

Corrective Action Plan (CAP) for the Blue Ridge Landfill, Estill County, Kentucky

Prepared for
Advanced Disposal Services Blue Ridge Landfill, Inc.
2700 Winchester Road
Irvine, KY 40336

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GRADIENT

www.gradientcorp.com
20 University Road
Cambridge, MA 02138
617-395-5000

Table of Contents

	<u>Page</u>
Executive Summary.....	ES-1
1 Introduction	1
2 Background	2
2.1 Blue Ridge Landfill Overview	2
2.1.1 Landfill Liner System	3
2.1.2 Leachate Collection System	4
2.1.3 Landfill Gas Management System	4
2.1.4 Stormwater Control	4
2.2 Physical Setting	5
2.2.1 Site Geology	5
2.2.2 Site Hydrogeology	7
2.2.3 Surface Water Bodies	8
2.2.4 Climate	9
2.2.5 Topography	9
2.3 Overview of BES Waste Disposal	9
2.4 Summary of Receptors and Risks.....	12
2.5 Regulatory Requirements	13
2.5.1 State of Kentucky Landfill Requirements.....	13
2.5.2 State of Kentucky Remediation Requirements.....	16
2.5.3 Relevant Federal Requirements	18
3 Remedial Action Objectives	21
4 Development of Remediation Alternatives	23
4.1 Preliminary Screening of Remediation Technologies.....	23
4.2 Remediation Alternatives Retained for Consideration.....	24
4.2.1 Remediation Alternative 1: Closure-in-Place and Monitoring.....	24
4.2.2 Remediation Alternative 2: Excavate and Redispose BES Waste	25
5 Corrective Action Evaluation Criteria	28
6 Evaluation of Remediation Alternatives	30
6.1 Overall Protectiveness	30
6.2 Compliance with Other Applicable Requirements	33
6.3 Long-term Effectiveness and Permanence	33
6.3.1 Long-term Radiological Risks (Remediation Alternative 1: Closure-in-Place and Monitoring)	33

6.3.2	Adequacy and Reliability of Engineering Controls.....	36
6.4	Reduction of Toxicity, Mobility, and Volume Through Treatment.....	36
6.5	Short-term Effectiveness	37
6.5.1	Short-term Radiological Risks	37
6.5.2	Physical Risks.....	38
6.5.3	GSR	41
6.6	Implementability.....	42
6.7	Cost	43
6.8	Regulatory Approval and Community Acceptance.....	44
7	Comparative Analysis of Remediation Alternatives	45
8	Radioactive Material Screening Plan	46
	References	47
Attachment A1	RAC 2016 Dose and Risk Assessment	
Attachment A2	RAC 2017 Radiological Risk Assessment	
Attachment B	Cornerstone Environmental 2017 BES Waste Depth Memo	
Attachment C	Weaver 2017 Radioactive Material Screening Plan	
Attachment D	Supporting Calculations: Physical Risk and GSR Analyses	
Attachment E	Supporting Calculations: Detailed Cost Estimate Calculations	
Attachment F	Glossary of Remediation Terminology	
Attachment G	Cornerstone Environmental 2017 Well Survey Work Plan	

List of Tables

Table 2.1	Waste Material Accepted at the Blue Ridge Landfill, 2014-2016
Table 2.2	Summary of Site Geological Formations
Table 2.3	Summary of Waste Generators that Provided BES Waste to the Blue Ridge Landfill
Table 2.4	Summary of Landfill Monitoring Requirements
Table 3.1	Site-specific Factors for Remedial Action Objective Determination
Table 4.1	Summary of Landfill Remediation Technologies
Table 4.2	Preliminary Screening of Remediation Technologies
Table 4.3	Summary of Site Factors for Remediation Alternative 2: Excavate and Redispose BES Waste
Table 6.1	Overall Protectiveness of the Remediation Alternatives
Table 6.2	Lifetime Cancer Morbidity Risk Estimates for the Remediation Alternatives Post-disposal
Table 6.3	Cancer Morbidity Risk Estimates for the Remediation Alternatives During Excavation
Table 6.4	Summary of Physical Risks for the Remediation Alternatives
Table 6.5	Summary of GSR Metrics for the Remediation Alternatives
Table 6.6	Summary of Incremental Remediation Alternative Costs
Table 7.1	Comparative Analysis of the Remediation Alternatives

List of Figures

- Figure 1.1 Blue Ridge Landfill Site Location Map
- Figure 2.1 Blue Ridge Landfill and Surrounding Land Use
- Figure 2.2a 1992 Water Well Survey Results
- Figure 2.2b 2017 Water Well Survey Results
- Figure 2.3 Blue Ridge Landfill Site Features
- Figure 2.4 Blue Ridge Landfill Geologic Cross Section
- Figure 2.5 Blue Ridge Landfill Geologic Cross Section Location
- Figure 2.6 Blue Ridge Landfill Groundwater Monitoring Locations and Flow Directions in the New Albany Shale
- Figure 2.7 Blue Ridge Landfill 1992 Groundwater Flow Directions in Bisher and Boyle Dolomites
- Figure 2.8 Surface Water Bodies in the Vicinity of the Blue Ridge Landfill
- Figure 2.9 Natural Thorium and Uranium Decay Chains (*Embedded in Section 2.3*)
- Figure 2.10 Blue Ridge Landfill 2016 Gamma Scan Survey
- Figure 2.11 Blue Ridge Landfill Soil and Groundwater Sampling Locations
- Figure 2.12 Blue Ridge Landfill Air, Sediment, and Surface Water Sampling Locations
- Figure 4.1 Enhanced Final Cover, Remediation Alternative 1
- Figure 4.2 BES Waste Excavation Areas, Remediation Alternative 2

Abbreviations

ADS	Advanced Disposal Services Blue Ridge Landfill, Inc.
ARAR	Applicable or Relevant and Appropriate Requirements
BOD	Biological Oxygen Demand
CAP	Corrective Action Plan
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CMIC	Central Midwest Interstate Low-Level Radioactive Waste Commission
ERICA	Environmental Risk from Ionising Contaminants: Assessment and Management
ft amsl	Feet Above Mean Sea Level
ft bgs	Feet Below Ground Surface
GHG	Greenhouse Gas
GSR	Green and Sustainable Remediation
KAR	Kentucky Administrative Regulation
KPDES	Kentucky Pollutant Discharge Elimination System
KRS	Kentucky Revised Statute
KCHFS	Kentucky Cabinet for Health and Family Services
KYDEP	Kentucky Department of Environmental Protection
MCL	Maximum Contaminant Level
MSW	Municipal Solid Waste
NCP	National Contingency Plan
NORM	Naturally Occurring Radioactive Material
NO _x	Nitrogen Oxides
NPDES	National Pollutant Discharge Elimination System
NRC	Nuclear Regulatory Commission
O&M	Operations and Maintenance
PADEP	Pennsylvania Department of Environmental Protection
PM ₁₀	Particulate Matter Less Than 10 Microns in Diameter
RAC	Risk Assessment Corporation
SO _x	Sulfur Oxides
TDS	Total Dissolved Solids
TENORM	Technologically Enhanced Naturally Occurring Radioactive Material
The Cabinet	Kentucky Energy and Environment Cabinet
TOC	Total Organic Carbon
TSS	Total Suspended Solids
US ACE	United States Army Corps of Engineers
US BLS	United States Bureau of Labor Statistics
US DOT	United States Department of Transportation
US EPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound

Executive Summary

Gradient prepared this Corrective Action Plan (CAP) on behalf of Advanced Disposal Services Blue Ridge Landfill, Inc. (ADS) in accordance with an Agreed Order entered into between the Kentucky Energy and Environment Cabinet (the Cabinet) and ADS (KYEEC and ADS, 2016). The purpose of this CAP is to provide an evaluation of remediation alternatives with regard to the disposal of 92 loads (1,157 tons) of oil field wastes delivered to the Blue Ridge Landfill by a company known as BES, LLC (the "BES Waste"). For the purposes of this CAP and to provide a conservative analysis, we have assumed that all of the material comprising the 92 loads constitutes technologically enhanced naturally occurring radioactive material (TENORM).¹ ADS, through routine disposal practices, mixed the BES Waste with municipal solid waste (MSW) and covered it in place with soil and additional MSW.

The Commonwealth of Kentucky currently regulates out-of-state TENORM differently than in-state TENORM. Under the Regional Management Plan issued by the Central Midwest Interstate Low-Level Radioactive Waste Commission, TENORM generated out-of-state is banned at concentrations of 5 pCi/g or greater, while TENORM generated in-state can be disposed of at concentrations below 2,000 pCi/g subject to the approval of the appropriate state regulatory agency. Under the proposed regulations recently issued by the Cabinet and the Kentucky Cabinet for Health and Family Services (KCHFS), in-state TENORM at concentrations less than 200 pCi/g may be disposed of in an approved Kentucky landfill, while out-of-state TENORM at 5 pCi/g and greater would remain banned.

Constituents of TENORM are radionuclides primarily from the uranium-238 (U-238) and thorium-232 (Th-232) decay series. These radionuclides are naturally occurring at elevated concentrations in local bedrock and soils (RAC, 2016). Professional environmental firms and government agencies have conducted a comprehensive series of environmental sampling investigations at the Blue Ridge Landfill, and in its vicinity, to characterize the BES Waste, to measure deviations from natural background radiation levels, and to evaluate potential impacts and exposures. The scope of the investigations included sampling environmental media, including air, soil, sediment, surface water, groundwater, and landfill leachate, and a gamma scan survey across the landfill's surface. The results of these environmental sampling investigations indicate that radionuclide concentrations in areas of the landfill containing a mixture of the BES Waste and MSW are below those of samples from naturally occurring radioactive material (NORM) inside and outside of the permitted solid waste boundary.

The environmental sampling investigation results served as the basis for the "Dose and Risk Assessment of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) Disposals at the Blue Ridge Landfill" completed by Risk Assessment Corporation (RAC) (Dose and Risk Report; RAC, 2016) in October 2016. RAC conducted this assessment to evaluate radiation doses and risks to on-Site workers and nearby community members during disposals of BES Waste and in the future (RAC, 2016). RAC conducted additional radiological analyses in support of the CAP to further evaluate the long-term and short-term human health risks associated with the Remediation Alternatives evaluated in the CAP (RAC, 2017). In addition, RAC conducted an assessment of radiological risk to ecological receptors, including terrestrial mammals, birds, and vascular plants, and aquatic receptors (amphibians and fish)

¹ The US EPA defines TENORM as, "Naturally occurring radioactive materials that have been concentrated or exposed to the accessible environment as a result of human activities such as manufacturing, mineral extraction, or water processing" (US EPA, 2016a).

using the Environmental Risk from Ionising Contaminants: Assessment and Management (ERICA) tool (RAC, 2017).

The assessments performed by RAC concluded that doses received by on-Site workers and nearby community members from the disposal of the BES Waste were extremely low in the past, are currently extremely low, and will continue to be extremely low in the future. RAC (2016) concluded that the dose for all receptors, including the most highly exposed individual (the on-Site landfill worker during disposal) was well below the level at which potential health effects may be observed. RAC (2016) found that the exposure levels associated with the BES Waste were a fraction of those associated with natural background radiation. The ecological assessment conducted by RAC (2017) demonstrated that the potential radiation doses would be well below established screening values and would be highly unlikely to cause deleterious effects to ecological receptors.

The Blue Ridge Landfill has highly engineered environmental controls, as required by the conditions of its operating and closure permit (Solid Waste Permit SW033-0004) and consistent with Kentucky State and federal non-hazardous landfill regulations. These environmental controls include the following:

- A multi-component liner system, including a low-permeability clay and geomembrane layer that prevents the migration of leachate constituents from the landfill into native groundwater beneath the landfill;
- A leachate extraction system that drains, extracts, and collects leachate, which reduces vertically downward hydraulic gradients and further minimizes the potential for leachate migration beyond the landfill's boundary;
- Stormwater management features that minimize infiltration into the landfill waste and, therefore, reduce leachate-generation potential; and
- A post-closure low-permeability cap that will further reduce infiltration into the landfill.

In addition, ADS routinely monitors groundwater and surface water at the landfill for a suite of constituents to screen for potential leachate infiltration.

To guide the remedy evaluation and selection process to specific endpoints that ensure protectiveness, Gradient developed Remedial Action Objectives for the impacted media at the Site and its vicinity. At the Blue Ridge Landfill, the primary medium of concern is MSW mixed with the BES Waste, which, for the purposes of this analysis, is assumed to contain radionuclides primarily from the U-238 and Th-232 decay series. In addition, leachate and landfill gas generated from the BES Waste are media of concern, as are surface water and groundwater beyond the landfill waste boundary.

The scope of this CAP included the preliminary screening of remediation technologies to address the BES Waste and its potential impacts to the media of concern. Based on this screening, we retained the following Remediation Alternatives for consideration in the CAP:

- **Remediation Alternative 1: Closure-in-Place and Monitoring.** This scenario consists of response actions at the Blue Ridge Landfill that are consistent with the operational and post-closure requirements promulgated by the Cabinet for solid waste landfills and that the Blue Ridge Landfill operating and closure permit (Solid Waste Permit SW033-00004), approved by the Cabinet, requires. This includes the existing and post-closure engineering controls as well as routine monitoring of surface water, groundwater, and leachate quality. In addition, ADS would perform the following additional actions as part of Remediation Alternative 1: develop and implement a Radionuclide Sampling Plan, place an enhanced cap over the BES Waste area as part

of the final cover system, and modify the landfill gas collection system to relocate landfill gas extraction wells from the BES Waste area.

- **Remediation Alternative 2: Excavate and Redispose BES Waste.** This alternative consists of uncovering, excavating, transporting, and redisposing the mixed MSW and BES Waste from the Blue Ridge Landfill to another landfill. Under this scenario, approximately 39,630 yd³ of BES Waste mixed with MSW (an estimated 1,823 truckloads, assuming a 15% fluff factor [45,575 yd³ total]) would be excavated and transported by truck to another disposal facility, where it would be redisposed, subject to similar environmental controls.

Gradient evaluated the Remediation Alternatives individually against nine remedy evaluation criteria,² using a combination of qualitative and quantitative methods. Per 401 Kentucky Administrative Regulation (KAR) 100:030 (Remediation Requirements), these nine criteria are used to evaluate "sites where the party or applicant will manage releases in place." This is the case for Closure-in-Place and Monitoring (Remediation Alternative 1) described above. These criteria also correspond to the nine federal National Contingency Plan (NCP) remedy selection criteria, which are used in the "Comparative Analysis" process to evaluate and compare remediation alternatives to ensure the rational selection of a remedy (NCP 300.430(f)).

The results of the comparative analysis demonstrate that Remediation Alternative 1 (Closure-in-Place and Monitoring) is the preferred remediation approach for the Blue Ridge Landfill, because it provides the highest degree of overall protectiveness, poses the lowest short-term physical and radiological exposure-related risks to workers and the community, and provides long-term effectiveness and protectiveness while also being cost-effective and implementable. This alternative avoids the uncertainties and risks (such as truck accidents) associated with excavating and removing the BES Waste from the landfill.

By containing and monitoring the BES Waste, Closure-in-Place and Monitoring (Remediation Alternative 1) limits direct exposure to impacted media and ensures that target risk levels are met at the points of exposure while also allowing for the long-term stability and controlled attenuation of associated leachate and landfill gas impacts. The use of institutional and engineering controls, a critical component of this alternative and required by the landfill's operating and closure permit, will allow for the long-term management of any residual risks, such as those associated with BES Waste and impacted media left in place. To further minimize the potential that out-of-state TENORM waste will be accepted at the landfill in the future, and pursuant to the requirements of the Agreed Order, ADS is submitting a Radioactive Material Screening Plan (Weaver Consultants Group, LLC, 2017) as part of this CAP report.

² (1) Overall Protection of Human Health and the Environment, (2) Compliance with Other Applicable Requirements, (3) Long-term Effectiveness and Permanence, (4) Reduction of Toxicity, Mobility, and Volume Through Treatment, (5) Short-term Effectiveness, (6) Implementability, (7) Cost, (8) Regulatory Approval, and (9) Community Acceptance.

1 Introduction

Gradient prepared this Corrective Action Plan (CAP) on behalf of Advanced Disposal Services Blue Ridge Landfill, Inc. (ADS) in accordance with an Agreed Order entered into between the Kentucky Energy and Environment Cabinet (the Cabinet) and ADS (KYEEC and ADS, 2016). The purpose of this report is to provide an evaluation of remediation alternatives with regard to the disposal of 92 loads (1,157 tons) of oil field wastes delivered to the Blue Ridge Landfill by a company known as BES, LLC (the "BES Waste"). For the purposes of this report and to provide a conservative analysis, we have assumed that all of the material comprising the 92 loads constitutes technologically enhanced naturally occurring radioactive material (TENORM).³ ADS, through routine disposal practices, mixed the BES Waste with municipal solid waste (MSW) and covered it in place with soil and additional MSW.

Professional environmental firms and government agencies have conducted a series of environmental investigations to characterize the BES Waste. The results of these studies served as the basis for both the October 2016 "Dose and Risk Assessment of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) Disposals at the Blue Ridge Landfill" report (Dose and Risk Report) (RAC, 2016) and the April 2017 "Radiological Risk Assessment" report (RAC, 2017), both prepared by Risk Assessment Corporation (RAC), which are being submitted concurrently with this CAP (Attachments A1, A2). Both the findings of the previous environmental investigations and the RAC human health risk assessments are summarized in brief below, because they are relevant to the evaluation of the Remediation Alternatives considered in the CAP.

Gradient prepared this report in accordance with 410 KAR 100:030(8) and analogous federal regulations set forth under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the National Contingency Plan (NCP). The following sections of the report provide a discussion of relevant Site background and regulatory requirements (Section 2), the Remedial Action Objectives (Section 3), the development of the Remediation Alternatives (Section 4), the corrective action evaluation criteria (Section 5), the evaluation of the alternatives using a combination of qualitative and quantitative methods based on those criteria (Section 6), a comparative analysis of the Remediation Alternatives (Section 7), and the Radioactive Material Screening Plan (Section 8). Attachments A-G provide supporting information.

³ The US EPA defines TENORM as, "Naturally occurring radioactive materials that have been concentrated or exposed to the accessible environment as a result of human activities such as manufacturing, mineral extraction, or water processing" (US EPA, 2016a).

2 Background

2.1 Blue Ridge Landfill Overview

This section summarizes the operational history and structural features of the Blue Ridge Landfill based on permit documents and technical applications, such as those developed in preparation for the landfill's horizontal expansion (Rust Environment & Infrastructure, Inc., 1992a, 1994a). The Blue Ridge Landfill is a dynamic system. For example, its leachate controls and gas extraction processes, as well as groundwater and surface water monitoring plans, are periodically adapted based on changing Site conditions.

The Blue Ridge Landfill is an MSW facility located on approximately 340 acres at 2700 Winchester Road in eastern Kentucky, near the town of Irvine in Estill County. About 70% of Estill County is forested land, with the remaining areas consisting of farms and urban development. The US Forest Service manages a small portion of the forested land in the county as part of the Daniel Boone National Forest, located east of the Blue Ridge Landfill. The portion of the Blue Ridge Landfill permitted for solid waste disposal is surrounded by dense, unevenly aged trees, understory, and ground cover vegetation (Rust Environment & Infrastructure, Inc., 1994b). Land use to the east of the landfill includes residential, rural, and agricultural uses. Directly southwest of the landfill are Estill County High School and Middle School (Figure 2.1). Southwest of the middle and high schools is an industrial park that includes mining operations and warehouses. Rust Environment & Infrastructure, Inc. (1992a) conducted a private water well survey in 1992 to evaluate water use in the vicinity of the landfill. Figure 2.2a shows the results of this survey.

An updated well search is underway. As part of that well search, the Kentucky Geological Survey database⁴ for water supply wells and springs was queried for wells and springs within 1 mile of the Site boundary. The results of the database query are provided in Figure 2.2b. In addition, a well survey within 1 mile of the downgradient (northwest) Site boundary is currently being implemented. Details about this well survey methodology are provided in Attachment G, and its results will be submitted to the Cabinet in a separate report upon its completion.

The landfill began operating in 1984 under Solid Waste Permit SW033-00004. It has accepted an average of 550 tons of waste materials per day in the approximately 60-acre area permitted for solid waste disposal (Figure 2.1; KYEEC, 2012). The Blue Ridge Landfill also maintains and operates a 1,600-kilowatt electrical generation plant that processes methane gas collected from the landfill to generate electricity, which is subsequently delivered to the grid. Materials accepted by the landfill include predominantly MSW and construction and demolition debris, with the remainder consisting of special waste and soil (see Table 2.1). Landfill operations are ongoing and expected to continue until 2034.

⁴ The Kentucky Groundwater Data Repository can be accessed at: <http://www.uky.edu/KGS/water/research/gwreposit.htm> (University of Kentucky and Kentucky Geological Survey, 2017a).

Table 2.1 Waste Material Accepted at the Blue Ridge Landfill, 2014-2016

Waste Material Accepted (4/23/14 to 3/22/16)	Tons	Percentage of Total
MSW	191,221	72%
Construction and Demolition Debris	25,404	10%
Special Waste	30,831	12%
Soil	17,190	6%
TOTAL:	264,646	100%

Note:
MSW = Municipal Solid Waste.

The following sections describe the engineered features of the Blue Ridge Landfill that are designed and operated to prevent landfill contaminants from entering the environment.

2.1.1 Landfill Liner System

The landfill contains an engineered liner system designed and constructed in compliance with Kentucky (401 KAR 48:080) and federal regulations (40 CFR 258.40(b)). The purpose of the engineered liner system is to prevent the migration of landfill leachate into groundwater. The liner system consists of the following components:

1. **Clay Soil Layer.** The bottom liner is composed of recompacted clay soil with a maximum permeability of 1×10^{-7} cm/sec. For horizontal-to-vertical slopes less than 3:1, the clay is 36 inches thick. For horizontal-to-vertical slopes greater than 3:1, the clay is 24 inches thick.
2. **High-density Polyethylene Geomembrane.** The second component (above the clay soil liner) is a high-density polyethylene geomembrane that is 60 mm thick, with a hydraulic conductivity of less than 1×10^{-12} cm/sec. This geomembrane has a maximum water vapor transmission rate of 0.03 g/m²/day and is able to prevent the migration of leachate while resisting material degradation from MSW and other solid wastes (Rust Environment & Infrastructure, Inc., 1992a).
3. **Geotextile Cushion or Geocomposite Drainage Layer.** The third component is either a geotextile cushion or a geocomposite drainage layer placed on top of the geomembrane. For horizontal-to-vertical slopes less than 3:1, a geotextile cushion is used. For horizontal-to-vertical slopes greater than 3:1, a geocomposite drainage layer is used.
4. **Granular Low-permeability Layer.** The fourth component is a 12-inch-thick granular layer that protects the liner and collects leachate. The collected leachate flows by gravity through a series of pipes to a collection sump. The leachate is lifted from the sump by an electric pump to aboveground storage tanks. This layer has a minimum permeability of 1×10^{-2} cm/sec.
5. **Geotextile Layer.** The fifth and top component is a geotextile laid on top of the granular layer to protect the structural integrity of the leachate collection system in the granular layer.

A subgrade foundation that consists of bedrock and soils designed to uphold the maximum landfill load with a safety factor of 2 supports this liner system (Rust Environment & Infrastructure, Inc., 1992a). Rust Environment & Infrastructure, Inc. constructed an underdrain system, consisting of a stone drainage medium, below the clay liner to remove water draining into the excavation. Collection pipes carry liquids captured in the underdrain and discharge them to a sedimentation pond (Rust Environment & Infrastructure, Inc., 1992a).

2.1.2 Leachate Collection System

The leachate collection system at the Blue Ridge Landfill (Figure 2.3) consists of a series of perforated high-density polyethylene collection pipes, risers, and storage tanks. After flowing through a 12-inch-thick drainage layer, the high-density polyethylene lateral pipes collect the leachate and route it to the leachate sump, which pumps the leachate from the landfill to holding tanks. The leachate holding tanks consist of a single walled, corrosion-protected steel within a concrete secondary containment system. The landfill can dispose of up to 100,000 gallons of leachate per day to the Irvine Municipal Utility Wastewater Treatment Plant (Rust Environment & Infrastructure, Inc., 1994a,b), which discharges treated water into the Kentucky River. An Industrial User Permit filed in August 1993 provided official authorization for the Blue Ridge Landfill to discharge collected liquid waste to the Irvine Municipal Utility Wastewater Treatment Plant (Rust Environment & Infrastructure, Inc., 1994a). This permit specifies the need for routine effluent monitoring and reporting every 6 months for biological oxygen demand (BOD), total suspended solids (TSS), ammonia nitrogen, oil and grease, metals, cyanide, and pH (Rust Environment & Infrastructure, Inc., 1994a). The Industrial User Permit for the Blue Ridge Landfill requires that concentrations of various analytes (including BOD, TSS, ammonia nitrogen, oil and grease, metals, and pH) in the leachate disposed of at the treatment facility be under or at daily maximum concentration limits (specified in the permit).

2.1.3 Landfill Gas Management System

The landfill also has a gas management system to extract, transport, and treat landfill gases (Rust Environment & Infrastructure, Inc., 1992a). The system is composed of vertical gas extraction wells spaced according to a calculated zone of influence (Rust Environment & Infrastructure, Inc., 1992a). These wells control both odor and migration of landfill gas (Rust Environment & Infrastructure, Inc., 1992a), consistent with 401 KAR 47:030(11), 401 KAR 48:070(10), and 401 KAR 48:090(4). The vertical gas extraction wells collect methane gas and transport it to an on-Site treatment facility. A header system collects condensate as the landfill gas is cooled. This condensate is removed and disposed of, along with the landfill leachate. The remaining treated gas is used for electricity generation at the landfill (RAC, 2016; Rust Environment & Infrastructure, Inc., 1992a). Figure 2.3 shows the gas monitoring points (*e.g.*, GMP-3).

2.1.4 Stormwater Control

The Blue Ridge Landfill contains a series of stormwater management structures to control surface runoff (Figure 2.3). Surface runoff is channeled *via* drainage berms that convey surface water to perimeter ditches and subsequently to sedimentation ponds that discharge to adjacent streams (Rust Environment & Infrastructure, Inc., 1994c). Rust Environment & Infrastructure, Inc. (1992a, 1994c) designed perimeter ditches to contain a 100-year, 24-hour storm flow without overflowing, consistent with 401 KAR 48:070 (2)(3). In addition, Rust Environment & Infrastructure, Inc. (1994c) designed sedimentation ponds with sloped bottoms to allow gravity drainage. A 12-inch low-permeability soil liner that minimizes seepage underlies the ponds (Rust Environment & Infrastructure, Inc., 1994c). Sedimentation ponds numbers 1, 2, and 3 discharge to an unnamed tributary to Calloway Creek, and sedimentation pond number 4 discharges to an unnamed tributary of the Dry Branch (Rust Environment & Infrastructure, Inc., 1994c).

2.2 Physical Setting

2.2.1 Site Geology

The Blue Ridge Landfill is located in the western edge of the Appalachian Basin's Plateau province. The Appalachian Basin is a collection of layered rocks that is dominated by fine-grained sedimentary formations such as siltstone, mudstone, and shale, often with interbedded sandstones. Surficial rocks in Estill County in the vicinity of the Blue Ridge Landfill were deposited approximately 490-320 million years ago and consist of a series of gently sloping shale, limestone, and dolomite formations (USGS, 1976). Table 2.2 provides a summary of Site geology.

Importantly, the Blue Ridge Landfill is located in a geologic region that has elevated concentrations of naturally occurring radionuclides. Generally, shales tend to contain more radionuclides relative to other rocks, because clay particles and organic matter that comprise shales absorb naturally occurring uranium and thorium. In fact, gamma ray emissions are used to differentiate shales from other stratigraphic layers by measuring the amount of gamma radiation emitted as a measurement tool is lowered vertically into a borehole (*i.e.*, gamma ray logs). The highest radionuclide concentrations generally occur in outcrop areas of New Albany or Nancy Shale Formations. In 2016, Chase Environmental Group, Inc. and the Kentucky Cabinet for Health and Family Services (KCHFS) found average radium-226 (Ra-226) concentrations of 5.6 pCi/g and average radium-228 (Ra-228) concentrations of 1.3 pCi/g in landfill-adjacent soil samples collected to represent the natural background geology of the area (Chase Environmental Group, Inc., 2016). These local average background concentrations are greater than the US average background concentrations of 1.1 pCi/g for Ra-226 and 1.0 pCi/g for Ra-228 (Perma-Fix Environmental Services, Inc., 2016). The RAC (2016) Dose and Risk Report provides further details regarding background radionuclide concentrations (see Attachment A1).

The Blue Ridge Landfill was constructed on the bedrock formations of the New Albany Shale and Borden Formation (Nancy Member) (Rust Environment & Infrastructure, Inc., 1992a), although the New Albany Shale and Bisher Dolomite are considered to be the only aquifers at the Site (*i.e.*, geologic formations that produce usable water). In most areas, the New Albany Shale immediately underlies the landfill and contains well-developed joints and fractures that act as conduits for groundwater flow in the uppermost saturated zone. Hydraulic conductivity and the density of fractures in the New Albany Shale decrease with depth, and, thus, groundwater flow is also reduced with depth. In addition to the New Albany Shale, the Bisher Dolomite acts as an aquifer in the northeastern portion of the Site (Rust Environment & Infrastructure, Inc., 1992a). Some of the groundwater that flows through the fractured New Albany Shale enters the underlying Bisher Dolomite and flows horizontally. The deepest geologic unit in the vicinity of the Blue Ridge Landfill is the Estill Shale, which consists of green-to-greenish gray silty shale and some carbonate or pyrite lenses (Rust Environment & Infrastructure, Inc., 1992a). This formation has very low permeability and, therefore, acts as a confining unit (Rust Environment & Infrastructure, Inc., 1992a).

Table 2.2 Summary of Site Geological Formations

Formation	General Description	Site-specific Description	Approximate Thickness (ft)	Approximate Elevation (ft amsl)	Hydraulic Conductivity (cm/sec)	Fracture Status	Relevance
Borden Formation	Dark gray and greenish-gray shale and siltstone.	Weathered iron-rich shale apparent on the northern and eastern slopes of the Site.	10-165	760-940	4.6×10^{-10}	Low to no fracture density.	Less pervious than underlying formations – blocks nearly all infiltration in the areas where it exists.
New Albany Shale	Olive-gray to dark brown very fine-grained, organic-rich sediment that contains pyrite nodules and some nodular concretions.	Greenish-gray clay shale found in an exposed high wall along the entrance road to the landfill and in some on-Site rock cores.	40-205	620-825	Fractured: 1×10^{-3} to 1×10^{-4} Unfractured: 1.7×10^{-9}	Well-developed joints and fractures. Fractures are more closely spaced near the ground surface and are less common at depth.	Fractures act as a conduit for groundwater flow in the uppermost saturated zone, but hydraulic conductivity in this unit decreases with depth as fracture density decreases.
Bisher Dolomite	Typically gray, medium- to coarse-grained, with occasional small pyrite crystals.	Generally present in the northeastern half of the Site and has been eroded from the southwestern portion of the Site.	2-45	625-680	1.2×10^{-4}	Sometimes very porous, but no distinct fracture zone.	Groundwater in the Bisher Dolomite moves southeast, with flow direction changing around the northeasternmost portion of the Site.
Boyle Dolomite	Gray, very fine- to fine-grained, and cherty, with areas of wavy laminations of darker material.	Exists mostly in the southwestern half of the Site, and the existing permitted fill area is completely underlain by gray, very fine-grained dolomite.	5-30	615-675	3.8×10^{-8}	Unlikely that fractures are prevalent due to low hydraulic conductivity.	Low hydraulic conductivity does not promote groundwater flow.
Estill Shale	Green to greenish-gray silty shale and some carbonate or pyrite lenses.	No on-Site rock cores have penetrated the Estill Shale.	–	680 and deeper	$<10^{-7}$	Unlikely that fractures are prevalent due to low hydraulic conductivity.	Packer tests performed in Estill Shale showed no measurable flow.

Note:

ft amsl = Feet Above Mean Sea Level.

Figure 2.4, an adapted cross section from Rust Environment & Infrastructure, Inc. (1992b), shows the rock formations from the western border to the eastern border of the Blue Ridge Landfill described above. Figure 2.5 shows the on-Site boring locations from which Rust Environment & Infrastructure, Inc. developed this cross section (F-F'). The cross section illustrates the nearly horizontal (*i.e.*, flat-lying) stratigraphy of the local geologic formations beneath the ground surface in the vicinity of the landfill. In addition, it also demonstrates the absence of near-surface faulting at the Site, consistent with prior investigations (*e.g.*, Rust Environment & Infrastructure, Inc., 1992a). Apart from the juxtaposition of the Bisher Dolomite, there are no other significant geologic structures at the Site. This cross section is consistent with others developed for the Blue Ridge Landfill (Rust Environment & Infrastructure, Inc., 1992a,c). Although this region of Kentucky is known for karst formations, the New Albany Shale and Borden Formations have a low karst potential (index of zero) and, thus, are considered to be in the "non-karst" category (University of Kentucky and Kentucky Geological Survey, 2017b).

2.2.2 Site Hydrogeology

Groundwater at the Blue Ridge Landfill is present in the New Albany Shale and the Bisher and Boyle Dolomites, as described below.

New Albany Shale

Based on Site measurements of static groundwater levels in February 2016, groundwater elevations in the New Albany Shale were between 708 and 745 feet above mean sea level (ft amsl) (as shown in Figure 2.6). Depth to groundwater varied between about 40 and 120 feet below ground surface (ft bgs). Potentiometric contours in Figure 2.6 demonstrate that groundwater in the New Albany Shale flows northwest, consistent with previous investigations (Cornerstone Environmental Group, LLC, 2016a; Herst & Associates, Inc., 2009, Figure 3). The primary porosity of the New Albany Shale is low (0.15), and thus, groundwater movement in this formation is predominantly through water-bearing fractures in the uppermost saturated zone (Rust Environment & Infrastructure, Inc., 1992a). Table 2.2 provides a summary of typical hydraulic conductivities.

Groundwater monitoring in the New Albany Shale is routinely performed as part of the landfill's Groundwater Monitoring Plan (Herst & Associates, Inc., 2009). Figure 2.3 shows monitoring wells that are sampled as part of the Groundwater Monitoring Plan, which we describe in Section 2.5.1.

Bisher and Boyle Dolomites

Groundwater flow direction in the Bisher and Boyle Dolomites is highly variable, based on previous water level measurements conducted at the Site in 1992. For example, Figure 2.7 shows groundwater flow in the Boyle Dolomite to be predominantly northward, whereas flow in the Bisher Dolomite is south/southeastward.

The New Albany Shale and the Bisher Dolomite are hydraulically connected in the central to north/northwestern part of the Site. Most of the underlying Bisher Dolomite has been eroded from the southwestern portion of the Site but is generally present in the northeast. Table 2.2 provides a summary of typical hydraulic conductivities.

The Boyle Dolomite exists primarily in the southwestern portion of the Site and is not considered to be an aquifer, due to its low hydraulic conductivity, low water yields, and naturally poor water quality (Rust Environment & Infrastructure, Inc., 1992a; Herst & Associates, Inc., 2009).

Estill Shale

The lowermost hydrogeologic unit encountered at the Site is the Estill Shale (Figure 2.4). It is considered to be a confining unit due to the lack of measureable flow during previous field tests, which indicated that the hydraulic conductivity of this formation is low (see Table 2.2) (Rust Environment & Infrastructure, Inc., 1992a).

2.2.3 Surface Water Bodies

The landfill is located within the Upper Kentucky watershed, which drains northwest to the Ohio River. The location of the landfill, relative to local water bodies, including the Kentucky River and several tributaries, is shown in Figure 2.8 and described below.

- **Kentucky River:** The Kentucky River is approximately 3,000 ft west of and 110 ft lower in elevation than the Site. The Kentucky River flows northwest past the towns of Beattyville and Irvine (Shaw, 1917). The river is underlain by mixed sediments (alluvium), Boyle Dolomite, and unrelated formations (*e.g.*, Crab Orchard and Brassfield Dolomite, and Drakes Formation Dolomite and Limestone). The Kentucky Department of Environmental Protection (KYDEP) has approved most segments of the Kentucky River for the following designated uses: warm water aquatic habitat, primary contact recreation, secondary contact recreation, and outstanding state resource,⁵ as defined in 401 KAR 010:026 (KYDEP, 2017a).
 - **Calloway Creek:** Calloway Creek is a tributary to the Kentucky River located northwest of the Blue Ridge Landfill. The creek is underlain by mixed sediments (alluvium), Boyle Dolomite, bits of Bisher Limestone, and unrelated formations (*e.g.*, Crab Orchard and Brassfield Dolomite, and Drakes Formation Dolomite and Limestone).
 - **White Oak Creek:** White Oak Creek is an approximately 6-mile-long tributary to the Kentucky River that juts eastward from the main stem of the Kentucky River south of the Blue Ridge Landfill. The creek is underlain by mixed sediments (alluvium), Boyle Dolomite, bits of Bisher Limestone, and unrelated formations (*e.g.*, Crab Orchard and Brassfield Dolomite).
 - ▶ **Masters Creek:** The Blue Ridge Landfill is located near Masters Creek (Rust Environment & Infrastructure, Inc., 1992b). Masters Creek is a tributary to White Oak Creek that runs southward to the western side of the Blue Ridge Landfill. It is underlain by mixed sediments (alluvium), Boyle Dolomite, and unrelated formations (*e.g.*, Crab Orchard and Brassfield Dolomite).
 - ▶ **Dry Branch:** The Dry Branch is a tributary to White Oak Creek that runs southward to the eastern side of the Blue Ridge Landfill. It is underlain mostly with mixed sediments (alluvium), with bits of Bisher Limestone.

The Blue Ridge Landfill contains four sedimentation ponds, as shown in Figure 2.3. Surface water runoff at the Site is directed to drainage ditches that convey surface water to the sedimentation ponds (Rust Environment & Infrastructure, Inc., 1994a). Surface runoff is sampled for iron, zinc, hardness, TSS, BOD, and pH prior to its discharge to sedimentation ponds (Rust Environment & Infrastructure, Inc., 1994a). The Blue Ridge Landfill obtained authorization to discharge materials collected in the sedimentation ponds to three outfalls at an unnamed tributary to Calloway Creek and at one outfall at an

⁵ "Outstanding state resource water may have unique water quality characteristics that shall be protected by additional criteria established in 401 KAR 10:031, Section 8" (KYDEP, 2017a).

unnamed tributary of the Dry Branch (Rust Environment & Infrastructure, Inc., 1994a). The Kentucky Pollutant Discharge Elimination System (KPDES) monitors these locations (which are shown on Figure 2.3).

The results from samples collected from Dry Branch at locations north of the landfill (upgradient) and south of the landfill (downgradient) showed no evidence of impacts from the BES Waste (RAC, 2016).

2.2.4 Climate

The climate in Irvine, Kentucky, is classified as "humid subtropical" and is characterized by relatively warm temperatures that generally consist of moderately cool winters and warm summers (USDA and Kentucky Agricultural Experiment Station, 1974). January is typically the coldest month in Irvine, with an average temperature of 33.2°F. The warmest month, July, experiences the most rainfall (Weatherbase.com, 2017). Precipitation is usually higher in the summer than the winter, with much of the rainfall resulting from convective storms (Weatherbase.com, 2017). The average annual rainfall in Irvine is 49 inches and average annual snowfall is about 11 inches (Weatherbase.com, 2017; US Climate Data, 2017). Groundwater recharge occurs primarily in winter and spring, with most soils saturated by early spring (USDA and Kentucky Agricultural Experiment Station, 1974). Dry periods typically occur in late summer and fall.

2.2.5 Topography

The Blue Ridge Landfill is located in the Knobs physiographic region of eastern Kentucky. This region is characterized by the presence of conical knobs, or erosion remnants, which constitute an escarpment separating the Outer Bluegrass and Eastern Kentucky Coal Field physiographic regions (McFarlan, 1943; Kentucky Geological Survey, 2005). The largest zones of flat land in the county are in the valleys of the Kentucky River and its tributaries. Elevations at the landfill range from about 710-940 ft, but are higher (>1,450 ft) on ridges and knobs within about 1.5 miles of the Site. The area surrounding the landfill is predominantly wooded. Bulldozing and logging activities have flattened parts of the landfill area to construct haul roads for waste material transport (USDA and Kentucky Agricultural Experiment Station, 1974; Rust Environment & Infrastructure, Inc., 1992b).

The topography of the landfill area is engineered such that a surface drainage system directs runoff to four sedimentation ponds (Rust Environment & Infrastructure, Inc., 1994a). In certain areas, the landfill has been backfilled to create a minimum 2% slope that promotes surface water runoff (Rust Environment & Infrastructure, Inc., 1994a).

2.3 Overview of BES Waste Disposal

Between July 20, 2015, and February 3, 2016, ADS accepted 92 loads (1,157 tons) of waste from BES, LLC, which that company represented to be exempt oil and gas field waste. For purposes of this report, we assumed that these loads contained TENORM only, although this has not been established by disposal data.

RAC (2016; Attachment A1) provided a detailed review of TENORM radionuclides. The two primary radionuclide decay series for any disposed TENORM at the Blue Ridge Landfill are uranium-238 (U-238) and thorium-232 (Th-232), shown below in Figure 2.9.

Table 2.3 Summary of Waste Generators that Provided BES Waste to the Blue Ridge Landfill

Generator	Total Waste (Tons)	Waste Description
Cambrian	9.97	Exploration and production soil and debris
Fairmont	865.33	Exploration and production soil and debris
GreenHunter	149.11	Used filters and debris, used filters, filter sludge
Nuverra	132.84	Filter cake, bag filters, debris, soil

Notes:

Generators: Cambrian = Cambrian Well Services; Fairmont = Fairmont Brine Processing; GreenHunter = GreenHunter Resources; Nuverra = Nuverra Environmental Services or Nuverra Environmental Resources.

Although the amount (tonnage) and general characteristics of the BES Waste placed in the landfill by the generators listed in Table 2.3 is known, as are the approximate disposal locations, the total *in situ* waste volume is not, because the BES Waste was mixed with existing MSW in the landfill as it was deposited. As a result, the total volume of BES Waste includes the amounts listed in Table 2.3 in addition to the amount of MSW with which it was mixed. To estimate the total volume of *in situ* BES Waste at the landfill, Cornerstone Environmental Group conducted an analysis of the landfill's surface topography, delivery information, cover reports, and other data sources; details of their methodology and sources are provided in Attachment B to this report (Cornerstone Environmental Group, LLC, 2017). Based on Cornerstone Environmental Group's review and analysis, approximately 39,630 yd³ of mixed waste (*i.e.*, BES Waste and MSW) is present at the landfill.⁶ In addition, Cornerstone Environmental Group's analysis also indicates that, as of March 16, 2016, about 16,300 yd³ of MSW overlaid the BES Waste.⁷ To date, no further MSW or soil has been placed over the BES Waste, though we understand that for operational reasons, ADS will soon begin to dispose of MSW over the BES Waste disposal area.

A comprehensive series of environmental sampling investigations was conducted at the Blue Ridge Landfill to characterize the BES Waste, determine the extent of deviations from natural background radiation levels, and evaluate potential impacts and exposures to human and ecological receptors. These investigations focused on Ra-226 and Ra-228.⁸ The State of Kentucky, the Army National Guard 41st Civil Support Team, and consultants of ADS conducted these investigations, as summarized below (KYEEC and ADS, 2016). RAC (2016; see Attachment A1) provides further details. These entities sampled environmental media such as air, soil, sediment, surface water, and groundwater, as well as landfill leachate, and one entity also conducted gamma scan surveys across the landfill's surface.

Chase Environmental Group, Inc. (2016) conducted gamma scan surveys on the surface of the landfill in March and May 2016. The results of these scans (shown in Figure 2.10) demonstrate that there is a wide array of background radionuclides in the area, likely related to outcrops of the New Albany Shale. For example, measurements north of the permitted solid waste area near outcrops of the New Albany Shale (adjacent to pond 3) were generally higher than those from areas inside the permitted solid waste area that contain the BES Waste. In addition, these scans did not show any surface radioactivity above background levels in areas where the BES Waste was placed. Three different entities collected air samples at the landfill on three separate occasions. In each sampling event, reported concentrations for Ra-226 and Ra-

⁶ Gradient calculated the volume of BES Waste mixed with MSW in each grid cell by multiplying the depth interval (ft) of BES Waste below the cover by the grid cell area (ft²). We converted the volume to cubic yards with the conversion 1 yd³ = 27 ft³.

⁷ Gradient calculated the volume of overlying MSW in each grid cell by multiplying the depth interval (ft) between the surface and the minimum depth of the BES Waste by the grid cell area (ft²). We converted the volume to cubic yards with the conversion 1 yd³ = 27 ft³.

⁸ Ra-226 and Ra-228 are important components of TENORM in terms of radiological dose and are used to identify measurable impacts from BES Waste.

228 were less than the analytical method detection limits and were below the criteria listed in 10 CFR 20 and 902 KAR 100.

Chase Environmental Group, Inc. and the State of Kentucky collected soil samples at the Blue Ridge Landfill from areas within the grid cells that contained the BES Waste (Figure 2.11) and in areas outside these grid cells (RAC, 2016). Results from these samples indicated that there was no difference between Ra-226 and Ra-228 levels within and outside of the BES Waste areas. The highest concentrations reported from this sampling event were in areas of exposed New Albany Shale. The State of Kentucky and Chase Environmental Group, Inc. collected surface water samples at Dry Branch in both upgradient (north of the landfill) and downgradient (south of the landfill) locations, as shown in Figure 2.12. Results from these samples suggested that there was no significant difference between concentrations of Ra-226 and Ra-228 measured upgradient and downgradient of the landfill. The State of Kentucky collected groundwater and sediment samples, and the results from these closely mirrored the soil sample results, which showed a significant amount of variability in radionuclide levels but did not indicate impacts from the BES Waste. Teledyne Brown Engineering, Inc., the State of Kentucky, and TestAmerica analyzed leachate samples (RAC, 2016). Results from these samples indicated elevated gross beta concentrations (greater than 100 pCi/L), but the results of the isotopic analyses did not support these results (RAC, 2016).

RAC (2016; Attachment A1) used the data collected during the investigations, coupled with radioanalytical data for each load or set of loads presumably delivered to the Blue Ridge Landfill, to conduct a radiological dose and risk assessment for landfill workers and members of the public both during disposal operations and in the future. In March 2017, RAC conducted an additional radiological dose and risk assessment in support of the Remediation Alternatives discussed in this report. The March 2017 RAC radiological dose and risk assessment was revised per Cabinet comments and is submitted herein (RAC, 2017; Attachment A2). Section 2.4 includes a discussion of the receptors and pathways evaluated in these risk assessments, as well as the conclusions from the risk assessments.

2.4 Summary of Receptors and Risks

RAC (2016) conducted a radiation dose assessment to assess doses and risks to on-Site workers and nearby community members, which we include as Attachment A1 to this report. RAC (2016) evaluated three on-Site receptors (Landfill Laborer, Landfill Office Worker, and Landfill Heavy-equipment Operator) and three off-Site receptors (Adult School Staff, Child Student, and Future Resident) in its human health risk assessment. RAC (2016) concluded that the dose for all the receptors, including the most highly exposed individual (the on-Site Landfill Laborer during disposal of TENORM) was well below the level at which potential health effects may be observed. While the calculations in the RAC (2016) Dose and Risk Report have been updated, the conclusions remain the same – radiation doses and risks at the Blue Ridge Landfill are extremely low (see RAC, 2017; Attachment A2).

RAC conducted additional analyses in support of the CAP to evaluate the long-term and short-term human health risks associated with each of the Remediation Alternatives that the CAP evaluates (RAC, 2017). RAC also conducted an assessment of radiological risk to ecological receptors, including terrestrial and aquatic biota, using the Environmental Risk from Ionising Contaminants: Assessment and Management (ERICA) tool. Sections 6.3 and 6.5 and Attachment A2 provide summaries of these additional dose and risk calculations.

2.5 Regulatory Requirements

2.5.1 State of Kentucky Landfill Requirements

The Cabinet promulgates solid waste landfill regulations under the statutory authority of Kentucky Revised Statute (KRS) 224.10-100 and 224.40-305 (KYDEP, 2017b). Operational requirements are described in 401 KAR 48:090. The Blue Ridge Landfill began operating in 1984 and currently operates under Solid Waste Permit SW033-00004 (KYEEC, 2012). The Cabinet approved a landfill expansion in 1994 (Rust Environment & Infrastructure, Inc., 1994a). As part of the approved expansion, Rust Environment & Infrastructure, Inc. prepared plans for long-term monitoring and closure activities, which were submitted to the Cabinet and remain in place at the Site, as described herein (Rust Environment & Infrastructure, Inc., 1994a).

The federal Low-Level Radioactive Waste Policy Act, 42 U.S. Code § 2021, encouraged the development of compacts between states as a mechanism to manage low-level radioactive waste (US Congress, 1985). Such a compact was developed for the Central Midwest region, which includes the states of Kentucky and Illinois (Kentucky Legislature, 2017a), to channel waste generated within the region to a proposed low-level radioactive waste site or to sites approved by the appropriate state agency. The Kentucky legislature recognized that the "safe and efficient management of low-level radioactive waste generated within the region requires that sufficient capacity to manage such waste be properly provided" (KRS 211.859; Kentucky Legislature, 2017a).

To further this objective, the radioactive waste compact allows for the disposal of compact-generated waste in contained landfills, but prohibits the disposal of the same material from states outside the compact. KRS 211.863 thus provides that:

naturally-occurring radioactive materials (NORM) as defined in KRS 211.862(8) [Kentucky Legislature, 2017b] shall be the exclusive regulatory responsibility of the states, except that no person shall import naturally occurring radioactive materials (NORM) from outside the region for disposal in Kentucky, or dispose of such imported material in Kentucky, if the imports or disposal are inconsistent with polices [sic] of the commission. (Kentucky Legislature, 2017c).

The Regional Management Plan indicates that TENORM import restrictions are based on public acceptance, not environmental protection. For example, the Plan states:

The history of the Policy Act and the authority it gives to the compact commission to limit the import of LLRW into these regions provide clear evidence that citizens of one state do not generally take a positive view of receiving and disposing of LLRW from another state or region. It is not possible to predict whether these public attitudes will eventually change when new LLRW disposal facilities are developed. For the present, the Commission intends to operate on the assumption that citizens are willing to accept responsibility for LLRW generated within their own region, but not a LLRW generated by others. (CMIC, 1999)

In 2016, the Kentucky Legislature passed HB563 to help address environmental concerns related to the management of radioactive materials from oil and gas production activities. Regulations will be revised under the direction of KRS 211.893 (KCHFS, 2017). In accordance with these actions, the Cabinet convened the Oil and Gas Workgroup in 2015 and convened an expanded version in 2016 to develop

TENORM regulations, among other goals (KYEEC and KCHFS, 2016). The Blue Ridge Landfill will operate in accordance with the new standards developed by this group with regard to landfills accepting TENORM waste.

Record-keeping and Reporting Requirements

As part of the landfill record-keeping and reporting requirements of 401 KAR 47:190(8), ADS provides quarterly reports for the landfill to the Cabinet that contain the following information (Rust Environment & Infrastructure, Inc., 1994a):

- Description of construction activities during the quarter;
- Monthly volume of waste received from each source;
- Description of compliance with other requirements;
- Environmental monitoring results, including water, groundwater, methane, and other permit conditions; and
- The quantity and concentrations of constituents in the leachate removed from the Site, where it was disposed of, and the method of disposal.

In addition to quarterly reporting, an annual survey is conducted to quantify the volume of the landfill that is available for additional waste disposal.

Monitoring Requirements

Blue Ridge Landfill's operating and closure permit (Solid Waste Permit SW033-00004), Industrial User Permit (Number 001), and 401 KAR 48:300 and 48:080 require routine monitoring of surface water, stormwater, groundwater, and leachate at the landfill. Table 2.4 provides a summary of the sampling requirements, which are also further described below.

Table 2.4 Summary of Landfill Monitoring Requirements

Medium	Locations ^a	Frequency	Analytes
Surface Water	SWM-1, SWM-2, SWM-3, SWM-4	Quarterly	Chlorides, sulfate, iron, sodium, TOC, chemical oxygen demand, specific conductance, TSS, TDS, total solids, and pH.
Stormwater	S-1, S-2, S-3, S-4	Monthly, Quarterly, Annual	Flow (mgd), iron, zinc, hardness, TSS, and BOD.
Groundwater	MW-7, MW-10, MW-13, MW-15R, MW-17R	Quarterly, Annual	Temperature, chloride, chemical oxygen demand, TSS, TOC, specific conductivity, pH, iron, sodium, and total organic halides (VOCs and inorganics sampled annually).
Leachate	Grab sample from leachate holding tanks	Monthly	BOD, TSS, ammonia nitrogen, oil and grease, metals, cyanide, and pH.

Notes:

BOD = Biological Oxygen Demand; mgd = Million Gallons Per Day; TDS = Total Dissolved Solids; TOC = Total Organic Carbon; TSS = Total Suspended Solids; VOC = Volatile Organic Compound.

(a) Figure 2.3 shows monitoring locations.

Consistent with 401 KAR 47:190(5), Rust Environment & Infrastructure, Inc. (1994a) developed a Surface Water Monitoring Plan for the Blue Ridge Landfill in accordance with 401 KAR 48:300. As required by 401 KAR 48:300(2)(2), the Blue Ridge Landfill 1994 Surface Water Monitoring Plan includes monitoring locations SWM-1, SWM-2, SWM-3, and SWM-4 (shown in Figure 2.3) (Rust Environment & Infrastructure, Inc., 1994a). Surface water discharged at these locations is tested routinely for the analytical parameters listed in 401 KAR 48:300(2)(3), as summarized in Table 2.4.

The facility monitors stormwater discharges at four separate locations as part of the KPDES monitoring program.⁹ The facility obtained a KPDES permit for an additional stormwater discharge point during the horizontal expansion, which increased the total number of discharge points to five (Rust Environment & Infrastructure, Inc., 1994a), although the fifth pond and stormwater discharge point have not yet been constructed. The monitoring locations are sampled during baseflow conditions (Rust Environment & Infrastructure, Inc., 1994a). The most recent KPDES permit (issued in November 2007) is KY0091707 (Cornerstone Environmental Group, LLC and Hodges, Harbin, Newberry & Tribble, Inc., 2012).

Groundwater monitoring is conducted at the landfill as required by 401 KAR 47:190. Herst & Associates, Inc. (2009) developed a Groundwater Monitoring Plan in accordance with 401 KAR 48:300. The current groundwater monitoring network at the landfill consists of five routinely sampled groundwater monitoring wells within the property boundary, as shown in Figure 2.3: MW-7, MW-10, MW-13, MW-15R, and MW-17R.¹⁰ These wells are all screened within the New Albany Shale aquifer at total depths between 64 and 110 ft bgs (Herst & Associates, Inc., 2009). The monitoring program consists of quarterly and annual inspections, during which static groundwater levels are measured, well casings are purged, and samples are collected. Table 2.4 lists the analytes that 401 KAR 48:300(11)(3) requires to be evaluated (Herst & Associates, Inc., 2009). Groundwater sampling results are evaluated for statistically significant changes, in accordance with 401 KAR 48:300(9) and 40 CFR 258.53(g) (US EPA, 2016b; Herst & Associates, 2009, Inc.), and certain inorganics and volatile organic compounds (VOCs) are compared to KYDEP Maximum Contaminant Levels (MCLs).

Six additional monitoring wells that are not part of the routine groundwater sampling plan are used to assess water levels on an annual basis: MW-8, MW-9, MW-14, MW-16, MW-17, and MW-18 (Herst & Associates, Inc., 2009). These measurements provide broader insight into the landfill's potentiometric surface and associated groundwater flowpaths.

The landfill's Industrial Use Permit requires leachate sampling, as summarized in Table 2.4 (Rust Environment & Infrastructure, Inc., 1994a; see Section 2.1.2).

Two underdrains (UD-1 and UD-2) located within the property boundary and west of the permitted solid waste boundary collect liquids and pump them to settling ponds. Underdrain liquids subsequently discharge to wetland treatment areas from settling ponds prior to off-Site discharge (Herst & Associates, Inc., 2009). Underdrain UD-1 receives surface water from a toe-drain around sedimentation pond 2, which is directly east of UD-1 (Figure 2.3). Both underdrain trenches were backfilled with limestone, which affects the quality of samples taken from these locations (Herst & Associates, Inc., 2009). UD-1 collects surface water and both underdrains are pretreated with lime prior to sampling; thus, the underdrains are not part of the groundwater monitoring program (Herst & Associates, Inc., 2009).

⁹ The KPDES monitoring program is a Kentucky-specific program based on the National Pollutant Discharge Elimination System (NPDES) requirements, which prohibit the discharge of pollutants through point sources into US waters without an NPDES permit.

¹⁰ Monitoring wells that were constructed, with screened intervals in the Boyle and Bisher Dolomites (MW-12, MW-20, MW-22, MW-23, and MW-24), were abandoned in 2009 due to poor water quality of the dolomite/limestone and the low permeability of the overlying New Albany Shale (Herst & Associates, Inc., 2009). Other wells were eliminated from the monitoring network due to close spacing (Herst & Associates, Inc., 2009).

Required Engineering Controls

As required by 401 KAR 48:080, the Blue Ridge Landfill has a composite liner system, leachate collection system, and landfill gas extraction system in place. See Sections 2.1.1-2.1.3 for details.

Closure Plan

Rust Environment and Infrastructure, Inc. (1994a) developed a Closure Plan for the landfill in 1994, in accordance with 401 KAR 48:070(15), with the intent to minimize releases of leachate and explosive gases and to protect human health and the environment, as required by 401 KAR 47:030 and 401 KAR 48:300. Rust Environment and Infrastructure, Inc. wrote the Closure Plan in accordance with the 401 KAR 48:090(13) requirements, including plans for the maintenance and operation of the leachate collection and explosive gas monitoring systems and for groundwater monitoring. As also required in 401 KAR 48:090(13), the operator of the landfill committed to recording a notice that may inform any potential purchaser of the location and time of operation of the facility, as well as the nature of waste disposed on-site, and caution against any future disturbance of the area, in accordance with KRS Chapter 382 (Rust Environment & Infrastructure, Inc., 1994a). Once ADS completes the closure period (at least 2 years) and closure care period (at least 30 years) for the unit, it must submit certification by a professional engineer that verifies completion in accordance with KRS Chapter 224 requirements (Rust Environment & Infrastructure, Inc., 1994a).

As landfilling progresses at the Blue Ridge Landfill, areas meeting final design heights will be capped in accordance with 401 KAR 48:080 (Rust Environment & Infrastructure, Inc., 1994a). In order to stabilize the capped area, drainage will be established and the area will be vegetated (Rust Environment & Infrastructure, Inc., 1994a). During closure and post-closure activities, leachate will continue to be removed for permitted disposal at the local municipal wastewater treatment plant (see Section 2.1.2; Rust Environment & Infrastructure, Inc., 1994a). Groundwater monitoring will continue as outlined in the Groundwater Monitoring Plan (Herst & Associates, Inc., 2009).

Rust Environment & Infrastructure, Inc. (1994a) developed a Closure Care Plan in accordance with 401 KAR 48:090 (13)(2) for monitoring and routine maintenance activities that will take place during a closure care period of at least 30 years. Monitoring activities during this closure care period will continue as outlined in the Explosive Gas Monitoring, Surface Water Monitoring, and Groundwater Monitoring Plans (Rust Environment & Infrastructure, Inc., 1994a). The Closure Care Plan focuses on maintenance and repair of the final cap, surface water management, leachate collection, groundwater monitoring, gas extraction, and security systems (Rust Environment & Infrastructure, Inc., 1994a). Records of maintenance activities associated with these systems will be kept and used to reevaluate the closure care cost estimate as the closure care period progresses (Rust Environment & Infrastructure, Inc., 1994a). The gas extraction system will be inspected weekly until the system is balanced, and will thereafter be inspected on a monthly basis (Rust Environment & Infrastructure, Inc., 1994a). Movement and settlement of landfill topography will be inspected annually, and all other systems will be inspected quarterly (Rust Environment & Infrastructure, Inc., 1994a).

2.5.2 State of Kentucky Remediation Requirements

The Cabinet regulates releases of hazardous substances under KRS 224.1-400. This regulation notes that, once a site characterization has been completed, a CAP should be submitted within 90 days of the

execution of the Agreed Order.¹¹ Identification of final remediation goals for the proposed remedy can be based on the most current version of the United States Environmental Protection Agency (US EPA) Regional Screening Level Table, pending review by the Cabinet of site-specific conditions (401 KAR 100:030(8) and KRS 224.1-530; KYDEP, 2017c,d). The following actions may be evaluated in the CAP, as provided in 401 KAR 100:030 and relevant to the Blue Ridge Landfill.

- **No Action Is Necessary:** This action requires a demonstration that the risk posed by contaminants of concern does not exceed target risk levels for unrestricted land use and does not exceed ecological risk endpoints, and inorganic contaminants of concern do not exceed ambient background levels for the respective media. These stipulations are in accordance with "Ecological Risk Assessment Guidance for Superfund: Process for Designing and conducting Ecological Risk Assessments" (US EPA, 1997a) and "Guidelines for Ecological Risk Assessment" (US EPA, 1998).
- **Management in Place:** The release will be managed in place with the goals of attaining target risk levels at the point of exposure and being protective of ecological health. Management in place includes engineering and institutional controls to contain the release and either eliminate exposure pathways or reduce exposure. The frequency of engineering and institutional control inspections, in addition to their assured protectiveness of health, safety, and the environment, must be specified.
- **Restoration:** Contaminants of concern will be removed and site concentrations of these contaminants will be restored to ambient background levels, target risk levels at the point of exposure, or levels derived from a site-specific risk assessment approved by the Cabinet that do not require engineering or institutional controls.
- A combination of the above actions.

The Kentucky state requirements for CAP remedy selection defined in 401 KAR 100:030(8) are as follows:

4. If the target risk levels at the point of exposure will not be achieved by the proposed remedy, the party or applicant shall demonstrate to the cabinet the protectiveness of the remedy using the criteria listed in clauses a through h of this subparagraph. The cabinet shall place emphasis on criteria listed in clauses a through d of this subparagraph when evaluating the remedy selected.
 - a. The overall protection of human health and the environment;
 - b. The compliance with any other applicable requirements;
 - c. The long-term effectiveness and permanence of the remedial option;
 - d. The reduction of toxicity, mobility, or volume through the use of treatment;
 - e. The short-term effectiveness of the remedy;
 - f. The ability to implement the remedy;
 - g. The cost of the remedy; and
 - h. Community acceptance of the remedy.

¹¹ Completed on January 3, 2017 (Case No. DWM 160048) (KYEEC and ADS, 2016). A 30-day extension was granted by the Cabinet for submittal of this CAP report.

Sections 5 and 6 of this report describe these criteria and the basis for their evaluation as part of the CAP, respectively.

2.5.3 Relevant Federal Requirements

Although not directly applicable to the Blue Ridge Landfill, federal regulations under CERCLA and the NCP provide guidance for the selection of remediation alternatives to ensure the protection of human health and the environment. These regulations are consistent with the State of Kentucky Remediation Requirements. The NCP was designed to standardize the performance of cost-effective, environmentally protective and human health-protective cleanups and provide a consistent and objective basis for remedy decision-making at a national level. US EPA defined its perspective on "CERCLA-quality" cleanup of hazardous waste in its NCP promulgation notice of 1990 (US EPA, 1990a), indicating that hazardous waste site remediation activity must:

- Be protective of human health and the environment;
- Utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable;
- Be cost-effective;
- Attain Applicable or Relevant and Appropriate Requirements (ARARs); and
- Provide for meaningful public participation.

Particularly relevant to this CAP, CERCLA and the NCP provides a remedy selection framework to "select remedies that are protective of human health and the environment, that maintain protection over time, and that minimize untreated waste" (40 CFR 300.430(a)(1)(i)). This framework is based on the following nine criteria that comprise the objective rationale for remedy selection (40 CFR 300.430(e)(9)(iii)):

- All selected remedies must satisfy the **Threshold Criteria**:
 1. Overall protection of human health and the environment; and
 2. Compliance with ARARs.
- Among the alternatives that satisfy the Threshold Criteria, the preferred remedy is selected based on an evaluation of the **Balancing Criteria**:
 3. Long-term effectiveness and permanence;
 4. Reduction in toxicity, mobility, and volume of waste;
 5. Short-term effectiveness;
 6. Implementability;
 7. Cost; and
- **Modifying Criteria**:
 8. State support/agency acceptance; and
 9. Community acceptance.

The NCP provides a framework for remedy selection based on these nine criteria, through which the "national goal of the remedy selection process is to select remedies that are protective of human health and the environment, that maintain protection over time, and that minimize untreated waste" (40 CFR 300.430(a)(1)(i)). Remediation alternatives are to be evaluated, compared, and selected on the basis of these nine criteria (40 CFR 300.430(e)(9)(iii); 40 CFR 300.430(f)), the purpose of which "is to implement remedies that eliminate, reduce, or control risks to human health of the environment" (40 CFR 300.430(a)(1)). These NCP criteria are consistent with Kentucky State requirements for CAP remedy selection, which 401 KAR 100:030(8) defines.

US EPA and other US regulatory agencies provide guidance for investigations of sites that have radioactive contamination in the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM). To distinguish between the contaminated site and background radiation, the guidance suggests that background samples be "collected upgradient of the area of potential contamination (either onsite or offsite) where there is little or no chance of migration of the contaminants of concern" (US NRC *et al.*, 2000a). These background samples provide a basis for comparison between natural geologic radiation and a contaminated site. These agencies also provides guidance on plotting and statistical techniques to help differentiate on-site and off-site (background) measurements (US NRC *et al.*, 2000b). Data visualization and statistical analyses can help to reveal trends in radioactivity between background and contaminated areas of a site and its vicinity. US EPA guidance also suggests that sampling both background and contaminated site radioactivity can help to verify gamma scan survey results (US NRC *et al.*, 2000b). Figure 2.10, which illustrates the gamma scan survey data collected at the Blue Ridge Landfill, provides an example visual comparison. This figure indicates that naturally occurring local background radioactivity in areas outside of the permitted solid waste boundary (*e.g.*, New Albany Shale outcrops) is higher than areas containing *in situ* BES Waste mixed with MSW (purple grid cells). Consistent with recommendations by US EPA (US NRC *et al.*, 2000b), a soil sampling investigation supported these results and demonstrated that the highest radionuclide concentrations are in areas of the landfill with naturally occurring radionuclides compared to areas containing *in situ* BES Waste.

US EPA has additional regulations and guidance that are relevant to radionuclide releases, as described in the following paragraphs.

US EPA established expected cleanup levels for CERCLA sites with radioactive contamination in a memorandum from its Office of Emergency and Remedial Response and the Office of Radiation and Indoor Air (OSWER No. 9200.4-18; US EPA, 1997b). This memorandum provides an attachment outlining radiation standards that are likely to be used as ARARs intended to establish cleanup levels or to conduct remedial actions (US EPA, 1997b). The guidance indicates that cleanup levels for CERCLA sites that have radioactive contamination must be established as they would for any chemical that poses unacceptable risks to human health and the environment (US EPA, 1997b). This means that cancer risks would be estimated using a slope factor approach, and cleanup levels would be expressed in units unique to radiation. US EPA (1997b) indicates that cleanup should achieve a level of risk within a carcinogenic risk range of 10^{-4} to 10^{-6} based on reasonable maximum exposure to humans. The maximum dose limit for humans should generally be 15 millirem per year effective dose equivalent (US EPA, 1997b), consistent with protective levels in other US EPA guidance documents. However, this memorandum states that dose limits in the Nuclear Regulatory Commission (NRC) decommissioning rule should generally not be used to establish cleanup levels under CERCLA (US EPA, 1997b).

An Office of Solid Waste and Emergency Response (OSWER) memorandum from July 2000 added certain response actions for sites contaminated with radiation to better ensure national consistency (US EPA, 2000, p. 2). The response actions outlined in this memorandum encourage consultation between US EPA Regional Offices and Headquarters on CERCLA decisions that involve on-site management of radioactive materials (*e.g.*, capping, building disposal cells) or potential national precedent-setting issues

related to radioactive substances, pollutants, or contaminants (US EPA, 2000). Since July 2000, the Interstate Technology and Regulatory Council has presented case studies to supplement the OSWER guidance principles and to introduce participants to long-term stewardship challenges associated with the management of large radioactively contaminated sites (US EPA, 2007).

The US EPA Clean Air Act regulates TENORM releases, and the US EPA Clean Water Act regulates certain liquid discharges of TENORM. US EPA, however, does not regulate TENORM waste byproducts, such as sludges from water and wastewater (RAC, 2016). Although the NRC regulates TENORM when uranium and thorium concentrations make up more than 0.05% of the material, it does not regulate TENORM waste byproducts. In particular, the State of Kentucky provides guidance for TENORM disposal only as part of the Central Midwest Interstate Low-level Radioactive Waste Commission (CMIC) Regional Management Plan, which was adopted in 1999 (CMIC, 1999). This plan prohibits the importation of TENORM wastes that have concentrations greater than or equal to 5 pCi/g. Under the CMIC Regional Management Plan, TENORM wastes with concentrations less than 2,000 pCi/g will be "disposed in accordance with the method approved by the appropriate party state regulatory agency" (CMIC, 1999). The current version of KRS 224.50-760 does not provide guidance relating to NORM, TENORM, or any radioactive materials.

3 Remedial Action Objectives

The purpose of remedial action at the Blue Ridge Landfill Site is to protect human health and the environment from exposure to the BES Waste (mixed with MSW) and its constituents. Remedial Action Objectives are medium-specific goals that guide the remedy evaluation and selection process to specific endpoints that ensure protectiveness.¹² Remedial Action Objectives for the Blue Ridge Landfill have been developed based on relevant US EPA and Kentucky guidance (*e.g.*, US EPA, 1988, 1989, 1995; 401 KAR 48:300; 401 KAR 100:030; KRS 224.01-400(18)) and Site-specific factors based on the results of previous investigations and the human health risk evaluations for the media of concern – BES Waste, landfill leachate, surface water, groundwater, and landfill gas. In this CAP, Gradient used the Remedial Action Objectives to evaluate the overall protectiveness of the Remediation Alternatives (see Section 6).

Overall, the landfill investigation and risk assessment results show that there are relatively few human health and ecological exposure pathways of concern based on current or reasonably anticipated land and water uses in the vicinity of the Blue Ridge Landfill (see Section 2.4). Table 3.1 describes the Site-specific factors relevant to the Remedial Action Objectives. Accordingly, the objectives for the Site are as follows.

- **BES Waste:** Control the potential for direct exposure to any BES Waste.
- **Landfill Leachate:** Minimize the potential for the release of leachate to groundwater.
- **Surface Water and Groundwater:** Control the potential for surface water and groundwater to become impacted by any TENORM constituents at levels that could cause adverse human health or ecological effects.
- **Landfill Gas:** Protect potential receptors from exposure to radon daughters at concentrations that may pose a human health risk *via* the inhalation exposure pathway.

¹² "Remedial action objectives consist of medium-specific or operable unit-specific goals for protecting human health and the environment. The objectives should be as specific as possible but not so specific that the range of [remediation] alternatives that can be developed is unduly limited" (US EPA, 1988).

Table 3.1 Site-specific Factors for Remedial Action Objective Determination

Site-specific Factor	Description
Nature of Release	The BES Waste was mixed with MSW at the landfill. The BES Waste is contained within the lined landfill boundary.
Nature and Extent of Contamination	The BES Waste contains low-level radiological constituents that have long half-lives. It is mixed with and buried adjacent to MSW. Soluble radiological constituents may leach into precipitation that infiltrates the waste. TENORM produces radon (Rn-222) as it decays.
Hydrogeological Features	Engineered features, including a low-permeability liner, a leachate extraction system that prevents leachate from migrating outside of the landfill, and stormwater controls, control the landfill hydrogeology. A cap will be installed at closure. Beneath the landfill, most of the higher-conductivity shallow fracture zone in the New Albany Shale was excavated to construct the landfill.
Current and Reasonably Anticipated Land Use ^a	The Site and its vicinity consists of the landfill, a largely wooded area, and some residential and residential/agricultural uses. A middle school and high school are located west of the Site. No residential use of the landfill property is anticipated.
Groundwater Use	There is no potable water use at the Site. The results of separate 1992 and 2017 well searches show wells that are within 1 mile radius and the broader vicinity of the Site boundary (Figures 2.2a and 2.2b). ¹³

Notes:

MSW = Municipal Solid Waste; TENORM = Technologically Enhanced Naturally Occurring Radioactive Material.

(a) "Remedial action objectives developed during the RI/FS should reflect the reasonably anticipated future land use or uses," and "Future land use assumptions allow the baseline risk assessment and the feasibility study to be focused on developing practicable and cost effective remedial alternatives" (US EPA, 1995).

¹³ The well search results are being confirmed by a well survey that will be performed pursuant to the 2017 Well Survey Work Plan prepared by Cornerstone Environmental Group (see Attachment G).

4 Development of Remediation Alternatives

This section summarizes the preliminary screening of remediation technologies that Gradient performed to identify potentially viable options to address the BES Waste at the Blue Ridge Landfill (Section 4.1). Section 4.2 describes the Remediation Alternatives that Gradient retained for further consideration.

4.1 Preliminary Screening of Remediation Technologies

In general, there are a number of available technologies that have been used to address landfill waste and environmental media impacted by landfill waste. These technologies may be categorized as follows.

Table 4.1 Summary of Landfill Remediation Technologies

Remediation Technology	Description	Examples
<i>In Situ</i> Treatment Technologies	Remediate contaminants/media as they exist, in place	Phytoremediation, <i>in situ</i> chemical oxidation (ISCO), <i>in situ</i> solidification/stabilization (ISS), <i>in situ</i> bioremediation, thermal treatment, monitored natural attenuation (MNA)
<i>In Situ</i> Containment Technologies	Prevent the migration of volatile and/or soluble constituents and limit direct contact exposure potential	Landfill caps and liner systems, vertical barrier walls, hydraulic containment
<i>Ex Situ</i> Treatment Technologies	Physical removal of solids, liquids, and/or gas for subsequent <i>ex situ</i> treatment	Solids – Excavation followed by redisposal (<i>e.g.</i> , in a landfill), incineration, thermal desorption, or chemical stabilization
		Liquids – Groundwater and leachate extraction followed by treatment, such as through air stripping, ion exchange, chemical redox, chemical adsorption, or discharge to POTW
		Gas – Landfill gas extraction followed by treatment, such as by flaring or recovery for energy production

Notes:

POTW = Publicly Owned Treatment Works.

Sources: US EPA (2006, 2010); FRTR (2007).

At the Blue Ridge Landfill, the primary media of concern is MSW mixed with the BES Waste. Constituents of TENORM are radionuclides primarily from the U-238 and Th-232 decay series (RAC, 2016), as shown in Figure 2.9 (embedded in report Section 2.3). Leachate and landfill gas generated from the BES Waste are also media of concern, as is surface water and groundwater beyond the landfill waste boundary.¹⁴ Thus, in the preliminary screening matrix we only considered technologies that can be applied to treat radionuclides. Unlike many organic contaminants, such as petroleum hydrocarbons, radionuclides cannot be destroyed or degraded (except through natural decay), and thus, the majority of available remediation technologies described in Table 4.1 are not feasible for any BES Waste at the Blue Ridge Landfill.

¹⁴ Airborne particulate exposure pathways are currently incomplete, because the BES Waste is buried under additional MSW and a protective 6-inch soil cover. Final Site plans include burial of the BES Waste with a minimum of 30 ft of additional MSW and the final cover system.

Table 4.2 presents the preliminary remediation technologies screening matrix for each of the media of concern. This matrix summarizes the available remediation technologies, including a description of each technology, and the rationale for selecting or rejecting each from further consideration. Gradient evaluated each remediation technology in the context of various factors and either retained or rejected the technology for the development of the Remediation Alternatives. The factors that influenced the selection of remediation technologies, as discussed in Table 4.2, included:

- The nature of contamination (constituents of TENORM);
- The depth and extent of impacts within the Blue Ridge Landfill;
- The current and future land and water uses at the landfill and in its vicinity;
- Relevant physical conditions (aquifer properties, local geology, topography, landfill construction, *etc.*);
- The current and future components of the landfill containment and monitoring system, as required by 401 KAR 48:070 and 48:080 (such as the current liner and leachate collection system and cap requirements at closure);
- Logistical considerations, such as the presence of landfill structures (*e.g.*, the underlying liner system); and
- The Remedial Action Objectives for the Site.

The following sections provide conceptual Remediation Alternatives considered for any TENORM waste at the Blue Ridge Landfill. These Remediation Alternatives consist of assemblages of the retained remediation technologies described in Table 4.2. Based on preliminary screening, the remedies retained include closure-in-place with monitoring and excavation and redisposal of the BES Waste. Remediation depths and waste volumes will be further refined, as needed, in the remedial design phase and will be based on actual conditions encountered at the Site.

4.2 Remediation Alternatives Retained for Consideration

4.2.1 Remediation Alternative 1: Closure-in-Place and Monitoring

This scenario consists of response actions at the Blue Ridge Landfill that are consistent with operational and post-closure requirements promulgated by the Cabinet (401 KAR 48:090) for MSW and that ADS's operating and closure permit (Solid Waste Permit SW033-00004), which the Cabinet approved, requires. These include surface and groundwater monitoring; leachate collection, removal, and discharge to the Irvine Municipal Utility Wastewater Treatment Plant (Industrial Use Permit Number 001); and final cap installation and maintenance, as described in Section 2. Under this scenario, the BES Waste would be left in place in its current location (mixed with MSW) and would be capped as part of the final cover system (Rust Environment & Infrastructure, Inc., 1994a), consistent with 401 KAR 48:080. As part of this Remediation Alternative, TENORM waste will not be added to the Site, a Radioactive Material Screening Plan (Weaver Consultants Group, LLC, 2017) will be implemented (see Section 8), and the existing BES Waste will remain undisturbed.

Prior to the construction of the final cover system, a minimum of 30 ft of additional MSW will be placed on top of the BES Waste. Upon the closure of the Blue Ridge Landfill, construction of the final cap will be conducted in phases as portions of the landfill are brought to final grade to minimize erosion and Site disturbance. The cap will be graded to control surface water runoff and will be revegetated for

Table 4.2 Preliminary Screening of Remediation Technologies

Medium	General Response Category	Process/Technology	Description	Retained as Viable Option?	Pros	Cons
BES Waste	Current Landfill Operations (containment and monitoring)	N/A	Operational and post-closure monitoring consistent with existing landfill operating and closure permit (SW033-00004).	Yes	Radiation doses are well below the level at which potential health effects may be observed. Risks are well within acceptable ranges (RAC, 2017). Containment (liner and cap) and monitoring are already required by the Blue Ridge Landfill's operating and closure permit (SW033-00004) and Kentucky regulations. This includes the engineered liner system (401 KAR 40:080), leachate collection and removal system (401 KAR 48:080), underdrain system, and ongoing surface water and groundwater monitoring (401 KAR 47:190, 48:300), in addition to a post-closure cap and its maintenance (401 KAR 48:090).	Given that the radioactivity of any TENORM will persist after the closure of the landfill, there are public concerns about the long-term protectiveness of this alternative.
	<i>In Situ</i> Stabilization	<i>In Situ</i> Stabilization	<i>In situ</i> blending of cement and source material to immobilize source material and minimize the generation of leachate.	No	Encapsulates the potentially mobile BES Waste constituents.	BES Waste is likely to be brought to the surface during drilling activities, increasing potential worker exposure. Landfill waste is heterogeneous, and thus, it is hard to predict the efficacy of potential binding agents. Drilling into the landfill poses unnecessary risks to the engineered liner and leachate extraction system (increased structural loads, inadvertent contact between drill augers and the liner/leachate extraction system components). BES Waste volume is likely to increase (typically 30-50%).
	Excavate and Redispose	Excavation and Off-site Disposal	Removal and off-Site disposal of BES Waste.	Yes	Reduces contaminant mass flux into landfill leachate. Removes radon source.	The implementation of this technology involves excavating, loading, and transporting the buried waste to another landfill for redispal. This operation requires heavy machinery and traffic, both on-Site and off-Site. It will increase the risk of physical injury and fatality due to accidents, both for workers and in the community. It also increases radiological exposures for workers and for the public along the haul route. Pinpointing the BES Waste location may be challenging, because it is buried by and mixed with MSW; thus, the contaminant mass flux may be reduced but not eliminated. Implementation of this technology may be costly.
Surface Water and Groundwater	Current Landfill Operations (containment and monitoring)	N/A	Operational and post-closure monitoring consistent with existing landfill operating and closure permit (SW033-00004).	Yes	Radiation doses are well below the level at which potential health effects may be observed. Risks are well within acceptable ranges (RAC, 2017). Groundwater and surface water monitoring are already required by the Blue Ridge Landfill operating and closure permit (SW033-00004), consistent with 401 KAR 47:190 and 48:300.	Given that the radioactivity of any TENORM will persist after the closure of the landfill, there are public concerns about the long-term protectiveness of this alternative.
	Physical Containment	Low-permeability Cap	Containment of source areas <i>via</i> a low-permeability cap to limit infiltration of water.	No	Reduces the risk of contaminant mass flux associated with leaching into the surface water and groundwater. There is currently a liner system in place, and a post-closure cap is required as part of the Blue Ridge Landfill's operating and closure permit (SW033-00004).	Installing an interim cap will interfere with existing landfill operations and environmental controls, such as the landfill gas extraction system. Given that the radioactivity of any TENORM will persist after the closure of the landfill, there are public concerns about the long-term protectiveness of this
	Monitored Natural Attenuation (MNA)	Sampling and Chemical Analysis	Monitoring dissolved-phase contamination in the surrounding surface water and groundwater bodies to ensure long-term protectiveness.	Yes	Groundwater and surface water monitoring are already required by the Blue Ridge Landfill's operating and closure permit (SW033-00004), consistent with 401 KAR 48:300. Groundwater and surface water monitoring plans have been previously developed and implemented (Herst & Associates, Inc., 2009; Rust Environment & Infrastructure, Inc., 1994a).	Quarterly and annual sampling parameters do not include radionuclides, according to 401 KAR 48:300(11)(3).
Leachate	Current Landfill Operations (containment and monitoring)	N/A	Operational and post-closure monitoring consistent with existing landfill operating and closure permit (SW033-00004).	Yes	Radiation doses are well below the level at which potential health effects may be observed. Risks are well within acceptable ranges (RAC, 2017). Leachate monitoring, collection, and removal are already required by the Blue Ridge Landfill's operating and closure permit (SW033-00004), consistent with 401 KAR 48:080.	Given that the radioactivity of any TENORM will persist after the closure of the landfill, there are public concerns about the long-term protectiveness of this alternative.
	Physical Containment	Low-permeability Cap	Containment of source areas <i>via</i> a low-permeability cap to limit infiltration of water.	Yes	Reduces the risk of contaminant mass flux associated with leaching into the surface water and groundwater. There is currently a liner system in place, and a post-closure cap is required as part of the Blue Ridge Landfill's operating and closure permit (SW033-00004).	Installing an interim cap will interfere with existing landfill operations and environmental controls, such as the landfill gas extraction system. Given that the radioactivity of any TENORM will persist after the closure of the landfill, there are public concerns about the long-term protectiveness of this
	Monitored Natural Attenuation (MNA)	Sampling and Chemical Analysis	Monitoring dissolved-phase constituents in the leachate to ensure long-term protectiveness.	Yes	Leachate collection and removal is required by the Blue Ridge Landfill's operating and closure permit (SW033-00004), consistent with 401 KAR 48:300. Leachate sampling is conducted under the landfill's Industrial User Permit (Number 001) prior to discharge to the Irvine WWTP (Rust Environment & Infrastructure, Inc., 1994a).	The landfill's Industrial User Permit (Number 001) for leachate discharge to the Irvine WWTP does not include radionuclides (Rust Environment & Infrastructure, Inc., 1994a).
Landfill Gas	Current Landfill Operations (containment and monitoring)	N/A	Operational and post-closure monitoring consistent with existing landfill operating and closure permit (SW033-00004).	Yes	Radiation doses are well below the level at which potential health effects may be observed. Risks are well within acceptable ranges (RAC, 2017). BES Waste will be buried by a minimum of an additional 30 ft (approximately) of MSW, further reducing radon flux.	Given that the radioactivity of any TENORM will persist after the closure of the landfill, there are public concerns about the long-term protectiveness of this alternative.
	Physical Containment	Vapor Barrier	Containment of source areas <i>via</i> a low-permeability vapor barrier to reduce radon flux.	No	Reduces radon mass flux.	Installing an interim cap will interfere with existing landfill operations and environmental controls, such as the landfill gas extraction system.
	Monitored Natural Attenuation (MNA)	Sampling and Chemical Analysis	Monitoring for radon levels to ensure long-term protectiveness.	Yes	Could ensure long-term protectiveness.	Elevated local background radiation will likely lead to false positives in sample results.

Notes:

BES Waste = Material delivered to the Blue Ridge Landfill by BES, LLC; KAR = Kentucky Administrative Regulation; MSW = Municipal Solid Waste; N/A = Not Applicable; TENORM = Technologically Enhanced Naturally Occurring Radioactive Materials; WWTP = Waste Water Treatment Plant.

stabilization and long-term erosion control. Structures to control surface runoff and erosion will include hay bales, filter fabric fences, sod-lined runoff swales, and sedimentation ponds. Leachate will be collected and removed with the existing system.

Long-term maintenance and monitoring of the final cover system will be conducted consistent with 401 KAR 48:090. Long-term monitoring of surface water and groundwater beyond the containment zone¹⁵ will be conducted to ensure protectiveness. The monitoring wells included in the sampling plan are MW-7, MW-10, MW-13, MW-15R, and MW-17R, consistent with the current Groundwater Monitoring Plan (Herst & Associates, Inc., 2009). Figure 2.3 shows the groundwater monitoring wells included in this plan. Sampling parameters for groundwater include temperature, chloride, chemical oxygen demand, total dissolved solids (TDS), total organic carbon (TOC), specific conductivity, pH, iron, sodium, and total organic halides (with sampling to be conducted on a quarterly basis), and additional parameters, including inorganics and VOCs, are to be sampled annually, consistent with 401 KAR 48:300(11)(3). Figure 2.3 shows surface water monitoring locations. Sampling parameters for surface water include chlorides, sulfate, iron, sodium, TOC, specific conductance, TSS, TDS, total solids, and pH, consistent with 401 KAR 48:300(2)(3). Sampling will be conducted for the closure period of 2 years and the post-closure care period of at least 30 years.

In addition, Remediation Alternative 1 would include the following additional actions (see Figure 4.1):

- **Develop and Implement a Radionuclide Sampling Plan:** ADS will develop a Radionuclide Sampling Plan. Given the elevated background NORM in the region, establishing statistically significant background concentrations will be an important component of the monitoring plan. The Radionuclide Sampling Plan will also factor in the regulations for TENORM waste that are currently being prepared by the Cabinet and the KCHFS, to the extent that they are relevant;
- **Place an Enhanced Cap Over the BES Waste Area as Part of the Final Cover System:** To further reduce long-term infiltration into the BES Waste area, ADS would augment the currently required final cap with an additional low-permeability geosynthetic clay liner; and
- **Modify the Landfill Gas Collection System to Relocate Landfill Gas Extraction Wells from the BES Waste Area:** This would reduce methane generation from the area of the landfill where BES Waste was disposed.

Further, ADS will comply with the final Cabinet regulations regarding TENORM as they may apply to its operation.

4.2.2 Remediation Alternative 2: Excavate and Redispose BES Waste

Alternative 2 consists of uncovering, excavating, transporting, and redisposing the BES Waste from the Blue Ridge Landfill to another landfill. Under this scenario, approximately 16,300 yd³ of soil cover and MSW overlying the BES Waste (which the BES Waste did not impact) would be excavated and relocated to another portion of the Site. Subsequently, approximately 39,630 yd³ (45,575 yd³ assuming a "fluff factor" of 15%) of the BES Waste mixed with MSW would be excavated and transported by truck to a designated disposal facility (see Figure 4.2), such as an MSW landfill permitted by the Pennsylvania Department of Environmental Protection (PADEP) that accepts BES Waste¹⁶ or a similarly licensed

¹⁵ The containment zone consists of waste that is located within the landfill containment systems, consisting of the landfill liner system, leachate collection system, landfill gas management system, and stormwater controls (as described in Section 2.1).

¹⁶ The Mostoller Landfill in Somerset, Pennsylvania, operated by Advanced Disposal Services, Inc., was identified as a possible facility for accepting the BES Waste. This facility accepts waste that contains TENORM constituents from oil and gas drilling activities in the region.

MSW landfill. Up to approximately 480 tons of BES Waste could be transported per day, consistent with Pennsylvania Title 25 Chapter 273.¹⁷ Based on the estimated volume of BES Waste-impacted waste (BES Waste mixed with MSW in the Blue Ridge Landfill cells in which it was originally placed), and assuming a 15% "fluff factor" (45,575 yd³ total), it would take approximately 1,823 truckloads (over about 93 days) to remove all the impacted waste and place it in the final disposal site. Following excavation, the Blue Ridge Landfill would be backfilled with MSW to the soil cover grade. At the time of landfill closure, the final cover system would be implemented according to the Closure Plan (Rust Environment & Infrastructure, Inc., 1994a) and consistent with 401 KAR 48:080.

Remediation Alternative 2 requires the following actions to be taken:

- **Stage 1:** Soil cover and MSW overlying the BES Waste (depicted in Figure 4.2) would be excavated and placed in a staging area of the Site. The amount of soil and overlying MSW to be excavated is approximately 16,300 yd³ (18,745 yd³ assuming a "fluff factor" of 15%).
- **Stage 2:** The BES Waste would be excavated and, to the extent possible, loaded directly into haul trucks. In areas of the excavation where it may be too deep to load the waste directly into haul trucks, the BES Waste would be staged on a bench cut within the impacted grid cells. Stormwater controls would be required during BES Waste excavation to control stormwater run-on and runoff during excavation.
- **Stage 3:** Approximately 20 tons of BES Waste per truckload would be hauled to the disposal landfill.
- **Stage 4:** Staged soil and MSW will be backfilled into the excavation where the BES Waste was removed and brought to grade with additional MSW.

It is expected that the total excavation, removal, and backfilling time will take approximately 93 working days, depending on Site conditions.

¹⁷ Adherence to Pennsylvania Title 25 Chapter 273 assumes that the Mostoller Landfill is the redisposal facility.

**Table 4.3 Summary of Site Factors for Remediation Alternative 2:
Excavate and Redispose BES Waste**

Factor	Value
Total BES Waste Area	170,000 ft ²
Depth Range of the BES Waste	0-19 ft ^a
Average Depth of the BES Waste	6 ft bws
BES Waste + MSW Waste Volume (removal volume, <i>in situ</i>)	39,630 yd ³
BES Waste + MSW Waste Volume (removal volume), assuming a 15% fluff factor (<i>ex situ</i>)	45,575 yd ³
MSW Volume Overlying the BES Waste (<i>in situ</i>)	16,296 yd ³
MSW Volume Overlying the BES Waste, assuming a 15% fluff factor (<i>ex situ</i>)	18,745 yd ³
Post-excavation Backfill ^b	55,926 yd ³
Amount of Mixed BES Waste and MSW Taken Off-Site Per Day	480 tons ^c
Total Duration of Excavation Operations	93 days ^d
Average Number of Trucks Per Day	24
One-way Distance to Disposal Facility	425 mi

Notes:

bws = Below Waste Surface; MSW = Municipal Solid Waste.

(a) BES Waste at a depth of 0 ft is located at the surface.

(b) Backfill amount includes overlying MSW/soil and BES Waste volumes.

(c) 1 ton = 1.25 yd³. Assuming a density for BES Waste of 1,600 lbs/yd³.

(d) Assuming 8-hour working days and including backfilling duration.

Potential exposures to low-level radioactive materials in this Remediation Alternative include direct contact with (*i.e.*, external exposure), inhalation of particulates from, and incidental soil ingestion of materials during excavation, transport, and redispisal, and leachate migration to groundwater. There are also physical risks to the workers and the community.

5 Corrective Action Evaluation Criteria

In accordance with Kentucky and federal regulations and guidance (*e.g.*, 401 KAR 100:030 [State of Kentucky Remediation Requirements]; US EPA, 1988, 1989; 40 CFR 300.430 [*i.e.*, the NCP]), Gradient used the following criteria to evaluate the Remediation Alternatives developed for the Blue Ridge Landfill (as described in Section 4).

- **Overall Protection of Human Health and the Environment:** This criterion is used to evaluate whether and how the remediation alternative as a whole achieves and maintains the protection of human health and the environment. In particular, Gradient used this criterion to evaluate the ability of the alternative to achieve the Remedial Action Objectives developed for the Blue Ridge Landfill.
- **Compliance with Other Applicable Requirements:** This criterion is used to evaluate whether the alternative complies with other applicable requirements. While included as a criterion within the scope of this CAP, we assumed that the Kentucky State regulators will evaluate the Remediation Alternatives in the context of State regulations and identify the need for compliance with additional requirements, if any.
- **Long-term Effectiveness and Permanence:** This criterion includes an evaluation of the magnitude of human health risk from untreated contaminated materials or treatment residuals remaining after remedial action has been concluded (which is known as residual risk), and the adequacy and reliability of controls to manage that residual risk.
- **Reduction of Toxicity, Mobility, and Volume Through Treatment:** This criterion refers to the evaluation of whether treatment processes can be used to address the source material, the amount of hazardous material treated (including the principal threat that can be addressed), and the degree of expected reduction in the toxicity, mobility, and volume of source material.
- **Short-term Effectiveness:** This criterion includes an evaluation of the effects of the remediation alternative during the construction and implementation phase, until remedial objectives are met. This criterion includes an evaluation of the protection of the community and workers during the remedial action and the short-term environmental impacts of implementing the remedial action.
- **Implementability:** This criterion is used to evaluate the technical feasibility of the remediation alternative, including construction and operation, reliability, monitoring, and the ease of undertaking remedial action in the context of any logistical constraints at the Site. It also considers the administrative feasibility of activities needed to coordinate with other third parties (*e.g.*, regulatory agencies), such as for obtaining permits, and the availability of services and materials necessary for the alternative, such as disposal facilities and qualified contractors.
- **Cost:**¹⁸ This criterion includes an evaluation of direct and indirect capital costs, including the costs of treatment and disposal; the annual costs of operating, maintaining, and monitoring the alternative; and the net present value of these costs.

¹⁸ According to US EPA guidance: "Cost is a critical factor in the process of identifying a preferred remedy. In fact, CERCLA and the NCP require that every remedy selected must be cost-effective" (US EPA, 1996, p. 5). Remediation alternatives, may be "screened out" if they provide equivalent effectiveness and implementability as another less-costly alternative (40 CFR 300.430(e)(7)(iii); US EPA, 1996, p. 4).

- **Regulatory Approval and Community Acceptance:** These criteria are used to evaluate the expected level of approval from the regulatory agency overseeing the remediation of the site and acceptance from community stakeholders, respectively.

These criteria correspond to those that, per 401 KAR 100:030 (Kentucky Remediation Requirements), are used to evaluate "sites where the party or applicant will manage releases in place." This is the case for the Remediation Alternative 1 (Closure-in-Place and Monitoring), which is described in Section 4 of this report. These criteria also correspond to the nine NCP remedy selection criteria that are used in the "Comparative Analysis" process to evaluate and compare remediation alternatives to ensure the rational selection of a remedy (40 CFR 300.430(f)).

6 Evaluation of Remediation Alternatives

This section provides a detailed assessment of the Remediation Alternatives using the evaluation criteria. Each alternative was individually evaluated for each criterion using a combination of qualitative and quantitative methods. The alternatives were then comparatively ranked against one another (Section 7).

6.1 Overall Protectiveness

The overall protectiveness criterion is used to evaluate whether and how the remediation alternative as a whole achieves and maintains the protection of human health and the environment. In particular, this criterion was used to evaluate the ability of each alternative to achieve the Remedial Action Objectives developed for the Blue Ridge Landfill.

As summarized in Table 6.1, Remediation Alternative 1 provides the greatest degree of overall protectiveness and is able to achieve all of the Remedial Action Objectives. Remediation Alternative 2 poses significantly higher risks associated with excavating, hauling, and redispersing the BES Waste.

Table 6.1 Overall Protectiveness of the Remediation Alternatives

Remedial Action Objective	Remediation Alternative 1: Closure-in-Place and Monitoring	Remediation Alternative 2: Excavate and Redisperse BES Waste
Control the potential for direct exposure to any BES Waste	The BES Waste will be buried by at least 30 ft of MSW, and therefore will not pose a direct exposure risk. Enhancing the post-closure cap will further reduce the potential for direct exposure.	Excavating the BES Waste will create the potential for direct exposure during excavation, transport, and redisposal.
Minimize the potential for the release of leachate to groundwater	The existing containment system (liner and leachate collection system) effectively controls leachate release. The required post-closure cap will minimize leachate generation after the landfill's closure.	<p>At the Blue Ridge Landfill, removal of the BES Waste would decrease contaminant flux to leachate, including from potentially soluble TENORM-related constituents.</p> <p>However, relocating the BES Waste to a different landfill would pose similar leaching concerns, and, therefore, there would be no net environmental benefit.</p>
Control the potential for surface water and groundwater to become impacted by any TENORM constituents at levels that could cause adverse human health or ecological effects	<p>The existing containment system (liner and leachate collection system) effectively controls leachate release and existing stormwater controls effectively protect receiving surface water bodies. The required post-closure cap will minimize leachate generation after the landfill's closure. Enhancing the post-closure cap will further reduce leachate generation potential.</p> <p>Surface water and groundwater monitoring ensures that conditions remain protective (<i>i.e.</i>, that there is not leachate breakthrough).</p> <p>The RAC (2017) Radiological Risk Assessment results demonstrate that potential doses and risks for human health or ecological receptors <i>via</i> the groundwater exposure pathway are extremely low and well within the acceptable range set by the US EPA.</p> <p>Long-term monitoring for leachate constituents provides assurance of the long-term protection of human health.</p>	<p>At the Blue Ridge Landfill, removal of the BES Waste would decrease potential contaminant flux to leachate, including from potentially soluble TENORM-related constituents, and would therefore reduce potential releases to surface water and groundwater.</p> <p>At the Blue Ridge Landfill, the groundwater exposure pathway is not a concern for human health or ecological receptors under this Remediation Alternative.</p> <p>However, the RAC (2017) Radiological Risk Assessment indicates that groundwater risks associate with redispersing these materials at a separate landfill would be similar to risks under Remediation Alternative 1.</p> <p>Relocating the BES Waste to a different landfill would pose similar leaching concerns, and, therefore, there would be no net environmental benefit.</p>

Table 6.1 Overall Protectiveness of the Remediation Alternatives

Remedial Action Objective	Remediation Alternative 1: Closure-in-Place and Monitoring	Remediation Alternative 2: Excavate and Redispose BES Waste
Protect potential receptors from exposure to radon daughters at concentrations that may pose a human health risk <i>via</i> the inhalation exposure pathway	The RAC (2017) Radiological Risk Assessment results demonstrate that the potential doses and risks for human health receptors <i>via</i> the radon inhalation exposure pathway are extremely low and well within the acceptable range set by the US EPA. Relocation of landfill gas extraction wells to outside of the BES Waste zone would decrease radon flux.	<p>At the Blue Ridge Landfill, removal of the BES Waste would decrease radon flux, including from TENORM-related constituents, and therefore would reduce the potential for exposure <i>via</i> the inhalation pathway.</p> <p>However, the RAC (2017) Radiological Risk Assessment results demonstrate that the potential doses and risks for human health receptors <i>via</i> the radon inhalation exposure pathway are extremely low and well within the acceptable range set by the US EPA.</p> <p>Further, relocating the BES Waste to a different landfill would pose similar radon concerns, and, therefore, there would be no net environmental benefit.</p>

Notes:

MSW = Municipal Solid Waste; RAC = Risk Assessment Corporation.

6.2 Compliance with Other Applicable Requirements

This criterion is used to evaluate whether a remediation alternative complies with other applicable requirements. While we include this as a criterion within the scope of this CAP, the Blue Ridge Landfill is a highly regulated entity subject to stringent state and federal requirements as part of its operating and closure permit (see Section 2.5). For purposes of this report, we have assumed that the Kentucky State regulators will evaluate the Remediation Alternatives in the context of Kentucky State regulations and highlight the need for compliance with additional requirements, if any, associated with the recommended Remediation Alternative.

6.3 Long-term Effectiveness and Permanence

This criterion includes an evaluation of the magnitude of human health risk from untreated contaminated materials or treatment residuals remaining after remedial action has been concluded (known as residual risk), and the adequacy and reliability of controls to manage that residual risk. At the landfill, Gradient evaluated long-term effectiveness and permanence using the results of the Radiological Risk Assessment prepared by RAC (2017; see Attachment A2), which specifically evaluated residual risk associated with the buried BES Waste at the Blue Ridge Landfill. (In this risk assessment, RAC also evaluated long-term effectiveness and permanence with respect to the adequacy and reliability of controls used to manage the residual risk.)

The radiological risk calculations performed for each Remediation Alternative represent bounding scenarios whereby the results are expected to overestimate actual doses and risks. Exposure parameters are generally representative of reasonable maximum exposures. Underlying transport calculations used to determine the air and groundwater concentrations were deliberately high-sided, resulting in higher estimates of risk than would actually be incurred.

6.3.1 Long-term Radiological Risks (Remediation Alternative 1: Closure-in-Place and Monitoring)

RAC (2017) evaluated the following exposure pathways that are relevant to Remediation Alternative 1 (Closure-in-Place and Monitoring).

- **Future On-Site Risks:**
 - RAC evaluated the Landfill Laborer,¹⁹ Landfill Office Worker, and Other Landfill Customer for inhalation of radon generated from the BES Waste left in place.
- **Future Off-Site Risks:**
 - RAC evaluated the Adult School Staff and Child Student for inhalation of radon generated from the BES Waste left in place.
 - RAC evaluated the Future Resident for inhalation of radon and ingestion of groundwater from a well located at the downgradient edge of the Site.
 - RAC evaluated ecological receptors using the ERICA tool to determine whether the potential radiation dose rate to ecological receptors would be within acceptable screening limits.

¹⁹ A Heavy-equipment Operator is expected to have lower exposures than the Landfill Laborer. Therefore, Remediation Alternatives that are protective of the Landfill Laborer would also be protective for the less-exposed Heavy-equipment Operator.

RAC (2017) evaluated receptors' potential exposure to long-term radon emissions from the BES Waste using NRC models and methods for assessing uranium mill tailings. In this assessment, RAC used a hypothetical diffusion model to calculate emissions from the BES Waste. RAC assumed that Ra-226 (the parent radionuclide of Rn-222) was uniformly distributed throughout the 15-ft thickness of compacted BES Waste, with BES Waste covered by 30 ft of compacted MSW. RAC assumed that the radon emanation coefficient for the BES Waste was similar to that of uranium mine tailings. This assumption represents a worst-case scenario, given that radon emanation from the total BES Waste mass (assuming it is TENORM) at the Blue Ridge Landfill is substantially lower than radon emanation from uranium mill tailings (RAC, 2017). RAC then used the Gaussian Plume model to estimate radon concentrations at the nearby landfill office buildings and schools. Estimated radon concentrations at nearby off-Site buildings were calculated assuming typical daytime atmospheric conditions and average local wind speed. RAC assumed that the wind is always blowing toward the receptor, thereby ensuring that doses and risks are not underestimated. The risk calculations for the landfill office workers and school building occupants assume that indoor concentrations of radon are the same at the nearby buildings as they are at the landfill. The RAC (2017) Radiological Risk Assessment report includes a detailed discussion of the diffusion model, including the parameters used in this analysis (see Attachment A2).

RAC evaluated the potential future migration of radionuclides from any assumed TENORM source to a receptor groundwater well using a simplified conceptual model that tends to overestimate concentrations. RAC assumed that a receptor well is located on the immediately downgradient edge of the source. Infiltration through the facility would leach radionuclides from the disposal cell into the vadose zone at a natural infiltration rate for 40 years, followed by a reduced infiltration rate after the final landfill cover is installed. To ensure that doses and risks were not underestimated, RAC eliminated the impact of the leachate collection system and the facility's liner from the analysis. RAC used a mixing cell model and the GWSCREEN groundwater transport model to model the fate and transport of dissolved constituents in groundwater and to calculate groundwater ingestion doses for the Future Resident. The RAC (2017) Radiological Risk Assessment report presents a detailed discussion of the groundwater fate and transport models, including parameters used in this analysis (see Attachment A2).

Table 6.2 provides a summary of the upper-bound lifetime (*i.e.*, 30-year) cancer morbidity risk estimates for the receptors after the disposal of the BES Waste for Remediation Alternative 1. Cancer morbidity risk calculations for Remediation Alternative 1 assume that the on-Site Landfill Laborer and Landfill Office Worker, and the off-Site Adult School Staff, Child Student, and Future Resident may inhale radon after the initial BES Waste disposal and the off-Site Future Resident may ingest contaminated drinking water and inhale radon after the initial BES Waste disposal. Cancer risks from inhalation of radon and ingestion of contaminated groundwater are expressed as a unitless probability (*e.g.*, 1 in 1 million, or 1×10^{-6}) of an individual developing cancer over a lifetime, above background risk, as a result of Site-related exposures. Kentucky's target cancer risk is 1×10^{-6} (401 KAR 100:030), and the US EPA has established a target cancer risk range of 1×10^{-6} to 1×10^{-4} (US EPA, 1990b, 1991). For the exposure scenarios evaluated in this risk assessment, lifetime risks²⁰ for the on-Site Landfill Office Worker and all off-Site receptors were less than or within US EPA's target cancer risk range (*i.e.*, at levels that US EPA considers protective of human health) and well below the level at which potential health effects may be observed. Kentucky's target cancer risk was exceeded for the potential Future Resident consuming groundwater immediately adjacent to the landfill 2,700 years from the present day. However, according to RAC (2017) maximum effective doses were well below the 25 mrem year⁻¹ (0.25 mSv year⁻¹) dose limit for low-level radioactive disposal sites (10 CFR 20), the maximum total radium (Ra-226 + Ra-228) concentration in groundwater was estimated to be less than the US EPA MCL for total radium presented in 40 CFR 141 (5 pCi L⁻¹ for Ra-226 + Ra-228), and the maximum predicted concentration of U-238 was

²⁰ Lifetime risks for the average US population, assuming over 30 years of exposure (RAC, 2017).

well below the US EPA MCL for uranium presented in 40 CFR 141 (30 µg L⁻¹). The calculated dose estimates for these receptors are many times lower than those that individuals are exposed to from natural background radiation sources; medical procedures, such as X-rays or computerized tomography scans; and transatlantic air travel (RAC, 2016).

RAC did not calculate cancer risk due to long-term inhalation of radon for on-Site Landfill Office Worker and the off-Site receptors for Remediation Alternative 2 (Excavate and Redispose BES Waste), because the assumed TENORM material would no longer be present at the landfill under this scenario. However, a similar radon inhalation exposure pathway would exist at the new landfill where the BES Waste would be redisposed.

Table 6.2 Lifetime Cancer Morbidity Risk Estimates for the Remediation Alternatives Post-disposal

Receptor	Maximum ^a Cancer Morbidity Risk Estimates for the Post-disposal Timeframe	
	Remediation Alternative 1: Closure-in-Place and Monitoring	Remediation Alternative 2: Excavate and Redispose BES Waste
Landfill Laborer	5.6E-07	Not evaluated (assumes the buried BES Waste has been removed ^b)
Landfill Office Worker	2.1E-07	
Other Landfill Customer	8.2E-08	
Adult School Staff/Child Student	7.4E-08	
Future Resident	4.3E-07 (radon) 4.9E-05 (groundwater) ^c	

Notes:

Regulation 401 KAR 100:0301(10) defines the Target Risk as 1×10^{-6} .

Groundwater risk reaches a maximum at 2,700 years from present day.

Source: RAC (2017); see Attachment A2.

(a) Lifetime risks for the average US population assuming 30 years of exposure (RAC, 2017).

(b) This Remediation Alternative assumes that the buried BES Waste has been removed from the landfill; therefore, RAC did not evaluate cancer risks from radon inhalation for workers and community members near the landfill.

(c) Although the risk estimate for a potential future resident consuming groundwater immediately adjacent to the landfill 2,700 years from the present day exceeds Kentucky's target cancer risk of 1×10^{-6} (401 KAR 100:030), according to RAC (2017): maximum effective doses were well below the 25 mrem yr⁻¹ (0.25 mSv yr⁻¹) dose limit for low-level radioactive disposal sites, the maximum total Ra (Ra-226+Ra-228) concentration in groundwater was estimated to be less than the MCL presented in 40 CFR 141 (5 pCi L⁻¹ Ra-226+Ra-228), and the maximum predicted concentration of U-238 was well below the MCL for uranium presented in 40 CFR 141 (30 µg L⁻¹).

Notably, both Remediation Alternatives would provide long-term protectiveness of human health, because estimated cancer morbidity risks associated with all viable exposure pathways (radon inhalation or groundwater ingestion) for all current and future receptors are either within or substantially lower than the US EPA's target cancer risk range of 1×10^{-6} to 1×10^{-4} (US EPA, 1990b, 1991) (though they do exceed Kentucky's target risk level, as noted above) and are well below the levels at which potential health effects could be observed (RAC, 2017).

In addition, for Remediation Alternative 2 (Excavate and Redispose BES Waste), RAC (2017) concluded, "The risks associated with redisposing these materials at a separate landfill would be comparable to the risks incurred during the original disposals, and the subsequent long-term risks [to receptors at or near the receiving landfill] would be comparable to the closure-in-place risks calculated for Alternative 1 at the Blue Ridge Landfill."

More detailed results and calculations for radiation doses and risks can be found in Attachment A2.

6.3.2 Adequacy and Reliability of Engineering Controls

Gradient also evaluated long-term effectiveness and permanence with respect to the adequacy and reliability of controls to manage the residual risk. The BES Waste is buried within the landfill, where it is mixed with and will be covered by at least 30 ft of MSW. As noted above, the landfill has highly engineered environmental controls, as required by the conditions of its operating and closure permit (Solid Waste Permit SW033-00004) and consistent with Kentucky and federal non-hazardous landfill regulations. As detailed in Section 2, these environmental controls consist of the following:

- A multi-component liner system, including a low-permeability clay and geomembrane layer that prevents the migration of leachate constituents from the landfill into native groundwater beneath the landfill;
- A leachate extraction system that drains, extracts, and collects leachate, which reduces vertically downward hydraulic gradients and further minimizes the potential for leachate migration beyond the landfill boundary;
- Stormwater management features that minimize infiltration into the landfill waste and, therefore, reduce leachate-generation potential; and
- A post-closure low-permeability cap that will further reduce infiltration of leachate constituents into the landfill.

Routine surface water and groundwater monitoring for a suite of constituents (see Section 2.5)²¹ is performed to ensure that leachate breakthrough does not occur.

Under Remediation Alternative 1, these environmental controls would remain in place with no changes except, as described in Section 4.2.1, ADS would: (1) develop and implement a Radionuclide Sampling Plan; (2) place an enhanced cap over the BES Waste area as part of the final cover system; and (3) modify the landfill gas collection system to relocate landfill gas extraction wells from the BES Waste area. This alternative, therefore, provides overall long-term effectiveness, because, under Remediation Alternative 2, the BES Waste would be relocated to a similar landfill with similar environmental controls and there would be no net long-term environmental benefit. For example, the potential for leachate breakthrough is already monitored at the Blue Ridge Landfill. Both Remediation Alternatives provide long-term protectiveness in that residual risks at the points of exposure are at levels considered protective of human health.

6.4 Reduction of Toxicity, Mobility, and Volume Through Treatment

This criterion refers to the evaluation of whether treatment processes can be used to address the source material; the amount of hazardous material treated, including the principal threat that can be addressed; and the degree of expected reduction in the toxicity, mobility, and volume of source material.

Both of the Remediation Alternatives reduce the potential environmental mobility of the BES Waste by containing it through a combined liner/cap/leachate extraction system/landfill gas extraction system. Remediation Alternative 1 achieves this at the Blue Ridge Landfill, while Remediation Alternative 2 would do so at a different landfill facility. Reduction of toxicity is not relevant, because radionuclides cannot be destroyed or degraded (other than by natural decay) and because radiation measurements at the

²¹ Wells are sampled quarterly as part of the Groundwater Monitoring Plan for temperature, chloride, chemical oxygen demand, TDS, TOC, specific conductivity, pH, iron, sodium, and total organic halides (Herst & Associates, Inc., 2009).

landfill are consistent with naturally occurring background levels of radiation. Reduction of volume is also not relevant, because there is no practical way to reduce the volume of the BES Waste. Further, excavation of the BES Waste under Remediation Alternative 2 would increase its *ex situ* volume.

6.5 Short-term Effectiveness

This criterion includes an evaluation of the effects of the remediation alternative during the construction and implementation phases, until remedial objectives are met; the protection of the community and workers during the remedial action; and the short-term environmental impacts of implementing the remedial action.

Gradient evaluated short-term effectiveness using two different methods: remedy risk analysis and Green and Sustainable Remediation (GSR) analysis. Gradient and RAC used remedy risk analysis to quantify and compare the physical and radiological risks, respectively, posed by executing each Remediation Alternative. In addition, RAC evaluated radiological risks to workers and the community by comparing a calculated dose to health-protective benchmarks. Gradient evaluated physical risks to workers by estimating, *via* actuarial techniques, the number of injuries and fatalities sustained by workers involved with remediation activities for each Remediation Alternative. We also evaluated physical risks to the community by estimating, *via* actuarial techniques, the number of injuries and fatalities sustained by individuals in the surrounding community from haul truck accidents. In the GSR analysis, Gradient calculated the environmental impacts associated with the "life cycle" of each Remediation Alternative on the basis of the following metrics: air emissions (greenhouse gases [GHGs], sulfur oxides [SO_x], nitrogen oxides [NO_x], particulate matter less than 10 microns in diameter [PM₁₀]), energy consumption, and resource consumption.

The following sub-sections describe the methodology and results of these analyses (refer to Attachments A2 and D for further details).

6.5.1 Short-term Radiological Risks

At the Blue Ridge Landfill, Gradient evaluated short-term effectiveness using the results of the Radiological Risk Assessment prepared by RAC (2017; see Attachment A2), which specifically evaluated risk associated with excavation of the BES Waste at the landfill for the following exposure pathways and receptors.

- **On-Site Risks During Excavation:**
 - RAC assumed that the Landfill Laborer, Supervisor, and Other Landfill Customer inhale particulates, ingest soil, and have external exposure resulting from contact with emissions during the excavation of the BES Waste disposed of at the landfill. Each receptor's exposure depended on the amount of time each was present at the landfill, with the Landfill Laborer representing the most exposed receptor.
 - RAC assumed that the Landfill Office Worker inhales airborne TENORM particulates while working in the landfill administrative buildings during the excavation of the BES Waste.
- **Off-Site Risks During Excavation:**
 - RAC assumed that the Adult School Staff, including a teacher or administrator, and the Child Student inhale airborne TENORM particulates while working or attending the nearby Estill County Middle and High Schools during the excavation of the BES Waste.

Table 6.3 provides the cancer morbidity risk estimates for the receptors during the excavation period for Remediation Alternative 2; RAC did not perform cancer risk calculations for this period in Remediation Alternative 1 because it does not involve excavation. The calculated cancer morbidity risk estimates for Remediation Alternative 2 were within US EPA's target cancer risk range of 1×10^{-6} to 1×10^{-4} (US EPA, 1990b, 1991) for all on-site and off-site receptors (*i.e.*, at levels that US EPA considers protective of human health) and well below the level at which potential health effects may be observed. Kentucky target risk levels were exceeded for both the Landfill Laborer and the Supervisor for this Remediation Alternative.

Table 6.3 Cancer Morbidity Risk Estimates for the Remediation Alternatives During Excavation

Receptor	Cancer Morbidity Risk Estimates During Excavation	
	Remediation Alternative 1: Closure-in-Place and Monitoring	Remediation Alternative 2: Excavate and Redispose BES Waste ^a
Landfill Laborer	Not evaluated (this Remediation Alternative does not include excavation)	1.8E-05
Landfill Office Worker		4.9E-10
Supervisor		2.2E-06
Other Landfill Customer		7.5E-07
Adult School Staff/Child Student		1.1E-10
Future Resident		Not evaluated

Notes:

(a) For Remediation Alternative 2 (Excavate and Redispose BES Waste), risk estimates for a future Landfill Laborer and Supervisor exceed Kentucky's target cancer risk of 1×10^{-6} (401 KAR 100:030), according to RAC (2017).

Source: RAC (2017); see Attachment A2.

More detailed results and calculations for radiation doses and risks can be found in Attachment A2.

6.5.2 Physical Risks

Gradient performed a physical risk analysis on a relative basis to estimate the impact of Remediation Alternative 2 compared to Remediation Alternative 1. Hence, for both Remediation Alternatives, the physical risk analysis included only those activities that would be performed in addition to the standard operational and post-closure requirements for the Blue Ridge Landfill. Therefore, we assumed that:

- Remediation Alternative 1 posed zero incremental physical safety risk;²² and
- Physical risks associated with the implementation of the Remediation Alternative 2 work elements (*i.e.*, excavation, transportation, and redisposal of the BES Waste), as well as additional personnel transport from and to the Site, were the bases of the calculated risks for Remediation Alternative 2.

Consistent with these general assumptions, Gradient calculated worker and community safety metrics (*i.e.*, injuries and fatalities) using several published methods (Leigh and Hoskin, 1999, 2000; Hoskin *et al.*, 1994; Cohen *et al.*, 1997; Herman, 2014) that rely on actuarial statistics of worker fatalities and injuries published by the United States Bureau of Labor Statistics (US BLS), vehicle crash statistics published by the United States Department of Transportation (US DOT), and estimates of the amount and

²² Gradient performed sensitivity analysis to confirm that there is minimal effect to Remediation Alternative 1 from adding an enhanced cap over the BES Waste area and from relocating landfill gas extraction wells to outside the BES Waste area (see Figure 4.1).

type of labor (*e.g.*, construction worker, engineer) and haul truck mileage required to implement each Remediation Alternative. We provide details and assumptions for these calculations below.

Injury and fatality risks for on-Site workers originate from two sources: general work risks and transportation-related risks. Gradient calculated general work risks from accidents for construction laborers, technicians, and engineers by estimating the hours for each labor category and multiplying it by corresponding fatality and injury rates published by the US BLS (US Dept. of Labor, 2016a,b). We calculated risks for personnel that travel between their residence and work places using SiteWise™ version 3.1, based on the same input data used for estimation of the emissions caused by personnel transportation. The reported risks for on-Site workers is the sum of the risks originating from these two sources.

Off-Site injury and fatality risks were calculated based on total travel mileage and truck crash data. Only Remediation Alternative 2 involved a significant amount of off-Site truck activities. We assumed that the BES Waste would be moved by 20-ton (25 yd³) dump trucks to a landfill 425 miles away, and then calculated the total travel mileage accordingly. We used truck accident rates from 2014, provided by US DOT's "Large Truck Crash Facts" report (US DOT, 2016), to estimate the total number of fatal and injury crashes involving trucks. This report also states that in 2014, 75.9% of the persons injured and 83.2% of the persons killed in large truck crashes were not truck occupants. These percentages provide the ratio of non-truck occupants (community) to truck occupants injured or killed in truck accidents.

Table 6.4 summarizes physical risks for on-Site workers and off-Site risks caused by truck traffic that were calculated using the methods described above. The results suggest that while there is minimal incremental on-Site work activity, and thus minimal incremental risks to on-Site workers, associated with Remediation Alternative 1, Remediation Alternative 2 would lead to 8.3E-2 non-fatal and 5.9E-4 fatal injuries among on-Site workers. The implementation of Remediation Alternative 2 requires significantly more labor than the implementation of Remediation Alternative 1, which accounts for this difference.

For off-Site risks, Remediation Alternative 2 requires significant off-Site truck activities. Our analysis indicates that the implementation of this Remediation Alternative involves over 1.5 million miles of truck travel. This amount of truck activity would lead to an expected 0.617 non-fatal and 0.022 fatal injuries in crashes involving trucks associated with Remediation Alternative 2. More detailed results and calculations for the physical risk analysis can be found in Attachment D.

Table 6.4 Summary of Physical Risks for the Remediation Alternatives

Risk Category	Remediation Alternative 1: Closure-in-Place and Monitoring	Remediation Alternative 2: Excavate and Redispose BES Waste	Notes
On-Site Workers			
Total worker labor (equivalent worker hours)	0.0	6,341	Estimated (see On-Site Safety Calculation Worksheet in Attachment D)
Weighted average worker injury rate (per 10,000 hours)	0.0	1.31E-1	Estimated (see On-Site Safety Calculation Worksheet in Attachment D)
Weighted average worker fatality rate (per 100,000 hours)	0.0	9.27E-03	Estimated (see On-Site Safety Calculation Worksheet in Attachment D)
Expected worker injuries (number of injury incidents)	0.0	8.31E-2	Sum of risks to on-Site workers (estimated by multiplying required labor hours by worker injury rate data) and risks originating from personnel transport (see Attachment D for details)
Expected worker fatalities (number of fatality incidents)	0.0	5.88E-4	Sum of risks to on-Site workers (estimated by multiplying required labor hours by worker fatality rate data) and risks originating from personnel transport (see Attachment D for details)
Off-Site Community Members			
Total truck travel miles	0.0	1,549,533	Estimated (see Off-Site Safety Calculation Worksheet in Attachment D)
Truck crash with injury rate (per mile of truck travel)	0.0	2.94E-7	Based on 2014 US DOT statistics (US DOT, 2016)
Expected truck crashes with injuries	0.0	0.456	Based on 2014 US DOT statistics (US DOT, 2016)
Injuries in truck crashes (persons)	0.0	0.617	Calculated based on 2014 US DOT statistics (75.9% of persons injured in truck crashes are not truck occupants; US DOT, 2016)
Truck crash with fatality rate (per mile of truck travel)	0.0	1.40E-08	Based on 2014 US DOT statistics (US DOT, 2016)
Expected truck crashes with fatalities	0.0	0.019	Based on 2014 US DOT statistics (US DOT, 2016)
Fatalities in truck crashes (persons)	0.0	0.022	Calculated based on 2014 US DOT statistics (83.2% of persons killed in truck crashes are not truck occupants; US DOT, 2016)

Note:

US DOT = US Department of Transportation.

6.5.3 GSR

We used SiteWise™ version 3.1 in this analysis to evaluate the sustainability metrics associated with the Remediation Alternatives for addressing any TENORM at the Blue Ridge Landfill. SiteWise™ is a Microsoft Excel-based tool jointly developed by the United States Navy, the United States Army, the United States Army Corps of Engineers (US ACE), and Battelle for estimating the environmental footprint of remediation alternative components (NAVFAC *et al.*, 2013). The following input categories and corresponding footprint databases are integrated into this modeling tool: material usage; transportation of the required materials, equipment, and personnel to and from the landfill; on-site activities (*e.g.*, equipment operation); and management of the waste produced by the activity (NAVFAC *et al.*, 2013). The default values used by the model for calculating footprint parameters are saved in lookup tables and may be overridden by site-specific values as needed.

Gradient performed the GSR analysis on a relative basis to estimate the environmental impact of Remediation Alternative 2 compared to Remediation Alternative 1. Hence, for Remediation Alternative 2, the GSR analysis included only those activities that would be performed in addition to the standard operational and post-closure requirements for the Blue Ridge Landfill. As such, we report all GSR metrics for Remediation Alternative 1 as equal to zero, and report the incremental metric values for Remediation Alternative 2.²³

The methodology and key assumptions for the GSR analysis are as follows.

- Material, water, and electricity usage do not significantly vary between the two Remediation Alternatives and, therefore, Gradient eliminated these factors from this analysis. Air emissions (GHGs, SO_x, NO_x, PM₁₀) and energy consumption were the GSR output metrics that vary significantly between the alternatives, and thus we included them in the analysis.
- The key work elements of Remediation Alternative 2 that we analyzed in the GSR analysis consist of: excavate the BES Waste and overlying MSW, redispose of uncompromised waste into a different waste cell, and transport the BES Waste 425 miles to a TENORM-licensed solid waste landfill.²⁴ We calculated GSR metrics for the operation of earthworking equipment, transportation of bulk materials (*i.e.*, MSW and BES Waste), and personnel transportation to and from the Site. For personnel transport, we assumed the total number of trips, distance traveled, number of travelers, type of vehicles, fuel used, and number of occupants in order to estimate the footprint. In the case of bulk material transportation, we used the total weight and the round-trip distance traveled by trucks to estimate environmental impacts.

Table 6.5 summarizes the results of the GSR analysis performed using the methods and tools described above. The GSR analysis results show that the environmental footprint of the implementation of Remediation Alternative 2 (Excavate and Redispose BES Waste) is significantly larger than Remediation Alternative 1 (Closure-in-Place and Monitoring). This gap is mostly due to energy consumption and environmental emissions associated with on-Site BES Waste excavation and off-Site BES Waste transportation. In addition, increased truck traffic during the implementation of Remediation Alternative 2 could cause damage to roadways, which would require repair. These repairs would further increase costs associated with labor, materials, and fuel, in addition to increasing air emissions from equipment

²³ Gradient performed sensitivity analysis to confirm that there is minimal effect to Remediation Alternative 1 from adding an enhanced cap over the BES Waste area and from relocating landfill gas extraction wells to outside the BES Waste area (see Figure 4.1).

²⁴ Assumed to be the Mostoller Landfill facility in Somerset, Pennsylvania, for the purposes of this analysis.

needed for road repairs. More detailed results and calculations for the GSR analysis can be found in Attachment D.

Table 6.5 Summary of GSR Metrics for the Remediation Alternatives

Risk Category	Remediation Alternative 1: Closure-in-Place and Monitoring	Remediation Alternative 2: Excavate and Redispose BES Waste
GHG emissions (metric ton)	0	4,323
Total energy used (MMBTU)	0	59,900
Total NO _x emissions (metric ton)	0	3.66
Total SO _x emissions (metric ton)	0	1.21
Total PM ₁₀ emissions (metric ton)	0	5.9

Notes:

GHG = Greenhouse Gas; GSR = Green and Sustainable Remediation; MMBTU = Million British Thermal Units; NO_x = Nitrogen Oxides; PM₁₀ = Particulate Matter Less Than 10 Microns in Diameter; SO_x = Sulfur Oxides.

6.6 Implementability

This criterion is used to evaluate the technical feasibility of the Remediation Alternatives, including construction and operation, reliability, monitoring, and the ease of undertaking remedial action in the context of any logistical constraints at the Site. It also considers the administrative feasibility of activities needed to coordinate with other third parties (*e.g.*, regulatory agencies), such as for obtaining permits, and the availability of services and materials necessary to the Remediation Alternative, such as disposal facilities and qualified contractors.

Remediation Alternative 1 is clearly implementable. The required technologies are available and qualified contractors are in place to perform the work this alternative requires. ADS has regulatory approvals, including permits, for the operation, closure, and post-closure monitoring of the landfill. Regulatory approval would, however, be required to leave the buried BES Waste in place.

Remediation Alternative 2 has significant implementability challenges, as described below.

- Implementing a significant excavation project at an active landfill with heterogeneous waste could be challenging to implement due to excavation stability concerns, the presence of landfill infrastructure, and the ongoing active landfill operations.
- The need to obtain permit approval to transport and dispose of the BES Waste at another landfill facility could be time-consuming.
- TENORM waste acceptance limits at the Somerset, Pennsylvania, Mostoller Landfill facility could slow excavation productivity and/or require shipping the waste to another facility.
- Transporting the estimated 40,000 yd³ of mixed BES Waste and MSW would require on the order of 2,000 truckloads traveling over 1.5 million miles. It could require the use of dedicated trucks and/or truck decontamination after each shipment.
- Decontamination of excavation equipment and trucks after hauling each shipment would generate additional waste that would require disposal.
- Health and safety monitoring would be required during remediation activities.

6.7 Cost

This criterion includes an evaluation of direct and indirect capital costs, including the costs of treatment and disposal; the annual costs of operating, maintaining, and monitoring the remediation alternative; and the net present value of these costs.

Gradient prepared a screening-level cost estimate to evaluate the relative cost of the Remediation Alternatives. We based the cost estimates on conceptual remedy designs for each alternative, including the major activities, transportation needs, and labor and material requirements. We performed this cost estimate on a relative basis, in that we only took the incremental costs associated with Remediation Alternative 2 (compared to Remediation Alternative 1) into consideration. Consequently, the costs reported in this section should only be used for relative comparison between the Remediation Alternatives.

Gradient developed the cost estimate based on industry standard cost estimation guidance (*e.g.*, *Environmental Remediation Cost Data – Unit Price (7th Annual Edition)* by R.S. Means Co., Inc. and Talisman Partners, Ltd. [2001]), the US EPA and US ACE joint guidance document, "A Guide to Developing and Documenting Cost Estimates During the Feasibility Study" (US EPA and US ACE, 2000), Gradient's experience with similar projects, and professional judgment. The utilized methodology and assumptions for the cost estimate are described below.

- **Capital Costs:**

- Remediation Alternative 1 includes costs for installing a geosynthetic composite liner over the BES Waste area as part of the final cover and for relocating landfill gas extraction wells to outside of the BES Waste area.
- Remediation Alternative 2 capital requirements include the costs of: (a) engineering design, (b) excavating the BES Waste and overlying soil and waste, (c) placing overlying waste and soil in other sections of the landfill and hauling the BES Waste to the Mostoller Landfill, and (d) disposing of the BES Waste at the Mostoller Landfill.

- **Future Costs:**

- Blue Ridge Landfill post-closure operation and maintenance (O&M) and standard post-closure monitoring activities are similar for the two alternatives, except that additional radionuclide monitoring is required under Remediation Alternative 1.
- Gradient used a 7.0% annual discount rate to calculate the net present value of the future costs (US EPA and US ACE, 2000).

- **Management and Contingency Costs:**

- Gradient included costs associated with project and construction management and contingency in the cost estimate, in accordance with standard recommendations for cost estimates of remediation alternatives (US EPA and US ACE, 2000).

Table 6.6 shows the summary of Remediation Alternative costs. Detailed cost estimate calculations can be found in Attachment E. Based on this analysis, Excavate and Redispose BES Waste (Remediation Alternative 2) costs approximately \$5.8 million dollars more than Closure-in-Place and Monitoring (Remediation Alternative 1).

Table 6.6 Summary of Incremental Remediation Alternative Costs

Remediation Alternative	Capital Cost	Future Cost	Total Cost = Capital Cost + NPV^a for Future Cost
1. Closure-in-Place and Monitoring	\$265,000	\$12,500	\$277,500
2. Excavate and Redispose BES Waste	\$6,100,000	\$0	\$6,100,000 ^b

Notes:

Costs are incremental above Remediation Alternative 1 and should be used for relative comparison purposes only.

(a) NPV stands for net present value and Gradient calculated the NPV based on a 7% annual discount rate.

(b) Equivalent to approximately \$150/yd³ "all-in."

6.8 Regulatory Approval and Community Acceptance

These criteria are used to evaluate the expected level of approval from the regulatory agency and acceptance from community stakeholders, respectively.

Both Remediation Alternatives considered may potentially receive regulatory approval because of their overall protectiveness of human health and the environment. Community acceptance will need to be evaluated after the CAP is submitted.

7 Comparative Analysis of Remediation Alternatives

As described in Table 7.1 and below, the results of the comparative analysis of the Remediation Alternatives demonstrate that Remediation Alternative 1 (Closure-in-Place and Monitoring) is the preferred remediation approach for the Blue Ridge Landfill, assuming regulatory approval and community acceptance, because it provides the highest degree of overall protectiveness, poses the lowest short-term physical and radiological exposure-related risks to workers and the community, and provides long-term effectiveness and protectiveness while also being cost-effective and implementable.

Remediation Alternative 1 would provide a higher level of overall protectiveness than Remediation Alternative 2. Remediation Alternative 2 would remove the BES Waste, but would not result in any net environmental benefit, because the BES Waste would be redispersed in a different landfill subject to similar environmental controls. In addition, excavating, transporting, and redispersing of the BES Waste would create radiological exposure pathways and additional radiological risks that are not currently present, and there are significant short-term physical risks associated with its excavation, transport, and redispersion. For both Remediation Alternatives, engineering controls, including the landfill liner layer, leachate extraction system, stormwater controls, and final post-closure cap, equally provide protectiveness by limiting direct contact with the BES waste and minimizing the potential for leachate generation and potential breakthrough to groundwater. Remediation Alternative 1 would also include a Radionuclide Sampling Plan, an enhanced cap over the BES Waste area, and the relocation of landfill gas extraction wells from the BES Waste area, further increasing its level of overall protectiveness.

Remediation Alternative 1 is readily implementable. The implementability challenges associated with Remediation Alternative 2, including worker/public safety, disruptions to the community (*e.g.*, truck traffic), and disruption to the landfill operations, are significant. Remediation Alternative 2 would also pose significant implementation challenges associated with the presence of heterogeneous landfill waste, landfill structures, and the structural stability of a large, open excavation in a waste zone.

Gradient eliminated Remediation Alternative 2 after comparing it to Remediation Alternative 1, based on its inferior implementability, greater cost, greater short-term impacts (*e.g.*, greater duration to complete remediation leads to more truck traffic; greater impact on the community; air/odor issues), and the lack of net environmental benefit. We selected Remediation Alternative 1 because it ensures long-term protectiveness while posing low short-term risks to workers and the community and is cost-effective.

Table 7.1 Comparative Analysis of the Remediation Alternatives

Evaluation Criteria	Remediation Alternative 1: Closure-in-Place and Monitoring	Remediation Alternative 2: Excavate and Redispose BES Waste
Overall Protection of Human Health and the Environment	High – There are no unacceptable human health risks from exposure to the BES Waste based on current and future exposures (see RAC, 2017).	Moderate – There are no unacceptable human health risks from exposure to the BES Waste based on current and future exposures (see RAC, 2017). Excavating, transporting, and re-disposing the BES Waste would create additional physical and radiological risks.
Long-term Effectiveness and Permanence	Moderate – The existing containment system (liner and leachate collection system) effectively controls leachate release, and the required post-closure cap would minimize leachate generation after closure. A geosynthetic composite liner would be placed over the BES Waste area, radionuclide monitoring of groundwater would be implemented, and landfill gas extraction wells would be relocated to outside the BES Waste area.	Moderate – At the Blue Ridge Landfill, removal of material would decrease contaminant flux to leachate and soil vapors over time, thus enhancing the long-term attenuation and stability of impacts to both media and decreasing long-term risks associated with exposure to BES Waste-related constituents. However, relocating the BES Waste to a different landfill would pose concerns regarding long-term effectiveness that are similar to those posed by the Blue Ridge Landfill, and therefore, there would be no net environmental benefit.
Reduction of Toxicity, Mobility, and Volume (TMV) Through Treatment	Moderate – Reduces the potential environmental mobility of the BES Waste by containing it through a combined liner/cap/leachate extraction system/landfill gas extraction system at the Blue Ridge Landfill. Volume and toxicity are not reduced, although exposure is mitigated.	Moderate – Reduces the potential environmental mobility of the BES Waste by containing it through a combined liner/cap/leachate extraction system/landfill gas extraction system at a different landfill. Volume and toxicity are not reduced, although exposure is mitigated. BES Waste volume would increase <i>ex situ via</i> excavation.
Short-term Effectiveness	High – Minimal incremental remedy risks from implementing this alternative.	Moderate – There are physical risks to workers and the community from implementing this alternative. There will also be greater short-term impacts, disruptiveness, and inconvenience for surrounding properties associated with heavy truck traffic and the noise, emissions, and accident risk. There will be increased environmental impacts (<i>e.g.</i> , air impacts, GHG emissions) relative to the other alternatives.
Implementability	High – The technologies are available and qualified contractors are in place to perform the work. Regulatory approval is required to leave the buried BES Waste in place.	Low – There are significant implementability challenges associated with a major excavation in an active landfill and hauling the BES Waste hundreds of miles to a different facility for re-disposal.
Cost	Low – Low capital cost to install the enhanced cap over the BES Waste area and to relocate landfill gas extraction wells. Low incremental costs are required for additional radionuclide sampling.	High – Significant capital costs for excavation, transport, and re-disposal of the BES Waste. High cost uncertainty.
Conclusion	This alternative was selected because it provides a high degree of overall protectiveness, poses the lowest short-term physical and radiological exposure-related risks to workers and the community, and provides long-term effectiveness and protectiveness while also being cost-effective and implementable.	This alternative was not selected because it is less protective, more costly, less implementable, and poses significantly greater short-term impacts than the other alternatives.

Notes:

BES Waste = Material delivered to the Blue Ridge Landfill by BES, LLC; GHG = Greenhouse Gas.

Subject to regulatory approval and community acceptance.

8 Radioactive Material Screening Plan

As part of the Agreed Order between the Cabinet and ADS, a plan for detecting and preventing the disposal of unpermitted TENORM waste and other radioactive materials at the Blue Ridge Landfill will be incorporated into the landfill permit. For the purposes of the agreement and this CAP report, "unpermitted TENORM waste" refers to TENORM waste generated out-of-state with combined concentrations of Ra-226 and Ra-228 more than the applicable regulatory standard, currently 5 pCi/g (dry weight) of waste material over background, at the Blue Ridge Landfill (KYEEC and ADS, 2016). We include the Radioactive Material Screening Plan prepared by Weaver Consultants Group, LLC (2017) in this CAP report as Attachment C.

The purpose of the Radioactive Material Screening Plan is to implement radiation monitoring protocols at the Blue Ridge Landfill to ensure that on-Site operations are protective of human health and the environment. The plan describes materials and methodologies that will be put in place to detect radioactive materials that may enter the Blue Ridge Landfill. Broadly, procedures that will be implemented include the following (details are provided in Attachment C):

- Profiling out-of-state waste and drilling mud waste;
- Installing radiation detectors on Site, including: radiation monitoring on inbound scales to screen trucks entering the Site, background radiation detectors, alarms for stationary vehicle detectors, and handheld survey meters;
- Performing daily monitor checks to ensure that equipment and alarms are operational;
- Putting systematic procedures in place to evaluate vehicles entering the landfill, in addition to verification and notification protocols when radiation alarms are triggered;
- Developing an Action Level Response Procedure, which provides details of response actions for different levels of radiation potentially detected;
- Describing radioactive material that can be accepted at the Blue Ridge Landfill after characterization; and
- Providing training guidance for Site personnel, Radioactive Material Screening Plan revision notification requirements, and record-keeping guidance.

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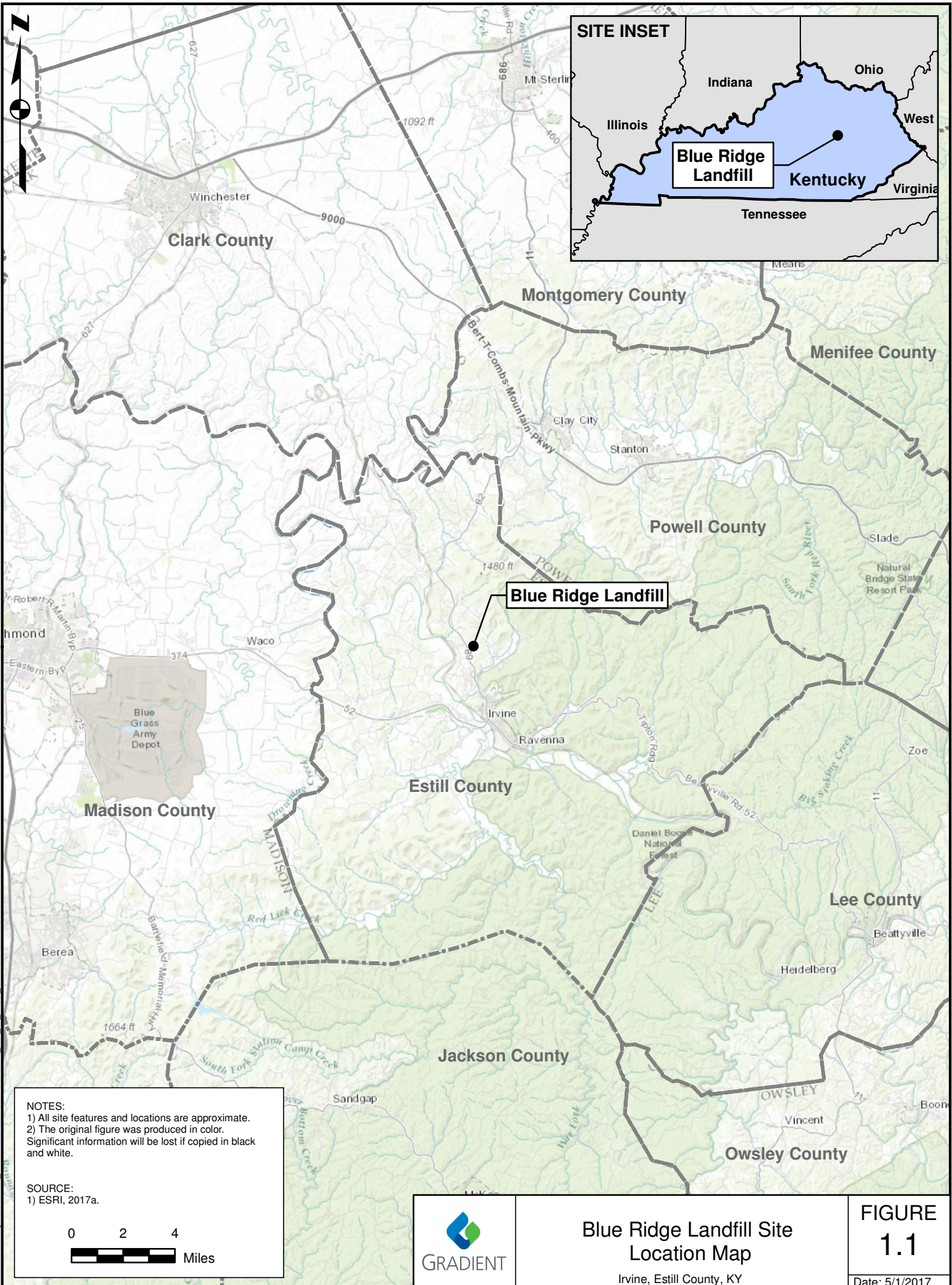
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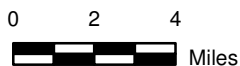
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Figures



NOTES:
 1) All site features and locations are approximate.
 2) The original figure was produced in color.
 Significant information will be lost if copied in black and white.

SOURCE:
 1) ESRI, 2017a.

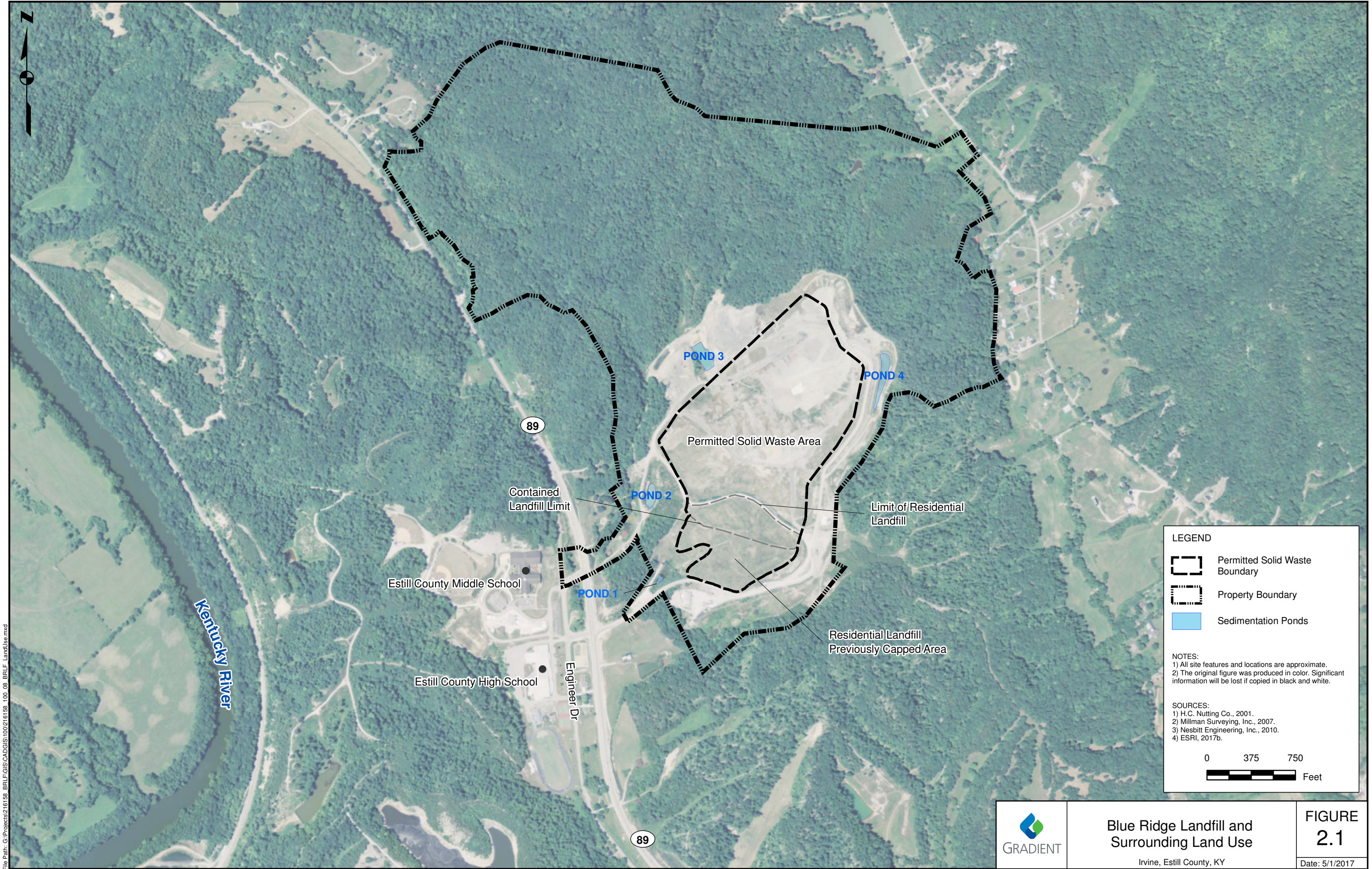


**Blue Ridge Landfill Site
 Location Map**

Irvine, Estill County, KY

**FIGURE
 1.1**

Date: 5/1/2017



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LEGEND

- Permitted Solid Waste Boundary
- Property Boundary
- Sedimentation Ponds

NOTES:

- 1) All site features and locations are approximate.
- 2) The original figure was produced in color. Significant information will be lost if copied in black and white.

SOURCES:

- 1) H.C. Nutting Co., 2001.
- 2) Millman Surveying, Inc., 2007.
- 3) Nesbitt Engineering, Inc., 2010.
- 4) ESRI, 2017b.

0 375 750
 Feet



PREPARED AUGUST, 1992

LEGEND

●³ WELL OR SPRING IDENTIFIED IN ONE-MILE SURVEY. IDENTIFICATION NUMBER IS KEYED TO TABLE 17-2. LOCATIONS ARE AS DESCRIBED BY OWNERS, AND ARE APPROXIMATE. SEE TABLE 17-2 FOR ADDITIONAL WELL DATA PROVIDED BY OWNER.

APPROXIMATE SURFACE ELEVATION, MSL

1 = 730	13 = 780	25 = 710	37 = 660	50 = 760
2 = 700	14 = 730	26 = 720	38 = 680	51 = 650
3 = 720	15 = 620	27 = 710	39 = 620	52 = 650
4 = 700	16 = 650	28 = 820	40 = 760	53 = 670
5 = 690	17 = 700	29 = 820	41 = 780	54 = 680
6 = 690	18 = 700	30 = 720	42 = 660	55 = 680
7 = 800	19 = 710	31 = 700	43 = 740	56 = 670
8 = 650	20 = 660	32 = 710	44 = 700	57 = 670
9 = 720	21 = 680	33 = 700	45 = 750	58 = 690
10 = 750	22 = 680	34 = 780	46 = 750	59 = 700
11 = 720	23 = 680	35 = 800	47 = 800	
12 = 780	24 = 780	36 = 700	49 = 820	



RESIDENTIAL WATER SUPPLY WELLS AND SPRINGS BLUE RIDGE RDF IRVINE, KENTUCKY		
SCALE: 1" = 2000'	FIGURE NO. 17-1	ATEC
PROJECT NO. 21-13035	ATEC ASSOCIATE, INC. 5150 E. 65th ST. INDIANAPOLIS, IND. 46220	

AS APPROVED: MAP 3 + 1995

File Path: G:\Projects\216158_BRL\Deliverables\Report\Figures\WaterWellSurvey_RustEnvironmental.ai

SOURCE: Rust Environment & Infrastructure, Inc., 1992a.

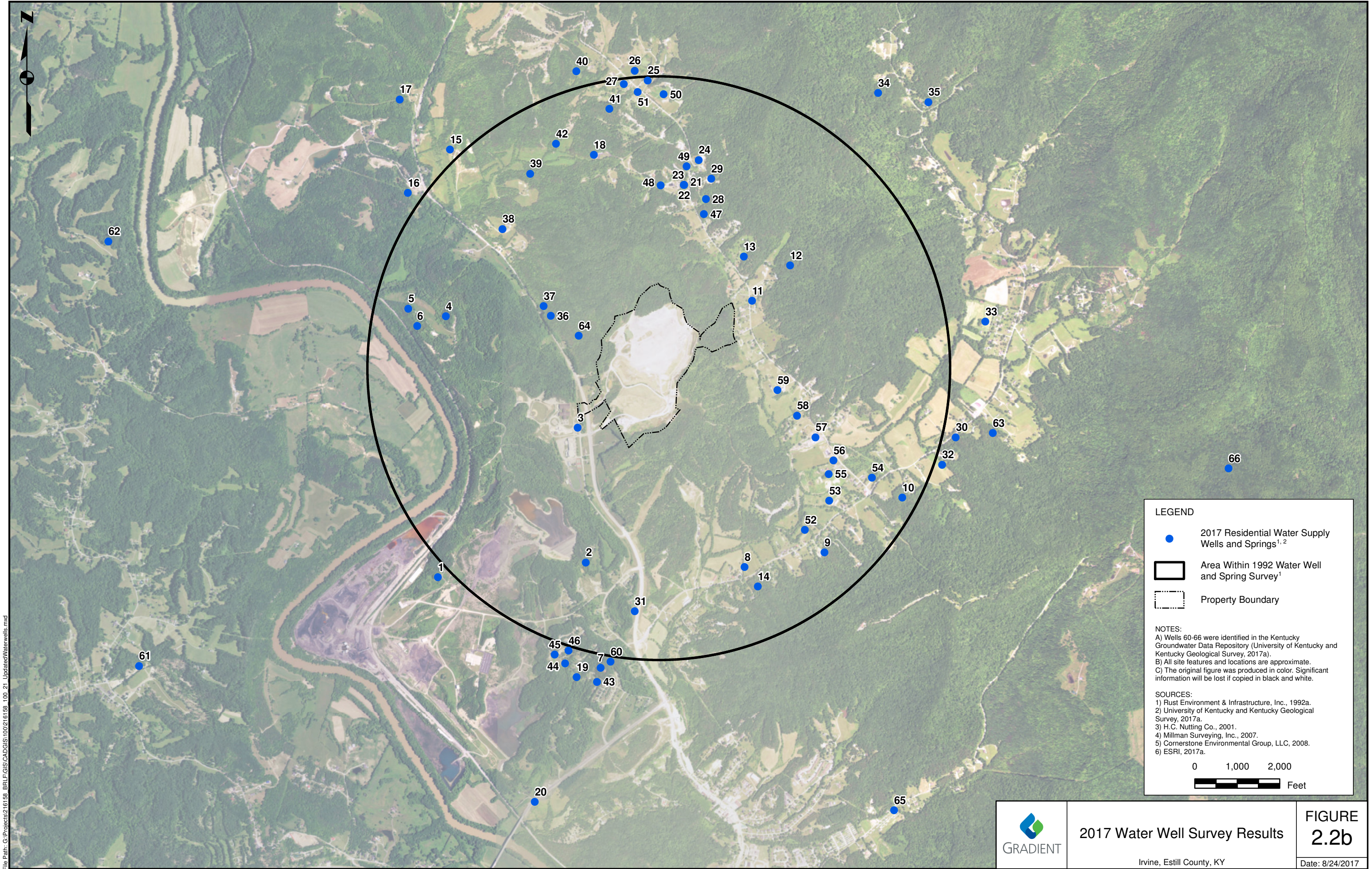


1992 Water Well Survey Results

FIGURE 2.2a

Irvine, Estill County, KY

Date: 8/23/2017



File Path: G:\Projects\216158_BRLF\GIS\CAD\GIS\100\216158_100_21_UpdatedWaterwells.mxd

LEGEND

- 2017 Residential Water Supply Wells and Springs^{1,2}
- Area Within 1992 Water Well and Spring Survey¹
- Property Boundary

NOTES:

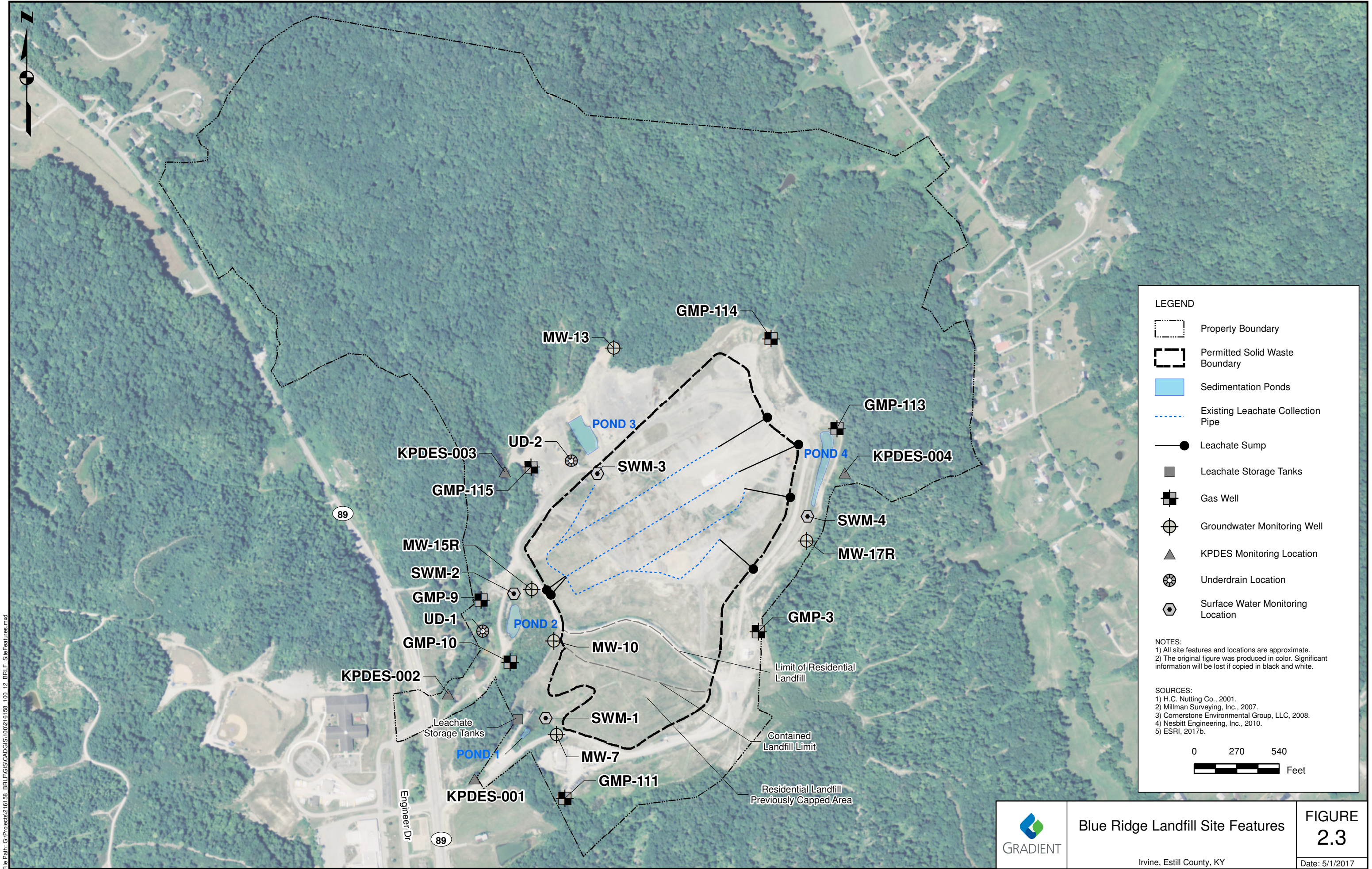
A) Wells 60-66 were identified in the Kentucky Groundwater Data Repository (University of Kentucky and Kentucky Geological Survey, 2017a).
 B) All site features and locations are approximate.
 C) The original figure was produced in color. Significant information will be lost if copied in black and white.

SOURCES:

1) Rust Environment & Infrastructure, Inc., 1992a.
 2) University of Kentucky and Kentucky Geological Survey, 2017a.
 3) H.C. Nutting Co., 2001.
 4) Millman Surveying, Inc., 2007.
 5) Cornerstone Environmental Group, LLC, 2008.
 6) ESRI, 2017a.

0 1,000 2,000

 Feet



LEGEND

- Property Boundary
- Permitted Solid Waste Boundary
- Sedimentation Ponds
- Existing Leachate Collection Pipe
- Leachate Sump
- Leachate Storage Tanks
- Gas Well
- Groundwater Monitoring Well
- KPDES Monitoring Location
- Underdrain Location
- Surface Water Monitoring Location

NOTES:

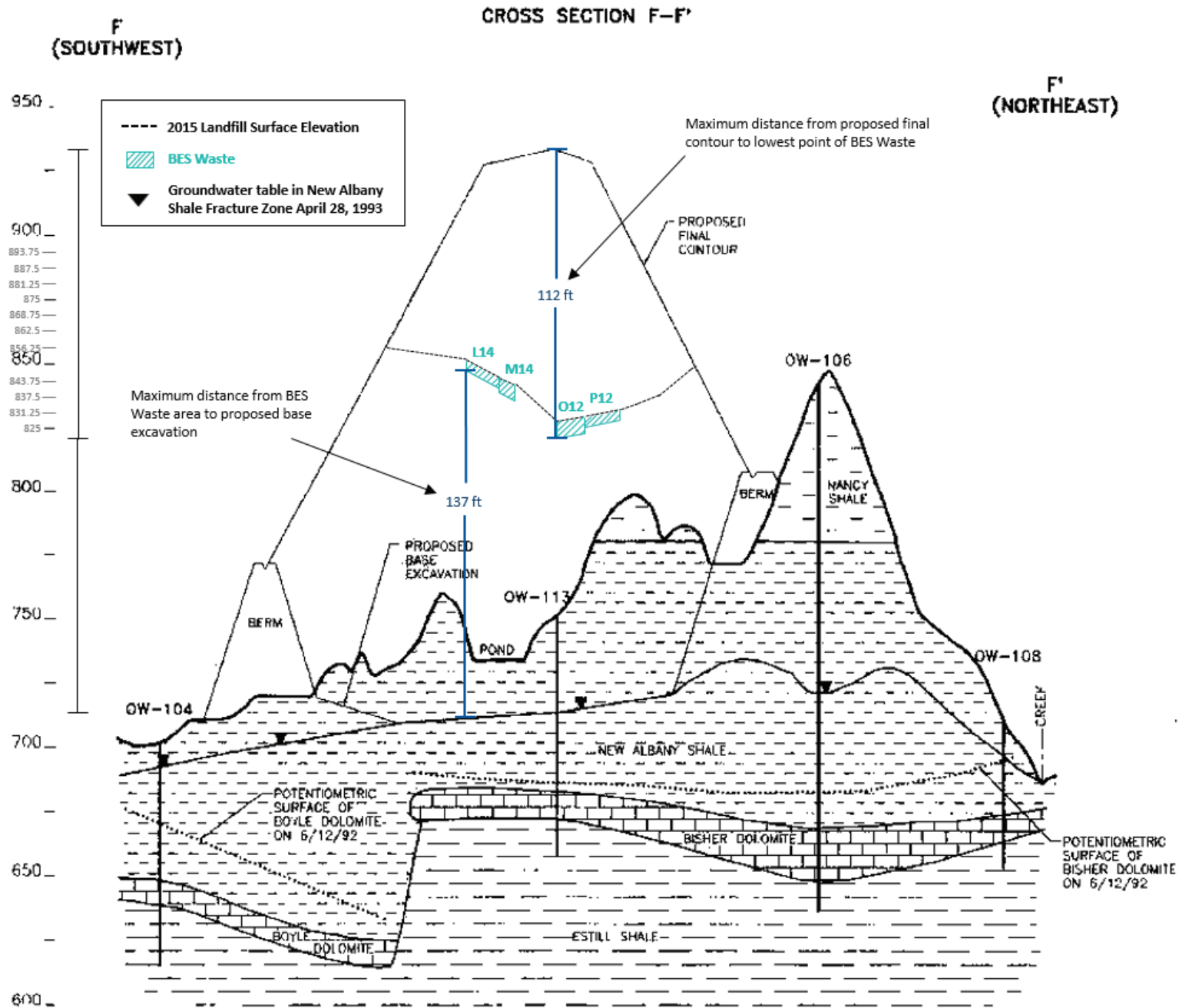
- 1) All site features and locations are approximate.
- 2) The original figure was produced in color. Significant information will be lost if copied in black and white.

SOURCES:

- 1) H.C. Nutting Co., 2001.
- 2) Millman Surveying, Inc., 2007.
- 3) Cornerstone Environmental Group, LLC, 2008.
- 4) Nesbitt Engineering, Inc., 2010.
- 5) ESRI, 2017b.

0 270 540
 Feet

File Path: G:\Projects\216158_BRLF\GIS\CADD\GIS\100\216158_100_12_BRLF_SiteFeatures.mxd



- Notes:
- (a) This figure was developed based on Figure 11-2 from Rust Environment & Infrastructure, Inc. (1992b) and supplemented with 2015 land surface elevation data based on topographic measurements and BES Waste depth information from Cornerstone Environmental Group, LLC (2016b).
 - (b) This figure does not depict the as-built liner or containment systems.
 - (c) Additional Source: Cornerstone Environmental Group, LLC (2017).

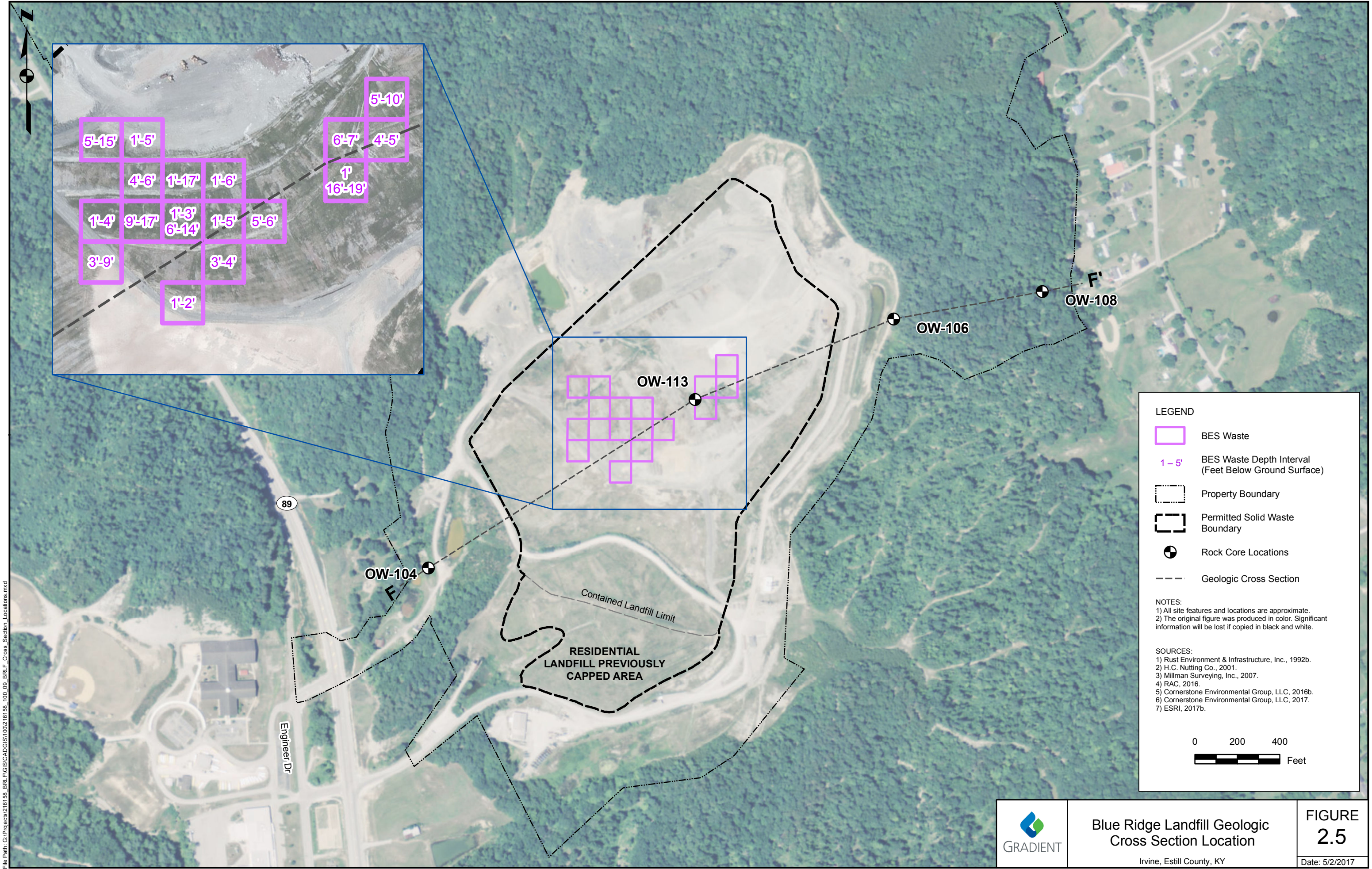


**Blue Ridge Landfill
Geologic Cross Section**

Irvine, Estill County, KY

**FIGURE
2.4**

Date: 5/2/2017



LEGEND

- BES Waste
- 1 - 5' BES Waste Depth Interval (Feet Below Ground Surface)
- Property Boundary
- Permitted Solid Waste Boundary
- Rock Core Locations
- Geologic Cross Section

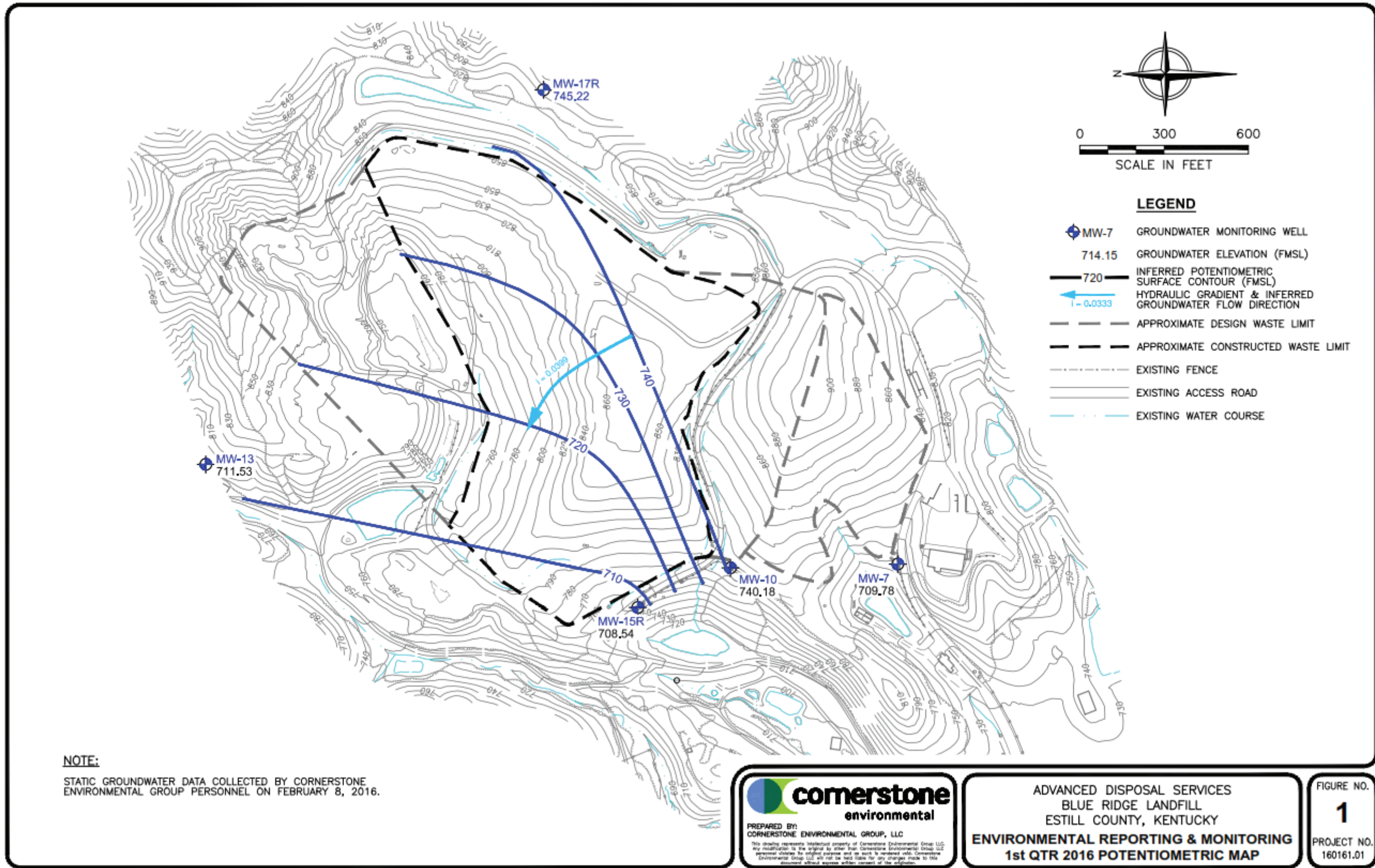
NOTES:
 1) All site features and locations are approximate.
 2) The original figure was produced in color. Significant information will be lost if copied in black and white.

SOURCES:
 1) Rust Environment & Infrastructure, Inc., 1992b.
 2) H.C. Nutting Co., 2001.
 3) Millman Surveying, Inc., 2007.
 4) RAC, 2016.
 5) Cornerstone Environmental Group, LLC, 2016b.
 6) Cornerstone Environmental Group, LLC, 2017.
 7) ESRI, 2017b.

0 200 400
 Feet

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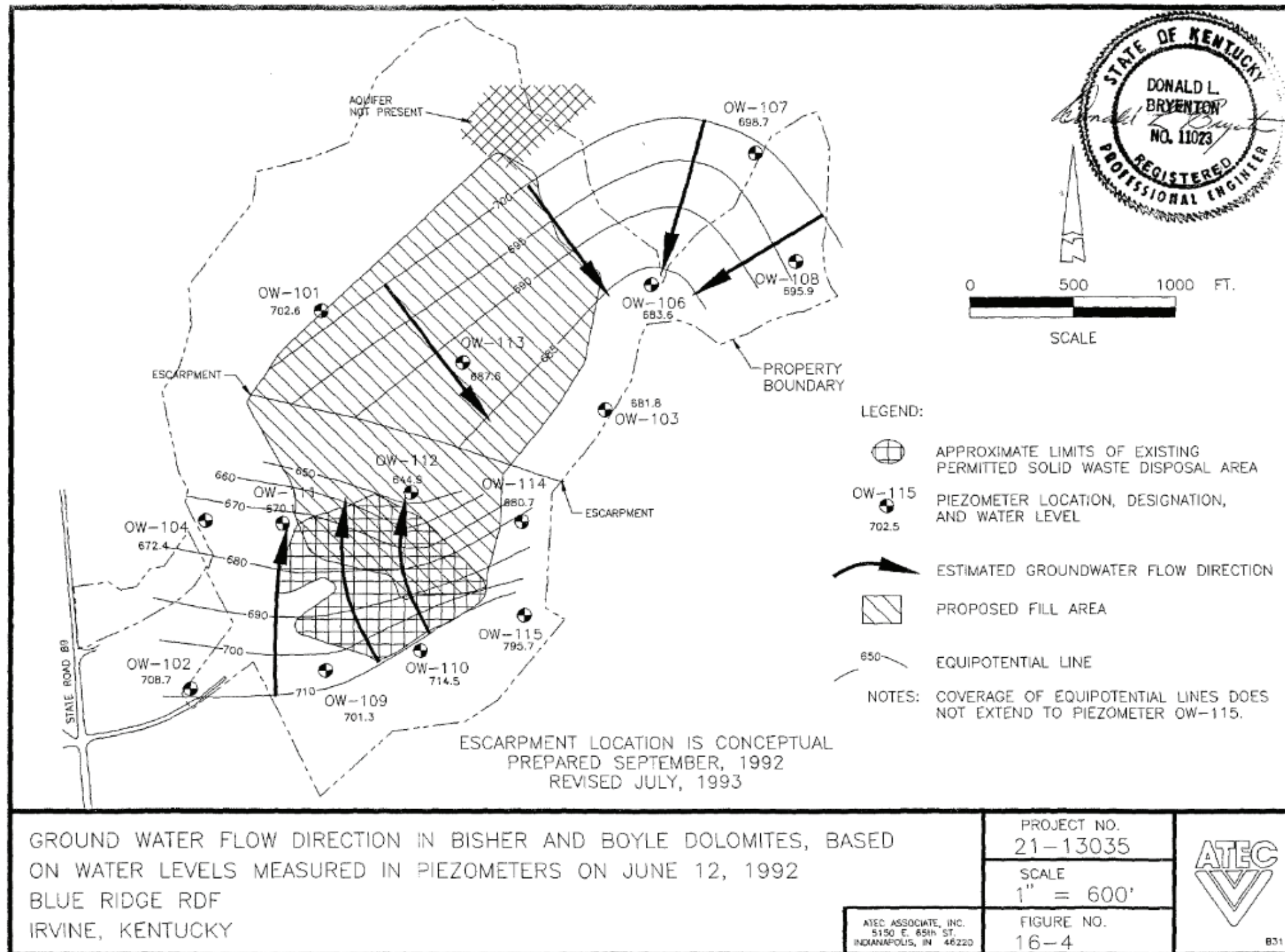
File Path: G:\Projects\216158_BRLF\Deliverables\Report\Figures\Fig 2.6 GroundwaterFlowPath_Cornerstone.al
 Fig. X:\PROJECTS\BLUE RIDGE\160161 - 2016 Environmental Monitoring\Task 1 - Groundwater\1st qtr 2016\BRLF 1Q 2016 GW.dwg Layout: BRLF 1Q 2015 GW User: lyer.schmidt Mar 30, 2016 - 11:19am



SOURCE: Cornerstone Environmental Group, LLC, 2016a.

	Blue Ridge Landfill Groundwater Monitoring Locations and Flow Directions in the New Albany Shale	FIGURE 2.6 Date: 5/2/2017
	Irvine, Estill County, KY	

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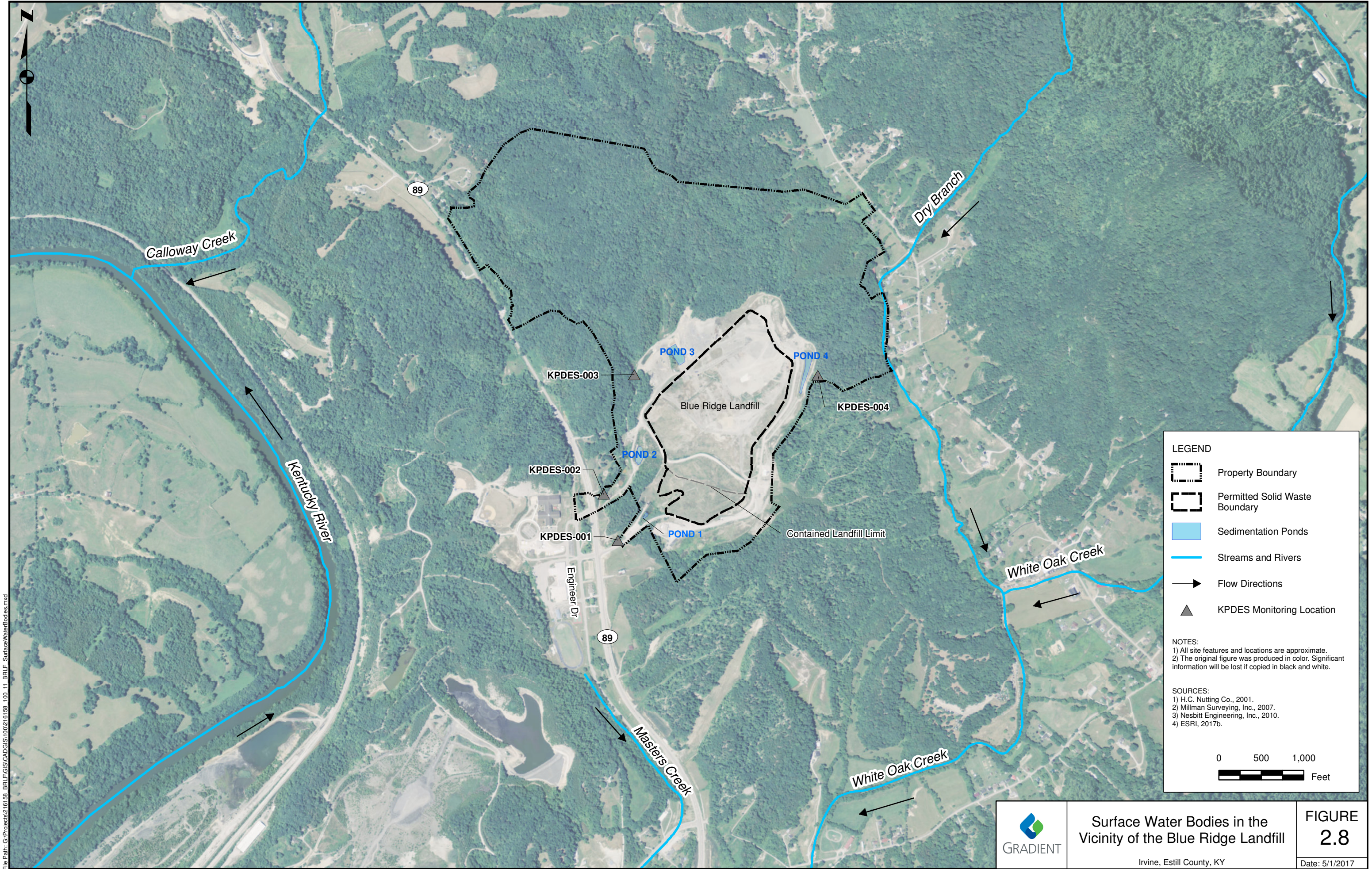


SOURCE: Rust Environment & Infrastructure, Inc., 1992a.



Blue Ridge Landfill
1992 Groundwater Flow Directions
in Bisher and Boyle Dolomites
Irvine, Estill County, KY

FIGURE
2.7
Date: 5/1/2017



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LEGEND

- Property Boundary
- Permitted Solid Waste Boundary
- Sedimentation Ponds
- Streams and Rivers
- Flow Directions
- KPDES Monitoring Location

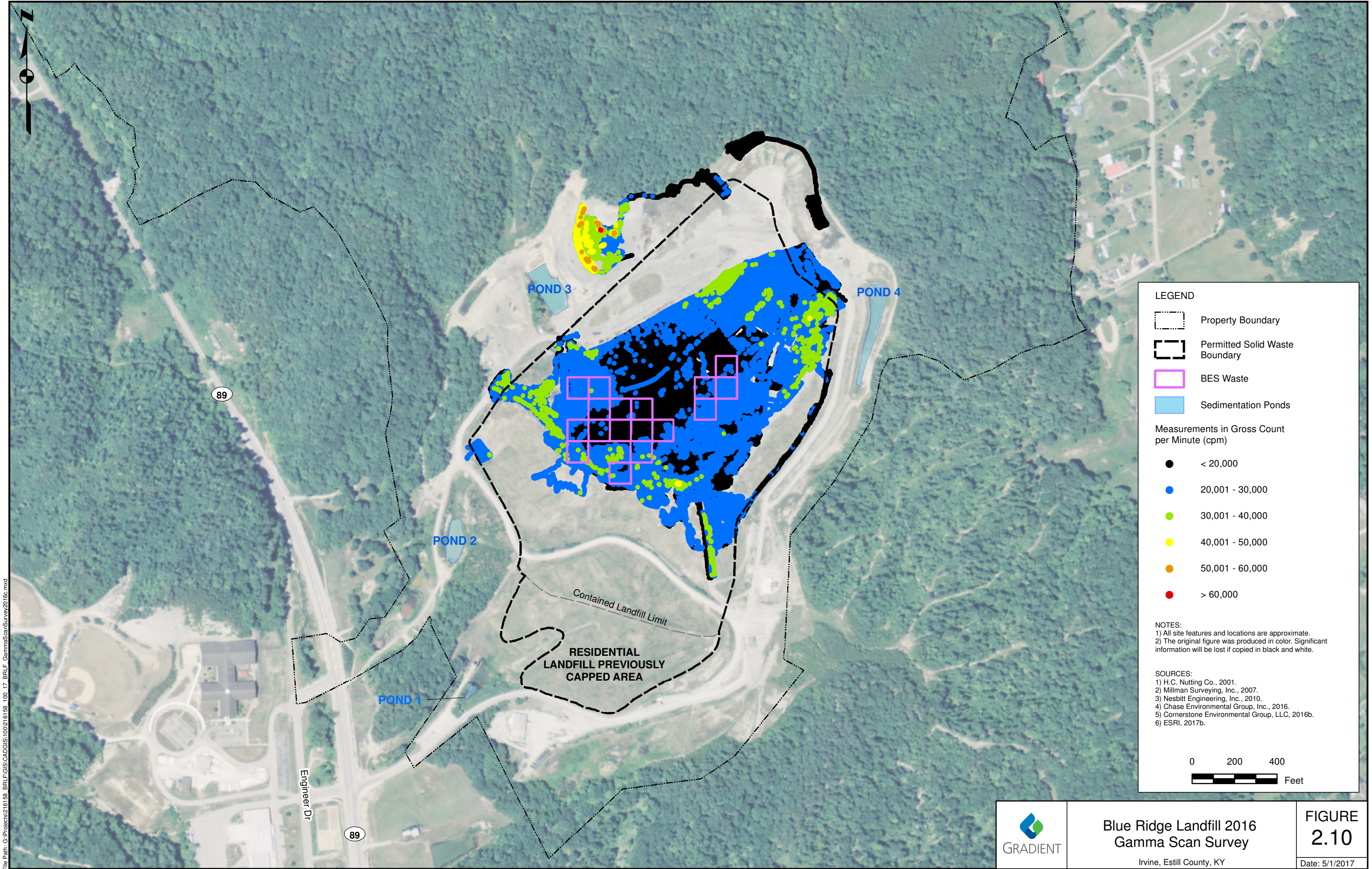
NOTES:

- 1) All site features and locations are approximate.
- 2) The original figure was produced in color. Significant information will be lost if copied in black and white.

SOURCES:

- 1) H.C. Nutting Co., 2001.
- 2) Millman Surveying, Inc., 2007.
- 3) Nesbitt Engineering, Inc., 2010.
- 4) ESRI, 2017b.

0 500 1,000
 Feet



File Path: G:\Projects\216158_BRLFGIS\CAD\GIS\100216158_100_17_BRLFGammaScanSurvey2016c.mxd

LEGEND

- Property Boundary
- Permitted Solid Waste Boundary
- BES Waste
- Sedimentation Ponds

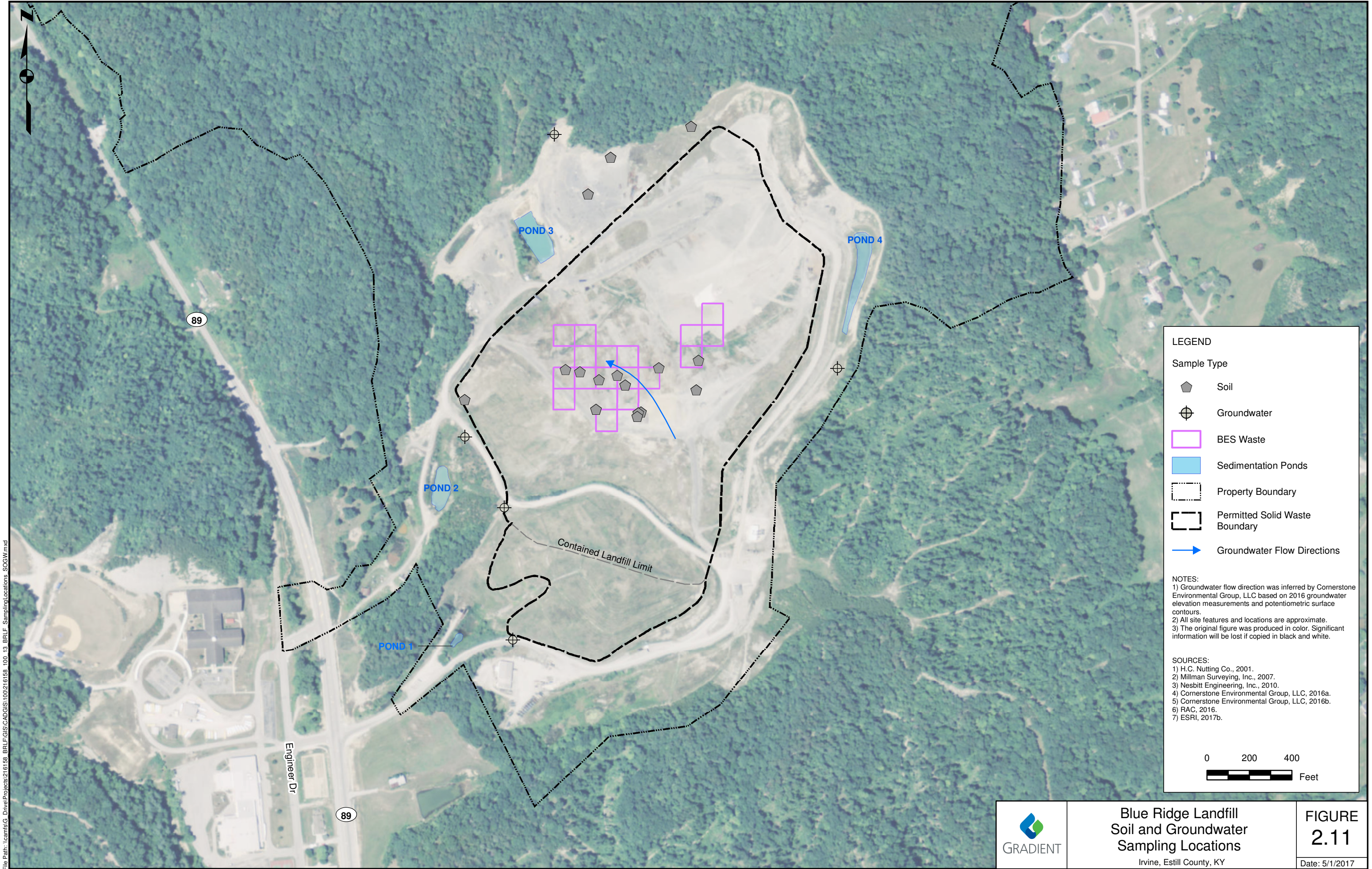
Measurements in Gross Count per Minute (cpm)

- < 20,000
- 20,001 - 30,000
- 30,001 - 40,000
- 40,001 - 50,000
- 50,001 - 60,000
- > 60,000

NOTES:
 1) All site features and locations are approximate.
 2) The original figure was produced in color. Significant information will be lost if copied in black and white.

SOURCES:
 1) H.C. Nutting Co., 2001.
 2) Millman Surveying, Inc., 2007.
 3) Nesbitt Engineering, Inc., 2010.
 4) Chase Environmental Group, Inc., 2016.
 5) Cornerstone Environmental Group, LLC, 2016b.
 6) ESRI, 2017b.








0 200 400
 Feet



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LEGEND

Sample Type


-  Soil
-  Groundwater
-  BES Waste
-  Sedimentation Ponds
-  Property Boundary
-  Permitted Solid Waste Boundary
-  Groundwater Flow Directions

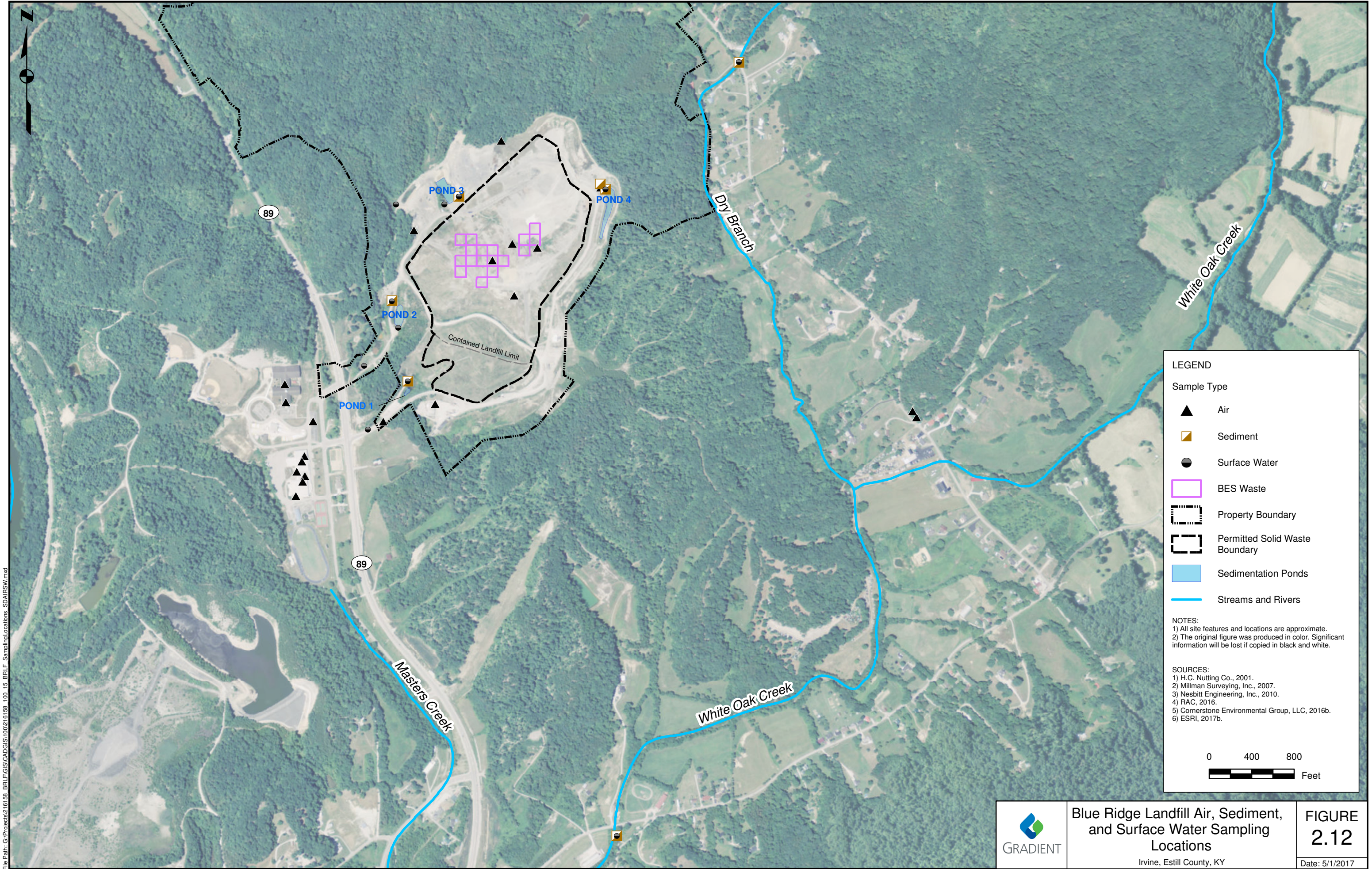
NOTES:

- 1) Groundwater flow direction was inferred by Cornerstone Environmental Group, LLC based on 2016 groundwater elevation measurements and potentiometric surface contours.
- 2) All site features and locations are approximate.
- 3) The original figure was produced in color. Significant information will be lost if copied in black and white.

SOURCES:

- 1) H.C. Nutting Co., 2001.
- 2) Millman Surveying, Inc., 2007.
- 3) Nesbitt Engineering, Inc., 2010.
- 4) Cornerstone Environmental Group, LLC, 2016a.
- 5) Cornerstone Environmental Group, LLC, 2016b.
- 6) RAC, 2016.
- 7) ESRI, 2017b.

0 200 400
 Feet



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LEGEND

Sample Type

- ▲ Air
- Sediment
- Surface Water
- BES Waste
- ⬡ Property Boundary
- ⬢ Permitted Solid Waste Boundary
- Sedimentation Ponds
- Streams and Rivers

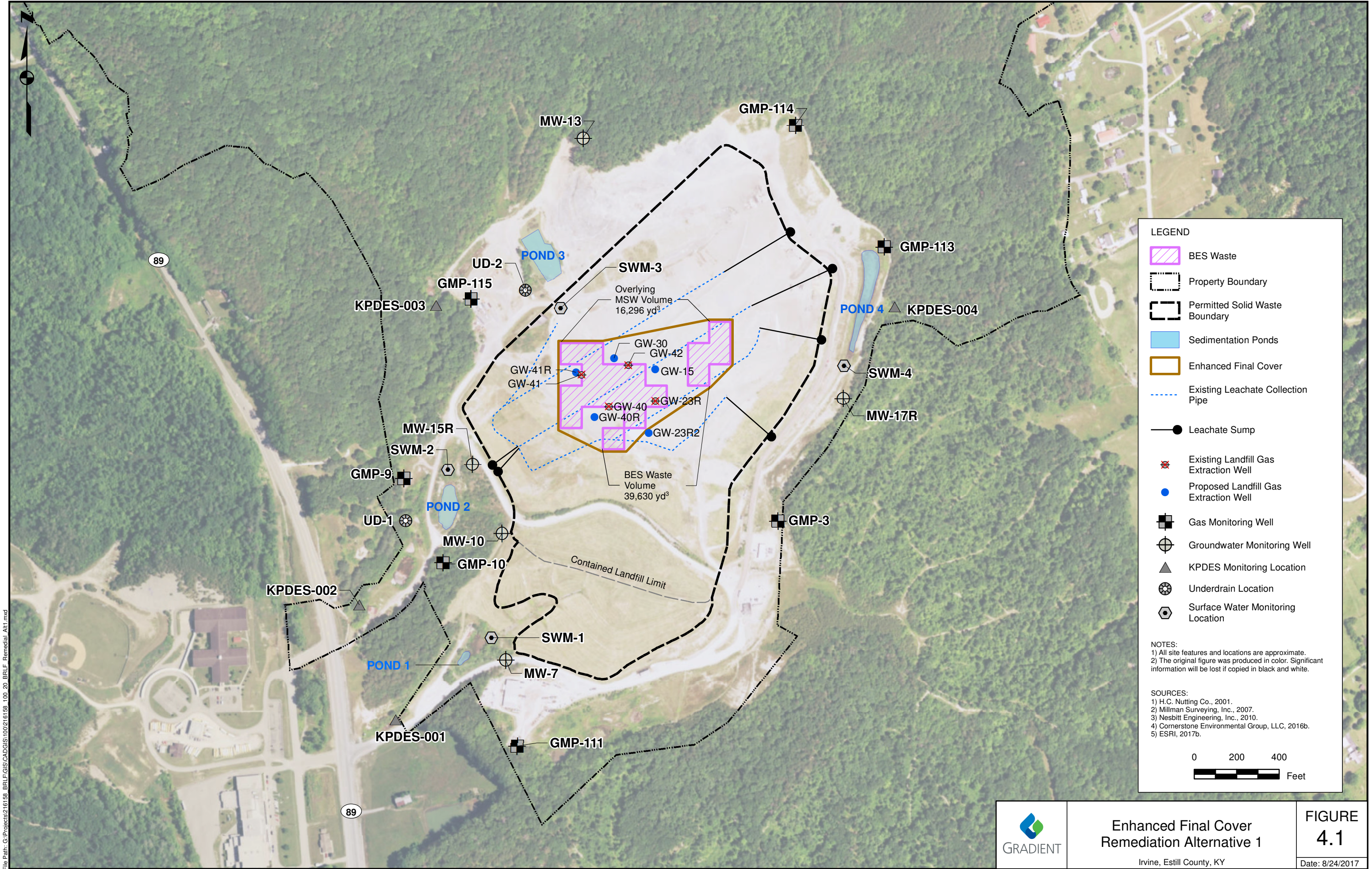
NOTES:

- 1) All site features and locations are approximate.
- 2) The original figure was produced in color. Significant information will be lost if copied in black and white.

SOURCES:

- 1) H.C. Nutting Co., 2001.
- 2) Millman Surveying, Inc., 2007.
- 3) Nesbitt Engineering, Inc., 2010.
- 4) RAC, 2016.
- 5) Cornerstone Environmental Group, LLC, 2016b.
- 6) ESRI, 2017b.

0 400 800
 Feet



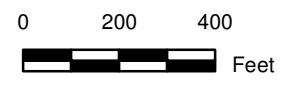
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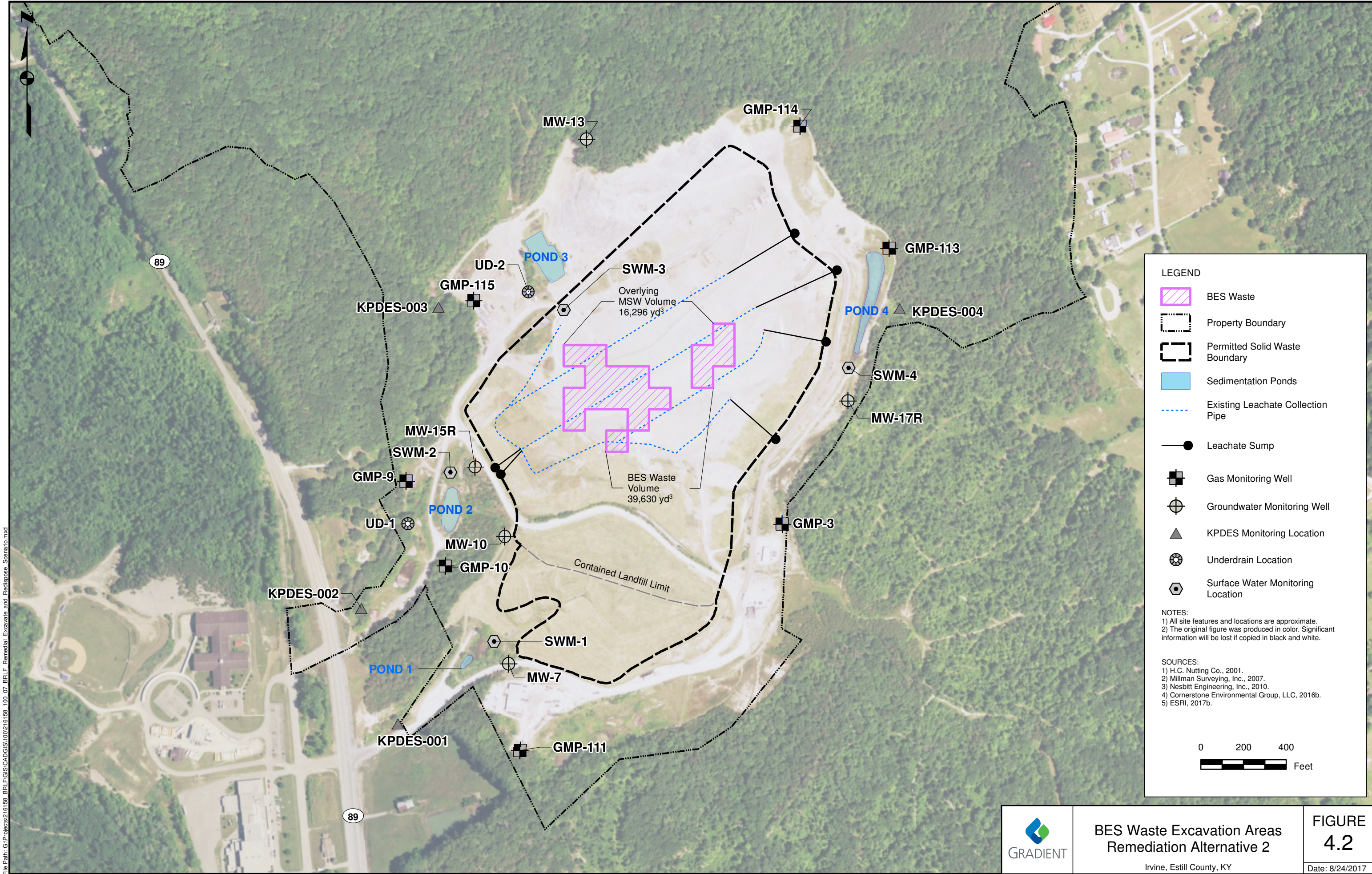
LEGEND

- BES Waste
- Property Boundary
- Permitted Solid Waste Boundary
- Sedimentation Ponds
- Enhanced Final Cover
- Existing Leachate Collection Pipe
- Leachate Sump
- Existing Landfill Gas Extraction Well
- Proposed Landfill Gas Extraction Well
- Gas Monitoring Well
- Groundwater Monitoring Well
- KPDES Monitoring Location
- Underdrain Location
- Surface Water Monitoring Location

NOTES:
 1) All site features and locations are approximate.
 2) The original figure was produced in color. Significant information will be lost if copied in black and white.

SOURCES:
 1) H.C. Nutting Co., 2001.
 2) Millman Surveying, Inc., 2007.
 3) Nesbitt Engineering, Inc., 2010.
 4) Cornerstone Environmental Group, LLC, 2016b.
 5) ESRI, 2017b.





LEGEND

- BES Waste
- Property Boundary
- Permitted Solid Waste Boundary
- Sedimentation Ponds
- Existing Leachate Collection Pipe
- Leachate Sump
- Gas Monitoring Well
- Groundwater Monitoring Well
- KPDES Monitoring Location
- Underdrain Location
- Surface Water Monitoring Location

NOTES:

- 1) All site features and locations are approximate.
- 2) The original figure was produced in color. Significant information will be lost if copied in black and white.

SOURCES:

- 1) H.C. Nutting Co., 2001.
- 2) Millman Surveying, Inc., 2007.
- 3) Nesbitt Engineering, Inc., 2010.
- 4) Cornerstone Environmental Group, LLC, 2016b.
- 5) ESRI, 2017b.

0 200 400
 Feet

File Path: G:\Projects\216158_BRLF\GIS\CADD\GIS\100\216158_100_07_BRLF Remedial Excavate and Redispose Scenario.mxd



**BES Waste Excavation Areas
Remediation Alternative 2**
Irvine, Estill County, KY

**FIGURE
4.2**
Date: 8/24/2017