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
cm/sec	Centimeter(s) Per Second
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., PBC
EPA	U.S. Environmental Protection Agency
FRTR	Federal Remediation Technologies Roundtable
ft	Foot or Feet
GLCC	Gude Landfill Concerned Citizens
GRAs	General Response Actions
HELP	Hydrologic Evaluation of Landfill Performance
HPAH	High Molecular Weight Polycyclic Aromatic Hydrocarbon
HQ	Hazard Quotient
in.	Inch(es)
J&E	Johnson and Ettinger
LDPE	Low Density Polyethylene
LEL	Lower Explosive Limit
LFGE	Landfill Gas-to-Energy
MCL	Maximum Contaminant Level
MDE	Maryland Department of the Environment

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

mg/L	Milligram(s) Per Liter (equivalent to parts per million, ppm)
mM	Millimoles Per Liter
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). In addition, MCL exceedances of total metals were evaluated as part of this ACM (**Appendix C**) using groundwater sampling results collected from Spring 2001 through Fall 2015. Groundwater sampling is performed on a semi-annual basis and the results will continue to be evaluated by the County.

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
- Toupee 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
- Alternative 6 – Toupee Capping and Additional Landfill Gas Collection

Note that in addition to the remedial technologies included in each alternative, it is anticipated that approximately nine (9) new groundwater monitoring well pairs 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 during remediation.

Detailed analysis of the six (6) 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 6, Toupee Capping and Additional Landfill Gas Collection. A work plan for Alternative 6 is provided in **Appendix J**, with descriptions and schedules for the recommended technologies. A Contingency Plan is provided in **Appendix K**.

1. BACKGROUND

EA Engineering, Science, and Technology, Inc., PBC (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.

- 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).

The original ACM Report was prepared and submitted to the Maryland Department of the Environment (MDE) in January 2014 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 MDE for regulating solid waste disposal facilities under COMAR. This ACM Report has been revised to address comments provided by MDE in a letter dated 22 April 2015, as well as comments provided by MDE in a subsequent letter dated 6 July 2015. The information requested for inclusion in the ACM Report is listed below in italics, with follow-up in plain text:

- *Discussion of corrective measures for metals exceeding MCLs, and reassessment of the level and extent of metal exceedances at the site following two (2) rounds of low-flow sampling. MDE requested the submission of data from the low-flow sampling for review prior to the submission of the Revised ACM Report.* County DEP submitted these data to MDE with the Fall 2015 semi-annual groundwater monitoring report. The ACM has been revised to consider metals as part of the evaluation of corrective measures. Reassessment of the metals exceedances is presented in **Appendix C**.

- *Justification for monitoring well spacing based on site-specific information, including discussion of the complex nature of groundwater flow in fractured bedrock and the effects of a soil cap on infiltration into the landfill.* See Section 4.14 for discussion of well spacing.

- *Specific information as to the percentage of waste in contact with groundwater, including a groundwater contour map based on water elevations from new borings installed through the landfill waste layer, as well as water elevations in existing groundwater monitoring wells.* A work plan for installation of temporary piezometers was approved by MDE on 31 July 2015. The waste evaluation has been included in **Appendix H** and an updated contour map is shown in **Figure 1-5** of this Revised ACM Report.

- *Key timeframes for reaching RAOs in **Table 6-1**.* Timeframes have been added to Table 6-1.

- *A viable contingency plan with a specific remedial alternative that meets all the RAOs should the preferred corrective measure fail to meet the objectives within the identified timeframe.* The contingency plan is presented in **Appendix K**.

- *A drainage analysis of the current soil cap, including infiltration rates and potential for infiltration on all areas of the cap.* Infiltration testing was performed in November 2015, and the results are presented in **Appendix B**.

- *A full evaluation of trends in concentration and mass utilizing guidelines established in the Office of Solid Waste and Emergency Response Directive (EPA 1999), if monitored natural attenuation (MNA) is part of a preferred alternative.* MNA has not been selected as part of the preferred alternative; therefore, an additional analysis is not required.

- *A New Groundwater and Surface Water Monitoring Plan to be submitted to MDE for review and approval.* The new Monitoring Plan has been submitted with this ACM Report.

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 were 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 between the County and M-NCPPC on 21 October 2014 transferred ownership of this additional waste disposal area to the County in exchange for a similar area of land without waste, which was 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.

Based on site topography, some amount of surface water infiltration likely occurs through the natural cover system (grassy surface and soil layer) of the Landfill. 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**. Geologic cross-sections were also developed for the Waste Evaluation, presented in Figures 9 through 11 of **Appendix H**.

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. Surface water elevations measured in 2011 from temporary stream gauges were consistent with groundwater table elevations from adjacent groundwater monitoring wells and locations, indicating a hydraulic connection between groundwater and surface water. In September 2015, temporary piezometers were installed through the waste mass, allowing for additional groundwater table elevation data to be collected. The above referenced data collection locations and the inferred groundwater flow contours for November 2015 have been overlain on the site topographic map, and are presented in **Figure 1-5**. The groundwater elevations at the temporary piezometers were consistent with expected elevations for the center of the Landfill and confirmed the groundwater flow direction previously predicted for the Landfill.

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. In 2015, an additional stormwater engineering evaluation was performed. 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. 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. A landfill drainage analysis was performed in 2015, and the results are presented in the Stormwater Engineering Evaluation (**Appendix A**).

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.

An updated drainage analysis was performed in November 2015 using recent topography data provided by EA's subcontractor, Wallace Montgomery. Included in the updated site topography map was the location of storm drain structures and inverts. Utilizing the location of storm drain structures and updated topographic survey data, site-wide drainage areas and flow directions to each structure were identified. Utilizing HydroCAD software, peak discharge rates were calculated for each sub-drainage area. A detailed technical memorandum with supporting information is included in **Appendix A**.

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 in **Appendix A**. The drainage area boundaries were delineated based upon the contours and surface features collected in the 2009 and 2015 topographic surveys. 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.

The majority of the site continued to have positive drainage in 2015, via overland flow, swales, and the closed storm drain network. Twenty-six (26) locations were identified in **Appendix A** as localized depressions that do not provide positive drainage. Storm drain structures on top of the Landfill are subject to settlement, and one (1) pipe was identified as no longer providing a positive slope for drainage.

The total area encompassing these twenty-six (26) low points is approximately eighteen thousand six hundred sixty-two (18,662) square feet. This equates to less than one-half (½) acre of area across the Landfill site, which has a waste disposal footprint of approximately one hundred fifty-seven (157) acres. While these low point areas have the potential for standing water and infiltration, the potential for impact from these areas across the Landfill site is minimal; however, to conform to post-closure care requirements for closed landfills, grading improvements and stormwater management repairs are required.

Appendix A provides recommendations for bringing localized depressions to grade to match surrounding positive drainage and provide a smooth transition with existing surfaces, as well as repairing the one (1) pipe and associated structures that no longer provide positive drainage.

To complement the drainage map in **Appendix A**, 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 the Stormwater Engineering Evaluation (**Appendix A**) and the NES Report, Appendix A, Attachment 3 – Technical Memorandum, Stormwater Infrastructure Review (EA 2010a).

Existing Cover Soil and Infiltration

The Landfill cover soil was analyzed at six (6) locations during November 2015, using a double ring infiltration test to estimate vertical hydraulic conductivity of the top two (2) ft of existing cover (Soil and Land Use Technology, Inc. 2015). The infiltration testing was performed to evaluate the potential benefit of landfill capping, which is evaluated as a potential remedial technology in this ACM (see Section 4.11). Results at two (2) of the locations indicated a hydraulic conductivity of zero (0) centimeters per second (cm/sec), which indicates the permeability is so low that the test method could not accurately measure it. At the four (4) other locations, the hydraulic conductivity ranged from approximately 2 x 10^{-4} cm/sec to 2 x 10^{-5} cm/sec. For further information, refer to the Infiltration Testing Summary Report (**Appendix B**). Although not as effective as a geosynthetic cap, the low hydraulic conductivity of the existing cover means it is capable of promoting stormwater runoff and minimizing infiltration if there is adequate vegetative cover and positive drainage throughout the Landfill.

The Hydrologic Evaluation of Landfill Performance (HELP) model was then employed to estimate average annual percolation/leakage through a one (1)-acre portion of the Landfill. Well construction logs for the piezometers adjacent to the test locations (TPZ-1, TPZ-3, TPZ-4, and TPZ-6) were used to estimate physical properties for the Landfill layers in the HELP model. The hydraulic conductivity of the top two (2) ft of the existing cover from the infiltration test was also used as an input in the HELP model. The HELP model was also run with a geosynthetic cap to estimate the potential effect of capping on leachate generation. The estimated average percolation/leakage volume per acre decreased by as much as ninety-nine (99) percent with the addition of a low-density polyethylene (LDPE) liner, drainage net, and topsoil layer over the existing layers.

The HELP model was also run for the one hundred forty (140) acres of the original Landfill footprint to estimate the average annual volume of precipitation which infiltrates (percolates) through the bottom of the waste as leachate. An average permeability from the four (4) infiltration test locations was used over the entire site. The leachate volumes produced with and without partial capping were compared assuming that a geocomposite drainage layer would be installed over the geosynthetic cap. The side-slopes were assumed to be uncapped in both scenarios, with the exception of the western side-slopes which would be capped. According to the model, the total leachate volume produced over the Landfill is expected to decrease from approximately eight and a half (8.5) million cubic feet per year to two (2) million cubic feet per year following capping. The leachate volume for only the capped portion of the Landfill decreased from approximately six and a half (6.5) million cubic feet per year to approximately fifty-one thousand (51,000) cubic feet per year after capping. This highlights the benefits of capping with a geomembrane with regards to decreased leachate production. For further information, refer to HELP model results (**Appendix B**).

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 1-6**. 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 1-6**.

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 1-7**. The surface water monitoring locations are identified below:

- Surface Water Monitoring Locations – 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 1-7**.

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 1-8**. 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.

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 1-8**. 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 stormwater structures to capture and divert clean stormwater runoff off of the Landfill's cover system. This infrastructure is presented in **Appendix A**.

As the landfill is inactive and unstaffed currently, there are no monitoring and quarterly inspections requirements for the stormwater. Visual inspections of the site conditions and stormwater discharges (if present) are conducted 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

- <u>Formalize the Landfill Gas Monitoring Plan</u> – 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 one (1) 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. MDE has requested that a new monitoring plan be prepared along with the submission of the Revised ACM Report in February 2016. MDE later extended the submission date to April 2016 and both the monitoring plan and the Revised ACM Report will be submitted on the revised submission date.

- 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.

- County and MDE Meeting Regarding Comments on the ACM (3 March 2015) – During this meeting, EA, the County, and MDE discussed initial comments on the Gude Landfill ACM Report. MDE requested revisions and submission of an Environmental Monitoring Plan, additional discussion of metals concentrations exceeding MCLs in the ACM Report, addition of landfill capping as an alternative in the ACM, and revision of trend analysis methods used in the semi-annual groundwater reports. Also discussed during this meeting were timeframes for reaching the RAOs, the condition and maintenance of the existing landfill cover, the MNA evaluation presented in the ACM, and the contingency plan.

- Low-Flow Groundwater Sampling (beginning Spring 2015) – The County began employing low-flow groundwater sampling methods during the Spring 2015 semi-annual sampling event with the goal of decreasing sample turbidity and collecting samples that are more representative of groundwater conditions (**Appendix C**). Sampling results for the first two (2) low-flow sampling events were submitted to MDE along with the Fall 2015 semi-annual groundwater monitoring report.

- <u>Waste Evaluation: Temporary Piezometer Installation Plan (17 July 2015)</u> – The County submitted a work plan with details of six piezometer locations for installation of temporary piezometers within the landfill's waste footprint, to confirm groundwater elevations inside the landfill footprint. MDE approved the Plan on 31 July 2015. It was not possible to complete two proposed piezometer locations (TPZ-2 and TPZ-5) due to combustible gas concentrations in the subsurface that remained above the LEL despite mitigation methods such as dry-ice and forced-air ventilation of the borehole. In addition, several attempts were made to offset the locations up to 30 ft away with similar results. EA considers the geographic distribution of the completed locations adequate to provide representative coverage of the landfill subsurface and achieve the project goals. Therefore, it was decided to abandon the TPZ-2 and TPZ-5 locations. The remaining four piezometers were installed in September 2015. Prior to installation of piezometers, the driller completed pilot borings which were used to characterize the subsurface and prepare geologic cross sections. Results of this investigation are presented in **Appendix H**.

- Well Re-development – Re-development of eight (8) select groundwater monitoring wells was conducted in September 2015 to address elevated turbidity during sampling and recent metals exceedances.

- <u>County and MDE Meeting Regarding the ACM (14 January 2016)</u> – During this meeting, EA, the County, and MDE discussed findings of additional work performed to address MDE's comments on the ACM Report. MDE stated that metals should be included as a constituent of concern for groundwater, and that changes made to obtain samples that are more representative of groundwater quality (e.g., well re-development or replacement) would be considered part of the corrective measure for metals. MDE stated that pore water sampling within the stream south of the Landfill could be used to supplement the groundwater monitoring and assess potential migration. MDE also stated that for a capping remedy, thirty (30) plus years would be reasonable to meet the groundwater RAO, and that an increase in concentrations would be expected in the short term and benchmarks can be established for monitoring. MDE noted that they would expect evaluation of RAO benchmarks at significant milestones (ten [10] to twenty [20] years).

1.4.2 County and Other Stakeholder Pre-Remediation Activities

- <u>Remediation Feasibility Memorandum (EA 2011b)</u> – 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.

- <u>Exchange of Land with M-NCPPC</u> – 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 received the land parcel containing waste and M-NCPPC received 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 required County Council approval, was completed on 21 October 2014.

- <u>Remediation Project Meetings with Community</u> – From June 2009 to present, representatives of County DEP, GLCC, and the County's technical support consultant (EA) have held meetings as needed, sometimes as often as monthly, at the Shady Grove Processing Facility and 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**.

- <u>Remediation Project Webpage</u> – 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[(a)]
Subsurface soil		X		X[(a)]
Surface water	X			X
Groundwater				
- **Tap Water**				[(b)]
- **Vapor Intrusion**				X

Notes:
(a) Potentially complete pathway for residents as recreational users
(b) 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:

- <u>Post-Closure Monitoring and Maintenance</u> – 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.

- <u>Water Quality Protection</u> – 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.

- <u>Explosive Gas Control</u> – 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.

- <u>Stormwater Management</u> – 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 2014 Gude Landfill SWPPP and COMAR 26.08.04.08. Future site redevelopment and construction activities at the Landfill will require compliance under the existing General Permit 12-SW, the County National Pollutant Discharge Elimination System (NPDES) Permit (State Discharge Permit No. 14GP), 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. Metals exceedances are discussed in more detail below.

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, March 2013, September 2013, and March 2014. There were no MCL exceedances of 1,1-DCE, 1,2-dibromoethane, and benzene in September 2014, March 2015, and August 2015. There were also no MCL exceedances of nitrate in September 2014 and August 2015. Dissolved arsenic concentrations slightly exceeding the MCL were also reported during 2012, 2013, and 2014.

The paragraphs below discuss in more detail these potential impacts to groundwater, based on MCL exceedances during the period from 2010 to 2015, 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 through 2015: antimony, arsenic, beryllium, cadmium, chromium, mercury, and thallium. Additionally, exceedances of the EPA action level for lead were also reported in unfiltered samples.

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 C**. 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 for any of the groundwater monitoring wells since dissolved mercury was first analyzed in April 2011. 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 provided 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 indicated that the high turbidity of routine groundwater samples from the Landfill likely results from sampling methodology. Based on these findings, beginning with the Spring 2015 sampling event, low-flow sampling was implemented for semi-annual groundwater monitoring at the Landfill with the goal of decreasing sample turbidity and obtaining groundwater samples that are more representative of groundwater conditions. The results of the Spring 2015 and Fall 2015 low-flow sampling events indicate an overall decrease in turbidity, particularly in shallow wells, following the change in sampling methodology. Metals exceeding MCLs in samples collected using low-flow methodology include arsenic, cadmium, chromium, and mercury. The majority of these MCL exceedances remain isolated and sporadic in their locations and frequencies, and appear likely related to persistent turbidity; despite the observed decrease in turbidity, elevated (greater than ten [10] nephelometric turbidity units) turbidity remained during low-flow sampling of certain wells. Additionally, consistent exceedances of dissolved metals were reported in samples from OB11 and MW-6 from the Spring and Fall 2015 low-flow sampling events. Eight (8) wells (OB11, MW-6, OB04A, MW-9, MW-10, MW-13A, OB025, OB105) were re-developed following the Fall 2015 sampling event to further reduce the potential for the presence of turbidity to impact data results. MCL exceedances will be reevaluated following the first round of sampling post re-development.

The low-flow sampling events further confirmed the inconsistency of MCL exceedances for metals, with the exception of OB11 and possibly MW-6. Based on the findings of the 2013 and 2015 investigations, and because COPCs in groundwater were not found to pose a concern for human health (see Section 2.2.1), metals are not considered the primary focus of remediation at the Landfill; however, metals exceedances will be addressed as part of the selected corrective measure, in accordance with MDE comments on the January 2014 ACM. A technical memorandum containing an updated summary of metals MCL exceedances and recommendations is included in **Appendix C**.

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 four (4) sampling events between 2011 and 2015. 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 only one (1) nitrate detection in MW-10. These comparative results indicate that the area of impact and extent of the MCL exceedances for nitrate are limited.

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 D**. 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 August 2015, using a Mann-Kendall statistical test for trend (results are presented in **Appendix E**). The statistical test indicated decreasing trends in the concentrations of several potential landfill-associated impacts to groundwater identified in the NES Amendment No. 1 in one (1) or more groundwater monitoring wells: 1,2-dichloropropane (OB01), benzene (MW-13A, OB03, OB03A, OB11A), cis-1,2-DCE (OB01, OB02, OB02A, OB06), methylene chloride (MW-13A, OB11A), nitrate (MW-13A, OB06, OB12), PCE (MW-13A, MW-13B, OB03, OB03A, OB11A), TCE (OB01, OB02A, OB08A, OB11A), and VC (MW-13A, OB01, OB015). The statistical analysis also indicated a decreasing trend in the concentration of total cadmium in groundwater monitoring well OB11A.

The statistical testing indicated increasing trends for the following potential landfill-associated impacts to groundwater identified in the NES Amendment No. 1: 1,2-dichloropropane (OB11, OB12), benzene (OB04, OB04A, OB12), cadmium, dissolved (OB11), cis-1,2-DCE (OB025, OB07, OB08, OB105, OB12), nitrate (MW-11B, MW-13B, MW-4, OB01, OB02A, OB07, OB07A), PCE (MW-11B), and VC (OB08, OB10). In addition, the statistical analysis indicated an increasing trend in the concentration of total cadmium in groundwater monitoring well OB11. The NES Amendment No. 1 (EA 2011a) also identified trends that indicate seasonal fluctuations in concentrations of constituents within the Landfill groundwater monitoring network.

Historical trends were evaluated as part of the Fall 2015 semi-annual groundwater monitoring report. The statistical analysis technical memorandum is included in **Appendix E**. As presented in the technical memorandum, the change in sampling methodologies from three (3)-volume well purge methods to low-flow sampling may require further evaluation and potential modification of the statistical methods in the future.

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 for Landfill-related VOCs 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 were used to assess extent of impacts, with a focus on MCL exceedances reported between 2010 and 2013. Data reported from the Fall 2013 to Fall 2015 sampling events confirmed these areas of impact.

Figure 2-3 presents the extent of MCL exceedances for Landfill-related VOCs 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 for Landfill-related VOCs along the new Landfill property boundary (following the land exchange with M-NCPPC which occurred in October 2014) 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 VOC 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-dichloropropane, benzene, cis-1,2-DCE, methylene chloride, PCE, TCE, and VC) have been reported in this area, in groundwater monitoring wells OB03, OB03A, 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.

- ***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 1,2-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 2015. 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. Following exchange of land with M-NCPPC in 2014, wells OB10 and MW-4 are now outside the Landfill 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.

While the extent of impacts was defined based on VOC exceedances of MCLs, metals exceedances have also been sporadically reported. More consistent exceedances have been reported in OB11 (cadmium), in the South Area, and MW-6 (chromium), in the West Area. Metals exceedances reported between 2013 and 2015 in wells outside the defined extent of impacts (e.g., OB102 and MW-2A) are isolated and intermittent. See the Updated Assessment of

Metals Concentrations in Groundwater technical memorandum in **Appendix C** for additional analysis and recommendations.

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 some weekly monitoring events in 2011 through 2016, 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, South, or Southeast 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 2014 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, May-June 2010, March 2013, August 2014, and July 2015 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.

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, 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 or Toupee 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 eleven (11) 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, Toupee, 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 F**.

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 2-4, 2-5, and 2-6**.

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. A preliminary evaluation of natural attenuation processes occurring at the Landfill is presented in **Appendix G**. 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. Note that prior to committing to implementation of MNA at the Landfill, it would be necessary to conduct additional evaluations in accordance with guidelines established in Office of Solid Waste and Emergency Response Directive 9200.4-17P.

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.

Implementability

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 preliminary MNA evaluation for the Landfill (**Appendix G**) 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.

Cost

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 (18th) 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.

Note that bioremediation programs designed to promote degradation of cVOCs would not be expected to address metals exceedances in groundwater.

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**). Following exchange of land along the northern and eastern boundaries of the Landfill with M-NCPPC in 2014, the waste now extends 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.

Implementability

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

Effectiveness

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.

Implementability

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 in recent years at the Landfill.

Cost

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 4.11, Partial, Toupee, or 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, TOUPEE, OR FULL CAPPING

4.11.1 Description

Partial, Toupee, 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. 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 or Toupee 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 or Toupee Capping, focusing on the top of the Landfill and select side-slopes, would require extensive site disturbance and would decrease the volume of leachate generated, which is the direct result of infiltration of water through the waste. The effectiveness of Full or Toupee Capping for decreasing impacts to groundwater would be diminished if waste remains in contact with groundwater; however, the Waste Evaluation presented in **Appendix H** indicates that there is limited groundwater incursion into the waste. It is difficult to quantitatively estimate the percentage of waste in contact with groundwater, due to fluctuating water table elevations and limited data points available from four (4) temporary piezometers installed during the Waste Evaluation; however, gauging results from the piezometers indicate that the uppermost aquifer was not encountered within the waste. Based on the limited information about groundwater in waste, the likelihood that groundwater will be in contact with waste and diminish the effectiveness of Full or Toupee Capping is low.

Partial Capping of only the side-slopes could also be conducted, and would address landfill gas migration and leachate seeps along the side-slopes. The partial cap could be installed along the existing side-slope, or could be 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

Effectiveness

Groundwater: Full or Toupee Capping of the surface of the Landfill could represent a method of controlling impacts to groundwater. Currently, 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. As described in Section 1.2.5 and documented in **Appendix B**, an evaluation performed in 2015 indicated that the average percolation/leakage volume for the capped area would decrease by approximately ninety-nine (99) percent if a geosynthetic cap was installed. If a Toupee Cap was installed on the top and western side-slopes, the overall percolation volume over the Landfill would decrease by approximately sixty-five (65) percent. Additionally, as indicated in the Waste Evaluation in **Appendix H**, it does not appear that groundwater is significantly in contact with the waste mass. Therefore, a cap would be expected to decrease infiltration of water into the waste mass and subsequent leachate production. A reduction in leachate production will likely reduce the overall mass of VOCs and metals leaching or dissolving into the groundwater from the waste mass, but concentrations of VOCs and metals are likely to increase initially due to less dilution in the groundwater. It is expected that gradually, over multiple decades, VOC and metals concentrations in groundwater would decrease to less than MCLs. Toupee Capping would likely achieve a similar change in groundwater quality, as the top of the Landfill is likely where the most infiltration occurs.

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 only a small portion of the total infiltration into the waste.

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.

Installation of an impermeable cap along the side-slopes, under Full Capping, Toupee Capping with side-slopes, or Partial Capping of the side-slopes, could prevent lateral migration of landfill gas toward the property boundary. Therefore, Partial, Toupee, 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 Full Capping, Toupee Capping with side-slopes, or Partial Capping of the side-slopes, would also prevent formation of leachate seeps in the capped areas.

Implementability

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 or Toupee Capping. The trees and any facilities currently present in the areas where capping is conducted would need to be removed. Full Capping or Toupee Capping could also 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 and likely also for Toupee 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. Toupee Capping would create similar but somewhat less disturbance, due to the smaller extent of capping.

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.

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 capital cost of Full Capping of the Landfill (approximately one hundred forty [157] acres) is estimated at approximately $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 capital cost of Toupee Capping (approximately one hundred ten [110] acres) is estimated at approximately $25,000,000. The capital 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 six (6) 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 nine (9) new shallow/deep groundwater monitoring well pairs would be installed along the current 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. The existing groundwater monitoring network and proposed wells are shown on **Figure 4-6**.

The groundwater monitoring well network at the Landfill has been significantly expanded with additional monitoring wells in the past five (5) years. Since the original NES in 2010, nineteen (19) permanent monitoring wells have been installed to close the gaps in lateral spacing between the wells. Prior to completion of the NES and addendum, the lateral spacing between the wells ranged from five hundred fifty (550) ft between wells along the southeast property boundary (OB08/OB08A and OB10) to one thousand seven hundred fifty (1,750) ft along the western boundary (OB02/OB02A and OB03/OB03A). The installation of nineteen (19) additional wells as part of the NES was intended to complete the delineation of potential off-site groundwater impacts from the Landfill. The location and number of the monitoring wells installed as part of this investigation were approved by MDE.

The current lateral spacing between monitoring wells along the property boundary, following installation of new wells as part of the NES, is up to approximately one thousand (1,000) ft. Following the proposed installation of nine (9) additional well pairs to close additional gaps (**Figure 4-6**), well spacing will be approximately five hundred (500) ft. MDE requested in their 22 April 2015 letter that justification be provided for well spacing greater than three hundred (300) ft between monitoring wells, based on site-specific information. There are three (3) primary factors at this site that justify the proposed groundwater monitoring well spacing:

hydrogeological factors, lack of health risk, and difficult well installation conditions, which are each described in more detail in this section.

Hydrogeological factors affecting well spacing include hydraulic conductivity and the velocity of groundwater flows beneath the site. At the Landfill, the crystalline rock that comprises the regional aquifer is overlain by unconsolidated material consisting of interbedded silts, clays, and saprolite. Groundwater flow is highly dependent on the composition and grain size of the sediments, and therefore water likely moves slowly but more readily in the unconsolidated material than in the underlying bedrock. Groundwater in the bedrock is stored in, and moves through, fractures at a much less rapid rate. A leachate plume released into slow-moving groundwater beneath the site will disperse more widely as it travels down-gradient and can be detected by wells spaced more widely. Additionally, unlined landfills release contaminants over a larger area, while lined landfills produce point discharges requiring closer well spacing to detect point discharge contaminant plumes; therefore, the monitoring wells for an unlined landfill such as Gude do not need to be as closely spaced as those for new landfills.

Secondly, in addition to the hydrogeological factors, the VOC and metals concentrations detected in the groundwater are mostly below MCLs, with concentrations elevated only slightly above MCLs in certain areas. These impacts currently represent no risk to human or ecological health, as there is no exposure pathway. Five hundred (500) ft is a reasonable well spacing for monitoring the low-level contamination at this Landfill, in the absence of risk.

Thirdly, the environmental impacts and cost to install additional wells along most of the northern, eastern, and southern property boundaries would be significant compared to the benefits. The northern, eastern, and southern Landfill side-slopes are extremely steep, long, and heavily wooded, and streams flow along most of the toe of the eastern and southern slopes. Installation of additional monitoring wells in the narrow (in places less than twenty [20]-ft-wide) space between the waste mass and the property boundary would require construction of access roads in steep, tree-covered areas. This would involve the destruction of significant portions of forest stand, in addition to exposure of waste materials during grading activities that would present odor, dust, and health and safety concerns for construction workers and nearby residents. Additionally, erosion potential would be significantly higher in excavated areas and would have an environmental impact on the streams at the bottom of the slopes. Installation of additional wells along the northern, eastern, and southern property boundaries is not warranted at this site because of the combination of the environmental impacts and costs.

With the installation of nineteen (19) additional wells as part of the NES, and an additional nine (9) well pairs proposed in this ACM, with the specific intention of closing lateral well spacing gaps and completing the delineation of potential off-site groundwater impacts from the Landfill, the proposed lateral spacing of approximately five hundred (500) ft between monitoring wells will provide a monitoring well network that is adequate for and capable of assessing if site RAOs are achieved.

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 2-4** through **2-6**) 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 from 2011 through 2015, 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 2013, in portions of the Northwest, North, 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**	**Toupee Capping**
Groundwater				X	X	X*
Landfill Gas	X	X	X			X
Non-Stormwater Discharges		X	X		X	X

* Toupee Capping may not meet RAOs for groundwater for several decades.

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. Sporadic LEL exceedances were reported in landfill gas monitoring wells located in the Northwest Area during monitoring in 2011 through 2016 (**Figure 2-5**). 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 by VOCs 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. Toupee Capping, with capping of the Landfill side-slopes in the Northwest and West areas, would be expected to address landfill gas and non-stormwater discharges. Decreasing concentrations of VOCs and metals (particularly concentrations less than the MCLs) in the groundwater would be expected, but the RAO may not be met for several decades.

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**	**Toupee Capping**
Groundwater				X	X	X*
Landfill Gas	X	X	X			X
Non-Stormwater Discharges		X	X		X	X

* Toupee Capping may not meet RAOs for groundwater for several decades.

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, W-26, and W-28 in the West Area during monitoring in 2011 through 2016 (**Figure 2-5**). 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, Groundwater P&T, or Toupee Capping would address groundwater impacts by VOCs 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. Groundwater P&T and Toupee Capping would also address the metals exceedances in this area. Following Toupee Capping, with capping of the Landfill side-slopes in the Northwest and West areas, the RAO may not be met for several decades.

Southwest Area

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

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

* Toupee Capping may not meet RAOs for groundwater for several decades.

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 2-5**). Enhanced Bioremediation, Groundwater P&T, or Toupee Capping would address groundwater impacts by VOCs 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. Following Toupee Capping, with capping of the Landfill side-slopes in the Northwest and West areas, the RAO may not be met for several decades.

South Area

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

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

* Toupee Capping may not meet RAOs for groundwater for several decades

Groundwater P&T, Enhanced Bioremediation, or Toupee Capping would address groundwater impacts by VOCs 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 VOC groundwater impacts at the Landfill. Groundwater P&T and Toupee Capping would also address the metals exceedances in this area. Following Toupee Capping, with capping of the Landfill side-slopes in the Northwest and West areas, the RAO may not be met for several decades.

Southeast Area

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

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

* Toupee Capping may not ,meet RAOs for groundwater for several decades.

Enhanced Bioremediation, Groundwater P&T, or Toupee Capping 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 TCE and VC have been reported in this area in recent years. Following Toupee Capping, the RAO may not be met for several decades.

4.14.2 Combination Alternatives

The Corrective Measure Technologies under consideration for each Remediation Area were combined into six (6) 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.

Alternative 6, Toupee Capping and Additional Landfill Gas Collection

- Toupee Capping of the top of the Landfill (inclusive of the Northwest, West, Southwest, South, and Southeast Areas), as well as the Landfill side-slopes in the Northwest and West Areas.
- Additional Landfill Gas Collection in the Northwest, West, and Southwest Areas.

Existing stormwater infrastructure on the top of the landfill would be demolished, the landfill gas collection system would be modified, the site graded, and a Toupee Cap would be constructed. Additional landfill gas extraction wells would be installed in the Northwest, West, and Southwest Areas.

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 I**.

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 landfill gas exceedances and leachate seeps 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 I**) 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 landfill gas exceedances and leachate seeps 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 I**) 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 G**). 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 landfill gas exceedances and leachate seeps have been observed (**Figures 2-5 and 2-6**), 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 G** for a preliminary 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. However, prior to committing to implementation of MNA at the Landfill, it would be necessary to conduct additional evaluations in accordance with guidelines established in Office of Solid Waste and Emergency Response Directive 9200.4-17P.

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 I**) 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 site-wide 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 I**) 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 VOC groundwater impacts to below MCLs, and thus meet the RAO for groundwater. As noted above, this groundwater treatment technology would not address metals in groundwater, as metals do not undergo biodegradation; rather, under this CMA, metals exceedances would be addressed through continued attempts to obtain samples that are more representative of groundwater quality, and through continued monitoring.

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 VOC-related 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, with respect to VOCs, 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). However, the time to achieve RAOs with respect to metals may be longer than for VOCs.

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 VOC 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 Areas. 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 5.5.2.

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 I**) 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.

5.6 ALTERNATIVE 6: TOUPEE CAPPING AND ADDITIONAL LANDFILL GAS COLLECTION

Alternative 6 includes installing a Toupee Cap on the top of the Landfill and on the Landfill side-slopes in the Northwest and West Areas, and reconstruction of the landfill gas collection system throughout the Landfill, including installation of new extraction wells in the Northwest, West, and Southwest Areas. An engineered geosynthetic cap would be installed over the top of the Landfill and on existing side-slopes of the Northwest and West Areas. The Toupee Cap would reduce the amount of precipitation that infiltrates the landfill and would decrease the occurrence of leachate seeps on the existing side-slopes in the Northwest and West Areas. The reconstruction of the landfill gas collection system and capping on the Landfill side-slopes in the Northwest and West Areas would also reduce landfill gas migration by increasing collection efficiency. In addition to the reconstruction of the collection system and improvements to existing extraction wells, approximately fifteen (15) additional landfill gas extraction wells would be installed to provide further control over gas migration along the property boundary.

Existing stormwater features within the area of the proposed cap and the landfill gas collection system, including horizontal conveyance and header piping, would be removed prior to regrading the top of the landfill and side-slopes. The landfill gas collection system would then be reconstructed following Toupee Capping, including the installation of new extraction wells.

This CMA would not require significant monitoring or maintenance activities above and beyond the current monitoring and inspection activities occurring at the landfill.

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

As mentioned in Section 4.11.3, installation of the Toupee Cap would decrease the potential for contaminants to leach from the site; however, due to the decreased volume of water infiltrating into the waste mass and diluting the leachate, concentrations of COPCs in groundwater have the potential to increase initially, following capping. This alternative likely would not reduce COPC concentrations below MCLs until years or decades after capping. If this alternative is implemented, subsequent monitoring and reporting over the agreed upon regulatory performance period will indicate its level of success for achieving the RAOs.

A Toupee Cap on the top of the Landfill and on 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 help control landfill gas migration and decrease leachate production and seep occurrences, thus increasing compliance with RAOs for landfill gas and leachate in these areas.

5.6.2 Short-Term Effectiveness

Installation of a Toupee Cap and gas extraction wells would temporarily create some potential for human contact with waste and leachate, specifically for the trained professionals and construction workers on-site. Regrading of the existing landfill cover and other surficial construction activities related to the installation of the Toupee Cap will create fugitive emissions of landfill gas along with increased levels of dust, odor, and noise, which would be managed through compliance measures to be developed in an operations plan. These concerns would be addressed in the site-specific Health and Safety Plan, using Personal Protective Equipment and other precautions as necessary. Overall, Alternative 6 is expected to produce fewer short-term negative impacts than CMAs that include waste excavation.

Leachate seep occurrences (**Figure 2-6**) would not be expected to recur following installation of a Toupee Cap on the Landfill side-slopes in the Northwest and West Areas. Landfill gas concentrations at the property boundary would be expected to decrease following reconstruction of the collection system, construction of the Toupee Cap on the side-slopes, and 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 installation of the Toupee Cap and landfill gas extraction wells could begin approximately two (2) years after approval of the ACM (**Figure 5-1**), once the project has been permitted and contracted, and that construction could be completed within approximately four (4) to five (5) years after approval of the ACM. Thus, site-wide compliance with the RAOs for non-stormwater discharges and landfill gas would be expected to occur within approximately four (4) to five (5) years of ACM approval.

As described in Section 1.2.5, HELP modeling indicates that the rate of percolation of water through the cap into the waste mass following installation of the Toupee Cap would be approximately one (1) percent of the current rate of water percolating through the soil cover in this area. If percolation through the uncapped side slopes is taken into account, then an overall decrease in percolation of sixty-five (65) percent is expected following capping. As stated above, the decreased percolation could cause leachate-derived constituents in groundwater to initially increase after capping, as the leachate present in the waste at the time of capping is gradually depleted. Following this initial response, the decreased volume of leachate and decreased mobility of leachate-derived constituents would be expected to result in a substantial decrease in constituent concentrations in groundwater.

The timeframe to meet the RAO for groundwater was estimated based on the decreased water infiltration and resulting leachate production expected following capping. The highest COPC concentrations in groundwater along the property boundary, which is the point of compliance for the RAO, occur in the northwest, southwest, and south portions of the Landfill, with concentrations up to approximately ten (10) times the MCL for cVOCs such as TCE, PCE, and VC.

Data indicate that anaerobic dechlorination of cVOCs is occurring at the Landfill (**Appendix G**). According to published literature values (Howard et al. 1991), the maximum estimated half-life for degradation of the cVOC COPCs under anaerobic conditions is approximately four (4) years. Thus, with no new inputs, and assuming four (4) overlapping degradation steps (PCE to TCE to cis-1,2-DCE to VC), the concentrations would be expected to fall below MCLs in approximately thirty (30) years. If inputs persisted at twenty-five (25) percent of their current rate, then the time to achieve MCLs would increase to approximately forty (40) years. Based on this, it is expected that, with respect to cVOCs, the RAO for groundwater at the Landfill would be met approximately thirty (30) to forty (40) years after installation of the Toupee Cap.

Concentrations of non-cVOC COPCs (e.g., benzene, methylene chloride, and metals) would also be expected to decrease to below MCLs within the thirty (30) to forty (40)-year timeframe. For the non-chlorinated VOCs, current concentrations are lower relative to the MCLs, and the rate of degradation is faster than the rate of degradation of cVOCs. For metals, the majority of exceedances are currently sporadic and inconsistent, and are suspected of being related to turbidity. These exceedances would continue to be addressed through low-flow sampling, well re-development, and possible well replacement. For the exceedances that are representative of groundwater quality and likely reflect Landfill-related impacts (e.g., cadmium in well OB11), current concentrations only slightly exceed the MCL. Additionally, the localized nature of these exceedances suggests a localized source, relatively near the impacted monitoring well. As infiltration into the waste mass decreases by an estimated sixty-five (65) percent following capping, it is expected that these concentrations will fall consistently below MCLs. Sorption of metals to the geologic substrate will also continue to promote the attenuation of metals concentrations in groundwater after capping.

The estimated groundwater flow rate through the saprolite and bedrock underlying the waste mass is approximately seven (7) feet/year (based on a hydraulic conductivity of twenty-eight one-hundredths (0.28) feet/day, a hydraulic gradient of two one-hundredths (0.02), and a porosity of thirty [30] percent). At this rate, it takes approximately five hundred (500) years for groundwater to flow from one side of the Landfill to the other (e.g., from the southwest to the southeast corner). If groundwater throughout the footprint of the Landfill were impacted, then it would take at least this long to meet RAOs, in the absence of degradation. However, the degradation of VOCs, described above, is expected to result in achievement of RAOs much faster than advection of the contaminants. For metals, the impacts are not widespread, impacting only a single well. Given a metal-contaminated area extending less than a few hundred feet from the well, progress toward meeting RAOs for metals, in the absence of sorption, should occur within the forty (40)-year timeframe for meeting groundwater RAOs.

Monitoring data collected over approximately twenty [20] years after installation of the Toupee Cap would be assessed to refine the projected timeframe to meet RAOs for groundwater. If this timeframe is determined to be unacceptable, additional remedies would be implemented as identified in a contingency plan to improve the short-term effectiveness.

5.6.3 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 minimize the occurrence of landfill gas exceedances at the boundary. Installation of a Toupee Cap covering the Northwest and West Areas is expected to be an effective, long-term remedy for preventing leachate seeps.

Installation of a Toupee Cap covering the top of the landfill (a majority of the landfill area) as well as the side-slopes in the West and Northwest Areas also is expected to be highly effective for minimizing the production of leachate within the Landfill and thus decreasing both the occurrence of leachate seeps and the mass of COPCs reaching the groundwater. As stated above, it is expected that the timeframe to meet RAOs would be multiple decades (estimated at thirty [30] to forty [40] years) after Toupee Capping.

5.6.4 Implementability of Alternative

Toupee Capping is implementable at the Landfill. Installation of a Toupee Cap would require some site disturbance along the top of the Landfill and portions of the Landfill boundary, including disturbance of existing vegetation and infrastructure currently present at the Landfill. Trees currently present on the Northwest and West side-slopes of the Landfill would need to be cleared and the existing landfill cover would need to be regraded prior to installation of the Toupee Cap. Additionally, horizontal conveyance and header piping of the Landfill Gas Collection system would need to be removed and then replaced above the new geomembrane, and the gas extraction wells would need to be raised in some locations to remain above the new Toupee Cap. In the future, if conditions at the Landfill required the installation of additional gas extraction wells below the Toupee Cap and within the waste, such activities would require the use of specialized, industry-standard procedures and precautions.

The existing stormwater features at the Landfill would also be removed prior to capping. The regrading and cover placement following Toupee Capping and supporting changes to infrastructure would need to take into account potential future land reuse options.

5.6.5 Protection of Human and Ecological Health

Short-term implications of this CMA for human health and the environment are discussed in Section 5.6.2.

In the long term, Additional Landfill Gas Collection and Toupee Capping would be protective of human and ecological health by reducing landfill gas emissions, leachate seeps, and production of leachate site-wide.

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.

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

This CMA would not decrease the source mass (i.e., the amount of waste that is creating contaminants, gas, and leachate) within the Landfill. Additional Landfill Gas Collection and Toupee Capping would decrease the mobility of landfill gas and leachate and would also reduce the mass of COPCs infiltrating into the groundwater. Toupee Capping reduces the volume of leachate in the landfill, offering a significant advantage in terms of minimizing the toxicity and volume of the impacts.

5.6.7 Cost of Alternative

The total estimated cost for implementation of Alternative 6 is approximately $27,000,000 (**Appendix I**) and includes the capital costs of Additional Landfill Gas Collection and the capital costs and O&M associated with Toupee Capping. The capital cost of reconstructing the landfill gas collection system and installing fifteen (15) additional landfill gas extraction wells is approximately $1,400,000. The capital cost of Toupee Capping is approximately $17,000,000. O&M costs for Toupee Cap Maintenance (approximately $30,000 per year) includes estimated repair of a quarter acre section of the cap every two (2) years.

5.6.8 Regulatory Acceptance of Alternative

Toupee Capping is a presumptive remedy for limiting the mobility of impacts from landfills, and Landfill Gas Collection is also a common tool. Based on input from MDE, this CMA would be readily accepted by MDE.

5.6.9 Community or Stakeholder Acceptance of Alternative

The community is expected to have concerns regarding increased truck traffic associated with construction and increased odors, dust, and noise during the regrading of site for the capping system construction and the reconstruction of the landfill gas collection system. However, the overall construction timeframe for this CMA is shorter than all the other CMAs (two [2] to three [3] years). There would be minimal to no impacts beyond the period of construction, and this CMA would provide additional protectiveness against landfill gas and leachate in the portions of the landfill adjacent to the community.

This CMA is compatible with the community’s recreational reuse preferences for the Landfill, as the Landfill would not experience long-term disturbance, and the final graded, capped surface could be developed for a variety of passive recreational activities. 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 six (6) 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, along with Alternative 3, have similar potential to achieve compliance with the RAO for groundwater. Alternatives 4 and 6 would have slightly lower compliance, due to the technical difficulty or time required to meet RAOs.

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, 5, and 6 would include installation of additional landfill gas extraction wells, which provides direct control over landfill gas migration. Alternative 6 would further control landfill gas via the addition of the cap combined with improvements in the landfill gas collection system. 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 Alternatives 4 and 5. Alternatives 3 and 6 would be the most likely to achieve full compliance with the RAO for landfill gas, by either removing the source of the gas or capping the top and the Northwest and West side-slopes and improving the collection system.

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 6 would address leachate seeps through capping of both the top of the landfill and the Northwest and West side-slopes, which would decrease leachate production and also minimize seeping of leachate along the side-slopes. Alternative 3 would eliminate leachate seeps by removing the waste mass. Thus, Alternatives 3 and 6 are 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 through 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 specifically for the trained professionals and construction workers on-site. 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. Similar impacts would also be associated with the regrading of the landfill cover and removal of the landfill gas collection system piping prior to Toupee Capping as part of Alternative 6, but to a lesser extent than would be associated with waste excavation.

Installation of landfill gas extraction wells under Alternatives 4, 5, and 6 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 is expected to create site disturbance similar to that associated with 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 through 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, 5, and 6 than for Alternatives 1 through 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, 5, and 6, the timeframe for addressing landfill gas and leachate seeps depends on the time required to implement gas extraction well installation and improvements to the cover system or Toupee Cap 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. The timeframes to meet groundwater RAOs under Alternatives 3 and 6 would likely be the longest, due to the prolonged timeframe for complete source removal and the relatively slow rate of attenuation under MNA, and because improvements in groundwater quality following capping are typically gradual.

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, followed by Alternatives 1, 2, and 6, 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, 5, and 6 would also address landfill gas and leachate in the long-term, as long as the improved cover system or Toupee Cap and landfill gas extraction wells are maintained. Alternative 3 is the most permanent, 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) and Toupee Capping (included in Alternative 6) are the most permanent. MNA relies on natural processes which will continue without intervention, and would achieve the groundwater RAO in the long-term, particularly when combined with complete source removal. Toupee Capping would permanently decrease leachate production and thus the mobility of both VOC and metals contamination, as long as the cap is maintained. 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 for VOCs 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, 5, and 6 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 thirty (30) year timeframe that would be required for Extensive Waste Excavation. It is expected that the full effectiveness of Alternative 6 will be realized in the long-term. 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 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. Alternative 6 would be highly implementable, due to the use of widely accepted technology, the short timeframe for construction, and minimal requirements after construction.

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 Alternatives 3 and 6 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. Besides Toupee Capping, 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 6 is the most implementable, followed by Alternative 5, then 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 six (6) 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. 5, and 6 would provide protection from leachate seeps, through Cover System Improvements and Toupee Capping, and would also control landfill gas migration through Landfill Gas Collection, with fewer short-term health concerns.

Overall, Alternatives 4, 5, and 6 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, 5, and 6 would not decrease the source mass. Cover System Improvements under Alternatives 1, 2, 4, and 5 and Toupee Capping under Alternative 6 would decrease the mobility of leachate. Toupee Capping under Alternative 6 would also decrease the volume of leachate produced, and thus decrease the volume and mobility of groundwater impacts within the aquifer. 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, 5, and 6 would control mobility through additional extraction of landfill gas.

Like Toupee Capping, 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, and 6, and then Alternatives 4 and 5.

6.7 COST OF ALTERNATIVE

The costs of Alternatives 1–3 are driven by Waste Excavation. The cost of Alternatives 4, 5, and 6, which do not include Waste Excavation, are lower. 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 capital cost of Alternative 6 is higher than Alternatives 4 and 5; however, the overall cost and annual O&M costs for this CMA are the lowest of the six (6) alternatives. The approximate estimated costs of the CMAs are summarized below:

Costs	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative 6**
Capital	$105,000,000	$52,000,000	$455,000,000	$8,000,000	$9,000,000	$26,300,000
Annual O&M	$2,400,000	$2,400,000	$48,000	$3,300,000	$2,400,000	$30,000
Total with 20 years O&M	**$152,000,000**	**$100,000,000**	**$456,000,000**	**$74,000,000**	**$57,000,000**	**$27,000,000**

6.8 REGULATORY ACCEPTANCE OF ALTERNATIVE

All six (6) 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). Because Alternative 6 includes capping, which is a presumptive remedy for landfills, it is expected to be the most readily accepted by MDE.

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, 5 and 6, which do not include waste excavation. The disturbance of the Landfill required for installation of a Toupee Cap under Alternative 6 would be of substantially shorter duration than excavation, and thus is not expected to generate substantial community concerns. Community opinion may favor Enhanced Bioremediation over Groundwater P&T, because P&T would require more construction activity at the Landfill. Alternative 6 would be associated with minimal disturbance following construction, unlike Enhanced Bioremediation and Groundwater P&T, which require continued operations and monitoring. 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 could ease community concerns.

All six (6) 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, 5, and 6 would cause the shortest disturbance to potential reuse of the property.

Overall, Alternatives 5 and 6 are expected to be the most acceptable to the community, followed by Alternative 4, Alternatives 1 and 2, and Alternative 3.

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 6, Toupee Capping and Additional Landfill Gas Collection. 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. Toupee Capping would decrease the occurrence of leachate seeps and comply with the RAO for non-stormwater discharge, and is also expected to achieve compliance with the RAO for groundwater, although likely not for a few decades after capping. Alternative 6 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 6 is included in **Appendix J**. This plan includes details of the pre-design activities and the design and construction of the Toupee Cap, descriptions of the additional landfill gas extraction wells to be installed, and an anticipated schedule including implementation of these components. Before remedial activities begin, nine (9) new groundwater monitoring well pairs would be installed along the current 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. A Contingency Plan, which provides a framework for the monitoring and evaluation of the recommended CMA and dictates criteria or “triggers” for the implementation of contingency measures, is included in **Appendix K**.

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 2-4, 2-5, and 2-6**).

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, Groundwater P&T, and Toupee Capping for groundwater (**Figure 4-2**); Selective or Extensive Waste Excavation, Landfill Gas Collection, Cover System Improvements, and Toupee Capping for landfill gas (**Figure 4-3**); and Selective or Extensive Waste Excavation, Cover System Improvements, and Toupee Capping for non-stormwater discharges (**Figure 4-4**). These Corrective Measure Technologies were combined into six (6) CMAs, each addressing all three (3) media of concern (**Figure 4-5**), for detailed evaluation.

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 6, Toupee

Capping and Additional Landfill Gas Collection, 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 6 is included in **Appendix J**, and provides descriptions and schedules for the recommended technologies. A Contingency Plan is provided in **Appendix K**.

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