation system to be implemented under Alternative 5 site investigations and pilot testing would be conducted to determine the optimal parameters for the full-scale system. The pilot test would be conducted using approximately five (5) to ten (10) injection wells. The results of the investigations and the pilot testing would be used to determine design parameters for the bioremediation systems, such as injection well spacing, amendment components and concentrations, frequency and volume of injections, and whether injection of a bioaugmentation culture is necessary to promote complete degradation and prevent accumulation of DCE and/or VC in the groundwater.

The site investigations and pilot study would likely be conducted in the Northwest Area, and assuming positive results, would be followed by installation of injection wells in all five (5) Areas, targeting the areas of highest concentrations of groundwater impacts. After the Northwest Area, Enhanced Bioremediation systems would likely be installed in the Southwest and South Areas, to enhance the bioremediation of the relatively high-concentration groundwater impacts reported in these Areas. In the West and Southeast Areas, where the lowest concentrations of groundwater impacts occur, groundwater would be monitored during implementation of Enhanced Bioremediation in the other areas. The need for Enhanced Bioremediation in these areas would then be reevaluated prior to implementation.

5.5.1 Compliance With Applicable or Relevant and Appropriate Requirements and Remedial Action Objectives

Installation of an improved cover along the side-slopes in the Northwest and West Areas, and installation of additional landfill gas extraction wells in these areas as well as the Southwest Area, would decrease leachate seep occurrences and help control landfill gas migration, and thus increase compliance with RAOs for landfill gas and leachate in these areas. If designed and implemented effectively, Enhanced Bioremediation would decrease groundwater impacts to below MCLs, and thus meet the RAO for groundwater.

5.5.2 Short-Term Effectiveness

Installation of an improved cover and gas extraction wells along the side-slopes would create some potential for human contact with waste and leachate. Human health concerns associated with Enhanced Bioremediation include contact with impacted groundwater during well installation and groundwater sampling. The process of drilling through the waste mass in this CMA would also create additional hazards, including the potential explosion hazard resulting from the combination of landfill gas with sparks created by metal drilling equipment impacting waste material. These concerns would be addressed in the site-specific Health and Safety Plan, using Personal Protective Equipment and other precautions as necessary. Overall, Alternative 5 is expected to produce fewer short-term negative impacts than CMAs that include waste excavation.

Leachate seep occurrences (**Figure 2-6**) would be expected to become less common following installation of an improved cover on the Landfill side-slopes in the Northwest and West Areas. Landfill gas concentrations at the property boundary would be expected to decrease following installation of additional landfill gas extraction wells in the Northwest, West, and Southwest Areas, where LEL exceedances have been observed (**Figure 2-5**). It is estimated that that cover system improvements and installation of landfill gas extraction wells could be completed as part of a first phase of remedial activities. This first phase could begin approximately one (1) year after approval of the ACM (**Figure 5-1**), after this phase of the project has been permitted and contracted, and could be completed in approximately (3) years. Thus, improved compliance with the RAOs for non-stormwater discharges and landfill gas would be expected to occur within approximately four (4) years of ACM approval.

The timeframe for implementation of the Enhanced Bioremediation systems would be dependent on site investigations and pilot testing activities as well as the phasing of technologies. It is estimated that the first phase of Enhanced Bioremediation, including site investigations and implementation and monitoring of a small-scale Enhanced Bioremediation system in the Northwest Area, could also be initiated approximately one (1) year after approval of this ACM, and would last approximately three (3) years. The second phase, full-scale implementation, could then begin in the Northwest Area, five (5) years after approval of the ACM. It is anticipated that installation of the Enhanced Bioremediation system would be phased to first target the Northwest, Southwest, and South Areas, which have the highest concentrations of groundwater impacts. Groundwater data for the West and Southeast Areas would then be reviewed to assess the need for implementation of systems in these areas, and installation of injection wells would proceed as necessary. Installation and optimization of the full-scale bioremediation system in each Area is expected to occur over a period of approximately two (2) years. The estimated timeframe for groundwater impacts to decrease after the first amendment injection is approximately six (6) to eighteen (18) months. Thus, the times between approval of the ACM and achievement of the remedial objective for groundwater would be expected to be approximately nine (9) years in the Northwest Area, and then ten (10) years in the South and Southwest Areas. Assuming that the Enhanced Bioremediation systems in the West and Southeast Areas are installed, the RAO for groundwater would be expected to be met in these areas in approximately eleven (11) years (or less if natural processes accelerate attenuation of the naturally low impacts in these Areas).

5.5.3 Long-Term Effectiveness and Permanence

Installation of additional landfill gas extraction wells in the Northwest, West, and Southwest Areas would provide further control of landfill gas migration, beyond the control provided by the existing collection system, and would thus decrease the occurrence of landfill gas exceedances at the boundary. Improvements to the cover system in the Northwest and West Areas is expected to be an effective, long-term remedy for decreasing the occurrence of leachate seeps.

Enhanced Bioremediation systems in all five (5) Remediation Areas, designed based on the results of site investigations and pilot testing, with appropriate enhancements thoroughly mixed into the groundwater aquifer, are expected to be highly effective for maintaining lower concentrations of groundwater impacts both within the unconsolidated material and the bedrock. Installation of wells through the waste is not expected to impact the mobility of groundwater impacts, because the wells would not penetrate a liner or an impermeable cap, and the wells would be constructed to prevent preferential vertical flow along the well casings. If the site investigations or pilot testing reveals a deficit of bacteria that degrade DCE and VC to ethene, then a single inoculation with a bioaugmentation culture of *Dehalococcoides* or similar may improve the long-term effectiveness of the systems. The volume of the aquifer in which lower concentrations are achieved would be constrained primarily by the location and depth of the wells used for injection. Regular injections would be necessary to maintain the lower concentrations achieved by Enhanced Bioremediation. The duration over which subsequent injections of bioremediation amendments would need to occur would be dictated by the attenuation of the mass of source material within the waste mass, as well as the amount of naturally occurring oxidant demand within the treatment zone. If injections were stopped prior to depletion of the source material within the waste mass, a rebound in groundwater impacts might occur once the amendments were exhausted. However, the effects of the amendments on groundwater chemistry and the resulting increase in degradation rates would be expected to persist for some period (months to years, to be better defined by pilot testing) after the last injection.

5.5.4 Implementability of Alternative

Installation of an improved cover on the side-slopes would require some site disturbance along portions of the Landfill boundary, including disturbance of existing vegetation and infrastructure currently present at the Landfill. Trees currently present on the side-slopes in areas where the cover requires improvement would need to be cleared. Additionally, the piping of the Landfill Gas Collection system would need to be removed and then replaced at approximately two (2) ft higher elevation, above the new cover surface, and the gas extraction wells would need risers to remain above the new cover. Installation of additional gas extraction wells within the waste would require use of specialized, industry-standard procedures and precautions.

Injection wells for Enhanced Bioremediation would be installed through the waste mass to the underlying groundwater in all five (5) Areas, to allow space between the system and the property boundary for enhanced degradation of groundwater impacts to occur before the groundwater flows off the property. Installation of injection wells on the side-slopes in some areas is likely to be required, and would require extensive clearing and construction of access roads in steep, tree-covered areas, particularly in the Southwest, South, and Southeast. Installation of injection wells through the waste would also present challenges, but these could be mitigated through use of standard industry procedures for drilling in waste. The only option for installing wells outside the waste mass for this CMA, which does not include Selective Waste Excavation, would be to install wells in the narrow (in places less than twenty [20]-ft-wide) space between the waste mass and the property boundary. Placing the injection wells farther from the property boundary would increase the time to meet the groundwater RAO at the property boundary, but would also allow the wells to be more widely spaced, as the amendment would have more time and space, up-gradient of the point of compliance, to spread through the aquifer. Therefore, the position of the injection wells would be selected to balance these two (2) considerations.

Proposed injection well numbers and spacing and amendment composition would be determined through site investigations and pilot testing. Challenges to developing effective systems for injection of bioremediation amendments at the Landfill are primarily related to the challenge of achieving effective distribution of amendments through both the unconsolidated material (which is clayey-silty) and the bedrock, which has unknown fracture density and pattern. These challenges would be addressed through site investigations and pilot testing, which would include evaluations of the coverage and persistence of the amendments within the aquifer, packer testing to determine the depths of impacted fractures within the bedrock, and possibly tracer tests to assess transport of injected materials. Achieving effective injection into both unconsolidated material and bedrock could require specialized well construction techniques and injection methods; however, implementation of an effective program for Enhanced Bioremediation is expected to be feasible.

5.5.5 Protection of Human and Ecological Health

Short-term implications of this CMA for human health and the environment are discussed in Section 5.3.2.

In the long term, Additional Landfill Gas Collection and Cover System Improvements would be expected to decrease the occurrence of leachate seeps and enable further improvements in the performance of the gas collection and control system along the perimeter of the site, and would thus be protective of human health and the environment.

As described in Section 2.2, the risk evaluations conducted as part of the NES and NES Amendment No. 1 for the Landfill (EA 2010b and 2011a) indicated that use of groundwater as a tap water source is an incomplete exposure pathway for groundwater for the area surrounding the Landfill, and that there were no human health concerns associated with the potentially complete vapor intrusion pathway. The pathway for ecological contact with groundwater is also assumed to be incomplete. Thus, protectiveness of human and ecological health is already achieved with respect to groundwater.

5.5.6 Source Treatment and Reduction of Toxicity, Mobility, and Volume

This CMA would not decrease the source mass within the waste. Additional Landfill Gas Collection and Cover System Improvements in the Northwest and West Areas would decrease the mobility of landfill gas and leachate. Enhanced Bioremediation would be expected to achieve significant reductions in the volume and concentrations of groundwater impacts. Enhanced Bioremediation destroys groundwater impacts *in situ*, offering a significant advantage in terms of reducing the toxicity and volume of the impacts. The associated reductions in the volume of groundwater impacts could be quantified using the groundwater monitoring data that would be collected as part of the Enhanced Bioremediation programs.

5.5.7 Cost of Alternative

The total estimated cost for implementation of Alternative 5 is approximately $57,000,000 (**Appendix F**) and includes the capital costs of Additional Landfill Gas Collection and Cover System Improvements and the capital costs and O&M associated with Enhanced Bioremediation site investigations, pilot testing, and full-scale implementation. The capital cost of installing fifteen (15) additional landfill gas extraction wells is approximately $250,000. The capital cost of Cover System Improvements is approximately $1,300,000. The capital costs of Enhanced Bioremediation (approximately $6,500,000) include well installation through the waste mass, well geophysics and packer testing as part of the site investigations, and an amendment delivery system. O&M costs for Enhanced Bioremediation (approximately $2,400,000 per year) include well maintenance and annual injection events.

5.5.8 Regulatory Acceptance of Alternative

Landfill Gas Collection and Cover System Improvements are common tools for limiting the mobility of impacts from landfills and are likely to be accepted by MDE.

It is expected that Enhanced Bioremediation would also be an acceptable remedy, given careful design of a system, supported by site investigations and pilot testing. As described in Section 4.3.3, MDE recently approved Enhanced Bioremediation as a remedy for treatment of a cVOC plume at a sanitary landfill in Baltimore County (EA 2012). MDE has also indicated that they would consider and evaluate the possibility of drilling through the waste mass to install the required injection wells (Section 1.4.1).

5.5.9 Community or Stakeholder Acceptance of Alternative

Community opinion is expected to favor the much smaller extent and shorter duration of substantial disturbance of the Landfill property under this CMA, relative to CMAs that include waste excavation.

Additional Landfill Gas Collection and Cover System Improvements are expected to be favored by the community, as they would provide additional protectiveness against landfill gas and leachate in the portions of the landfill adjacent to the community, with minimal impacts beyond a period of construction along the side-slope.

The community is not expected to have significant concerns regarding Enhanced Bioremediation, as it would cause minimal site disturbance while addressing groundwater impacts.

This CMA is compatible with the community's recreational reuse preferences for the Landfill, as the Landfill would not experience long-term disturbance. Short-term limitations on access would be necessary during construction activities.

6. COMPARATIVE ANALYSIS OF ALTERNATIVES FROM CORRECTIVE MEASURE SCREENING

This section presents a comparison of the five (5) CMAs, using the criteria evaluated in Section 5. The comparison of CMAs is intended to identify the advantages and disadvantages of the alternatives relative to one another, based upon the nine (9) criteria, so that the key decision-making trade-offs can be identified.

The CMAs are compared in the sections below, and a numerical comparison is presented in **Table 6-1**. For each CMA and evaluation criterion, rankings are assigned with "5" being the most favorable and "1" being least favorable.

6.1 COMPLIANCE WITH APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS AND REMEDIAL ACTION OBJECTIVES

Groundwater

Alternatives 1, 2, and 5, which incorporate Enhanced Bioremediation for groundwater remediation, have similar potential to achieve compliance with the RAO for groundwater. Alternative 3 would have similar compliance, although the time to meet RAOs would likely be longer (see discussion of short-term effectiveness in Section 6.2). Compliance under Alternative 4 is rated slightly lower, due to the difficulty of achieving hydraulic control sufficient to achieve the RAO using Groundwater P&T.

Landfill Gas

Alternatives 1 and 2 would address the LEL exceedances for landfill gas in the Northwest and West Areas through Selective Waste Excavation, which would remove some of the source of landfill gas while creating a buffer between the limit of waste and the property boundary point of compliance. Alternative 3 would address LEL exceedances by removing the waste mass that is the source of the landfill gas. Alternatives 4 and 5 would include installation of additional landfill gas extraction wells, which provides direct control over landfill gas migration, while Alternatives 1 and 2 would provide the existing level of gas extraction, with the addition of a buffer between the waste and the property boundary. Alternatives 1 and 2 are therefore expected to provide somewhat better control over landfill gas at the property boundary than Alternative 4 and 5. Alternative 3 would be the most likely to achieve full compliance with the RAO for landfill gas, as it includes removing the source of the gas.

Non-Stormwater Discharges

Alternatives 1, 2, 4, and 5 would address leachate seeps in the Northwest and West Areas through Cover System Improvements of the side-slopes in these Areas. Alternative 3 would eliminate leachate seeps by removing the waste mass. Thus, Alternative 3 is the most likely to achieve full compliance with the RAO for non-stormwater discharges, and the other alternatives are somewhat less likely to achieve full compliance.

6.2 SHORT-TERM EFFECTIVENESS

Alternatives 1-3, which include Waste Excavation, would be associated with short-term human health and safety concerns resulting from contact with exposed waste and with higher levels of landfill gas. These alternatives could also create fugitive emissions of dust, odor, and noise, which would need to be managed through compliance measures to be developed in an operations plan. The potential for these short-term impacts would be greatest under Alternative 3, which includes Extensive Waste Excavation and somewhat less under Alternatives 1 and 2, which include only Selective Waste Excavation.

Installation of landfill gas extraction wells under Alternatives 4 and 5 is expected to present minimal human health concerns. Of the groundwater treatment technologies, installation of the Groundwater P&T system as part of Alternative 4 would create more site disturbance, and thus more potential human health concerns associated with contact with waste or contaminated media, than the installation of Enhanced Bioremediation systems in Alternatives 1, 2, and 5. Implementation of MNA in Alternative 3 would produce the fewest short-term impacts to human health, associated primarily with potential contact with contaminated groundwater during sampling of monitoring wells. Therefore, as described above, the short-term human health concerns under Alternatives 1-3 would be driven by the Waste Excavation activities rather than by the groundwater treatment. The potential short-term hazards associated with the selected CMA would be addressed in a site-specific Health and Safety Plan.

The timeframe for addressing landfill gas exceedances and leachate seeps would be shorter for Alternatives 4 and 5 than for Alternatives 1–3. Under Alternatives 1 and 2, this timeframe would be coincident with the timeframe for Selective Waste Excavation and Cover System Improvements in the Northwest and West Areas, and would thus be similar. The timeframe for Extensive Waste Excavation as part of Alternative 3 to address landfill gas exceedances and leachate seeps would also be similar if the west/northwest boundary of the Landfill were excavated first. Under Alternatives 4 and 5, the timeframe for addressing landfill gas and leachate seeps depends on the time required to implement improvements to the cover system and gas extraction well installation, which is expected to be shorter than the timeframe for waste excavation.

Groundwater impacts would be addressed in the same timeframe, through Enhanced Bioremediation, in Alternatives 1, 2, and 5. The time to address groundwater impacts under Alternative 4 would likely be longer, due to the longer expected time to achieve hydraulic control compared to the time required for degradation of groundwater impacts by Enhanced Bioremediation. Alternative 3 would require the longest time to address groundwater impacts, due to the prolonged timeframe for complete source removal and the relatively slow rate of attenuation under MNA.

Overall, taking into consideration both short-term human health concerns and the timeframe to meet RAOs, the short-term effectiveness is highest for Alternatives 4 and 5, similar and slightly lower for Alternatives 1 and 2, and lowest for Alternative 3.

6.3 LONG-TERM EFFECTIVENESS AND PERMANENCE

Alternatives 1 and 2 would permanently address landfill gas exceedances and leachate seeps, through removal of waste, regrading, Cover System Improvements, and creation of a buffer between the limit of waste and the property boundary in the Northwest and West Areas. Alternatives 4 and 5 would also address landfill gas and leachate in the long-term, as long as the improved cover system and landfill gas extraction wells are maintained. Alternative 3 is expected to be the most effective in the long term, due to complete removal of the source of landfill gas and leachate.

Groundwater P&T (included in Alternative 4) is the least permanent Corrective Measure Technology for addressing groundwater impacts, as its effectiveness dissipates almost immediately when groundwater extraction stops. Its effectiveness is also uncertain, given the difficulties of achieving hydraulic control over groundwater in bedrock. MNA (included in Alternative 3) is the most permanent, due to its reliance on natural processes which will continue without intervention. MNA would achieve the groundwater RAO in the long-term, particularly when combined with complete source removal. Enhanced Bioremediation builds upon the permanence and effectiveness of MNA, by increasing the rate of the natural attenuation processes already occurring. Maintaining the accelerated degradation rates requires periodic injections of amendments to provide long-term effectiveness, but the persistence of the amendments in the subsurface can provide some continued enhancement of degradation rates after injections are stopped. Because Enhanced Bioremediation and MNA with source removal offer similar long-term effectiveness and permanence for treating groundwater VOC impacts, Alternatives 1, 2, 3, and 5 were determined to have the highest long-term effectiveness and permanence. While Alternative 3 would remove the source of groundwater impacts, it may not offer substantially greater permanence or long-term effectiveness, if the source of groundwater impacts within the waste mass undergoes substantial natural degradation over the 30 (thirty) year timeframe that would be required for Extensive Waste Excavation. Alternative 4 is expected to have the lowest long-term effectiveness and permanence for groundwater treatment.

6.4 IMPLEMENTABILITY OF ALTERNATIVE

The implementability associated with Selective Waste Excavation would be similar for Alternatives 1 and 2, which would require removal and reconstruction of portions of the landfill gas extraction and stormwater systems, clearing of trees, dewatering of the waste during excavation, and extensive operations and contingency measures to mitigate potential problems resulting from the waste excavation. Under Alternative 3, Extensive Waste Excavation would require similar activities and contingency measures, but on a larger scale and over a longer timeframe. Alternatives 4 and 5 would be more implementable, due to the lack of Waste Excavation activities, but it would likely also require tree removal and reconfiguration of portions of the landfill gas extraction system and tree removal, in preparation for Cover System Improvements.

The requirements for design, construction, and O&M of a Groundwater P&T system (included in Alternative 4) make it the least implementable Corrective Measure Technology for groundwater treatment. A large-scale Enhanced Bioremediation system, as included in Alternatives 1, 2, and 5, would also require site investigations and pilot testing for development of an effective design and would require periodic injections of amendments; however, overall, its less complex construction and O&M requirements make it more implementable. All alternatives except for Alternative 3 would likely involve challenges associated with the installation of wells for groundwater remediation through the waste mass and into groundwater; however, this is expected to be implementable using standard industry practices and precautions, and the challenges are expected to be much less significant than those associated with Waste Excavation. MNA is the most implementable of the groundwater Corrective Measure Technologies, as its primary requirements include groundwater monitoring and data analysis.

Based on these considerations, Alternative 5 is the most implementable, followed by Alternative 4, then Alternatives 1 and 2, and Alternative 3 is the least implementable CMA.

6.5 PROTECTION OF HUMAN AND ECOLOGICAL HEALTH

The short-term implications of the CMAs for human health and the environment are discussed in Section 6.2.

The protectiveness of human and ecological health is already achieved with respect to groundwater; therefore, protection from impacted groundwater is assumed to be high under all five (5) CMAs.

With regards to landfill gas and leachate seeps, Alternatives 1 and 2 provide long-term protection associated with Selective Waste Excavation and Cover System Improvements; however, these technologies would also create relatively more short-term health concerns. Alternative 3 would provide somewhat better protection in the long term, through Extensive Waste Excavation that would remove the sources of both landfill gas and leachate; however, it would create the most short-term health concerns. Alternatives 4 and 5 would provide protection from leachate seeps, through Cover System Improvements, and would also control landfill gas migration through Landfill Gas Collection, with fewer short-term health concerns.

Overall, Alternatives 4 and 5 are expected to be the most protective of human and ecological health, followed by Alternative 3, and then Alternatives 1 and 2.

6.6 SOURCE TREATMENT AND REDUCTION OF TOXICITY, MOBILITY, AND VOLUME

Under Alternative 3, the waste mass, which is the source of groundwater impacts, leachate, and landfill gas, would be removed; therefore, this CMA provides the greatest reduction in the toxicity, mobility, and volume of potential impacts. Alternatives 1 and 2 would achieve source removal through Selective Waste Excavation. Alternatives 4 and 5 would not decrease the source mass. Cover System Improvements under Alternatives 1, 2, 4, and 5 would decrease the mobility of leachate. Selective Waste Excavation under Alternatives 1 and 2 would decrease the mobility of landfill gas across the property boundary, whereas Landfill Gas Collection under Alternative 4 and 5 would control mobility through additional extraction of landfill gas.

Enhanced Bioremediation and Groundwater P&T would both be expected to accelerate the decrease in the volume and concentrations of groundwater impacts within the aquifer, and thus decrease the toxicity and mobility of groundwater impacts. MNA has similar effects, but typically decreases toxicity and mobility more slowly than the other Corrective Measure Technologies for groundwater treatment. However, Enhanced Bioremediation and MNA both offer a significant advantage in that they destroy groundwater impacts *in situ*, rather than pumping them to the surface and then transferring them to a treatment medium.

Overall, Alternative 3 would achieve the greatest source treatment and reduction and toxicity and mobility, followed by Alternatives 1, 2, 4, and 5.

6.7 COST OF ALTERNATIVE

The costs of Alternatives 1–3 are driven by Waste Excavation. The cost of Alternatives 4 and 5, which do not include Waste Excavation, are the lowest. The capital costs of Groundwater P&T and Enhanced Bioremediation are similar, but the anticipated O&M costs for Groundwater P&T (Alternative 4) are higher, driven primarily by the cost of discharging treated water to WSSC. The approximate estimated costs of the CMAs are summarized below:

Costs	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**
Capital	$105,000,000	$52,000,000	$455,000,000	$8,000,000	$9,000,000
Annual O&M	$2,400,000	$2,400,000	$48,000	$3,300,000	$2,400,000
Total with 20 years O&M	**$152,000,000**	**$100,000,000**	**$456,000,000**	**$74,000,000**	**$57,000,000**

6.8 REGULATORY ACCEPTANCE OF ALTERNATIVE

All five (5) CMAs rely on Corrective Measure Technologies that are commonly used and are therefore expected to be acceptable to MDE. MDE acceptance of Alternatives 3 would depend on acceptance of a Monitoring and Contingency Plan developed in conjunction with MNA. MDE has indicated that they would consider and evaluate the possibility of drilling through the waste mass to groundwater to install injection wells in Alternatives 1, 2, and 5 (Section 1.4.1).

6.9 COMMUNITY OR STAKEHOLDER ACCEPTANCE OF ALTERNATIVE

Some concerns from the community are expected to arise from the proposal to perform Waste Excavation at the Landfill, due to the potential for dust, odors, noise, etc. during the excavation.

These concerns would need to be addressed prior to community acceptance of a Waste Excavation program as part of Alternatives 1–3. The extended timeframe for Extensive Waste Excavation under Alternative 3 would likely produce additional concerns, relative to Alternatives 1 and 2. Community opinion is expected to favor the much smaller extent and shorter duration of substantial disturbance of the Landfill property under Alternatives 4 and 5, which do not include waste excavation. Community opinion may also favor Enhanced Bioremediation over Groundwater P&T, which would require more construction activity at the Landfill. Although the community may have some concerns associated with initial use of MNA rather than a more active treatment technology in areas with MCL exceedances under Alternative 3, the implementation of an MDE-approved monitoring and contingency plan should ease community concerns.

All five (5) CMAs are compatible with the community's recreational reuse preferences for the Landfill. The property would be unavailable for recreational use longest under Alternative 3, and Alternatives 4 and 5 would cause the shortest disturbance to potential reuse of the property.

Overall, Alternative 5 expected to be the most acceptable to the community, followed by Alternative 4, Alternatives 1 and 2, and Alternative 3.

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7. RECOMMENDED CORRECTIVE MEASURE ALTERNATIVE

Based on the evaluation of the CMAs according to the nine (9) criteria (Sections 5 and 6 and **Table 6-1**), the recommended CMA is Alternative 5, Additional Landfill Gas Collection and Cover System Improvements with Enhanced Bioremediation. This CMA is expected to provide the best combination of compliance with RAOs, short-term effectiveness, long-term effectiveness, implementability, and protectiveness, and is therefore expected to be most acceptable to regulators and the community. Additional landfill gas extraction wells included in this CMA would provide additional control over gas migration and achieve compliance with the RAO for landfill gas. Cover System Improvements would decrease the occurrence of leachate seeps and comply with the RAO for non-stormwater discharge. Enhanced Bioremediation of groundwater is a proven *in situ* remediation strategy, and is likely to achieve compliance with the RAO for groundwater by enhancing the natural attenuation that is currently occurring at the site (**Appendix E**). Alternative 5 is therefore recommended based on its overall effectiveness and implementability for addressing all three (3) media of concern (groundwater, landfill gas, and non-stormwater discharge/leachate seeps).

A work plan for implementation of Alternative 5 is included in **Appendix G**. This plan includes details of how the site investigations and pilot study for Enhanced Bioremediation would be implemented, descriptions of how an improved cover and landfill gas extraction wells would be installed, and an anticipated schedule including implementation of these components. Before remedial activities begin, seven (7) new groundwater monitoring wells would be installed along the property boundary (as revised following the exchange of land with M-NCPPC), to fill in gaps along areas of the property boundary and enable better monitoring of COC concentrations during the remediation. Also included in the work plan are contingency corrective measure technologies to be considered in the event that it is determined that the recommended technologies are not meeting RAOs in an acceptable timeframe (**Appendix G**).

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8. SUMMARY AND CONCLUSIONS

Three (3) media of concern, and associated RAOs, have been identified at the Landfill: groundwater, landfill gas, and non-stormwater discharges (e.g., leachate seeps). The RAOs for the Landfill are long-term remediation goals for the site that were established by MDE based on applicable ARARs, and include no exceedances of MCLs in groundwater at the property boundary, no LEL exceedances for landfill gas (including methane) at the property boundary, and no non-stormwater discharges to the waters of the state. During monitoring activities between 2007 and 2012, exceedances and occurrences related to the media of concern and RAOs were reported:

- MCL exceedances were consistently reported in groundwater at the property boundary in the northwestern, western, southwestern, southern, and southeastern portions of the Landfill.

- LEL exceedances for methane gas were reported at the property boundary in the western portion of the Landfill.

- Leachate seeps were identified and repaired along the northern and western slopes of the Landfill (**Figures 2-5, 2-6 and 2-7**).

Approximate Remediation Areas where corrective measures may be implemented at the Landfill (**Figure 4-1**) were identified based on the areas where these exceedances and occurrences have been observed.

Through screening of Remedial Technologies for their implementability, cost, and effectiveness for achieving the RAOs at the Landfill, seven (7) Corrective Measure Technologies were retained. Corrective Measure Technologies for addressing each medium of concern were identified: MNA, Enhanced Bioremediation, and Groundwater P&T for groundwater (**Figure 4-2**); Selective or Extensive Waste Excavation, Landfill Gas Collection, and Cover System Improvements, for landfill gas (**Figure 4-3**); and Selective or Extensive Waste Excavation, and Cover System Improvements for non-stormwater discharges (**Figure 4-4**). These Corrective Measure Technologies were combined into five (5) CMAs, each addressing all three (3) media of concern (**Figure 4-5**), for detailed evaluation. Note that Partial Capping was also retained, as a potential contingency measure for addressing landfill gas exceedances and leachate seeps.

The identified CMAs were evaluated and compared based on their adherence to nine (9) criteria, pursuant to EPA guidance. Based on the results of the evaluation, Alternative 5, Additional Landfill Gas Collection and Cover System Improvements with Enhanced Bioremediation, was selected as the recommended CMA, based on its overall effectiveness and implementability for addressing all three (3) media of concern (groundwater, landfill gas, and non-stormwater discharge/leachate seeps). A work plan for Alternative 5 is included in **Appendix G**, and provides descriptions, schedules, and contingency measures for the recommended technologies.

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FIGURES

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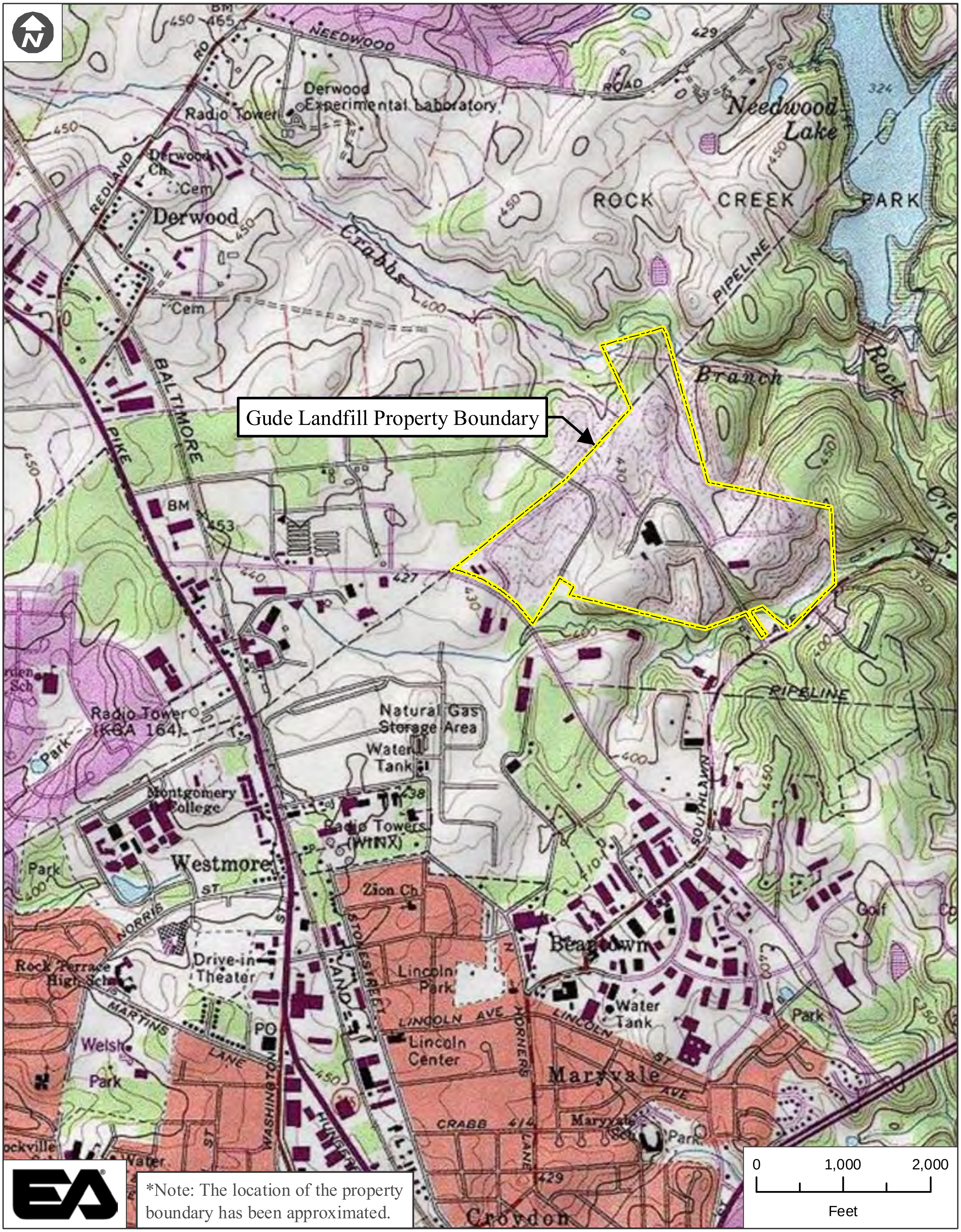

Gude Landfill
Montgomery County, Maryland

Figure 1-1. Site Location Map

Sources:
- EDR, 2009

H:\projects\6219608_out\MXD\Figure1

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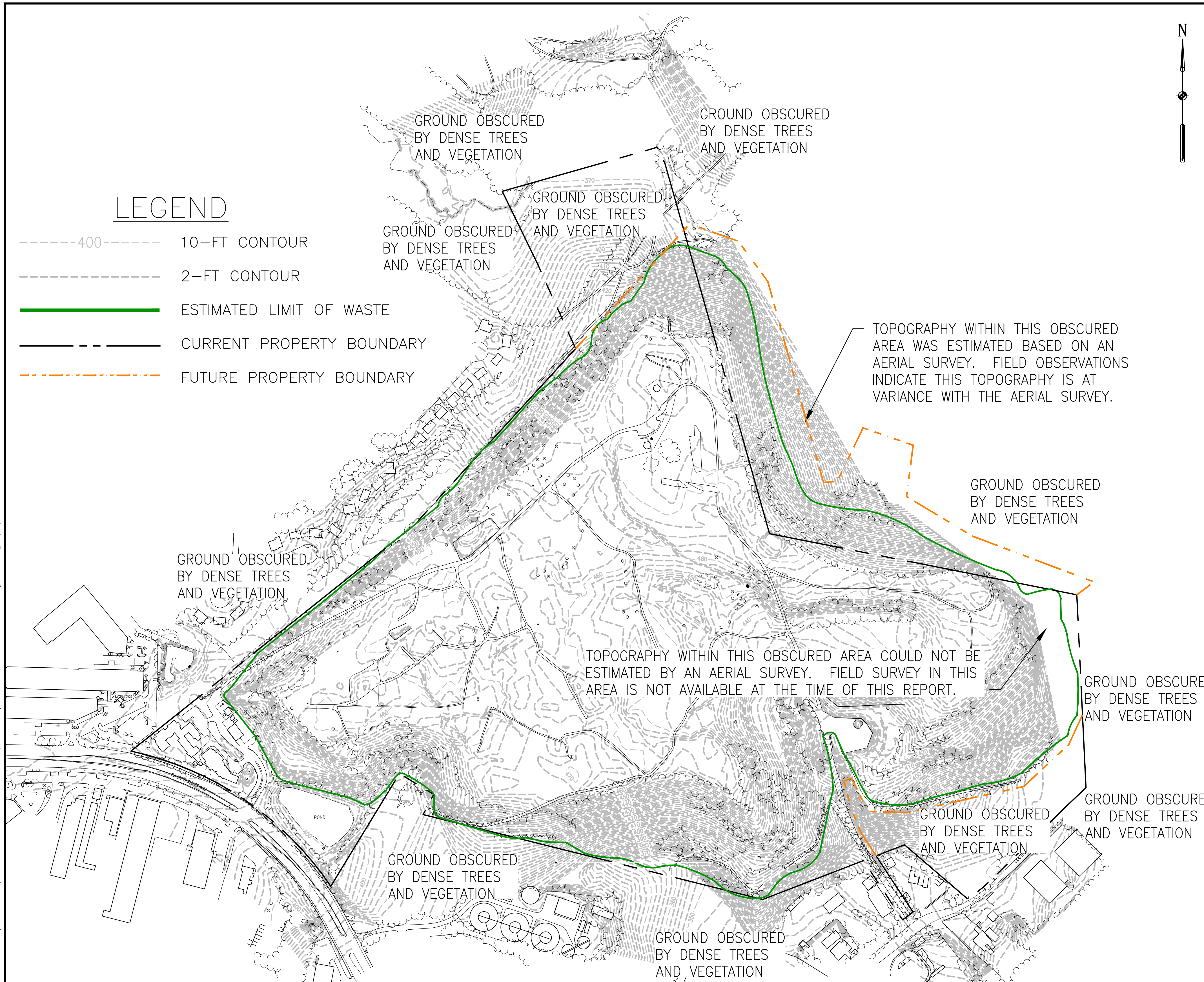

NOTES:

1. TOPOGRAPHY COMPILED BY APPLIED MAPPING SOLUTIONS, INC. USING PHOTOGRAMMETRIC METHODS WITH PHOTOGRAPHY DATED 06/24/09 AND SUPPLEMENTED WITH FIELD SURVEY PERFORMED BY C.C. JOHNSON & MALHOTRA, P.C., OCTOBER 2009.

2. HORIZONTAL DATUM IS NORTH AMERICAN DATUM OF 1983/91 (NAD-83/91). COORDINATE SYSTEM IS MARYLAND STATE PLANE, U.S. SURVEY FEET. VERTICAL DATUM IS NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD-88) WITH ELEVATIONS SHOWN IN FEET.

3. THE PROPERTY BOUNDARY WAS LAID OUT AND THE PLAT THEREOF PREPARED BY A REGISTERED PROPERTY LINE SURVEYOR OF THE STATE OF MARYLAND, IN COMPLIANCE WITH SECTION 3-108 OF THE REAL PROPERTY ARTICLE OF THE ANNOTATED CODE OF MARYLAND, EDITION 2005.

4. THE PROPERTY BOUNDARY REPRESENTS THE LANDS OWNED BY MONTGOMERY COUNTY, MARYLAND KNOWN AS THE GUDE LANDFILL WHICH IS A COMPILATION OF THREE DEEDS, LISTED BELOW, RECORDED IN THE LAND RECORDS OF MONTGOMERY COUNTY, MARYLAND, WITHOUT BENEFIT OF FULL TITLE COMMITMENT.
   LIBER 2975 FOLIO 213
   LIBER 4501 FOLIO 453
   LIBER 5174 FOLIO 309

5. THE HORIZONTAL LIMIT OF WASTE DEPICTED IS ESTIMATED BASED UPON TEST PIT FINDINGS AND SITE TOPOGRAPHY. IN AREAS WHERE A DEFINITIVE LIMIT OF WASTE WAS NOT ESTABLISHED BY EA ENGINEERING, THE LIMIT OF WASTE WAS ESTIMATED BASED UPON COUNTY STAFF KNOWLEDGE.

6. MONTGOMERY COUNTY IS CURRENTLY IN NEGOTIATIONS WITH M-NCPPC TO EXCHANGE TWO PARCELS OF LAND (LOCATED TO THE NORTH AND SOUTHEAST OF THE GUDE LANDFILL) FOR PROPERTY TO THE NORTHEAST. THE FUTURE PROPERTY BOUNDARY LINE REPRESENTS THE AGREED UPON PROPERTY BOUNDARY FOR THE GUDE LANDFILL FOLLOWING THE PROPERTY EXCHANGE. THE FUTURE PROPERTY BOUNDARY WAS ESTABLISHED WITH PERMANENT PROPERTY BOUNDARY MARKERS AND SURVEYED BY C.C. JOHNSON AND MALHOTRA, P.C. IN MAY 2012.

500 250 0 500
GRAPHIC SCALE IN FEET

FIGURE 1-2
SITE TOPOGRAPHY AND LIMIT OF WASTE

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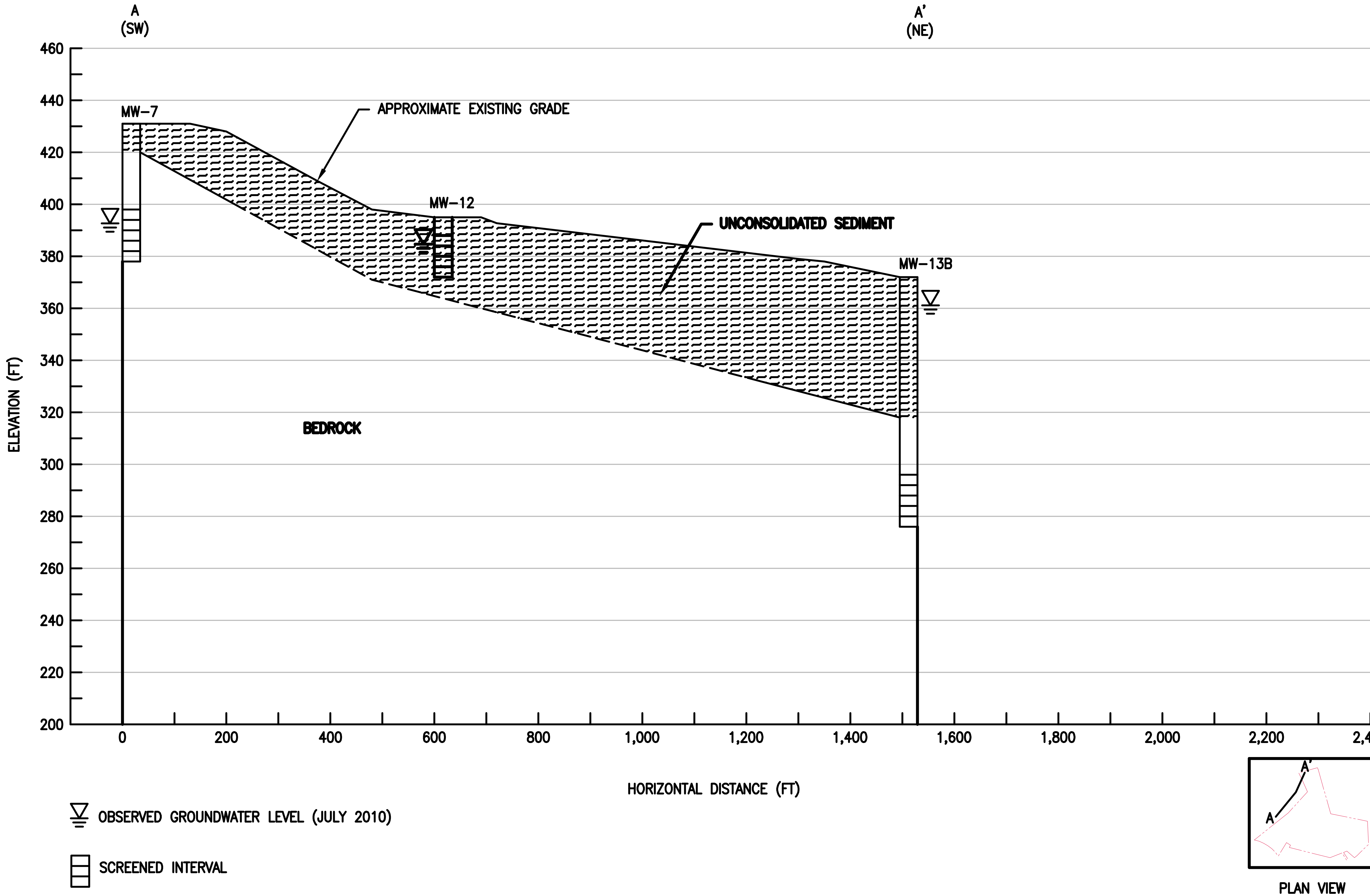


OBSERVED GROUNDWATER LEVEL (JULY 2010)

SCREENED INTERVAL

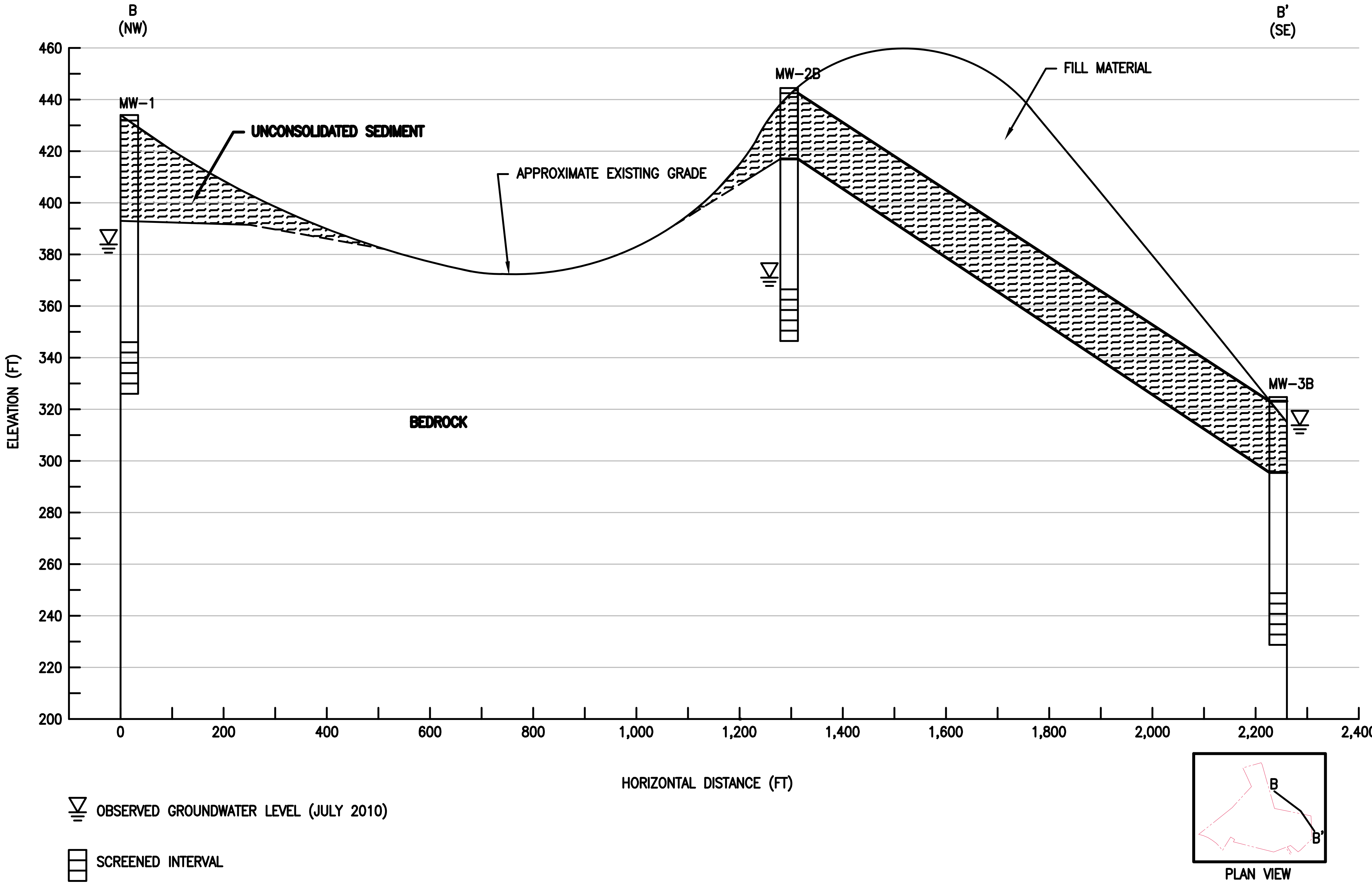
EA ENGINEERING, SCIENCE, AND TECHNOLOGY

GUDE LANDFILL
ASSESSMENT OF CORRECTIVE MEASURES
MONTGOMERY COUNTY, MARYLAND

FIGURE 1-3
GEOLOGIC CROSS SECTION A-A'

DESIGNED BY	DRAWN BY	DATE	PROJECT NO.
–	RMC	APR. 2013	14982.01
CHECKED BY	PROJECT MGR.	DRAWING NO.	FIGURE
–	JK	–	1-3

FILE PATH: Q:\PROJECTS\1498201 GUDE PHASE 2 ACM\2013-04-01\FIG 1-3.DWG [LAYOUT1] 4/11/13



FILE PATH: Q:\PROJECTS\1498201 GUDE PHASE 2 ACM\2013-04-01\FIG 1-4.DWG [LAYOUT1] 4/11/13

EA ENGINEERING, SCIENCE, AND TECHNOLOGY	GUDE LANDFILL ASSESSMENT OF CORRECTIVE MEASURES MONTGOMERY COUNTY, MARYLAND	FIGURE 1-4 GEOLOGIC CROSS SECTION B-B'	DESIGNED BY –	DRAWN BY RMC	DATE APR. 2013	PROJECT NO. 14982.01
			CHECKED BY –	PROJECT MGR. JK	DRAWING NO. –	FIGURE 1-4

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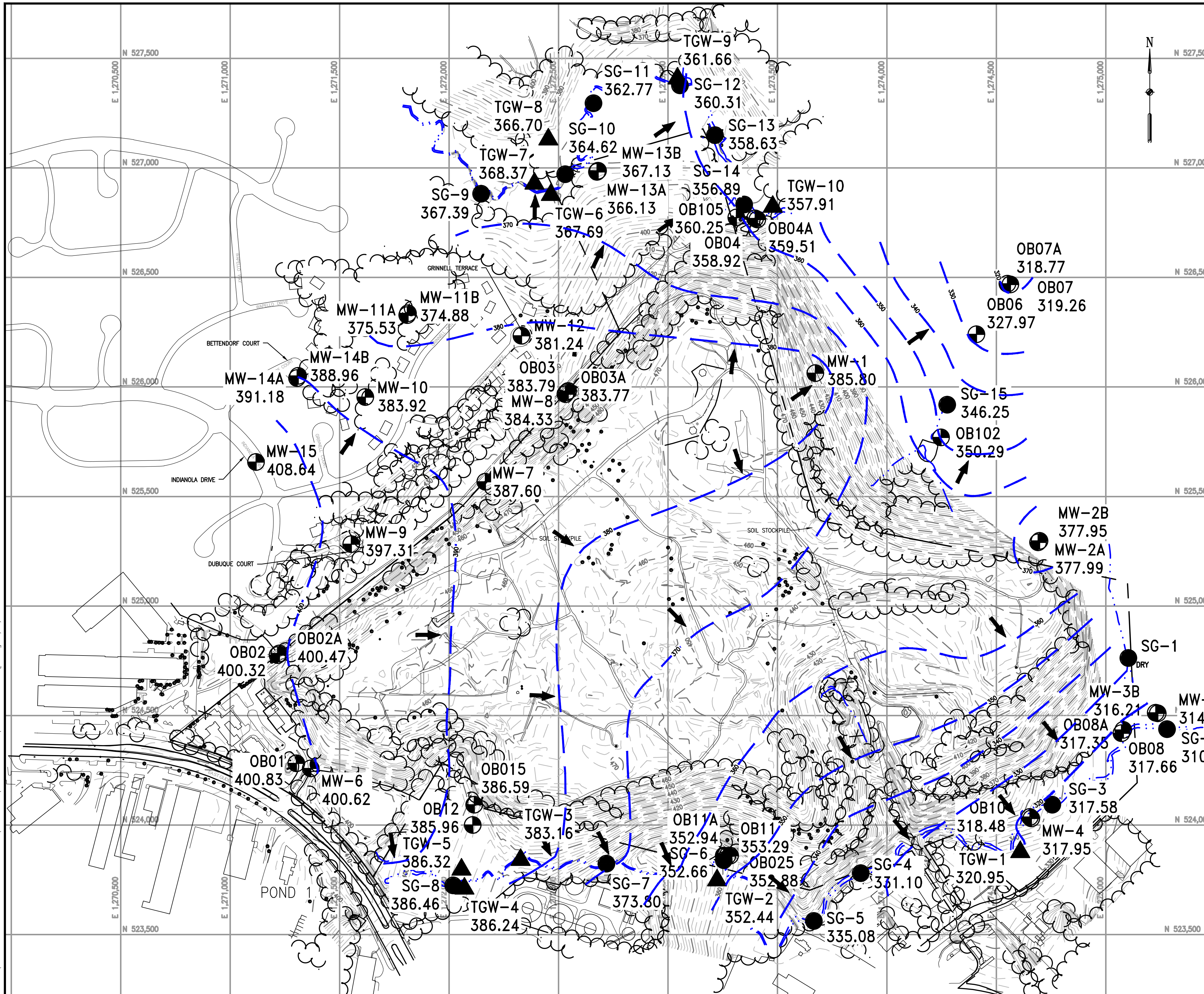

NOTES:

1. TOPOGRAPHY COMPILED BY APPLIED MAPPING SOLUTIONS, INC. USING PHOTOGRAMMETRIC METHODS WITH PHOTOGRAPHY DATED 06/24/09 AND SUPPLEMENTED WITH FIELD SURVEY PERFORMED BY C.C. JOHNSON & MALHOTRA, P.C., OCTOBER 2009.
2. SURVEY OF STREAMS TAKEN FROM 2007 PHOTOGRAMMETRY BY AXIS GEOSPATIAL, LLC.
3. HORIZONTAL DATUM IS NORTH AMERICAN DATUM OF 1983/91 (NAD-83/91). COORDINATE SYSTEM IS MARYLAND STATE PLANE, U.S. SURVEY FEET. VERTICAL DATUM IS NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD-88) WITH ELEVATIONS SHOWN IN FEET.
4. TOPOGRAPHY IS APPROXIMATE IN AREAS NOTED "GROUND OBSCURED BY DENSE TREES AND VEGETATION".
5. FIELD SURVEY OF MW-14A, MW-14B, & MW-15, TEMPORARY GROUNDWATER MONITORING LOCATIONS, AND STREAM GAUGE LOCATIONS PERFORMED BY C.C. JOHNSON & MALHOTRA, P.C., AUGUST 2011.
6. GROUNDWATER ELEVATION DATA FOR OB102 (350.19') NOT USED IN CONTOURING BECAUSE IT IS INCONSISTENT WITH SURROUNDING DATA.

LEGEND

- 400 — 10-FT ELEVATION CONTOUR
- 2-FT ELEVATION CONTOUR
- PROPERTY BOUNDARY
- STREAM
- GROUNDWATER CONTOUR INTERVAL (10 FEET)
- SG-X — TEMPORARY STREAM GAUGE LOCATION (2011)
- MW-X — EXISTING GROUNDWATER MONITORING WELL
- TGW-X — TEMPORARY GROUNDWATER MONITORING LOCATION (2011)
- 318.40 — GROUNDWATER ELEVATION (FT. MSL.)
- INFERRED GROUNDWATER FLOW

500 250 0 500
GRAPHIC SCALE IN FEET

FILE PATH: Q:\PROJECTS\1498201 GUDE PHASE 2 ACM\FIGURES\NEW FOLDER\FIG 1-5.DWG [4-1] 6/4/13

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

GUDE LANDFILL
ASSESSMENT OF CORRECTIVE MEASURES
MONTGOMERY COUNTY, MARYLAND

FIGURE 1-5
INFERRED GROUNDWATER FLOW MAP
DATA DATE: AUGUST 30, 2011

DESIGNED BY	DRAWN BY	DATE	PROJECT NO.
PL/LJO	TJP	APR. 2013	14982.01
CHECKED BY	PROJECT MGR.	DRAWING NO.	FIGURE
PC	JK	-	1-5

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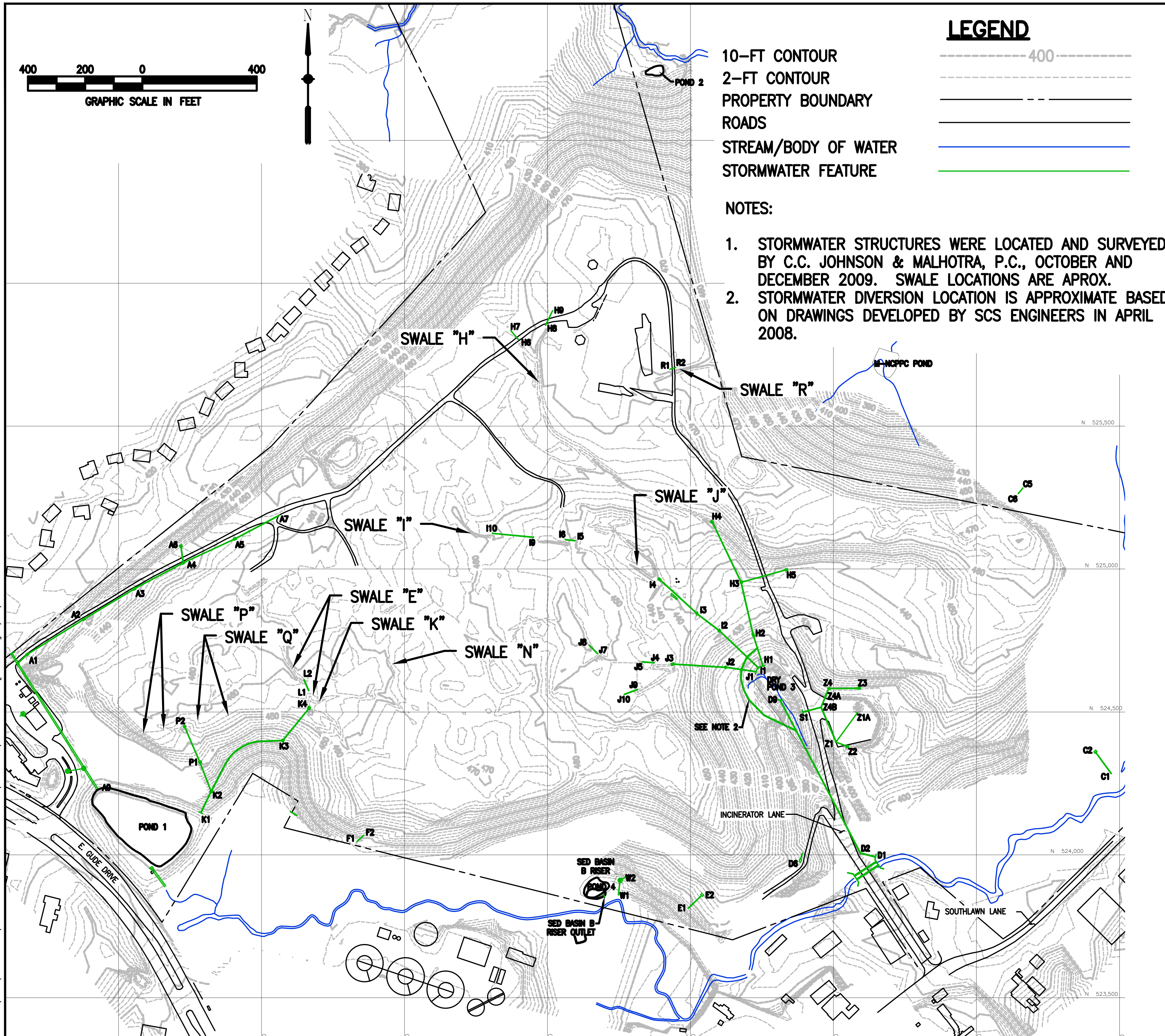

NOTES:

1. STORMWATER STRUCTURES WERE LOCATED AND SURVEYED BY C.C. JOHNSON & MALHOTRA, P.C., OCTOBER AND DECEMBER 2009. SWALE LOCATIONS ARE APROX.
2. STORMWATER DIVERSION LOCATION IS APPROXIMATE BASED ON DRAWINGS DEVELOPED BY SCS ENGINEERS IN APRIL 2008.

Point No	Description	Condition
A0	Manhole to 60" CMP	Not available
A1	Inlet to 18" HDPE	Good
A2	Inlet to 18" HDPE	Vegetative overgrowth and debris
A3	Inlet to 18" HDPE	Vegetative overgrowth and debris
A4	Inlet to 18" HDPE	Vegetative overgrowth and debris
A6	Inlet to 18" HDPE	Rip rap settlement
A5	Inlet to 18" HDPE	Rip rap settlement
A7	Inlet to 24" HDPE	Heavy vegetative overgrowth
P1	Inlet to 18" CPP	Vegetative overgrowth and debris
P2	Inlet to 18" CPP	Good
K2	Tie in Point for 18" CPP To 30" CPP	Vegetative overgrowth
K3	Inlet to 30" CPP	Vegetative overgrowth
K4	Inlet to 30" CPP	Minimal erosion
L1	24" CPP Culvert	Heavy vegetative overgrowth
L2	24" CPP Culvert	Moderate vegetative overgrowth
J1	30" CPP Outlet	Trees in channel
J2	Inlet to 24" CPP	Vegetative overgrowth and debris
J3	Inlet to 24" CPP	Concrete bowing – overgrowth
J4	24" CMP Culvert	Good
J5	24" CMP Culvert	Good
J7	24" CPP Culvert	Vegetative overgrowth
J8	24" CPP Culvert	Good
J9	24" CMP Culvert	Vegetative overgrowth
J10	24" CMP Culvert	Vegetative overgrowth
I1	30" CPP Outlet	Trees in channel
I2	Inlet to 24" CPP	Concrete in need of repair
I3	Inlet to 24" CPP	Vegetative overgrowth
I4	Inlet to 24" CPP	Vegetative overgrowth and debris
I5	24" RCP Culvert	Heavy vegetative overgrowth
I6	24" RCP Culvert	Heavy vegetative overgrowth
I9	24" RCP Culvert	Heavy vegetative overgrowth
I10	24" RCP Culvert	Good
H2	Inlet to 24" CPP	Heavy vegetative overgrowth
H3	Tie in Point for 18" pipe to 24" pipe	Excellent
H5	Inlet to 24" CPP	Potentially clogged with debris
H4	Inlet to 24" CPP	Rip rap settlement and vegetation
H6	12–18" CMP Culvert	Minimal erosion
H7	12–18" CMP Culvert	Good
H8	15" CMP Culvert	Not available
H9	15" CMP Culvert	Not available
Z1	Tie in Point for 18" and 8" pipes to 24" pipe	Silt fence around inlet
Z1A	Inlet to 8" pipe	
Z2	Inlet to 18" pipe	Rip rap settlement and vegetation
Z3	Inlet to 18" pipe	Silt fence around inlet and vegetation
Z4	Inlet to 18" pipe	Silt fence around inlet and vegetation
Z4A	Inlet to 24" pipe	
Z4B	Tie in Point for 18" and 8" pipes to 24" pipe	
S1	30" RCP Outlet	Heavy vegetative overgrowth
D9	Inlet to 30" RCP	Debris around inlet
D2	Inlet	Debris around inlet
D1	Outlet	Debris around inlet
R1	8" PVC Culvert	Not available
R2	8" PVC Culvert	Not available
C2	Inlet to 18" CPP	Debris around inlet
C1	18" CPP Outlet	Debris around inlet
B5	12" Concrete Culvert	Minimal erosion and leaf debris
B6	12" Concrete Culvert	Debris around inlet
E2	Inlet to 18" CPP	Rip rap settlement
E1	18" CPP Outlet	Good
W2	15" RCP Culvert	Vegetative overgrowth
W1	15" RCP Culvert	Good
Sed Basin B Riser	15" Pipe	Requires further evaluation
Sed Basin B Riser Outlet	15" Pipe	Requires further evaluation

FILE PATH: \\LOVETONCAD\CAD\PROJECTS\1498201 GUDE PHASE 2 ACM\FIGURES\FIG 1-6.DWG [FIG 3-3] 6/28/13

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ASSESSMENT OF CORRECTIVE MEASURES
MONTGOMERY COUNTY, MARYLAND

FIGURE 1-6
STORMWATER STRUCTURE LOCATION MAP

DESIGNED BY	DRAWN BY	DATE	PROJECT NO.
REO	REO	JUNE 2013	14982.01
CHECKED BY	PROJECT MGR.	DRAWING NO.	FIGURE
LJO	MG	–	1-6

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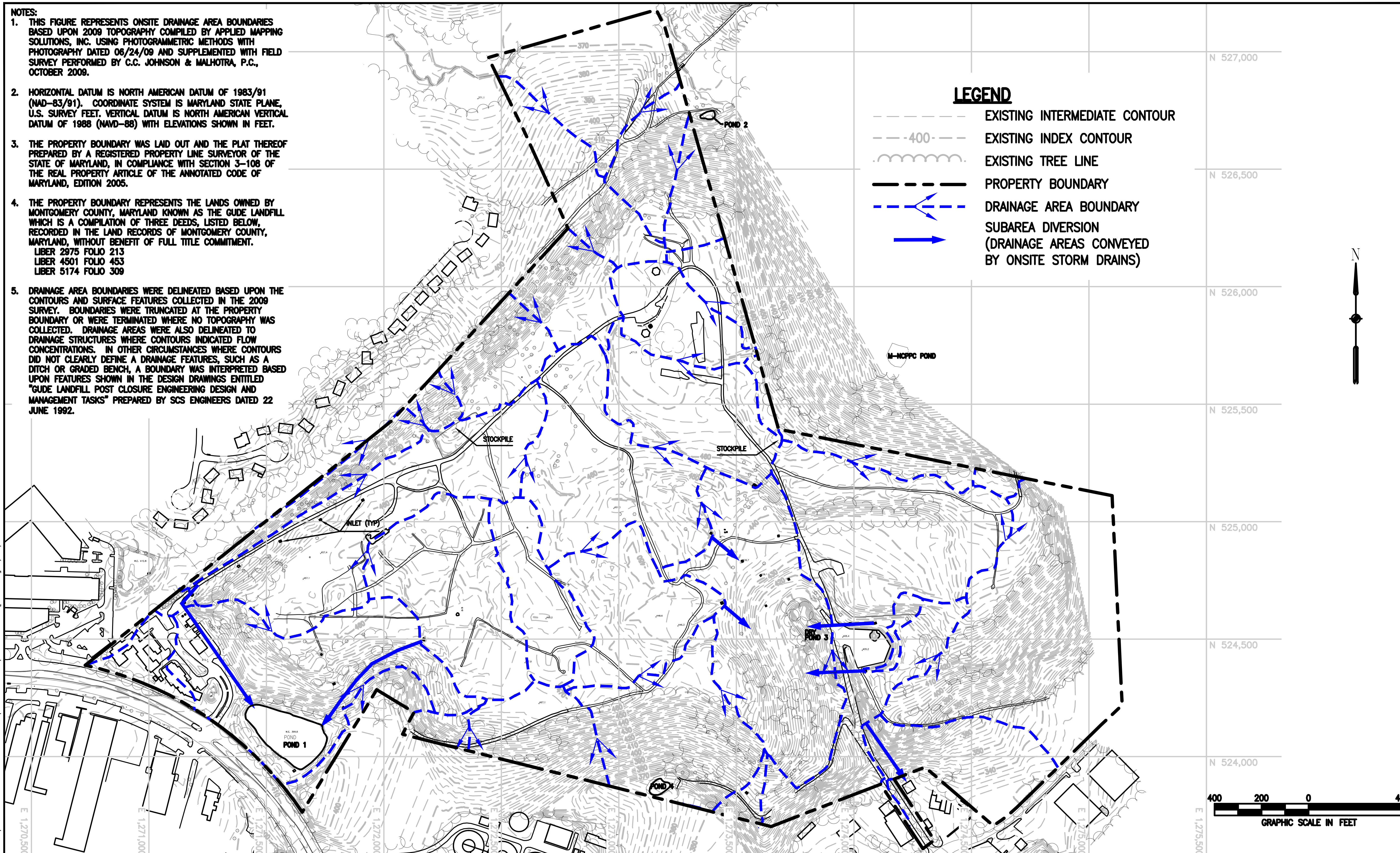
NOTES:

1. THIS FIGURE REPRESENTS ONSITE DRAINAGE AREA BOUNDARIES BASED UPON 2009 TOPOGRAPHY COMPILED BY APPLIED MAPPING SOLUTIONS, INC. USING PHOTOGRAMMETRIC METHODS WITH PHOTOGRAPHY DATED 06/24/09 AND SUPPLEMENTED WITH FIELD SURVEY PERFORMED BY C.C. JOHNSON & MALHOTRA, P.C., OCTOBER 2009.
2. HORIZONTAL DATUM IS NORTH AMERICAN DATUM OF 1983/91 (NAD–83/91). COORDINATE SYSTEM IS MARYLAND STATE PLANE, U.S. SURVEY FEET. VERTICAL DATUM IS NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD–88) WITH ELEVATIONS SHOWN IN FEET.
3. THE PROPERTY BOUNDARY WAS LAID OUT AND THE PLAT THEREOF PREPARED BY A REGISTERED PROPERTY LINE SURVEYOR OF THE STATE OF MARYLAND, IN COMPLIANCE WITH SECTION 3–108 OF THE REAL PROPERTY ARTICLE OF THE ANNOTATED CODE OF MARYLAND, EDITION 2005.
4. THE PROPERTY BOUNDARY REPRESENTS THE LANDS OWNED BY MONTGOMERY COUNTY, MARYLAND KNOWN AS THE GUDE LANDFILL WHICH IS A COMPILATION OF THREE DEEDS, LISTED BELOW, RECORDED IN THE LAND RECORDS OF MONTGOMERY COUNTY, MARYLAND, WITHOUT BENEFIT OF FULL TITLE COMMITMENT.
   - LIBER 2975 FOLIO 213
   - LIBER 4501 FOLIO 453
   - LIBER 5174 FOLIO 309
5. DRAINAGE AREA BOUNDARIES WERE DELINEATED BASED UPON THE CONTOURS AND SURFACE FEATURES COLLECTED IN THE 2009 SURVEY. BOUNDARIES WERE TRUNCATED AT THE PROPERTY BOUNDARY OR WERE TERMINATED WHERE NO TOPOGRAPHY WAS COLLECTED. DRAINAGE AREAS WERE ALSO DELINEATED TO DRAINAGE STRUCTURES WHERE CONTOURS INDICATED FLOW CONCENTRATIONS. IN OTHER CIRCUMSTANCES WHERE CONTOURS DID NOT CLEARLY DEFINE A DRAINAGE FEATURES, SUCH AS A DITCH OR GRADED BENCH, A BOUNDARY WAS INTERPRETED BASED UPON FEATURES SHOWN IN THE DESIGN DRAWINGS ENTITLED "GUDE LANDFILL POST CLOSURE ENGINEERING DESIGN AND MANAGEMENT TASKS" PREPARED BY SCS ENGINEERS DATED 22 JUNE 1992.



FILE PATH: Q:\PROJECTS\1498201 GUDE PHASE 2 ACM\2013-04-01\FIG 1-7.DWG [FIG 3-4] 4/11/13

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MONTGOMERY COUNTY, MARYLAND

FIGURE 1–7
DRAINAGE AREA MAP

DESIGNED BY	DRAWN BY	DATE	PROJECT NO.
PL	JP	APR. 2013	14982.01
CHECKED BY	PROJECT MGR.	DRAWING NO.	FIGURE
BR	JK	–	1–7

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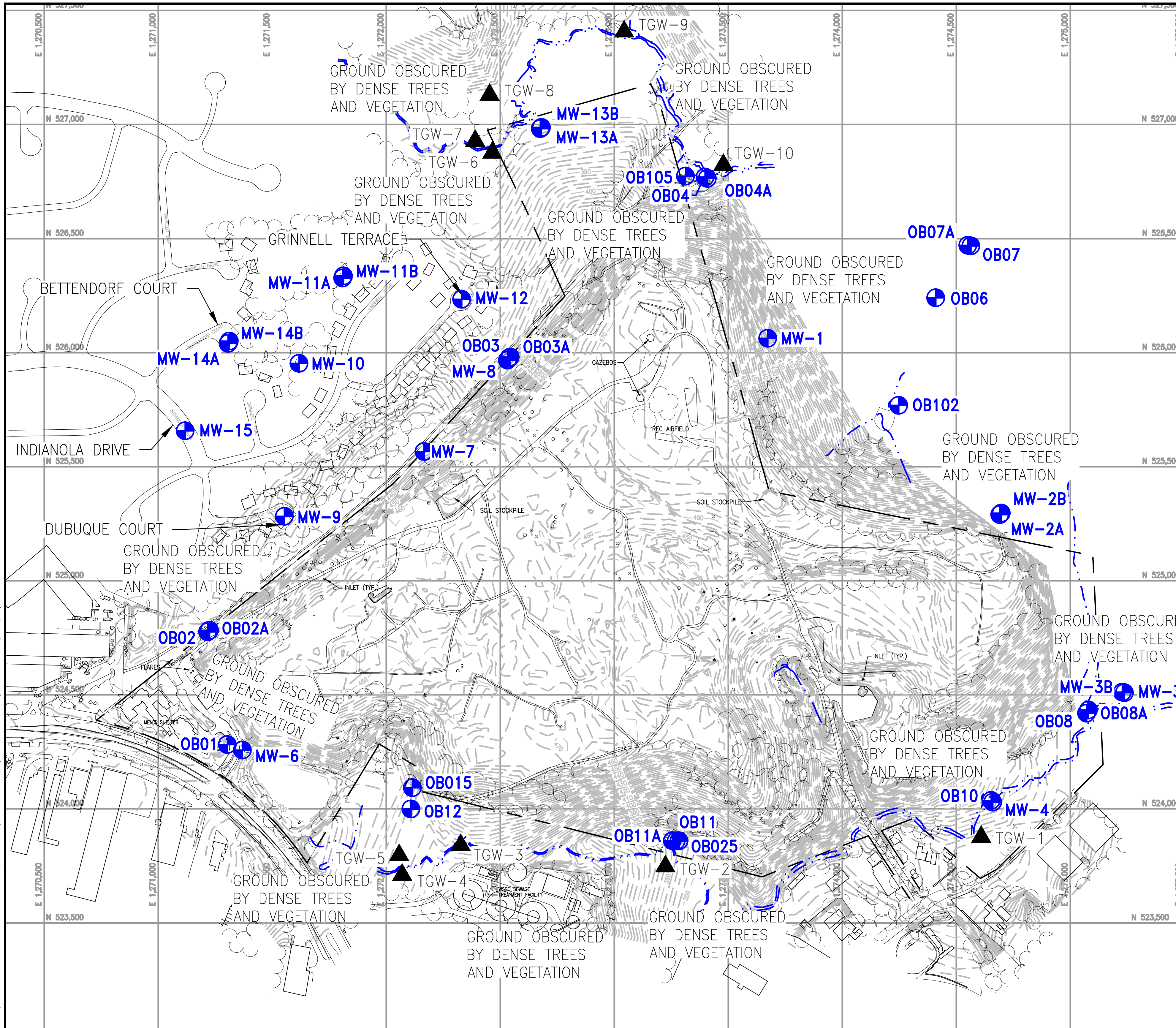

NOTES:

1. TOPOGRAPHY COMPILED BY APPLIED MAPPING SOLUTIONS, INC. USING PHOTOGRAMMETRIC METHODS WITH PHOTOGRAPHY DATED 06/24/09 AND SUPPLEMENTED WITH FIELD SURVEY PERFORMED BY C.C. JOHNSON & MALHOTRA, P.C., OCTOBER 2009.
2. SURVEY OF STREAMS TAKEN FROM 2007 PHOTOGRAMMETRY BY AXIS GEOSPATIAL, LLC.
3. HORIZONTAL DATUM IS NORTH AMERICAN DATUM OF 1983/91 (NAD-83/91). COORDINATE SYSTEM IS MARYLAND STATE PLANE, U.S. SURVEY FEET. VERTICAL DATUM IS NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD-88) WITH ELEVATIONS SHOWN IN FEET.
4. TOPOGRAPHY IS APPROXIMATE IN AREAS NOTED "GROUND OBSCURED BY DENSE TREES AND VEGETATION".
5. FIELD SURVEY OF MW-14A, MW-14B, & MW-15, TEMPORARY GROUNDWATER MONITORING LOCATIONS, AND STREAM GAUGE LOCATIONS PERFORMED BY C.C. JOHNSON & MALHOTRA, P.C., AUGUST 2011.

N

LEGEND

Symbol	Description
— 400 —	10-FT CONTOUR
- - - -	2-FT CONTOUR
— - - —	PROPERTY BOUNDARY
—·—·—	STREAM
MW-X	GROUNDWATER MONITORING WELL
TGW-X	TEMPORARY GROUNDWATER MONITORING LOCATION (2011)

500 250 0 500

GRAPHIC SCALE IN FEET

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

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MONTGOMERY COUNTY, MARYLAND

FIGURE 1-8
GROUNDWATER MONITORING WELLS

DESIGNED BY	DRAWN BY	DATE	PROJECT NO.
PL/LJO	TJP	APR. 2013	14982.01
CHECKED BY	PROJECT MGR.	DRAWING NO.	FIGURE
PC	JK	–	1-8

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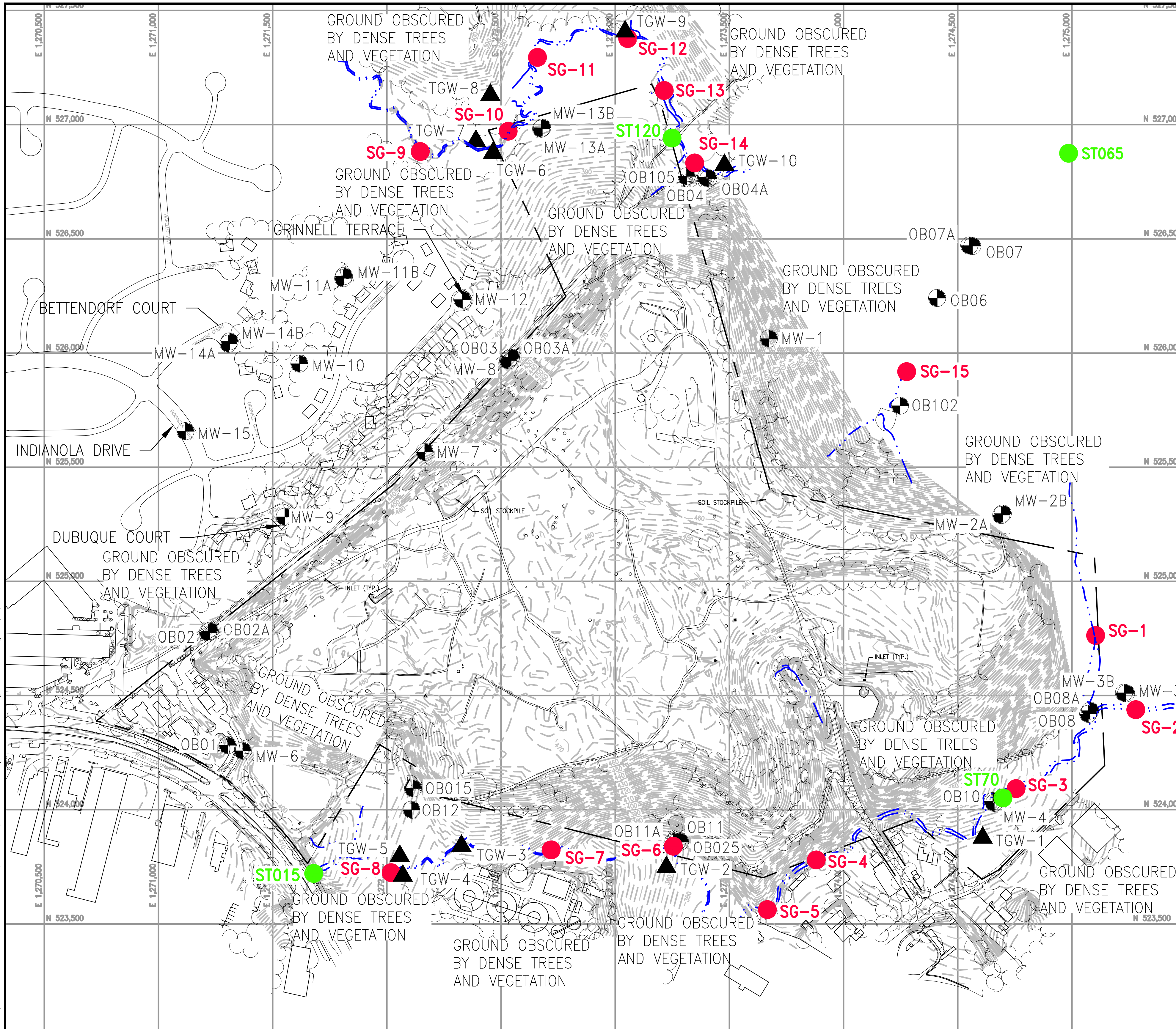

N

NOTES:

1. TOPOGRAPHY COMPILED BY APPLIED MAPPING SOLUTIONS, INC. USING PHOTOGRAMMETRIC METHODS WITH PHOTOGRAPHY DATED 06/24/09 AND SUPPLEMENTED WITH FIELD SURVEY PERFORMED BY C.C. JOHNSON & MALHOTRA, P.C., OCTOBER 2009.
2. SURVEY OF STREAMS TAKEN FROM 2007 PHOTOGRAMMETRY BY AXIS GEOSPATIAL, LLC.
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4. TOPOGRAPHY IS APPROXIMATE IN AREAS NOTED "GROUND OBSCURED BY DENSE TREES AND VEGETATION".
5. FIELD SURVEY OF MW-14A, MW-14B, & MW-15, TEMPORARY GROUNDWATER MONITORING LOCATIONS, AND STREAM GAUGE LOCATIONS PERFORMED BY C.C. JOHNSON & MALHOTRA, P.C., AUGUST 2011.

LEGEND

Symbol	Description
— — -400- — —	10-FT CONTOUR
— — — — —	2-FT CONTOUR
——— - - ———	PROPERTY BOUNDARY
— · · — · · —	STREAM
SG-X	TEMPORARY STREAM GAUGE LOCATION (2011)
ST#	SURFACE WATER MONITORING LOCATION
MW-X	GROUNDWATER MONITORING WELL
TGW-X	TEMPORARY GROUNDWATER MONITORING LOCATION (2011)

500 250 0 500
GRAPHIC SCALE IN FEET

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MONTGOMERY COUNTY, MARYLAND

FIGURE 1-9
SURFACE WATER MONITORING NETWORK

DESIGNED BY	DRAWN BY	DATE	PROJECT NO.
PL/LJO	TJP	APR. 2013	14982.01
CHECKED BY	PROJECT MGR.	DRAWING NO.	FIGURE
PC	JK	–	1-9

FILE PATH: Q:\PROJECTS\1498201 GUDE PHASE 2 ACM\FIGURES\NEW FOLDER\FIG 1-9.DWG [2-1_11X17] 10/8/13

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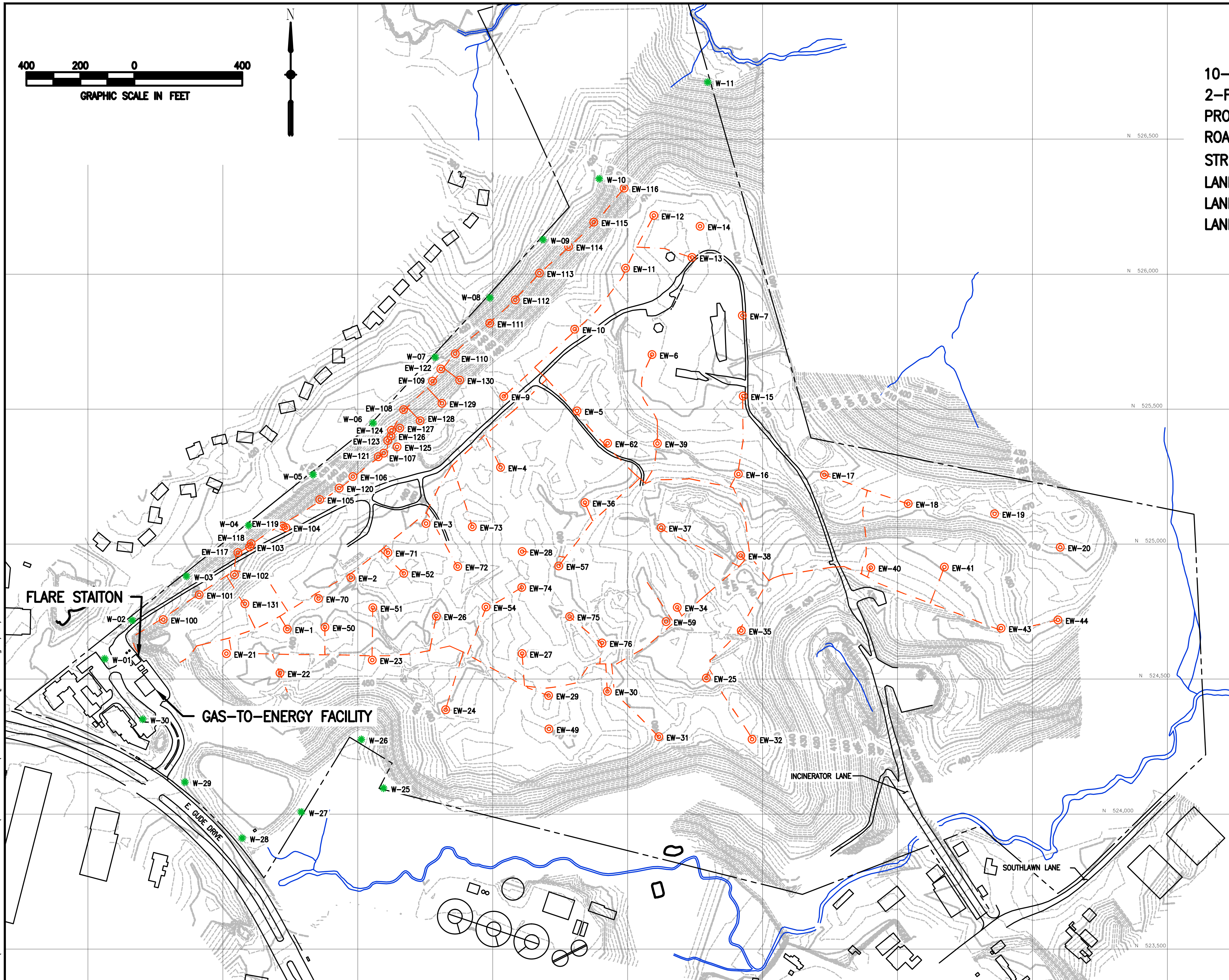

LEGEND

- 10-FT CONTOUR — 400
- 2-FT CONTOUR
- PROPERTY BOUNDARY
- ROADS
- STREAM/BODY OF WATER
- LANDFILL GAS EXTRACTION PIPING
- LANDFILL GAS EXTRACTION WELL
- LANDFILL GAS MONITORING WELL — W-07

NOTES:

1. 2009 TOPOGRAPHY COMPILED BY APPLIED MAPPING SOLUTIONS, INC. USING PHOTOGRAMMETRIC METHODS WITH PHOTOGRAPHY DATED 06/24/09 AND SUPPLEMENTED WITH FIELD SURVEY PERFORMED BY C.C. JOHNSON & MALHOTRA, P.C., OCTOBER 2009.

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3. THE PROPERTY BOUNDARY WAS LAID OUT AND THE PLAT THEREOF PREPARED BY A REGISTERED PROPERTY LINE SURVEYOR OF THE STATE OF MARYLAND, IN COMPLIANCE WITH SECTION 3-108 OF THE REAL PROPERTY ARTICLE OF THE ANNOTATED CODE OF MARYLAND, EDITION 2005.

4. THE PROPERTY BOUNDARY REPRESENTS THE LANDS OWNED BY MONTGOMERY COUNTY, MARYLAND KNOWN AS THE GUDE LANDFILL WHICH IS A COMPILATION OF THREE DEEDS, LISTED BELOW, RECORDED IN THE LAND RECORDS OF MONTGOMERY COUNTY, MARYLAND, WITHOUT BENEFIT OF FULL TITLE COMMITMENT.
   LIBER 2975 FOLIO 213
   LIBER 4501 FOLIO 453
   LIBER 5174 FOLIO 309

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MONTGOMERY COUNTY, MARYLAND

FIGURE 1-10
GUDE LANDFILL GAS EXTRACTION AND MONITORING SYSTEMS

DESIGNED BY	DRAWN BY	DATE	PROJECT NO.
PL	JP	APR. 2013	14982.01
CHECKED BY	PROJECT MGR.	DRAWING NO.	FIGURE
BR	JK	-	1-10

FILE PATH: Q:\PROJECTS\1498201 GUDE PHASE 2 ACM\2013-04-01\FIG 1-10.DWG [FIG 3-5] 4/11/13

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FIGURE 2-1
HUMAN HEALTH CONCEPTUAL SITE MODEL
GUDE LANDFILL

Summary: The risk evaluation determined no potential concerns for human contact with complete exposure pathways. Only complete exposure pathways are evaluated in the risk evaluation. A complete exposure pathway requires the following four components: a source of chemicals, a transport/release mechanism for chemicals, a point for potential human contact, and a route of human exposure. Potential risk to humans from chemicals requires a complete exposure pathway. Incomplete exposure pathways do result in a risk to human receptors.

References: EPA. 1989. *Risk Assessment Guidance for Superfund, Volume 1 Human Health Evaluation Manual (Part A)* . EPA/540/1-89/002, December.
EPA. 2010. *Regional Screening Levels, User's Guide* . May. Available at http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/usersguide.htm.
MDE. 2008. *Cleanup Standards for Soil and Groundwater* . Interim Final Guidance (Update 2.1). June.

PRIMARY SOURCE	PRIMARY RELEASE MECHANISM	SECONDARY SOURCE	SECONDARY RELEASE MECHANISM	EXPOSURE ROUTE	POTENTIAL RECEPTORS: Residents (Adult and Child)	County Workers	Recreational Users	Residents of Men's Shelter
Gude Landfill	Groundwater Transport/ Leachate Seeps			Ingestion	I	I	I	I
				Dermal Contact	I	I	I	I
				Inhalation VOCs	I	I	I	I
			Vapor Intrusion	Inhalation VOCs Indoor Air	C	I	I	C
		Surface Water		Ingestion	I*	I	C	I
				Dermal Contact	I*	I	C	I
		Subsurface Soil		Ingestion	C*	C	I	I
				Dermal Contact	C*	C	I	I
				Inhalation of Particulate	C*	C	I	I
		Surface Soil		Ingestion	I*	C	C	C
				Dermal Contact	I*	C	C	C
			Particulate Emission/Suspension	Inhalation of Particulate	I*	C	C	C

LEGEND

I	Incomplete or not significant exposure pathway
I*	Incomplete pathway for a residential scenario, evaluated as part of the recreational user scenario
C	Potentially complete exposure pathway
C*	Of the subsurface soil locations evaluated in the human health risk evaluation performed as part of the Nature and Extent Study, potentially complete exposure pathway present only at subsurface sample locations within the Derwood Station residential development: MW-9 (Dubuque Court), MW-10, MW-11A and MW-11B (Grinnel Drive) and MW-12 (Grinnell Terrace).

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FIGURE 2-2
ECOLOGICAL CONCEPTUAL SITE MODEL
GUDE LANDFILL

Summary: The risk evaluation determined no potential concerns for ecological receptors contact with complete exposure pathways. Only complete exposure pathways are evaluated in the risk evaluation. A complete exposure pathway requires the following four components: a source of chemicals, a transport/release mechanism for chemicals, a point for potential ecological contact, and a route of ecological exposure. Potential risk to ecological receptors from chemicals requires a complete exposure pathway. Incomplete exposure pathways do result in a risk to ecological receptors.

References: EPA. 1998. *Guidelines for Ecological Risk Assessment*. EPA/630/R-95/002F. April.
EPA. 2005. Guidance for Developing Ecological Soil Screening Levels. OSWER Directive 9285.7-55. Revised February.

PRIMARY SOURCE	PRIMARY RELEASE MECHANISM	SECONDARY SOURCE	EXPOSURE MEDIA	EXPOSURE PATHWAYS	POTENTIAL RECEPTORS: Aquatic Organisms	Terrestrial Plants	Terrestrial Invertebrates	Birds	Mammals
Gude Landfill		Surface Soil	Surface Soil	Ingestion	I	I	C*	C	C
				Direct/Dermal Contact*	I	C	C	C*	C*
	Groundwater Transport/ Leachate Seeps	Surface Water	Surface Water	Biouptake	C	I	I	C	C
				Direct/Dermal Contact*	C	I	I	C*	C*
		Terrestrial food chain	Terrestrial food chain	Ingestion of prey/vegetation	I	I	I	C	C

* Direct contact is identified as a complete pathway for higher tropic level wildlife. However, example calculations and information provided in EPA guidance demonstrates that this pathway is insignificant compared to ingestion (EPA 2005).

LEGEND

C	Complete Pathway
C*	Complete Pathway, but not significant
I	Incomplete Pathway

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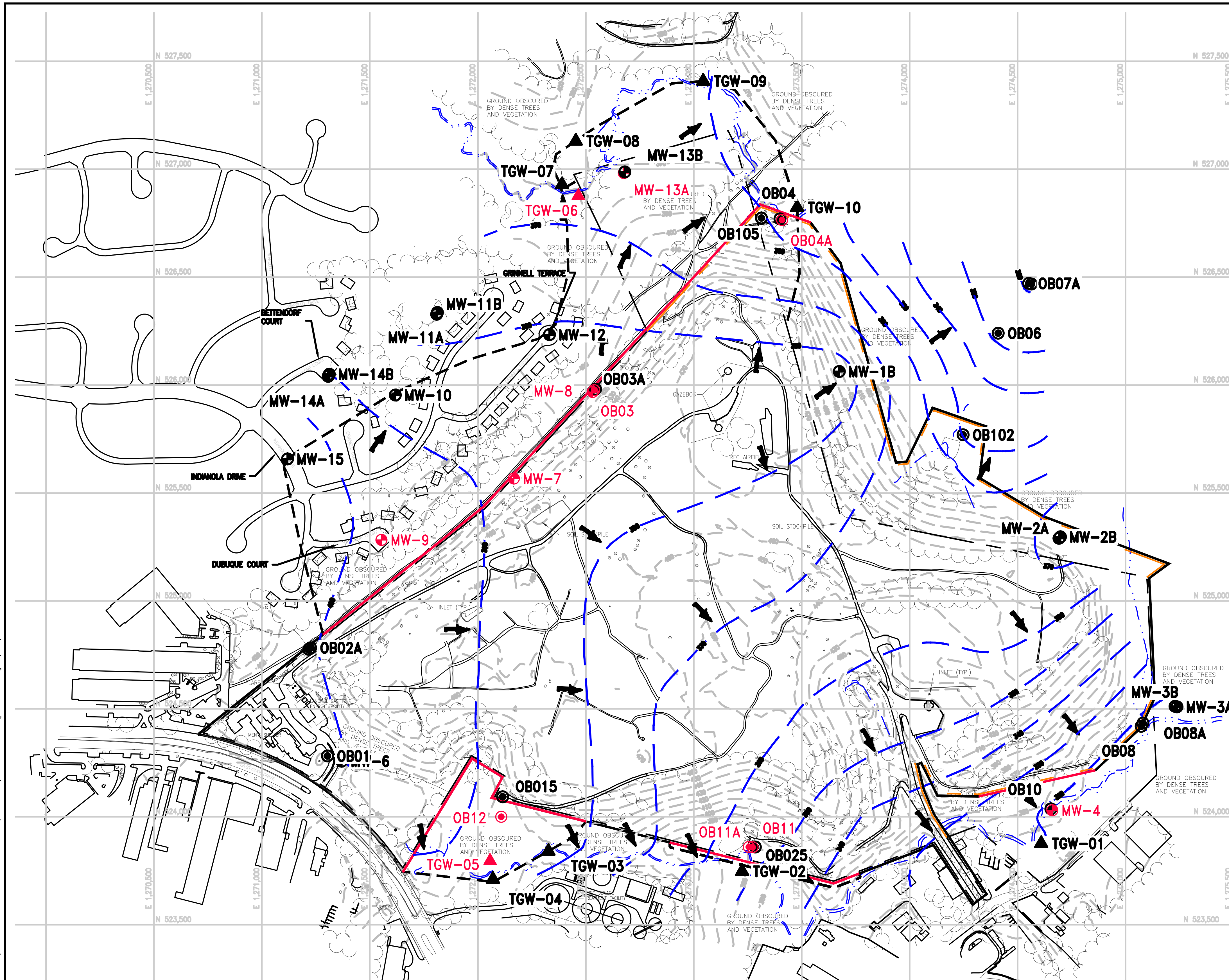

NOTES:

1. TOPOGRAPHY COMPILED BY APPLIED MAPPING SOLUTIONS, INC. USING PHOTOGRAMMETRIC METHODS WITH PHOTOGRAPHY DATED 06/24/09 AND SUPPLEMENTED WITH FIELD SURVEY PERFORMED BY C.C. JOHNSON & MALHOTRA, P.C., OCTOBER 2009.
2. HORIZONTAL DATUM IS NORTH AMERICAN DATUM OF 1983/91 (NAD-83/91). COORDINATE SYSTEM IS MARYLAND STATE PLANE, U.S. SURVEY FEET. VERTICAL DATUM IS NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD-88) WITH ELEVATIONS SHOWN IN FEET.
3. MCL EXCEEDANCES AND INFERRED EXTENT OF POTENTIAL MCL EXCEEDANCES ARE A COMPOSITE OF THE APRIL (COUNTY) AND SEPTEMBER (NES AMENDMENT) 2011 SAMPLING EVENTS. (1,1-DICHLOROETHENE, 1,2-DIBROMOETHANE, 1,2-DICHLOROPROPANE, BENZENE, CADMIUM, CIS-1,2 DICHLOROETHENE, METHYLENE CHLORIDE, NITRATE, TETRACHLOROETHENE, TRICHLOROETHENE, AND VINYL CHLORIDE).

LEGEND

- 10-FT CONTOUR
- CURRENT PROPERTY BOUNDARY
- STREAM
- OBX — EXISTING GROUNDWATER MONITORING WELL (INSTALLED PRIOR TO 2010)
- MW-X — NEW GROUNDWATER MONITORING WELL (INSTALLED IN 2010 OR 2011)
- TGW-X — TEMPORARY GROUNDWATER MONITORING LOCATION
- OBX — SAMPLING LOCATION WITH ALL PARAMETERS DETECTED BELOW MCLs
- OBX — SAMPLING LOCATION WITH PARAMETERS DETECTED AT OR ABOVE MCLs
- COMPLIANCE WITH MCLs AT FUTURE PROPERTY BOUNDARY
- MCL EXCEEDANCES AT FUTURE PROPERTY BOUNDARY
- FUTURE PROPERTY BOUNDARY
- INFERRED EXTENT OF POTENTIAL MCL EXCEEDANCES
- GROUNDWATER CONTOUR INTERVAL (10 FEET)
- INFERRED GROUNDWATER FLOW

500 250 0 500
GRAPHIC SCALE IN FEET

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FIGURE 2-3
OVERALL MCL COMPLIANCE EXTENT MAP
APRIL AND SEPTEMBER 2011 SAMPLING EVENTS

DESIGNED BY	DRAWN BY	DATE	PROJECT NO.
PL/LJO	AA	JUNE 2013	14982.01
CHECKED BY	PROJECT MGR.	DRAWING NO.	FIGURE
LJO	MG	-	2-3

FILE PATH: Q:\PROJECTS\1498201 GUDE PHASE 2 ACM\FIGURES\FIG 2-3.DWG [TOTAL VOC] 9/30/13

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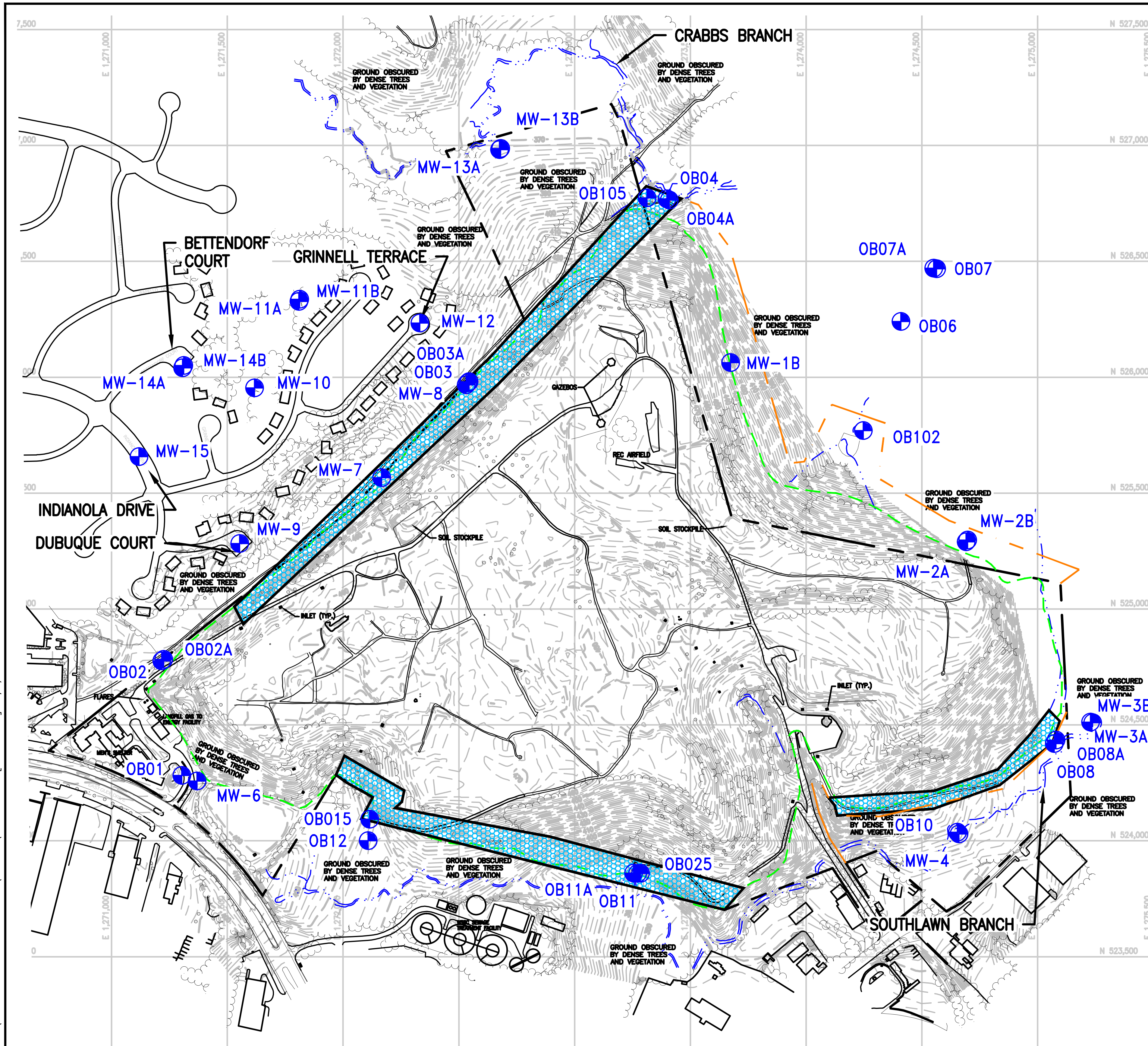

NOTES:

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3. TOPOGRAPHY IS APPROXIMATE IN AREAS NOTED "GROUND OBSCURED BY DENSE TREES AND VEGETATION".
4. MONTGOMERY COUNTY IS CURRENTLY IN NEGOTIATIONS WITH M-NCPPC TO EXCHANGE TWO PARCELS OF LAND (LOCATED TO THE NORTH AND SOUTHEAST OF THE GUDE LANDFILL) FOR PROPERTY TO THE NORTHEAST. THE FUTURE PROPERTY BOUNDARY LINE REPRESENTS THE AGREED UPON PROPERTY BOUNDARY FOR THE GUDE LANDFILL FOLLOWING THE PROPERTY EXCHANGE. THE FUTURE PROPERTY BOUNDARY WAS ESTABLISHED WITH PERMANENT PROPERTY BOUNDARY MARKERS AND SURVEYED BY C.C. JOHNSON AND MALHOTRA, P.C. IN MAY 2012.
5. MCL = MAXIMUM CONTAMINANT LEVEL. AREAS OF MCL EXCEEDANCES ALONG THE PROPERTY BOUNDARY ARE BASED ON THE OVERALL MCL COMPLIANCE EXTENT MAP" (APRIL AND SEPTEMBER 2011 SAMPLING EVENTS) FROM THE NATURE AND EXTENT STUDY AMENDMENT NO. 1 (2012), WITH MODIFICATIONS TO ALIGN WITH THE PROPOSED FUTURE PROPERTY BOUNDARY.

LEGEND

- 400 — 10-FT CONTOUR
- 2-FT CONTOUR
- CURRENT PROPERTY BOUNDARY
- FUTURE PROPERTY BOUNDARY
- LIMIT OF WASTE
- STREAM
- TREELINE
- MW-X/OBX — GROUNDWATER MONITORING WELL
- APPROXIMATE AREAS OF CONCERN FOR GROUNDWATER BASED ON MCL EXCEEDANCES

500 250 0 500 1000

GRAPHIC SCALE IN FEET

EA ENGINEERING, SCIENCE, AND TECHNOLOGY	GUDE LANDFILL ASSESSMENT OF CORRECTIVE MEASURES MONTGOMERY COUNTY, MARYLAND	FIGURE 2-4 APPROXIMATE AREAS OF CONCERN FOR GROUNDWATER BASED ON MCL EXCEEDANCES ALONG THE PROPERTY BOUNDARY	DESIGNED BY SS	DRAWN BY JSP	DATE JUNE 2013	PROJECT NO. 14982.01
			CHECKED BY LJO	PROJECT MGR. MG	DRAWING NO. -	FIGURE 2-4

FILE PATH: Q:\PROJECTS\1498201 GUDE PHASE 2 ACM\FIGURES\FIG 2-4.DWG [4-1 11X17] 10/8/13

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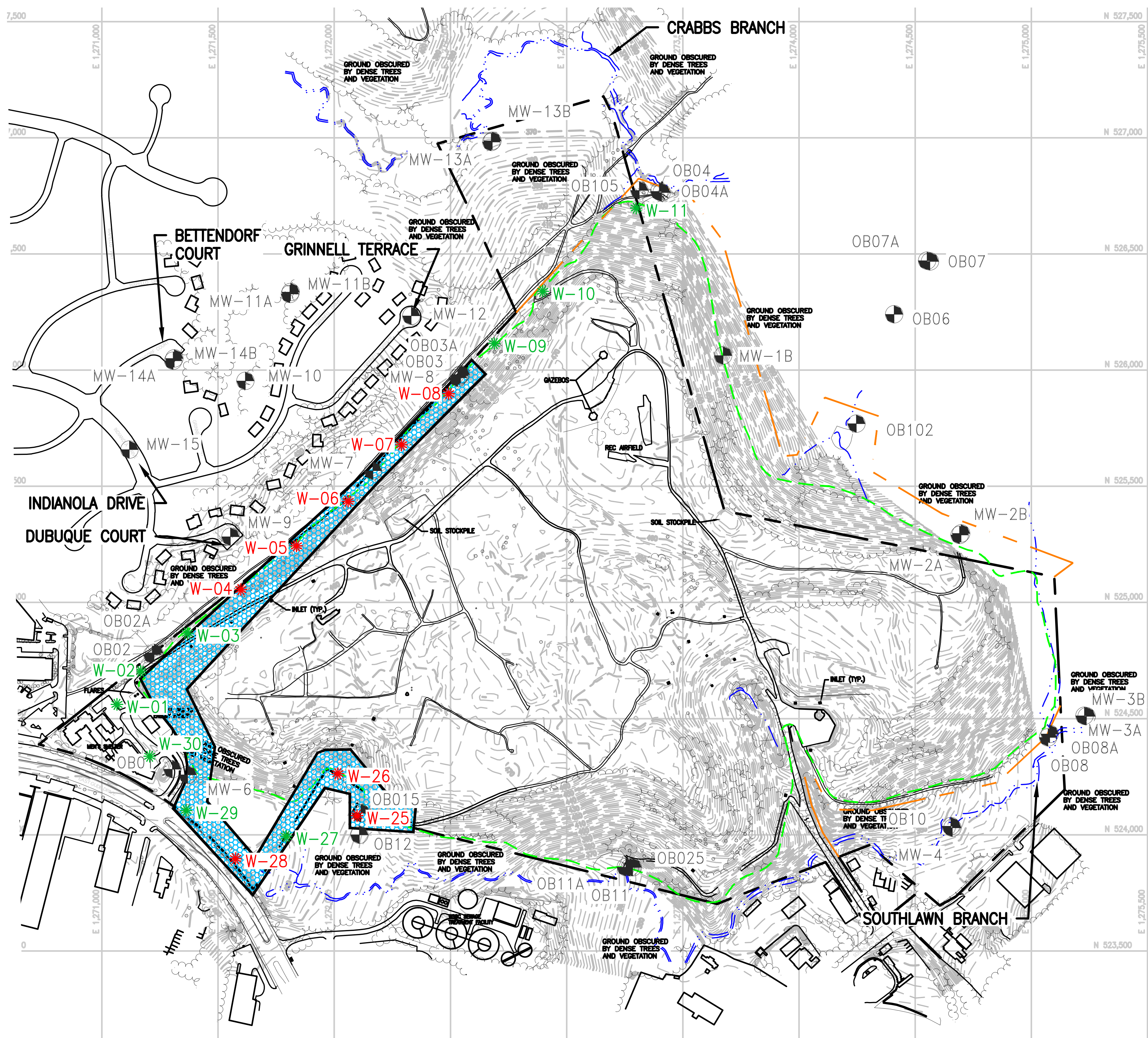

NOTES:

1. TOPOGRAPHY COMPILED BY APPLIED MAPPING SOLUTIONS, INC. USING PHOTOGRAMMETRIC METHODS WITH PHOTOGRAPHY DATED 06/24/09 AND SUPPLEMENTED WITH FIELD SURVEY PERFORMED BY C.C. JOHNSON & MALHOTRA, P.C., OCTOBER 2009.
2. HORIZONTAL DATUM IS NORTH AMERICAN DATUM OF 1983/91 (NAD-83/91). COORDINATE SYSTEM IS MARYLAND STATE PLANE, U.S. SURVEY FEET. VERTICAL DATUM IS NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD-88) WITH ELEVATIONS SHOWN IN FEET.
3. TOPOGRAPHY IS APPROXIMATE IN AREAS NOTED "GROUND OBSCURED BY DENSE TREES AND VEGETATION".
4. MONTGOMERY COUNTY IS CURRENTLY IN NEGOTIATIONS WITH M-NCPPC TO EXCHANGE TWO PARCELS OF LAND (LOCATED TO THE NORTH AND SOUTHEAST OF THE GUDE LANDFILL) FOR PROPERTY TO THE NORTHEAST. THE FUTURE PROPERTY BOUNDARY LINE REPRESENTS THE AGREED UPON PROPERTY BOUNDARY FOR THE GUDE LANDFILL FOLLOWING THE PROPERTY EXCHANGE. THE FUTURE PROPERTY BOUNDARY WAS ESTABLISHED WITH PERMANENT PROPERTY BOUNDARY MARKERS AND SURVEYED BY C.C. JOHNSON AND MALHOTRA, P.C. IN MAY 2012.
5. LEL = LOWER EXPLOSIVE LIMIT. EXCEEDANCES INDICATED ARE METHANE CONCENTRATIONS EXCEEDING LEL OF 5 PERCENT DURING WEEKLY MONITORING BY MONTGOMERY COUNTY DEPARTMENT OF ENVIRONMENTAL PROTECTION IN 2011 AND 2012.

LEGEND

- 400 — 10-FT CONTOUR
- 2-FT CONTOUR
- CURRENT PROPERTY BOUNDARY
- FUTURE PROPERTY BOUNDARY
- LIMIT OF WASTE
- STREAM
- TREELINE
- MW-X/OBX — GROUNDWATER MONITORING WELL
- W-26 — LANDFILL GAS MONITORING WELL (NO LEL EXCEEDANCES 2011-2012)
- W-26 — LANDFILL GAS MONITORING WELL (LOCATION OF LEL EXCEEDANCE IN 2011-2012)
- APPROXIMATE AREAS OF CONCERN FOR LANDFILL GAS BASED ON LEL EXCEEDANCES

500 250 0 500 1000

GRAPHIC SCALE IN FEET

EA ENGINEERING, SCIENCE, AND TECHNOLOGY	GUDE LANDFILL ASSESSMENT OF CORRECTIVE MEASURES MONTGOMERY COUNTY, MARYLAND	FIGURE 2-5 APPROXIMATE AREAS OF CONCERN FOR LANDFILL GAS BASED ON LEL EXCEEDANCES ALONG THE PROPERTY BOUNDARY	DESIGNED BY SS	DRAWN BY JSP	DATE JUNE 2013	PROJECT NO. 14982.01
			CHECKED BY LJO	PROJECT MGR. MG	DRAWING NO. -	FIGURE 2-5

FILE PATH: Q:\PROJECTS\1498201 GUDE PHASE 2 ACM\FIGURES\FIG 2-5.DWG [4-1 11X17] 10/8/13

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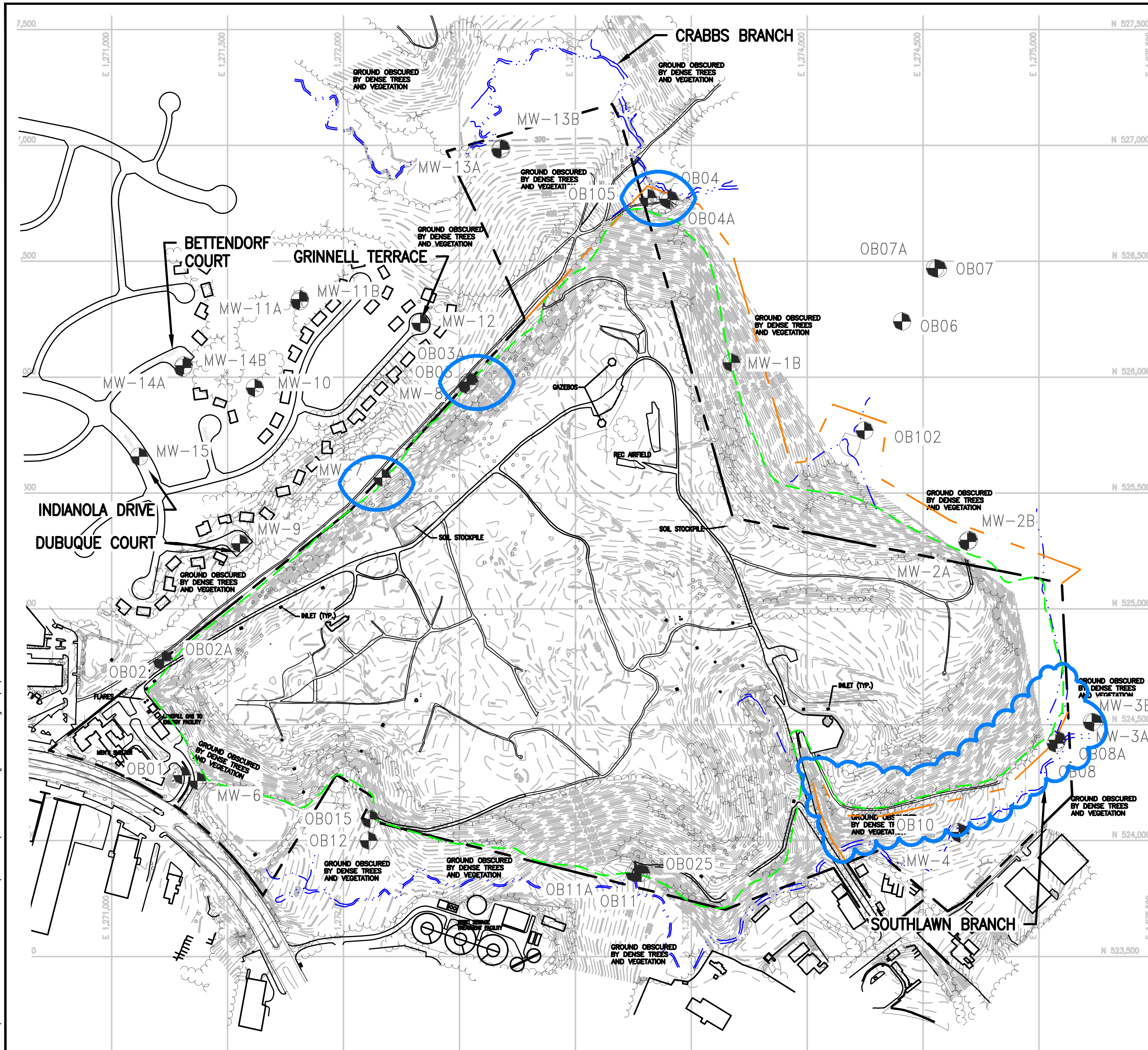

NOTES:

1. TOPOGRAPHY COMPILED BY APPLIED MAPPING SOLUTIONS, INC. USING PHOTOGRAMMETRIC METHODS WITH PHOTOGRAPHY DATED 06/24/09 AND SUPPLEMENTED WITH FIELD SURVEY PERFORMED BY C.C. JOHNSON & MALHOTRA, P.C., OCTOBER 2009.
2. HORIZONTAL DATUM IS NORTH AMERICAN DATUM OF 1983/91 (NAD-83/91). COORDINATE SYSTEM IS MARYLAND STATE PLANE, U.S. SURVEY FEET. VERTICAL DATUM IS NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD-88) WITH ELEVATIONS SHOWN IN FEET.
3. TOPOGRAPHY IS APPROXIMATE IN AREAS NOTED "GROUND OBSCURED BY DENSE TREES AND VEGETATION".
4. MONTGOMERY COUNTY IS CURRENTLY IN NEGOTIATIONS WITH M-NCPPC TO EXCHANGE TWO PARCELS OF LAND (LOCATED TO THE NORTH AND SOUTHEAST OF THE GUDE LANDFILL) FOR PROPERTY TO THE NORTHEAST. THE FUTURE PROPERTY BOUNDARY LINE REPRESENTS THE AGREED UPON PROPERTY BOUNDARY FOR THE GUDE LANDFILL FOLLOWING THE PROPERTY EXCHANGE. THE FUTURE PROPERTY BOUNDARY WAS ESTABLISHED WITH PERMANENT PROPERTY BOUNDARY MARKERS AND SURVEYED BY C.C. JOHNSON AND MALHOTRA, P.C. IN MAY 2012.
5. LOCATIONS OF HISTORICAL SEEPS SHOWN WERE IDENTIFIED AND REPAIRED BY MONTGOMERY COUNTY (2007-2010).

LEGEND

- 400 — 10-FT CONTOUR
- 2-FT CONTOUR
- CURRENT PROPERTY BOUNDARY
- FUTURE PROPERTY BOUNDARY
- LIMIT OF WASTE
- STREAM
- TREELINE
- MW-X/OBX — GROUNDWATER MONITORING WELL
- AREAS OF HISTORICAL NON-STORMWATER DISCHARGE OCCURENCES (LEACHATE SEEPS)
- PREVIOUS AREA OF NON-STORMWATER DISCHARGE OCCURRENCE EVALUATION (NOT LEACHATE SEEP RELATED)

500 250 0 500 1000

GRAPHIC SCALE IN FEET

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

GUDE LANDFILL
ASSESSMENT OF CORRECTIVE MEASURES
MONTGOMERY COUNTY, MARYLAND

FIGURE 2-6
APPROXIMATE AREAS OF CONCERN FOR NON-STORMWATER DISCHARGES BASED ON PAST OCCURRENCES OF LEACHATE SEEPS

DESIGNED BY	DRAWN BY	DATE	PROJECT NO.
SS	JSP	JUNE 2013	14982.01
CHECKED BY	PROJECT MGR.	DRAWING NO.	FIGURE
LJO	MG	–	2-6

FILE PATH: Q:\PROJECTS\1498201 GUDE PHASE 2 ACM\FIGURES\FIG 2-6.DWG [4-1 11X17] 10/8/13

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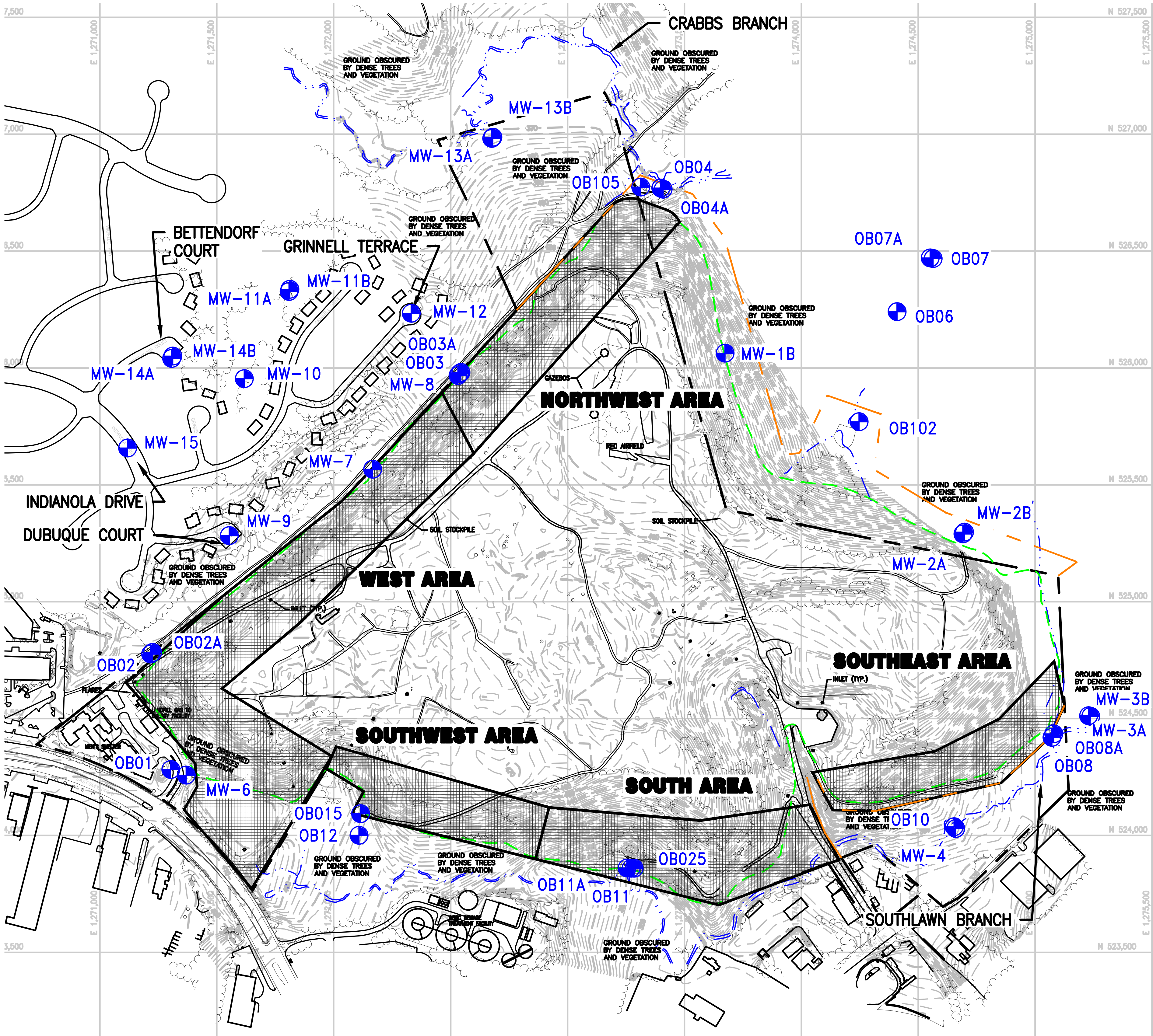

NOTES:

1. TOPOGRAPHY COMPILED BY APPLIED MAPPING SOLUTIONS, INC. USING PHOTOGRAMMETRIC METHODS WITH PHOTOGRAPHY DATED 06/24/09 AND SUPPLEMENTED WITH FIELD SURVEY PERFORMED BY C.C. JOHNSON & MALHOTRA, P.C., OCTOBER 2009.
2. HORIZONTAL DATUM IS NORTH AMERICAN DATUM OF 1983/91 (NAD-83/91). COORDINATE SYSTEM IS MARYLAND STATE PLANE, U.S. SURVEY FEET. VERTICAL DATUM IS NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD-88) WITH ELEVATIONS SHOWN IN FEET.
3. TOPOGRAPHY IS APPROXIMATE IN AREAS NOTED "GROUND OBSCURED BY DENSE TREES AND VEGETATION".
4. MONTGOMERY COUNTY IS CURRENTLY IN NEGOTIATIONS WITH M-NCPPC TO EXCHANGE TWO PARCELS OF LAND (LOCATED TO THE NORTH AND SOUTHEAST OF THE GUDE LANDFILL) FOR PROPERTY TO THE NORTHEAST. THE FUTURE PROPERTY BOUNDARY LINE REPRESENTS THE AGREED UPON PROPERTY BOUNDARY FOR THE GUDE LANDFILL FOLLOWING THE PROPERTY EXCHANGE. THE FUTURE PROPERTY BOUNDARY WAS ESTABLISHED WITH PERMANENT PROPERTY BOUNDARY MARKERS AND SURVEYED BY C.C. JOHNSON AND MALHOTRA, P.C. IN MAY 2012.

LEGEND

400	10-FT CONTOUR
	2-FT CONTOUR
	CURRENT PROPERTY BOUNDARY
	FUTURE PROPERTY BOUNDARY
	LIMIT OF WASTE
	STREAM
	TREELINE
MW-X/OBX	GROUNDWATER MONITORING WELL
	APPROXIMATE REMEDIATION AREAS FOR CORRECTIVE MEASURE ALTERNATIVES ANALYSIS

500 250 0 500 1000

GRAPHIC SCALE IN FEET

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EA ENGINEERING, SCIENCE, AND TECHNOLOGY

GUDE LANDFILL
ASSESSMENT OF CORRECTIVE MEASURES
MONTGOMERY COUNTY, MARYLAND

FIGURE 4-1
APPROXIMATE REMEDIAL AREAS FOR CORRECTIVE MEASURE ALTERNATIVES ANALYSIS

DESIGNED BY	DRAWN BY	DATE	PROJECT NO.
SS	JSP	APR. 2013	14982.01
CHECKED BY	PROJECT MGR.	DRAWING NO.	FIGURE
PC	JK	-	4-1

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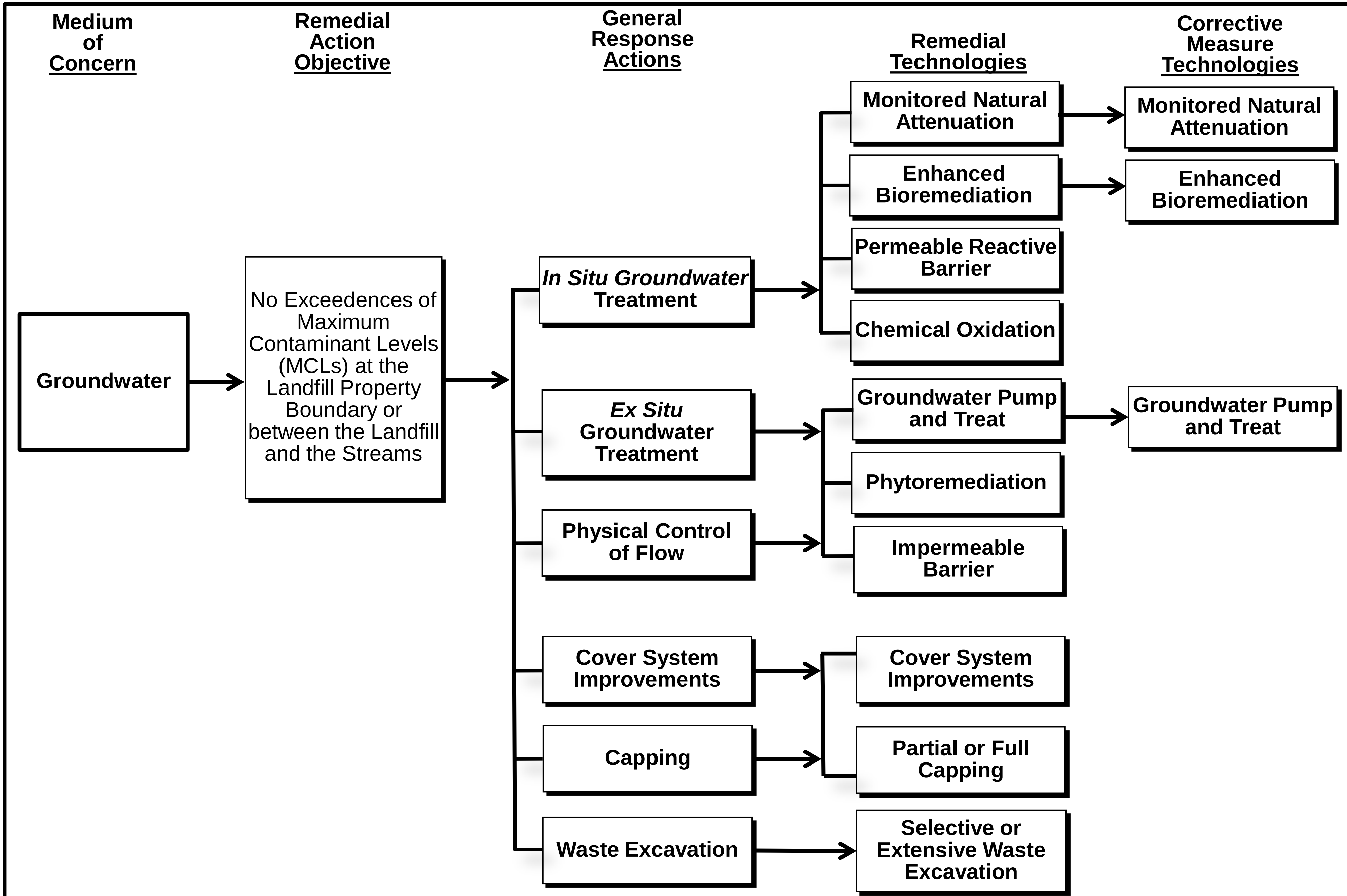

EA ENGINEERING, SCIENCE, AND TECHNOLOGY	GUDE LANDFILL ASSESSMENT OF CORRECTIVE MEASURES	FIGURE 4-2 Screening of Remedial Technologies to be Retained for Groundwater	DATE OCTOBER 2013 PROJECT NO. 14982.01

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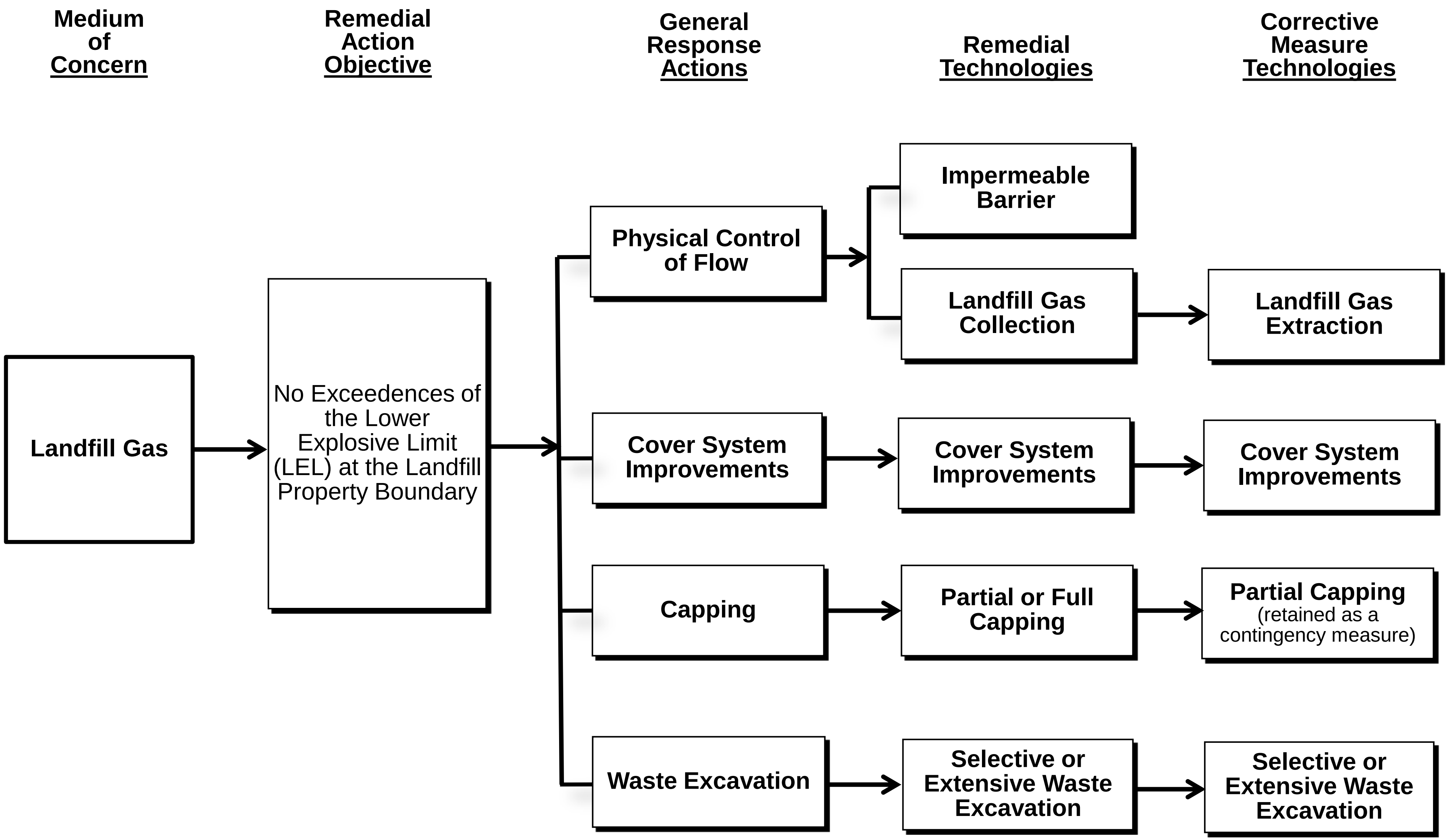

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

GUDE LANDFILL ASSESSMENT OF CORRECTIVE MEASURES

FIGURE 4-3
Screening of Remedial Technologies to be Retained for Landfill Gas

DATE OCTOBER 2013

PROJECT NO. 14982.01

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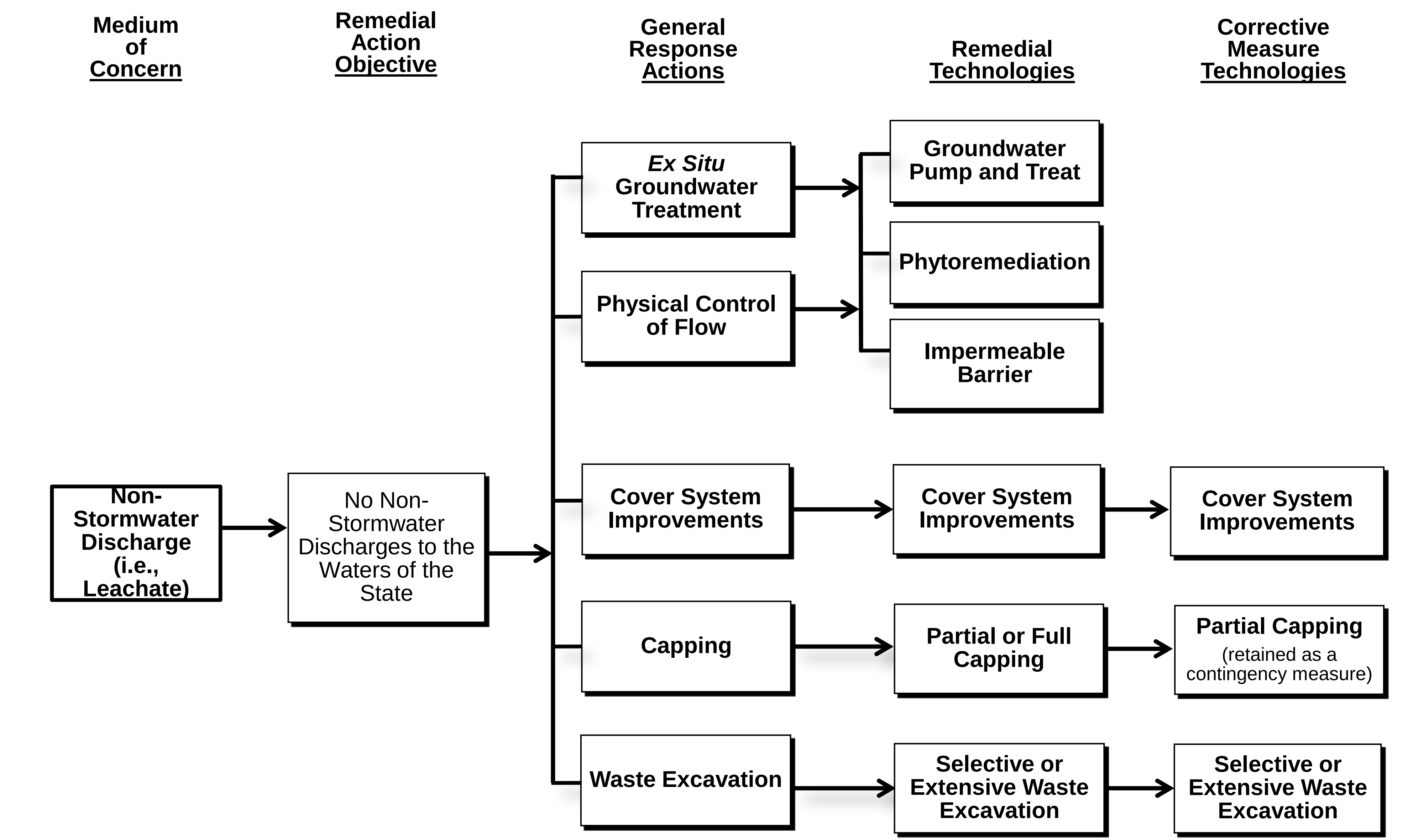

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

GUDE LANDFILL
ASSESSMENT OF CORRECTIVE MEASURES

FIGURE 4-4
Screening of Remedial Technologies to be Retained for Non-Stormwater Discharge

DATE OCTOBER 2013

PROJECT NO. 14982.01

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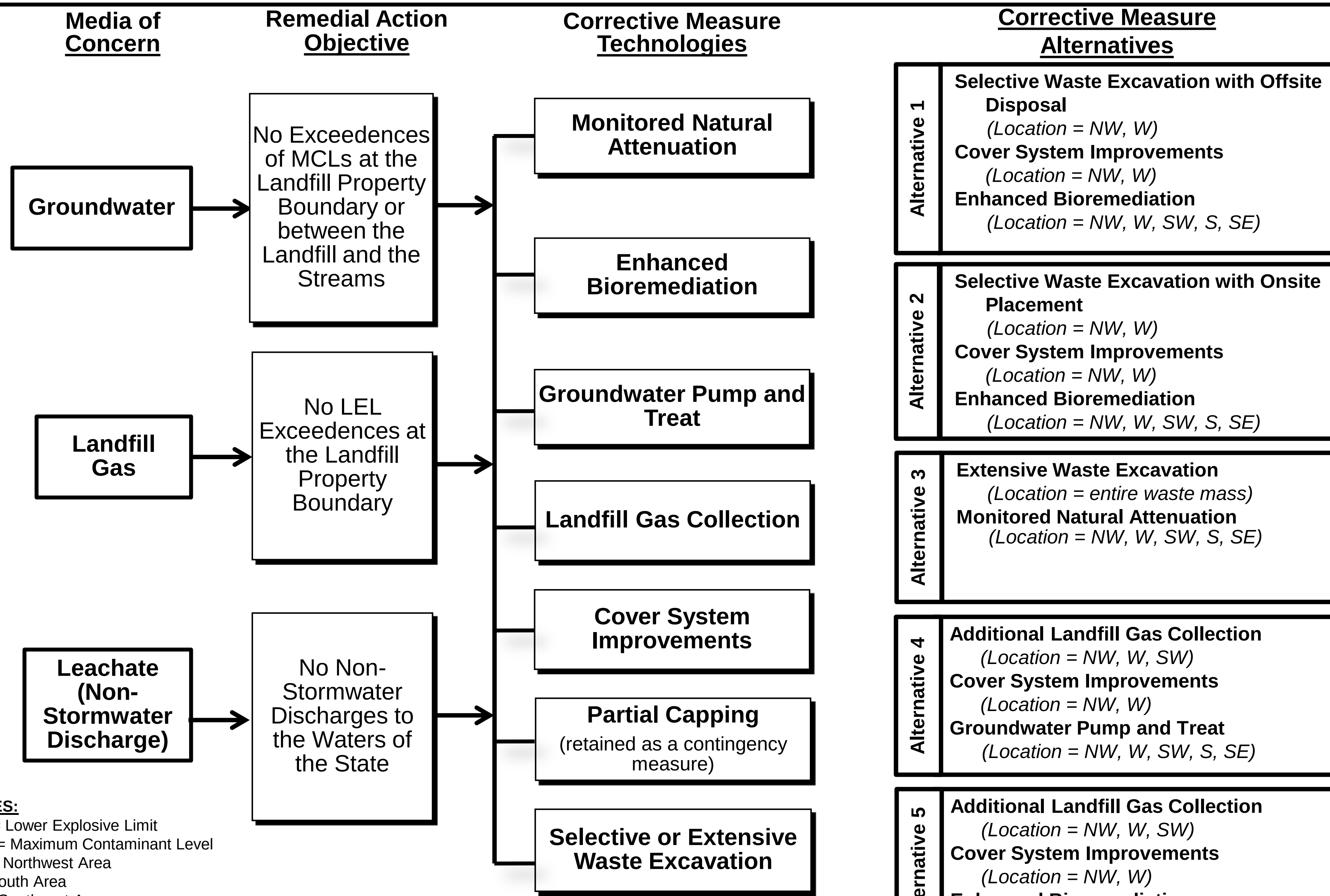

NOTES:

LEL = Lower Explosive Limit
MCL = Maximum Contaminant Level
NW = Northwest Area
S = South Area
SE = Southeast Area
SW = Southwest Area
W = West Area
(See Figure 4-4 for Area locations)

Note: A phased approach will be designed, to prioritize remediation by location and to address changes in environmental conditions as each technology is applied.

EA ENGINEERING, SCIENCE, AND TECHNOLOGY	GUDE LANDFILL ASSESSMENT OF CORRECTIVE MEASURES	FIGURE 4-5 Corrective Measure Alternatives for Implementation of Technologies for All Media	DATE OCTOBER 2013 PROJECT NO. 14982.01

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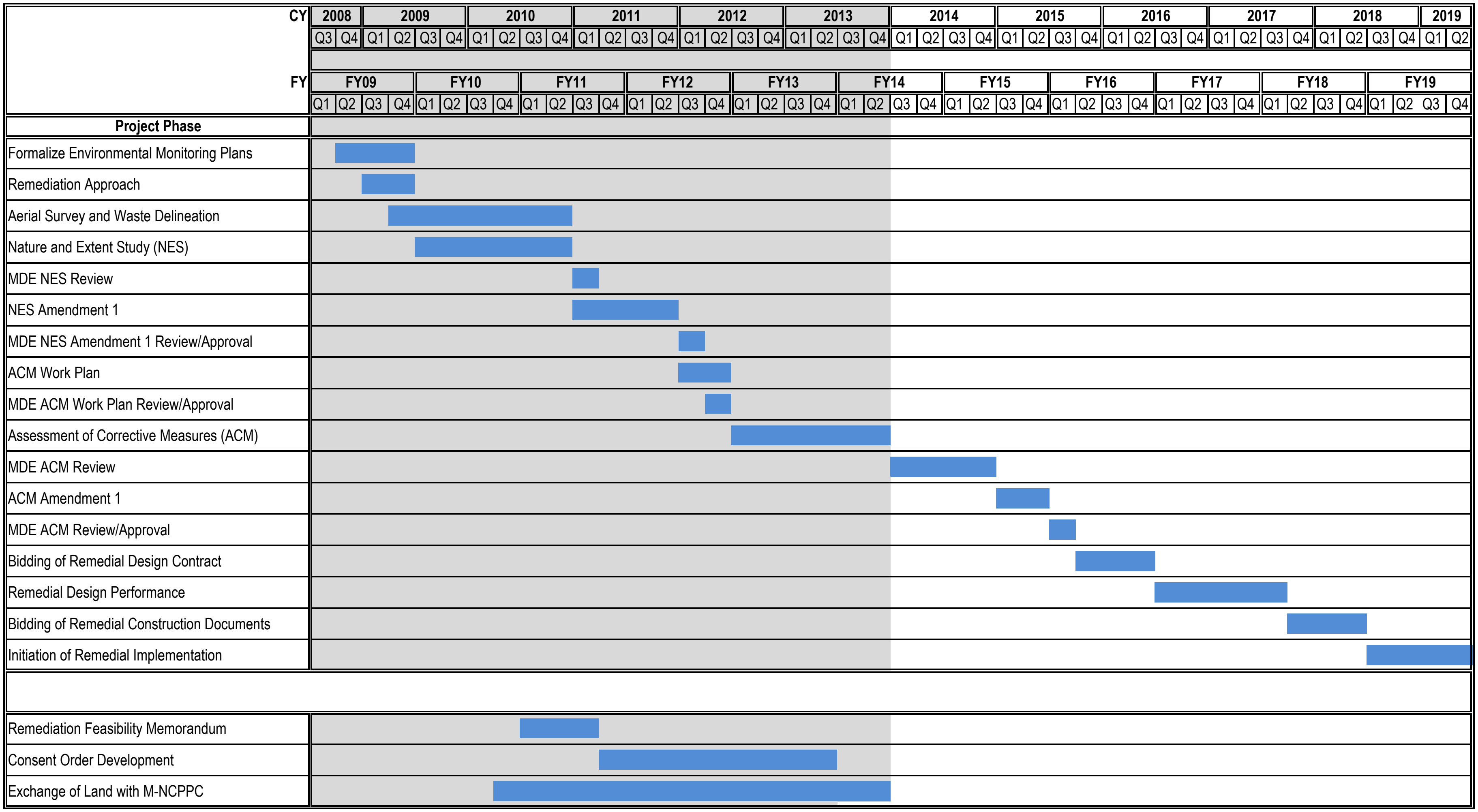
FIGURE 5-1
GUDE LANDFILL REMEDIATION PRELIMINARY PROJECT SCHEDULE

10/17/2013



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TABLES

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TABLE 1-1 SUMMARY OF CONSTRUCTION DATA FOR GROUNDWATER MONITORING WELLS CONSTRUCTED PRIOR TO 2010
600 EAST GUDE DRIVE, ROCKVILLE, MARYLAND 20850

Well ID	Permit #	Date Installed	Drilling Method	Diameter (inches)	Reported Total Depth (ft bgs)	Measured Total Depth - 10/22/2009 and 10/23/2009 (ft bgs)	Casing Depth (ft bgs)	Screen Depth (ft bgs)	Historical Depth to GW (ft bgs)	Geology
OB01	MO880058	4/26/88	HSA / Mud Rotary	2	75	76.42	35	35-75	10-15	0-30 feet : unknown, 30-77 feet : rock
OB02	MO880059	5/20/88	Mud Rotary	2	121	113.25	71	no screen - open from 71-121'	10-17	0-21 feet : red clay & saprolite, 21-121 feet : rock
OB02A	MO880060	5/13/88	Mud Rotary	2	77	76.4	37	37-77	10-17	0-26.5 feet : unknown, 26.5-77 feet : rock
OB03	MO880061	6/30/88	Mud Rotary	2	154	133.13	104	104-154	16-24	0-54 feet : red clay & saprolite, 54- 154 feet : rock
OB03A	MO880062	7/8/88	Mud Rotary	2	97	94.55	50	50-97	15-25	0-47 feet : red clay & saprolite, 47-97 feet : rock
OB04	MO880063	7/22/88	Mud Rotary	2	136	131.66	86	86-136	1-3	0-30 feet : red clay & saprolite, 30-36 feet : decomposed rock, 36-136 feet : rock
OB04A	MO880064	7/29/88	Mud Rotary	2	83	81.92	33	33-83	1-4	0-3 feet : fill, 3-33 feet sandy silt with rock & quartz, 33-83 feet : rock
OB06	MO880065 *			2		66.63	Well Completion Report Missing		4-10	
OB07	MO880066 *	8/7/88	Mud Rotary	2	81	142.87	31	31-81	2-10	0-31 feet : saprolite, 31-81 feet : rock
OB07A	MO880067 *	8/30/88	Mud Rotary	2	76	97.17	26	26-76	2-8	0-26 feet : clay & saprolite, 26-76 feet : rock
OB08	MO880068 *	8/26/88	Mud Rotary	2	109	137.01	59	59-109	0-5	0-57 feet : saprolite, 57-109 feet : rock
OB08A	MO880069 *	10/5/88	Mud Rotary	2	145	79.25	95	95-145	1-6	0-40 feet : saprolite, 40-145 feet : rock
OB10	MO880070 *			2		66.82	Well Completion Report Missing		1-5	
OB11	MO880071 *	10/12/88	Mud Rotary	2	90	100.9	40	40-90	4-7	0-40 feet : saprolite, 40-90 feet : rock
OB11A	MO880072*			2		64.3	Well Completion Report Missing		3-7	
OB12	MO880073*			2		25.58	Well Completion Report Missing		12-17	
OB15	*			4	27.5	22.79	Well Completion Report Missing		16-21	
OB25	*			4	15	15.46	Well Completion Report Missing		3-7	
OB102	*			4	24.5	22.2	Well Completion Report Missing		7-11	
OB105	*			4	13	16.5	Well Completion Report Missing		0-2	

Notes:
GW=groundwater
ft=feet
HSA=hollow stem auger
bgs=below ground surface
* indicates missing well completion reports or reports that indicate conflicting well identification information and total depth measurements that do not match the total depths on the completion reports
Reported total depth data is from well completion reports. For wells OB15, OB25, OB102 and OB105 the total reported total depth data was provided by Montgomery County

TABLE 1-2 SUMMARY OF CONSTRUCTION DATA FOR GROUNDWATER MONITORING WELLS INSTALLED AS PART OF THE NATURE AND EXTENT STUDY (2010)
600 EAST GUDE DRIVE, ROCKVILLE, MARYLAND 20850

Well ID	Permit #	Date Installed	Drilling Method	Diameter (inches)	Total Depth (ft bgs)	Casing Depth (ft bgs)	Screen Depth (ft bgs)	Depth to GW - July 2010 (nearest ft bgs)	Geology
MW-1	MO951146	6/4/2010	HSA and Air Rotary	2	98	78	78-98	45	0-40 ft: brown-yellow, dry fine sand and silt, 40-98 ft: rock
MW-2A	MO951137	6/9/2010	HSA and Air Rotary	2	78	55	55-75	62	0-28 ft: brown, dry fine sand and silt, 28-75 ft: rock
MW-2B	MO951138	6/17/2010	HSA and Air Rotary	2	110	89	88-108	61	0-22 ft: brown, dry fine sand and silt, 22-108 ft: rock
MW-3A	MO951140	6/18/2010	HSA	2	25	5	5-25	10	0-25 ft: brown, moist to wet, fine to medium sand and silt
MW-3B	MO951139	6/22/2010	HSA and Air Rotary	2	96	76	76-96	11	0-35 ft: brown, moist to wet fine sand and silt; 35-96 ft: rock
MW-4	MO951151	7/6/2010	HSA	2	25	5	5-25	7	0-25 ft: brown, wet fine sand and silt
MW-6	MO951149	6/22/2010	HSA	2	25	5	5-25	16	0-10 ft: brown, dry fine sand and silt, 10-26 ft: brown and white, wet sand and clay
MW-7	MO951147	6/24/2010	HSA and Air Rotary	2	53	33	33-53	43	0-16 ft: brown and white, moist to dry fine sand and silt, 16-58 ft: rock
MW-8	MO951148	6/23/2010	HSA and Air Rotary	2	30	10	10-30	24	0-25 ft: brown fine sand and silt (moist 0-10 ft), 25-30 ft: rock
MW-9	MO951141	7/6/2010	HSA	2	25	5	5-25	19	0-1 ft: asphalt and base, 1-25 ft: brown sand and silt (moist 15-25 ft)
MW-10	MO951142	7/2/2010	HSA	2	25	5	5-25	8	0-9 ft: gray-brown, dry clay and silt, 9-25 ft: brown, moist fine sand and silt
MW-11A	MO951143	6/30/2010	HSA	2	30	10	10-30	17	0-31 ft: brown dry silt with fine sand (moist 15-31 ft)
MW-11B	MO951136	6/30/2010	HSA and Air Rotary	2	93	73	73-93	18	0-35 ft: brown fine sand and silt (some moist 15-30 ft), 35-93 ft: rock
MW-12	MO951144	7/6/2010	HSA	2	25	5	5-25	15	0-1 ft: asphalt and base, 1-25 ft: brown fine sand and silt (moist 13-25 ft)
MW-13A	MO951150	6/25/2010	HSA	2	25	5	5-25	7	0-25 ft: brown, moist to wet, fine sand and silt
MW-13B	MO951152	6/29/2010	HSA and Air Rotary	2	95	75	75-95	6	0-49 ft: brown fine sand and silt (moist to wet below 6 ft); 49-95 ft: rock

Notes:
GW = groundwater
ft = feet
HSA = hollow stem auger
bgs=below ground surface

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TABLE 1-3

SUMMARY OF CONSTRUCTION DATA FOR GROUNDWATER MONITORING WELLS INSTALLED AS PART OF THE NATURE AND EXTENT STUDY, AMENDMENT NO. 1 (2011)

Well ID	Permit #	Date Installed	Drilling Method	Diameter (inches)	Total Depth (ft bgs)	Casing Depth (ft bgs)	Screen Depth (ft bgs)	Depth to GW - August 2011 (nearest ft bgs)	Geology
MW-14A	MO100151	8/1/2011	HSA and Air Hammer	2	40	30	30-40	21	0-2 ft: asphalt and fill; 2-40 ft: brown silt and fine sand
MW-14B	MO100149	8/2/2011	HSA and Air Hammer	2	98	88	88-98	23	0-2 ft: asphalt and fill; 2-40 ft: brown silt and fine sand; 40-70 ft: weathered rock; 70-100 ft: rock
MW-15	MO100150	8/3/2011	HSA	2	40	30	30-40	6	0-2 ft: asphalt and fill; 2-40 ft: brown silt and fine sand
TGW-1	NA	8/22/2011	Power Auger	1	8	3	3-8	4	Boring locations was installed using a 4" power auger. As such, soils were highly disturbed and unconsolidated. In general, soils consisted of brown clayey silt with clay content increasing with depth.
TGW-2	NA	8/23/2011	Power Auger	1	8	3	3-8	5	Boring locations was installed using a 4" power auger. As such, soils were highly disturbed and unconsolidated. In general, soils consisted of brown clayey silt with clay content increasing with depth.
TGW-3	NA	8/23/2011	Power Auger	1	8	3	3-8	5	Boring locations was installed using a 4" power auger. As such, soils were highly disturbed and unconsolidated. In general, soils consisted of brown clayey silt with clay content increasing with depth.
TGW-4	NA	8/22/2011	Power Auger	1	8	3	3-8	5	Boring locations was installed using a 4" power auger. As such, soils were highly disturbed and unconsolidated. In general, soils consisted of brown clayey silt with clay content increasing with depth.
TGW-5	NA	8/22/2011	Power Auger	1	8	3	3-8	7	Boring locations was installed using a 4" power auger. As such, soils were highly disturbed and unconsolidated. In general, soils consisted of brown clayey silt with clay content increasing with depth.
TGW-6	NA	8/8/2011	Hand and Power Augers	1	7	2	2-7	3	0-0.5 ft: topsoil; 0.5-1 ft: brown silt and clay; 1-3 ft: clay; 3-4 ft: clay and soft cobbles; 4-7 ft: cobbles
TGW-7	NA	8/8/2011	Hand and Power Augers	1	7	2	2-7	4	0-0.5 ft: topsoil; 0.5-1 ft: brown silt and clay; 1-3 ft: clay; 3-4 ft: clay and soft cobbles; 4-7 ft: cobbles
TGW-8	NA	8/8/2011	Hand and Power Augers	1	7	2	2-7	3	0-0.5 ft: topsoil; 0.5-2 ft: brown silt; 2-4 ft: clay; 4-7 ft: cobbles
TGW-9	NA	8/8/2011	Hand and Power Augers	1	6	1	1-6	2	0-0.5 ft: topsoil; 0.5-1 ft: brown silt and clay; 1-3 ft: clay; 3-6 ft: cobbles and sand
TGW-10	NA	8/5/2011	Hand Auger	1	6	2.5	2.5-6	3	0-0.5 ft: topsoil; 0.5-1 ft: brown silt and clay; 1-4 ft: clay; 4-6 ft: clay and gravel

Notes:

(1) MW-14A, MW-14B and MW-15 were installed as permanent groundwater monitoring wells in 2011.

(2) TGW-1 through TGW-10 were installed and decommissioned as temporary groundwater monitoring wells in 2011 following data collecti

Abbreviations:

GW = groundwater

ft = feet

HSA = hollow stem auger

bgs = below ground surface

NA = Not Applicable

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TABLE 1-4 SUMMARY OF CONSTRUCTION DETAILS FOR LANDFILL GAS EXTRACTION WELLS AND DEWATERING SUMPS

WELL ID	NORTHING	EASTING	ELEV. (ft)	TOTAL DEPTH (ft)	SOLID PIPE LENGTH (ft)	SLOTTED PIPE LENGTH (FT)
EW-1	524685.00	1271739.00	457.2	30	NA	NA
EW-2	524876.02	1271974.08	459.2	38	NA	NA
EW-3	525075.99	1272253.00	460.2	46	NA	NA
EW-4	525283.77	1272528.88	462.2	33	NA	NA
EW-5	525493.34	1272811.88	462.3	32	NA	NA
EW-6	525701.57	1273090.18	471.5	36	NA	NA
EW-7	525846.59	1273424.41	473.9	51	NA	NA
EW-9	525547.12	1272540.42	463.3	36	NA	NA
EW-10	525795.74	1272803.67	467.5	42	NA	NA
EW-11	526021.70	1272991.79	471.4	41	NA	NA
EW-12	526216.87	1273096.54	473.7	49.5	NA	NA
EW-13	526061.43	1273237.95	475.9	50	NA	NA
EW-14	526177.00	1273268.00	475.1	41	NA	NA
EW-15	525548.12	1273428.12	466.6	35	NA	NA
EW-16	525259.00	1273410.00	458.8	46	NA	NA
EW-17	525256.92	1273728.72	467.7	49	NA	NA
EW-18	525149.25	1274038.96	462.2	38	NA	NA
EW-19	525112.14	1274359.13	465.1	30	NA	NA
EW-20	524988.08	1274602.77	461.2	30	NA	NA
EW-21	524593.90	1271512.61	457.3	32	NA	NA
EW-22	524521.95	1271711.42	460.1	NA[1]	NA	NA
EW-23	524570.40	1272053.18	455.5	NA[1]	NA	NA
EW-24	524386.03	1272325.10	462.6	52	NA	NA
EW-25	524503.28	1273291.42	446.5	28	NA	NA
EW-26	524732.78	1272290.61	456.2	31	NA	NA
EW-27	524593.89	1272608.79	462.2	31	NA	NA
EW-28	524972.00	1272609.00	462.7	30.5	NA	NA
EW-29	524439.03	1272706.65	463.5	25	NA	NA
EW-30	524454.54	1272924.70	461.8	47	NA	NA
EW-31	524286.07	1273115.03	456.2	NA[2]	NA	NA
EW-32	524277.02	1273460.89	455.7	33	NA	NA
EW-34	524765.29	1273183.56	453.1	52	NA	NA
EW-35	524679.16	1273420.41	444.3	41	NA	NA
EW-36	525153.10	1272841.37	459.0	36	NA	NA
EW-37	525060.72	1273123.93	448.3	32	NA	NA
EW-38	524957.57	1273418.77	442.2	31	NA	NA
EW-39	525372.84	1273110.22	463.5	44	NA	NA
EW-40	524912.83	1273900.40	434.4	44	NA	NA
EW-41	524914.46	1274173.29	439.8	44	NA	NA
EW-43	524687.94	1274382.92	440.8	40	NA	NA
EW-44	524718.77	1274594.03	449.9	29	NA	NA
EW-50	524691.93	1271877.94	459.9	22.5	NA	NA
EW-51	524763.79	1272055.46	456.1	25	NA	NA
EW-52	524891.63	1272170.36	462.8	28	NA	NA
EW-54	524766.93	1272474.42	461.7	35	NA	NA

Notes:

Total Depth for Wells EW-1 to EW-76 is based on well sounding data, with the exception of EW-07, EW-14, EW-19, and EW-20, for which depth was measured using a water level meter. No information regarding pipe lengths is available for these wells.

1. Field observations note that EW-22 and EW-23 make a 90-degree turn underground; therefore, total depth was undetermined.
2. Well blockage at 9 ft prevented measurement of total depth of EW-30.

EW = Extraction Well
ft = foot/feet
NA = Not Available.

TABLE 1-4 SUMMARY OF CONSTRUCTION DETAILS FOR LANDFILL GAS EXTRACTION WELLS AND DEWATERING SUMPS

WELL ID	NORTHING	EASTING	ELEV. (ft)	TOTAL DEPTH (ft)	SOLID PIPE LENGTH (ft)	SLOTTED PIPE LENGTH (FT)
EW-57	524919.03	1272744.09	458.1	20	NA	NA
EW-62	525373.34	1272925.64	463.4	37	NA	NA
EW-70	524798.39	1271853.88	457.8	44	NA	NA
EW-71	524968.25	1272111.25	460.4	54	NA	NA
EW-72	524916.85	1272370.37	462.7	58	NA	NA
EW-73	525063.91	1272423.74	467.5	60	NA	NA
EW-74	524839.17	1272607.41	462.1	35	NA	NA
EW-75	524731.77	1272784.69	463.3	26	NA	NA
EW-76	524633.45	1272904.48	461.7	86	NA	NA
EW-100	524720.11	1271278.73	424.2	31	26	9
EW-101	524811.95	1271412.16	430.4	46	26	22
EW-102	524886.23	1271542.61	436.8	39	26	15
EW-103	524988.85	1271598.64	441.5	42	26	18
EW-104	525060.49	1271733.51	447.0	47	26	23
EW-105	525164.44	1271858.58	454.1	53	26	29
EW-106	525249.97	1271981.61	457.1	52	26	28
EW-107	525336.35	1272096.28	458.7	53	26	29
EW-108	525497.90	1272169.22	441.5	27	17	12
EW-109	525603.00	1272277.00	436.6	29	17	14
EW-110	525704.87	1272360.68	431.4	37	26	13
EW-111	525817.47	1272488.84	429.0	45	26	21
EW-112	525904.52	1272583.62	430.8	46	26	24
EW-113	526003.53	1272672.42	431.0	46	26	24
EW-114	526101.61	1272780.92	438.9	39	26	15
EW-115	526192.18	1272873.96	441.4	35	26	11
EW-116	526318.49	1272986.92	445.6	35	26	11
EW-117	524967.94	1271555.75	438.8	25	17	10
EW-118	525001.19	1271605.01	440.7	25	17	10
EW-119	525066.58	1271720.89	448.0	27	17	10
EW-120	525207.25	1271930.45	456.4	20	8	15
EW-121	525323.59	1272075.20	458.6	20	8	15
EW-122	525648.32	1272307.35	432.6	20	8	15
EW-123	525383.41	1272110.40	452.9	25	13	15
EW-124	525421.31	1272125.05	448.1	25	13	15
EW-125	525359.90	1272145.69	459.2	50	20	35
EW-126	525400.00	1272123.00	452.6	35	20	20
EW-127	525429.53	1272155.44	450.5	45	20	30
EW-128	525456.40	1272230.71	459.2	40	20	25
EW-129	525521.55	1272311.17	457.9	40	20	25
EW-130	525607.48	1272377.21	455.6	45	20	30
EW-131	524778.92	1271581.48	455.5	52	20	37
EW-132	524846.00	1271685.00	456.8	52	20	37
EW-133	525261.61	1271909.81	439.5	29	14	19
EW-134	525199.19	1271828.98	439.0	29	14	19
EW-135	524680.43	1271206.29	422.0	21	11	14

Notes:

Total Depth for Wells EW-1 to EW-76 is based on well sounding data, with the exception of EW-07, EW-14, EW-19, and EW-20, for which depth was measured using a water level meter. No information regarding pipe lengths is available for these wells.

EW = Extraction Well

ft = foot/feet
NA = Not Available.

TABLE 1-4 SUMMARY OF CONSTRUCTION DETAILS FOR LANDFILL GAS EXTRACTION WELLS AND DEWATERING SUMPS

WELL ID	NORTHING	EASTING	ELEV. (ft)	TOTAL DEPTH (ft)	SOLID PIPE LENGTH (ft)	SLOTTED PIPE LENGTH (FT)
EW-136	524640.94	1271284.24	440.0	39	20	19
EW-137	524523.32	1271403.94	442.0	42	20	22
EW-138	524486.44	1271599.57	460.0	60	20	40
EW-139	524359.00	1271494.71	432.0	31	20	11
EW-140	524316.23	1271661.36	436.0	36	20	16
EW-141	524387.61	1271785.77	449.0	49	20	29
EW-142	524255.40	1271845.55	425.0	25	15	10
EW-143	524564.48	1271882.53	461.0	61	20	41
EW-144	524421.88	1271991.25	436.0	36	20	16
EW-145	524488.22	1272141.68	452.0	57	20	37
EW-146	524322.34	1272152.77	440.0	40	20	20
EW-147	524204.35	1272207.62	447.0	46	20	26
EW-148	524199.79	1272396.11	467.0	55	20	35
EW-149	524182.15	1272617.55	467.0	51	20	31
EW-150	524994.77	1271870.80	458.0	48	20	28
EW-151	525099.63	1272020.66	459.0	49	20	29
EW-152	525204.94	1272172.12	459.0	52	20	29
EW-153	525227.79	1272360.73	462.0	52	20	32
DS-0	524837.00	1271493.74	439.0	20	NA	NA
DS-1	525047.36	1271945.43	453.0	48	20	28
DS-2	525241.55	1272058.82	459.0	53	20	29
DS-3	525295.36	1272221.31	459.0	51	20	29
DS-4	525516.11	1272404.03	464.0	54	20	34
DS-5	525386.30	1272671.91	449.0	50	20	30

Notes:
EW = Extraction Well
ft = foot/feet
DS = Dewatering Sump
NA = Not Available.

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TABLE 1-5

TIMELINE OF PRE-REMEDIATION SITE ACTIVITIES AT THE GUDE LANDFILL

ID	Activity	Designation	MDE Notice (County Initiation)	County Submission	MDE Approval
1	Formalize the Landfill Gas Monitoring Plan	Site Management	December 2008	April 2009	April 2009
2	Formalize the Groundwater and Surface Water Monitoring Plan	Site Management	January 2009	March 2009	May 2009
3	Remediation Approach Work Plan	Site Management	January 2009	April 2009	May 2009
4	Waste Delineation Study	Site Characterization	May 2009	January 2010	March 2012
5	Nature and Extent Study	Site Characterization	May 2009	November 2010	Comments Received (1)
6	Nature and Extent Study Amendment No.1	Site Characterization	February 2011	November 2011	March 2012
7	Assessment of Corrective Measures Work Plan	Site Management	March 2012	May 2012	June 2012
8	Consent Order	Site Management	May 2011	Multiple Submissions (2)	May 2013

ID	Activity	Designation	County Initiation	County Completion	Entity Approval
9	Remediation Feasibility Memorandum	Site Evaluation	July 2010	January 2011	---
10	Exchange of Land with M-NCPPC	Site Management	April 2010	September 2013	To Be Determined
11	Remediation Project Meetings with Community	Information Sharing	June 2009	On-Going	---
12	Remediation Project Webpage	Information Sharing	June 2009	On-Going	---

Notes:

1. This activity received MDE comments in February 2011 that required additional investigative field work and reporting.
2. This activity required multiple submissions and reviews by Montgomery County and MDE.

MDE = Maryland Department of the Environment

M-NCPPC = Maryland-National Capitol Park and Planning Commission

TABLE 1-6
COUNTY CONTACT AND WEBPAGE INFORMATION

Montgomery County Department of Environmental Protection, Division of Solid Waste Services
County Contact Information

Name	Title	Address	Telephone	Email
Peter R. Karasik	Central Operations Section Chief	Shady Grove Processing Facility and Transfer Station 16101 Frederick Road, Derwood, MD 20855	(240)-777-6569	Peter.Karasik@montgomerycountymd.gov
Jamie C. Foster	Engineer I	Shady Grove Processing Facility and Transfer Station 16101 Frederick Road, Derwood, MD 20855	(240)-777-6564	Jamie.Foster@montgomerycountymd.gov

Montgomery County Department of Environmental Protection, Division of Solid Waste Services
Remediation Webpage Address

http://www6.montgomerycountymd.gov/swstmpl.asp?url=/content/dep/solidwaste/facilities/gude/index.asp

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TABLE 4-1: CASE STUDIES FOR REMEDIAL TECHNOLOGIES

Site, Location, and Citation(s)	Dates Operation	Contaminants and Site Characteristics	Technological Details	Outcomes	Approximate Costs
			Monitored Natural Attenuation		
Onalaska Municipal Landfill Superfund Site, Onalaska, Wisconsin (EPA 2006, 2008a)	2001-present	• VOCs (including Toluene and TCE), metals, SVOCs • Contaminated groundwater area 10-70 ft bgs	• MNA study began in 2001 and P&T system shutdown • 26 monitoring points including air injection wells, piezometers, monitoring wells, and residential wells	• P&T system shutdown in 2001 for a natural attenuation study. • After 2 years of MNA, trimethylbenzenes, methylene chloride, iron and manganese remained at concentrations above cleanup goals. • Potential for reductive dechlorination observed at the site, aerobic conditions in groundwater. • 2008 MNA Study did not recommend the adoption of MNA as a remedy because data supporting MNA is not strong enough.	Not Available
Somersworth Sanitary Landfill Superfund Site, Somersworth, New Hampshire (EPA 2005a)	1996-2004	• Unconfined sand and gravel aquifer 15-75 ft thick over fractured metamorphic bedrock • Groundwater discharges to brook and wetland • Groundwater contains low concentrations of VOCs	• Preferred Source Control Remedy includes installation of a chemical treatment wall (CTW) and a permeable cover • Management of Migration Remedy includes bedrock groundwater extraction and natural attenuation occurring downgradient of the CTW • Groundwater monitoring • Landfill gas venting trench (2003)	• Groundwater monitoring network installed in 1980s. • In 1994 VOCs in groundwater appeared to have reached a steady state condition, extending to 1,700 ft downgradient. • In 4 years, the extent and overall VOC concentration had decreased even more, indicating natural attenuation is occurring. • Sampling for natural attenuation parameters supports that this is ongoing. • Thorough evaluation of lines of evidence for natural attenuation is necessary.	• $900,000 for O&M and monitoring excluding landfill gas trench

Note: Definitions for abbreviations are provided on Page 12.

TABLE 4-1: CASE STUDIES FOR REMEDIAL TECHNOLOGIES

Site, Location, and Citation(s)	Dates Operation	Contaminants and Site Characteristics	Technological Details	Outcomes	Approximate Costs
Monitored Natural Attenuation (continued)					
Former Railroad Maintenance Facility, Sanford, Florida (Lacko et al. 2001)	1994-2000	• Industrial site • 15 ft of fine grained sand with some silt • Groundwater depth: 5 ft • VOCs including PCE; TCE; DCE, and VC • Anaerobic conditions in affected area, high alkalinity and suitable pH range for natural attenuation	• Removal of 6,700 gallons of liquid and sludge from maintenance pits and excavation of 6,000 tons of impacted soil • 15-25 wells sampled to determine groundwater quality in 1994 and 1999 • Further assessment and monitoring of VOCs continued to evaluate groundwater quality • Subsequent monitoring reduced to six wells	• VOCs appear to be naturally attenuating due to anthropogenic and biologically available native organic matter • VOCs only detected in a few wells. • Maximum concentration of VOCs is VC, indicating natural attenuation is occurring. • VC is reducing to ethane and ethane under reducing conditions.	Not Available
Enhanced Bioremediation					
Savannah River Site, Aiken South Carolina (Ross et al. 2007)	1999-2005	• PCE and TCE in groundwater • Contaminants in upper 30 ft of aquifer	• Closed with geosynthetic cap in1997 • Biosparging began 1999 • Horizontal wells 60 ft bgs • Methane and air injected to stimulate methane oxidizing organisms to mineralize TCE • Air injected for aerobic degradation of VC	• Biosparging suspended in 2005 because VOC levels dropped below alternate concentration limits. • Landfill cap and natural physical attenuation are expected to decrease chlorinated VOC concentrations to below MCL.	• $ 1 million – 2 horizontal wells • $750,000 - construction of injection pad/ piping • $225,000/yr-biosparging • $215,000/yr-monitoring
Avco Lycoming Superfund Site, Williamsport, Pennsylvania (EPA 2000a)	1995-1996 (pilot) 1997-2000 (full-scale)	• TCE, DCE, VC, • Groundwater 10-15 ft bgs • Sandy silt over fractured bedrock	• P&T in the late 1980s for onsite and offsite • Molasses injection to remediate groundwater in overburden	• Within 18 months, redox levels decreased to anaerobic conditions from aerobic environments. • Concentrations of TCE, DCE and Cr+6 have decreased to less than the cleanup goals in many of the monitoring wells.	• $145,000 for pilot • $220,000 to construct full scale injection system • $50,000/yr O&M

Note: Definitions for abbreviations are provided on Page 12.

TABLE 4-1: CASE STUDIES FOR REMEDIAL TECHNOLOGIES

Site, Location, and Citation(s)	Dates Operation	Contaminants and Site Characteristics	Technological Details	Outcomes	Approximate Costs
			Enhanced Bioremediation (continued)		
Kelly Air Force Base Demonstration, San Antonio, Texas (USDOD 2007)	1999-2001	• 20-40 ft of alluvial gravel, sand, and silt overlying impermeable clay • Groundwater 5-10 ft bgs	• Methanol and acetate (electron donors) injected continuously (2000) • Closed loop recirculation for hydraulic isolation • Bioaugmentation with *Dehalococcoides*	• 90% reduction in PCE after methanol and acetate. • DCE reduction to ethene observed only after the addition of KB-1 culture. • Site biologically limited, all dechlorinating bacteria were from the bioaugmentation culture.	• $78,000, estimated, microcosm testing • $255,936, estimated, for field testing
Case Study #7, Watertown, Massachusetts (EPA 2000b)	1996-2000	• Industrial site • Sand, gravel, silt overlying impermeable till and bedrock • Groundwater 8 ft bgs	• Pilot Study, groundwater recirculation system • Nutrients, carbon source pulsed in for 8 months, for reductive dechlorination of PCE and TCE. • Oxygen Release Compound (ORC®) then introduced, to aerobically degrade VC and DCE.	• Lag time of 4-5 months before reductive dechlorination increased. • At end of 8 months, TCE concentrations had decreased from 12 ppm to <1 ppm, with an 80% reduction in the mass of total VOCs, and VC concentrations had increased. • Lag period of 1 month after introduction of ORC®, before aerobic conditions established. • DCE and VC levels started to decrease within 3 months after ORC® introduced.	• $150,000 (1-year pilot study with 6 shallow wells)
Caldwell Trucking Superfund Site, Essex County, New Jersey (Finn et al. 2003)	2001-2002	• PCE, TCE (up to 700 ppm) in groundwater in glacial deposits and fractured bedrock • Biodegradation was substrate-limited	• Injected culture of natural microooganisms including *Dehalococcoides ethenogenes* • Injections of carbon substrates: methanol, lactate, acetate	• *Dehalococcoides* sustained in all wells. • Average reductions in PCE and TCE over 90%. • Increased concentrations of DCE, VC, and ethene.	• Not Available
Six Groundwater Sites, Aberdeen Proving Ground, Maryland (EA 2010b)	2006-2008	• PCE, TCE in groundwater • Shallow groundwater in unconsolidated sediments	• *Dehalococcoides* and carbon substrate injected • Recirculation cells, passive biobarriers, direct injection	• Reducing conditions established . • Decreased concentrations of PCE and TCE, to levels below interim remedial goals. • Production of DCE, VC, and ethane.	• Not Available

Note: Definitions for abbreviations are provided on Page 12.

TABLE 4-1: CASE STUDIES FOR REMEDIAL TECHNOLOGIES

Site, Location, and Citation(s)	Dates Operation	Contaminants and Site Characteristics	Technological Details	Outcomes	Approximate Costs
			Permeable Reactive Barrier		
Moffet Federal Airfield, Mountain View, California (EPA 1998a)	1996-1997	• Former service and support facility • VOCs including TCE, PCE, DCE • Shallow aquifer zone is 25 ft deep • Water table is 5 ft bgs • Silty sand aquifer with several sand channels	• 18-ft-deep permeable, 100% reactive iron barrier • Funnel and gate system – 2 sheet pile walls perpendicular to flow • 2 ft of pea gravel flow control zone, then 6 ft iron treatment wall, then 2 ft of pea gravel flow control • Designed to treat uppermost permeable zone of upper aquifer	• 284,000 gallons of groundwater treated. • Chlorinated VOC concentrations reduced to below detection limit within the 4th foot of iron. • Max flux data has increased, indicating an increase in influent concentration, but treatment goals continue to be met.	• \$32,000 operating cost for first year (\$1,400 per 1,000 gallons treated) • \$373,000 capital costs
Landfill, 3Altus Air Force Base, Oklahoma (USDOD 2008)	2003-2005	• Unlined, closed landfill • Chlorinated aliphatic hydrocarbons in groundwater • High sulfate concentrations in the shallow groundwater • Limited hydraulic head to produce a significant downward gradient	• 30-ft by 30-ft by 11-ft recirculation bioreactor • Excavated, backfilled with organic material and sand • Groundwater extraction trench downgradient in shallow aquifer • Extracted groundwater distributed to bioreactor using drip irrigation • Desired remediation zone is approximately 10-20 ft below water table	• Removal efficiencies from recirculated groundwater: 97-100% for TCE, 76-96% for the sum of TCE, DCE, and VC. • Objective of reducing chlorinated VOC concentrations by 90% not achieved. • 6.5 pounds of TCE removed from 690,000 gallons of groundwater.	• \$171,872 for 2-year pilot study
Offutt Air Force Base, Nebraska (AFCEE 2004)	1999-present	• VOCs including TCE • Stiff, low plastic, silty clay • Groundwater depth 3-10 ft bgs	• 100 ft pilot scale wall was successful (1999). • 500-ft-long mulch wall filled with coarse sand mixed with mulch	• Pilot scale decreased TCE by 70% with minimal VC generation. • 95% reduction of TCE observed (between 2001 and 2003). • Ethene and ethane concentrations increased dramatically. • TCE, DCE, VC below MCLs by October 2003.	Not Available

Note: Definitions for abbreviations are provided on Page 12.

TABLE 4-1: CASE STUDIES FOR REMEDIAL TECHNOLOGIES

Site, Location, and Citation(s)	Dates Operation	Contaminants and Site Characteristics	Technological Details	Outcomes	Approximate Costs
			Chemical Oxidation		
Site 11, Old Camden County Landfill, Naval Submarine Base Kings Bay, Georgia (NAVFAC 1999, Chapelle et al. 2005)	1994-1999	• PCE, TCE, DCE, VC (>4.5 ppm total) • Municipal waste disposal site • Impacted groundwater 30-40 ft bgs in sandy aquifer • Discrete PCE sources identified by direct-push sampling	• P&T at perimeter of landfill, adjacent to residential area (1994-1999) • *In situ* chemical oxidation (Fenton's) of sources near landfill edge (4 events, 1998-2001) • Injection of vegetable oil after chemical oxidant, to promote sulfate reducing conditions • MNA of concentrations <100 ppb	• Chemical oxidation of sources reduced concentrations to below cleanup levels, allowing pump and treat system to be shut off. • Oxidant caused decrease in bacterial activity, but bacteria rebounded within 6 months.	• $1,500,000 to install pump and treat system + $400,000 annual maintenance • $1,050,000 for chemical oxidation (2 events)
Unnamed Facility (Applebaum and Smith 2009)	Not Available	• TCE plume in bedrock (up to 8.4 ppm) and overburden (up to 19 ppm) aquifers • Plume extending from Facility to residential neighborhood • 15-20 ft of till overburden underlain by fractured bedrock	• Injection into overburden and bedrock of chemical oxidant (carbonate and ferrous sulfate=less exothermic than Fenton's), • Single month-long injection event • Enhanced bioremediation (lactate, soybean oil, proprietary additives)	• Effectiveness of chemical oxidant was "highly dependent upon distribution through the subsurface environment." • Injections to promote bioremediation successfully created reducing conditions and decreased TCE concentrations in the short term.	Not Available
Tenneco Automotive Site, Hartwell, Georgia (EPA 2009a)	2003-present	• TCE plume (up to 12 ppm) • Impermeable saprolite 20-50 ft bgs • Permeable weathered rock 50-60 ft contain contamination • Underlain by bedrock	Semiannual injections of chemical oxidant (permanganate) (2003-2011+)	• Plume size decreased 30% in five years (maximum TCE concentration of 120 ppb). • Effectiveness dependent on understanding of the fracture porosity of the material.	$170,000 capital + $45,000 annually

Note: Definitions for abbreviations are provided on Page 12.

TABLE 4-1: CASE STUDIES FOR REMEDIAL TECHNOLOGIES

Site, Location, and Citation(s)	Dates Operation	Contaminants and Site Characteristics	Technological Details	Outcomes	Approximate Costs
			Groundwater Pump and Treat		
Skinner Landfill Superfund Site, Butler County, West Chester, Ohio (EPA 2004, 2009b)	2001-present	• Dump area with buried hazardous waste lagoon • Groundwater downgradient of lagoon is VOC-contaminated • Most concentrated contamination is below former dump • Site underlain by glacial drift (0-40 ft thick) over bedrock	• Installation of multilayered cap • Groundwater Interception System including cut-off wall of soil-bentonite slurry mixture keyed into bedrock, interceptor trenches and P&T system • Groundwater discharged into sewer system • Wells to monitor the groundwater/waste contact status	• 7,654,570 gallons of groundwater pumped. • Groundwater elevations under the landfill cap indicate that groundwater levels have dropped below the buried waste. • Various inorganics detected in groundwater below trigger levels. • Target compounds have declined or remained stable below trigger levels or non-detectable.	Not Available
Onalaska Municipal Landfill Superfund Site, Onalaska, Wisconsin (EPA 2006, 2008a)	1994-2001	• Site was a sand and gravel quarry in 1960s • VOCs (including toluene and TCE), metals, SVOCs • P&T 10-70 ft bgs • Underlying sandstone bedrock about 118-140 ft bgs	• P&T system (1994-2001) to remove VOCs and iron • Air stripping used to remove VOCs • Dewatered clarifier sludge disposed in landfill	• 2.17 billion gallons of groundwater treated from 1994 through 2001. • Concentrations of organic compounds (except benzene and trimethylbenzene) decreased below cleanup goals, May 2001. • Metals continued to be detected at concentrations above cleanup goals. • P&T system shut down because of low levels of contamination and limited exposure pathways.	Not Available
Solvents Recovery Service of New England, Inc. Superfund Site, Southington, Hartford County, Connecticut (EPA 2010a)	1995-present	• VOCs, SVOCs, metals, pesticides and PCBs • Groundwater contamination in both overburden and bedrock aquifers • Overburden groundwater table 0-10 ft bgs	• Onsite interceptor system (1986-1991) • P&T system installed in 1990s • 15 groundwater extraction wells including: 12-in. overburden, 2-in.-deep overburden, and 1 in the bedrock • Treatment includes metals pretreatment, filtration, ultraviolet/oxidation, granular activated carbon, and vapor phase carbon adsorption.	• 196 million gallons treated from 1995-2010. • 16,000 pounds of VOCs removed.	• \$1,625,285: O&M cost from 2005-2008 • \$1,160,202: groundwater remedy, including remedial design, from 2008 to 2010

Note: Definitions for abbreviations are provided on Page 12.

TABLE 4-1: CASE STUDIES FOR REMEDIAL TECHNOLOGIES

Site, Location, and Citation(s)	Dates Operation	Contaminants and Site Characteristics	Technological Details	Outcomes	Approximate Costs
Phytoremediation					
Edgewood Area J-Field Toxic Pits Site, Aberdeen Proving Grounds, Edgewood, Maryland (EPA 2000c, 2002a)	1996 - 1999	• TCA and TCE plume (up to 170 and 61 ppm, respectively) • Perched groundwater 2-8 ft bgs • Silty sand aquifer	• 184 hybrid poplars planted in 1996 on 1 acre, 5-6 ft bgs • Used deep rooting and plastic pipe around upper roots • Additional trees planted in 1998 • 156 viable trees remained in 2001	• Groundwater uptake: 2-10 gallons/day/tree in 1997, 1,091 gallons/day in 2001, projected 1,999 gallons/day in 2026. • Groundwater is depressed beneath trees. • Plume does not migrate offsite during growing season. • Minimal contaminant uptake after 5 years.	• $15,000 for installation of 184 trees, or $80 per tree
Former Carswell Air Force Base, Fort Worth, Texas (EPA 2000c, 2005b)	1996 - 2006	• TCE plume (<1 ppm) • Shallow aerobic silty fine sand aquifer (<12 ft bgs)	• 660 cottonwoods of different sizes planted in 1-acre area	• Average transpiration rate was 1,872 liters/day in 1997. • DO in aquifer lower beneath trees (which contribute organic carbon to aquifer) • Transpiration reduced TCE flux for first 3 years; biodegradation was dominant by 6th year.	• $8 per 5-gallon tree
Edward Sears Properties Site, New Gretna, New Jersey (EPA 2000c, 2002b)	1996	• TCE and PCE plume (up to 390 ppb and 160 ppb, respectively), and other VOCs • Contamination 5-18 ft bgs in layer of sand, silt, and clay	• 118 hybrid poplars planted on 1/3-acre • Deep rooting (9 ft bgs)	• Concentrations of non-chlorinated VOCs decreased within three growing seasons. • Evidence that anaerobic degradation of PCE, TCE is promoted in the root zone.	• $105,000 for installation, $10,000-30,000 annual maintenance
317/319 Area, Argonne National Laboratory-East, Illinois (ANL 2010, EPA 2003)	1999 (anticipated 20-year timeframe)	• VOC and tritium from a Landfill and French Drain • TCE (up to 47 ppm), PCE (up to 190 ppm) • DNAPL source of chlorinated VOCs • Glacial till aquifer • Top of contaminated unit 22-34 ft bgs	• 809 hybrid poplars and willows planted at various depths on 5-acre site • Used deep rooting (TreeMediation system), for treatment of groundwater to over 30 ft bgs • Previously installed P&T system	• Estimated transpiration of 1,440 liters/day during 2001 growing season (compared to groundwater flux of 4,860 liters/day). • No clear impact on VOC concentrations as of 2001. • Water levels depressed up to 0.5 ft as of 2001, with diurnal fluctuations.	• $1,200,000 for total project as of 2004

Note: Definitions for abbreviations are provided on Page 12.

TABLE 4-1: CASE STUDIES FOR REMEDIAL TECHNOLOGIES

Site, Location, and Citation(s)	Dates Operation	Contaminants and Site Characteristics	Technological Details	Outcomes	Approximate Costs
Impermeable Barrier					
Western Processing Superfund Site, Kent, Washington (EPA 2008b)	1988-present	• Former waste processing facility • VOCs, metals, PCBs • Sandy and silty loam surface soil • Contaminated groundwater 5-30 ft bgs, in alluvium	• 4,400-ft-long, 40-ft-deep slurry wall around site, through aquitard (1988) • Additional slurry wall (1996) to separate clean from contaminated areas • Pump and treat system (1988) • Engineered cap (1999)	• Increased efficiency of the pump and treat remedy. • Contaminants did not spread offsite into nearby groundwater. • Original pump and treat system removed 100,000 pounds of contaminants between 1988 and 1997.	Not Available
Gilson Road Superfund Site, New Hampshire (EPA 2009c)	1981-present	• VOCs, arsenic • Unpermitted waste disposal facility • 8-53 ft of glacial outwash underlain by fractured bedrock • Overburden and bedrock aquifers contaminated	• 90-110-ft-deep slurry wall encompassing 20 acres (1982) • Engineered cap • Pump and treat (1986-1996) • MNA	• Cleanup goals within slurry wall were attained 1995. • Prevented contaminant migration in overburden, but 7,800 gallons of water per day flowed out of the containment area through bedrock fractures beneath the slurry wall.	Not Available
Site 5, Northeastern United States (EPA 1998b)	Not Available	• VOCs and metals • Municipal solid waste landfill • Interbedded sand, silt, and clay	• 7,000-ft-long, 10-ft-deep clay barrier around the landfill, keyed into clay layer • Soil/clay cap • Leachate and landfill gas collection	• Reduced landfill leachate generation and migrated lateral migration of leachate. • Met hydraulic head criteria. • Improved groundwater quality outside wall (meets required quality standards).	Not Available
Site 15, Northeastern United States (EPA 1998b)	Not Available	• VOCs, ammonia, arsenic • Sanitary landfill • Glacial lake deposits (silt, clay)	• 11,230-ft-long, 20-ft-deep soil-bentonite cutoff wall, keyed into a clay layer • Leachate collection	• Achieved inward groundwater gradient and prevented migration of site contaminants. • Improvements in groundwater quality outside the barrier.	Not Available
Site 17, Northeastern United States (EPA 1998b)	Not Available	• VOCs (including TCE), metals • Landfill • Atlantic Coastal Plain • Small zones of 2 aquifers are contaminated	• 5,965-ft-long, 15-33-ft-deep slurry wall keyed into a confining layer • Leachate and methane collection • Drain and extraction wells, and water treatment • Engineered cap	• Inward groundwater gradient established. • Leachate levels have dropped.	$55-60 million

Note: Definitions for abbreviations are provided on Page 12.

TABLE 4-1: CASE STUDIES FOR REMEDIAL TECHNOLOGIES

Site, Location, and Citation(s)	Dates Operation	Contaminants and Site Characteristics	Technological Details	Outcomes	Approximate Costs
Landfill Gas Collection					
Somersworth Sanitary Landfill Superfund Site, Somersworth, New Hampshire (EPA 2005a)	2003-present	• Methane detected near the perimeter of the landfill during soil gas monitoring in 2001 and 2002.	• LFG venting trench installed 2003-2004. • Depth of trench extends 15 to 27 ft bgs (to seasonal low groundwater level). • 3-ft-wide trench • Gravel from bottom of trench to 3 ft bgs, geotextile fabric separator, followed by 2.5 ft of compacted clay, and 0.5 ft of topsoil. • Vertical geomembrane on outside wall of the trench. • 4-in. vent pipes embedded vertically within the gravel	• Reduced methane concentrations in soil gas outside of the landfill were observed in data collected prior to 2005. • Frequency of monitoring soil gas was reduced in 2006.	• $40,000 for O&M
Colbert Landfill Superfund Site, Spokane County, Washington (EPA 2010c)	1996-present	• Landfill (1968-1986) accepted municipal and chemical waste • Engineered cover, but no liner. • Potential for off-site gas migration, including methane	• LFG collection system part of landfill closure. • Interior and perimeter wells and trenches. • Activated carbon treatment of gas, followed by discharge to the atmosphere. • Condensate treated off-site.	• Landfill produces low volumes of methane and carbon dioxide. • Production volumes are relatively stable.	• $352,000 annual cost for operating the water treatment plant and LFG system
Coakley Landfill Superfund Site, North Hampton and Greenland, Rockingham County, New Hampshire (EPA 2011)	1996-present	• Landfill (1972-1985) accepted municipal waste and waste incinerator residue. • Waste placed in open tranches created by quarrying • Methane migration off-site	• Passive gas collection and venting system, with turbine vents on several gas vent pipes • Landfill gas monitoring occurs quarterly • Methane gas alarms installed in buildings in adjoining properties in 2007	• Remedy determined to be protective of human health and the environment • No violations reported in buildings with methane gas alarms • Sporadic violations of methane detected above the state standard in LFG monitoring probes (6.5% of readings in 5 years).	• $46,000 average annual O&M (monitoring of landfill cap, surface water drainage, ambient air, landfill gas, groundwater, and surface water)

Note: Definitions for abbreviations are provided on Page 12.

TABLE 4-1: CASE STUDIES FOR REMEDIAL TECHNOLOGIES

Site, Location, and Citation(s)	Dates Operation	Contaminants and Site Characteristics	Technological Details	Outcomes	Approximate Costs
Cover System Improvements/Partial or Full Capping					
Mica Landfill, Spokane, Washington (Washington Ecology 2001, 2008)	1994-present	• Unlined municipal solid waste landfill • Lined leachate pond for landfill drainage • VOCs detected in wells offsite • Groundwater occurs in competent bedrock and the weathered bedrock/loess • Groundwater flows through waste	• Installation of a double-layered geosynthetic and engineered clay cap • Installation of methane and leachate collection system and stormwater control system	• Leachate quantities show a reducing trend, but groundwater still drives the leachate volumes. • Chlorinated ethene reduction. • Decreasing trend for PCE and TCE. • Increasing trend for DCE and VC. • Contamination does not migrate offsite.	Not Available
Coshocton Landfill, City of Coshocton, Ohio (EPA 2008c)	1995-present	• Approximately 30 chemicals in groundwater, surface water and sediment including VOCs • Landfill built on abandoned strip-mined land and received various industrial wastes	• Low permeability landfill cap in accordance with state requirements, runoff gradation, groundwater, surface water and landfill gas monitoring. • Ongoing O&M activities for settlement/ consolidation management, vegetation management, and cover monitoring system	• Contaminants contained in the landfill remain intact at low levels below action levels. • Settlement of the cap has not occurred. • Selected remedy successfully implemented and containment components remained satisfactory.	Not Available
Site 10, Northend Landfill, Naval Magazine Indian Island, Port Hadlock, Washington (NAVFAC 1999)	1996-present	• Unlined • Groundwater at elevations near sea level; perched water in zones • Lower portion of landfill is saturated • Groundwater flow dependent on tide • COCs include metals, pesticides and one SVOC	• Excavated material regraded over old landfill surface and compacted • Landfill cap placed over approximately 3 acres • Shoreline protection system • Three layers of vegetative geogrids along seaward side of landfill • Gas-collection system	• Groundwater monitoring indicates few significant changes in quality from historical results and chemical analysis was discontinued.	Not Available

Note: Definitions for abbreviations are provided on Page 12.

TABLE 4-1: CASE STUDIES FOR REMEDIAL TECHNOLOGIES

Site, Location, and Citation(s)	Dates Operation	Contaminants and Site Characteristics	Technological Details	Outcomes	Approximate Costs
Selective or Extensive Waste Excavation					
Clovis Landfill, Clovis, California (Serpa 2008)	1998-2008	• Landfill projected to reach capacity around 2015 • Unlined portion of landfill causing VOC contamination of groundwater	• Waste excavated and sorted • Sorted waste placed in lined portion of landfill • Sorted soil stockpiled for future use • Conveyor used to transport soil, trucks are used to transport the waste	• 2.3 million yd^3 mined. • Odors are present but they are not severe and do not migrate far. • Vectors are more attracted to active landfill area than excavation area. • Litter blown from excavation face is easily collected. • Groundwater VOC levels steadily decreased as project progressed and will continue to attenuate. • Enough soil recovered to meet facility's operational needs for 20 years. • Actual quantity of waste was more than estimated amount. • Actual daily productivity was less than estimated productivity.	• Expected cost of $3.8 million • Actual cost of $9 million
Ionia City Landfill Superfund Site, Ionia County, Michigan (EPA 2010b)	1994-1995	• 20-acre closed landfill • Former dump collected municipal and industrial wastes • Shallow aquifer	• Landfill cap (1984) • Source removal of waste and contaminated soil impacting groundwater in older fill area (1994) • Clean sand used to backfill excavated area • P&T system ('99-'03) to contain higher VOC concentrations • MNA	• 12,250 tons of waste material (drums containing solvents and paint thinners) and contaminated soil removed and disposed offsite. • Source removal eliminated need for further soil remediation. • Remaining contaminant plume is stable. • MNA is reducing the remaining concentration.	Not Available
Perdido Landfill, Cantonment, Escambia County, Florida (Florida DEP 2009)	2008	• Closed and active landfill areas • Unlined landfill cells potentially causing groundwater contamination	• 2.5 acres of an unlined cell was mined • Screened waste was disposed in a lined cell	• 54,300 yd^3 mined. • 38,00 yd^3 soil reclaimed for use as daily and intermediate cover. • Post-closure care cost avoidance.	• $8.6 per yd^3 mined

Note: Definitions for abbreviations are provided on Page 12.

Notes:

AFCEE – Air Force Center for Environmental Excellence
ANL – Argonne National Laboratory
bgs – below ground surface
COC – contaminant of concern
Cr+6 – chromium(VI)
CTW – chemical treatment wall
DCE – dichloroethene
DEP – Department of Environmental Protection
DNAPL – dense non-aqueous phase liquid
DO – dissolved oxygen
ft – foot/feet
EPA – U.S. Environmental Protection Agency
in. – inch(es)
LFG – landfill gas
MCL – maximum contaminant level
MNA – monitored natural attenuation
NAVFAC – Naval Facilities Engineering Command
O&M – operations and maintenance
ORC – oxygen release compound
P&T – Pump and Treat
PCB – polychlorinated biphenyl
PCE - tetrachloroethene
ppb – parts per billion
ppm – parts per million
SVOC – semivolatile organic compound
TCA – trichloroethane
TCE – trichloroethene
USDOD – United States Department of Defense
VC – vinyl chloride
VOC – volatile organic compound
yd^3 – cubic yard
yr – year

TABLE 4-2 REMEDIAL TECHNOLOGIES SCREENING SUMMARY

Remedial Technology	Effectiveness	Implementability	Cost[1]	Retained as a Corrective Measure Technology?	Additional Notes
Monitored Natural Attenuation	Moderate—natural attenuation is active at site, but COC concentrations in groundwater exceed MCLs at the point of compliance	High—relies upon sampling and analysis; detailed assessment required for regulatory approval	Low—mainly long-term monitoring and analysis	Retained	
Enhanced Bioremediation	High—could decrease COC concentrations in shallow and deep groundwater to less than MCLs	Moderate—some well installation challenges; would require periodic injections in the long term	Moderate-High—capital costs and long-term O&M	Retained	
Permeable Reactive Barrier	Low—would not address COCs in groundwater within bedrock	Moderate—would require waste relocation, long-term maintenance	High—capital costs and O&M	Not retained, due to inability to treat groundwater within bedrock	
Chemical Oxidation	Moderate—oxidant delivery to deep bedrock would likely be limited	Low—would require frequent reapplication of oxidizant; not typically used where COC source cannot be treated	Moderate-High—mostly associated with multiple annual injections for many decades	Not retained, due to need for frequent injections in the long-term	
Groundwater Pump and Treat	Moderate—would extract impacted groundwater and remove COCs, but may not completely control deep impacts	Moderate—would require careful design and significant long-term maintenance	Moderate-High—capital costs and long-term O&M	Retained	
Phytoremediation	Low—small decrease in flow of impacted groundwater across a portion of the property boundary	High—requires tree clearing prior to planting and maintenance of trees	Low—relatively low level of effort involved	Not retained, due to limited short-term effectiveness and need to remove trees	Possible enhancement to remedial alternatives
Impermeable Barrier	Low—would only marginally reduce migration of landfill gas and shallow groundwater	Moderate—would require waste relocation, trench construction	Low—cost of constructing the barrier	Not retained, due to inability to control flow of groundwater within bedrock	
Landfill Gas Collection	High—would provide direct control over landfill gas migration	High—requires drilling through waste using specialized procedures	Low—cost of gas extraction well installation	Retained	

(1) Low = <$1 million
Moderate = $1-10 million
High = >$10 million
(assuming 20 years of operations and maintenance [O&M], where applicable)

TABLE 4-2 REMEDIAL TECHNOLOGIES SCREENING SUMMARY

Remedial Technology	Effectiveness	Implementability	Cost[1]	Retained as a Corrective Measure Technology?	Additional Notes
Cover System Improvements	Moderate—could decrease occurrence of leachate seeps	High—requires minimal site disturbance	Low-Moderate—cost of additional topsoil	Retained	
Partial or Full Capping	Partial Capping (side-slopes): High—would likely achieve RAOs for landfill gas and leachate seeps Full Capping: Moderate—would likely improve gas collection and eliminate seeps; likely would not achieve the groundwater RAO	Partial Capping (side-slopes): High—could be implemented on side slopes after waste excavation Full Capping: Low—requires extensive site disturbance and rebuilding of landfill gas and stormwater collection systems	Partial Capping (side-slopes): Moderate—includes site preparation and cap placement Full Capping: High—costs of cap construction and rebuilding displaced systems	Partial Capping (side-slopes): Retained as a potential contingency measure Full Capping: Not retained, due to unknown benefits for groundwater in contact with waste, and extensive site disturbance and reconstruction required	
Selective or Extensive Waste Excavation	Selective Excavation: Moderate—would decrease fugitive gas exceedances at the property boundary. Regrading and cap or improved cover could address leachate seeps. Extensive Excavation: High—Would remove sources of groundwater VOCs, landfill gas, and leachate. Would not address current groundwater contamination.	Selective Excavation: Moderate—land and waste disturbance, disturbance to landfill gas recovery system Extensive Excavation: Low—requires extensive site and waste disturbance, and would likely take decades to excavate entire landfill	Selective Excavation: High—includes cost of excavation and off-site disposal or on-site placement Extensive Excavation: High—may be offset to some degree by recycling of waste	Selective Excavation: Retained Extensive Excavation: Retained	
No Action	Low—would not provide monitoring and thus would not guarantee lack of unacceptable risk	Low—unlikely regulatory agency approval	Minimal—no capital or annual O&M costs	Not retained	

(1) Low = <$1 million
Moderate = $1-10 million
High = >$10 million
(assuming 20 years of operations and maintenance [O&M], where applicable)

TABLE 6-1 NUMERICAL COMPARISON OF CORRECTIVE MEASURE ALTERNATIVES

Criterion	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
ARARs and Objectives – Groundwater*	4	4	4	3	4
ARARs and Objectives – Landfill Gas*	4	4	5	3	3
ARARs and Objectives – Leachate*	4	4	5	4	4
ARARs and Objectives – Average	**4**	**4**	**5**	**3**	**4**
Short-Term Effectiveness	**3**	**3**	**1**	**4**	**4**
Long-Term Effectiveness	**4**	**4**	**4**	**2**	**4**
Implementability	**2**	**2**	**1**	**3**	**4**
Protection of Human and Ecological Health	**3**	**3**	**4**	**5**	**5**
Source Treatment and Reduction of Toxicity, Mobility, and Volume	**4**	**4**	**5**	**3**	**3**
Cost	**2**	**4**	**1**	**4**	**4**
Regulatory Acceptance	**5**	**5**	**5**	**5**	**5**
Community Acceptance	**3**	**3**	**1**	**4**	**5**
Total	**30**	**32**	**27**	**33**	**38**

5 = best; 1 = worst
* Rankings for these items are not included in the total; instead, the average of the rankings for ARARs and Objectives are included.

For costs:
1 = over $200,000,000
2 = $150,000,000-$200,000,000
3 = $100,000,000-$150,000,000
4 = $50,000,000-$100,000,000
5 = under $50,000,000

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