Isolation Barrier Alternatives Analysis
West Lake Landfill Superfund Site

Prepared for:
United States Environmental Protection Agency Region VII

Prepared on behalf of:
Bridgeton Landfill, LLC

Prepared by:

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October 10, 2014

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U.S. Environmental Protection Agency
Region VII SUPR/MOKS
11201 Renner Boulevard
Lenexa, KS 66219

ATTENTION: Mr. Dan Gravatt

SUBJECT: Isolation Barrier Alternatives Analysis
West Lake Landfill Superfund Site, Bridgeton, Missouri

Dear Mr. Gravatt,

Pursuant to the U.S. Environmental Protection Agency's August 26, 2014 letter to Ms. Jessica Merrigan of Lathrop & Gage, Engineering Management Support Inc. (EMSI), on behalf of Bridgeton Landfill LLC, hereby submits the Isolation Barrier Alternatives Analysis – West Lake Landfill Superfund Site. We are submitting this report electronically and per your request, will also provide you with one paper copy and a compact disk containing an electronic version of the report. If you have any questions or desire additional information related to this report, or any other aspect of the work being performed at the Site, please do not hesitate to contact me.

Sincerely,
ENGINEERING MANAGEMENT SUPPORT, Inc.

Paul V. Rosasco, P.E.

Attachment: Isolation Barrier Alternatives Evaluation – West Lake Landfill Superfund Site

Distribution:
- Lynn Slugantz – EPA Region VII
- Alyse Stoy – EPA Region VII
- Jeff Field – EPA Region VII
- Brian Power – Bridgeton Landfill LLC
- Joe Benco – Republic Services, Inc.
- Jessie Merrigan – Lathrop & Gage
- Dan Feezor – Feezor Engineering, Inc.
- Peter J. Carey – P.J. Carey & Associates
- Mike Bollenbacher – Auxier & Associates
- Rolph Davis – LGL Limited

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1.0 INTRODUCTION

The U.S. Army Corps of Engineers (USACE) prepared an Isolation Barrier Alternatives Assessment Report for the West Lake Landfill Site dated August 25, 2014. In its report the USACE performed an analysis of various assessment factors as well as identification and comparison of advantages and disadvantages related to three proposed alignments for a potential isolation barrier envisioned to be located between the North Quarry area of the Bridgeton Landfill and the adjacent, and in part underlying, Radiological Area 1 (Area 1) of Operable Unit-1 (OU-1) of the West Lake Landfill Superfund Site (Figure 1). In the August 26, 2014 letter transmitting the USACE report (EPA, 2014a), the United States Environmental Protection Agency (EPA) requested the Responsible Parties to use the USACE report as a basis to further develop more detailed plans for an Isolation Barrier, specifically including bird mitigation plans, for each of the proposed alignment alternatives. This report addresses EPA's request and presents additional details and plans for the various alignment alternatives for an Isolation Barrier.

The objective of an isolation barrier would be to prevent possible hypothesized impacts that may occur if radiologically-impacted material (RIM) in Area 1 of OU-1 were to be heated to levels consistent with those observed in conjunction with the subsurface smoldering event (SSE) in the South Quarry area of the Bridgeton Landfill. This objective presumes that the SSE would migrate north-eastward from the South Quarry area of the Bridgeton Landfill into and through the North Quarry area of the Bridgeton Landfill and continue into Area 1.

The scope of the additional evaluation of potential isolation barrier alternatives presented in this report includes the following:

- Development of site plans and preliminary (10% level) design drawings for potential isolation barrier alignment alternatives (described in Section 2);
- Development of preliminary estimates of the amount of waste material that may need to be excavated and relocated to construct the barrier options;
- Development of preliminary schedules for the design and construction phases for each alternative;
- Evaluation of potential bird attractions that may occur as a result of isolation barrier construction activities and development of preliminary approaches to mitigate potential bird activity and resultant possible hazards to aircraft using the Lambert- St. Louis International Airport (the Airport) for each alternative;
- Evaluation of potential risks associated with each alternative; and
- Evaluation of potential advantages and disadvantages of each alternative.

Development of additional information for each alternative is based on evaluation of currently known information, the results of the evaluations presented in USACE report, and information provided by EPA Region VII during a September 18, 2014 meeting and subsequent September 23, 2014 e-mail from Jeff Field of EPA Region VII (EPA, 2014b).

This report has been developed by Feezor Engineering, Inc., P.J. Carey & Associates, Auxier & Associates and Engineering Management Support, Inc. with input on potential bird hazards and mitigation measures provided by Dr. Rolph Davis of LGL Limited.

Section 2 of this report includes descriptions of each of the isolation barrier alternatives and a discussion of the criteria that are used to evaluate the alternatives. One alternative is evaluated in each of Sections 3 through 7. Specific design criteria and performance objectives for each potential isolation barrier alternative are stated and the alternative is subjected to the following evaluation criteria in these sections:

- Waste Excavation and Relocation Volume Estimates;
- Preliminary Design and Construction Schedules;
- Potential for the Alternative to Result in Odor Releases;
- Potential for the Alternative to Attract Birds;
- Potential Risks Associated with the Alternative; and
- Potential Advantages and Disadvantages of the Alternative.

A comparative summary of the alternatives and conclusions are provided in Section 8. References consulted in preparation of this alternatives analysis are included as Section 9.

Four attachments are included with the analysis:

A: Radon Flux Analysis for Isolation Barrier Alternatives Analysis
B: Barrier Wall Design Memorandum
C: Heat Extraction System Design Memorandum
D: Isolation Barrier Alternatives Analysis – Bird Control Issues

2.0 ISOLATION BARRIER ALTERNATIVES AND EVALUATION CRITERIA

A description of the potential Isolation Barrier alternatives and the criteria used to evaluate the alternatives are provided in this section.

2.1 Isolation Barrier Alternatives

Based on direction from EPA during a September 18, 2014 meeting and subsequent communication from EPA (EPA, 2014b), the Isolation Barrier Alternatives to be evaluated include the following:

- No Action – No engineered measures would be implemented (provides a baseline for the alternatives evaluation);
- Option 1 – Inert Barrier located along the northern boundary of the North Quarry area of the Bridgeton Landfill / southern boundary of Area 1 (Alignment 1);
- Option 2 – Excavation of an Air Gap (open trench) Barrier down through the bottom of the waste materials in the northern portion of the North Quarry area of the Bridgeton Landfill;
- Option 3 – Inert Barrier located within the northern portion of the North Quarry area of the Bridgeton Landfill, south of the currently identified known occurrences of RIM (Alignment 3); and
- Option 4 – Heat Extraction Barrier located along the southern portion of Area 1 / northern portion of the North Quarry area of the Bridgeton Landfill.

The USACE report also considered an additional alignment (Alignment 2) that would consist of installation of an inert barrier located south of OU-1 Area 1 to ensure that all RIM is located to the north of the Isolation Barrier. This would require the Isolation Barrier to be placed within the deepest part of North Quarry area of the Bridgeton Landfill where the depth of waste is reported to be 180 feet deep. Because installation of a barrier along this alignment would require significantly more waste material to be excavated and relocated and the greatest duration of exposure of waste materials of all of the options, this option poses the highest potentials for odor release and risk of bird hazards and the greatest potential risks to on-site workers and the off-site public. Consequently, the USACE determined that installation of a barrier along this alignment potentially may not be feasible, among other factors. Therefore, EPA did not request evaluation of this alignment.

2.2 Isolation Barrier Alternatives Evaluation Criteria

The USACE report identified twelve assessment factors for evaluation of potential isolation barrier alternatives. These factors include:

- Excavation Volume
- Odor Potential
- Bird Hazard Potential
- RIM Remaining South of the Isolation Barrier
- Potential for Future SSE North of the Isolation Barrier
- On-Site Worker Safety
- Off-Site Public Safety
- Off-Site Waste Transportation and Disposal
- Duration of Design
- Duration of Construction
- Impact to Existing Infrastructure
- Technical Feasibility

The USACE also indicated that the depth of waste excavation drives the majority of the advantages and disadvantages of the alternatives.

Two additional factors were also identified for consideration: overall protection of human health and the environment and potential impacts on implementation of remedial actions for OU-1. The Isolation Barrier alternatives, including the No Action Alternative, were evaluated in terms of these factors.

3.0 NO ACTION ALTERNATIVE

Under the No Action Alternative, no additional engineered structure or other actions would be implemented relative to possible migration of an SSE from the South Quarry area of the Bridgeton Landfill, through the North Quarry area of the Bridgeton Landfill and into Area 1 (Figure 2).

Although no additional engineered structures or other actions would be taken under this alternative, ongoing measures to evaluate and manage the SSE in the South Quarry area of the Bridgeton Landfill are currently being performed pursuant to Administrative and Court Orders and agreements between the Missouri Department of Natural Resources (MDNR) and Missouri Attorney General's Office (collectively the "State") and Bridgeton Landfill, LLC. Additional actions are also being implemented by Bridgeton Landfill, LLC on a voluntary basis. Collectively, these actions include ongoing monitoring of subsurface temperatures in the "Neck Area" between the South Quarry and North Quarry areas of the Bridgeton Landfill, monitoring of landfill gas quality within the Bridgeton Landfills, and monitoring settlement of the surface of the South Quarry area. The results of these activities are reported to MDNR on a regular (weekly, monthly or quarterly) basis. In addition, Bridgeton Landfill, LLC voluntarily proposed and has begun implementation of a Heat Extraction Pilot Study in the South Quarry area of the Bridgeton Landfill to evaluate potential mechanisms for controlling heat buildup and limiting heat migration into the "Neck Area" (Bridgeton Landfill, LLC, 2014a, b and c). Bridgeton Landfill, LLC is in the process of performing heat transfer modeling and conducting additional demonstrations and evaluations of factors controlling migration of the SSE. These and other measures currently being taken or expected to be taken to gain further understanding of the SSE and to manage the SSE in the South Quarry area of the Bridgeton Landfill would still occur under this alternative.

3.1 Preliminary Design Criteria and Performance Objectives

Because no engineered structures or other actions would be implemented under this alternative, there are no design criteria or performance objectives for this alternative.

3.2 Waste Excavation and Relocation Volume Estimates

Because no engineered structures or other actions would be implemented under this alternative, excavation or relocation of any waste material would not occur under this alternative.

3.3 Preliminary Design and Construction Schedules

Because no engineered structures or other actions would be implemented under this alternative, nothing would be designed or constructed. However, ongoing monitoring of the SSE and associated conditions in the landfill and additional demonstrations/evaluations of factors controlling migration of the SSE would be performed under this alternative as discussed above.

3.4 Potential for Release of Odors

Because no engineered structures or other actions would be implemented under this alternative, no waste materials would be excavated or relocated. Therefore, this alternative does not pose any potential for odor emission.

3.5 Potential for Bird Attraction

Because no engineered structures or other actions would be implemented under this alternative, no waste materials would be excavated or relocated. Therefore, this alternative does not pose any potential for additional bird attraction.

3.6 Potential Risks Associated with the Alternative

The potential risks that may result from occurrence of a SSE in Area 1 should be considered under the No Action Alternative. The likelihood of any potential risks that may occur under this alternative is of course affected by the potential for the SSE in the South Quarry area of the Bridgeton Landfill to migrate into and through the North Quarry area of the Bridgeton Landfill and extend into Area 1. As discussed below, the primary potential impact of an SSE reaching Area 1 would be the potential for increased radon emission. The potential for increased radon emissions if a SSE were to occur in Area 1 was previously assessed qualitatively (EMSI, 2014) and has been further evaluated in a quantitative manner as part of the evaluation of the No Action Alternative.

3.6.1 Potential for a SSE to Migrate from the South Quarry to Area 1

The configuration of the South Quarry and North Quarry areas of the Bridgeton Landfill is shown on Figure 2. In accordance with the court orders and agreements between the State and Bridgeton Landfill, LLC, Bridgeton Landfill personnel and consultants retained by Bridgeton Landfill have been conducting extensive monitoring of the conditions associated with the SSE, and assessments of the potential for the SSE to migrate into the North Quarry area of the Bridgeton Landfill. These activities include monitoring of the volume and quality of landfill gas in the North Quarry and South Quarry areas of the Bridgeton Landfills, monitoring the temperature of the waste materials and landfill gas, and monitoring of settlement of the surface of the South Quarry area of the Bridgeton Landfill. Results of this monitoring are submitted to the State regularly (weekly, monthly or quarterly).

Evaluation of the occurrence and extent of accelerated settlement of the South Quarry area of landfill cover over time indicates that the SSE in the South Quarry area of the Bridgeton Landfill appears to have originated in the eastern portion of the South Quarry area of the Bridgeton Landfill and generally has migrated to the west through the South Quarry portion of the Landfill

(CEC, 2014). Monitoring of waste and landfill gas temperatures, landfill gas quality (e.g., carbon monoxide and hydrogen), and surface settlement all indicate that the SSE occurs only in the South Quarry area of the Bridgeton Landfill and has not and does not extend into the North Quarry area of the Bridgeton Landfill.

Additionally, available data indicate that the zone of increased heat generation associated with the SSE in the South Quarry area of the Bridgeton Landfill is located in the upper portions of the landfill and does not extend to the base of the floor of the South Quarry. Specifically, review of the temperature profiles from the temperature monitoring probes indicates that in the northern part of the South Quarry area, the heat generating material occurs at elevations of greater than or equal to approximately 360 to 380 ft above mean sea level (amsl). This interval corresponds with heights of approximately 110 to 130 feet and higher above the base of the South Quarry area of the Bridgeton Landfill (bottom elevation of approximately 250 ft amsl) and depths below the landfill surface (approximately 500 -550 ft amsl) ranging from approximately 120 to 190 feet depending upon location within the South Quarry area. Observed temperatures in the waste materials below this interval decline, indicating they these materials are undergoing heat loss rather than heat generation. The occurrence of heat generating material at elevations of 360 to 380 ft amsl may reflect the limit of the depth of reactive waste materials or may reflect thermal constraints associated with the configuration of the South Quarry (i.e., dissipation of heat through the bottom and sides of the quarry wall which control the vertical position of the pyrolysis). Evaluations of these and other possible constraints on the migration of the SSE are ongoing. A similar pattern of heat dissipation is seen as the ground surface is approached, which is reflective of the upper boundary of the landfill being a cooler boundary condition.

The overall thickness of the waste column decreases significantly across the North Quarry area of the Bridgeton Landfill, from approximately 275 feet in the “Neck Area” to approximately 180 – 200 feet beneath the southwestern portion of the North Quarry area to approximately 75 feet beneath the northernmost portion of the North Quarry area to approximately 50 feet or less beneath Area 1 (Figure 2). The significant reduction in waste thickness in the north section of the North Quarry area of the Bridgeton Landfill will result in reduced insulation, and a far greater dissipation of heat from the waste mass to the cooler boundaries of the bottom of fill and the ground surface. The resulting heat dissipation and reduction in temperature will be significant at the boundary between the North Quarry area of the Bridgeton Landfill and the occurrence of RIM in Area 1. If a SSE were to extend into Area 1, the thickness of heated material would be on the order of 30 feet or less with cool boundaries only 15 feet away (total waste thickness of approximately 50 feet or less in contrast to the total waste thickness of 225 feet as exists in the South Quarry area of the Bridgeton Landfill). Due to the overall thinner nature of the waste materials in Area 1, the effective rate of heat dissipation in the vertical direction will be approximately 25 times greater than the rates observed in the South Quarry area of the Bridgeton Landfill. It is doubtful that any significant pyrolysis would occur at these shallow waste depths due to the lack of insulation. Such behavior would be consistent with observations at other sites that indicated no pyrolysis in waste depths of less than 60 feet.

The area in which the RIM is located stopped receiving waste in 1974. Therefore, RIM material is expected to occur within materials that were disposed at the landfill prior to 1975. The 1975 topographic surface was developed and evaluated on historical aerial photography as part of the

Phase 1 Investigation of potential isolation barrier alignments (report in preparation). Consequently, in areas further to the south of the previously defined extent of RIM, where limited amounts of additional RIM may be present, any additional RIM occurs below the 1975 topographic surface. In the southern portion of Area 1/northern portion of the North Quarry area of the Bridgeton Landfill, this surface is located very close to the bottom of waste. Therefore, any RIM that may be present in this area is expected to be located near the bottom of the waste column near the underlying alluvial and bedrock materials. Consequently, such RIM will not experience any significant increase in temperature because heat losses to the underlying alluvial and bedrock materials will act as a natural heat sink below such RIM, serving to limit any temperature increases.

Beyond the hindrance to migration that is created by the depth reduction and narrowing of the landfill mass, it is possible that there are features within the landfill that could serve as natural barriers. However, this concept is still under investigation. Review of 1996 aerial photography of the site area conducted by one of the Responsible Parties (August 26, 2014 letter from J. McGahren of Morgan Lewis to David Hoefer and Dan Gravatt of EPA Region VII) indicated that a large soil berm associated with an access road was present in the North Quarry area just to the north of the “Neck Area”. This feature is evident in several aerial photographs taken during 1996. However its initial creation, detailed construction and continued existence have not yet been determined. Evaluations of this feature in terms of its permanence over time and the configuration of this berm relative to the elevation of the quarry rim and the elevation of the zone of increased heat generation is ongoing. If this berm can be demonstrated to be a permanent feature (i.e., meaning it was not subsequently removed as landfill activities progressed) and its height is sufficient to limit an SSE, this could act as another limitation on potential migration of the SSE into or through the North Quarry area of the Bridgeton Landfill.

Overall, based on the factors described above, it is highly unlikely that the SSE could ever migrate laterally and vertically from its location deep within the South Quarry area of the Bridgeton Landfill, into and through the North Quarry area of the Bridgeton Landfill and subsequently into Area 1. As described above, evaluations of the nature and extent of the SSE and factors contributing to its origin, distribution and potential further migration are ongoing.

3.6.2 Potential Impacts if a SSE were to Occur in Area 1

An Evaluation of Possible Impacts of a Potential Subsurface Smoldering Event on the Record of Decision (ROD)-Selected Remedy for OU-1 (hereinafter referred to as the SSE Impact Evaluation) was previously prepared (EMSI, 2014) and reached the following conclusions with respect to potential impacts if a SSE were to occur within OU-1 Areas 1 and 2:

- The RIM would not become more or less radioactive in the presence of heat and the RIM is not explosive and would not become explosive in the presence of heat.

- A SSE would not create conditions that could carry RIM particles or dust off the site and the heat of a SSE is not high enough to ignite non-RIM wastes or chemical compounds or to cause them to explode.

- A SSE may allow radon gas to more easily rise through the ground and reach the surface of the landfill than would otherwise occur, because heat would reduce the amount of moisture in the buried solid waste (trash) thereby increasing the amount of air between the soil particles and thus limiting the ability of the buried solid waste to retain radon below ground. Any radon gas that does make it to the surface would dissipate quickly in open air. This potential increase in the rate of release of radon gas at the surface of the landfill would be limited to the area of the SSE and would stop when the SSE ends.

EPA's Office of Research and Development (ORD) and the MDNR's consultant, Todd Thalhamer, reviewed the SSE Impact Evaluation report and provided comments (EPA-ORD, 2014 and Thalhamer, 2014 a and b). Revisions to the report and responses to address these comments are currently in process. The EPA-ORD comments indicated that EPA generally concurred with the three points listed above; however, EPA-ORD did offer additional points in particular highlighting its opinion that if a SSE were to occur in OU-1 it could create the potential for additional leachate generation. This opinion was based in part on ORD's conclusion that there had been an increase in leachate generation within the South Quarry area of the Bridgeton Landfill; however, the actual data regarding leachate extraction rates do not indicate that the rate of leachate generation has increased, but instead reflect changes in the manner and locations at which leachate is being produced, extracted and managed.

Because the RIM would remain buried beneath other waste materials and soil or inert fill, no changes in other exposure pathways (direct contact with or dermal exposure to the RIM or exposure to gamma radiation) are expected to occur if a SSE were to migrate into Area 1. Implementation of the ROD-selected remedy would result in even greater protection against direct contact or dermal exposure to any of the RIM. Therefore, as indicated in the SSE Impact Evaluation and the EPA-ORD comments on the SSE Impact Evaluation, the principal impact of a SSE or any increase in heat within Area 1 would be the potential increase in the amount of radon exhaled (emitted) at the surface of Area 1. To build upon the qualitative assessment of potential changes in radon emissions described in the SSE Impact Evaluation, this Isolation Barrier Alternatives Evaluation includes a quantitative assessment of the potential increases in radon emissions that may occur if a SSE were to impact the RIM in Area 1 (see Attachment A). Notably, the installation of a new engineered landfill cover included in the ROD-selected remedy for OU-1 would substantially reduce the potential for any increase in radon emissions as shown by the calculated radon emissions both with and without potential impacts associated with a SSE as discussed further below.

Under the current (no remedy in-place) conditions, the average radon emissions from the surface of that portion of Area 1 that contains RIM are calculated to be 13.5 pCi/m^2/sec (Attachment A) which compares very closely with the average of 13 pCi/m^2/sec of the measured values of radon emissions at the surface of Area 1 obtained during the Remedial Investigation (EMSI, 2000). Upon implementation of the ROD-selected remedy, the radon emissions at the surface of Area 1 are calculated to decline significantly to 0.023 pCi/m^2/sec. Under both the current conditions and under the ROD-selected remedy, the average radon emissions from Area 1 are less than the standards established by EPA for emissions of radon from inactive uranium mill tailings (40 CFR 192.02(b)(1)) and EPA's emission standard for radon established pursuant to the National Emissions Standards for Hazardous Air Pollutants (40 CFR 61), also referred to as the Radon NESHAP, both of which establish a standard for average surface emissions of radon of 20 pCi/m^2/sec.

The projected increase in radon emissions if a SSE were to enter Area 1 have been estimated (see Attachment A) based on application of established numerical models used to estimate radon emissions. These same models were also used for development of the Supplemental Feasibility Study (SFS) for OU-1 (EMSI, 2011) as approved by EPA. The calculations presented in Attachment A examined three potential conditions associated with radon emissions under elevated temperatures and occurrence of a SSE in Area 1 including:

- Initial thermal expansion of landfill gas due to increased temperature as a hypothetical SSE approaches and enters into Area 1 resulting in exhalation (emission at the ground surface) of the incremental increase in the volume of landfill/soil gas due to expansion of the gas volume in response to an increase in subsurface temperature;

- Subsequent increase in radon emissions due to increased soil gas permeability resulting from vaporization of soil moisture in response to increased temperature; and

- Subsequent destruction (pyrolysis) of a portion of the waste mass and associated loss of pore space resulting in further displacement and resultant emission of an additional portion of the landfill/soil gas.

Results of these calculations (Attachment A) indicate that even if these conditions were to occur, the radon emission rate from Area 1 could still be less than the standard established by the radon NESHAP. Specifically, even with the use of conservative assumptions, the magnitude of the expected increase in radon emissions that may occur under the three scenarios listed above is approximately 2 pCi/m^2/sec; that is an increase from the calculated average value (13.5 pCi/m^2/sec) of 21.5% or from the average value measured during the RI (13 pCi/m^2/sec) of 26%. The average rate of radon emission from Area 1 (16.4 pCi/m^2/sec) estimated to occur if a SSE were to enter and move through Area 1 would not result in radon emission levels that would exceed the Radon NESHAP of 20 pCi/m^2/sec (see Figure 3 and Attachment A). Therefore, in the unlikely event that a SSE were to occur in Area 1, the magnitude of radon emissions would still be less than the established standard even without implementation of the ROD-selected remedy.

Installation of the engineered landfill cover under the ROD-selected remedy would greatly reduce the magnitude of radon emissions from Area 1 insuring that this area continues to meet the radon emissions standards established by EPA. In fact, following installation of the ROD-selected remedy, even the radon emissions resulting from an SSE impact, 0.29 pCi/m^2/sec, would be substantially less than the measured average radon emissions from Area 1 of 13 pCi/m^2/sec.

Additionally, radon flux can be relatively easily measured and, because cover is so effective at retaining radon to allow for natural decay, relatively easily mitigated. So if a SSE were to impact Area 1 it would be possible to institute management systems to ensure monitoring of radon flux and mitigation of the radon flux, if needed.

3.7 Potential Advantages and Disadvantages of the Alternative

With the exception of the transfer station, overall access to the West Lake Landfill site is restricted to landfill and remediation workers only. Access to the transfer station is limited to the main access road and the transfer station itself and does not allow for access to the remaining portions of the Site including Areas 1 and 2. Access to Areas 1 and 2 is further restricted by a fence which contains signage notifying workers and others of potential risks of radiation exposure. Therefore, direct access to the RIM and exposure to radiation from the RIM is controlled. Installation of the engineered landfill cover and other measures included under EPA's ROD-selected remedy would further limit any access to RIM or any possible exposure to radiation from the RIM.

Based on the evaluations described above, occurrence of a SSE in Area 1 would not result in substantially increased radon emissions for Area 1, even under the current conditions where no cover system has been installed. Implementation of the ROD-selected remedy would greatly reduce potential radon emission further insuring that the health-based standards continue to be met, even in the unlikely event that a SSE were to occur in Area 1 in the future. Therefore, the No Action Alternative would be protective of human health and the environment.

Advantages of the No Action Alternative

- This alternative would not require any waste excavation.
- Because no waste materials would be excavated or disturbed this alternative would not result in any odor releases.
- Because no waste materials would be excavated or disturbed this alternative would not result in any additional attraction for birds and resultant bird hazard potential.
- The potential for a SSE to originate within Area 1 would not be increased under this alternative.
- Because no waste excavation or other construction activities would be performed under this alternative, this alternative would not create any risks to on-site worker safety.

- Because no waste excavation or other construction activities would be performed under this alternative, this alternative would not create any risks to off-site public safety.

- Because no waste excavation or other construction activities would be performed under this alternative, this alternative would not entail off-site transportation and disposal of any waste.

- Because no engineered structure would be installed or other actions taken, no design activities would be conducted. Existing monitoring of the SSE-related conditions in the South Quarry area of the Bridgeton Landfill and the North Quarry area of the Bridgeton Landfill would continue under the direction of the MDNR.

- Because no engineered structure would be installed or other actions taken, no construction activities would be conducted.

- Because no engineered structure would be installed or other actions taken, this alternative would not impact any North Quarry area of the Bridgeton Landfill infrastructure (e.g., landfill gas collection wells and conveyance piping).

- This alternative would not impact planned (ROD-selected remedy) or future actions with regard to closure or other remedial alternatives for OU-1.

- Because no engineered structure would be installed or other actions taken, this alternative is technically feasible.

Disadvantages of the No Action Alternative

- No barrier would be installed under this alternative so the RIM in Area 1 would not be isolated from waste materials in the North Quarry area of the Bridgeton Landfill. However, as discussed above, migration of the SSE in the South Quarry area of the Bridgeton Landfill into and through the North Quarry area of the Bridgeton Landfill and into Area 1 is highly unlikely. Further, the potential impacts in the unlikely event that a SSE were to occur in Area 1 would not result in health and safety risks since radon emissions would remain, or could be kept, within the radon NESHAP. Therefore, decisions to perform remedial or mitigative measures between Area 1 and the North Quarry area do not require the consideration of negative health impacts associated with heating the RIM, because none can be identified.

4.0 OPTION 1 – INERT BARRIER ALONG ALIGNMENT 1

Under Option 1, an inert barrier would be installed within the southern portion of Area 1 along the northern boundary of the North Quarry area of the Bridgeton Landfill. This barrier would consist of a subsurface, reinforced concrete wall extending from the ground surface down through the bottom of the waste material. The anticipated location of the Option 1 barrier alignment is provided on Drawing 002. Preliminary estimates of the extent and depths of waste excavation required to implement this alternative are provided on Drawing 003. A profile view and cross-sections of the anticipated extents of waste excavation required by this alternative are provided on Drawing 004. The anticipated areas on-site where the excavated wastes would be relocated are shown on Drawing 005. A schematic of the anticipated barrier configuration is provided on Drawing 016.

4.1 Design Criteria and Performance Objectives

Preliminary design criteria have been developed for this alternative (Attachment B). These criteria are based on the presumption that the SSE reaction would move to the north from the South Quarry area of the Bridgeton Landfill into the North Quarry area of the Bridgeton Landfill and towards Area 1 into the area of the proposed alignment of Option 1. Furthermore, it is assumed that the heat fluxes associated with the migrating front would be similar in nature to those found within the area currently impacted by the SSE. Therefore, preliminarily, the design criteria of this alternative would be based on a conservative assumption that pyrolosis driven settlement would occur wherever temperatures are projected to occur at levels greater than 200° F. The allowable temperatures within the barrier wall would be limited to 200° C (approximately 400° F) which is well within the levels that studies have shown that reinforced concrete can continue to provide performance (Attachment B). However, in order to insure that elevated temperatures would not be conducted across the barrier wall to the waste materials on the north side, the barrier wall would include heat exchange tubes that would be built into the concrete wall during construction to enable extraction of heat and cooling of the wall. Design of the heat extraction component would be based on published heat conduction values for concrete and a preliminary design value for the temperature of the circulated liquid of 85° F, consistent with the use of adiabatic air coolers with closed loop liquid circulation systems. Additional details regarding the preliminary evaluation of the design criteria and performance objectives for this alternative are presented in Attachment B.

4.2 Waste Excavation and Relocation Volume Estimates

Construction of an inert barrier would require excavation of some of the existing waste materials in order to provide the necessary working platform required for operation of equipment, to reduce the overall depth of excavation, and to reduce the height of the barrier and the resultant potential deformations and stresses that may affect the barrier (Drawing 003). Pre-excavation volumes based upon a flat platform width of 60 feet would result in a volume of approximately 47,000 bank (i.e., in-place) cubic yards (bcy) of existing waste materials (Drawings 003 and 004). The total area of waste excavation would have a plan view area of approximately 3.4 acres

(Drawing 003). Construction of the barrier would result in removal and relocation of additional existing waste materials. Assuming a barrier width of 3.0 feet (36 inches) the volume of waste excavation associated with barrier construction is estimated to be approximately 5,000 bcy (Drawings 003 and 004).

The excavated waste would need to relocated and re-disposed on-site. The area required for waste relocation under this alternative is estimated to be approximately 3.5 acres within the fill area south of OU-1 Area 1 and overlapping the northeast slope of the North Quarry area (Drawing 005). It is assumed that upon excavation and loading, the volume of waste would swell (expand) approximately 50%. Therefore the volume of waste to be transported is estimated to be 78,000 loose cubic yards (lcy). It is assumed that there would be a waste swelling factor between excavation, transportation, and relocation that could be over 20% ultimate swell resulting in a total volume to be re-disposed of approximately 62,400 lcy. Relocation and placement of the waste would require additional daily soil cover and installation of a final cover over the waste materials, which is estimated to increase the overall volume of materials to be placed in the waste relocation area by an additional 25%. Consequently, the total volume required for relocation of waste materials under this alternative is estimated to be approximately 78,000 bcy.

4.3 Preliminary Design and Construction Schedules

Installation of a reinforced concrete wall in municipal solid waste (MSW), even to depths of 40 feet, would include design features associated with withstanding potentially large deformations and stresses, depending on the results of the prediction of heat flux to the area. These requirements would dictate use of some elements that are typically not found in structural slurry walls. Development and testing of these elements would be required. Design of a subsurface, reinforced concrete wall would require a large number of design parameters to be estimated that involve the specific behavior of a heterogeneous material (waste), a reaction that has been observed but is not completely understood, and undefined circumstances associated with the arrival and magnitude of settlements associated with the reaction. These conditions can only be bounded approximately. Trench construction using slurry would require slurry decanting/liquid. Management of stormwater during barrier construction could be difficult due to existing limits with respect to stormwater management at the site. Procedures for management of slurry and stormwater would need to be developed during the design phase. In addition, due to delay between inert barrier installation and the time if, and when, a barrier could be needed, monitoring/testing would likely be required to demonstrate the continued integrity/performance of the barrier over time. The scope and adequacy of such monitoring would need to be developed. Consequently, this alternative would require a large amount of time for investigation, design, and design review, resulting in a significant design time frame of approximately 103 weeks (Figure 4).

Based on preliminary discussions with one vendor, the total time required to construct this alternative is estimated to be 53 weeks (see Figure 5). This schedule is based on an assumption that other than screening by field instruments, no testing would be necessary to support excavation and relocation of waste removed during the pre-excavation phase (i.e., waste located above the 1975 topographic surface which does not contain any RIM (Feezor Engineering, Inc., 2014). Testing would be required for waste excavation conducted in conjunction with installation of the barrier wall because portions of the barrier excavation are expected to extend below the elevation of the 1975 topographic surface.

4.4 Potential for the Alternative to Result in Odor Releases

Because excavation and relocation of waste materials would be required to implement this alternative, this alternative poses a strong potential for generation and release of odors. Performance of the pre-excavation and waste relocation activities is expected to result in exposure of waste materials to the atmosphere for approximately 12 weeks (Figure 5). The overall area of the pre-excavation disturbance is estimated to be 3.4 acres for this alternative. The overall size of the waste relocation area(s) for this alternative is estimated to be 3.5 acres. Excavation and exposure of waste materials during the construction of the barrier wall is estimated to last approximately 28 weeks.

Procedures that could potentially mitigate odor releases would include placement of daily soil or other cover materials on waste relocation areas and/or use of a masking fragrance. It may also be possible to install vacuum gas piping adjacent to the trench during trench excavation but the practicality, effectiveness and anticipated durability of such piping would need to be evaluated during the design phase. This technique is not considered to be implementable during the pre-excavation activities when the majority of waste excavation and relocation activities would occur. It should also be noted that the pre-excavation activities would occur in relatively younger waste (post 1995), which is expected to have a greater potential for odor generation and emission than the underlying older (pre-1995 up to pre-1975) more decomposed waste materials.

4.5 Potential for the Alternative to Attract Birds

Because excavation and relocation of waste materials would be required to implement this alternative, this alternative poses a strong potential for generation and release of odors and exposure of waste which could attract birds to the area. Planning for bird mitigation measures indicates that the highest risk for attracting birds to the excavation areas would occur during winter months (Attachment D) which could limit the periods when waste excavation could be conducted.

Performance of the pre-excavation and waste relocation activities is expected to result in exposure of waste materials to the atmosphere for approximately 12 weeks. The overall area of the pre-excavation disturbance is estimated to be 3.4 acres for this alternative. The overall size of the waste relocation area(s) for this alternative is estimated to be 3.5 acres. Excavation and exposure of waste materials during the construction of the barrier wall is expected to last approximately 28 weeks.

As detailed in the attached Isolation Barrier Alternatives Analyses – Bird Control Issues document (Attachment D), a bird monitoring and control program would need to be developed for implementation at the start of invasive work and continuing throughout the time that waste materials are exposed. Construction of Option 1 would disturb the least amount of waste of the inert barrier alternatives and is expected to primarily result in disturbances of older waste which should result in a lower level of attraction to birds. For that reason the anticipated risk of bird attractant is lower than for the other invasive alternatives due to the lesser risk of organic material in older waste, the smaller volume of waste disturbed and the shorter duration over which waste would be exposed. However, whether any exposed waste would contain organic material that could be a bird attractant cannot be definitively known until if and when such waste is actually exposed. Because successful bird control is dependent upon maintaining effective control from the start of any work that would expose waste, it must be presumed for planning purposes that the waste could present an attractant and appropriate procedures employed.

Based upon the assessment of LGL Limited as detailed in Attachment D, an effective bird mitigation plan could be prepared and implemented for Option 1. A detailed plan would be prepared during the engineering design phase in close coordination with the Airport.

4.6 Potential Risks Associated with the Alternative

Based on the results of the Phase 1 Bridgeton Landfill Thermal Isolation Barrier Investigation (report in preparation), isolated occurrences of RIM would be expected to be present outside of a barrier installed along Alignment 1. Specifically, RIM was identified at drilling locations 1C-6 and 1C-12 which would be located outside (south) of the Option 1 barrier alignment (Drawing 003). In addition, material located below the 1975 topographic surface, which could potentially contain RIM, is present to the south of the proposed alignment for Option 1.

Potential occurrences of RIM outside of the barrier would not pose a significant risk (see Attachment A). The presence of RIM outside of the barrier would not result in an exceedance of the Radon NESHAP or other impacts or risks to human health or the environment (see Attachment A). In addition, this area would ultimately be covered with an ethyl-vinyl alcohol cap which would limit any surface emissions of landfill gas and radon from this area.

4.7 Potential Advantages and Disadvantages of the Alternative

The RIM material that would remain outside of the barrier wall is currently covered by 25 to 50 feet of solid waste and a landfill cover that prevents direct contact with the RIM and provides shielding from gamma radiation. Radon emissions from the RIM material located outside of the barrier would not result in an exceedance of the Radon NESHAP. Therefore, Option 1 is protective of public health and the environment.

<u>Advantages of Option 1</u>

- This alternative results in the lowest volume of waste excavation and the shallowest depths of waste excavation of all of the alternatives except for the No Action and the Heat Extraction Barrier Options.

- Because this alternative requires the least amount of waste materials to be excavated and relocated, this alternative poses the lowest potential for odor emissions of all of the inert barrier alternatives.

- Because this alternative requires the least amount of waste materials to be excavated and relocated, this alternative poses the lowest potential for attraction of birds and resultant bird hazard potential of all of the inert barrier alternatives.

- Because this alternative is located along the northern boundary of the North Quarry area of the Bridgeton Landfill wastes, it offers the lowest potential for a SSE to originate on the north side of the barrier.

- Because this alternative requires the least amount of waste materials to be excavated and relocated, this alternative poses the lowest potential risks to on-site worker safety of all of the inert barrier alternatives.

- Because this alternative requires the least amount of waste materials to be excavated and relocated and all of the excavated waste is expected to be relocated on-site, this alternative should not pose any risks to off-site public safety.

- With the exception of any RIM that may be encountered, the volume of which is expected to be relatively small and could potentially be relocated into Area 1, all of the waste materials excavated under this alternative would be relocated on-site. Therefore, this alternative would not entail off-site transportation and disposal of waste.

Construction of a subsurface, reinforced concrete wall is an established technology; therefore application of this technology is considered technically feasible.

Disadvantages of Option 1

- This alternative would require excavation and relocation of approximately 52,000 bcy of waste (to provide a working platform plus the barrier volume), including excavations to depths up to 54 feet.

- Trench excavation would occur in areas of known RIM requiring testing and potentially management and disposal of RIM. Testing for thorium would require samples to be analyzed in an on-site or off-site laboratory and at least a 24-hour sample turnaround period which could impact/slow/delay construction.

- This alternative would not isolate 100% of the RIM and would result in the greatest amount of RIM being located outside (south) of the barrier wall of the inert barrier alternatives; however, the presence of RIM outside of the barrier is not expected to pose unacceptable risks (see Section 4.6 and Attachment A).

- Excavation would extend into areas of identified occurrences of RIM posing a potential hazard to on-site workers (and the community if any of the waste containing RIM would be transported off-site for disposal).

- Delivery of significant amounts of equipment and materials for barrier construction would result in increased traffic into, out of and adjacent to the site.

- Once the barrier is installed, its performance cannot be significantly altered. While it is believed that a reinforced concrete wall in MSW can be designed and constructed, there would be elements of uncertainty with respect to the barrier performance over time.

- The appropriate spacing of cooling points within the barrier is currently uncertain and would require additional design basis information (likely to be obtained from ongoing heat extraction testing in the South Quarry area of the Bridgeton Landfill).

- Although the total construction time for this alternative is estimated to be 53 weeks, potential delays and/or increased construction periods are possible with this alternative. These delays could be associated with greater slurry losses than expected or the need to pre-grout the waste to limit slurry loss, issues relating to RIM contaminated slurry management or other features involving the slurry wall excavation techniques.

- This alternative would entail excavation of waste along the northern boundary of the North Quarry area of the Bridgeton Landfill, potentially requiring removal or other impacts to the operation of some of the North Quarry area infrastructure (e.g., landfill gas [LFG] collection wells and conveyance piping).

- Although implementation of this option is considered to be feasible, it is based on a technology that incorporates elements that are sensitive to movement, corrosion and degradation with time, which are difficult to predict with accuracy in a landfill setting.

- The presence of an inert barrier and associated heat extraction system along this alignment could impact the design and implementation of remedial actions for OU-1.

- Although construction of a concrete barrier is considered to be feasible, installation of a non-deformable barrier within a matrix of solid wastes is an application which has not previously been applied or demonstrated in solid waste, so uncertainty as to the success of such a barrier exists.

5.0 OPTION 2 – AIR GAP BARRIER

Another option (Option 2) consisting of excavation of an air gap barrier (open trench) within the northern portion of the North Quarry (Drawing 006) was initially considered but was not proposed for additional detailed evaluation due to the significant disadvantages associated with this approach.

The significant disadvantages associated with this option include the following:

- A large volume of waste (preliminarily estimate of 540,000 bcy) would be required to implement this alternative (Drawing 007).

- A significant depth of waste excavation (estimated at up to 86 ft) would be required for this alternative (Drawings 007 and 008).

- A large areal extent of waste (estimated at 8 acres) would be disturbed under this alternative (Drawing 007).

- Waste excavation could include approximately 110,000 bcy of material potentially containing RIM (i.e., from below the 1975 topographic surface) which would increase time to perform, potential risks to on-site workers and potential risks to the community associated with any off-site disposal of RIM.

- Time to construct – at a projected rate of 1400 bcy/day (average of rate above the 1975 topographic surface and a lesser rate due screening for RIM below the 1975 surface), waste excavation activities alone would take at least 400 days to complete. Planning for bird mitigation measures indicates that the highest risk for attracting birds to the excavation areas would occur during winter months (Attachment D) which could limit the periods when waste excavation could be conducted and consequently the actual time required to implement this alternative could be significantly longer.

- The large volume of waste to be excavated would necessitate use of multiple waste relocation areas on-site and potential off-site transport and disposal of some of the excavated waste.

- The large volume of waste to be excavated, large area of waste excavation and long duration of waste excavation activities would pose a significant risk of increased attraction to birds to the site and resultant potential hazard to aircraft landing and taking off from nearby Lambert-St. Louis International Airport. As detailed in the Isolation Barrier Alternatives Analyses – Bird Control Issues prepared by LGL Limited (Attachment D) it is less than certain that a successful bird control program could be developed and implemented for the extensive excavation required by Option 2.

- The large volume of waste to be excavated, large area of waste excavation and long duration of waste excavation activities would pose a significant potential for release of odors at the site and into the adjacent community.

- The large area disturbed under this alternative would result in destruction of significant amounts of existing infrastructure (e.g., LFG extraction wells and conveyance piping and landfill cover system) associated with the North Quarry area of the Bridgeton Landfill.

- Creation of an air gap would require re-design/re-construction of significant portions of the North Quarry area of the Bridgeton Landfill infrastructure (e.g., LFG extraction wells and conveyance piping, leachate conveyance piping, air lines, etc.) to route around or over the air gap.

- Creation of an air gap would result in excavation of a large depression into the North Quarry area of the Bridgeton Landfill wastes that represents a significant problem with respect to stormwater management because the air gap excavation would extend between 25 to 50 ft below adjacent grades and as such would collect stormwater runoff with no way to gravity drain such runoff. Excavation of a large depression would require design and installation of a complex stormwater pumping system or alternatively import and placement of large volumes of soil/ inert fill material to re-establish positive drainage, eliminating a portion of the air-gap.

Although the air gap barrier alternative offered the advantage of no physical structure, based on the significant disadvantages of this alternative, this alternative is not considered to be feasible at this Site. All parties (EPA, EPA-ORD, USACE, and Bridgeton Landfill) agreed that this option would not be retained for further consideration.

6.0 OPTION 3 – INERT BARRIER ALONG ALIGNMENT 3

Under Option 3, an inert barrier would be installed within the northern portion of North Quarry area of the Bridgeton Landfill. Similar to Option 1, the barrier considered under Option 3 would consist of a subsurface, reinforced concrete wall extending from the ground surface down through the bottom of the waste material. In order to minimize potential differential stresses across the barrier that could occur from destruction, consolidation and settlement of waste material if an SSE reaction/pyrolysis of waste were to occur along the south side of the barrier, the Option 3 barrier alignment has been stepped back from the deeper portions of the North Quarry area of the Bridgeton Landfill. The step-back distance is based on an angle of 45° from the edge of the deeper portion of the North Quarry area of the Bridgeton Landfill extending upward to the north to the ground surface. The resultant alignment is provided on Drawing 009.

Preliminary estimates of the extent and depths of waste excavation required to implement this alternative are provided on Drawing 010. A profile view and cross-sections of the anticipated extents of waste excavation required by this alternative are provided on Drawing 011. The anticipated areas on-site where the excavated wastes would be relocated are shown on Drawing 012. A schematic of the anticipated barrier configuration is provided on Drawing 016.

6.1 Design Criteria and Performance Objectives

The preliminary design criteria for this alternative are similar to those described for Option 1 and are based on the presumption that the SSE reaction would move to the north from the South Quarry area of the Bridgeton Landfill into the North Quarry area of the Bridgeton Landfill and towards Area 1 into the area of the proposed alignment of Alternative 3. Furthermore, it is assumed that the heat fluxes associated with the migrating front would be similar in nature to those found within the area currently impacted by the SSE. Therefore, the preliminary design criteria for this alternative would be based on a conservative assumption that pyrolosis driven settlement would occur wherever temperatures are projected to occur at levels greater than 200° F. The allowable temperatures within the barrier wall would be limited to 200° C (approximately 400° F) which is well within the levels that studies have shown that reinforced concrete can continue to provide performance (Attachment B). However, in order to insure that elevated temperatures would not be conducted across the barrier wall to the waste materials on the north side, the barrier wall would include heat exchange tubes that would be built into the concrete wall as it is constructed to enable extraction of heat and cooling of the wall. Design of the heat extraction component would be based on published heat conduction values for concrete and a preliminary design value for the temperature of the circulated liquid of 85° F, consistent with the use of adiabatic air coolers with closed loop liquid circulation systems. Additional details regarding the preliminary evaluation of the design criteria and performance objectives for this alternative are presented in Attachment B.

6.2 Waste Excavation and Relocation Volume Estimates

Construction of a inert barrier would require excavation of existing waste materials from the North Quarry area of the Bridgeton Landfill in order to provide the necessary working platform required for operation of equipment, to reduce the overall depth of excavation, and to reduce the height of the barrier and the resultant potential deformations and stresses that may affect the barrier (Drawing 010). Pre-excavation volumes based upon a flat platform width of 60 feet would result in a volume of approximately 52,500 bcy of existing waste materials (Drawings 010 and 011). The total area of waste excavation would have a plan view area of approximately 3.4 acres (Drawing 010). Construction of the barrier would result in removal and relocation of additional existing waste materials. Assuming a barrier width of 5.0 feet (60 inches), the volume of waste excavation associated with barrier construction is estimated to be approximately 11,000 bcy (Drawings 010 and 011).

The excavated waste would need to relocated and re-disposed on-site. The area required for waste relocation under this alternative is estimated to be approximately 3.5 acres within the fill area south of OU-1 Area 1 and overlapping the northeast slope of the North Quarry area (Drawing 012). It is assumed that upon excavation and loading, the volume of waste would swell (expand) approximately 50%. Therefore the volume of waste to be transported is estimated to be 95,250 lcy. It is assumed that there would be a waste swelling factor between excavation, transportation, and relocation that could be over 20% ultimate swell, resulting in a total volume to be re-disposed of approximately 76,200 lcy. Relocation and placement of the waste would require additional daily soil cover and installation of a final cover over the waste materials, which is estimated to increase the overall volume of materials to be placed in the waste relocation area by an additional 25%. Consequently, the total volume required for relocation of waste materials under this alternative is estimated to be approximately 95,250 bcy.

6.3 Preliminary Design and Construction Schedules

Installation of a non-deformable barrier within a matrix of solid wastes is an application that has not previously been applied or demonstrated in solid waste. Installation of a reinforced concrete wall in MSW to depths of up to 68 feet would include design features associated with withstanding potentially large deformations and stresses, as at least portions of the alignment are located near areas of significantly greater waste thickness than the Option 1 alignment. This will result in greater total waste thicknesses being potentially exposed to pyrolyzing temperatures, resulting in greater settlements than expected for the Option 1 alignment. These requirements would dictate use of some elements that are typically not found in structural slurry walls. Development and testing of these elements would be required.

Design of a subsurface, reinforced concrete wall would require a large number of design parameters to be estimated that involve the specific behavior of a heterogeneous material (waste), a reaction that has been observed but is not completely understood, and undefined circumstances associated with the arrival and magnitude of settlements associated with the reaction. These conditions can only be bounded approximately and once the barrier is installed, its performance cannot be significantly altered. Design of this alternative may require use of 3-

dimensional modeling that would be more difficult and more time consuming that would be required for the other alternatives.

The design may also require some additional time for testing of the rebar details for tension and some mockups, which could add additional time to the design effort. Installation of a rigid, subsurface, reinforced concrete wall would require development of a plan and procedures for monitoring during construction to verify continuity/connectivity of adjacent panels. Trench construction using slurry would require slurry decanting/liquid. Management of stormwater during barrier construction could be difficult due to existing limits with respect to stormwater management at the site. Procedures for management of slurry and stormwater would need to be developed during the design phase.

Due to delay between inert barrier installation and the time if, and when, a barrier could be needed, monitoring/testing would likely be required to demonstrate the continued integrity/ performance of the barrier over time. The scope and adequacy of such monitoring would need to be developed during the design phase. The complexity of and uncertainties associated with the design of this alternative would also likely result in significant increase in the amount of time required for EPA and USACE review and approval of the design submittals. Consequently, the total time required to prepare a final design for this Option 3 alternative is estimated to be 122 weeks (see Figure 6).

Based on preliminary discussions with one potential vendor, the total time required to construct this alternative is estimated to be 61 weeks (see Figure 7). This schedule is based on an assumption that other than screening by field instruments, no testing would be necessary to support excavation and relocation of waste removed during the pre-excavation phase (i.e., waste located above the 1975 topographic surface which does not contain any RIM). Testing would be required for waste excavation conducted in conjunction with installation of the barrier wall because portions of the barrier excavation are expected to extend below the elevation of the 1975 topographic surface.

6.4 Potential for the Alternative to Result in Odor Releases

Because excavation and relocation of waste materials would be required to implement this alternative, this alternative poses a strong potential for generation and release of odors. Performance of the pre-excavation and waste relocation activities is expected to result in exposure of waste materials to the atmosphere for approximately 13 weeks (Figure 7). The overall area of the pre-excavation disturbance is estimated to be 3.4 acres for this alternative. The overall size of the waste relocation area(s) for this alternative is estimated to be 3.5 acres. Excavation and exposure of waste materials during the construction of the barrier wall is estimated to last approximately 35 weeks.

Procedures that could potentially mitigate odor releases would include placement of daily soil or other cover materials on waste relocation areas and/or use of a masking fragrance. It may also be possible to install vacuum gas piping adjacent to the trench during trench excavation but the practicality, effectiveness and anticipated durability of such piping would need to be evaluated during the design phase. This technique is not considered to be implementable during the pre-excavation activities when the majority of waste excavation and relocation activities would occur. It should also be noted that the pre-excavation activities would occur in relatively younger waste (post 1995), which is expected to have a greater potential for odor generation and emission than the underlying older (pre-1995 up to pre-1975) more decomposed waste materials.

6.5 Potential for the Alternative to Attract Birds

Because excavation and relocation of waste materials would be required to implement this alternative, this alternative poses a strong potential for generation and release of odors and exposure of waste which could attract birds to the area. Planning for bird mitigation measures indicates that the highest risk for attracting birds to the excavation areas would occur during winter months (Attachment D) which could limit the periods when waste excavation could be conducted.

Performance of the pre-excavation and waste relocation activities is expected to result in exposure of waste materials to the atmosphere for approximately 13 weeks. The overall area of the pre-excavation disturbance is estimated to be 3.4 acres for this alternative. The overall size of the waste relocation area(s) for this alternative is estimated to be 3.5 acres.   Excavation and exposure of waste materials during the construction of the barrier wall is expected to last approximately 35 weeks.

As detailed in the attached Isolation Barrier Alternatives Analyses – Bird Control Issues document (Attachment D), a bird monitoring and control program would need to be developed for implementation at the start of invasive work and continuing throughout the time that waste materials are exposed. Option 3 would disturb more waste than Option 1 and is expected to disturb younger waste, increasing the likelihood that the waste could retain organic material attractive to birds. However, whether any exposed waste would contain organic material that could be a bird attractant cannot be definitively known until if and when such waste is actually exposed. Because successful bird control is dependent upon maintaining effective control from the start of any work that would expose waste, it must be presumed for planning purposes that the waste could present an attractant and appropriate procedures employed.

Based upon the assessment of LGL Limited as detailed in Attachment D, an effective bird mitigation plan could be prepared and implemented for Option 3. A detailed plan would be prepared during the engineering design phase in close coordination with the Airport.

6.6 Potential Risks Associated with the Alternative

Although the Phase 1 Bridgeton Landfill Thermal Isolation Barrier Investigation did not extend to the area of the western portion of Alignment 3, material located below the 1975 topographic surface (which could potentially contain RIM) is present to the south of the proposed alignment for Option 3. Therefore, isolated occurrences of RIM may potentially be present outside of a barrier installed along Alignment 3.

Based on the results of the evaluations performed for Option 1, potential occurrences of RIM outside of the barrier would not be expected to pose a significant risk (see Attachment A). Similarly, the presence of RIM outside of the barrier would not be expected to result in an exceedance of the Radon NESHAP or other impacts or risks to human health or the environment (see Attachment A).

6.7 Potential Advantages and Disadvantages of the Alternative

The RIM material that would potentially remain outside of the barrier wall is currently covered by 25 to over 50 feet of solid waste and a landfill cover that prevents direct contact with the RIM and provides shielding from gamma radiation. Radon emissions from the RIM material located outside of the barrier would not result in an exceedance of the Radon NESHAP. In addition, this area would ultimately be covered with an ethyl-vinyl alcohol cap which would limit any surface emissions of landfill gas and radon from this area. Therefore, Option 3 is protective of public health and the environment.

Advantages of Option 3

- This alternative may not isolate 100% of the RIM but would result in the least potential amount of RIM being located outside (south) of the barrier wall of all of the alternatives considered. Regardless, the presence of RIM outside of the barrier is not expected to pose unacceptable risks (see Section 6.6 and Attachment A).

- With the exception of any RIM that may be encountered, the volume of which is expected to be relatively small and could potentially be relocated into Area 1, all of the waste materials excavated under this alternative would be relocated on-site. Therefore, this alternative would not entail off-site transportation and disposal of waste.

- Construction of a subsurface, reinforced concrete wall is an established technology; application of this technology is considered technically feasible. However, application of this technology within solid waste has not previously been demonstrated so some uncertainty exists.

- The presence of an inert barrier and associated heat extraction system along this alignment is not expected to impact the design and implementation of remedial actions for OU-1.

Disadvantages of Option 3

- This alternative would require excavation and relocation of approximately 63,500 bcy of waste including excavations to depths up to 68 feet. This alternative would result in the largest volume of waste excavation and the greatest depths of waste excavation of all of the alternatives being considered.

- Trench excavation would occur in areas of potential RIM requiring testing and potentially management and disposal of RIM. Testing for thorium would require samples to be analyzed in an on-site or off-site laboratory and at least a 24-hour sample turnaround period, which could impact/slow/delay construction.

- Because this alternative would require the greatest amount of waste materials to be excavated and relocated, this alternative poses the greatest potential for odor emissions of all of the alternatives.

- Because this alternative would require the greatest amount of waste materials to be excavated and relocated, this alternative poses the greatest potential for attraction of birds and resultant bird hazard potential of all of the alternatives.

- Because the alignment for this alternative would be located within the North Quarry area of the Bridgeton Landfill resulting in significant amounts of waste to the north of the barrier, the highest potential for a SSE to originate on the north side of the barrier is associated with Option 3. This alternative would result in the maximum quantity of waste material of the same age and character as that deposited in the South Quarry area of the Bridgeton Landfill remaining on the north side of the barrier.

- Because this alternative would entail the greatest amount of waste excavation and relocation, this alternative poses the greatest potential risks to on-site worker safety of all of the alternatives.

- Delivery of significant amounts of equipment and materials for barrier construction would result in increased traffic into, out of, and adjacent to the site. Of all the barrier alternatives, this option would require the greatest amount of materials for barrier construction and therefore would result in the largest amount of increased traffic.

- This alternative would require a large amount of time for design investigation, design, and design review, resulting in a significant design time frame of approximately 122 weeks.

- The appropriate spacing of cooling points within the barrier is currently uncertain and would require additional design basis information (likely to be obtained from ongoing heat extraction testing in the South Quarry area of the Bridgeton Landfill).

- The total construction time for this alternative is estimated to be 61 weeks; however, because installation of an inert barrier within solid waste is a new, previously undemonstrated application, potential delays and/or increased construction periods are possible with this alternative, as for Option 1, but to a greater extent given the greater settlements anticipated.

- Because this alternative would entail excavation of significant amounts of waste from the North Quarry area of the Bridgeton Landfill, this alternative poses the greatest potential to affect North Quarry area infrastructure (e.g., LFG collection wells and conveyance piping, leachate collection conveyance piping, and air lines used to operate pumps).

- While it is believed that a reinforced concrete wall in MSW can be designed and constructed, the level of uncertainty in the final performance of the system increases greatly as the wall height, the waste depth, and the likely thickness of pyrolizing waste increases. Therefore, the uncertainty with respect to performance of a barrier wall at this location is the greatest of all of the alternatives under consideration.

7.0 OPTION 4 – HEAT EXTRACTION BARRIER

This alternative would include installation of a heat extraction barrier along the northern boundary of the North Quarry area of the Bridgeton Landfill (Drawing 013). The heat extraction barrier would be installed along the existing access road and/or areas of low slope so as to minimize or eliminate the need for any waste excavation and such that depths of the extraction points would be relatively shallow allowing for easier and quicker installation. The heat extraction barrier would consist of two or more rows of heat extraction (cooling) points (Drawings 014 and 015) into which cool water or other liquid would be circulated in a closed system (no exposure to waste or the air) to remove heat (Drawing 016).

7.1 Design Criteria and Performance Objectives

Preliminary design criteria for this alternative were developed and are presented in Attachment C. Similar to the inert barrier alternatives, the design criteria for the heat extraction alternative presumes that the SSE reaction in the South Quarry area of the Bridgeton Landfill would migrate to the north from the South Quarry area of the Bridgeton Landfill into the North Quarry area of the Bridgeton Landfill and towards Area 1 into the area of the proposed alignment of Alternative 1. Furthermore, it is assumed that the heat fluxes associated with the migrating front of a SSE reaction would be similar in nature to those found within the South Quarry area of the Bridgeton Landfill.

The heat extraction barrier would consist of two or more rows of heat extraction points. Each heat extraction well would consist of an inner pipe delivering cool liquid (from a closed loop header from the cooler) to the base of the outer pipe (see Drawing 016). Cooled liquid would flow from the base of the outer pipe to the upper end of the outer pipe where the temperature of the liquid would be measured and the warmed liquid would be conveyed to a cooler via a closed loop header. The cooler would consist of an adiabatic air cooler installed with a closed loop liquid circulation system. Cooling liquid would be water based with additives to prevent freezing. The system would be sized for the maximum temperature extraction needed, based on the results of the thermal landfill modeling, to maintain the waste on the north side of the barrier at an average temperature of 175 degrees Fahrenheit (a temperature at which the waste would not pyrolyze). The materials used to construct the heat extraction barrier would be composed of corrosion resistant metals. The spacing of the heat extraction points would be based on the necessary heat extraction rates predicted from the ongoing heat extraction study in the South Quarry area of the Bridgeton Landfill and heat modeling simulations. Specifically, results from the South Quarry Heat Extraction Pilot Study would be used to develop waste heat conduction and heat capacity information for the wastes located along the proposed alignment of Option 4. The finite element program FEFLOW would be utilized to model the potential heat flux migration rates within the North Quarry area, and for the barrier design.

For purposes of the design evaluations, it would be conservatively presumed that migration of the SSE from the South Quarry area of the Bridgeton Landfill through the North Quarry area of the Bridgeton Landfill to the area of the proposed heat extraction barrier would occur within 15 years. Based upon experience at other sites, reactions in a given area subside within 10 years of reaction initiation after which time the stored energy in the form of elevated temperature begins to dissipate slowly. The active extraction of heat should allow this dissipation time to be accelerated. In the case of Option 4, the thickness of the waste mass is limited, which would allow significant heat loss to the ground surface and bottom of waste, even without the active heat extraction component. Once, and if, the SSE reaction is at the barrier and including a 10 year cooling period after the end of active heat generation locally, a design life of 20 years is considered appropriate for the unreplaceable elements of the barrier. Therefore, the overall service life of the heat extraction barrier would be expected to be on the order of 35 years or less (i.e., 15 years for the SSE to arrive, 10 years of excess heat, and 10 years of heat dissipation).

It should also be noted that in contrast to an inert barrier, a heat extraction barrier is a flexible system. The design and performance of a heat extraction system can be modified over time to adjust operations to meet the performance criteria. The system can be adjusted through addition of heat extraction points or changes in the cooling system, thereby providing significant potential for operational adjustments to address any unanticipated conditions in overall system performance that may arise.

7.2 Waste Excavation and Relocation Volume Estimates

Because the heat extraction barrier wells and associated piping would be installed along the existing road between Area 1 and the North Quarry area of the Bridgeton Landfill and within low, generally flat areas within Area 1, no or only minimal waste excavation/relocation is anticipated to be necessary to implement this alternative.

7.3 Preliminary Design and Construction Schedules

The total time required to design this alternative is estimated to be 62 weeks (see Figure 8). A portion of this time period (approximately 13 weeks) would be associated with completion of the currently ongoing heat extraction pilot study in the South Quarry area of the Bridgeton Landfill (Figure 8). Bridgeton Landfill, LLC has already begun implementation of this pilot study which would reduce the overall duration of the design activities. Results of this study would be required to prepare designs for any of the barrier options.

The total construction time required for this option is estimated to be 21 weeks (see Figure 8).

7.4 Potential for the Alternative to Result in Odor Releases

Because this alternative would not include any waste excavation and the casing for the heat extraction points would be driven in place resulting in no generation of drill cuttings (e.g., waste), this alternative is not expected to pose a potential for odor release.

7.5 Potential for the Alternative to Attract Birds

Because this alternative would not include any waste excavation and the casing for the heat extraction points would be driven in place resulting in no generation of drill cuttings (e.g., waste), this alternative is not expected to pose a potential for attracting birds and should not require any bird mitigation/management measures.

7.6 Potential Risks Associated with the Alternative

Based on the results of the Phase 1 Bridgeton Landfill Thermal Isolation Barrier Investigation, isolated occurrences of RIM are expected to be present outside of the heat extraction barrier that would be installed under Option 4. Specifically, RIM was identified at drilling locations 1C-6 and 1C-12 which would be located outside (south) of the Option 4 alignment (Drawing 014). In addition, material located below the 1975 topographic surface, which could potentially contain RIM, is present to the south of the proposed alignment for Option 4.

Potential occurrences of RIM outside of the barrier are not expected to pose a significant risk (see Attachment A). The presence of RIM outside of the barrier would not result in an exceedance of the Radon NESHAP (see Attachment A) or other impacts or risks to human health or the environment.

7.7 Potential Advantages and Disadvantages of the Alternative

The RIM material that would remain outside of the barrier wall is currently covered by 25 to 50 of solid waste and a landfill cover that prevents direct contact with the RIM and provides shielding from gamma radiation. Radon emissions from the RIM material located outside of the barrier would not result in an exceedance of the Radon NESHAP. Installation of the engineered landfill cover and other measures included under EPA’s ROD-selected remedy would further limit any access to RIM, any possible exposure to radiation from the RIM, and radon emissions from RIM located to the north or south of the heat extraction barrier. Therefore, Option 4 is protective of public health and the environment.

Advantages of the Option 4

- This alternative would not require any, or at most only minimal, waste excavation and relocation.
- This alternative would not require the use of slurry and associated management and disposal and would not impact stormwater generation or drainage as would occur with the inert barrier options.

- Because only direct push drilling and installation of wells without any waste excavation or generation of drill cuttings would be performed under this alternative, this alternative is not expected to cause any release of odors.

- Because only direct push drilling and installation of wells without any waste excavation or generation of drill cuttings would be performed under this alternative, this alternative is not expected to result in any attraction for birds and resultant bird hazard potential.

- Because this alternative is located along the northern boundary of the North Quarry area of the Bridgeton Landfill wastes, it offers the lowest potential for a SSE to originate on the north side of the barrier.

- Because only drilling and installation of wells without any waste excavation would be performed under this alternative, this alternative would pose very low risks to on-site worker safety.

- Because only drilling and installation of wells without any waste excavation would be performed under this alternative, this alternative would not pose risk to off-site public safety.

- Because no waste excavation would be performed under this alternative, this alternative would not entail off-site transportation and disposal of waste.

- This alternative would be the easiest and quickest (estimated 21 weeks) to install of all of the options considered and would be expected to have the lowest potential for delays and/or increased construction period of all of the alternatives.

- Because this alternative would be installed along the north side of the North Quarry area of the Bridgeton Landfill and would not require any waste excavation, this alternative would not impact North Quarry area infrastructure;

- Implementation of this alternative would not change or otherwise affect stormwater management at the site.

- Installation of heat extraction points is a common technology used for geothermal energy development and therefore this alternative is technically feasible. Uncertainty does exist as to the design requirements and expected performance of such a system; however, these uncertainties are expected to be addressed based on the results of the currently ongoing heat extraction study in the South Quarry area of the Bridgeton Landfill. In addition, unlike the inert barrier wall options, installation and operation of heat extraction points would include significant flexibility allowing for future adjustments to both the design and/or operation of system in response to observed performance.

Disadvantages of Option 4

- Although heat extraction systems are common technologies used in geothermal energy applications, use of such technology to cool MSW is an unproven application that has not previously been applied or demonstrated. Therefore, this alternative would require a large amount of time for design and design review resulting in a significant estimated design time frame of approximately 62 weeks (Figure 8). The appropriate spacing of cooling points for such a barrier is currently uncertain and would require additional design basis information (likely to be obtained from ongoing heat extraction pilot study in the South Quarry area of the Bridgeton Landfill).

- Because this alternative would entail installation of infrastructure within and adjacent to Area 1, this alternative could impact the design and/or implementation of remedial actions for OU-1. However, because adjustments to well heights and conveyance piping in response to changes in grades over time is a common activity at landfills, any such potential impacts are not expected to be significant.

8.0 SUMMARY AND CONCLUSIONS

A summary comparison of the advantages and disadvantages of the various alternatives is presented on Table 1. Overall, Option 4, the Heat Extraction Barrier, appears to offer the greatest number of advantages and the least number of disadvantages of all of the alternatives other than the No Action Alternative. Specifically, Option 4 offers the following advantages:

- Option 4 would not require any waste excavation or relocation;
- Option 4 would not require handling, management and disposal of slurry material;
- Option 4 would not impact or change stormwater management at the Site;
- Because no waste excavation or relocation would be performed, Option 4 would not cause any odors;
- Because no waste excavation or relocation would be performed, Option 4 would not attract birds or pose a bird hazard potential to aviation;
- Some RIM may remain on the south side of the Heat Extraction Barrier; however, implementation of heat extraction under Option 4 would minimize the potential for a SSE to migrate into the areas where the RIM may be present;
- Option 4 would be located as close as possible to the RIM in Area 1 and thereby minimize the volume of waste on the north side of the barrier and thus minimize the potential for a SSE to occur on the north side of the barrier;
- Because the only construction activities included under Option 4 would drilling (direct push without cuttings return and recovery) and installation of cooling points, this option would pose the least risk of exposure to RIM or other risks to on-site workers;
- Because no waste excavation or relocation would be performed, Option 4 would not pose any risks to the public;
- The estimated duration of the design activities for Option 4 is the shortest of all of the options;
- The estimated duration of the construction phase for Option 4 is the shortest of all of the options;
- Because Option 4 would only entail installation of wells, it would not impact existing infrastructure;
- Option 4 would be the simplest and most easily implemented of all of the options;

- Option 4 would be the only option that offers a flexible system that could easily be augmented or modified in the future if necessary; and

- Although Option 4 would be installed in an area where future regrading and landfill cover installation would be performed under the ROD-selected remedy, it would be relatively simple to modify the heights of the heat extraction points and re-route/replace header piping associated with the heat extraction system to account for future regrading and landfill cover installation activities as such actions are routinely and commonly performed at landfills.

9.0 REFERENCES

Auxier & Associates, Inc. (Auxier), 2000, Baseline Risk Assessment (Appendix A to Remedial Investigation Report), West Lake Landfill Operable Unit 1, April 24.

Bridgeton Landfill, LLC, 2014a, Expanded Heat Removal Pilot Study, Bridgeton Landfill, Bridgeton Missouri, Permit No. 0118912, July 22.

Bridgeton Landfill, LLC, 2014b, electronic mail from James Getting (Bridgeton Landfill, LLC) to Chris Nagel (MDNR) re: Bridgeton Landfill: Alternative Heat Extraction Pilot Study – Addendum 1, August 15.

Bridgeton Landfill, LLC, 2014c, electronic mail from James Getting (Bridgeton Landfill, LLC) to John Boessen (MDNR) re: Bridgeton – Heat Extraction – Cooler and Pum, August 18.

Civil & Environmental Consultants, Inc. (CEC), 2014, Comments on Thalhamer Data Review Memo, Bridgeton Landfill, Bridgeton, Missouri, CEC Project 131-178, September 16.

Engineering Management Support, Inc. (EMSI), 2014, Evaluation of Possible Impacts of a Potential Subsurface Smoldering Event on the Record of Decision – Selected Remedy for Operable Unit-1 at the West Lake Landfill, January 14.

EMSI, 2011, Supplemental Feasibility Study for Operable Unit-1, West Lake Landfill Superfund Site, December.

EMSI, 2000, Remedial Investigation Report, West Lake Landfill Operable Unit 1, April 10.

Feezor Engineering, Inc., 2014, Bridgeton Landfill Thermal Isolation Barrier Investigation Phase 1 Report, Bridgeton Landfill, LLC, *in preparation*.

RAECOM web calculator used in this evaluation is hosted at http://www.wise-uranium.org/ctc.html (March 21, 2011).

Thalhamer, Todd, P.E., 2014a, Memorandum: Comments on the Evaluation of Possible Impacts of a Potential Subsurface Smoldering Event on the Record of Decision – Selected Remedy for Operable Unit-1 at the West Lake Landfill – Dated January 14, February 13.

Thalhamer, Todd, P.E., 2014b, Memorandum: Addendum to the February 14, 2014 Comments on the Evaluation of Possible Impacts of a Potential Subsurface Smoldering Event on the Record of Decision – Selected Remedy for Operable Unit-1 at the West Lake Landfill – Dated January 14, April 14.

United States Army Corps of Engineers (USACE), 2014, Isolation Barrier Alignment Alternatives Assessment, West Lake Landfill, Bridgeton, Missouri, August 25.

United States Environmental Protection Agency (EPA), 2014a, Letter from Alyse Stoy (EPA) to Jessie Merrigan, Lathrop & Gage Re: Isolation Barrier Alternatives Assessment Report, West Lake Landfill Superfund Site, August 26.

EPA, 2014b, electronic mail from Jeff Field (EPA) to Joe Benco (Republic Services) and Paul Rosasco (EMSI), Re: Alternative Clarification, September 23.

EPA, Office of Research and Development (ORD), National Risk Management Research Laboratory (NRMRL), Engineering Technical Support Center (ETSC), 2014, Memorandum: Observations on the EMSI report: *Evaluation of Possible Impacts of a Potential Subsurface Smoldering Event on the Record of Decision – Selected Remedy for Operable Unit-1 at the West Lake Landfill*, Dated January 14, 2014, March 28.

EPA, 2008, Record of Decision – West Lake Landfill Site, Bridgeton, Missouri, Operable Unit 1, May.

Table

Table 1 - Comparative Summary of Alternatives

Criteria	No Action Alternative	Option 1 Inert Barrier Along Alignment 1	Option 3 Inert Barrier Along Alignment 3	Option 4 Heat Extraction Barrier
Protective of Human Health and Environment	Yes	Yes	Yes	Yes
Waste Excavation				
Volume (bank cubic yards)	None	52,000	64,000	None
Depth (feet)	None	54	68	None
Area of waste exposed (acres)	None	3.4	3.4	None
Waste Relocation Area (acres)	None	3.5	3.5	None
Odor				
Potential?	None	Yes, excavation of young trash	Yes, excavation of young trash	None
Weeks waste is exposed (waste relocation + barrier construction)	NA	40	48	NA
Bird Hazard				
Potential (duration of waste exposure and odor potential)?	None	Yes	Yes	None
Duration waste exposed (weeks)	NA	40	48	NA
RIM remaining South of Isolation Barrier	NA - no barrier	Yes, IC-6, IC-12, and MSW below 1975 topography	Possibly if excavate MSW below 1975 topography	Same as Option 1
Potential for SSE North of Isolation Barrier	NA - no barrier	Very low	Yes, large amount of waste North of Isolation Barrier	Very low
On-Site Worker Safety Risk	None	Yes, possible RIM	Possibly	Minimal
Off-Site Public Safety Risk	None	No, unless off-site RIM disposal	No, unless off-site RIM disposal	None
Off-Site Transportation and Disposal	None	No, unless off-site RIM disposal	No, unless off-site RIM disposal	None
Design Duration (weeks)	NA	103	122	62
Construction Duration (weeks)	NA	53	61	21
Impact to Existing Infrastructure	None	Some, but minimal	Yes	None
Technically Feasible?	Yes	Yes	Yes	Yes
Impact to West Lake Landfill OU-1 Remedy	None	Potentially	Minimal	Minimal

Figures

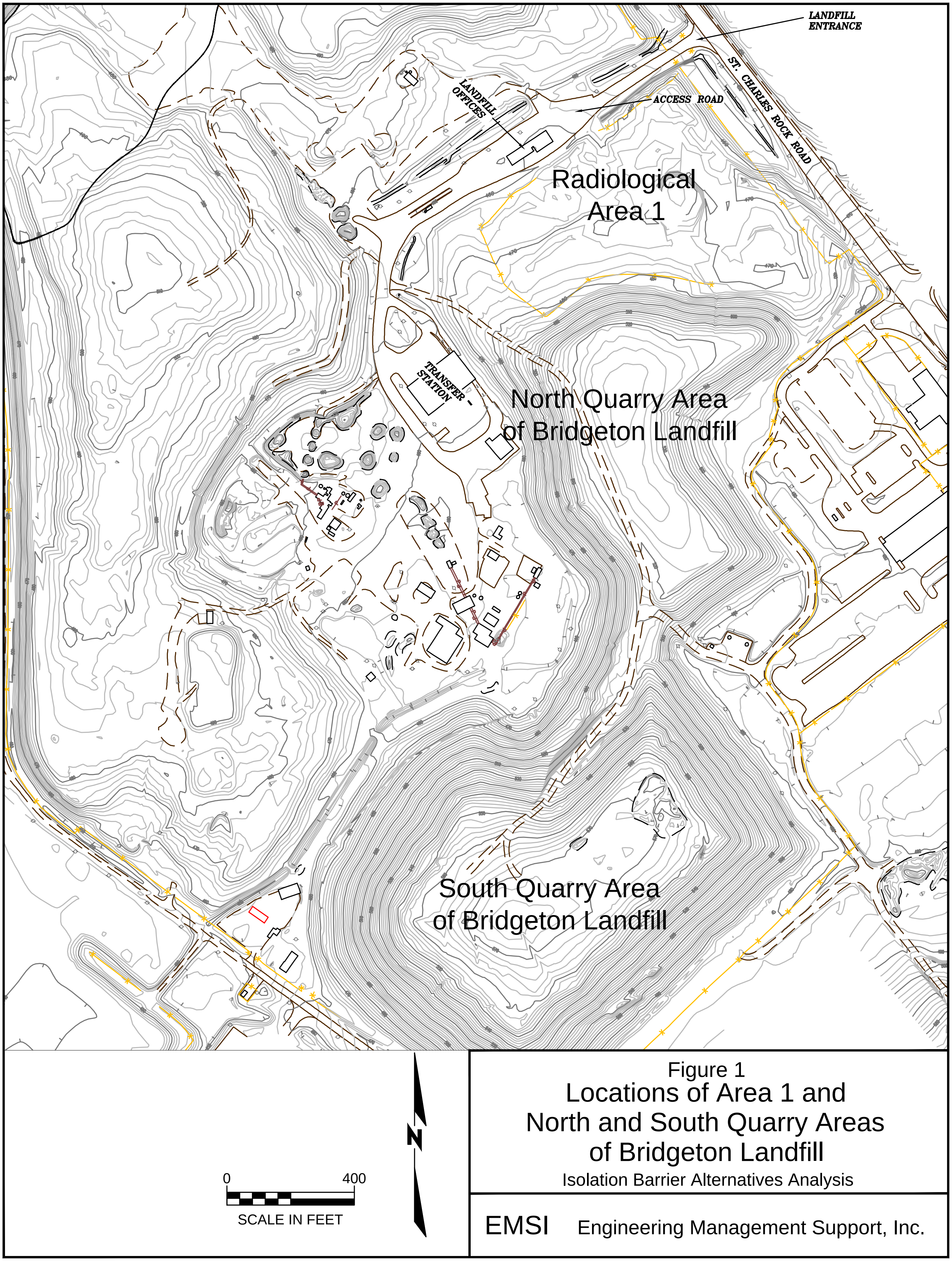


Figure 1

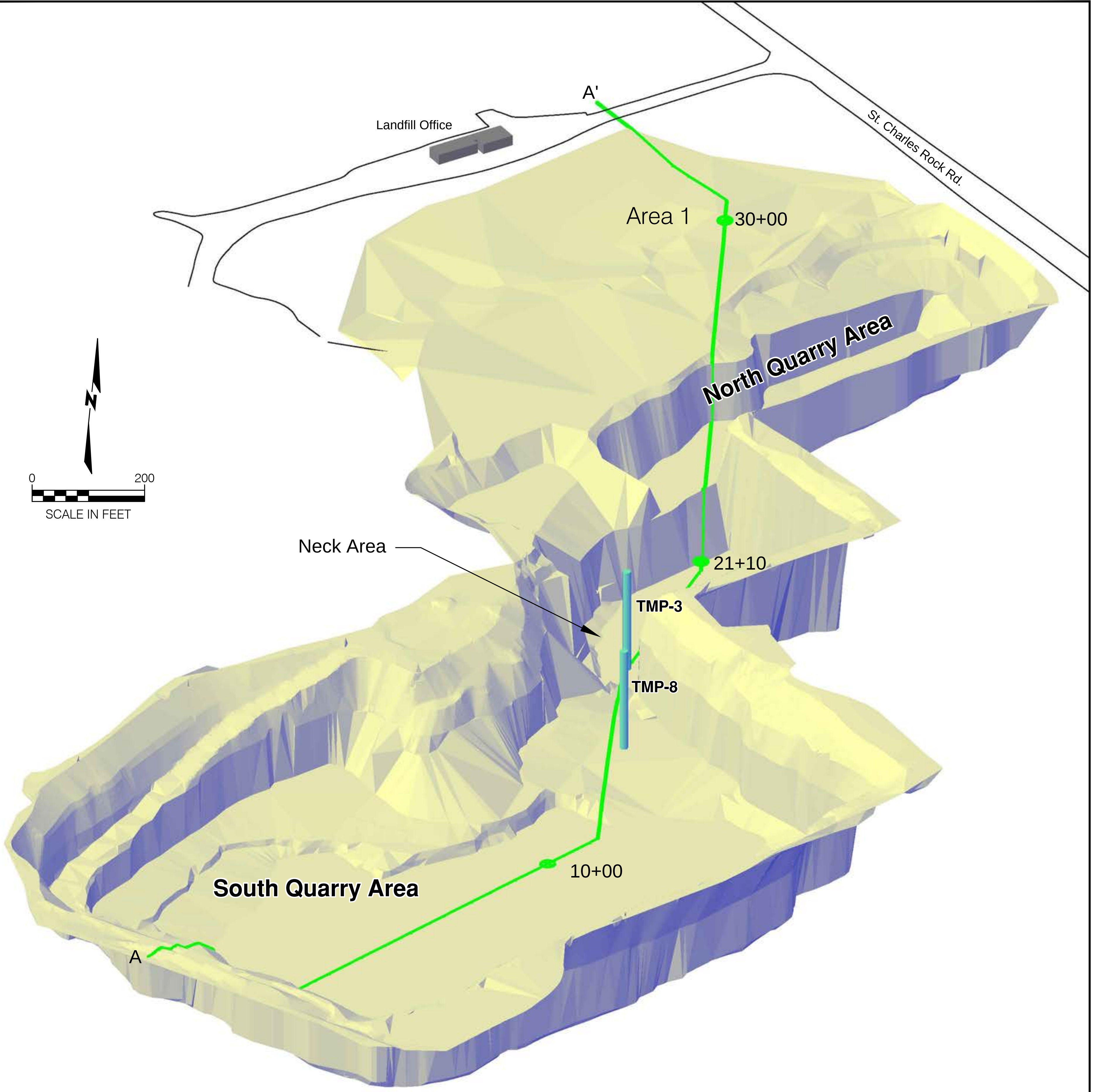
Locations of Area 1 and North and South Quarry Areas of Bridgeton Landfill

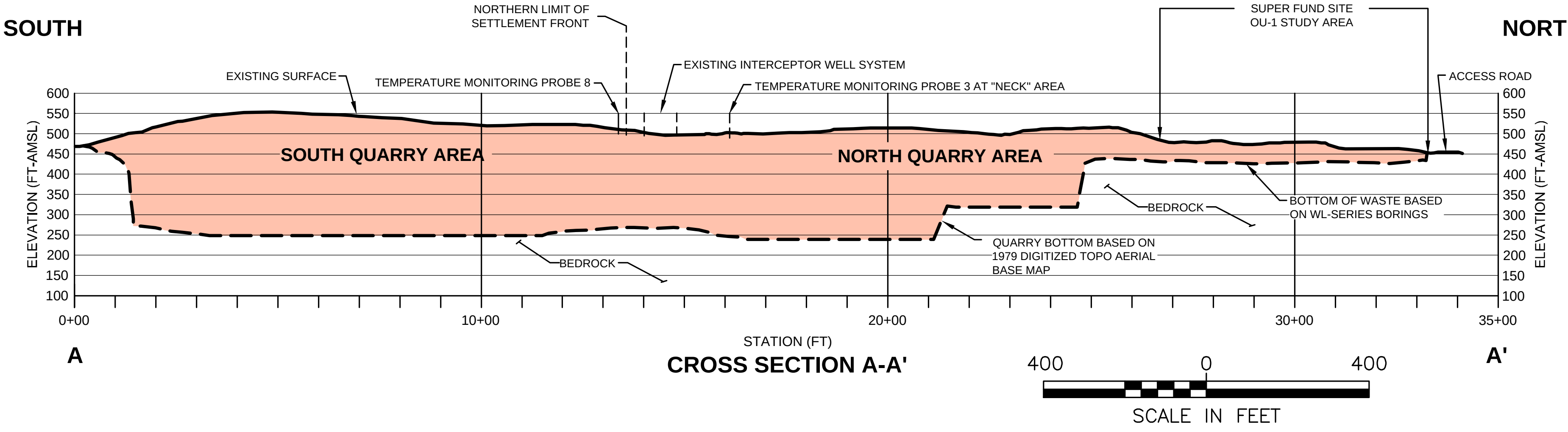
Isolation Barrier Alternatives Analysis

EMSI Engineering Management Support, Inc.

M:\clients\EMSI\westlake\2014\10\Thermal-Alignment.dwg plotted: 10/10/2014

M:\clients\EMSI\westlake\2014\10\3D-Quarry.dwg plotted: 10/10/2014

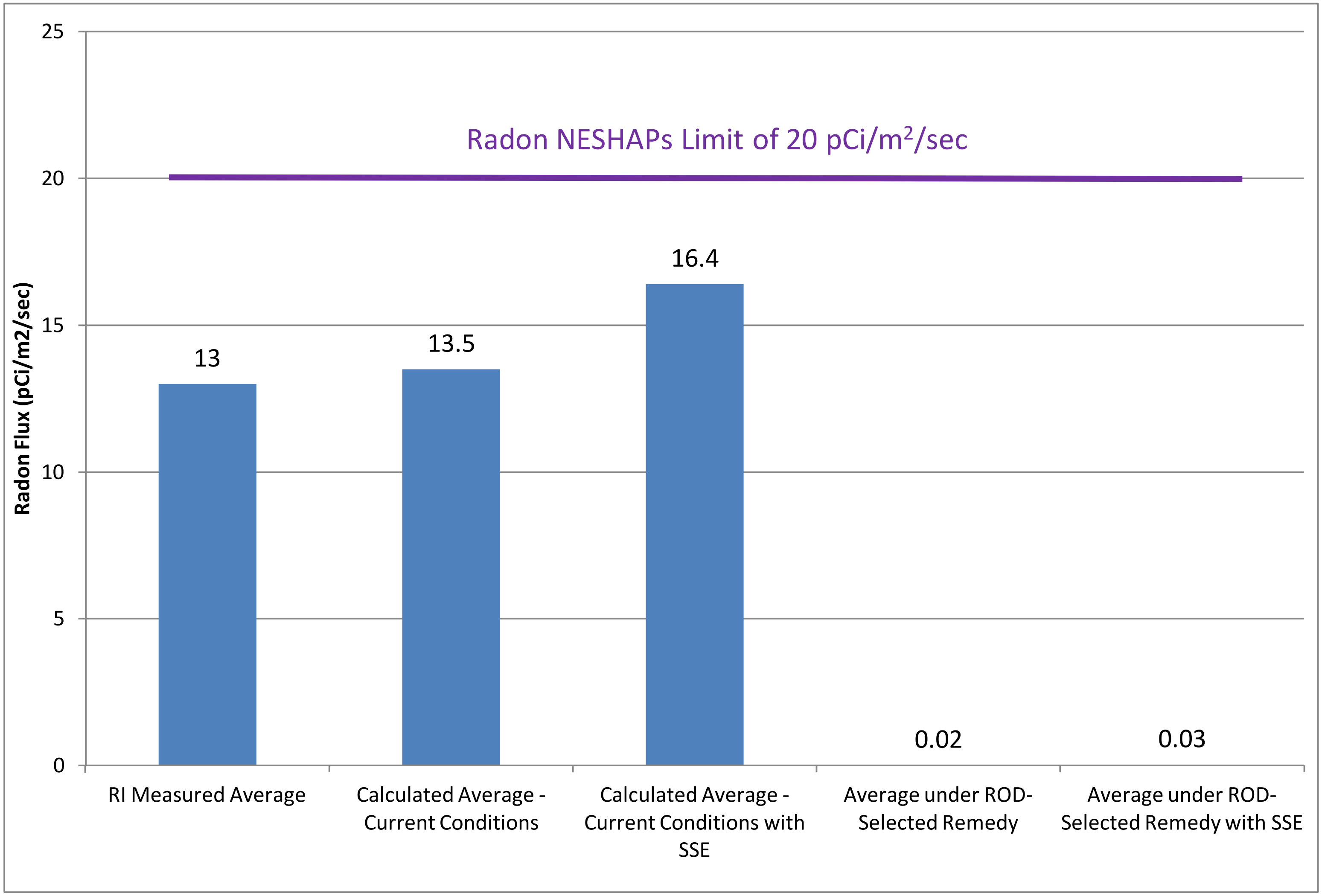




CROSS SECTION A-A'

Figure 2
Three Dimensional Drawing of Bottom of North and South Quarry Areas of Bridgeton Landfill Relative to Area 1
Isolation Barrier Alternatives Analysis

EMSI Engineering Management Support, Inc.



Note: Values are derived in Attachment A

Figure 3

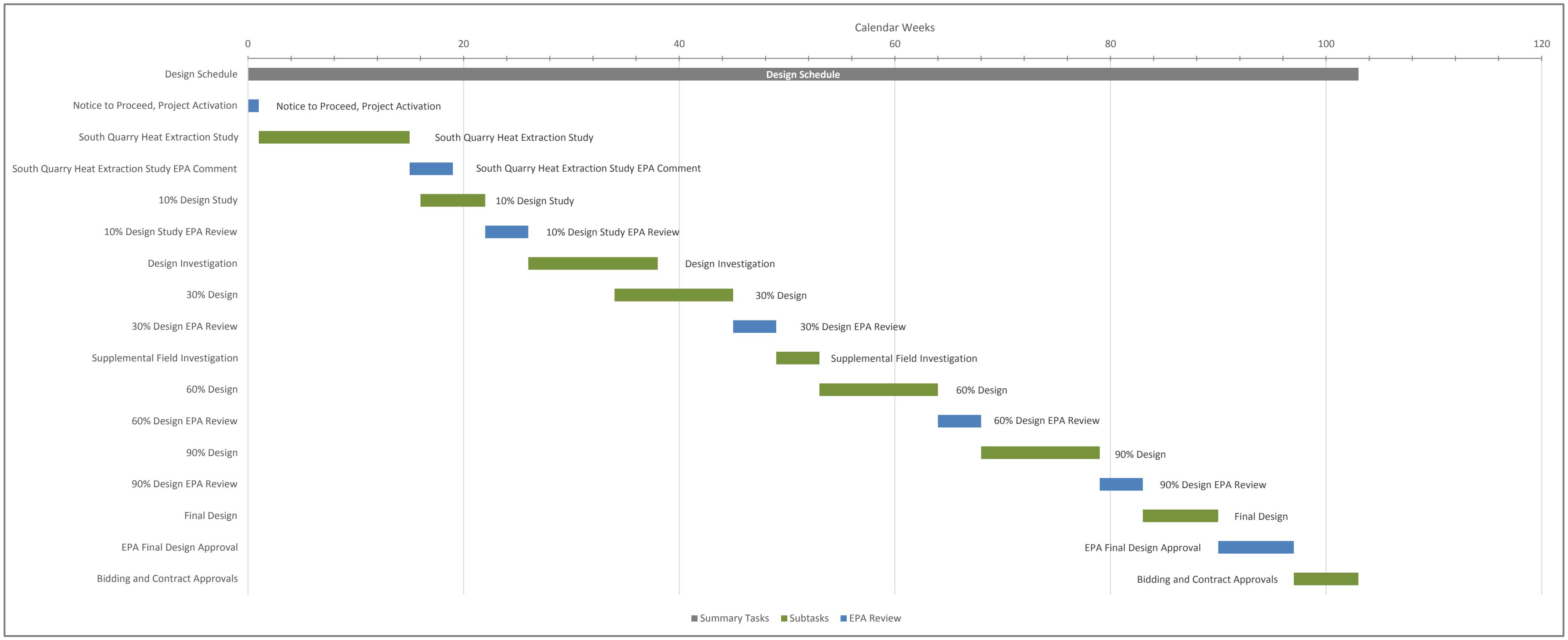
Summary of Potential Radon Emission Rates

West Lake Landfill Superfund Site

EMSI Engineering Management Support, Inc.

Figure 4 - Estimated Design Schedule

Option 1 (Inert Barrier along Alignment 1)



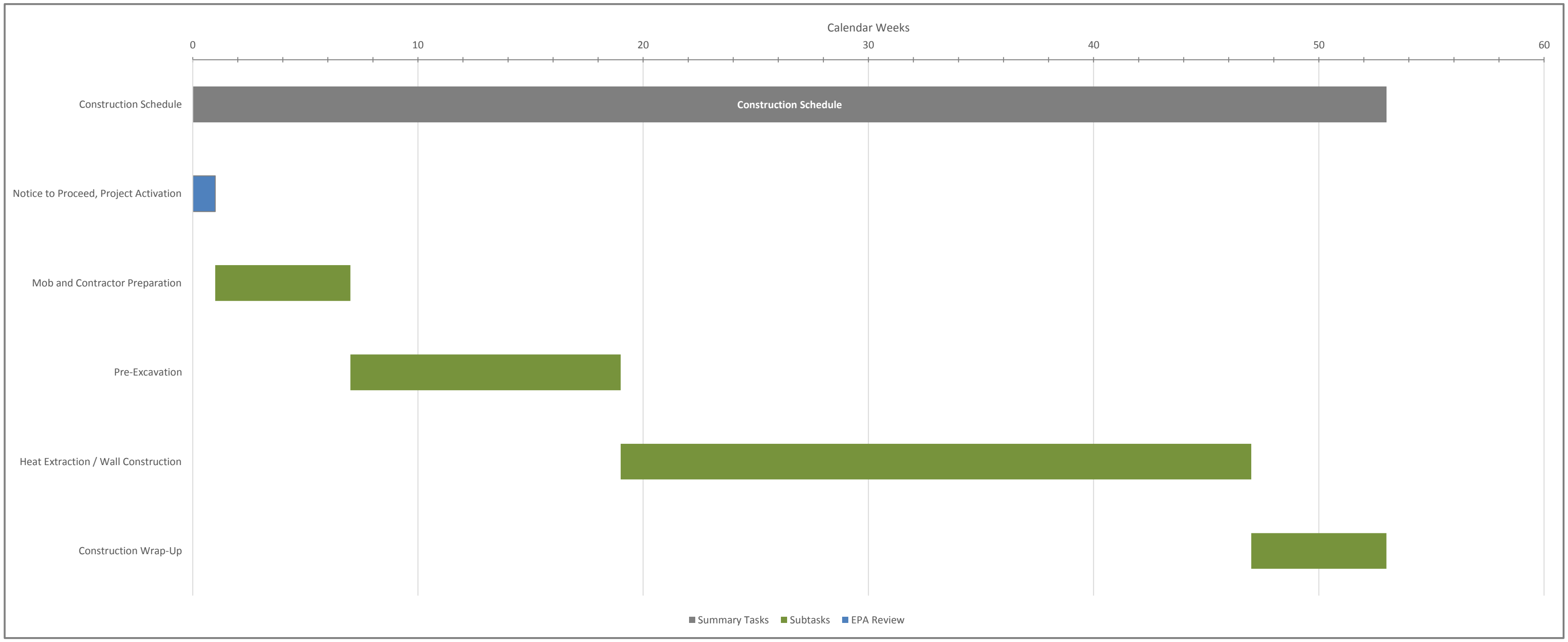
	Option 1 Design Estimate	Duration (weeks)
1	**Design Schedule**	**103**
1.1	Notice to Proceed, Project Activation	1
1.2	South Quarry Heat Extraction Study	14
1.3	South Quarry Heat Extraction Study EPA Comment	4
1.4	10% Design Study	6
1.5	10% Design Study EPA Review	4
1.6	Design Investigation	12
1.7	30% Design	11
1.8	30% Design EPA Review	4
1.9	Supplemental Field Investigation	4
1.10	60% Design	11
1.11	60% Design EPA Review	4
1.12	90% Design	11
1.13	90% Design EPA Review	4
1.14	Final Design	7
1.15	EPA Final Design Approval	7
1.16	Bidding and Contract Approvals	6

Notes:

- Design Investigation does not include time or effort to identify additional occurrences of (or the extent of) RIM south of the barrier alignment
- Schedule assumes EPA review and approval to proceed will occur in the durations listed

Figure 5 - Estimated Construction Schedule

Option 1 (Inert Barrier along Alignment 1)



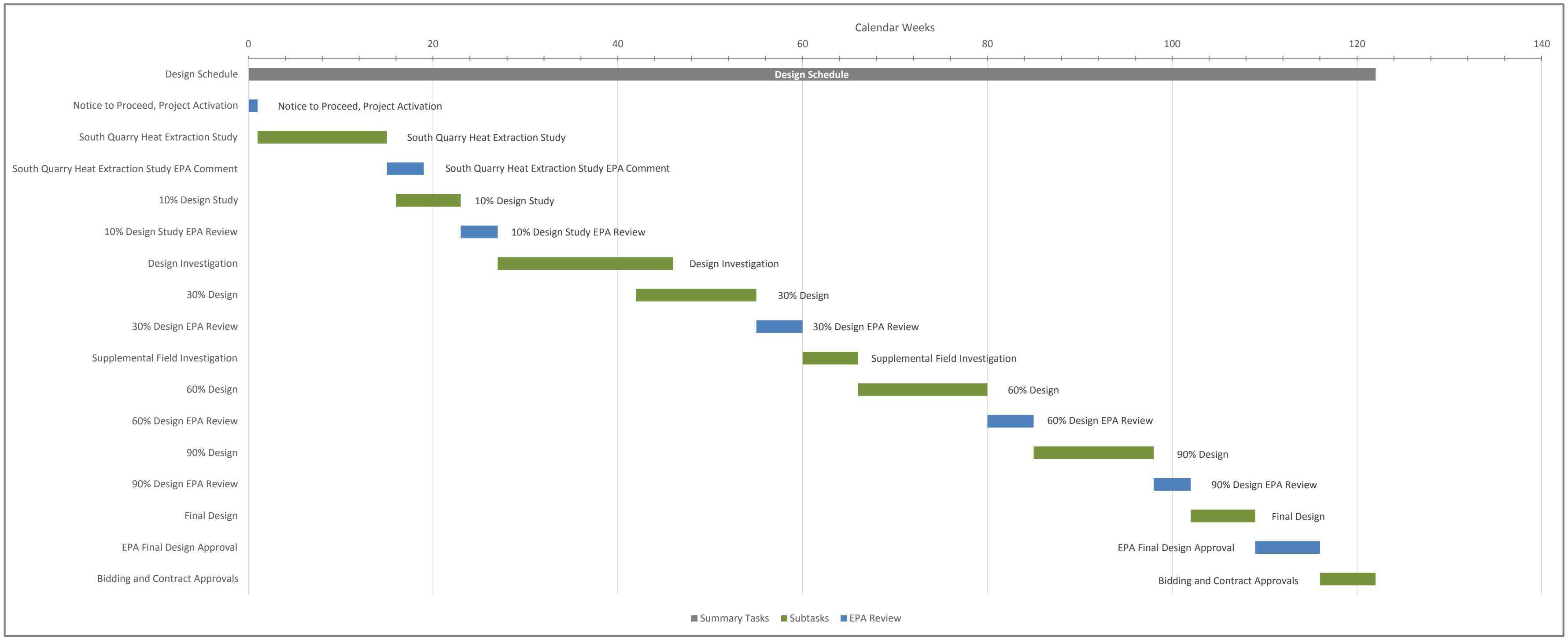
Option 1 Construction Estimate		Duration (weeks)
1	**Construction Schedule**	**53**
1.1	Notice to Proceed, Project Activation	1
1.2	Mob and Contractor Preparation	6
1.3	Pre-Excavation	12
1.4	Heat Extraction / Wall Construction	28
1.5	Construction Wrap-Up	6

Notes:

- Schedule is based on typical working conditions and does not include seasonal inefficiencies or stoppages

Figure 6 - Estimated Design Schedule

Option 3 (Inert Barrier along Alignment 3)



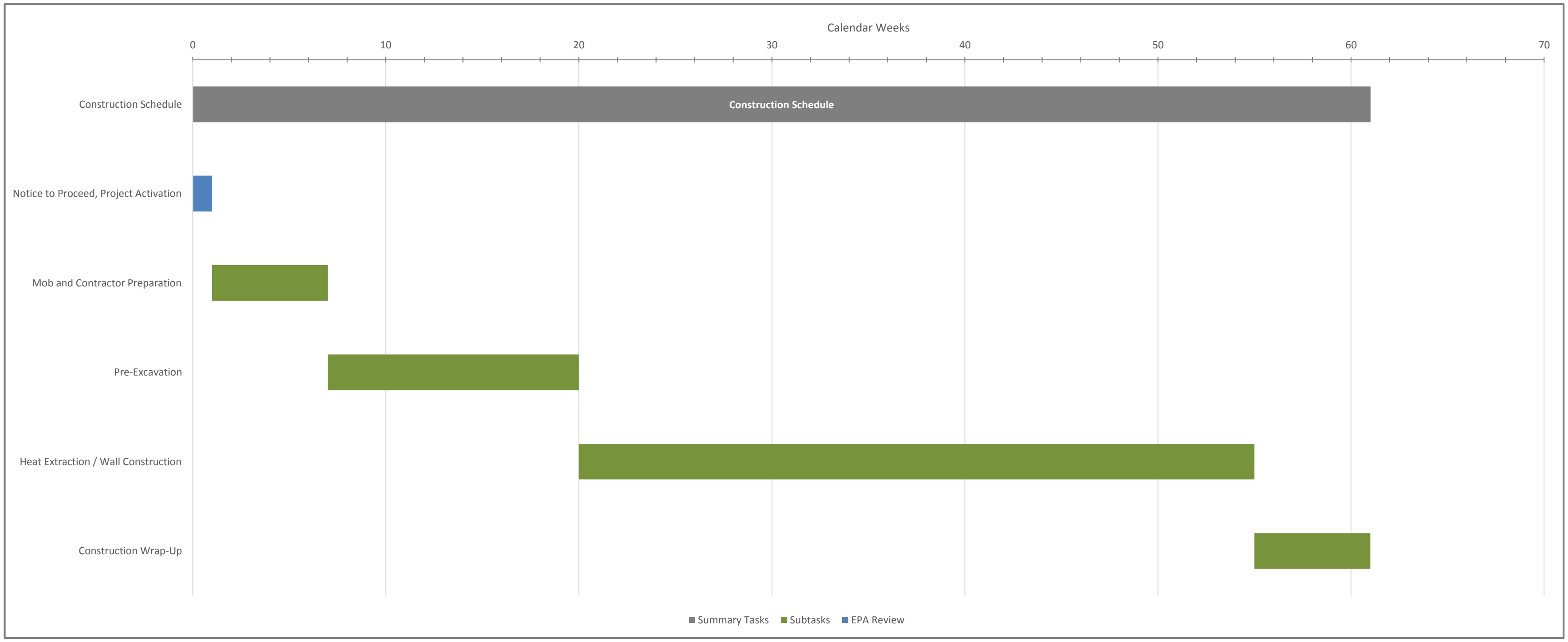
Option 3 Design Estimate		Duration (weeks)
1	**Design Schedule**	**122**
1.1	Notice to Proceed, Project Activation	1
1.2	South Quarry Heat Extraction Study	14
1.3	South Quarry Heat Extraction Study EPA Comment	4
1.4	10% Design Study	7
1.5	10% Design Study EPA Review	4
1.6	Design Investigation	19
1.7	30% Design	13
1.8	30% Design EPA Review	5
1.9	Supplemental Field Investigation	6
1.10	60% Design	14
1.11	60% Design EPA Review	5
1.12	90% Design	13
1.13	90% Design EPA Review	4
1.14	Final Design	7
1.15	EPA Final Design Approval	7
1.16	Bidding and Contract Approvals	6

Notes:

- Design Investigation does not include time or effort to identify additional occurrences of (or the extent of) RIM south of the barrier alignment
- Schedule assumes EPA review and approval to proceed will occur in the durations listed

Figure 7 - Estimated Construction Schedule

Option 3 (Inert Barrier along Alignment 3)



	Option 3 Construction Estimate	Duration (weeks)
1	**Construction Schedule**	**61**
1.1	Notice to Proceed, Project Activation	1
1.2	Mob and Contractor Preparation	6
1.3	Pre-Excavation	13
1.4	Heat Extraction / Wall Construction	35
1.5	Construction Wrap-Up	6

Notes:

- Schedule is based on typical working conditions and does not include seasonal inefficiencies or stoppages

Figure 8 - Estimated Design Schedule

Option 4 (Heat Extraction Barrier)

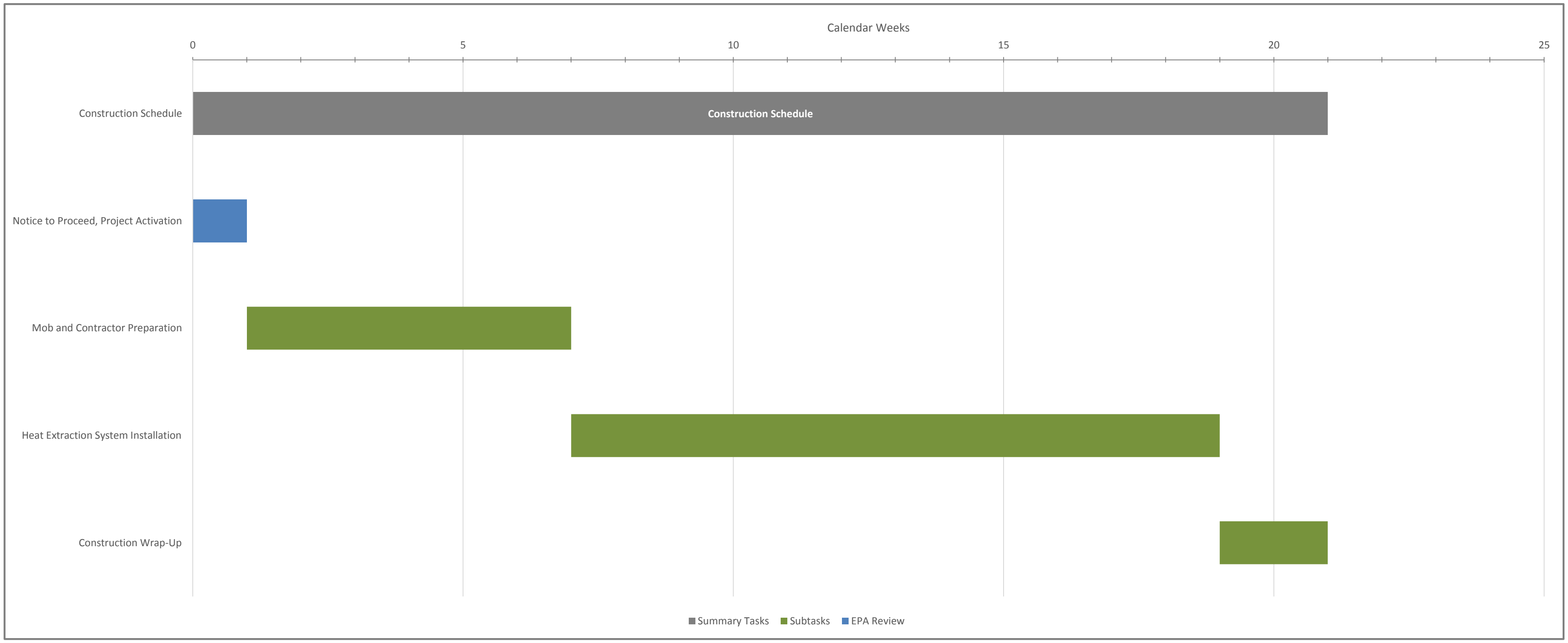
Option 4 Design Estimate		Duration (weeks)
1	**Design Schedule**	**62**
1.1	Notice to Proceed, Project Activation	1
1.2	South Quarry Heat Extraction Study	13
1.3	South Quarry Heat Extraction Study EPA Comment	4
1.4	10% Design Study	5
1.5	10% Design Study EPA Review	4
1.6	30% Design	4
1.7	30% Design EPA Review	4
1.8	60% Design	4
1.9	60% Design EPA Review	4
1.10	90% Design	4
1.11	90% Design EPA Review	4
1.12	Final Design	4
1.13	EPA Final Design Approval	4
1.14	Bidding and Contract Approvals	6

Notes:

- Design Investigation does not include time or effort to identify additional occurrences of (or the extent of) RIM south of the barrier alignment
- Schedule assumes EPA review and approval to proceed will occur in the durations listed

Figure 9 - Estimated Construction Schedule

Option 4 (Heat Extraction Barrier)



Option 4 Construction Estimate		Duration (weeks)
1	**Construction Schedule**	**21**
1.1	Notice to Proceed, Project Activation	1
1.2	Mob and Contractor Preparation	6
1.3	Heat Extraction System Installation	12
1.4	Construction Wrap-Up	2

Notes:

- Schedule is based on typical working conditions and does not include seasonal inefficiencies or stoppages

Drawings

Please Note:

The electronic file containing Drawings 001 through 016 was transmitted separately via DropBox from the rest of the report. The drawings can be accessed at Barrier Presentation Drawings 001-016 however, this link will only be active for a short period after submittal of the report on October 10, 2014. If you did not receive a file of the drawings, please contact EPA or alternatively Paul Rosasco at Engineering Management Support, Inc., at paulrosasco@emsidenver.com to arrange to receive the drawing file.

PRESENTATION DRAWINGS FOR THE

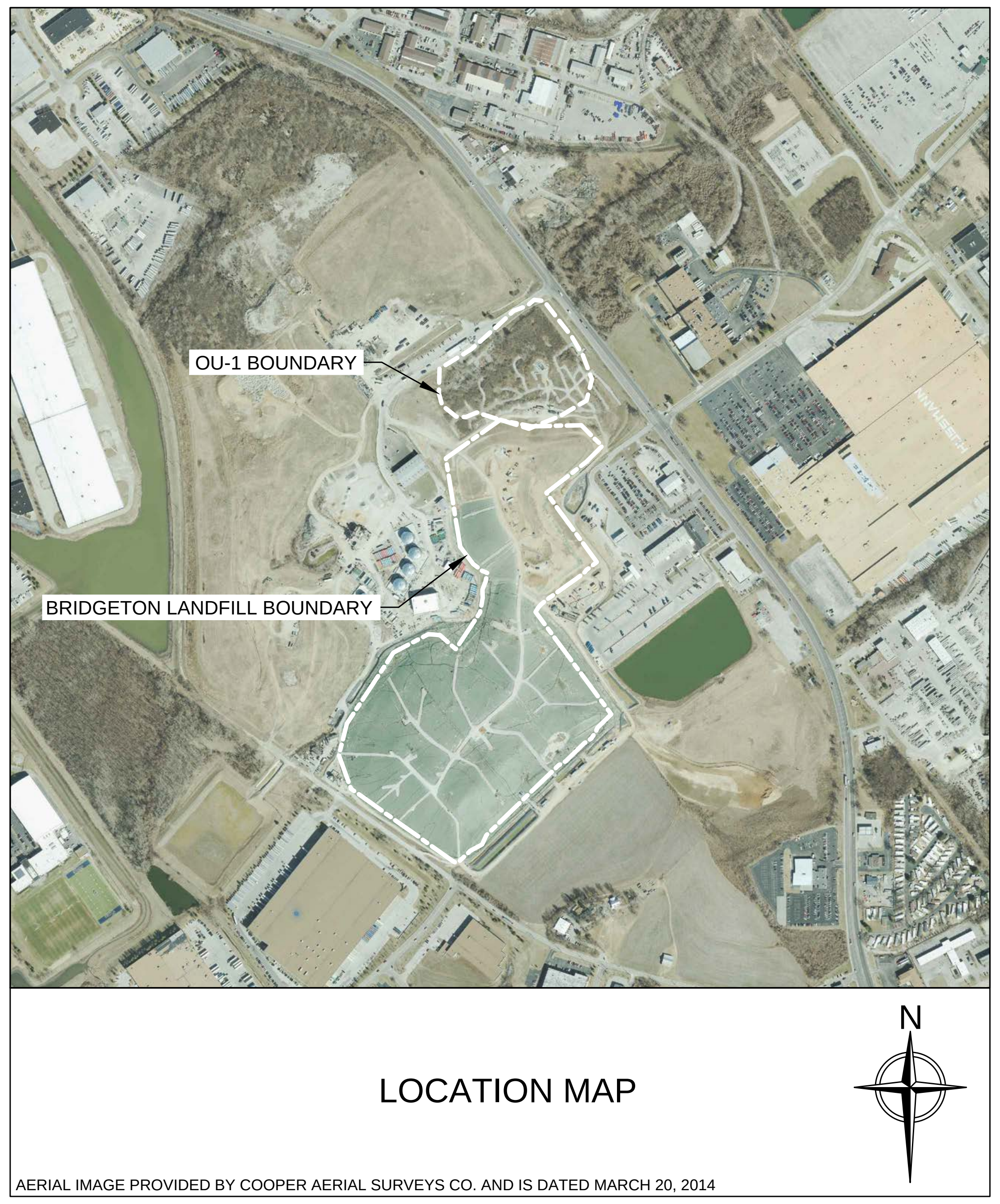
ISOLATION BARRIER ALTERNATIVES ANALYSES REPORT

BRIDGETON LANDFILL

BRIDGETON, ST. LOUIS COUNTY, MISSOURI

OCTOBER 2014

PREPARED FOR:
BRIDGETON LANDFILL



LOCATION MAP

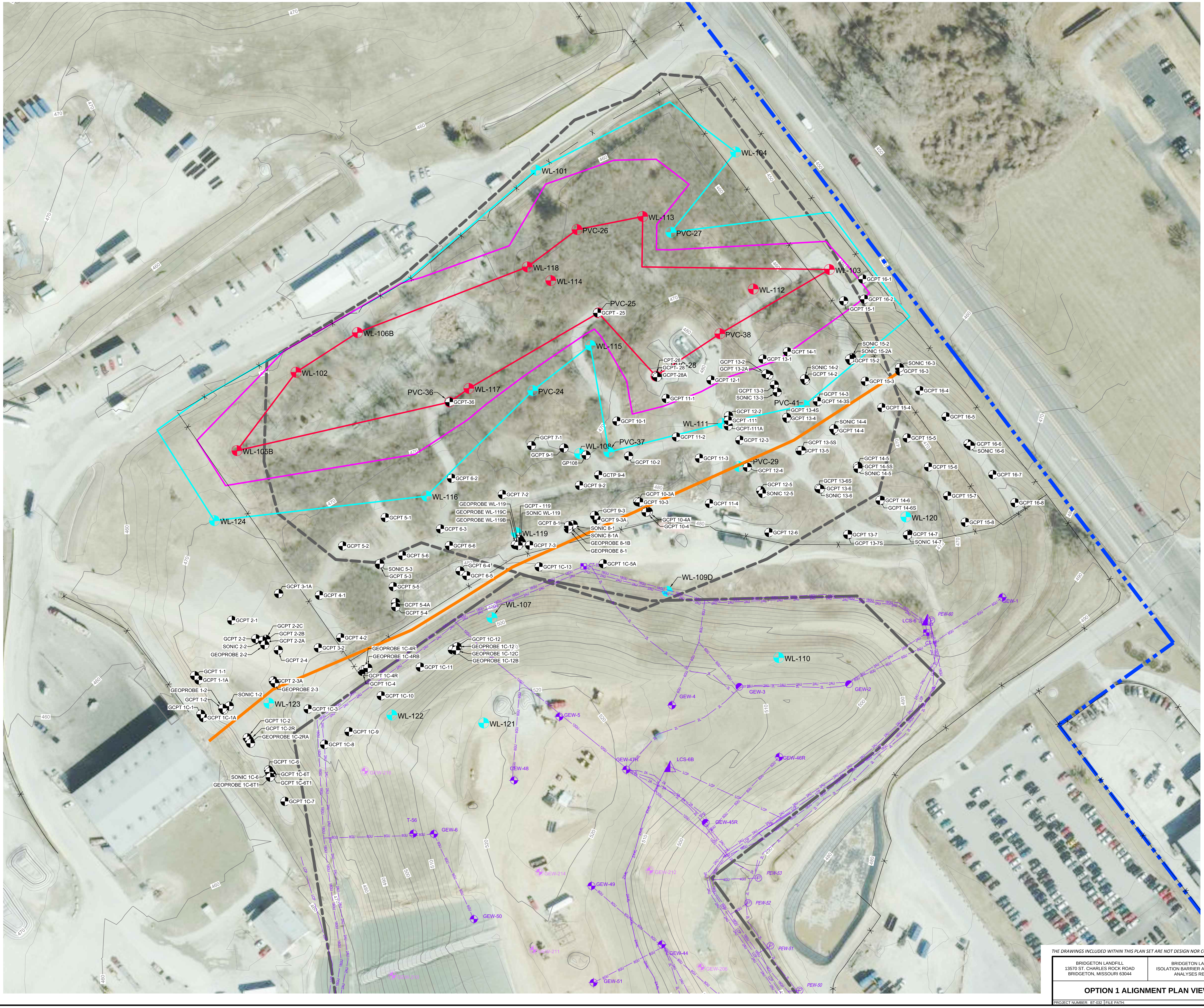
AERIAL IMAGE PROVIDED BY COOPER AERIAL SURVEYS CO. AND IS DATED MARCH 20, 2014

Engineering for a Better World
FEEZOR
ENGINEERING, INC.

406 EAST WALNUT STREET
CHATHAM, IL 62629
TEL. (217) 483-3118
FAX. (217) 483-2356

INDEX OF DRAWINGS

THE DRAWINGS INCLUDED WITHIN THIS PLAN SET ARE NOT DESIGN NOR CONSTRUCTION LEVEL DRAWINGS. THEY ARE INTENDED FOR ILLUSTRATIVE PURPOSES ONLY.



0 50 100
Feet

LEGEND

◓	PHASE 1 BORING LOCATION
◓	ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
━	HISTORIC BOUNDARY OF ELEVATED DOWNHOLE READINGS
◓	NON-ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
━	HISTORIC BOUNDARY OF NON-ELEVATED DOWNHOLE READINGS
━	HISTORIC BOUNDARY OF INTERPOLATED RIM LIMITS
—✕—	FENCE
▬ ▬ ▬	OU-1 BOUNDARY
▬ ▬ ▬	BRIDGETON LANDFILL BOUNDARY
▬ ▪ ▪ ▬	PROPERTY LINE
—480—	03-20-14 TOPOGRAPHY (10' CONTOUR)
—	03-20-14 TOPOGRAPHY (2' CONTOUR)
━	INERT BARRIER ALIGNMENT
—	EXISTING INFRASTRUCTURE PIPE
⊕	EXISTING GAS EXTRACTION WELL
⊕	EXISTING GAS EXTRACTION WELL - NEWLY INSTALLED (NOT PART OF ACTIVE GAS SYSTEM)
◐	EXISTING DUAL GAS EXTRACTION WELL
Ⓟ	EXISTING PERIMETER GAS EXTRACTION WELL
△	EXISTING LEACHATE COLLECTION SUMP
▚	EXISTING CONDENSATE SUMP

NOTES:
- AERIAL TOPOGRAPHY PROVIDED BY COOPER AERIAL SURVEYS CO. AND IS DATED MARCH 20, 2014
- ALL ELEVATIONS ARE ABOVE MEAN SEA LEVEL (AMSL)

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BRIDGETON LANDFILL
13570 ST. CHARLES ROCK ROAD
BRIDGETON, MISSOURI 63044

BRIDGETON LANDFILL
ISOLATION BARRIER ALTERNATIVES
ANALYSES REPORT

OPTION 1 ALIGNMENT PLAN VIEW

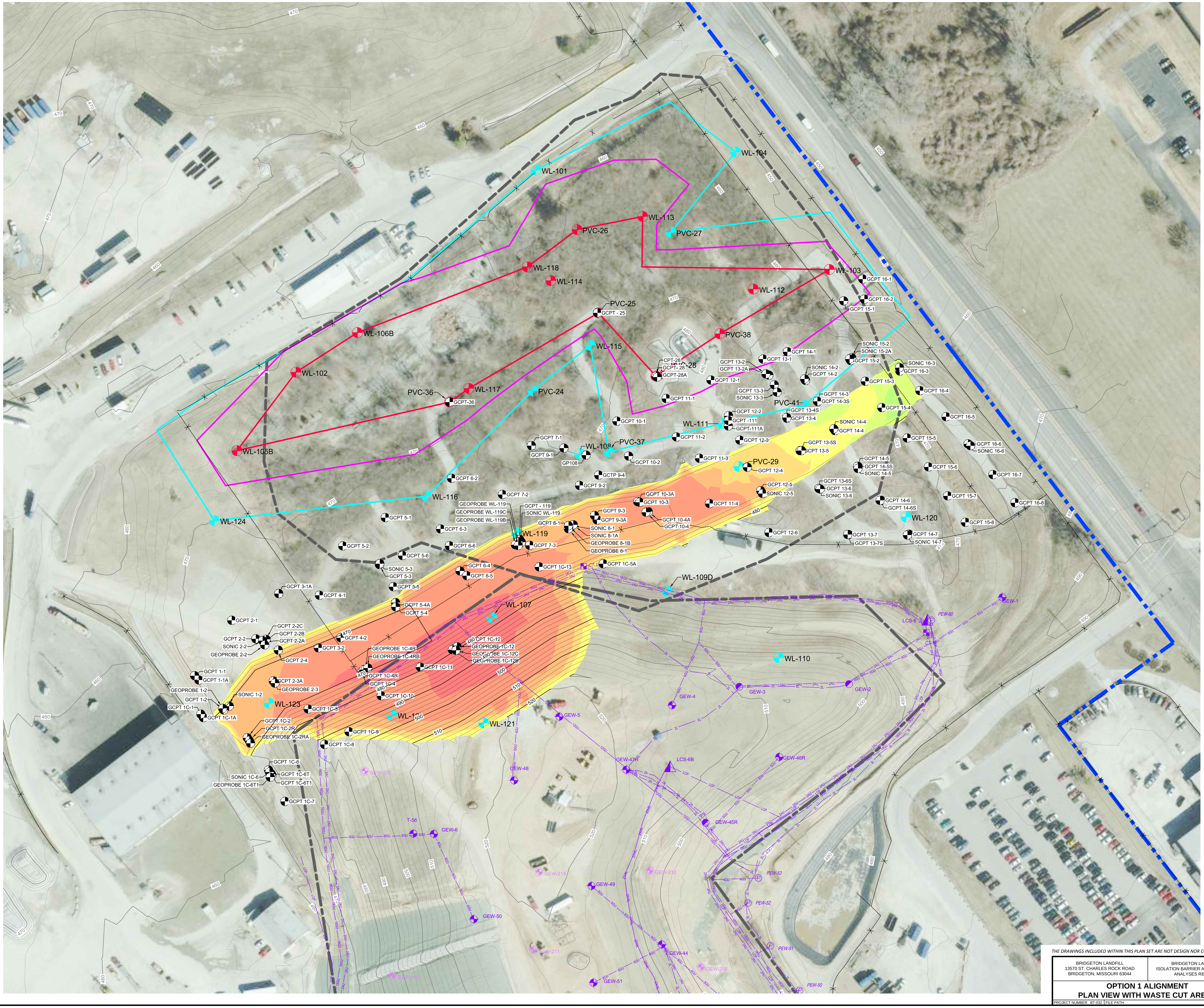
Engineering for a Better World
FEEZOR
ENGINEERING, INC.

OCTOBER 2014
DESIGNED BY: PML
APPROVED BY: DRF

REVISION	DATE

DRAWING NO.:
002

PROJECT NUMBER: BT-032 FILE PATH:



Thickness Map

Maximum Depth - Ft.	Minimum Depth - Ft.	Color
-104	-64	🟪
-64	-32	🟪
-32	-16	🟥
-16	-8	🟥
-8	-4	🟧
-4	-2	🟨
-2	0	🟨

Pre-Excavation Volume:
47,500 c.y.

Barrier Volume:
7,500 c.y.

0 50 100
Feet

LEGEND

⊕	PHASE 1 BORING LOCATION
⊕	ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
━	HISTORIC BOUNDARY OF ELEVATED DOWNHOLE READINGS
⊕	NON-ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
━	HISTORIC BOUNDARY OF NON-ELEVATED DOWNHOLE READINGS
━	HISTORIC BOUNDARY OF INTERPOLATED RIM LIMITS
—×—	FENCE
▬ ▬ ▬ ▬	OU-1 BOUNDARY
▬ ▬ ▬	BRIDGETON LANDFILL BOUNDARY
━ ━ ━ ━	PROPERTY LINE
—480—	03-20-14 TOPOGRAPHY (10' CONTOUR)
—	03-20-14 TOPOGRAPHY (2' CONTOUR)
—480—	EXCAVATION GRADING (10' CONTOUR)
—	EXCAVATION GRADING (2' CONTOUR)
—	EXISTING INFRASTRUCTURE PIPE
⊕	EXISTING GAS EXTRACTION WELL
⊕	EXISTING GAS EXTRACTION WELL - NEWLY INSTALLED (NOT PART OF ACTIVE GAS SYSTEM)
◐	EXISTING DUAL GAS EXTRACTION WELL
Ⓟ	EXISTING PERIMETER GAS EXTRACTION WELL
△	EXISTING LEACHATE COLLECTION SUMP
▚	EXISTING CONDENSATE SUMP

NOTES:

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BRIDGETON LANDFILL
13570 ST. CHARLES ROCK ROAD
BRIDGETON, MISSOURI 63044

BRIDGETON LANDFILL
ISOLATION BARRIER ALTERNATIVES
ANALYSES REPORT

OPTION 1 ALIGNMENT
PLAN VIEW WITH WASTE CUT AREAS

Engineering for a Better World
FEEZOR
ENGINEERING, INC.

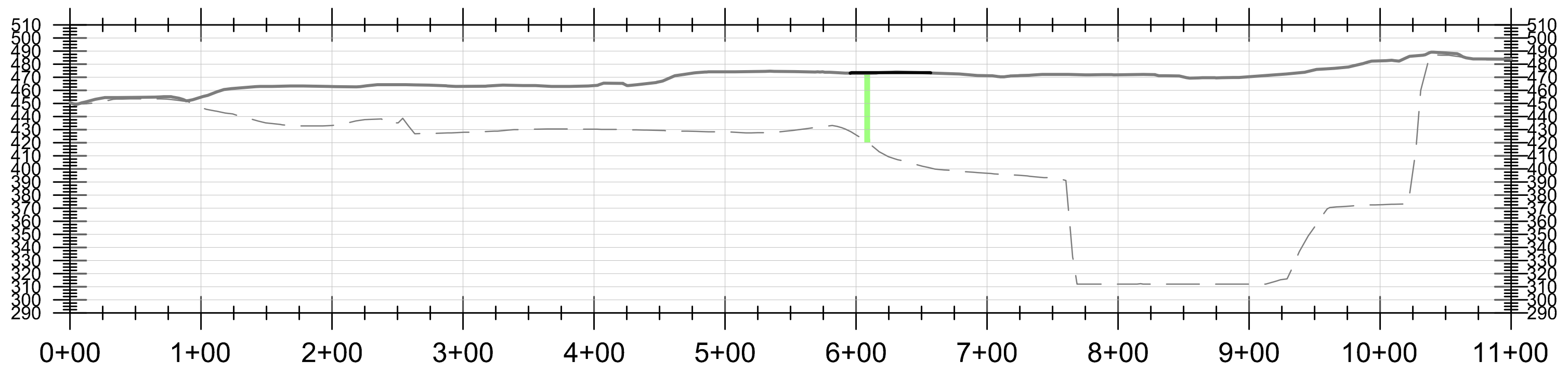
OCTOBER 2014
DESIGNED BY: PML
APPROVED BY: DRF

REVISION	DATE

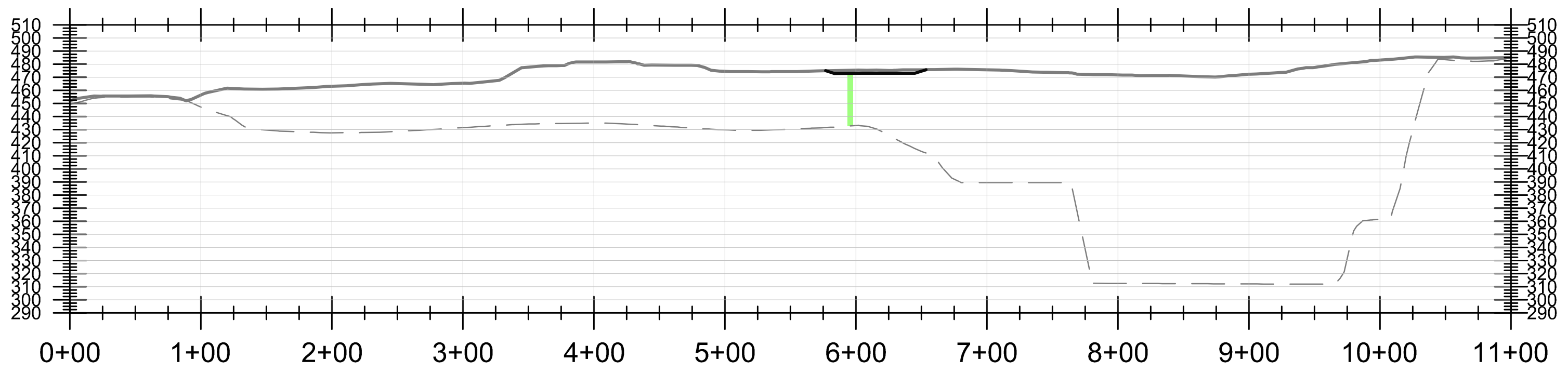
DRAWING NO.:
003

PROJECT NUMBER: BT-032
FILE PATH:

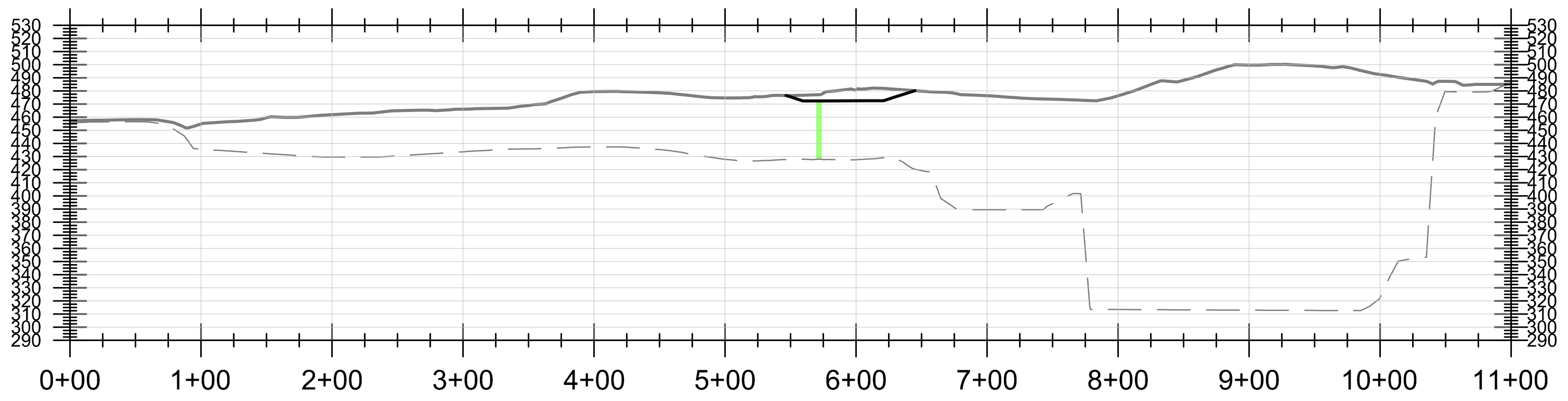
Cross Section A-A' (1H:1V)



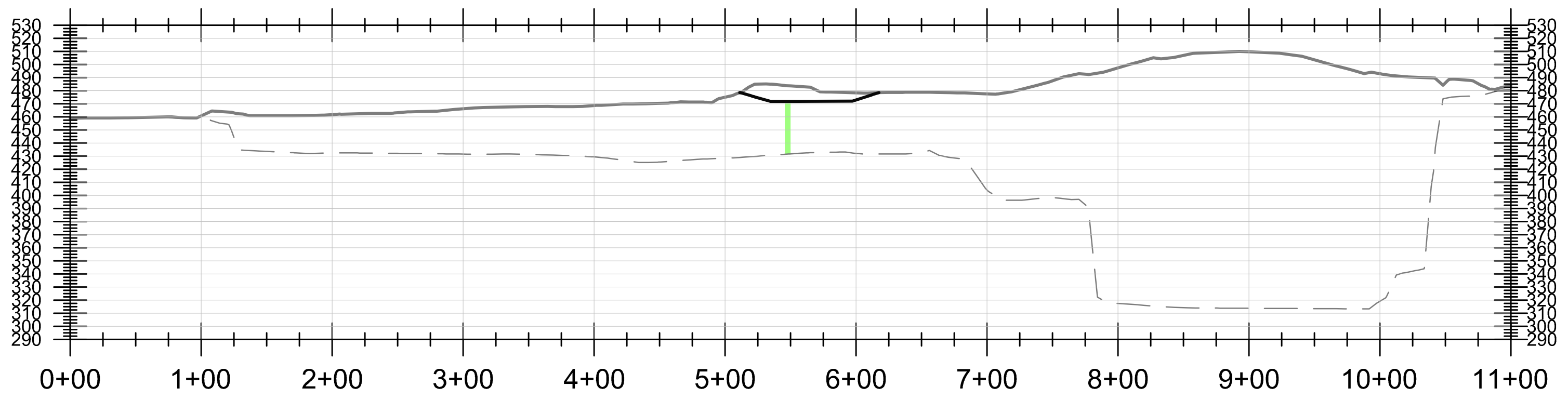
Cross Section B-B' (1H:1V)



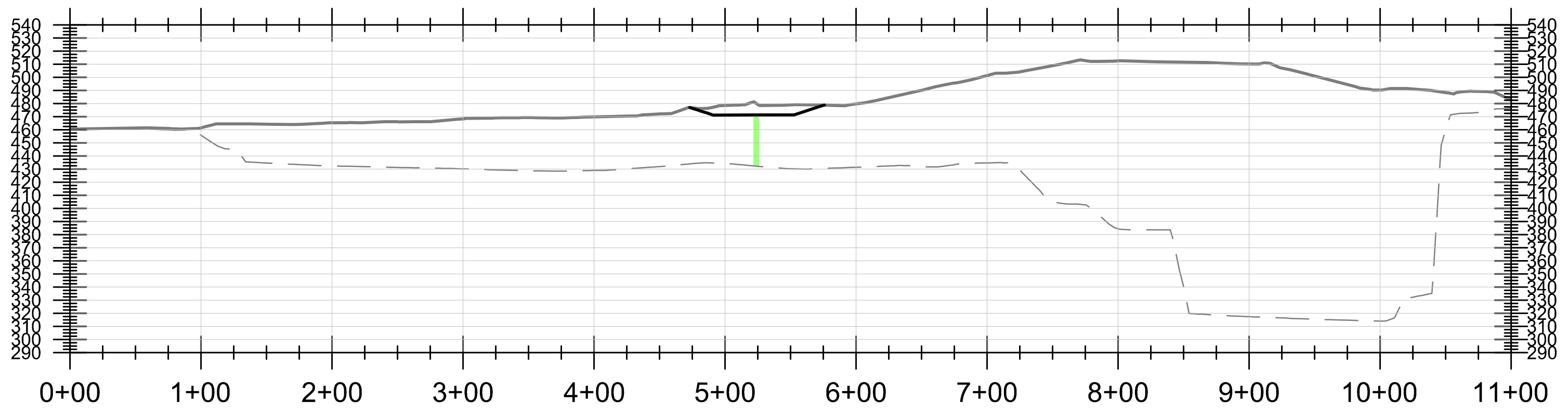
Cross Section C-C' (1H:1V)



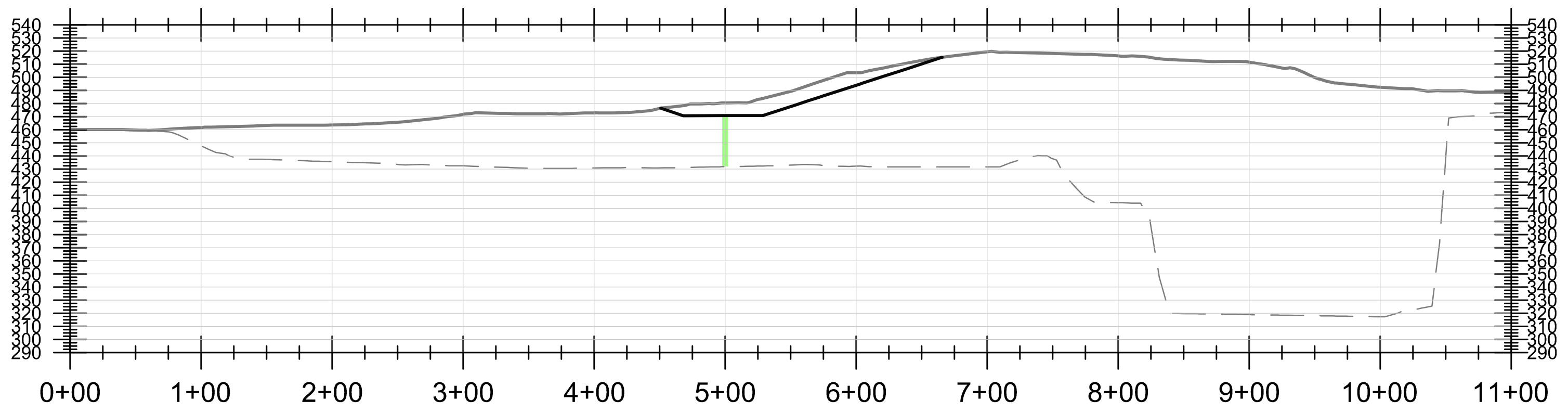
Cross Section D-D' (1H:1V)



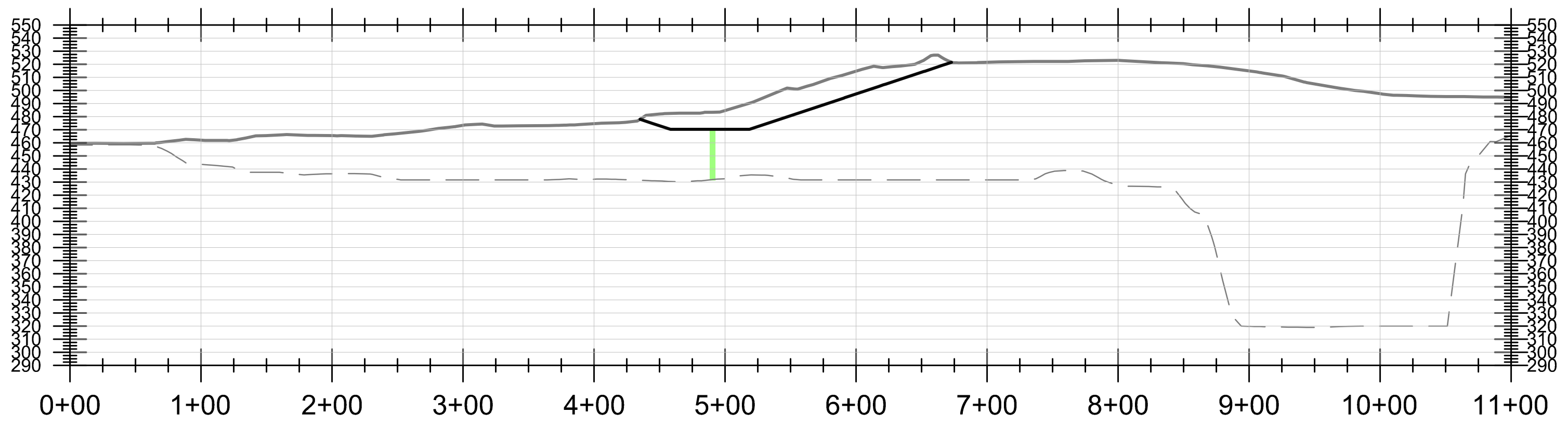
Cross Section E-E' (1H:1V)



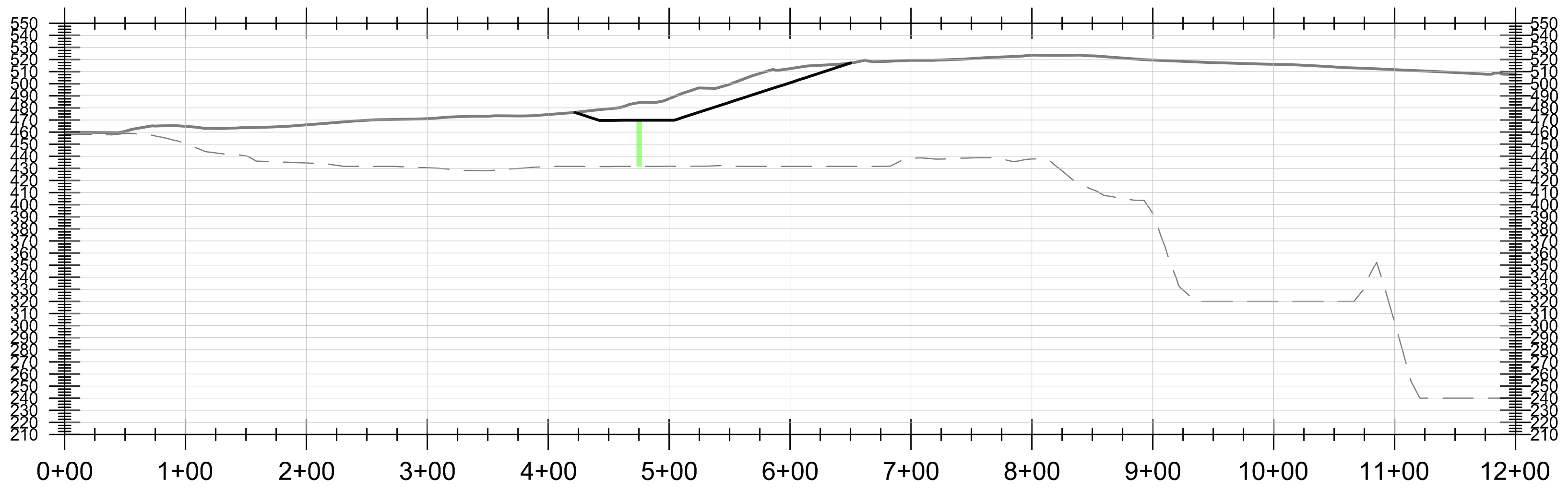
Cross Section F-F' (1H:1V)

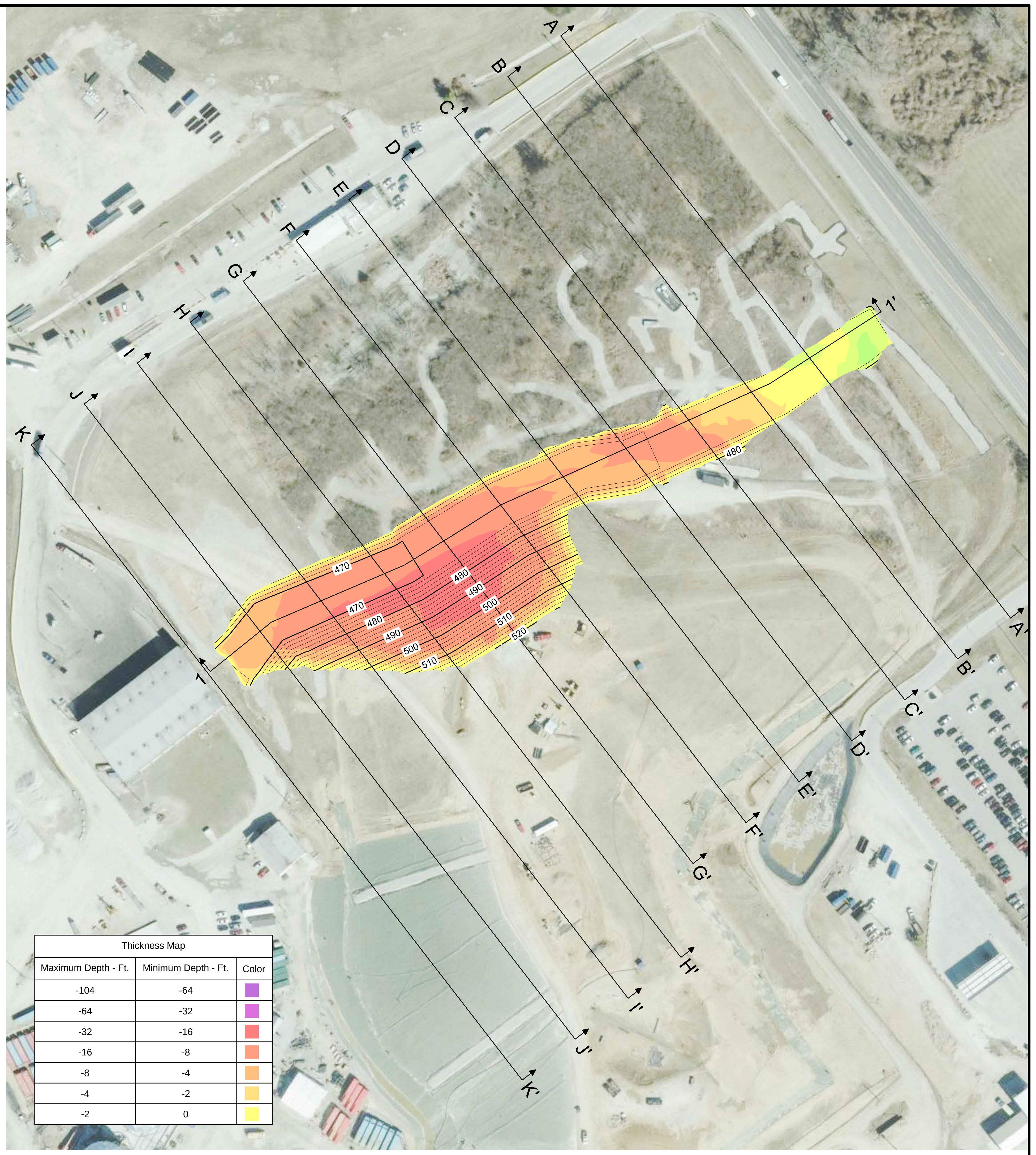


Cross Section G-G' (1H:1V)



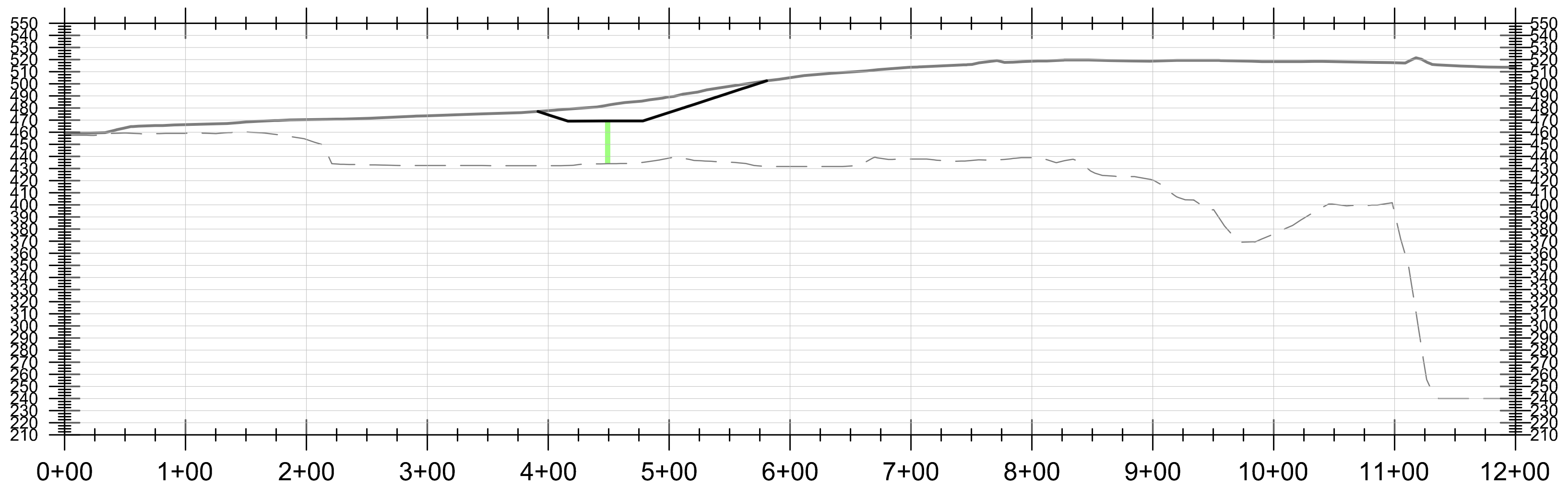
Cross Section H-H' (1H:1V)



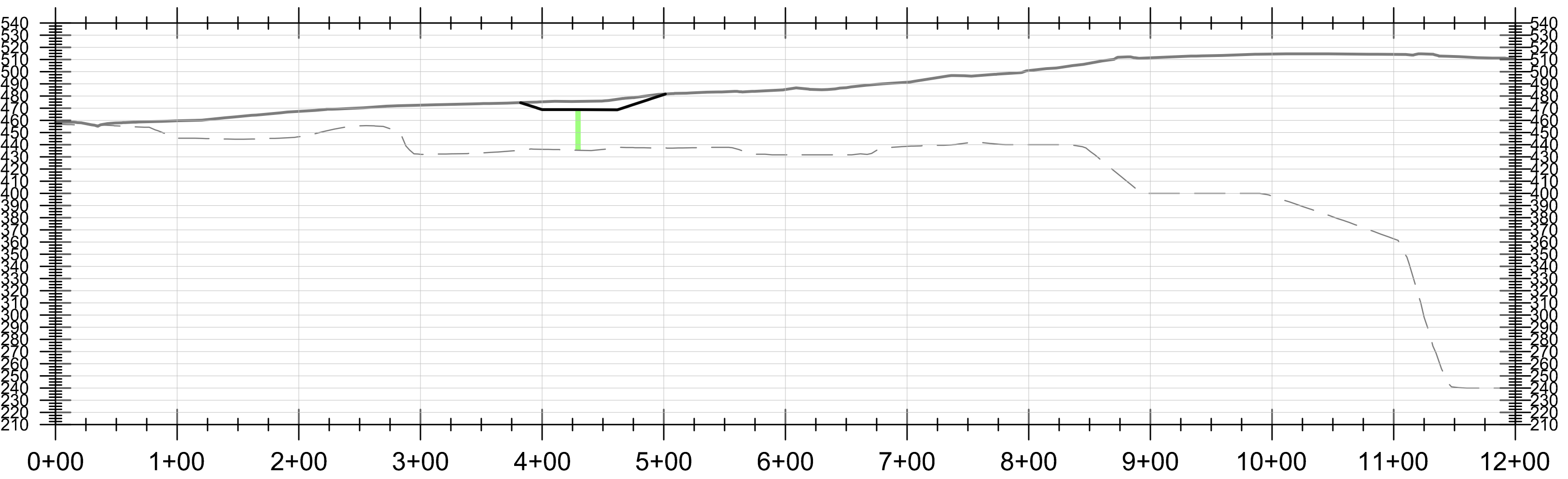


Thickness Map		
Maximum Depth - Ft.	Minimum Depth - Ft.	Color
-104	-64	🟪
-64	-32	🟪
-32	-16	🟥
-16	-8	🟧
-8	-4	🟧
-4	-2	🟨
-2	0	🟨

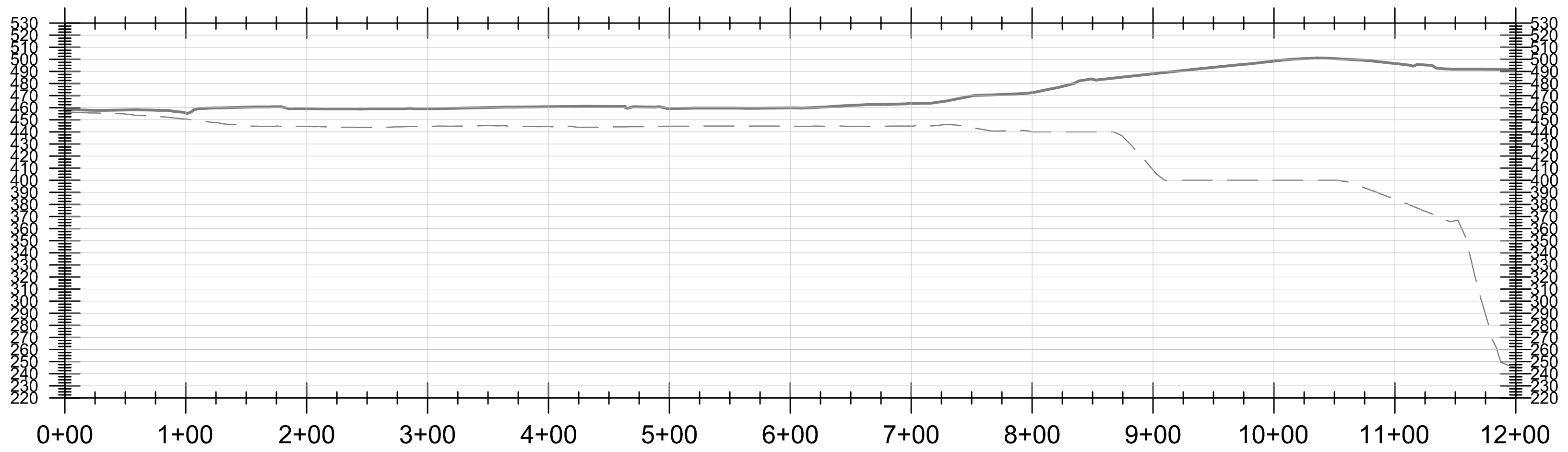
Cross Section I-I' (1H:1V)



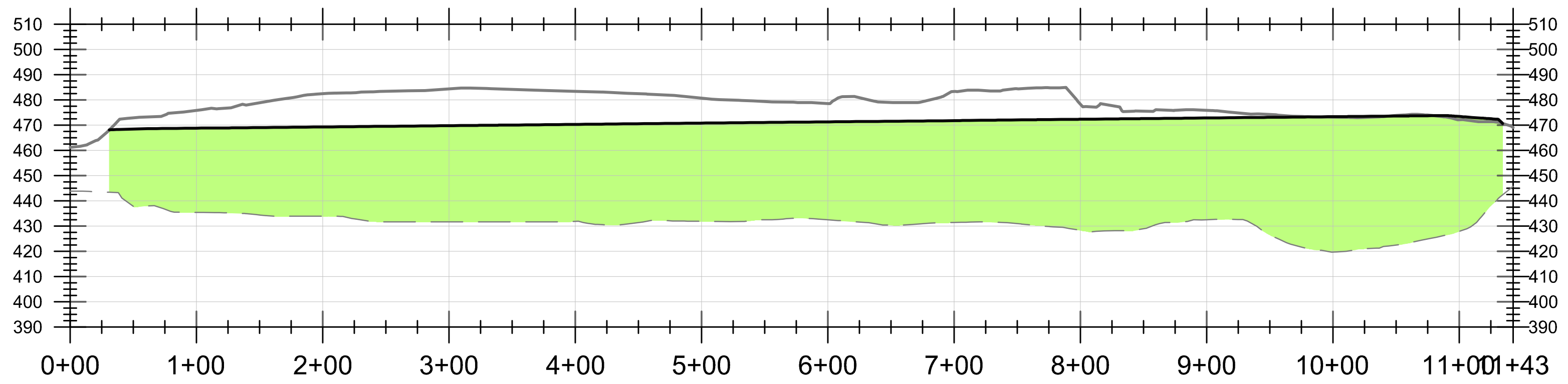
Cross Section J-J' (1H:1V)



Cross Section K-K' (1H:1V)



Profile View of Alignment 1 (1H:2V)



LEGEND

─── 03-20-14 TOPOGRAPHY

– – – ESTIMATED BOTTOM OF WASTE

─── EXCAVATION GRADING

🟩 INERT BARRIER

NOTES:
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- ESTIMATED BOTTOM OF WASTE WAS DEVELOPED BY COMPARING HISTORIC AND GEOLOGIC SURFACE DATA PROVIDED BY MULTIPLE SOURCES, SOME OF WHICH ARE INTERPOLATED ESTIMATES IN AND OF THEMSELVES. THE LOWEST ELEVATION AT EACH POINT ON A 10' X 10' GRID WAS SELECTED FOR INCLUSION IN THE ESTIMATED BOTTOM OF WASTE SURFACE.
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BRIDGETON LANDFILL
13570 ST. CHARLES ROCK ROAD
BRIDGETON, MISSOURI 63044

BRIDGETON LANDFILL
ISOLATION BARRIER ALTERNATIVES
ANALYSES REPORT

OPTION 1 ALIGNMENT
PROFILE VIEW AND CROSS SECTIONS

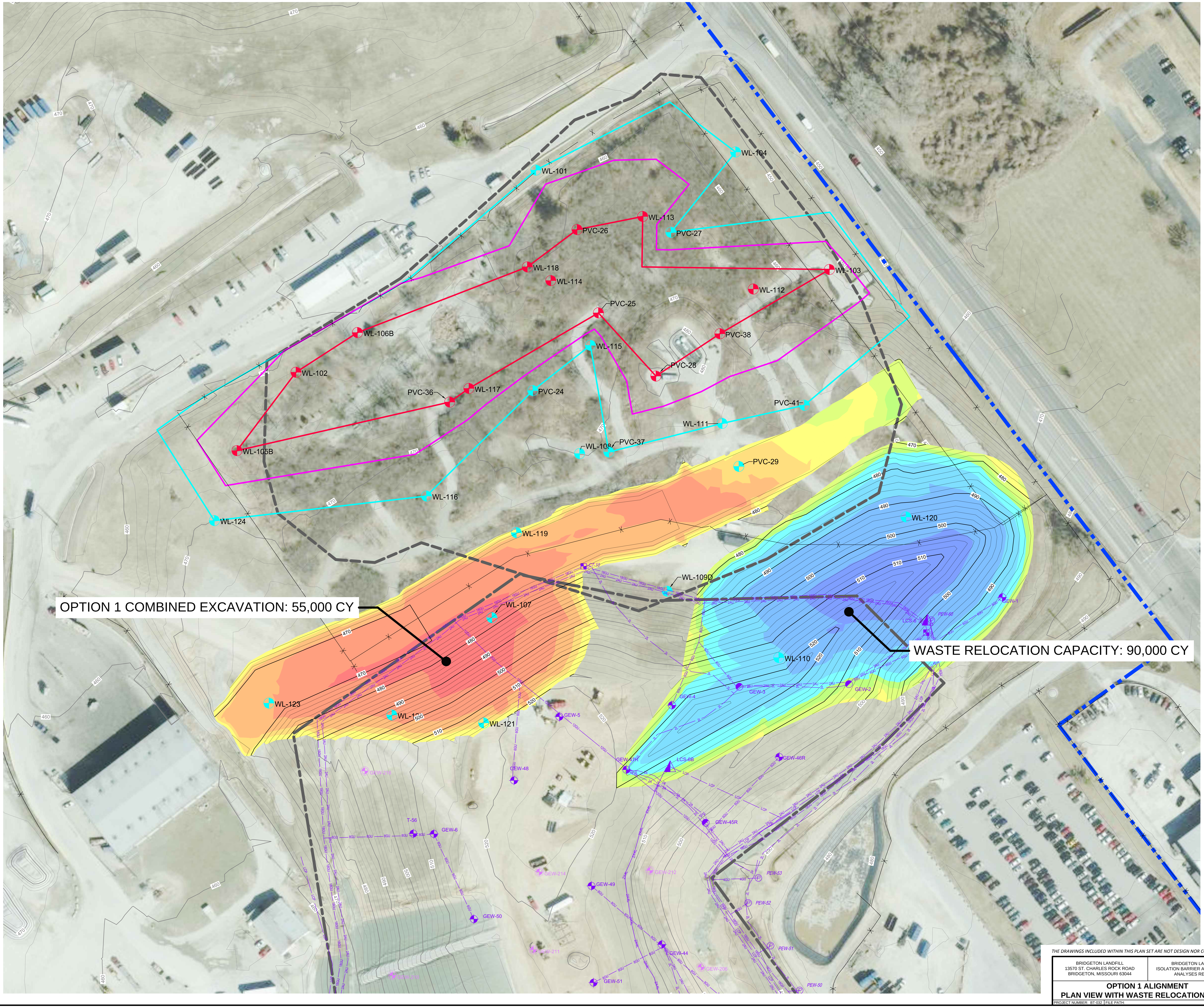
Engineering for a Better World
FEEZOR
ENGINEERING, INC.

OCTOBER 2014
DESIGNED BY: PML
APPROVED BY: DRF

REVISION	DATE

DRAWING NO.:
004

PROJECT NUMBER: BT-032
FILE PATH:



Thickness Map		
Maximum Depth - Ft.	Minimum Depth - Ft.	Color
-104	-64	🟪
-64	-32	🟪
-32	-16	🟥
-16	-8	🟧
-8	-4	🟧
-4	-2	🟨
-2	0	🟨

Thickness Map		
Minimum Depth - Ft.	Maximum Depth - Ft.	Color
0	2	🟩
2	4	🟩
4	8	🟦
8	16	🟦
16	32	🟦
32	47	🟦

LEGEND

●	PHASE 1 BORING LOCATION
●	ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
━	HISTORIC BOUNDARY OF ELEVATED DOWNHOLE READINGS
●	NON-ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
━	HISTORIC BOUNDARY OF NON-ELEVATED DOWNHOLE READINGS
━	HISTORIC BOUNDARY OF INTERPOLATED RIM LIMITS
─×─	FENCE
━ ━ ━	OU-1 BOUNDARY
━ ━ ━	BRIDGETON LANDFILL BOUNDARY
━ ━ ━	PROPERTY LINE
—480—	03-20-14 TOPOGRAPHY (10' CONTOUR)
─	03-20-14 TOPOGRAPHY (2' CONTOUR)
—480—	EXCAVATION GRADING (10' CONTOUR)
─	EXCAVATION GRADING (2' CONTOUR)
━	EXISTING INFRASTRUCTURE PIPE
●	EXISTING GAS EXTRACTION WELL
○	EXISTING GAS EXTRACTION WELL - NEWLY INSTALLED (NOT PART OF ACTIVE GAS SYSTEM)
◐	EXISTING DUAL GAS EXTRACTION WELL
Ⓟ	EXISTING PERIMETER GAS EXTRACTION WELL
▲	EXISTING LEACHATE COLLECTION SUMP
▚	EXISTING CONDENSATE SUMP

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BRIDGETON LANDFILL
13570 ST. CHARLES ROCK ROAD
BRIDGETON, MISSOURI 63044

BRIDGETON LANDFILL
ISOLATION BARRIER ALTERNATIVES
ANALYSES REPORT

OPTION 1 ALIGNMENT
PLAN VIEW WITH WASTE RELOCATION AREAS

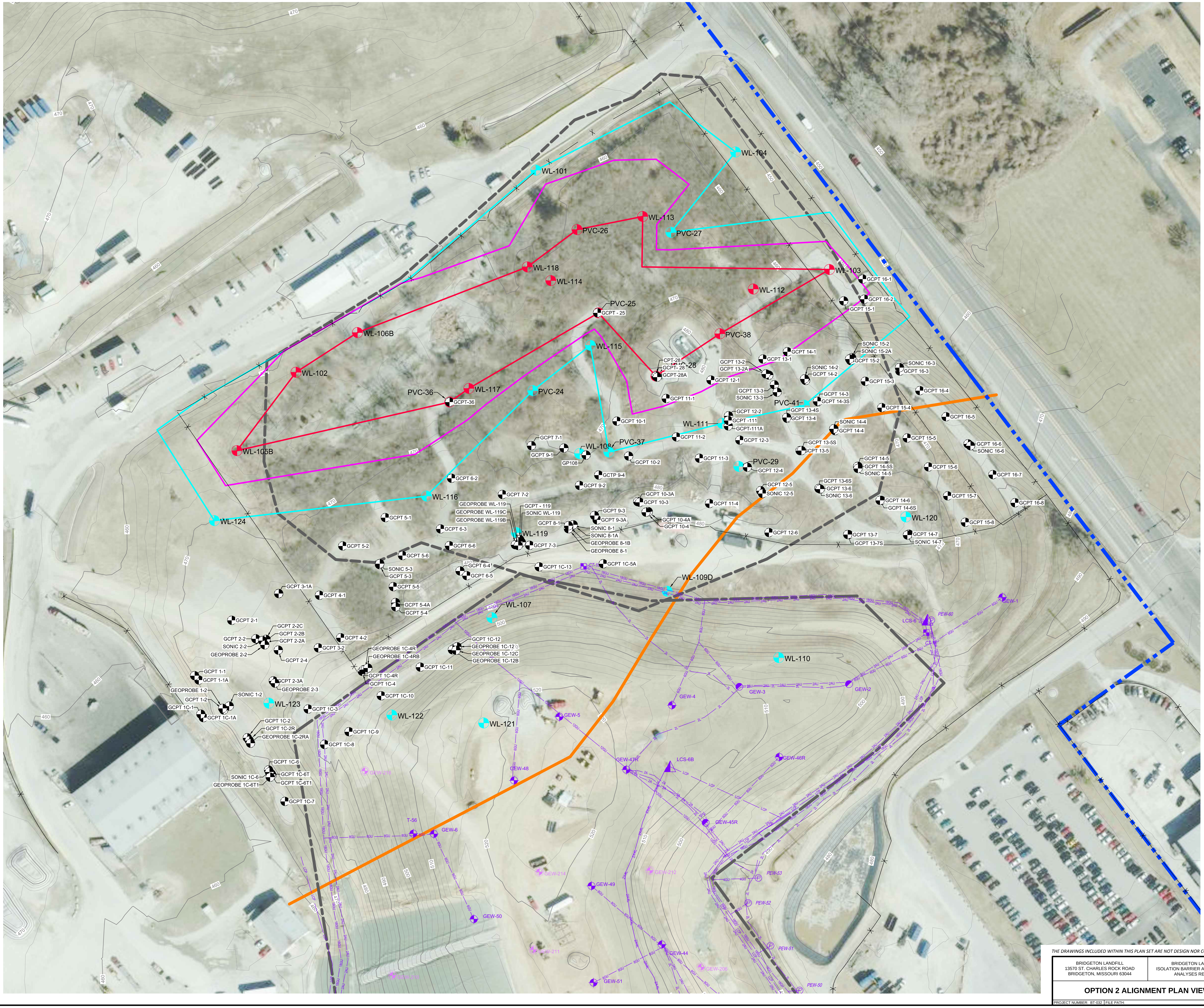
PROJECT NUMBER: BT-032
FILE PATH:

Engineering for a Better World
FEEZOR
ENGINEERING, INC.

OCTOBER 2014
DESIGNED BY: PML
APPROVED BY: DRF

REVISION	DATE

DRAWING NO.:
005



0 50 100 Feet

LEGEND

●	PHASE 1 BORING LOCATION
●	ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
🟥	HISTORIC BOUNDARY OF ELEVATED DOWNHOLE READINGS
●	NON-ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
	HISTORIC BOUNDARY OF NON-ELEVATED DOWNHOLE READINGS
	HISTORIC BOUNDARY OF INTERPOLATED RIM LIMITS
—X—	FENCE
— — —	OU-1 BOUNDARY
— - —	BRIDGETON LANDFILL BOUNDARY
— - - —	PROPERTY LINE
—480—	03-20-14 TOPOGRAPHY (10' CONTOUR)
—	03-20-14 TOPOGRAPHY (2' CONTOUR)
—	AIR GAP BARRIER ALIGNMENT
—	EXISTING INFRASTRUCTURE PIPE
⊕	EXISTING GAS EXTRACTION WELL
⊕	EXISTING GAS EXTRACTION WELL - NEWLY INSTALLED (NOT PART OF ACTIVE GAS SYSTEM)
◐	EXISTING DUAL GAS EXTRACTION WELL
Ⓟ	EXISTING PERIMETER GAS EXTRACTION WELL
▲	EXISTING LEACHATE COLLECTION SUMP
▨	EXISTING CONDENSATE SUMP

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13570 ST. CHARLES ROCK ROAD
BRIDGETON, MISSOURI 63044

BRIDGETON LANDFILL
ISOLATION BARRIER ALTERNATIVES
ANALYSES REPORT

OPTION 2 ALIGNMENT PLAN VIEW

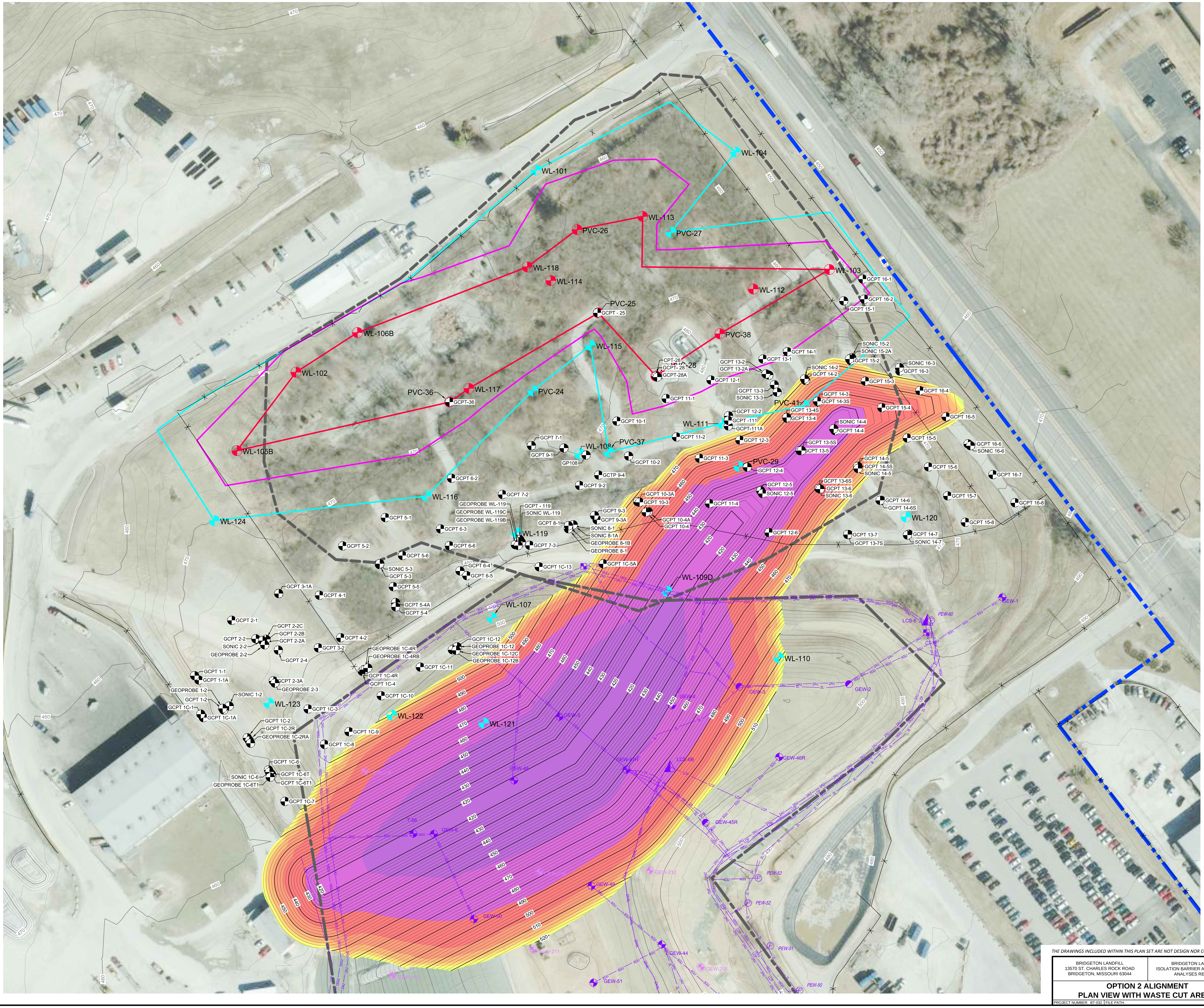
Engineering for a Better World
FEEZOR
ENGINEERING, INC.

OCTOBER 2014
DESIGNED BY: PML
APPROVED BY: DRF

REVISION	DATE

DRAWING NO.:
006

PROJECT NUMBER: BT-032
FILE PATH:



Thickness Map		
Maximum Depth - Ft.	Minimum Depth - Ft.	Color
-104	-64	🟪
-64	-32	🟪
-32	-16	🟥
-16	-8	🟧
-8	-4	🟧
-4	-2	🟨
-2	0	🟨

Excavation Volume:
535,000 c.y.

0 50 100
Feet

LEGEND

◉	PHASE 1 BORING LOCATION
◉	ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
━	HISTORIC BOUNDARY OF ELEVATED DOWNHOLE READINGS
◉	NON-ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
━	HISTORIC BOUNDARY OF NON-ELEVATED DOWNHOLE READINGS
━	HISTORIC BOUNDARY OF INTERPOLATED RIM LIMITS
—✕—	FENCE
▬ ▬ ▬ ▬	OU-1 BOUNDARY
▬ ▬ ▬	BRIDGETON LANDFILL BOUNDARY
━ ━ ━	PROPERTY LINE
—480—	03-20-14 TOPOGRAPHY (10' CONTOUR)
—	03-20-14 TOPOGRAPHY (2' CONTOUR)
—480—	EXCAVATION GRADING (10' CONTOUR)
—	EXCAVATION GRADING (2' CONTOUR)
—	EXISTING INFRASTRUCTURE PIPE
⊕	EXISTING GAS EXTRACTION WELL
⊕	EXISTING GAS EXTRACTION WELL - NEWLY INSTALLED (NOT PART OF ACTIVE GAS SYSTEM)
◐	EXISTING DUAL GAS EXTRACTION WELL
Ⓟ	EXISTING PERIMETER GAS EXTRACTION WELL
▲	EXISTING LEACHATE COLLECTION SUMP
▚	EXISTING CONDENSATE SUMP

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13570 ST. CHARLES ROCK ROAD
BRIDGETON, MISSOURI 63044

BRIDGETON LANDFILL
ISOLATION BARRIER ALTERNATIVES
ANALYSES REPORT

OPTION 2 ALIGNMENT
PLAN VIEW WITH WASTE CUT AREAS

Engineering for a Better World
FEEZOR
ENGINEERING, INC.

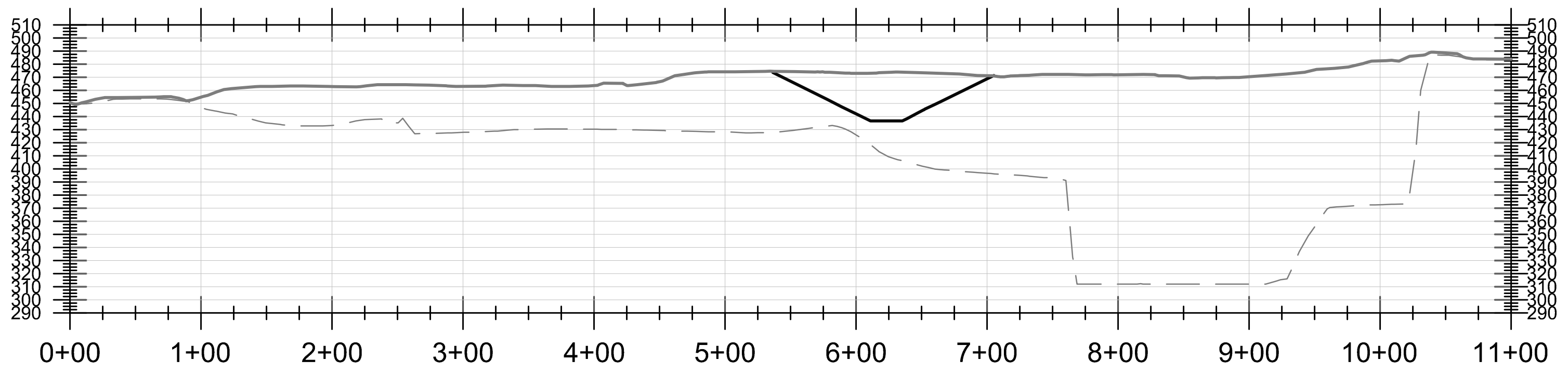
OCTOBER 2014
DESIGNED BY: PML
APPROVED BY: DRF

REVISION	DATE

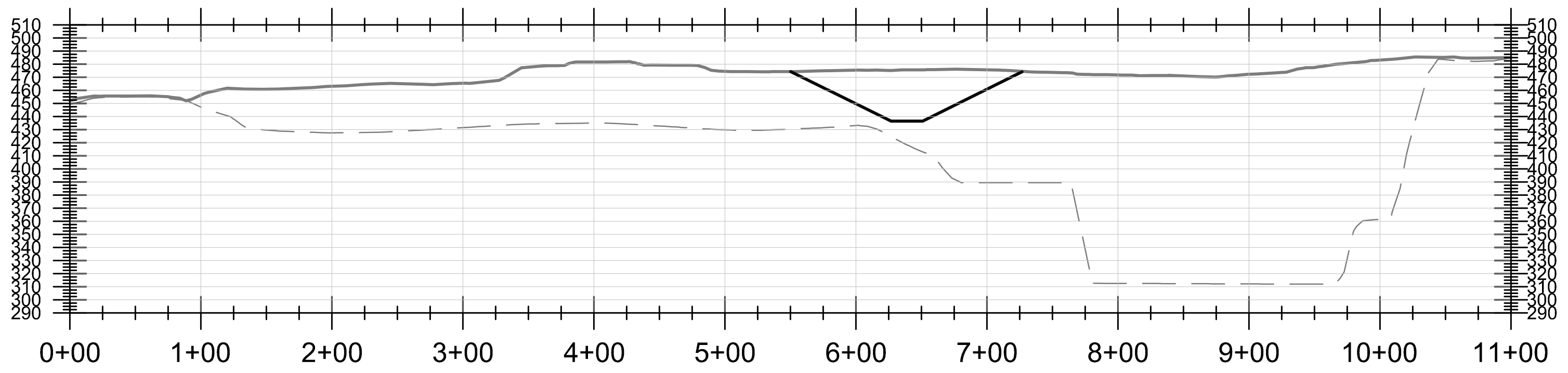
DRAWING NO.:
007

PROJECT NUMBER: BT-032
FILE PATH:

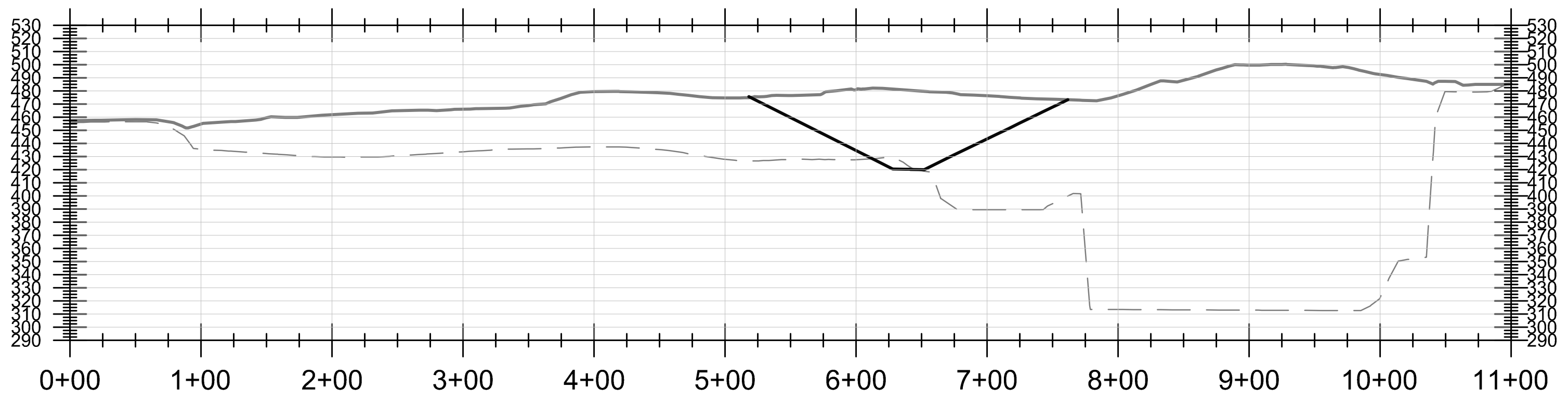
Cross Section A-A' (1H:1V)



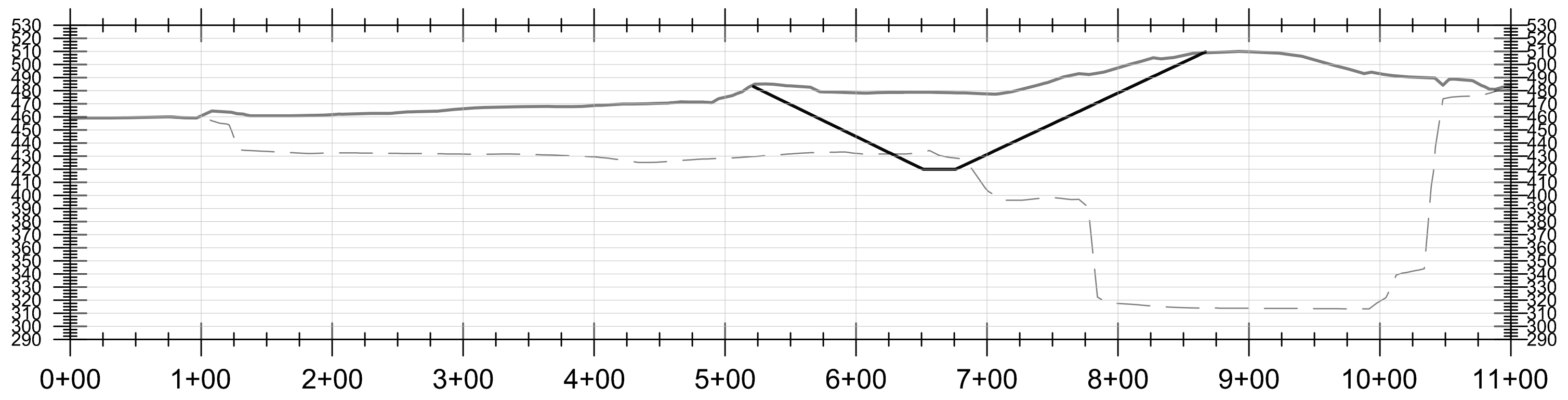
Cross Section B-B' (1H:1V)



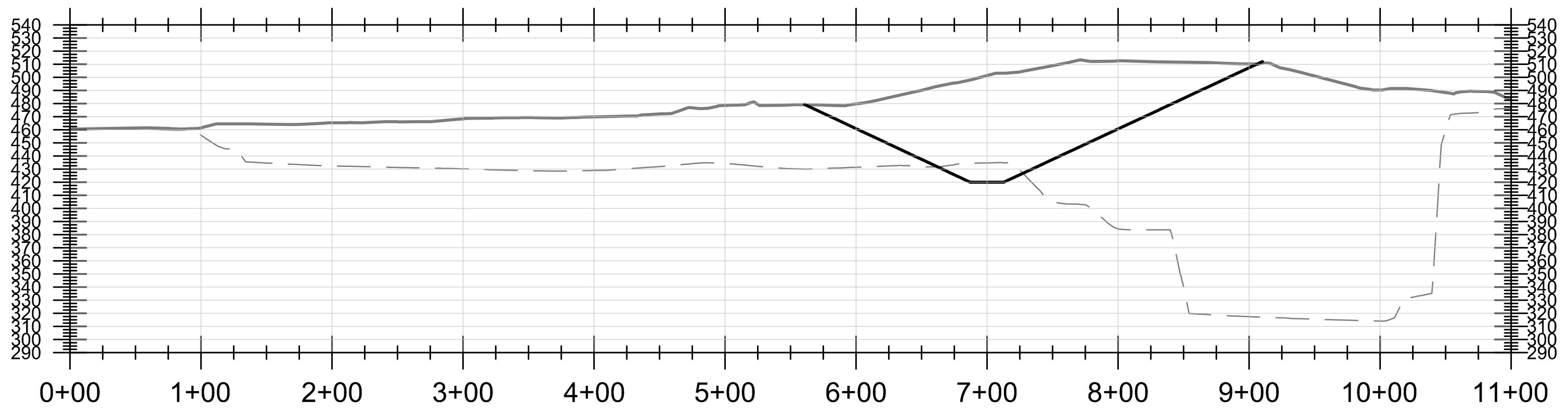
Cross Section C-C' (1H:1V)



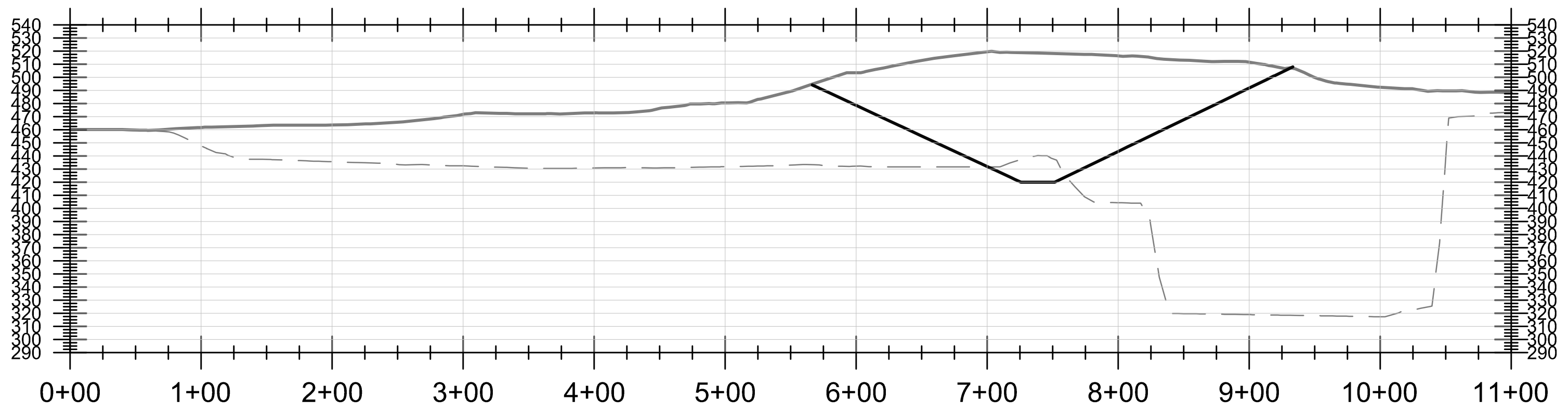
Cross Section D-D' (1H:1V)



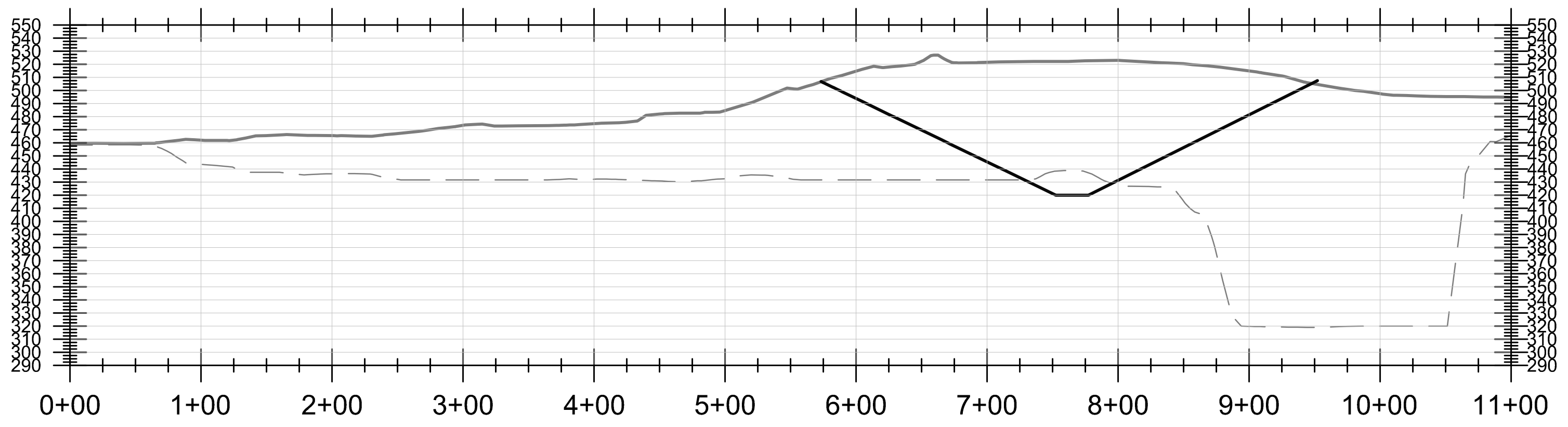
Cross Section E-E' (1H:1V)



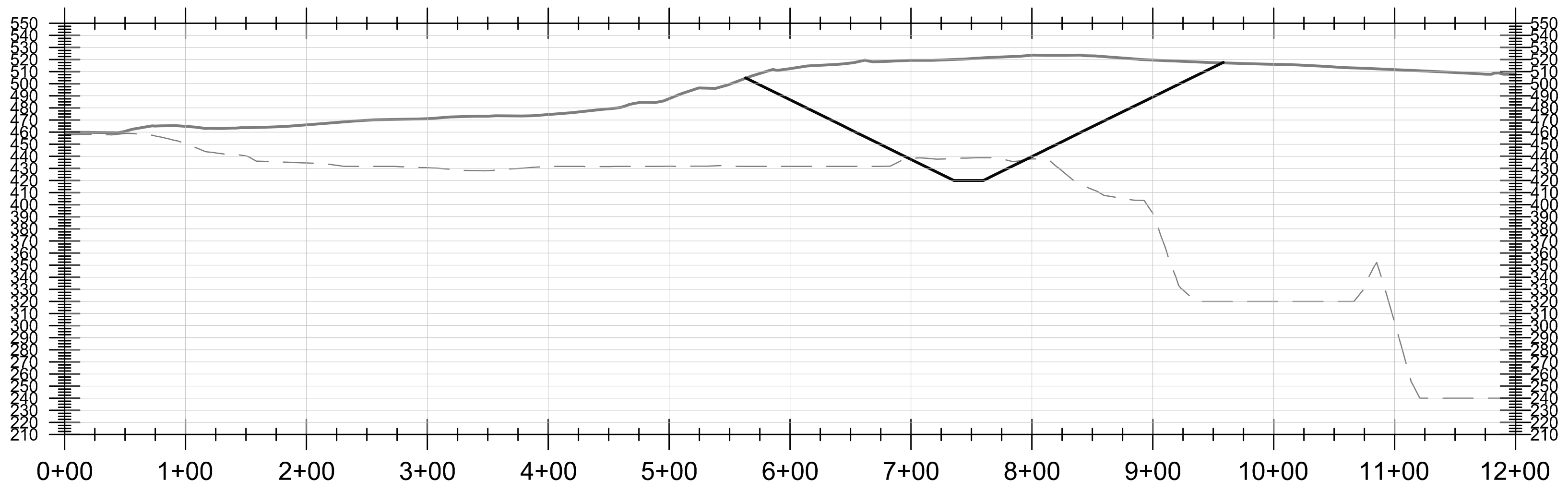
Cross Section F-F' (1H:1V)

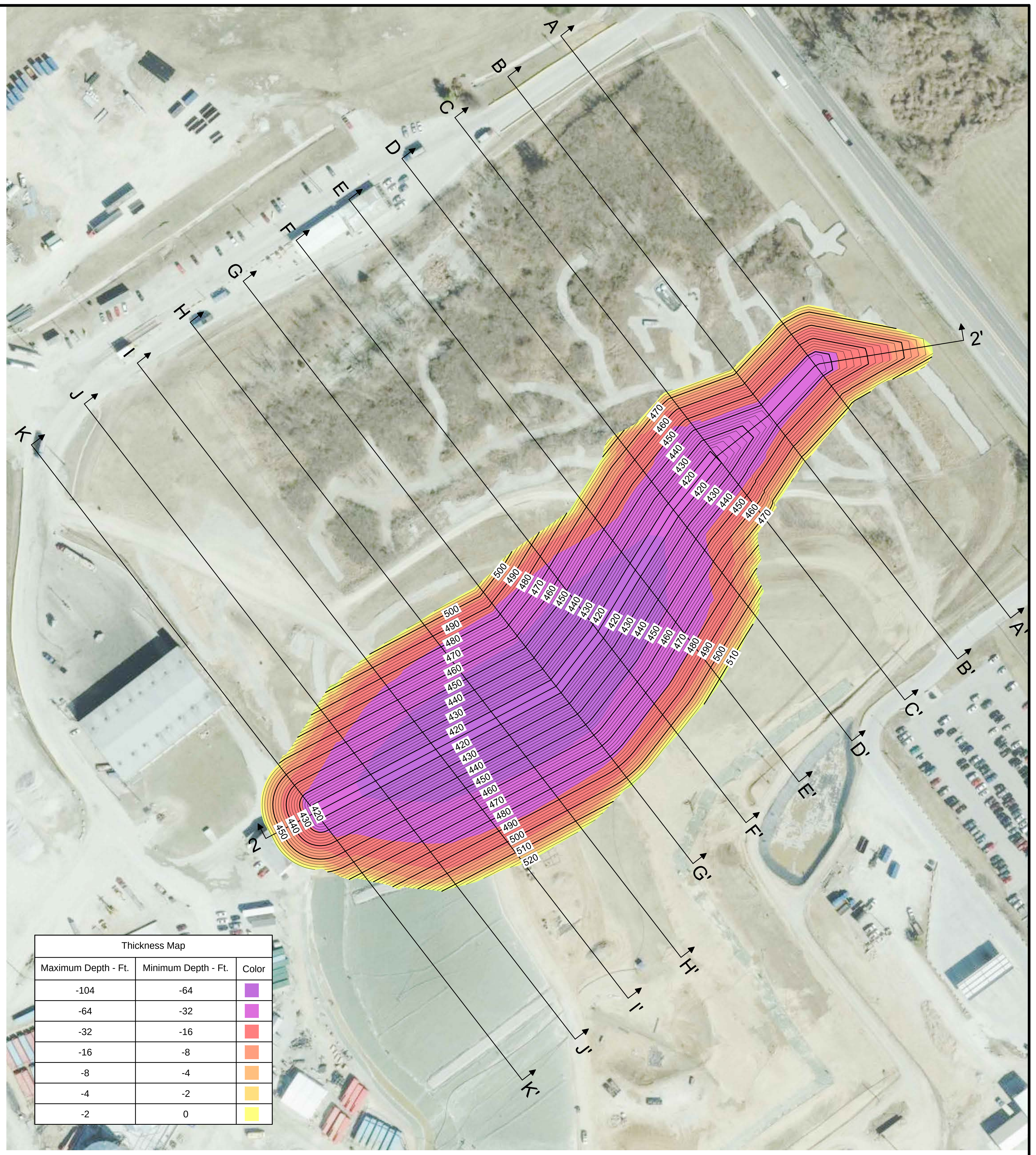


Cross Section G-G' (1H:1V)



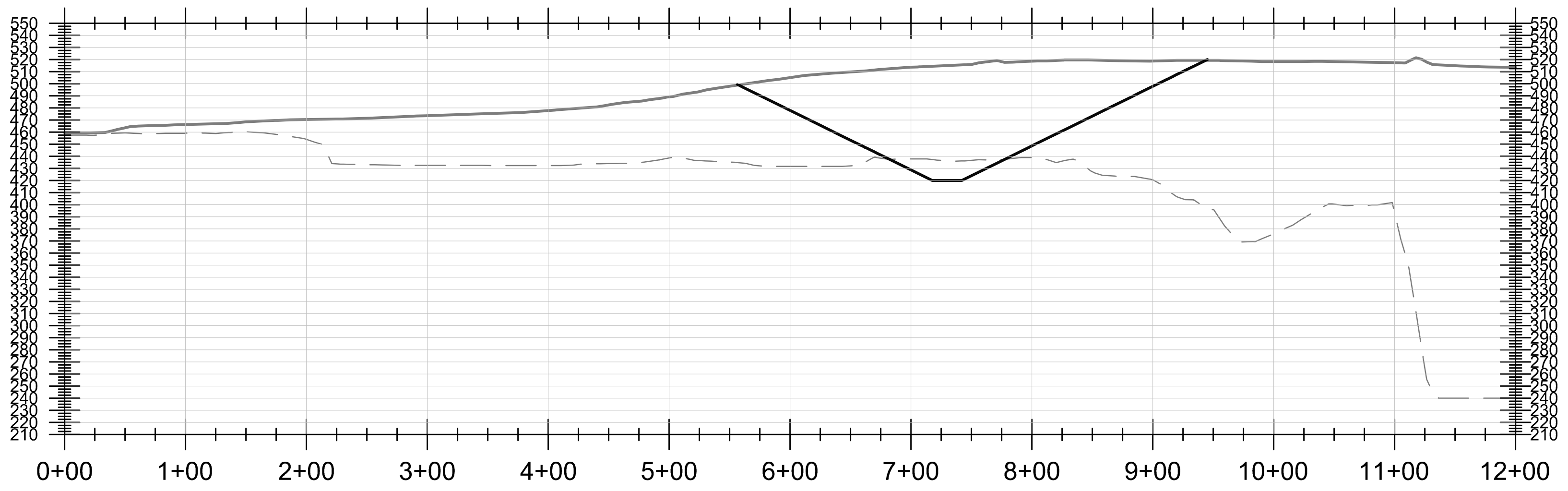
Cross Section H-H' (1H:1V)



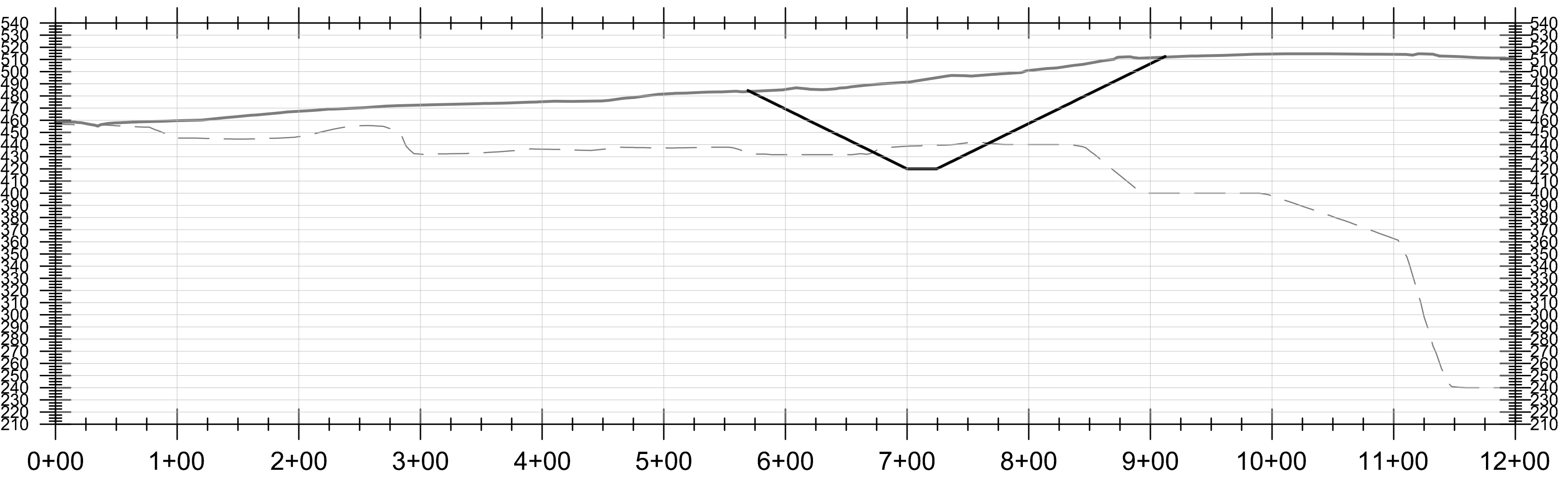


Thickness Map		
Maximum Depth - Ft.	Minimum Depth - Ft.	Color
-104	-64	🟪
-64	-32	🟪
-32	-16	🟥
-16	-8	🟧
-8	-4	🟧
-4	-2	🟨
-2	0	🟨

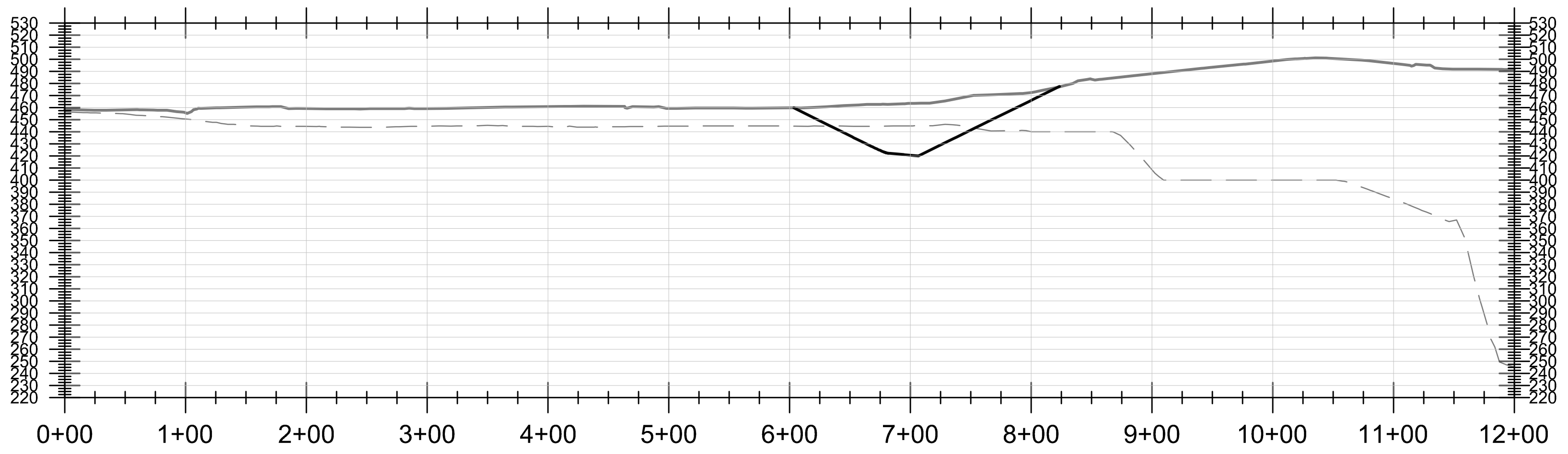
Cross Section I-I' (1H:1V)



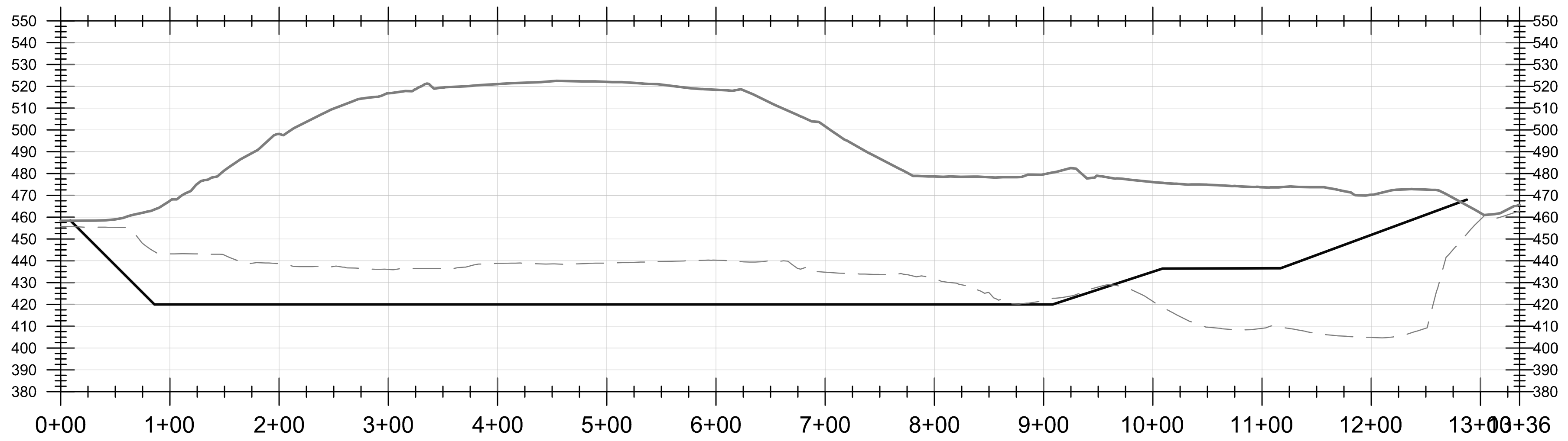
Cross Section J-J' (1H:1V)



Cross Section K-K' (1H:1V)



Profile View of Alignment 2 (1H:2V)



LEGEND

———	03-20-14 TOPOGRAPHY
— — —	ESTIMATED BOTTOM OF WASTE
———	EXCAVATION GRADING

NOTES:
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BRIDGETON LANDFILL
13570 ST. CHARLES ROCK ROAD
BRIDGETON, MISSOURI 63044

BRIDGETON LANDFILL
ISOLATION BARRIER ALTERNATIVES
ANALYSES REPORT

OPTION 2 ALIGNMENT
PROFILE VIEW AND CROSS SECTIONS

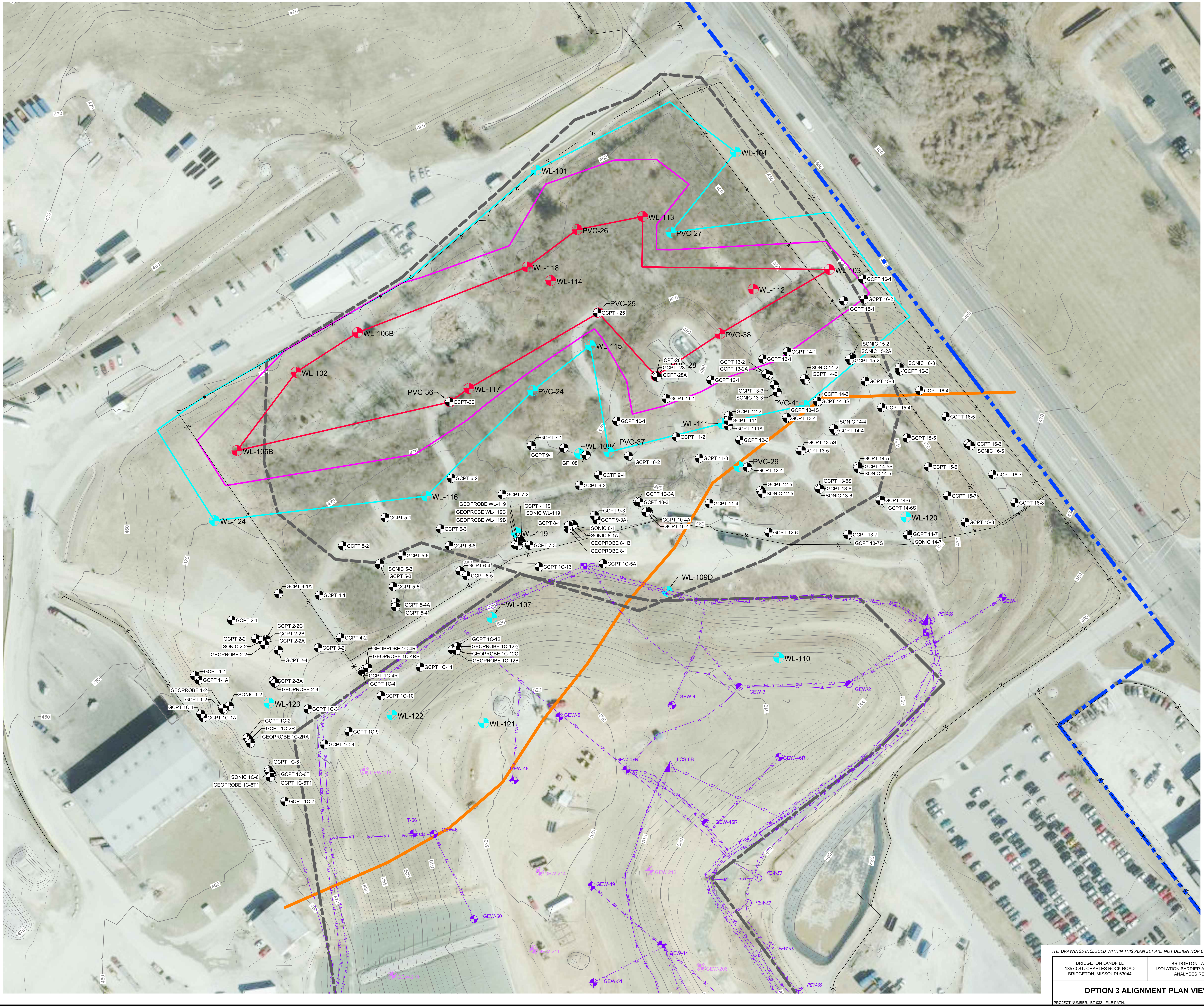
Engineering for a Better World
FEEZOR
ENGINEERING, INC.

OCTOBER 2014
DESIGNED BY: PML
APPROVED BY: DRF

REVISION	DATE

DRAWING NO.:
008

PROJECT NUMBER: BT-032
FILE PATH:



LEGEND

◐	PHASE 1 BORING LOCATION
◐	ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
━	HISTORIC BOUNDARY OF ELEVATED DOWNHOLE READINGS
◐	NON-ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
━	HISTORIC BOUNDARY OF NON-ELEVATED DOWNHOLE READINGS
━	HISTORIC BOUNDARY OF INTERPOLATED RIM LIMITS
─╳─	FENCE
━ ━ ━	OU-1 BOUNDARY
━ ━ ━	BRIDGETON LANDFILL BOUNDARY
━ ━ ━	PROPERTY LINE
—480—	03-20-14 TOPOGRAPHY (10' CONTOUR)
—	03-20-14 TOPOGRAPHY (2' CONTOUR)
━	INERT BARRIER ALIGNMENT
—	EXISTING INFRASTRUCTURE PIPE
⊕	EXISTING GAS EXTRACTION WELL
⊕	EXISTING GAS EXTRACTION WELL - NEWLY INSTALLED (NOT PART OF ACTIVE GAS SYSTEM)
◐	EXISTING DUAL GAS EXTRACTION WELL
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▲	EXISTING LEACHATE COLLECTION SUMP
▚	EXISTING CONDENSATE SUMP

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BRIDGETON, MISSOURI 63044

BRIDGETON LANDFILL
ISOLATION BARRIER ALTERNATIVES
ANALYSES REPORT

OPTION 3 ALIGNMENT PLAN VIEW

Engineering for a Better World
FEEZOR
ENGINEERING, INC.

OCTOBER 2014
DESIGNED BY: PML
APPROVED BY: DRF

REVISION	DATE

DRAWING NO.:
009

PROJECT NUMBER: BT-032
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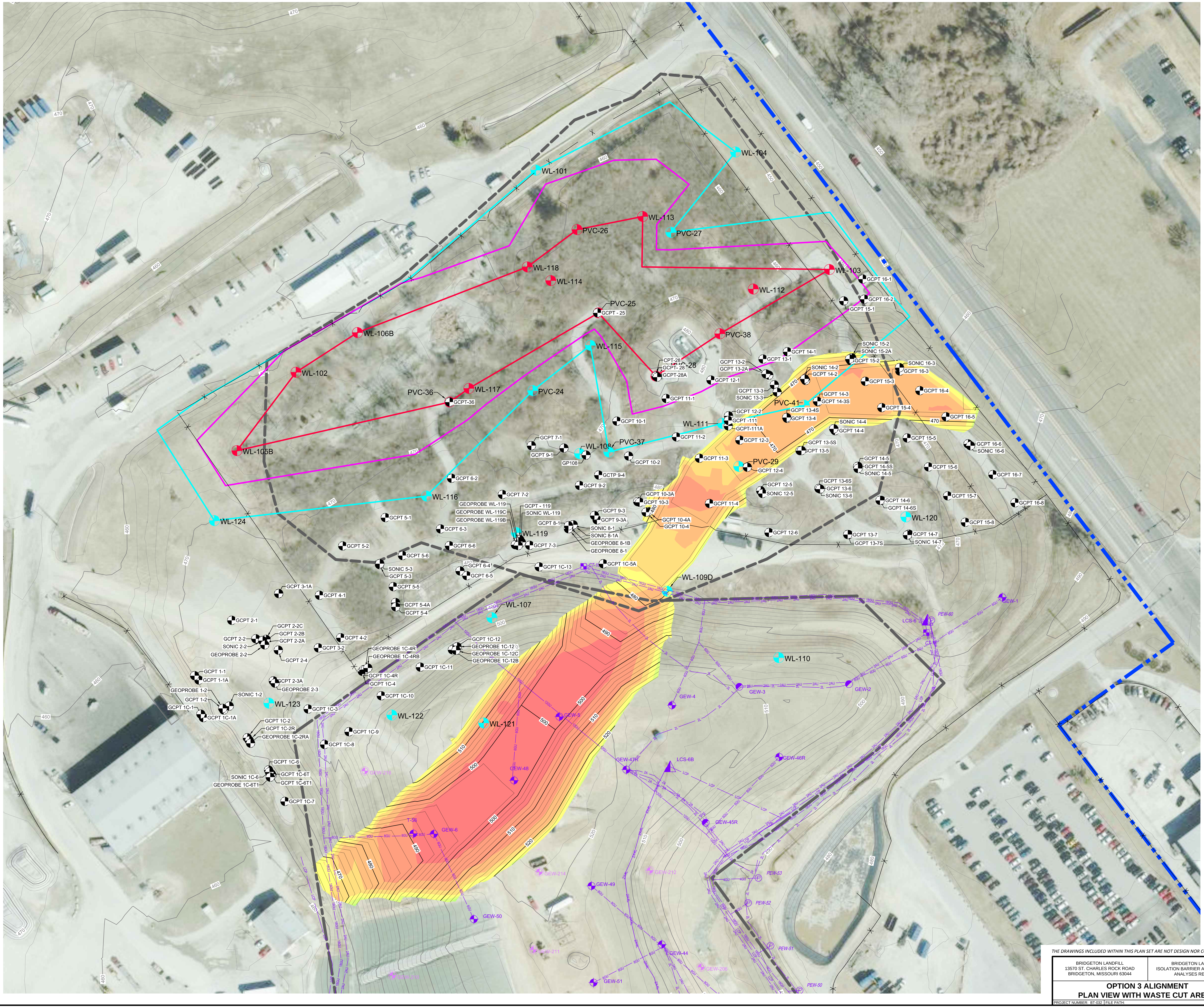

Thickness Map		
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-64	-32	🟪
-32	-16	🟥
-16	-8	🟥
-8	-4	🟧
-4	-2	🟨
-2	0	🟨

Excavation Volume:
52,500 c.y.

Barrier Volume:
7,500 c.y.

0 50 100
Feet

LEGEND

⊕	PHASE 1 BORING LOCATION
⊕	ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
━	HISTORIC BOUNDARY OF ELEVATED DOWNHOLE READINGS
⊕	NON-ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
━	HISTORIC BOUNDARY OF NON-ELEVATED DOWNHOLE READINGS
━	HISTORIC BOUNDARY OF INTERPOLATED RIM LIMITS
—×—	FENCE
▬ ▬ ▬ ▬	OU-1 BOUNDARY
▬ ▬ ▬	BRIDGETON LANDFILL BOUNDARY
▬ ▬ ▬ ▬	PROPERTY LINE
—480—	03-20-14 TOPOGRAPHY (10' CONTOUR)
—	03-20-14 TOPOGRAPHY (2' CONTOUR)
—480—	EXCAVATION GRADING (10' CONTOUR)
—	EXCAVATION GRADING (2' CONTOUR)
—	EXISTING INFRASTRUCTURE PIPE
⊕	EXISTING GAS EXTRACTION WELL
⊕	EXISTING GAS EXTRACTION WELL - NEWLY INSTALLED (NOT PART OF ACTIVE GAS SYSTEM)
◐	EXISTING DUAL GAS EXTRACTION WELL
Ⓟ	EXISTING PERIMETER GAS EXTRACTION WELL
▲	EXISTING LEACHATE COLLECTION SUMP
▚	EXISTING CONDENSATE SUMP

NOTES:
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BRIDGETON LANDFILL
13570 ST. CHARLES ROCK ROAD
BRIDGETON, MISSOURI 63044

BRIDGETON LANDFILL
ISOLATION BARRIER ALTERNATIVES
ANALYSES REPORT

OPTION 3 ALIGNMENT
PLAN VIEW WITH WASTE CUT AREAS

PROJECT NUMBER: BT-032 | FILE PATH:

Engineering for a Better World
FEEZOR
ENGINEERING, INC.

OCTOBER 2014
DESIGNED BY: PML
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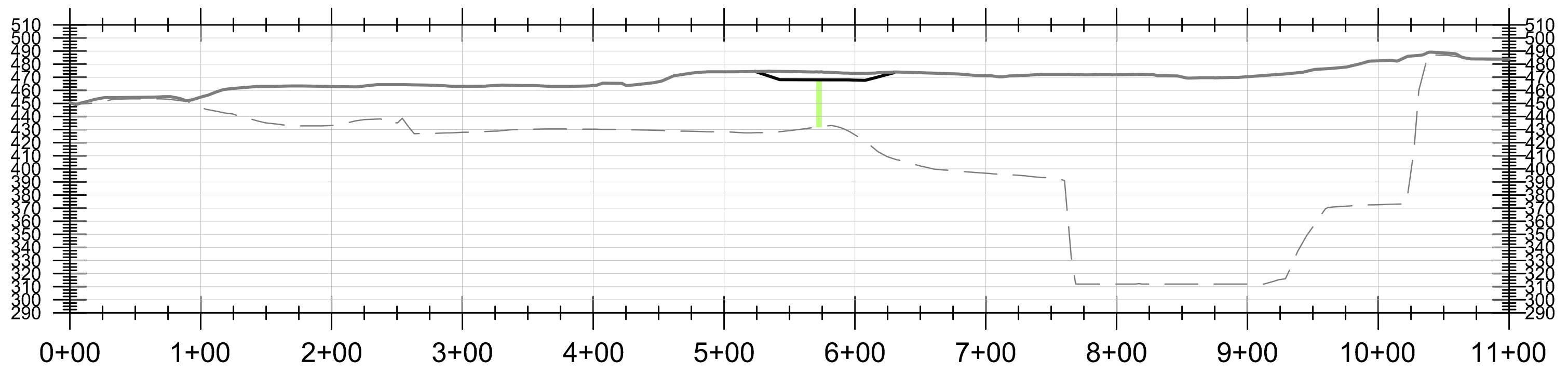
DRAWING NO.:
010

Cross Section A-A' (1H:1V)



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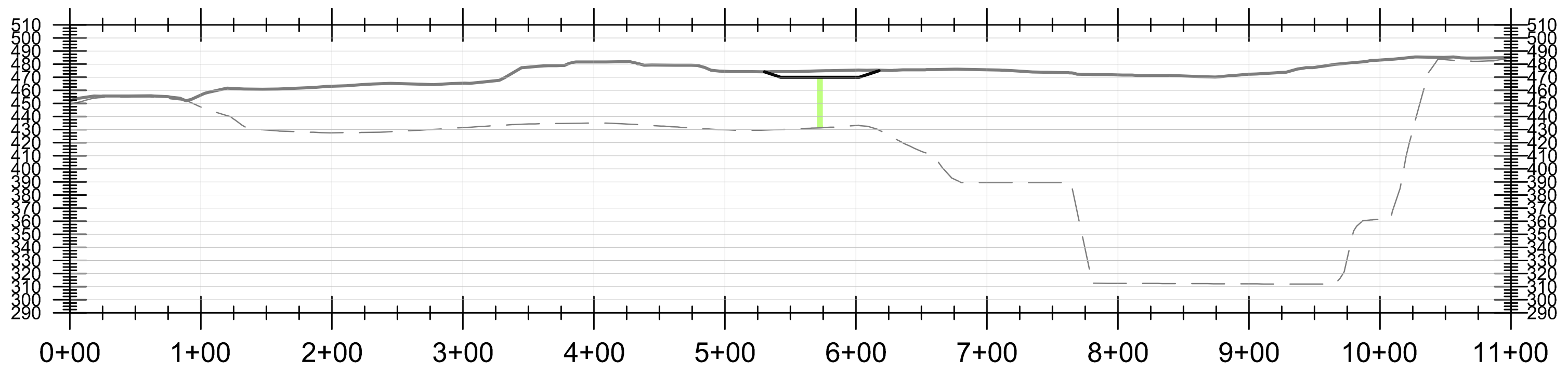

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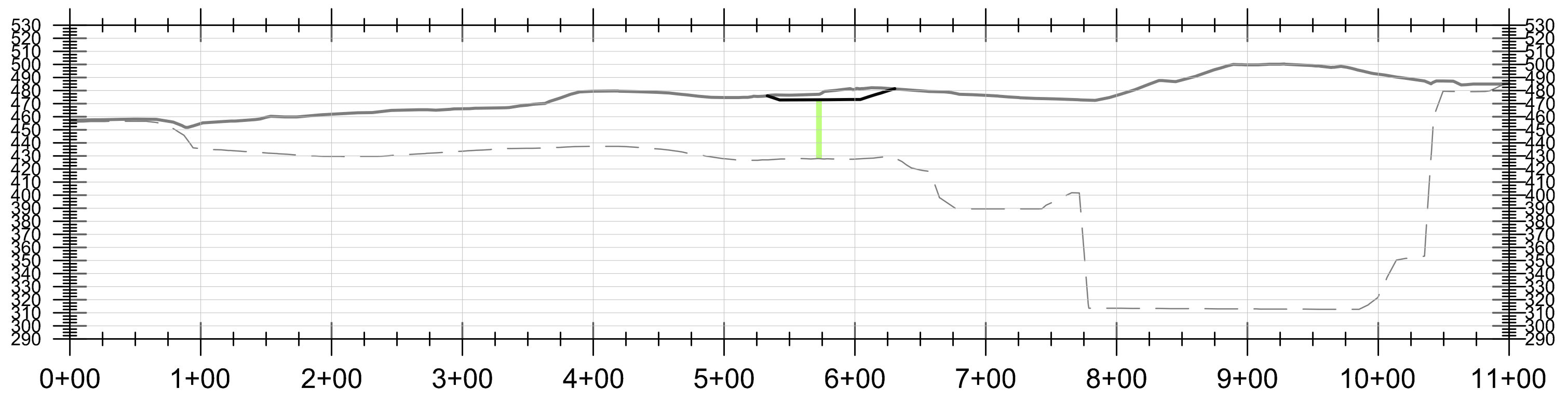

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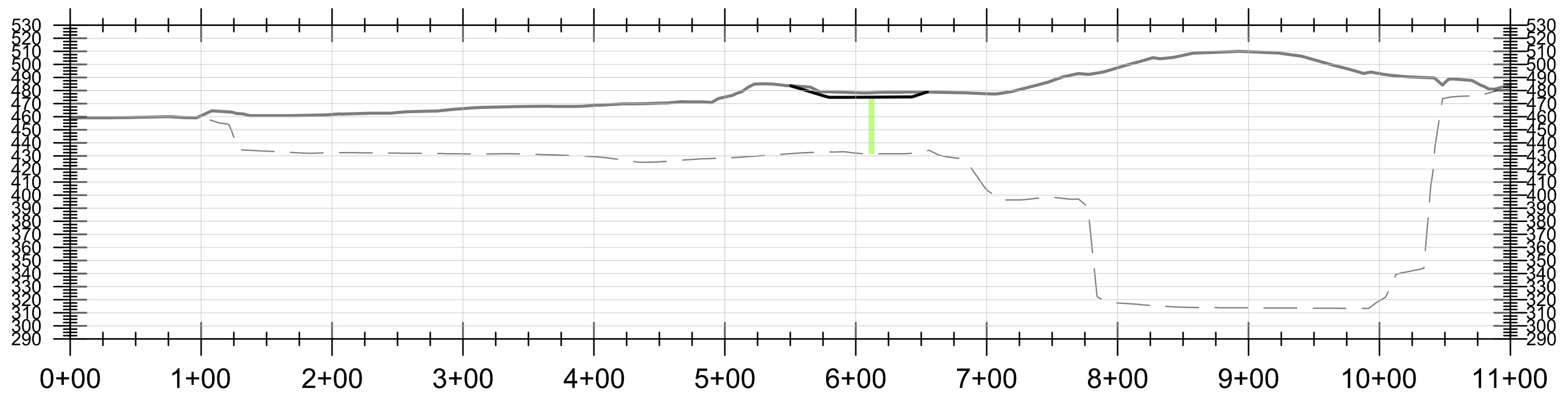

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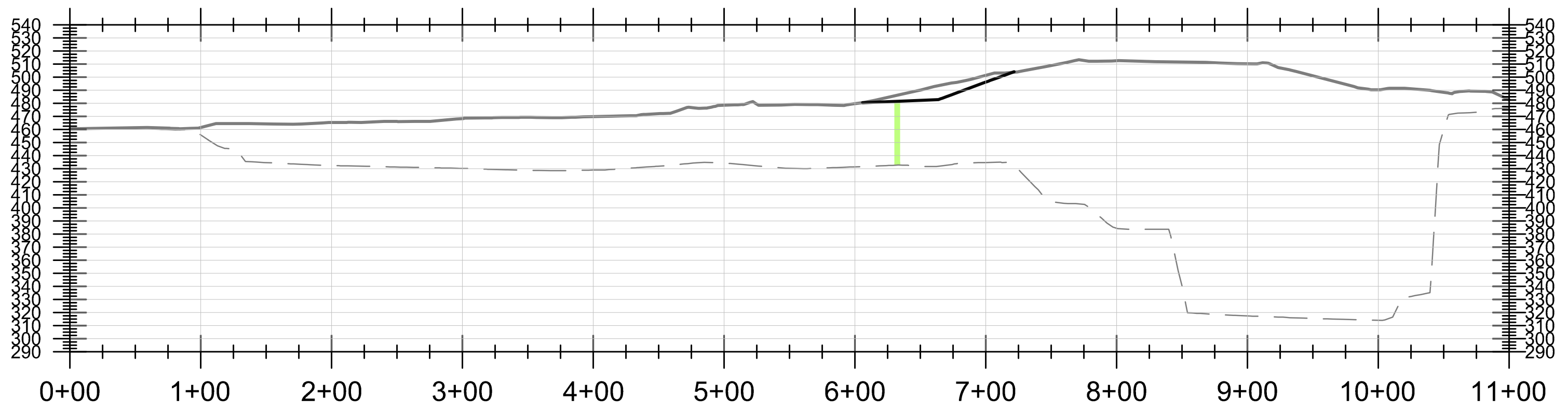

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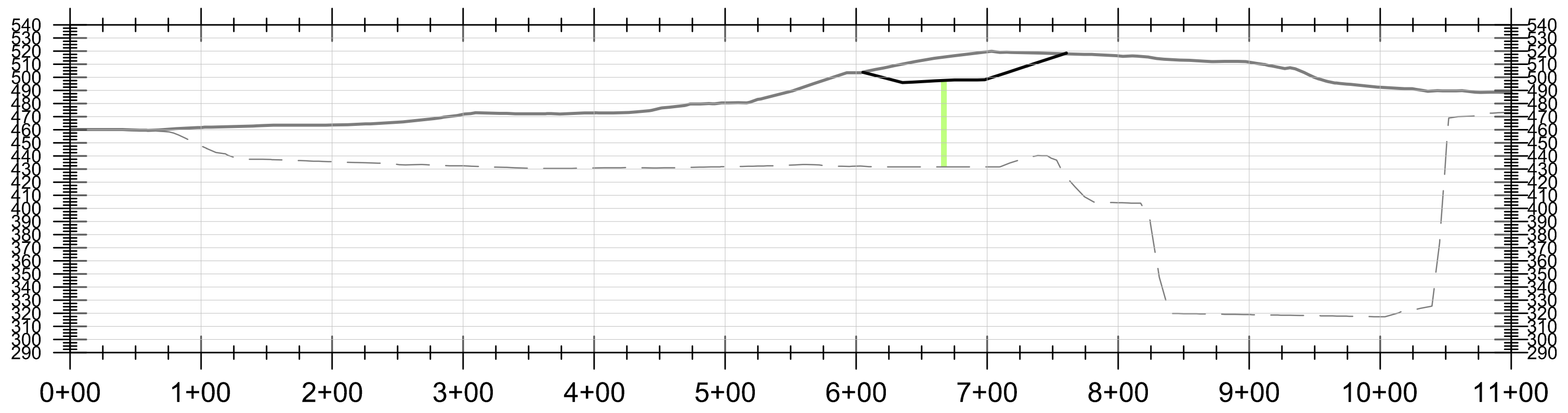

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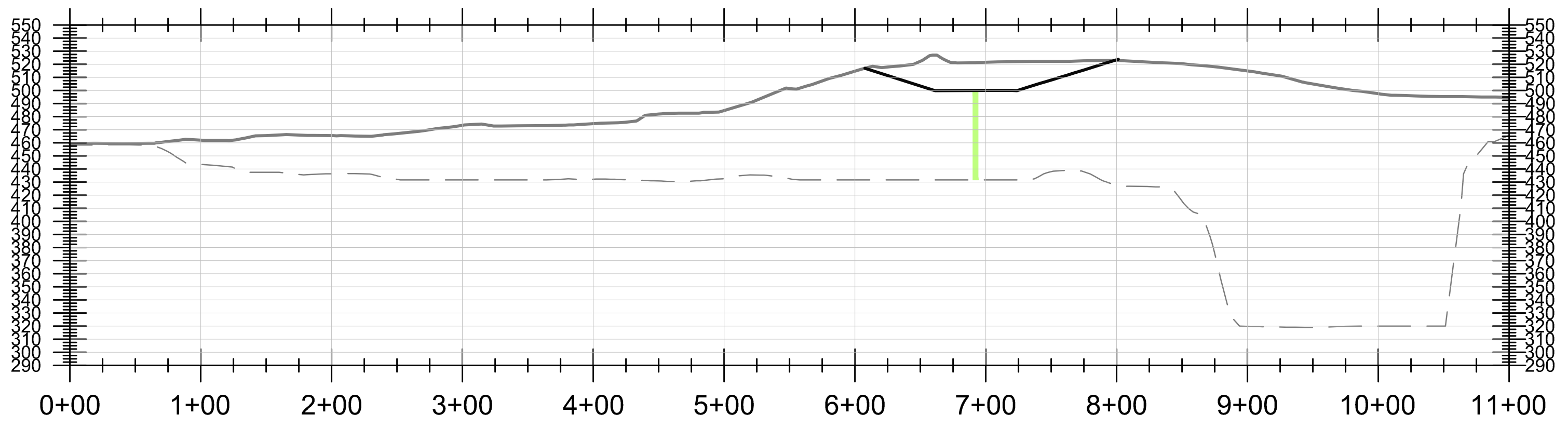

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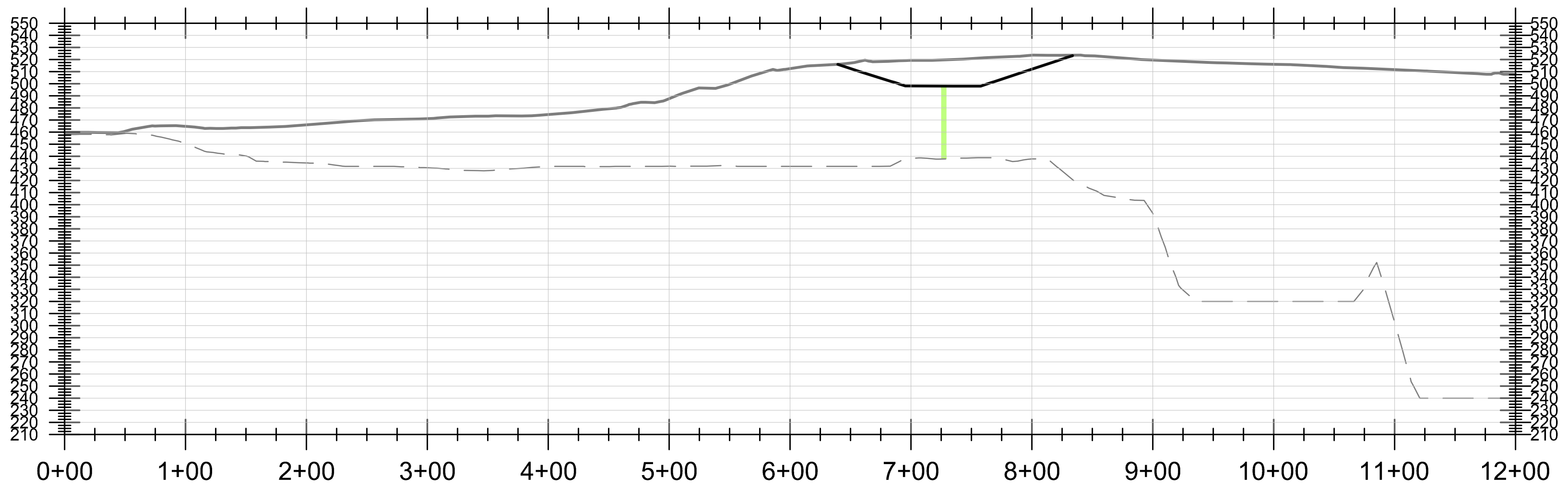

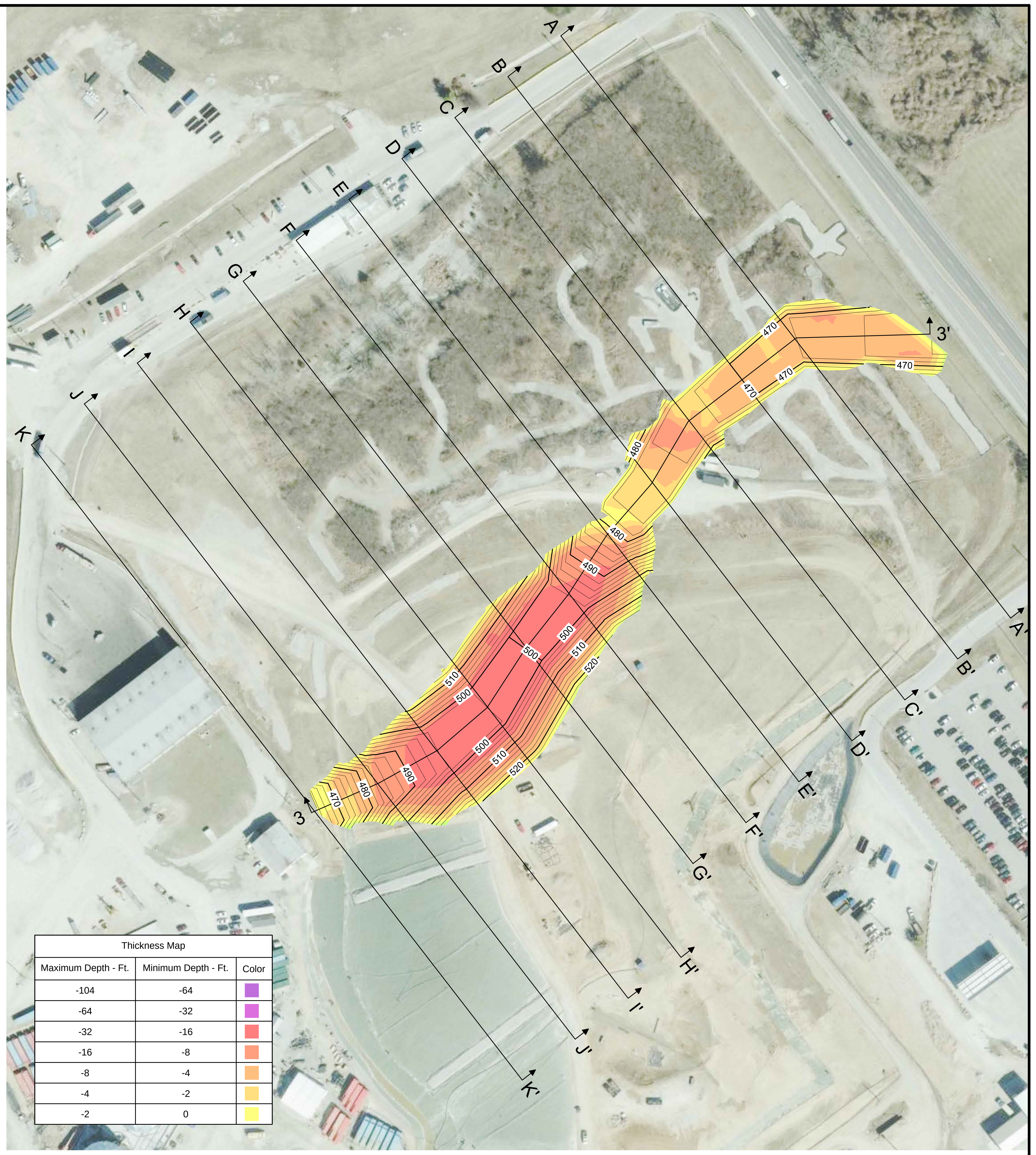

Thickness Map		
Maximum Depth - Ft.	Minimum Depth - Ft.	Color
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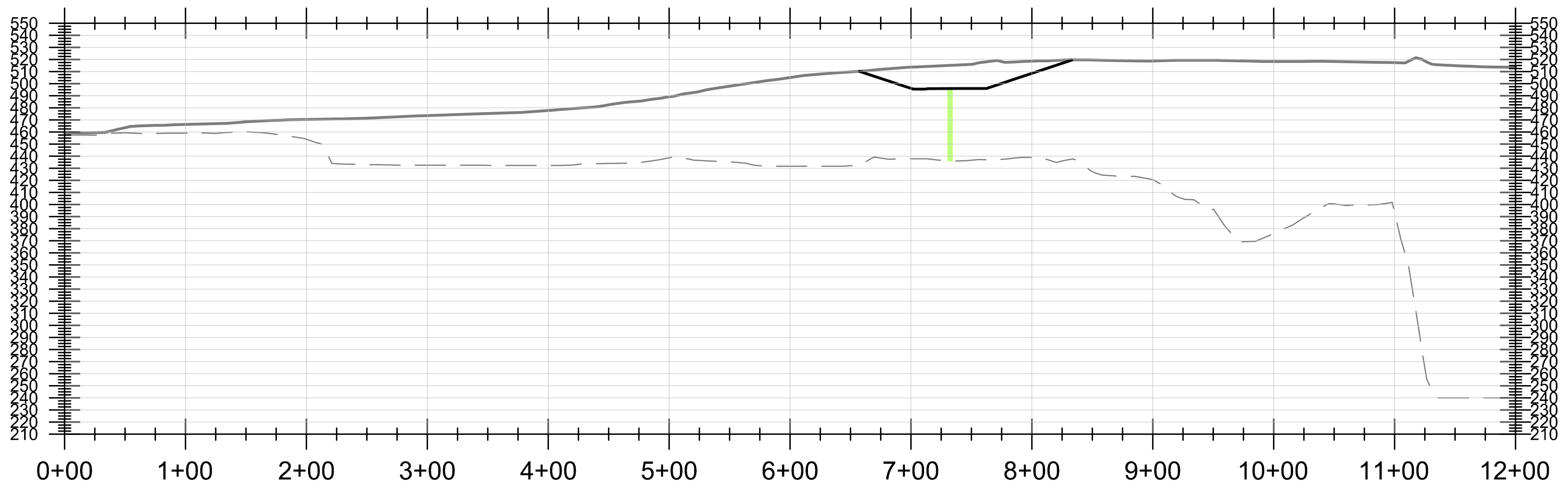
-64	-32	🟪
-32	-16	🟥
-16	-8	🟧
-8	-4	🟧
-4	-2	🟨
-2	0	🟨

Cross Section I-I' (1H:1V)



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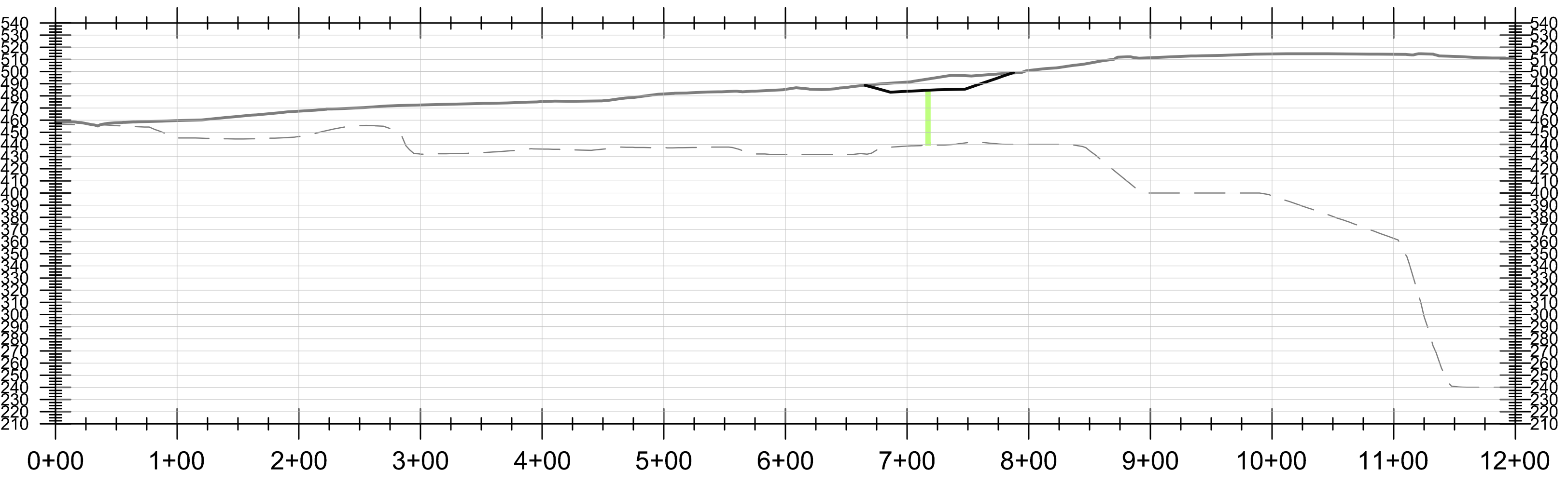

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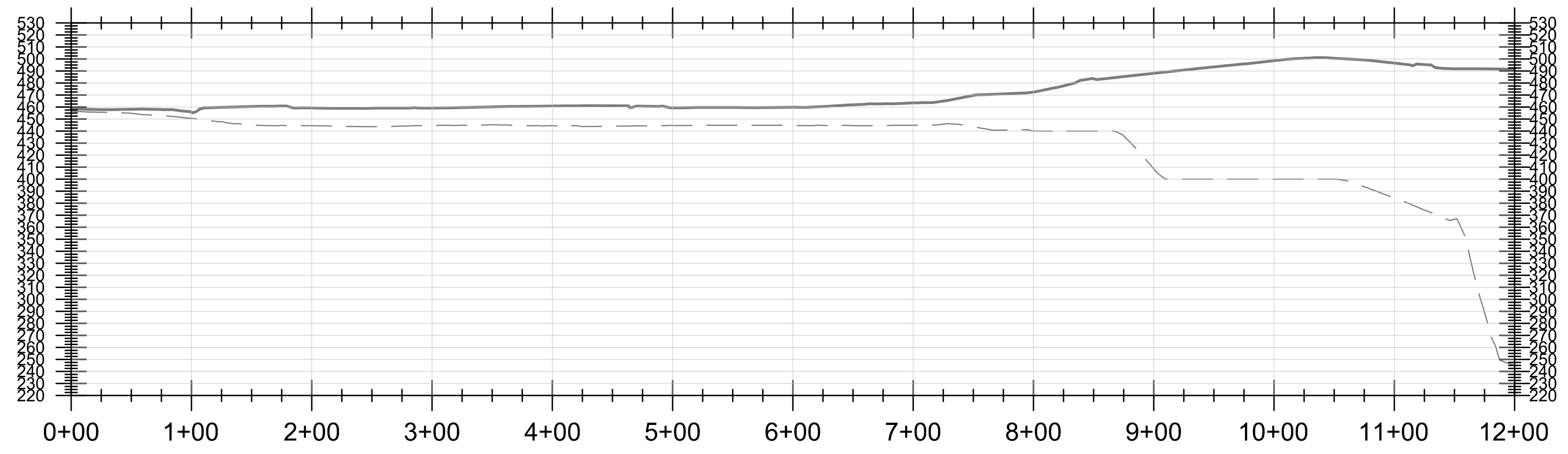
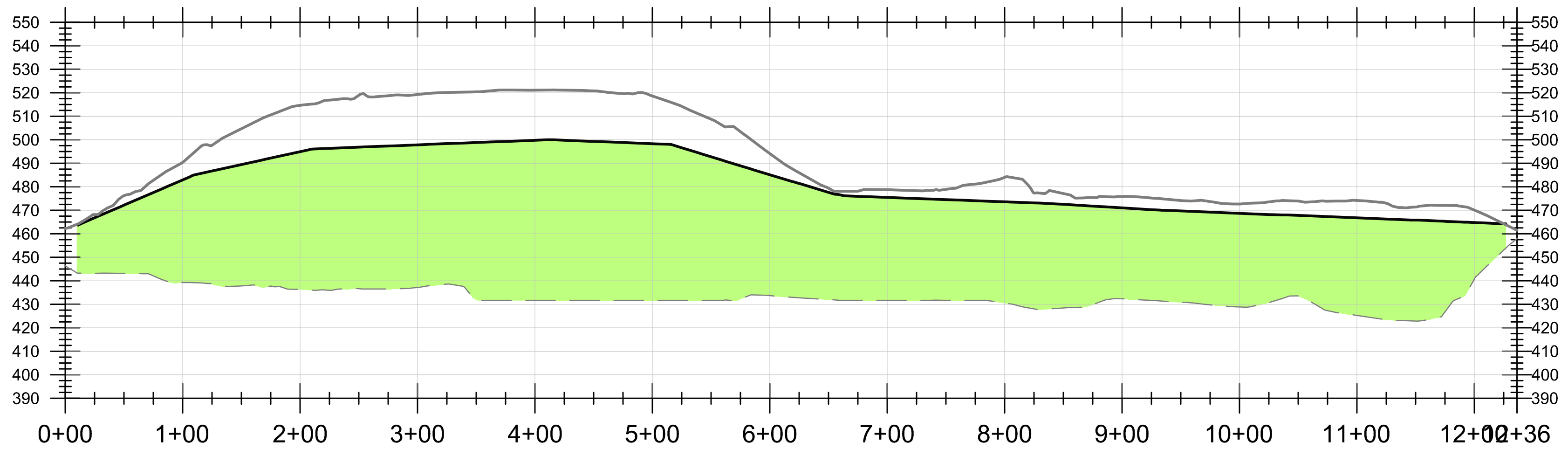


Profile View of Alignment 3 (1H:2V)



LEGEND

- ── 03-20-14 TOPOGRAPHY
- – – ESTIMATED BOTTOM OF WASTE
- ━━ EXCAVATION GRADING
- 🟩 INERT BARRIER

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13570 ST. CHARLES ROCK ROAD
BRIDGETON, MISSOURI 63044

BRIDGETON LANDFILL
ISOLATION BARRIER ALTERNATIVES
ANALYSES REPORT

OPTION 3 ALIGNMENT
PROFILE VIEW AND CROSS SECTIONS

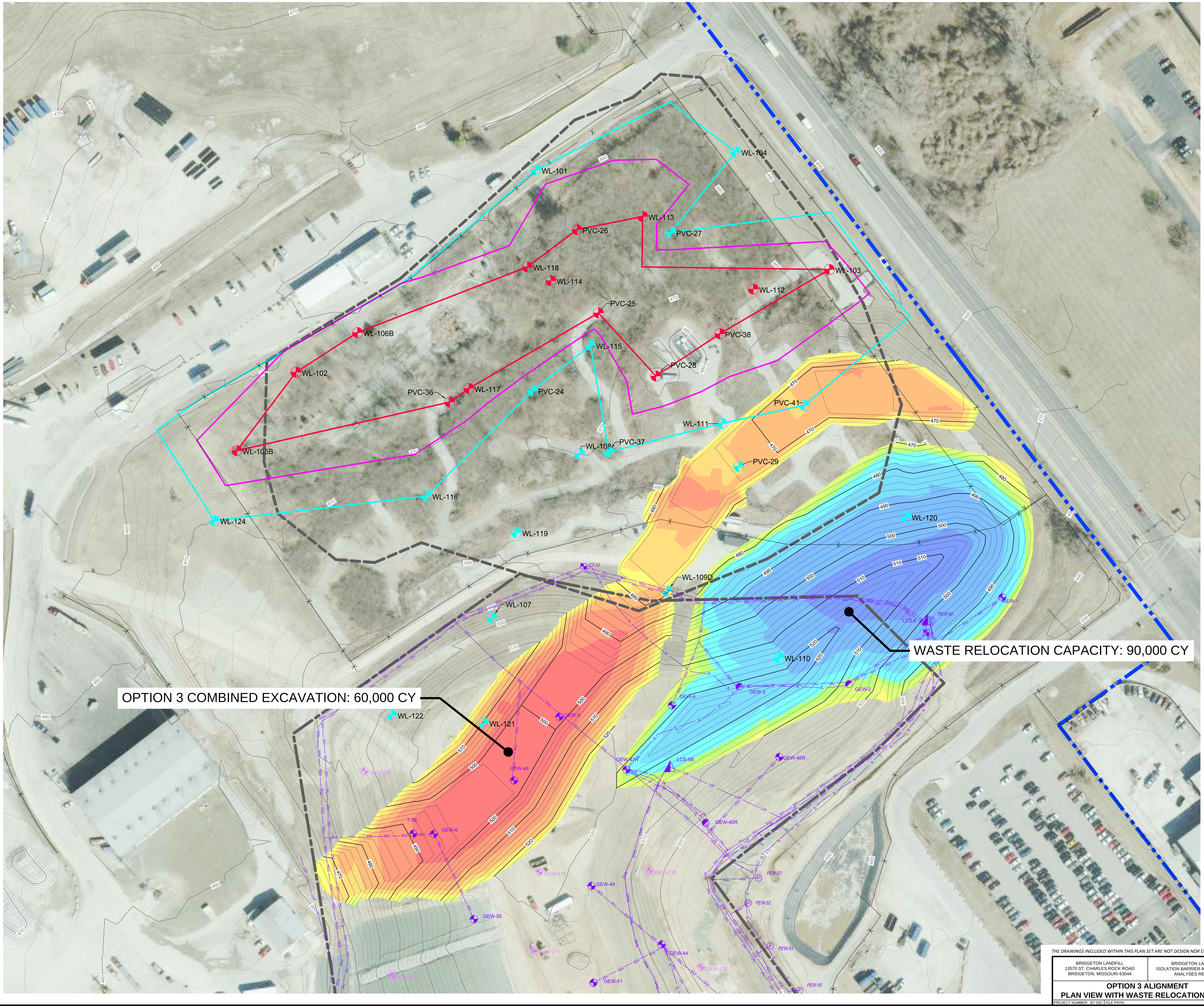
Engineering for a Better World
FEEZOR
ENGINEERING, INC.

OCTOBER 2014
DESIGNED BY: PML
APPROVED BY: DRF

REVISION	DATE

DRAWING NO.:
011

PROJECT NUMBER: BT-032
FILE PATH:



WASTE RELOCATION CAPACITY: 90,000 CY

OPTION 3 COMBINED EXCAVATION: 60,000 CY

Thickness Map

Maximum Depth - Ft.	Minimum Depth - Ft.	Color
-104	-64	🟪
-64	-32	🟪
-32	-16	🟥
-16	-8	🟧
-8	-4	🟧
-4	-2	🟨
-2	0	🟨

Thickness Map

Minimum Depth - Ft.	Maximum Depth - Ft.	Color
0	2	🟩
2	4	🟩
4	8	🟦
8	16	🟦
16	32	🟦
32	47	🟦

0 50 100 Feet

LEGEND

⊕	PHASE 1 BORING LOCATION
⊕	ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
━	HISTORIC BOUNDARY OF ELEVATED DOWNHOLE READINGS
⊕	NON-ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
━	HISTORIC BOUNDARY OF NON-ELEVATED DOWNHOLE READINGS
━	HISTORIC BOUNDARY OF INTERPOLATED RIM LIMITS
—X—	FENCE
▬ ▬ ▬	OU-1 BOUNDARY
▬ ▬ ▬	BRIDGETON LANDFILL BOUNDARY
━ ‑ ‑ ━	PROPERTY LINE
—480—	03-20-14 TOPOGRAPHY (10' CONTOUR)
—	03-20-14 TOPOGRAPHY (2' CONTOUR)
—480—	EXCAVATION GRADING (10' CONTOUR)
—	EXCAVATION GRADING (2' CONTOUR)
—	EXISTING INFRASTRUCTURE PIPE
⊕	EXISTING GAS EXTRACTION WELL
⊕	EXISTING GAS EXTRACTION WELL - NEWLY INSTALLED (NOT PART OF ACTIVE GAS SYSTEM)
◐	EXISTING DUAL GAS EXTRACTION WELL
Ⓟ	EXISTING PERIMETER GAS EXTRACTION WELL
▲	EXISTING LEACHATE COLLECTION SUMP
▚	EXISTING CONDENSATE SUMP

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13570 ST. CHARLES ROCK ROAD
BRIDGETON, MISSOURI 63044

BRIDGETON LANDFILL
ISOLATION BARRIER ALTERNATIVES
ANALYSES REPORT

OPTION 3 ALIGNMENT
PLAN VIEW WITH WASTE RELOCATION AREAS

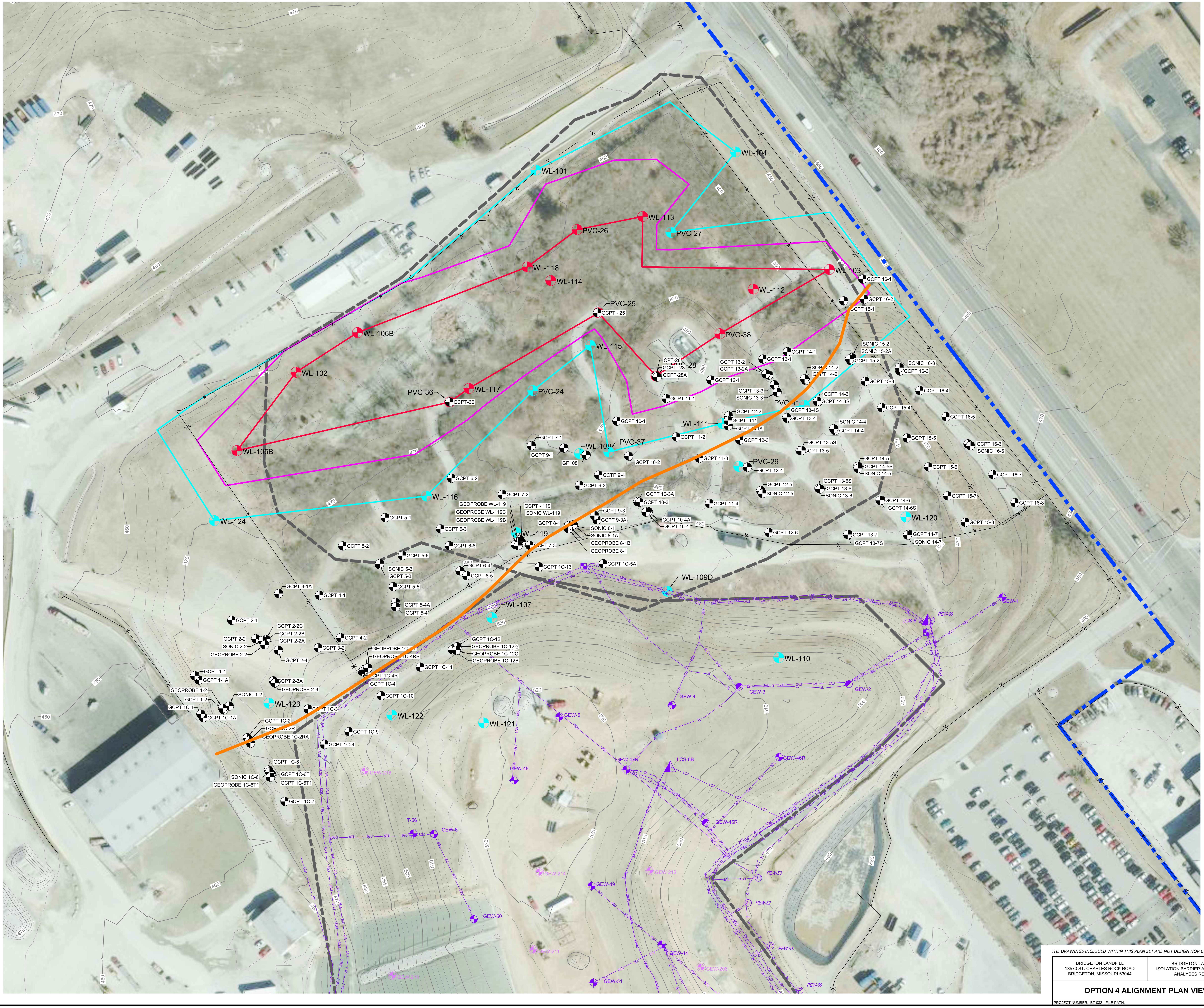
Engineering for a Better World
FEEZOR
ENGINEERING, INC.

OCTOBER 2014
DESIGNED BY: PML
APPROVED BY: DRF

REVISION	DATE

DRAWING NO.:
012

PROJECT NUMBER: BT-032 | FILE PATH:



LEGEND

◕	PHASE 1 BORING LOCATION
◕	ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
━	HISTORIC BOUNDARY OF ELEVATED DOWNHOLE READINGS
◕	NON-ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
━	HISTORIC BOUNDARY OF NON-ELEVATED DOWNHOLE READINGS
━	HISTORIC BOUNDARY OF INTERPOLATED RIM LIMITS
—X—	FENCE
▬ ▬ ▬	OU-1 BOUNDARY
▬ ▬ ▬	BRIDGETON LANDFILL BOUNDARY
▬ ▬ ▬	PROPERTY LINE
——480——	03-20-14 TOPOGRAPHY (10' CONTOUR)
——	03-20-14 TOPOGRAPHY (2' CONTOUR)
━	HEAT EXTRACTION BARRIER ALIGNMENT
—	EXISTING INFRASTRUCTURE PIPE
⊕	EXISTING GAS EXTRACTION WELL
⊕	EXISTING GAS EXTRACTION WELL - NEWLY INSTALLED (NOT PART OF ACTIVE GAS SYSTEM)
◐	EXISTING DUAL GAS EXTRACTION WELL
Ⓟ	EXISTING PERIMETER GAS EXTRACTION WELL
▲	EXISTING LEACHATE COLLECTION SUMP
▚	EXISTING CONDENSATE SUMP

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BRIDGETON LANDFILL
ISOLATION BARRIER ALTERNATIVES
ANALYSES REPORT

OPTION 4 ALIGNMENT PLAN VIEW

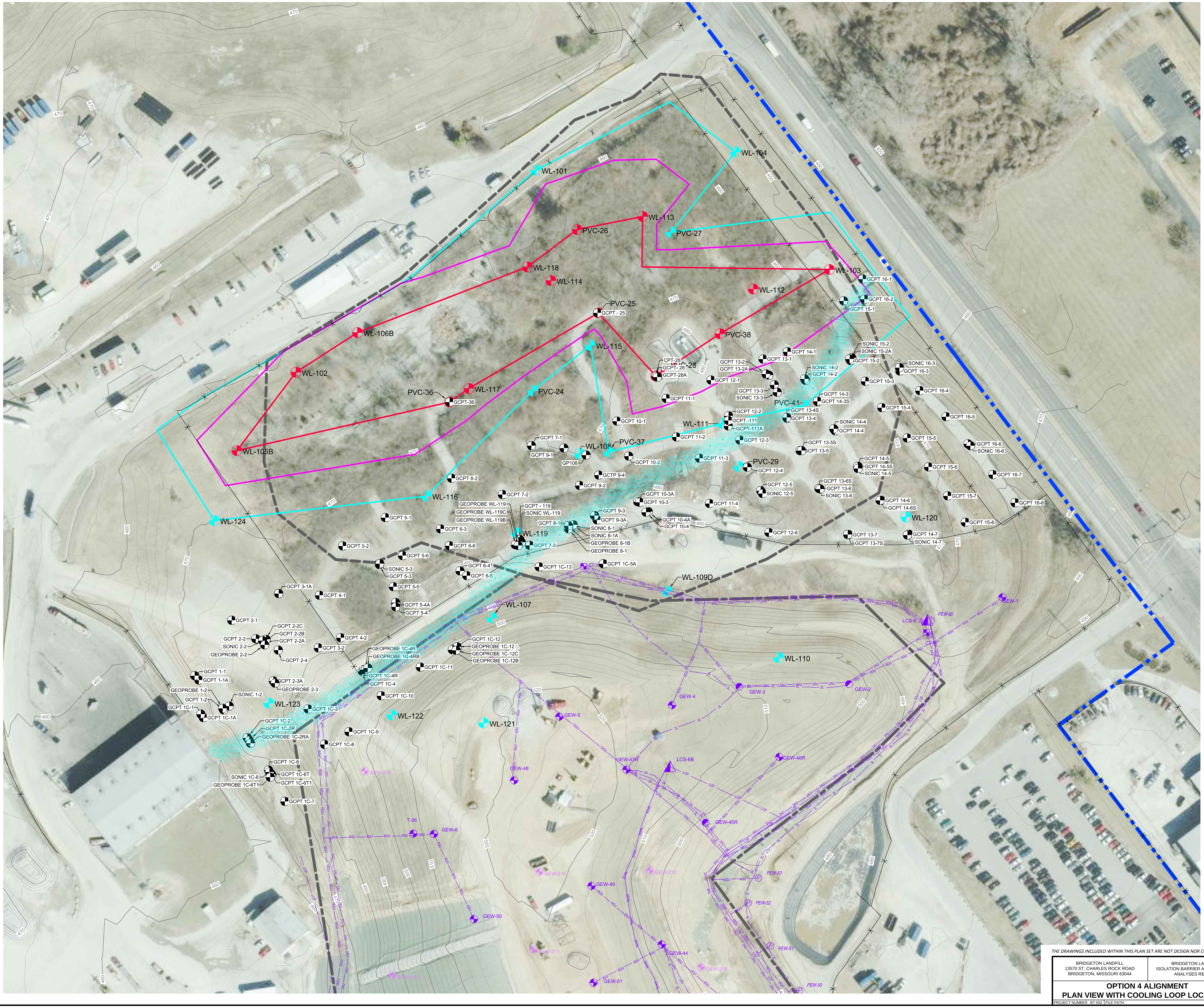
Engineering for a Better World
FEEZOR
ENGINEERING, INC.

OCTOBER 2014
DESIGNED BY: PML
APPROVED BY: DRF

REVISION	DATE

DRAWING NO.:
013

PROJECT NUMBER: BT-032
FILE PATH:



LEGEND

◒	PHASE 1 BORING LOCATION
◒	ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
━	HISTORIC BOUNDARY OF ELEVATED DOWNHOLE READINGS
◒	NON-ELEVATED DOWNHOLE GAMMA READING FROM PREVIOUS STUDY
━	HISTORIC BOUNDARY OF NON-ELEVATED DOWNHOLE READINGS
━	HISTORIC BOUNDARY OF INTERPOLATED RIM LIMITS
—×—	FENCE
▬ ▬ ▬	OU-1 BOUNDARY
▬ ▬ ▬	BRIDGETON LANDFILL BOUNDARY
━ ━ ━	PROPERTY LINE
—480—	03-20-14 TOPOGRAPHY (10' CONTOUR)
—	03-20-14 TOPOGRAPHY (2' CONTOUR)
—480—	EXCAVATION GRADING (10' CONTOUR)
—	EXCAVATION GRADING (2' CONTOUR)
◍	COOLING POINT (WITH 10' RADIUS)
—	EXISTING INFRASTRUCTURE PIPE
◒	EXISTING GAS EXTRACTION WELL
◒	EXISTING GAS EXTRACTION WELL - NEWLY INSTALLED (NOT PART OF ACTIVE GAS SYSTEM)
◐	EXISTING DUAL GAS EXTRACTION WELL
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BRIDGETON LANDFILL
ISOLATION BARRIER ALTERNATIVES
ANALYSES REPORT

OPTION 4 ALIGNMENT
PLAN VIEW WITH COOLING LOOP LOCATIONS

Engineering for a Better World
FEEZOR
ENGINEERING, INC.

OCTOBER 2014
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REVISION	DATE

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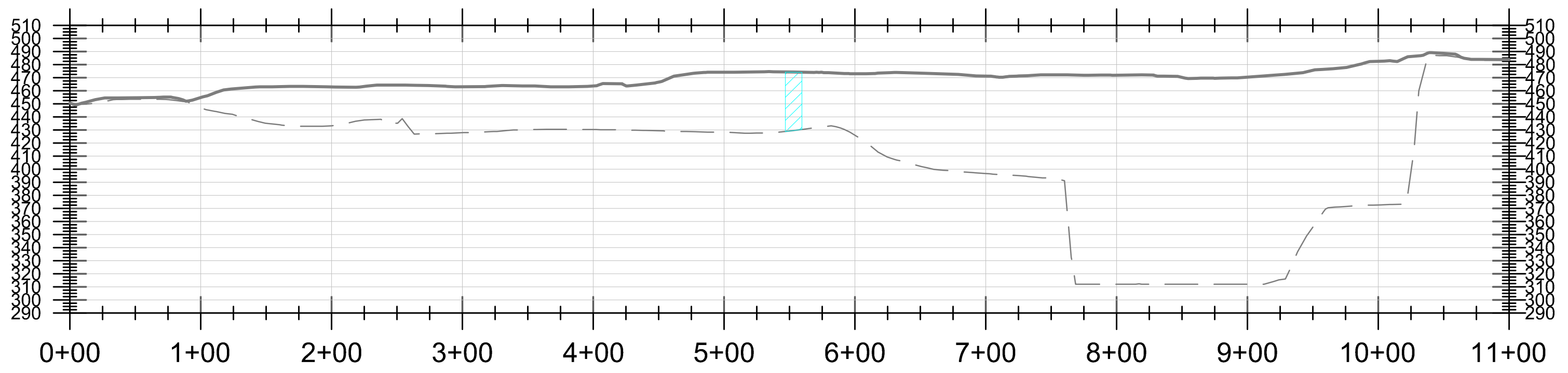
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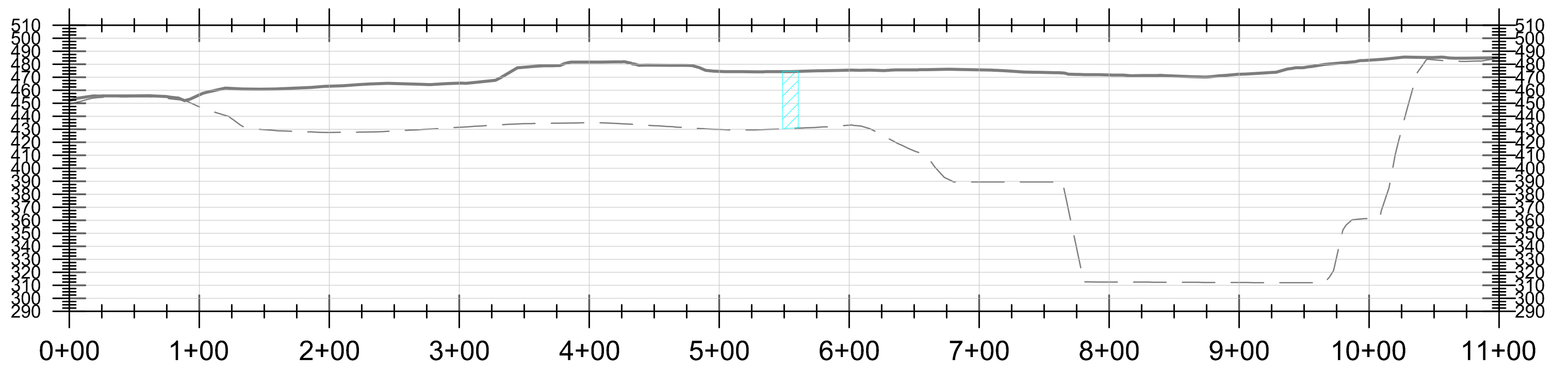
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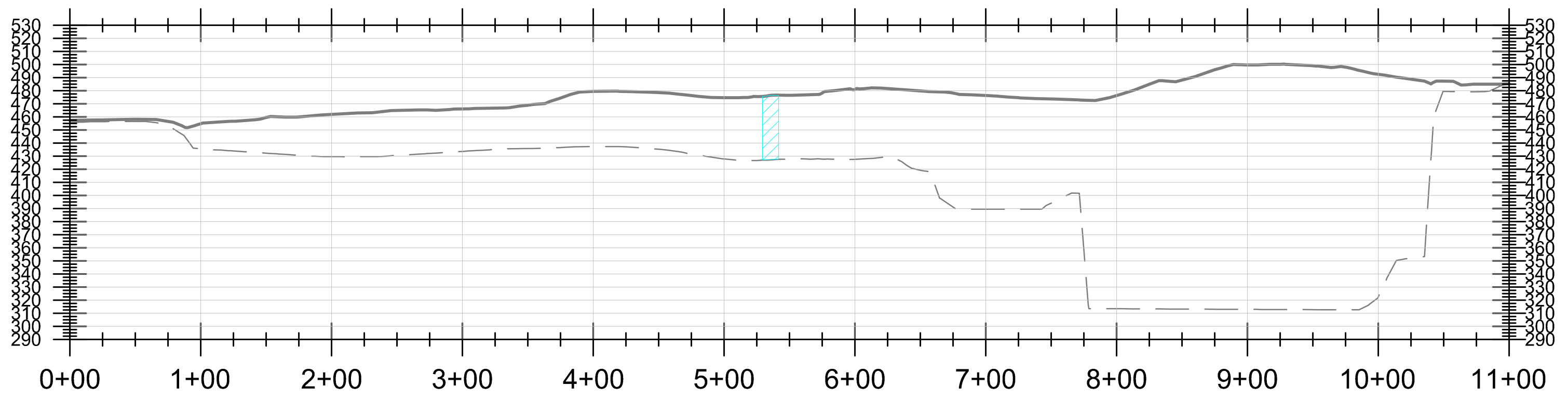
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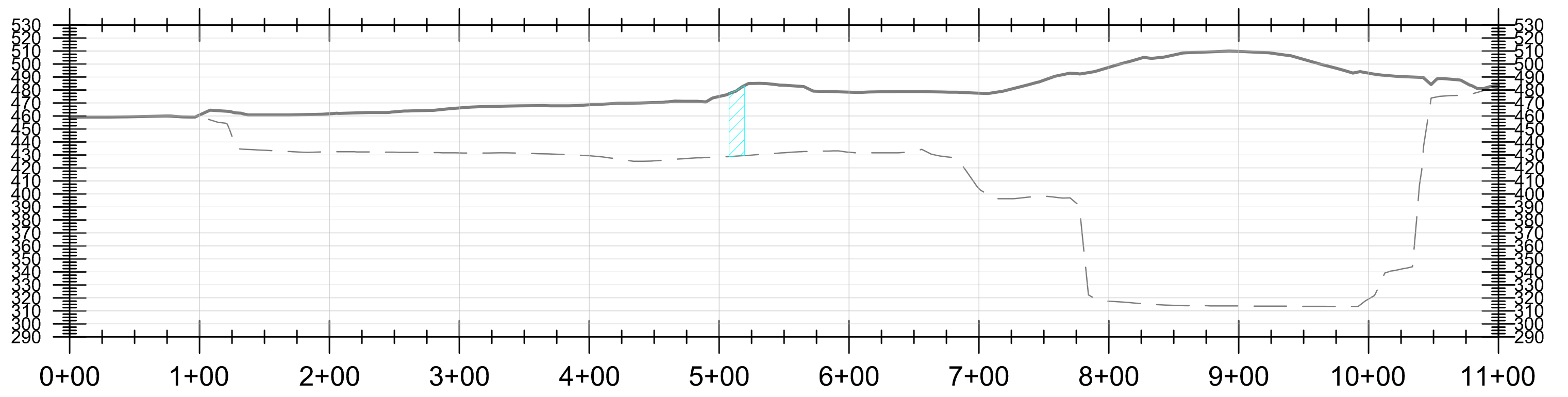
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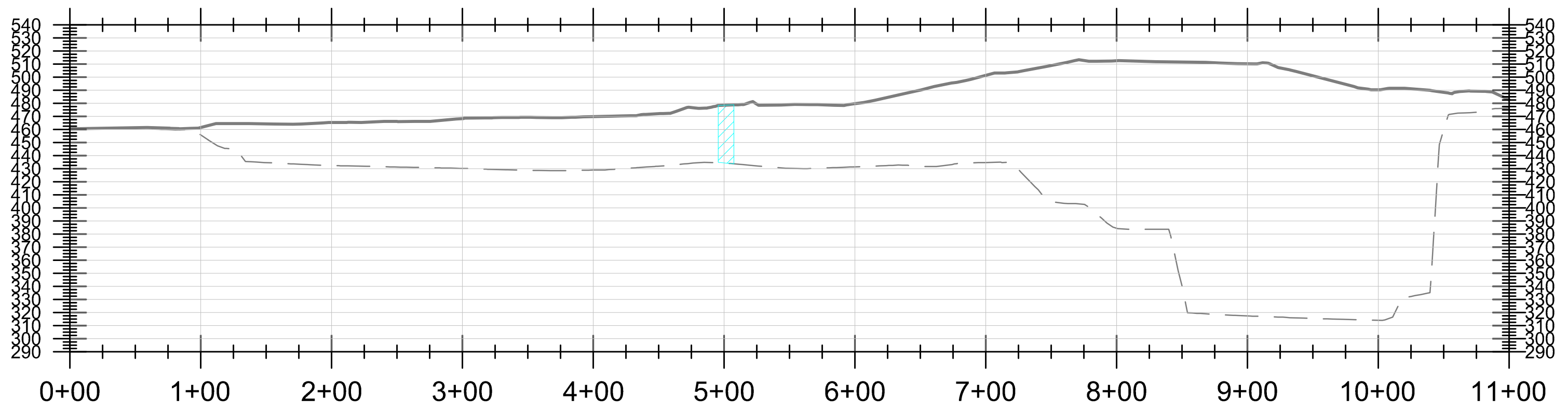
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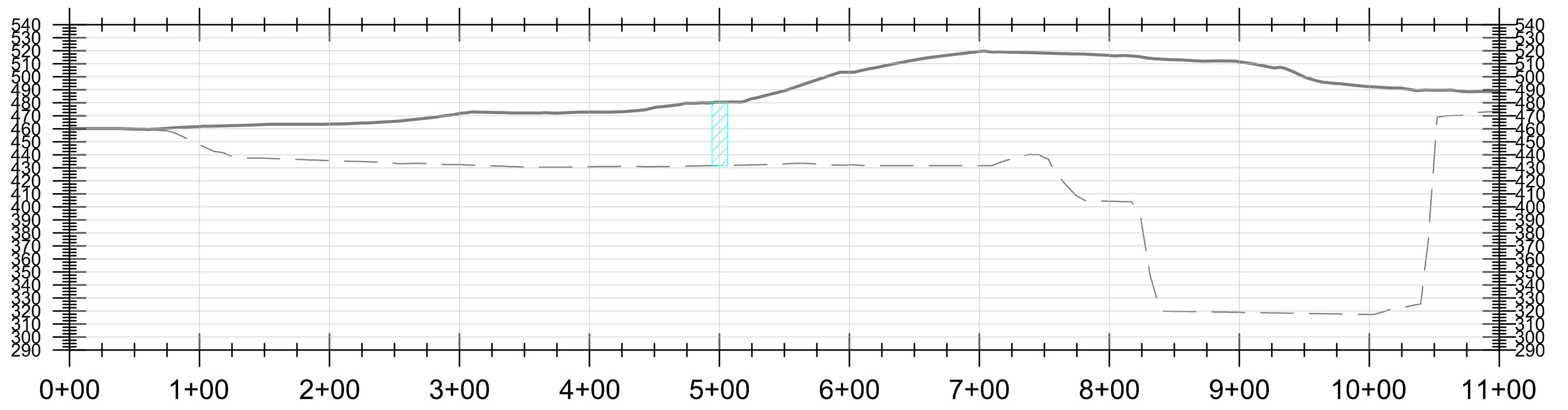
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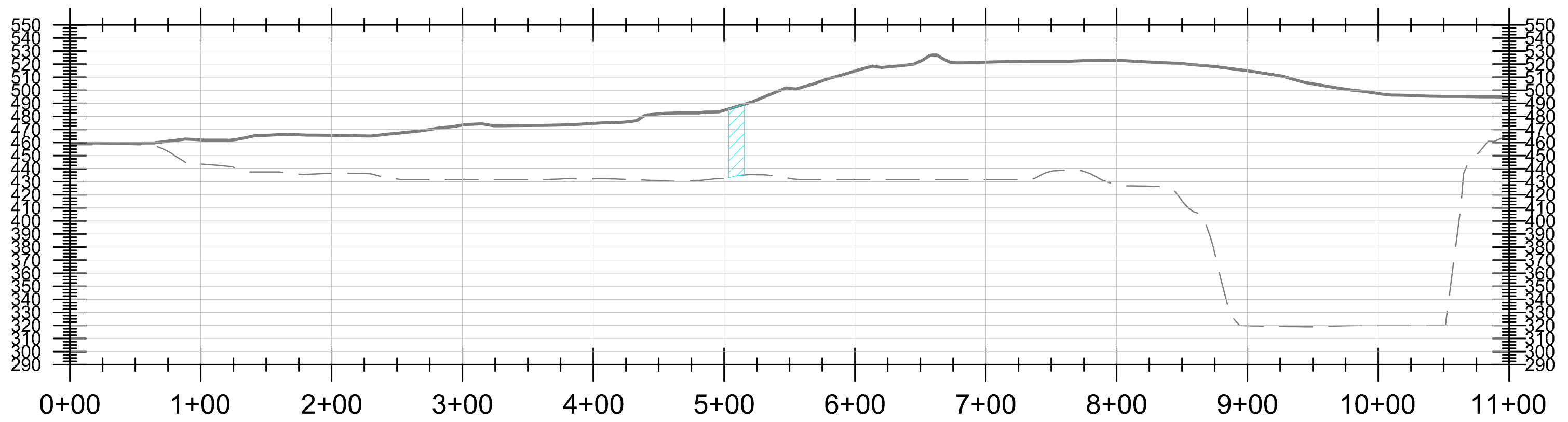
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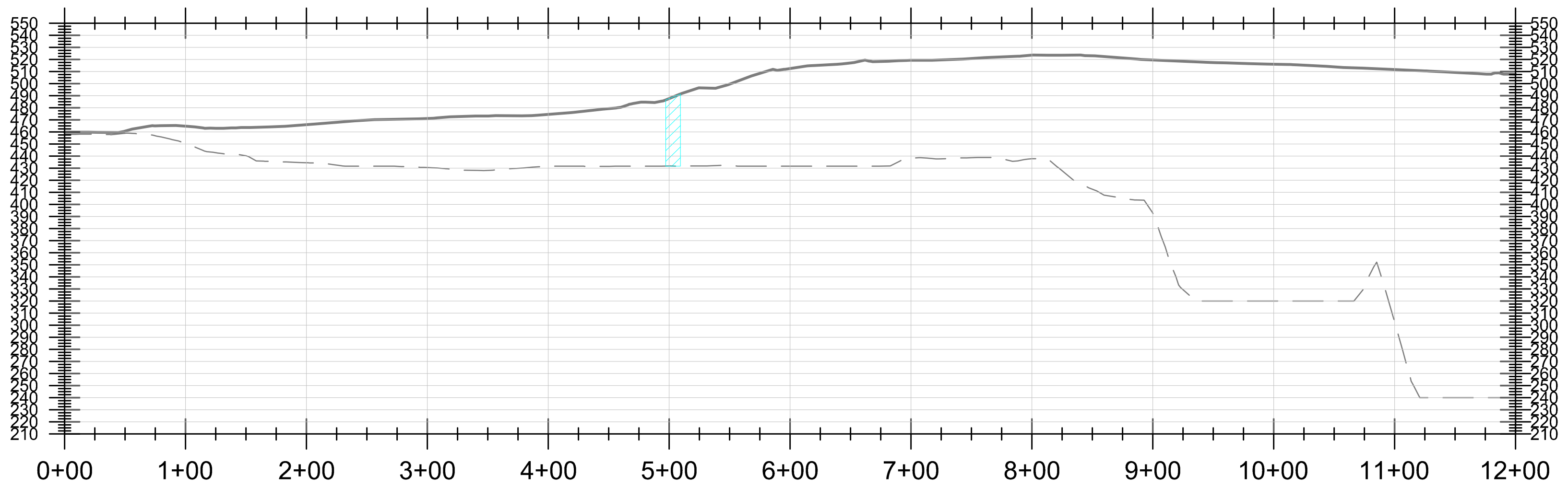
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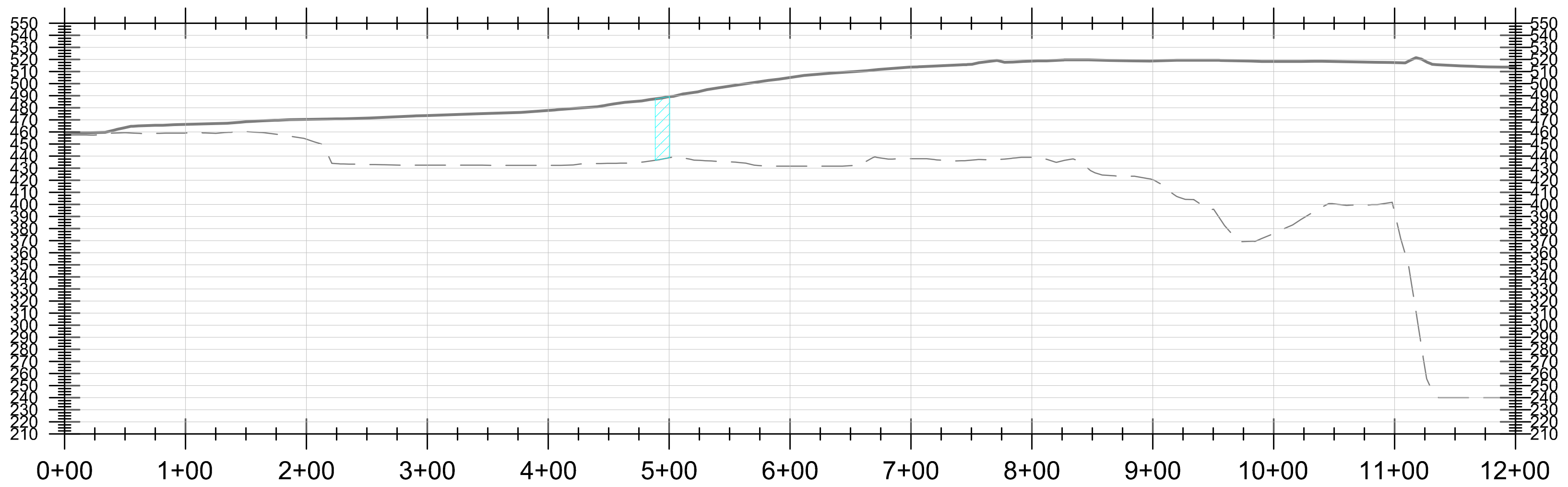
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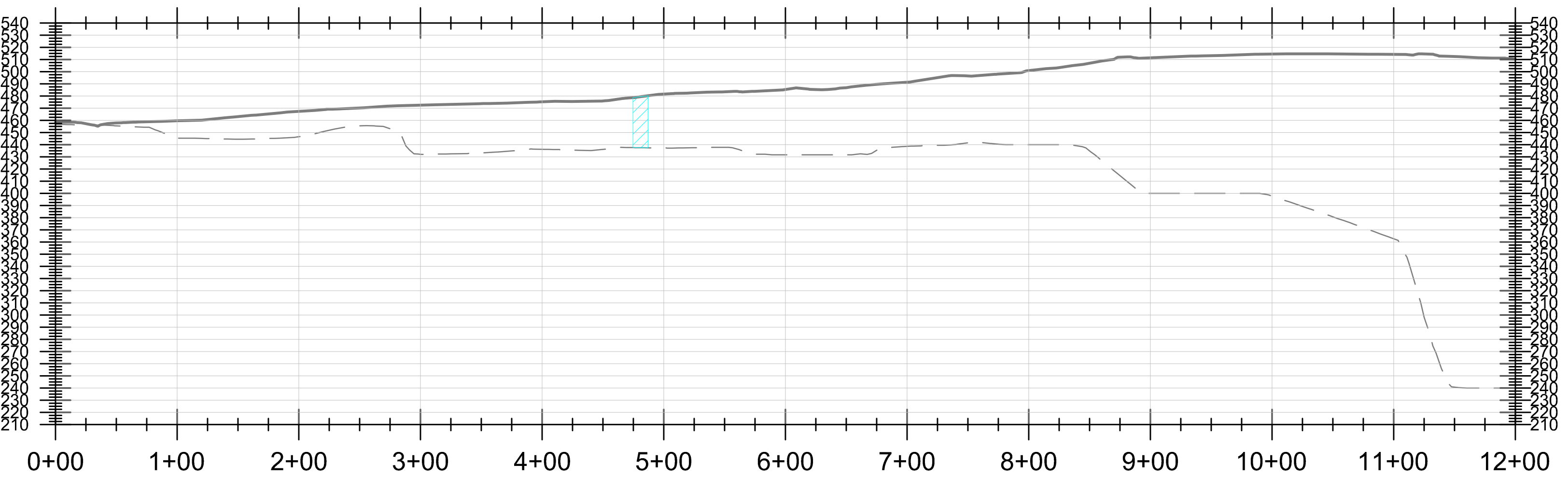
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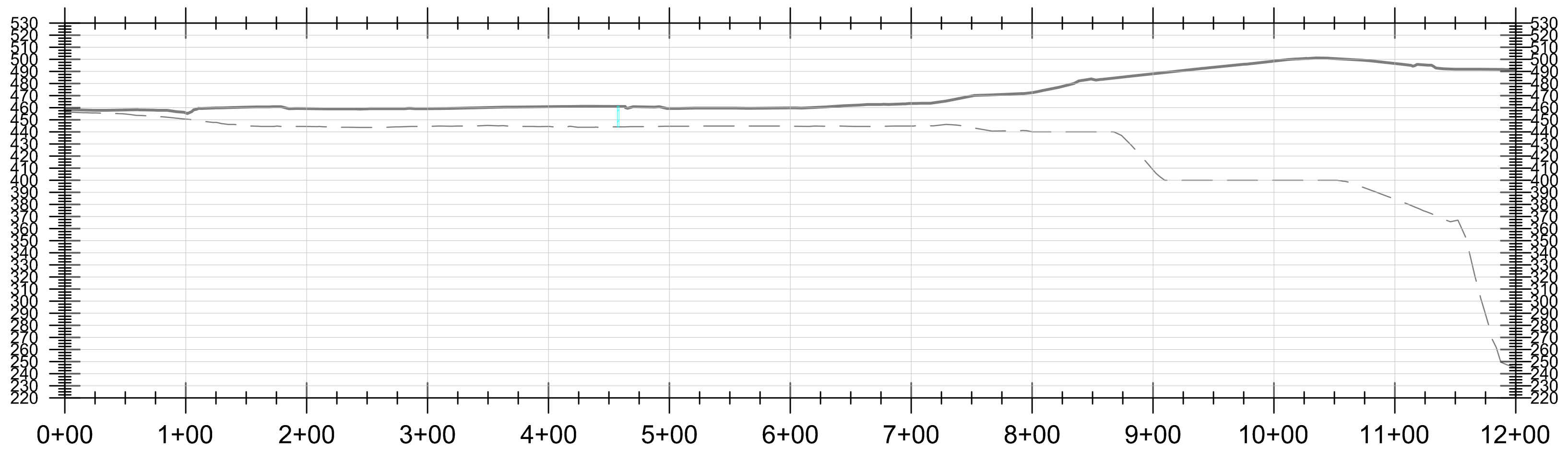
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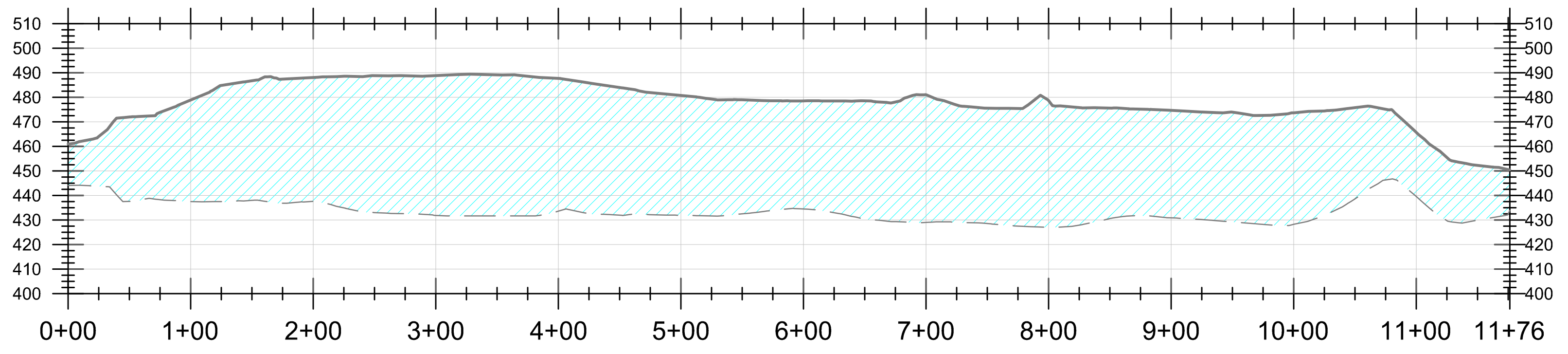
Profile View of Alignment 4 (1H:2V)

LEGEND

—— 03-20-14 TOPOGRAPHY
— — ESTIMATED BOTTOM OF WASTE
▨ DRILLED OR DRIVEN COOLING POINT AREA
● COOLING POINT (WITH 10' RADIUS)

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BRIDGETON LANDFILL
ISOLATION BARRIER ALTERNATIVES
ANALYSES REPORT

OPTION 4 ALIGNMENT
PROFILE VIEW AND CROSS SECTIONS

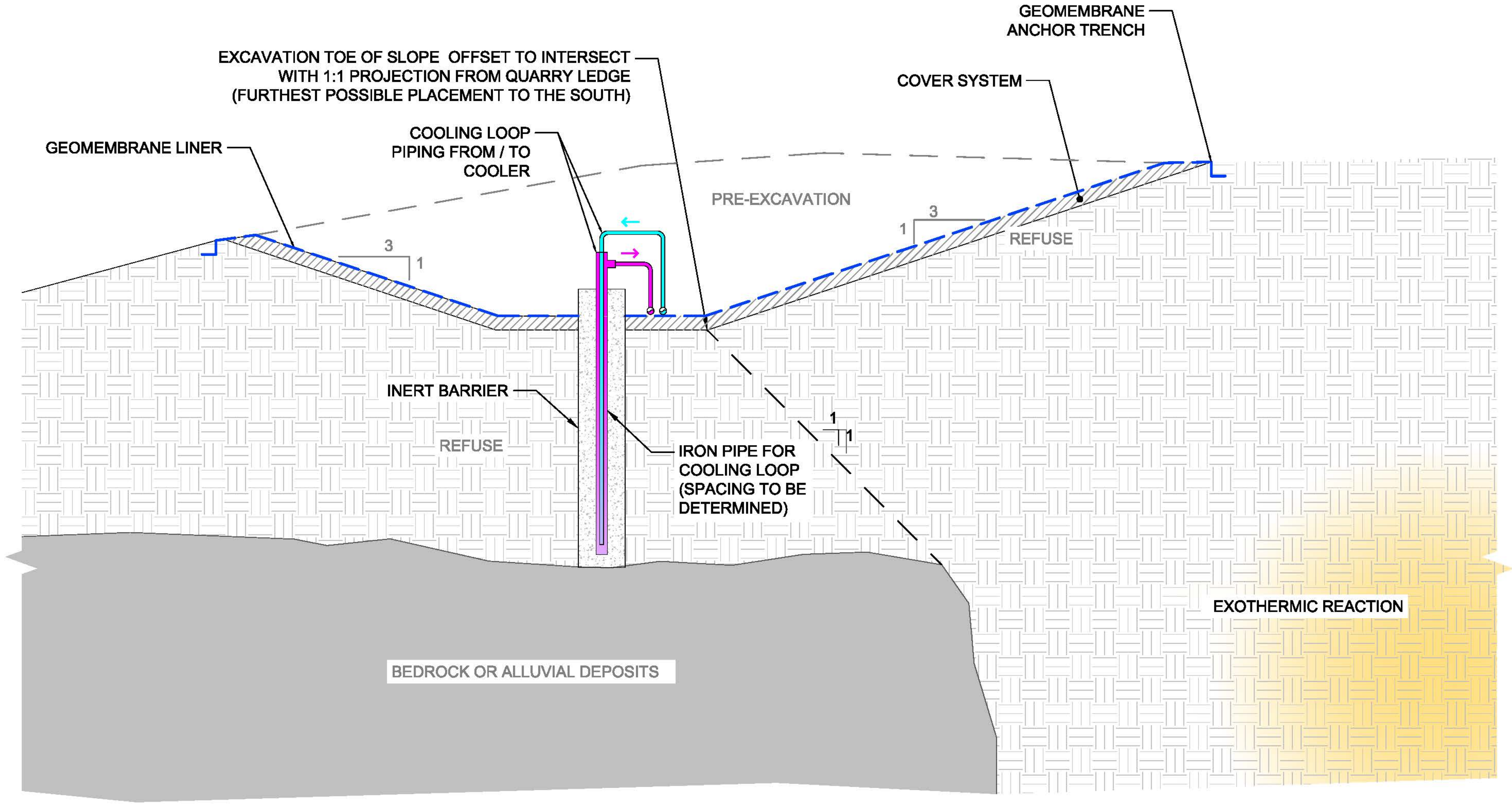
Engineering for a Better World
FEEZOR
ENGINEERING, INC.

OCTOBER 2014
DESIGNED BY: PML
APPROVED BY: DRF

REVISION	DATE

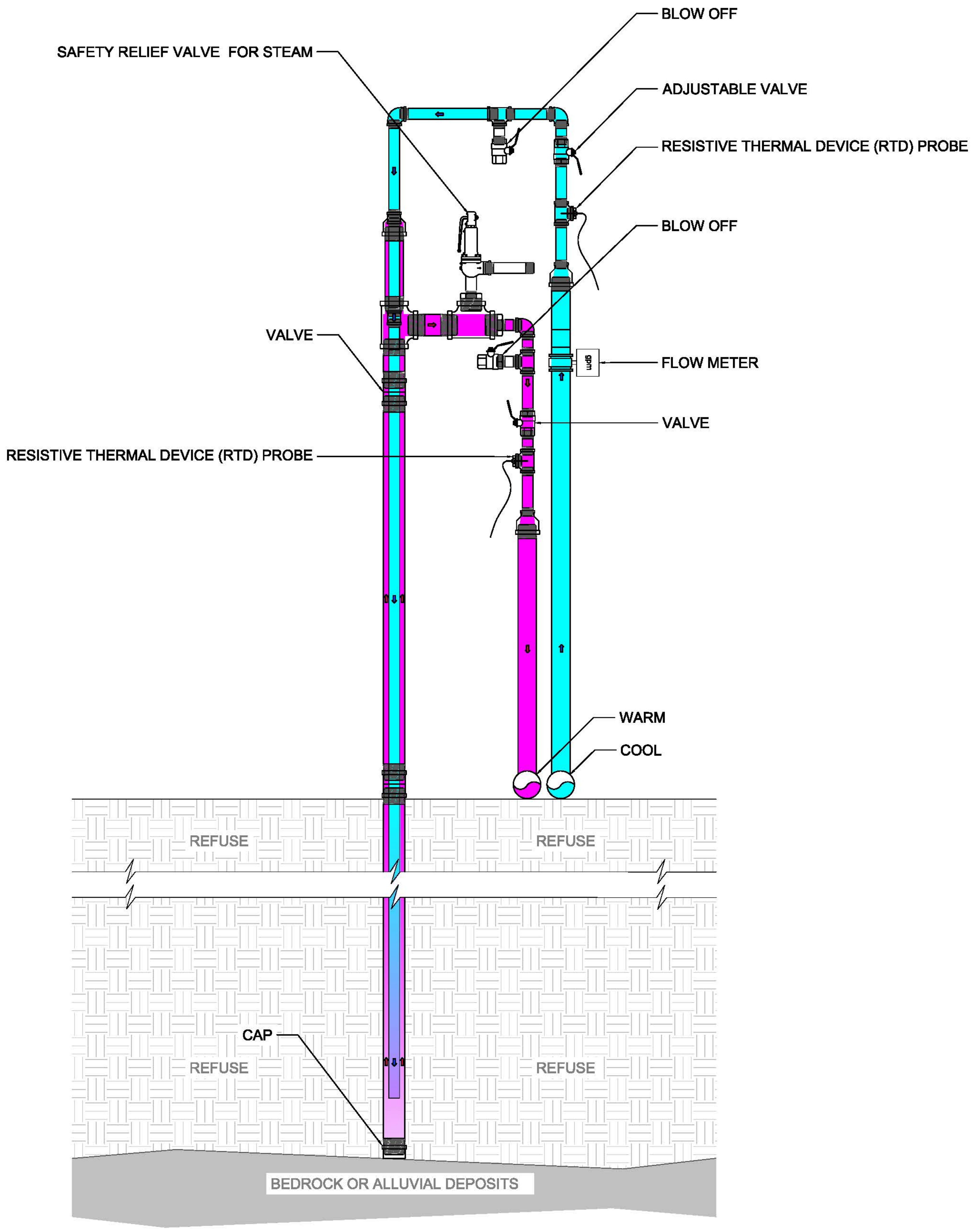
DRAWING NO.:
015

PROJECT NUMBER: BT-032
FILE PATH:



1/16 OPTION 1 AND 3 - TYPICAL INERT BARRIER

NOT TO SCALE



2/16 OPTION 4 - DRILLED OR DRIVEN COOLING POINT

NOT TO SCALE

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BRIDGETON LANDFILL
ISOLATION BARRIER ALTERNATIVES
ANALYSES REPORT

DETAILS

Engineering for a Better World
FEEZOR
ENGINEERING, INC.

OCTOBER 2014
DESIGNED BY: PML
APPROVED BY: DRF

REVISION	DATE

DRAWING NO.:
016

PROJECT NUMBER: BT-032 | FILE PATH:

Attachment A

Radon Flux Analysis
for
Isolation Barrier Alternatives Analysis

Radiological Health, Safety and Environmental Services
A USA Environment, L.P. Company

ATTACHMENT A

RADON FLUX ANALYSIS FOR ISOLATION BARRIER ALTERNATIVES ANALYSIS WEST LAKE LANDFILL SUPERFUND SITE

October 10, 2014

PREPARED FOR:

ENGINEERING MANAGEMENT SUPPORT, INC.
7220 W. JEFFERSON AVE, SUITE 406
LAKEWOOD, CO 80235

PREPARED BY:

AUXIER & ASSOCIATES, INC.
9821 COGDILL ROAD, SUITE 1
KNOXVILLE, TN 37932
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1. INTRODUCTION

The following evaluations of potential radon-222 emissions from selected alternatives have been prepared:

- The no-action alternative in Area 1,
- The Record of Decision (ROD)-Selected remedy alternative in Area 1 (EPA, 2008), and
- Isolation of a smaller subsurface deposit of radiologically impacted material (RIM) by a thermal barrier.

These calculations combine the expected surface radon flux generated by diffusion and any additional advective flux produced by a smoldering subsidence event (SSE). The calculated emissions were compared to permissible radon flux levels, as determined by National Emission Standards for Hazardous Air Pollutants in 40 CFR 61.192 (NESHAPS).

2. NO-ACTION ALTERNATIVE

This section contains calculations of radon-222 emissions (a decay product of radium-226) which would reach the landfill's surface if a SSE were to move through Area 1, assuming existing conditions remained unchanged from those described in the Supplemental Feasibility Study (EMSI, 2011). A SSE would not uncover the RIM, and exposures via other pathways such as direct exposure would be expected to remain unchanged from those discussed in the West Lake Landfill OU-1 Baseline Risk Assessment (Auxier, 2000) published as Appendix A in the West Lake Landfill OU-1 Remedial Investigation Report (EMSI, 2000), and Appendix H (Auxier, 2011) of the Supplemental Feasibility Study (EMSI, 2011).

2.1 DESCRIPTION OF APPROACH

A web-based radon calculator [based on RAECOM[1] (Wise, 2011)] was used to calculate the baseline radon flux from the current configuration of Area 1 without a SSE (Subsection 2.2). Emissions from a postulated SSE were calculated separately and added to the baseline flux to estimate the average flux from Area 1 if a SSE were to occur there (Subsections 2.3 and 2.4). The impacts of these events on a fixed location within Area 1 are described in Subsection 2.5 and the combined effects of a SSE crossing Area 1 are estimated in Subsection 2.6. Subsection 2.7 contains a series of sensitivity analyses to determine the impacts of changing key parameter values have on the predicted results.

2.2 RADON FLUX CALCULATION – BASELINE CONDITIONS

The majority of the radium-226 source in Area 1 is located below surface soil. The thickness of that overburden is variable and, in places, many feet thick. The two-layer geometry described by the values listed in Table 2-1 was selected to represent current conditions in Area 1 (Auxier, 2011a, Appendix F). The 72 pCi/g radium-226 concentration used in the calculation is the 95% upper confidence limit on the arithmetic mean (95% UCL) of the radium-226 concentrations measured in Area 1 during the Remedial Investigation (EMSI, 2000).[2]

Table 2-1 Radon Flux Estimate - RAECOM Input and Results – Baseline Conditions

```
---------------- Input Parameters ----------------
 Number of Layers:  2
 Radon Flux into Layer 1:  0 pCi/m^2s
 Surface Radon Concentration:  0 pCi/L
 Bare Source Flux (Jo) from Layer 1:  23.19 pCi/m^2s
 Specific Bare Source Flux from Layer 1:  0.322 pCi/m^2s per pCi_Ra-226/g

                                                         Moisture     Diff Coeff
   Layer     Thickness    Ra-226    Emanation            [dry wt_%]
    No.        [m]        [pCi/g]    Fraction   Porosity               [m^2/s]
    1          1.4          72         0.2       0.671      25        1.95E-06
    2          0.3          0          0.2       0.419      11.5      1.50E-06

-------- Results of Radon Diffusion Calculation --------
   Layer     Thickness   Exit Flux   Exit Conc.    MIC
    No.        [m]       [pCi/m^2s]   [pCi/L]
    1          1.4         14.32      7.29E+03    0.755
    2          0.3       | 13.46 |    0.00E+00    0.681

Total cover radon retention: 41.95%
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[1] RAECOM is a standard, widely used radon flux model. It is the model used in previous radon flux calculations performed in the Baseline Risk Assessment (Auxier, 2000) and the Supplemental Feasibility Study (EMSI, 2011). The version used may be found at http://www.wise-uranium.org/ctc.html.

[2] Extracted from Baseline Risk Assessment (Auxier, 2000)

Table 2-1 also lists results of the calculations. The calculated radon flux from the current configuration of Area 1, as represented by this simulation, is 13.46 pCi/m^2/s. This result compares well to the average flux from Area 1 of 13 pCi/m^2/s measured during the remedial investigation (RI) and reported in Table 7-1 of the West Lake Landfill Remedial Investigation Report (EMSI, 2000). The baseline simulation described here produces a radon flux that is less than the NESHAPS radon flux limit of 20 pCi/m^2/s.

2.3 RADON EMISSIONS PRODUCED BY A SSE

A SSE is expected to warm the landfill contents as it progresses across Area 1. This warming will cause thermal expansion of the gas within the soil's interstitial spaces. A portion of this expanding soil gas, and the radon it contains, is assumed to be vented from the surface of the landfill.

The postulated increase in temperature and gas movement would take time, but for the purpose of this calculation this heating and transport were assumed to be instantaneous. This approach simplified the calculation, but overestimated the results. First, the increase in temperature would not occur instantaneously, but rather would gradually occur over time. This more gradual increase in temperature would lower the rate of gas expansion and reduce the amount of radon transported to the surface each second. Secondly, neglecting the transit time that radon gas would actually spend moving to the surface also neglects the corresponding reduction in radon flux produced by radioactive decay during that movement. Given the short half-life of radon-222 (3.8 days), this decay would be expected to reduce radon fluxes from a SSE by another 40%.[3] The radon fluxes predicted by the following calculations likely overestimate radon emissions and should be viewed with this in mind.

Calculations were performed using the standard conceptual model described below:

a) A single-layer system was used to evaluate the effect a SSE would have on radon flux from the source layer.
b) Radium-226 concentration in the source layer was 72 pCi/g based on the RI sample results previously discussed.
c) Density of the radium-bearing material in the layer was assumed to be 1.4 g/cm^3 (or 1.4 x 10^6 g/m^3).
d) Porosity of the material in the radium-bearing layer was 0.671, which is an extremely high value and likely an overestimate allowing for an atypically large volume of interstitial soil gas. A larger volume of soil gas provided a larger reservoir of radon and likely overestimated the amount of free radon in the soil that would be available for movement.
e) Thickness of the radium-bearing layer was 1.4 meters based on the RI data.
f) The event evaluated was a chemically driven heating event that progressed as a pseudo wave front through Area 1 (Figure 2-1).

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[3] From Table 2-1, the flux from the bare layer (Layer 1, without SSE) is 23.2 pCi/m^2/s, and the flux to the surface from Layer 2 is 13.5 pCi/m^2/s. Assuming the reduction for radon produced by a SSE is similar to that calculated for the baseline case, then including the reduction in radon activity resulting from decay as it moves through the non-RIM waste material and soil that overlie the RIM would reduce the radon flux at the surface by approximately 40 percent (23.2 pCi/m^2/s -13.5 pCi/m^2/s)/23.5 x 100%.

g) The active part of the wave front was a maximum of 300 m long and its rate of advance was 0.25 meters/day (m/d),[4] producing an active surface area above a SSE each day of 75 m^2 (300 m x 0.25 m).

h) The subsurface heating event caused the temperature of the interstitial soil gas along the wave front to increase 60°C from 20°C to 80°C (~70°F to 175°F).

i) This degree of heating caused the interstitial soil gas in the source layer along the wave front to expand.

The degree of heating assumed in the Standard Model described in the previous bulleted items would cause the interstitial soil gas in the source layer along the wave front to expand and progress to the surface above the wave front where it would be vented (exhaled) to the overlying air.[5] This thermal expansion of the soil gas would "push" approximately 18.6% of the gas (and the radon in that gas) to the surface.

$$\begin{aligned}&\text{Volume Change (\%)=}\\&= \left[\text{Thermal Coefficient of air } \left(3.1 \text{ x } 10^{-3}\,\frac{\mathrm{m}^3}{\mathrm{m}^3\cdot{}^\circ\mathrm{C}}\right) \text{ x Temperature Change } (80^\circ\mathrm{C} - 20^\circ\mathrm{C})\right] \text{ x } 100\%\\&\approx\ 18.6\%\end{aligned}$$

The surface area of the soil actively involved in a SSE with the assumed dimensions during one day would be 75 m^2 and the volume of soil affected in one day would be 105 m^3 (75 m^2 x 1.4 m). The volume of gas in this soil volume would be approximately 70 m^3:

$$\mathrm{V_{gas}} = \mathrm{V_{soil}}(105\ \mathrm{m}^3) \text{ x Porosity } (0.671) \text{ or}$$
$$\mathrm{V_{gas}} = 70\ \mathrm{m}^3.$$

As described above, heating this volume of interstitial soil gas by 60°C (105°F) would expel 18.6% (13 m^3) of the gas through the surface soil above a SSE wave front.

$$\mathrm{V_{Expelled\ Gas}} = \mathrm{V_{gas}}(70\ \mathrm{m}^3) \text{ x Expelled Fraction } \left(\frac{18.6\%}{100\%}\right) \text{ or}$$
$$\mathrm{V_{Expelled\ Gas}} = 13\ \mathrm{m}^3$$

The concentration of radon-222 in the expelled gas can be estimated by assuming the initial radon-222 in Area 1 soil is in equilibrium with the radium-226, and that 0.2 of the radon produced in the source layer enters the interstitial soil gas:[6]

$$\mathrm{C_{gas}} = \mathrm{C_{soil}}\left(\frac{72\ \mathrm{pCi}}{\mathrm{g_{soil}}}\right) \text{ x Density}_{\mathrm{soil}}\left(1.4 \text{ x } 10^6\,\frac{\mathrm{g_{soil}}}{\mathrm{m^3}_{\mathrm{soil}}}\right) \text{ x } \left(\frac{\mathrm{m^3}_{\mathrm{soil}}}{0.671\ \mathrm{m^3}_{\mathrm{gas}}}\right) \text{ x } \mathrm{E_{radon}}(0.2), \text{or}$$
$$\mathrm{C_{gas}} = 3 \text{ x } 10^7\ \mathrm{pCi/m^3}.$$

---

[4] This is in reasonable agreement with current measurements of the SSE in the South Quarry area of the Bridgeton Landfill, which indicate an advance rate of 0.73 ft/d or 0.22 m/d.

[5] The thermal expansion coefficient used in the calculation was the average coefficient listed for the 20-80 °C temperature range at http://www.engineeringtoolbox.com/air-properties-d_156.html.

[6] Indicated by its emanation coefficient, E_{radon}. $E_{radon} \approx 0.2$ for most soil and is the default value used in RAECOM.

If 13 m^3 of soil gas with a radon-222 concentration of 3×10^7 pCi/m^3 were expelled each day as a result of a SSE, then 3.9×10^8 pCi would be released each day:

$$\text{Activity}_{\text{Radon}-222\text{ expelled}} = \text{V}_{\text{soil gas}}(13\text{ m}^3)\text{ x C}_{\text{gas}}\left(3\text{ x }10^7\ \frac{\text{pCi}}{\text{m}^3}\right)\text{ or}$$
$$\text{Activity}_{\text{Radon}-222\text{ expelled}} = 3.9\text{ x }10^8\text{ pCi.}$$

This release would occur over a 75 m^2 area, which produces a flux over a SSE of 5.2×10^6 pCi/m^2/day:

$$\text{Flux} = \frac{\text{Activity}_{\text{Radon}-222\text{ expelled}}\ (3.9\text{ x }10^8\text{ pCi})}{\text{Area }(75\text{ m}^2)\text{ x Time }(1\text{ day})}\text{ or}$$
$$\text{Flux} = 5.2\text{ x }10^6\,\frac{\text{pCi}}{\text{m}^2\cdot\text{day}}.$$

The flux converts to 60 pCi/m^2/s:

$$\text{Flux} = \left(5.2\text{ x }10^6\,\frac{\text{pCi}}{\text{m}^2\cdot\text{day}}\right)\left(\frac{1\text{ day}}{24\text{ hours}}\right)\left(\frac{1\text{ hour}}{60\text{ minutes}}\right)\left(\frac{1\text{ minute}}{60\text{ seconds}}\right)\text{ or}$$
$$\text{Flux} = 60\text{ pCi/m}^2\text{/s.}$$

So, during each second, 60 pCi of radon-222 would move through each square meter of the ground surface above the area of initial temperature increase in front of the leading edge of a SSE. Assuming a SSE would advance at a rate of 0.25 m/d, it would take 4 days to cross any 1 m x 1 m location in Area 1. Therefore, the average flux in that particular m^2 would come from a smaller 1 m x 0.25 m strip inside that one m^2 area, and the average flux would be 15 pCi/m^2/s (Figure 2-1):

$$\text{Average Flux} = (60\text{ pCi/m}^2\text{/s})\left(\frac{1}{4}\right)\text{ or}$$
$$\text{Average Flux} = 15\text{ pCi/m}^2\text{/s.}$$

This increased value of 15 pCi/m^2/s, when added to the baseline flux emanating from the same square meter, would be 28.5 pCi/m^2/s (15 pCi/m^2/s + 13.5 pCi/m^2/s). The estimated flux from the area experiencing temperature driven expansion on the leading edge of a SSE would be larger than the NESHAPS limit of 20 pCi/m^2/s. The NESHAP limit actually applies to the average from an entire waste area (in this case Area 1) and thus this thermally induced increase in radon flux would need to be evaluated in the larger context of its impact on the average radon flux in Area 1. The average radon flux across Area 1 is calculated in Subsection 2.6.

In addition, the NESHAP is based on the average radon flux from a waste unit over the course of a one year time period so the temporary increase in radon flux resulting from soil gas displacement should be evaluated in terms of the overall average radon flux over the course of a year.

2.4 RADON PRODUCED BEHIND THE THERMAL EXPANSION

Immediately after the thermal expansion has expelled a fraction of the available radon in the soil gas, a slight reduction in radon flux would be expected until decay of radium-226 replaces the radon that was expelled. As radon-222 levels return to equilibrium with radium-226, radon-222 flux levels from the landfill would be related to the moisture of the landfill's contents. Moisture in soil can fill void spaces or coat radium-bearing particles, retarding the movement of soil gases like radon. A SSE could produce changes to the moisture content and porosity of the landfill contents as the pyrolytic reaction progresses.

These changes take place during the lifecycle of a SSE, which may last for many months or years, but for the purpose of this calculation, these changes are assumed to occur sequentially over the relatively short duration of 90 days. During the first 90 days after the increased temperature front of a SSE reaches a location, the increased temperature associated with an SSE was assumed to vaporize a portion of the soil moisture thereby reducing the moisture content in the landfill material and overlying cover soil. In the next 90 days the volume of the material may decrease, reducing the porosity of the radium-bearing soil and its overburden.

If pyrolysis were to occur within the RIM material itself (unlikely given the shallow nature of the RIM and thus the presence of the heat dissipation boundary condition posed by the overlying ground surface that would limit the potential increase in heat within the shallow zone), the waste material containing the RIM would be destroyed by pyrolysis. This would result in the consolidation of the waste and a consequent displacement of soil gas from the interstitial spaces in the soil. Therefore, it was assumed that over the next 90 days the volume of the waste material (conservatively assumed to be the RIM layer) would decrease and a portion of the soil gas contained in this layer would be displaced through the surface of the landfill.

Using these shorter durations compresses the postulated radon emissions produced by the changes into a shorter time. Compressing these effects into a relatively short duration will likely overestimate the calculated peak radon fluxes from Area 1. The impacts of these postulated changes on radon flux were calculated and are presented in the following subsections.

2.4.1 Reduction of Moisture Content

Radon-222 flux levels from soil are related to the moisture content of those soils. A SSE may change the moisture content of the soil, increasing the average flux in Area 1. The impact of this variation on the calculated radon flux was evaluated by reducing the moisture content in RAECOM by 20%. This change increased the calculated radon exit flux to 15.9 pCi/m^2/s (15.86 pCi/m^2/s in Table 2-2, rounded to 15.9 pCi/m^2/s), an increase of approximately 18% from the calculated baseline flux of 13.46 pCi/m^2/s. A radon flux of 15.86 pCi/m^2/s is less than the NESHAPS limit of 20 pCi/m^2/s.

Table 2-2 RAECOM Input and Results – Baseline Conditions, Moisture Reduced

```
---------------- Input Parameters ----------------
 Number of Layers:  2
 Radon Flux into Layer 1:  0 pCi/m2s
 Surface Radon Concentration:  0 pCi/L
 Bare Source Flux (Jo) from Layer 1:  25.25 pCi/m2s
 Specific Bare Source Flux from Layer 1:  0.351 pCi/m2s per pCi_Ra-226/g

                                                              Moisture      Diff Coeff
  Layer    Thickness    Ra-226    Emanation                  [dry wt_%]       [m2/s]
   No.        [m]       [pCi/g]    Fraction     Porosity
    1         1.4         72         0.2          0.671          20          2.54E-06
    2         0.3          0         0.2          0.419          9.2         1.92E-06

-------- Results of Radon Diffusion Calculation --------
  Layer    Thickness    Exit Flux    Exit Conc.     MIC
   No.        [m]       [pCi/m2s]     [pCi/L]
    1         1.4         16.65       6.50E+03      0.804
    2         0.3         15.86       0.00E+00      0.745

Total cover radon retention: 37.21%
```

2.4.2 Displacement of Soil Gas Due to Subsidence

The volume of landfill materials would be reduced as the pyrolytic process progresses. This volume reduction would manifest as a visible settling of the landfill surface. It would be a gradual process, taking months. This calculation assumes settling would displace 20% of the gas (and the radon in that gas) from the interstitial soil spaces during a 90 d (7,776,000 s) period between 90 days and 180 days after the beginning of a SSE.

The volume of the radium-226 bearing source layer beneath one square meter of landfill surface area is 1.4 m^3 (thickness of layer (1.4 m) x Unit Area (1 m^2)). The initial volume of gas within the source layer is 0.939 m^3 (1.4 m^3 x porosity (0.671)). Assuming 20% of the gas is expelled during a 90-day period due to settling, then 2.4 x10^{-8} m^3 gas/m^2 surface/s would be expelled from one m^2 of landfill surface during settlement.

$$V_{\text{gas expelled}\left(\frac{m^3}{m^2 \cdot s}\right)} = \frac{V_{\text{gas in source layer}}(0.939\ m^3) \times \left(\frac{20\%}{100\%}\right)}{\text{Unit Area}(1\ m^2) \times (90\text{ days}) \times \left(\frac{24\text{ hours}}{1\text{ day}}\right) \times \left(\frac{60\text{ minutes}}{1\text{ hour}}\right) \times \left(\frac{60\text{ seconds}}{1\text{ minute}}\right)} \quad \text{or}$$

$$V_{\text{gas expelled per second}} = 2.4 \text{ x } 10^{-8}\ \frac{m^3}{m^2 \cdot s}$$

The initial concentration of radon is 3 x 10^7 pCi/m^3 (Subsection 2.3). Assuming instantaneous transport of short-lived radon-222 from the source to the surface over the 90-day period, the radon-222 flux from displacement due to settling would be 0.72 pCi/m^2/s:

$$\text{Flux from Settling} = V_{\text{gas expelled per second}}\left(2.4 \text{ x } 10^{-8}\ \frac{m^3}{m^2 \cdot s}\right) \text{ x } C_{\text{radon}-222}\left(3 \text{ x } 10^7\ \frac{pCi}{m^3}\right) \quad \text{or}$$

$$\text{Flux from Settling} = 0.72\ pCi/m^2/s.$$

Adding this flux from settling to the landfill's baseline flux of 13.46 pCi/m^2/s yields a flux of 14.8 pCi/m^2/s. This source of radon emission would increase the calculated radon flux from the landfill's baseline case by about 5% for three months.

2.5 RADON FLUX PROGRESSION AT ONE LOCATION IN AREA 1

The effects that a postulated SSE might have on a particular location as it moves across Area 1 are listed below and are illustrated in Figure 2-1:

- The initial conditions at the location would be disturbed by a temperature rise that would expand the gas in the soil. This expansion would expel a fraction of the soil gas over a comparably short period of time.
- Following this expulsion, radon flux levels would fall below the baseline case due to depletion of radon-222 in the soil by the temperature change. In the absence of other effects, radon flux levels would return to the baseline flux level as a result of radon ingrowth from radium-226 in the soil.
- The rising temperature levels in the landfill would drive some of the moisture out of its contents and produce a reduction in the material's moisture content during the next 90 days. As the material dried, its permeability to radon-222 would increase and the radon flux would increase slightly.
- As a SSE continued to progress, it would produce a reduction in the volume of that portion of the landfill's contents that were subjected to pyrolysis over time. The resulting consolidation of this material would gradually expel more soil gas. The reduction in porosity would lower the diffusive component of the radon-222 flux while the physical displacement of the soil gas to the surface would increase the radon flux for the duration of the subsidence.

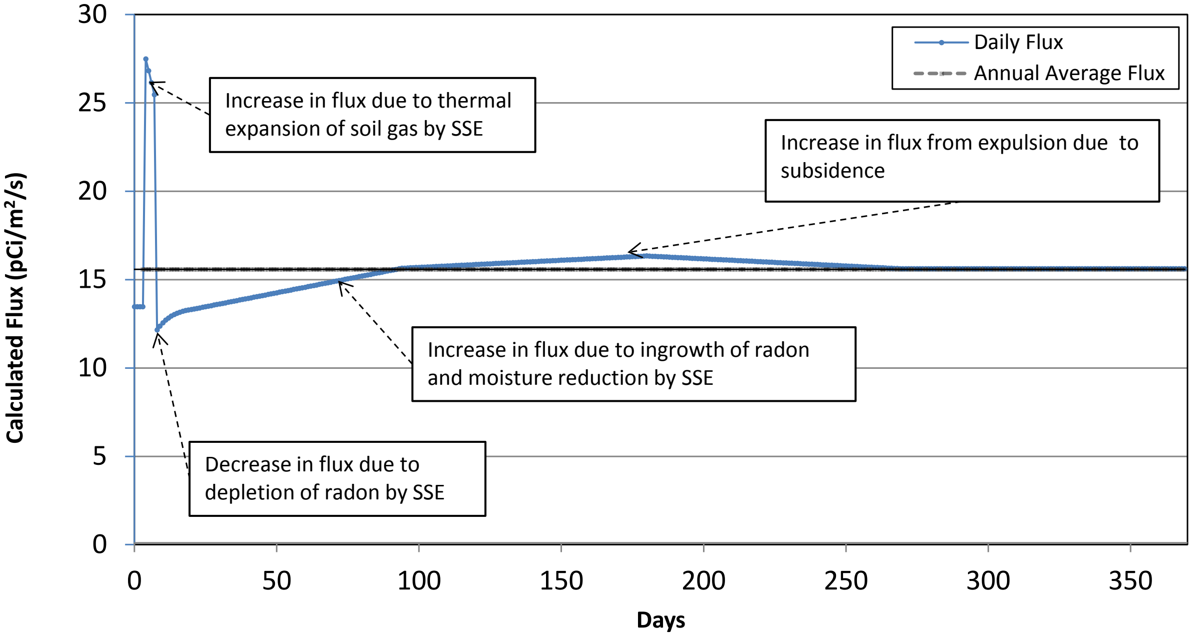

Figure 2-1 Changes in Radon Flux over Time at a Fixed Location during a SSE

2.6 COMBINED RADON FLUX FROM AREA 1 DURING A SSE

The baseline configuration of Area 1 is estimated to produce a radon-222 flux of 13.46 pCi/m^2/s over an 18,000 m^2 area (EMSI, 2011, Appendix H, Table 5-4). This would be the flux from the portions of Area 1 that were in front of a SSE. Assuming that increased temperature reduced the moisture content of the waste and overlying soil, the radon-222 flux could increase from the 13.5

pCi/m^2/s baseline flux to the 15.5 pCi/m^2/s value presented in Subsection 2.4.1. This would be the new baseline condition after a SSE passed through the study area. The flux from Area 1 was calculated just prior to the time a SSE exits Area 1. This configuration would maximize the contribution from the area producing the higher flux behind a SSE.

A SSE would produce an additional 60 pCi/m^2/s flux (from Subsection 2.3) from a 72 pCi/g average radium-226 concentration over a 75 m^2 area.

The flux from subsidence behind a SSE thermal front was calculated to be 0.72 pCi/m^2/s in Section 2.4.2. This flux would occur over a period of 90 days. Using 0.25 m/d as the rate of advance and a maximum width of 300 m for the thermal front, the surface area of rapid subsidence will be 6,750 m^2:

$$\text{Area}_{Settle} = (300\ \text{m})\ \text{x}\ (0.25\ \text{m/d})\ \text{x}\ (90\ \text{d})\ \text{or}$$
$$\text{Area}_{Settle} = 6{,}750\ \text{m}^2.$$

The sum of the effects from soil moisture changes, thermal expulsion of soil gas and the displacement of soil gas due to subsidence/settlement produce an average flux across Area 1 of 16.4 pCi/m^2/s during a SSE:

$$\text{Average Flux} =$$
$$= \frac{\begin{bmatrix} \text{Flux}_{\text{Area}} \left(\dfrac{15.86 \frac{\text{pCi}}{\text{m}^2}}{\text{s}} \right) \times \text{Area}_{\text{Area 1}}\ (18{,}000\ \text{m}^2) \\ +\text{Flux}_{\text{Thermal}} \left(\dfrac{60 \frac{\text{pCi}}{\text{m}^2}}{\text{s}} \right) \times \text{Area}_{\text{Thermal}}\ (75\ \text{m}^2) \\ +\text{Flux}_{\text{Settle}} \left(\dfrac{0.72 \frac{\text{pCi}}{\text{m}^2}}{\text{s}} \right) \times \text{Area}_{\text{Settle}}\ (6{,}750\ \text{m}^2) \end{bmatrix}}{\text{Surface Area}\ (18{,}000\ \text{m}^2)}\ \text{or}$$

$$\text{Average Flux} = 16.4\ \text{pCi/m}^2/\text{s}.$$

This change would increase the calculated average radon-222 flux (13.46 pCi/m^2/s) from Area 1 without a SSE to 16.4 pCi/m^2/s (a 22% increase). This combined average flux is below the NESHAPS limit of 20 pCi/ m^2/s (Figure 2-2).

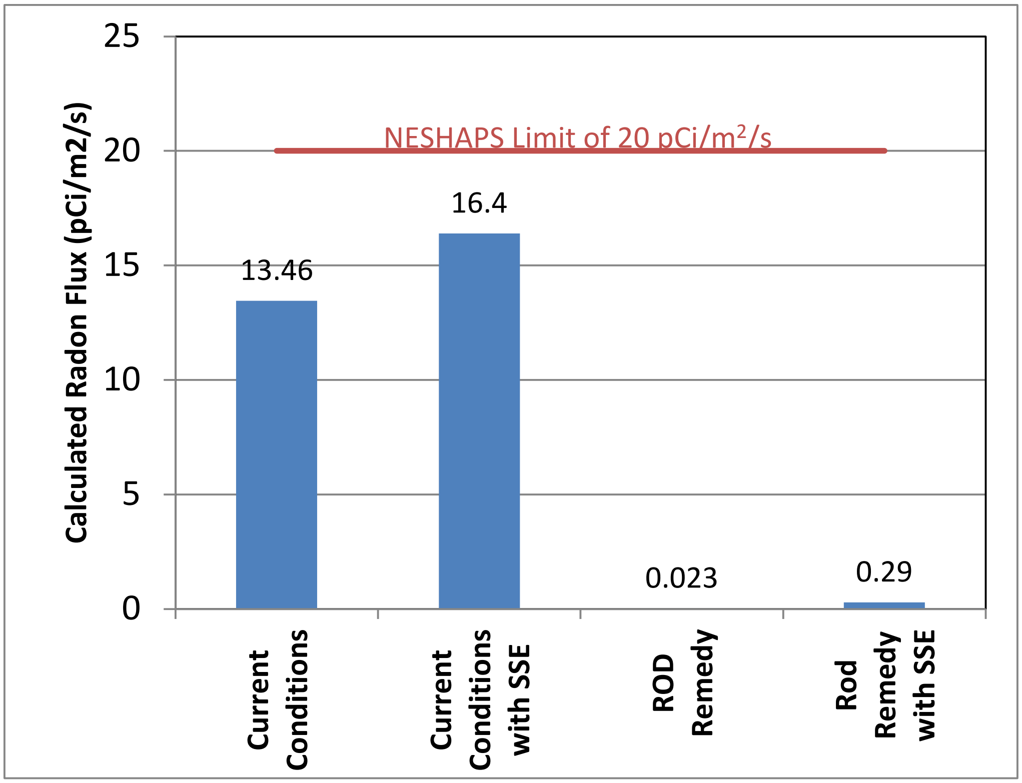

Figure 2-2 Average Radon Flux from Area 1 for Four Scenarios

2.7 SENSITIVITY ANALYSIS

Changes in input parameters can increase the calculated radon flux results. The impact of changing the radium-226 concentration, physical dimension of a SSE, and the rate of advance of a SSE have been semi-quantitatively investigated and presented in this sub-section.

2.7.1 Sensitivity of Results to Changes in Radium-226 Concentrations

Radon-222 flux levels from soil are directly related to the radium-226 concentrations in that soil. To increase the average flux in Area 1 to a value greater than the NESHAPS limit of 20 pCi/m^2/s during a SSE, the average radon flux along a SSE wave front would have to exceed 1,560 pCi/m^2/s:

$$\text{Average Flux } (20\ \text{pCi/m}^2\text{/s}) = $$
$$= \frac{\text{Exit Flux } (13.5\ \text{pCi/m}^2\text{/s}) \text{ x Surface Area } (18{,}000\ \text{m}^2) + \text{SSE Flux } (\text{X pCi/m}^2\text{/s}) \text{ x SSE Area } (75\ \text{m}^2)}{\text{Surface Area } (18{,}000\ \text{m}^2)}.$$

Solving the equation for SSE Flux:

$$\text{SSE Flux } (\text{X pCi/m}^2\text{/s})$$
$$= \frac{[\text{Average Flux } (20\ \text{pCi/m}^2\text{/s}) - \text{Exit Flux } (13.5\ \text{pCi/m}^2\text{/s})] \text{ x Surface Area } (18{,}000\ \text{m}^2)}{\text{SSE Area } (75\ \text{m}^2)} \text{ or}$$
$$\text{SSE Flux} = 1{,}560\ \text{pCi/m}^2\text{/s}\,.$$

In the calculation (Section 2.3), 72 pCi/g radium-226 produced a radon flux of 60 pCi/m^2/s, indicating a production efficiency of 0.833 pCi of radon-222/m^2/s per pCi/g of radium-226. To produce a radon flux greater than 1,560 pCi/m^2/s would require the average radium-226 concentration across the entire SSE to be greater than 1,872 pCi/g:

$$\mathrm{C}_{\text{radium}-226,\text{average}} = \frac{1{,}560 \text{ pCi }/\text{m}^2/\text{s}}{[0.833 \text{ pCi radon} - 222/\text{m}^2/\text{s}/\text{pCi}/\text{g radium} - 226]} \text{ or}$$

$$\mathrm{C}_{\text{radium}-226,\text{average}} = 1{,}872 \text{ pCi/g.}$$

This would require the average radium-226 concentration along a SSE wave front to increase from 72 pCi/g to 1,872 pCi/g.

In comparison, the highest radium concentration in Area 1 reported in Table A.2-4 of the Baseline Risk Assessment was 906 pCi/g (Auxier, 2000).

2.7.2 Sensitivity of Results to Changes in Physical Dimensions

The NESHAPS limit is based on the average flux from the source. To increase the average flux in Area 1 to a value greater than the NESHAPS limit of 20 pCi/m^2/s during a SSE, the active surface area of a SSE producing the thermal-driven flux would have to increase from 75 m^2 to more than 1,950 m^2.

$$\text{Average Flux } (20 \text{ pCi}/\text{m}^2/\text{s}) =$$

$$= \frac{\text{Exit Flux } (13.5 \text{ pCi}/\text{m}^2/\text{s}) \text{ x Surface Area } (18{,}000 \text{ m}^2) + \text{SSE Flux } (60 \text{ pCi}/\text{m}^2/\text{s}) \text{ x SSE Area } (\text{X m}^2)}{\text{Surface Area } (18{,}000 \text{ m}^2)}$$

Solving the equation for SSE Area:

$$\text{SSE Area } (X\ m^2) = \frac{(20 \text{ pCi}/\text{m}^2/\text{s} \ \ - 13.5 \text{ pCi}/\text{m}^2/\text{s}) \text{ x } (18{,}000 \text{ m}^2)}{(60 \text{ pCi}/\text{m}^2/\text{s})} \text{ or}$$

$$\text{SSE Area } (X\ m^2) = 1{,}950 \text{ m}^2.$$

For comparative purposes, the area of 1,950 m^2 (0.48 acres) is approximately 11% of the 18,000 m^2 (4.45 acres) surface area of Area 1.

2.7.3 Sensitivity of Results to Changes in the Rate of SSE Advance

A SSE in this evaluation was modelled as a straight line with a constant rate of advance to simplify calculations. This does not describe the reported behavior of a SSE in the South Quarry area of the Bridgeton Landfill. The thermal changes at the leading edge of that SSE advance at an irregular rate on a non-uniform front. A SSE's rate of advance increases and decreases over time, its direction of advance changes, and the shape of the advancing SSE is amorphous.

In a SSE standard model (Subsection 2.2) a typical rate of advance (0.25 m/d) along a line 300 m long was selected to represent the rate of a SSE's advance across the landfill as a whole. That representation produced a calculated value for the surface area of the thermally-driven radon flux of 75 m^2. The average calculated radon flux in Area 1 produced by that rate of advance was 16.4 pCi/m^2/s. As discussed in Subsection 2.7.2, the surface area producing thermally-driven flux would have to increase to be greater than 1,950 m^2 before the NESHAPS limit was exceeded. Using the same width as the previous simulations, a SSE would need to produce a sustained speed in excess of 6 m/d to exceed the NESHAPS limit.

$$\text{Rate of Advance} = \frac{\text{Area of Thermally Driven Outgassing by SSE } \left(\frac{1{,}950\ \text{m}^2}{\text{d}}\right)}{\text{Width of SSE (300 m)}} = 6.5\ \text{m/d}$$

This rate of advance (6.5 m/d or almost 650 ft/mo) is not expected to be sustainable in the shallow, aged landfill material present in Area 1.

2.7.4 Sensitivity of Results to Changes in Moisture Content

As stated previously, radon-222 flux levels from soil are related, in part, to the moisture content of those soils. A SSE may change the moisture content of the soil, thus changing the flux from the soil. A moisture reduction of 20% was chosen to represent the average moisture reduction posited in Section 2.4.1. Moisture in this simulation could have been reduced by as much as 55% before the NESHAPS limit of 20 pCi/m^2/s was exceeded (Table 2-3).

Table 2-3 Moisture Content Required to Exceed NESHAPS Limit

```
---------------- Input Parameters ----------------
 Number of Layers: 2
 Radon Flux into Layer 1: 0 pCi/m2s
 Surface Radon Concentration: 0 pCi/L
 Bare Source Flux (Jo) from Layer 1: 28.54 pCi/m2s
 Specific Bare Source Flux from Layer 1: 0.396 pCi/m2s per pCi_Ra-226/g

                                                   Moisture     Diff Coeff
  Layer   Thickness   Ra-226   Emanation          [dry wt_%]
   No.       [m]      [pCi/g]   Fraction  Porosity                [m2/s]
    1        1.4        72        0.2      0.671    11.25       4.05E-06
    2        0.3         0        0.2      0.419    5.175       2.83E-06

-------- Results of Radon Diffusion Calculation --------
  Layer   Thickness  Exit Flux  Exit Conc.   MIC
   No.       [m]     [pCi/m2s]   [pCi/L]
    1        1.4       20.61     5.30E+03   0.890
    2        0.3       19.94     0.00E+00   0.857

Total cover radon retention: 30.13%
```

2.7.5 Summary of Sensitivity Analysis for Selected Parameters Used to Calculate Radon Flux in Area 1

Three variations of potential impacts of a SSE have been evaluated. Table 2-4 lists each variation with the resulting average flux for ease of comparison.

Table 2-4 Changes to Selected Parameter Values Needed to Exceed NESHAPS Radon Flux Limit of 20 pCi/m^2/s

Variation	Initial Value	Maximum Value Needed to Exceed 20 pCi/m^2/s	Comment
Radium-226 Concentration	72 pCi/g	1,872 pCi/g	Change required to exceed NESHAPS radon flux limit. Max concentration found in Area 1 during RI: 906 pCi/g.
Surface Area of Thermally Driven Flux	75 m^2	1950 m^2	2500% increase in surface area required to exceed NESHAPS radon flux limit.
Increase in Rate of SSE Advance	0.25 m/d	6.5 m/d	Sustained rate of advance would need to exceed 650 ft/mo to exceed NESHAPS radon flux limit.
Reduction in Moisture Content	20%	55%	Moisture content would need to decrease by a factor of 2.75 below the assumed value to exceed limit.

3. ROD-SELECTED REMEDY ALTERNATIVE

As noted in the previous section, the current configuration of Area 1 will not produce radon levels that exceed the radon flux limit specified in NESHAPS unless 1,950 m^2 of Area 1 are involved in a SSE at one time. The ROD-Selected Remedy would add a cover over the current configuration, limiting the upward movement of the radon-222 from the involved source layer.

3.1 DESCRIPTION OF APPROACH

A web-based radon calculator (based on RAECOM) was used to calculate the radon flux from Area 1's ROD-Selected Remedy configuration excluding effects of a SSE (Subsection 3.2). Emissions from a SSE through a crack in the cover were calculated separately (Subsections 3.3 and 3.4) and integrated with the baseline flux to estimate the average flux from Area 1 (Section 3.4). The maximum area within Area 1 that must be involved before the NESHAPS limit of 20 $pCi/m^2/s$ is exceeded was also calculated (Subsection 3.5).

3.2 RADON FLUX CALCULATION – ROD-SELECTED REMEDY

For this case, the radium-226 source in Area 1 was assumed to be located below the ROD-Selected Remedy Cap described in the Supplemental Feasibility Study (EMSI, 2011). The four-layer geometry described by the values listed in Table 3-1 is a reproduction of Figure 1-1 in Appendix F of that document (EMSI, 2011). The 72 pCi/g radium-226 concentration used in the calculation is the 95% UCL of the arithmetic mean radium-226 concentration in Area 1.

Table 3-1 RAECOM Input and Results – ROD-Selected Remedy

---------------- Input Parameters ----------------

Number of Layers: 4

Radon Flux into Layer 1: 0 pCi/m^2s
Surface Radon Concentration: 0 pCi/L

Bare Source Flux (Jo) from Layer 1: 23.19 pCi/m^2s

Specific Bare Source Flux from Layer 1: 0.322 pCi/m^2s per pCi_Ra-226/g

Layer No.	Thickness [m]	Ra-226 [pCi/g]	Emanation Fraction	Porosity	Moisture [dry wt_%]	Diff Coeff [m^2/s]
1	1.4	72	0.2	0.671	25	1.95E-06
2	0.6	0	0.2	0.397	0.8	4.04E-06
3	0.6	0	0.2	0.427	23.7	4.66E-08
4	0.3	0	0.2	0.419	11.5	1.50E-06

-------- Results of Radon Diffusion Calculation --------

Layer No.	Thickness [m]	Exit Flux [pCi/m^2s]	Exit Conc. [pCi/L]	MIC
1	1.4	8.17	1.23E+04	0.755
2	0.6	0.715	1.43E+04	0.976
3	0.6	0.025	6.06E+00	0.365
4	0.3	$\boxed{0.023}$	0.00E+00	0.681

Total cover radon retention: 100%

The calculated radon flux from the configuration used to represent the ROD-Selected Remedy in Area 1 is 0.023 $pCi/m^2/s$ (Table 3-1). That flux is less than the NESHAPS limit of 20 $pCi/m^2/s$.

3.3 RADON PRODUCED BY A SSE

The amount of radon-222 expelled from the source layer by a SSE has been calculated in Subsection 2.3 to produce 60 $pCi/m^2/s$ through the upper surface of the layer actively experiencing a SSE. The same approach and results have been applied to this evaluation.

The reduction in radon emissions attributable to radioactive decay that will occur when the additional radon from a SSE moves through overlying layers of material are not considered when using this approach. By neglecting this mode of radon reduction, the calculation overestimates the fluxes released through the landfill's surface (Subsection 2.3).

3.4 RADON PRODUCED UNDER POST SSE CONDITIONS

As discussed in Subsection 2.4, radon-222 flux levels from the landfill are related to the moisture content and porosity of the landfill's contents. Moisture in soil can fill void spaces or coat radium-bearing particles, retarding the movement of soil gases like radon. Porosity is a measure of the void space (and cross-sectional area of the open space) in the material. A SSE could produce changes to the moisture content and porosity of the landfill contents as a pyrolytic reaction progressed.

Pyrolysis during a SSE may reduce both the moisture and the volume of the landfill contents. The impact of these changes on the calculated radon flux was evaluated by reducing the values representing the porosity and moisture content in the source layer by 20%. This change increased the calculated radon exit flux from 0.023 to 0.038 pCi/m^2/s (Table 3-2). This calculated radon-222 flux is less than the NESHAPS limit of 20 pCi/m^2/s.

Table 3-2 RAECOM Input and Results – ROD-Selected Remedy, Moisture and Pressure Reduced

```
---------------- Input Parameters ----------------
 Number of Layers:  4

 Radon Flux into Layer 1:  0 pCi/m^2s
 Surface Radon Concentration:  0 pCi/L

 Bare Source Flux (Jo) from Layer 1:  28.03 pCi/m^2s

 Specific Bare Source Flux from Layer 1:  0.389 pCi/m^2s per pCi_Ra-226/g


    Layer     Thickness    Ra-226    Emanation                 Moisture      Diff Coeff
     No.         [m]       [pCi/g]    Fraction     Porosity   [dry wt_%]      [m^2/s]
      1          1.4         72         0.2         0.537        20.0         1.29E-06
      2          0.6          0         0.2         0.397         0.8         4.04E-06
      3          0.6          0         0.2         0.427        23.7         46.6E-09
      4          0.3          0         0.2         0.419        11.5         1.50E-06

--------  Results of Radon Diffusion Calculation  --------
    Layer     Thickness   Exit Flux   Exit Conc.      MIC

     No.         [m]     [pCi/m^2s]    [pCi/L]
      1          1.4        13.37     17.5E+03      0.655
      2          0.6        1.170     23.4E+03      0.976
      3          0.6        0.040     9.90E-00      0.365
      4          0.3        0.038     0.00E+00      0.681
Total cover radon retention: 99.86%
```

3.5 COMBINED RADON FLUX FROM AREA 1 DURING A SSE

Installation of the engineered landfill cover included in the ROD-Selected Remedy will reduce the average radon flux from Area 1's covered surface after a SSE to 0.038 pCi/m^2/s over an 18,000 m^2 area (Subsection 3.2). Radon flux from a SSE was calculated to produce an additional 60 pCi/m^2/s from a 75 m^2 surface area above of the source layer in the zone of thermal expansion at the leading edge of a SSE (Subsection 2.3). Even though this cover would mitigate radon releases from a SSE wave front, this reduction was neglected in this calculation.[7] Instead, the flux from a SSE was instantaneously transported through the intact cover and added to the flux from the ROD-Selected Remedy determined in Subsection 3.2. This would produce an average flux of 0.29 pCi/m^2/s during a SSE:

$$\text{Average Flux over Area 1} \\ = \frac{\text{Exit Flux}\left(0.038\ \text{pCi/m}^2/\text{s}\right)\text{ x Surface Area}\left(18{,}000\ \text{m}^2\right) + \text{Flux}\left(60\ \text{pCi/m}^2/\text{s}\right)\text{ x SSE Area}\left(75\ \text{m}^2\right)}{\text{Surface Area}\left(18{,}000\ \text{m}^2\right)} \text{ or}$$

$$\text{Average Flux over Area 1} = 0.29\ \text{pCi/m}^2/\text{s}.$$

This combined average flux is below the NESHAPS limit of 20 pCi/ m^2/s (Figure 2-2).

Removing part or all of this cover due to cracking or mechanical disturbance would allow the radon-222 generated by a SSE to vent directly to the atmosphere. To raise the average radon-222 flux over Area 1 to 20 pCi/m^2/s, the area of a cover breach and the area of a SSE would need to coincide and exceed 5,989 m^2:

$$\text{Average Flux (20 pCi/m}^2\text{/s)} \\ = \frac{\text{Exit Flux (0.038 pCi/m}^2\text{/s) x Surface Area (18,000 m}^2\text{)} + \text{Flux (60 pCi/m}^2\text{/s) x SSE Area (X m}^2\text{)}}{\text{Surface Area (18,000 m}^2\text{)}}$$

Solving the equation for SSE Area:

$$\text{SSE Area }(X\ m^2) = \frac{(20\ \text{pCi/m}^2/\text{s}\ - 0.038\ \text{pCi/m}^2/\text{s})\text{ x }\left(18{,}000\ \text{m}^2\right)}{\left(60\ \text{pCi/m}^2/\text{s}\right)} \text{ or}$$

$$\text{SSE Area }(X\ m^2) = 5{,}993\ \text{m}^2.$$

To place this in perspective, 5,989 m^2 (1.48 acres) is almost one-third of the 18,000 m^2 (4.45 acres) area containing RIM in Area 1.

---

[7] From Table 3-1, the flux from the bare layer (Layer 1, without SSE) is 13.37 pCi/m^2/s, and the flux to the surface from Layer 4 is 0.038 pCi/m^2/s. Assuming the reduction for radon produced by a SSE is similar to that calculated for the covered source, then neglecting the cover overestimates the radon flux from the SSE by a factor of 352.

4. RADON FLUX FROM ISOLATED RIM

Placement of a thermal barrier or thermal mitigation system may result in some subsurface RIM (EMSI, 2011) deposits remaining south of the thermal barrier. This evaluation postulates that this RIM is located within an area that is subject to landfill gas collection as a normal part of landfill operations. Emissions from this subsurface deposit were assumed to be mixed with gas produced by the surrounding landfill material and collected by a landfill gas collection system. This gas collection system feeds a larger system which processes the gas before venting it to the atmosphere. The incremental radon-222 component of this effluent must meet the 10 CFR 20 Appendix B limit of 1×10^{-10} μCi/mL for radon-222 in airborne effluent.

4.1 DESCRIPTION OF APPROACH

A web-based radon calculator (based on RAECOM) was used to calculate the radon flux at the surface from the current configuration of the RIM located at sampling location 1C-6 in Area 1 (Feezor, 2014, Figure 4). This location was selected because the RIM was among the shallower deposits (26 to 27 feet below ground surface) encountered during sampling. The highest radium-226 concentration south of the projected placement (i.e. Alignment 1) of the thermal barrier (and, therefore, subject to the landfill gas collection system) was 31 pCi/g at sampling location 1C-12 in Area 1 (Feezor, 2014, Figure 4). Combining the greatest radium-226 concentration with one of the shallower depths provides a conservative estimate of the radon-222 available for gas collection.

The emissions from this subsurface deposit were assumed to be mixed with gas produced by the surrounding landfill material as it was collected by a landfill gas collection system. The collected gas was then fed into a larger system which processed the gas before venting it to the atmosphere.

4.2 RADON-222 PRODUCTION FROM RIM

The values of the input parameters used in the RAECOM flux calculation and the results of that calculation are presented in Table 4-1. From Table 4-1, 4.87 pCi/m^2/s of radon are generated at the surface of the RIM deposit.

The surface area of RIM producing radon south of the thermal barrier was estimated as the area around borings with elevated radium-226 (1C-6 and 1C-12), and the depth to the shallowest RIM reported in the two locations (allowing the fastest transit time to the surface). The area of the RIM deposit around 1C-12 is defined by the distance between 1C-06 and 1C-08 (86 ft.) and 1C-06 and 1C-07 (45 ft.). The area of the RIM deposit around 1C-12 is defined by the distance between 1C-12 and 1C-11 (55 ft.) and 1C-12 and WL121 (110 ft.). The surface area of the RIM deposit used in this calculation was the sum of those two areas, or 921.6 m^2:

$$\text{Deposit Area} = [(55\text{ ft})(110\text{ ft}) + (86\text{ ft})(45\text{ ft})] \text{ x } \left(\frac{0.0929\text{ m}^2}{1\text{ ft}^2}\right) \text{ or}$$

$$\text{Deposit Area} = 921.6\text{ m}^2.$$

Using the calculated flux in Table 4-1 and the deposit area, approximately 269,292 pCi of radon are produced each minute at the interface of the RIM:

$$\text{Radon} - 222\ \text{Activity}$$
$$= \text{Flux at surface}\ (4.87\ \text{pCi/m}^2\text{/s})\ \text{x Deposit Area}\ (921.6\ \text{m}^2)\ \text{x}\ \left(\frac{60\ \text{sec}}{1\ \text{min}}\right)\ \text{or}$$

$$\text{Radon} - 222\ \text{Activity} = 269{,}292\ \text{pCi/min.}$$

Table 4-1 RAECOM Input and Results – 1C-6 Geometry and 1C-12C Concentration

```
---------------- Input Parameters ----------------
 Number of Layers:  2

 Radon Flux into Layer 1:  0 pCi/m^2s
 Surface Radon Concentration:  0 pCi/L

 Bare Source Flux (Jo) from Layer 1:  8.656 pCi/m^2s

 Specific Bare Source Flux from Layer 1:  0.279 pCi/m^2s per pCi_Ra-226/g

    Layer     Thickness    Ra-226    Emanation                 Moisture       Diff Coeff
     No.         [m]       [pCi/g]    Fraction    Porosity    [dry wt_%]       [m^2/s]
      1           1          31         0.2         0.671         25           1.95E-06
      2           8           0         0.2         0.671         25           1.95E-06

              -------- Results of Radon Diffusion Calculation --------
    Layer     Thickness   Exit Flux   Exit Conc.     MIC

     No.         [m]      [pCi/m^2s]    [pCi/L]
      1           1          4.87       3.59E+03     0.755
      2           8           0          0E+00       0.755

Total cover radon retention: 100%
```

4.3 GAS PRODUCTION AND RETENTION TIME

The total calculated flow from the North and South Quarry areas of the Bridgeton Landfill through 3 stacks was 219 m^3/min[8]:

$$\text{Landfill Gas Flow Rate} = \left(\frac{7{,}734\ \text{ft}^3}{1\ \text{minute}}\right)\ \text{x}\ \left(\frac{0.0283\ \text{m}^3}{1\ \text{ft}^3}\right)\ \text{or}$$

$$\text{Landfill Gas Flow Rate} = 219\ \text{m}^3\text{/min.}$$

The calculated flow from one collection well would be 0.566 m^3/min[9]:

$$\text{Well Flow Rate} = \left(\frac{20\ \text{ft}^3}{1\ \text{minute}}\right)\ \text{x}\ \left(\frac{0.0283\ \text{m}^3}{1\ \text{ft}^3}\right)\ \text{or}$$

$$\text{Well Flow Rate} = 0.566\ \text{m}^3\text{/min.}$$

The rate that a material like radon is removed from a closed volume of gas is called the retention time in these calculations. It is dependent on the interstitial soil volume and the rate that the gas in that volume is replaced via some mechanism (i.e., inflow volume equals outflow volume). In

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[8] Flow rate from a stack is from January – September average of daily flare monitoring data, Bridgeton Landfill.

[9] Flow rate from a well is assumed for calculation.

this case, the calculation assumes all the gas in the interstitial space will eventually be removed by a well; and the rate the gas is removed is the flow rate of the gas extraction well.

The area of the landfill subject to gas extraction by one well was assumed to be circular with a diameter of 200 ft:

$$\text{Area well influence} = \pi \text{ x Diameter } (200\text{ ft})^2/4 \text{ x } 0.0929\text{ m}^2/\text{ft}^2\text{, or } 2919\text{ m}^2.$$

The depth of extraction is assumed to be equal to 7 m, which is the shallowest RIM reported in the two locations (allowing the fastest transit time to the surface) making the interstitial soil gas volume subject to eventual extraction:

$$\mathrm{V_{Extracted\ Gas}} = \mathrm{Area_{Well\ Influence}}\ (2{,}919\ \mathrm{m^2}) \text{ x Deposit Thickness } (7\ \mathrm{m}) \text{ x Porosity } (0.671) \text{ or}$$

$$\mathrm{V_{Extracted\ Gas}} = 13{,}711\ \mathrm{m^3}.$$

The retention time for this volume and stated rate of extraction would be 16.8 days:

$$\text{Retention Time} = \frac{\mathrm{V_{Extracted\ Gas}}\ (13{,}711\ \mathrm{m^3})}{\text{Extraction Rate } (0.566\ \mathrm{m^3/min}) \text{ x } 1440\ \mathrm{min/day}} \text{ or } 16.8\text{ d.}$$

4.4 PROJECTED STACK GAS CONCENTRATIONS AND EFFLUENT LIMITS

The RIM-derived radon concentration in the stack gas will be determined by the initial radon produced at the source, the volume of landfill gas that mixes with the produced radon, and the radon decay that occurs due to the delay in transporting the radon from the subsurface location of the RIM (located south of a proposed thermal barrier) to the gas extraction well.

Calculated radon production rate at the source was 269,292 pCi/min (Subsection 4.2). By the time the gas containing radon reached the well (an average of 17 days), radon decay had reduced the production rate at the well to 12,571 pCi/min.

Final Radon-222 Concentration (pCi/min) =

$$= Initial\ Rn_{222}\ Conc\left(269{,}292\,\frac{\mathrm{pCi}}{\mathrm{min}}\right) \times e^{\left(ln(0.5) \times \frac{Decay\ Time(16.8\ d)}{Half-life(3.8d)}\right)}$$

$$\text{Final Radon-222 Concentration (pCi/min)} = 12{,}571\text{ pCi/min.}$$

After mixing with gas from other areas of the landfill in the treatment system, this production rate is estimated to produce a radon concentration in the stack gas (effluent) of 6.6×10^{-11} µCi/mL:

$$\mathrm{C_{Radon-222}} = \frac{\text{Radon Production Rate at Well } (12{,}571\ \mathrm{pCi/min})}{\text{Landfill Gas Flow Rate } (219\ \mathrm{m^3/min})} \text{ x } \left(\frac{1 \text{ x } 10^{-12}\ \mathrm{\mu Ci \cdot m^3}}{\mathrm{pCi \cdot mL}}\right) \text{ or}$$

$$\mathrm{C_{Radon-222}} = 5.74 \text{ x } 10^{-11}\ \mathrm{\mu Ci/mL}.$$

The calculation used to estimate the RIM-derived radon concentration in the effluent generated by landfill gas extraction system is based on the maximum radium-226 concentration encountered in the study area. This approach likely over estimates the radon available for transport through the landfill to the gas extraction well. This overestimation results in higher effluent concentrations than would be expected if the average concentration in the study area were used.

4.5 COMPARISON OF EFFLUENT CONCENTRATION TO 10 CFR 20 APPENDIX B LIMIT

The calculated additional radon-222 concentration of 5.74×10^{-11} µCi/mL in the effluent from the gas collection system's stacks is less than the 10 CFR 20 Appendix B effluent limit of 1×10^{-10} µCi/mL above background for radon-222.

It is notable that the United States Geological Service, in conjunction with US Environmental Protection Agency, Region 7, found radon in soil gas levels in Region 7 "…ranging from tens of pCi/L to more than 100,000 pCi/L, but typically in the range of hundreds to low thousands of pCi/L." (USGS, 1993) More recently, samples of gas were collected from the intake stream of Bridgeton Landfill Flare #2 gas flare stack. This radon-222 content of this gas was analyzed, and the radon concentration of the gas ranged from 8.3 ± 0.8 pCi/L to 64.4 ± 6.5 pCi/L.[10] These concentrations can be converted from pCi/L to µCi/mL using a conversion factor of 1×10^{-9} µCi•L/pCi•mL. Assuming these levels are typical of emissions at the Bridgeton Landfill, it would be difficult to differentiate the predicted RIM-derived radon effluent concentration of 5.74×10^{-11} µCi/mL from typical background radon levels that are collected and vented by the landfill gas collection system (in the range of 1×10^{-7} µCi/mL to 1×10^{-6} µCi/mL in soil gas and 1×10^{-9} µCi/mL to 1×10^{-8} µCi/mL in flare influent).

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[10] Samples collected in Lucas Cells on April 4, 2006 (RSE, 2006).

5. REFERENCES

40 CFR 61.192	Title 40, Code of Federal Regulations, Chapter I, Subchapter C, Part 61, Subpart Q, Section 61, Subsection 192, "*National Emission Standards for Hazardous Air Pollutants*", October 2014.
Auxier, 2000	*"Baseline Risk Assessment West Lake Landfill Operable Unit 1"* by Auxier & Associates. Published by Engineering Management Support, Incorporated, as Appendix A of Remedial Investigation Report. West Lake Operable Unit 1, April 2000.
Auxier 2011	*"Evaluation of Potential Risks Associated with the Proposed Remedial Alternatives for the Supplemental Feasibility Study, Radiological-Impacted Material, Excavation Alternatives Analysis, West Lake Landfill Operable Unit-1,"* by Auxier & Associates. Published by Engineering Management Support, Incorporated, as Appendix F of the Supplemental Feasibility Study, Radiological-Impacted Material Excavation Alternatives Analysis, West Lake Landfill Operable Unit-1, December 2011.
Auxier 2011a	*"Cover Thickness Calculations for the Supplemental Feasibility Study, Radiological-Impacted Material, Excavation Alternatives Analysis, West Lake Landfill Operable Unit-1,"* by Auxier & Associates. Published by Engineering Management Support, Incorporated, as Appendix F of the Supplemental Feasibility Study, Radiological-Impacted Material Excavation Alternatives Analysis, West Lake Landfill Operable Unit-1, December 2011.
EMSI, 2000	"*West Lake Remedial Investigation Report,"* Engineering Management Support, Incorporated, 2000.
EMSI, 2011	"*Supplemental Feasibility Study, Radiological-Impacted Material Excavation Alternatives Analysis, West Lake Landfill Operable Unit-1", *Engineering Management Support, Incorporated, 2011.
EPA, 2008	Record of Decision, West Lake Landfill Site, Bridgeton, MO. OU 1, U.S. EPA Region 7, May 2008.
Feezor, 2014	*"Bridgeton Landfill Thermal Isolation Barrier Investigation Phase 1 Report,"* in preparation by Feezor Engineering, 2014.
RSE, 2006	*"Radiochemical Activity in Air, Bridgeton Landfill,"* Report to Bridgeton Landfill, prepared by Radiation Safety Engineering, Inc., Chandler, AZ April 25, 2006.
USGS, 1993	USGS 1993 "*Geologic Radon Potential of EPA Region 7, Iowa, Kansas, Missouri, and Nebraska*", Open-File Report 93-292-G, US Department of the Interior, US Geological Survey, 1995.

Wise, 2011 Uranium Mill Tailings Cover Calculator, a modification of the RAECOM model, 21 Mar 2011, Retrieved from http://www.wise-uranium.org/ctc.html.

Attachment B

Inert Barrier Design Memorandum

1.0 BRIDGETON OU-1/NORTH QUARRY INERT BARRIER SYSTEM – DESIGN OUTLINE

The Option 1 and Option 3 barriers would consist of a subsurface, reinforced concrete wall extending from the ground surface down through the bottom of the waste material. This memorandum lists the design criteria for these types of barriers.

1.1 DESIGN PERFORMANCE CRITERIA

1.1.1 OVERALL DESIGN GOALS

The overall design goals are to:

- Provide a continuous non-combustible zone through the width and depth of waste materials along the alignment chosen; and

- Maintain a temperature on the face of the non-combustible zone opposite the current SSE that is no greater than 175 °F.

LIFETIME OF BARRIER

Based on reasonable expectation of life of reaction capability and the time to dissipate heat energy, the design life is approximately 40 years for non-replaceable elements once a reaction would encounter the area. Non-replaceable elements would include the non-combustible barrier and anything embedded within it.

1.1.2 DESIGN SPECIFICS

DESIGN CONDITIONS

General

The design conditions will presume the SSE reaction continues to move north toward the chosen alignment. Further it would be assumed that heat fluxes associated with the migrating front would be similar in nature as those found within the South Quarry, as is discussed in Attachment C but focused on the location of chosen alignment. The design conditions will presume that pyrolysis driven settlement will occur wherever temperatures would be predicted to be higher than 200 °F, which is a conservative estimate since based upon experience at other facilities, pyrolysis does not occur until 220°F. Because precise knowledge as to the specific rate that such settlements would occur along the chosen alignment is not available, as evidenced by varying spatial settlement patterns in the South Quarry, a probabilistic approach would be utilized in the design of barrier functions that cannot be conservatively calculated by assuming uniform worst case conditions. This probabilistic approach would apply primarily in calculation of stresses and strains within the non-combustible element itself associated with the varying patterns of settlement and lateral strains of the potentially pyrolyzed wastes south of the alignment. The general design criteria and steps are described in more detail subsequently.

TEMPERATURES

The allowable temperature within the wall will be limited to 200 C° (392 °F), significantly lower than studies show reinforced concrete can continue to provide performance if significant numbers of thermal cycles do not occur, as should be the case in proposed systems. Temperatures within the waste measured in the South Quarry have not approached this value, so no specific action should be required to meet this objective.

Temperature controls within the non-combustible zone will be controlled using heat exchange tubes that are built into the unit as it is constructed. Spacing of these elements will be based on the calculations performed, as described in Attachment C, to determine the appropriate design heat fluxes. Heat extraction from the wall will be performed assuming literature based heat conduction values for the concrete and a design circulation liquid value of 85 °F, consistent with use of adiabatic air coolers with a closed loop liquid circulation.

Cooling elements will be attached to reinforcing materials so as to limit strains of the elements to the strains of the reinforcement.

Deformations of the Non-Combustible Element

Deformation of the non-combustible element (NCE) is a structure/waste material interaction problem. The proposed NCE has a relatively small width-to-length ratio and will be founded on the first encountered non-waste layer at the base of the NCE with zero fixity with the underlying layer. Given the significant depth to this layer (40 to 80+ feet) and the relatively low moduli of the waste materials, it has been determined that attempting to embed or anchor the NCE into the alluvium/bedrock is not feasible. Instead the NCE will be a relatively stiff material capable of developing tensile stress embedded in a deforming waste mass.

The deformations that will occur will be dependent on the deformation of the waste mass. Given the necessity of maintaining continuity along the NCE, its panels will require continuity of tensile capacity, or alternatively, multiple units with significant overlap (for example, two rows of wall separated by small slip zone) with offset joints. In any case, deformations and stresses must be predicted or bound to perform the needed designs. The NCE is most likely going to experience arrival of the SSE at different times and rates along the length of the feature, resulting in some dependence on the surrounding area deformations and their time history as well. The various design methods required to define the bounds and possibilities are presented below.

DEFINITION OF LIMITS TO SETTLEMENT AMOUNTS WITHIN INFLUENCE ZONE OF NCE

Design will require estimating the settlement amounts. The key parameters to be included are the thickness and location of pyrolyzed waste that will occur south of the wall. Pyrolysis at a lower temperature, results in the development of approximately 45% char, while the rest of the materials are in non-solid form. This is generally consistent with observations within settlements within the South Quarry in terms of depth of the heated zone and the observations at other sites that significant pyrolysis did not occur shallower than 60 or so feet from the ground surface or within of 20 feet above the bottom of waste, reflecting the heat absorption of the bottom. These values will be used to project maximum settlements. These values may be varied, as to the bottom of the waste or influence of quarry walls on pyrolytic development zones based on the results of heat flow modeling as described in Attachment C.

The lateral zone of influence of the above settlements, along with the differential settlements associated with normal waste degradation, will be used to identify zones along the alignment that have the likelihood of experiencing lateral strains that could be avoided by moving further away from the source of significant strains. This analysis will presume both maximum conditions and likely non-coincidental occurrence of the settlement. This will be performed as part of the initial alignment detailed evaluation. Two dimensional Finite Element (FE) analysis with typical waste deformation properties (used by PJ Carey and Associates with success on other projects) will be utilized for this analysis.

In the event that an alignment is chosen close enough to the quarry wall to invalidate normal infinitesimal strain assumptions, a finite strain program such as Fast Lagrangian Analysis of Continua (FLAC) will be utilized to more fully understand and predict strain patterns.

STRESS AND STRAINS WITHIN THE NCE

The predicted vertical settlements to the south of the NCE along with proposed stiffness of the wall would be utilized in two and three dimensional model to determine:

- Settlement induced stresses and strains;
- Influence of filling settlement depressions to the south of the wall on wall stress and deformations;
- Influence of mild arch shapes within the alignment to reduce tensile stresses in the horizontal direction and improve NCE stability; and
- Variation in stress and strain for a range of possible scenarios (monte carlo style) that would be within the bounds of reality for both the maximum settlements and varied times of arrival of settlement fronts to the influence zone of the wall.

It is presumed that this procedure would be iterative with respect to the NCE design geometry (thickness) and determination of the needed reinforcement.

NCE STRUCTURAL DESIGN

The NCE, assumed at present to be a reinforced concrete structural slurry wall, would be designed based on the above described study. The reinforcing details and concrete strengths etc, would be designed in general accordance of ACI 318. Modifications in mix designs and reinforcement steel (and possibly metal or glass fiber) would be done to reduce the impact of leachate contact on the functionality of the NCE. This would include use of additives to increase sulfate and chloride resistance, use of epoxy coated rebar, etc.

In the event a NCE with continuous horizontal reinforcement is selected, special terminal units that allow development of reinforcement across wall elements will be developed and tested. This will be needed because continuous horizontal reinforcement using special terminal rebar units is not a standard practice in slurry wall construction at present. Final checks of the design will be performed using the aforementioned FE soil structure interaction analysis.

1.1.3 OTHER DESIGN ELEMENTS

EXCAVATION SLOPES

Slope stability analysis will be performed to demonstrate that the proposed pre-excavations for the pre-NCE insertion surface are stable under both static and seismic conditions.

MONITORING SYSTEMS

The ongoing management would include monitoring for temperature within and south of the wall. It may also be necessary to perform deformation monitoring. The design would likely include casting of inclinometer type casing in the NCE at approximately 100 foot centers to provide for deformation monitoring. This would allow measurements to be taken at the end of construction and then at such times as NCE behavior warranted.

Additionally, electrical continuity cables that would break if significant differential movement occurred locally in the wall, would be installed at approximately 20 foot centers, vertically along the alignment.

Attachment C

Heat Extraction Barrier Design Memorandum

1.0 INTRODUCTION

This memorandum provides preliminary design criteria for potential heat extraction systems that may be installed as part of Isolation Barrier Alternatives 1, 3 and 4. The flow of heat to the proposed barrier location will be studied and heat flux values will be estimated for the design of the heat exaction system. Several properties pertaining to the heat generating capacity and the heat conductance capacity of the waste are variable due to the heterogeneity of the waste. Therefore, computer modeling simulations will be used to determine the anticipated maximum heat flux at the selected barrier location.

1.1 Heat Extraction Studies in the South Quarry of the Bridgeton Landfill

In order to help assess heat conductive properties of waste materials, a heat extraction study has been ongoing since fall 2013 in the South Quarry Area of the Bridgeton Landfill. In September of 2013, Gas Interceptor Well (GIW)-4 was modified to remove heat through the circulation of water in a closed loop within the well.

The operation and monitoring of GIW-4 as a heat removal point is on-going. The primary data collection period was conducted from 9/26/13 to 12/6/13. The primary data parameters recorded were the inflow and outflow water temperatures, flow rate and the temperature within the casing as measured by thermocouples at multiple depths. Using these data, a calculated heat removal rate in kilowatts (kW) was determined.

Based on evaluation of the data, a quantitative heat removal rate and temperature effect was determined. The data collected showed a significant reduction in temperatures within the casing outside of the outer heat removal piping and that the heat exchanger element within the casing operated on a ΔT of about 10 °F with an extraction rate of approximately 25kW. The extraction rate was maintained during this period, due to constantly falling inlet temperatures caused by dropping ambient temperatures during the initial test period.

The next phase of the heat extraction study, which is currently being constructed, includes measurement of thermocouples installed within adjacent Temperature Monitoring Probes (TMPs). Multiple GIW (6 additional) wells are being retrofitted with recirculation coolant tubes connected to a closed loop header system which conveys the cooling water to a mechanical cooler.

The proposed TMP location and depths were designed to be offset near the heat extraction points. Specifically, the proposed TMP measurements will be utilized to allow the determination of thermal conductivity and heat storage properties during a relatively short period of time (3 to 6 months) based on non-steady state conditions. For this reason the TMPs that are close to the extraction points are only extended to a depth where the conditions are expected to be free of bottom effects associated with the end of the extraction points. The other existing TMPs are deep enough to allow longer term impacts associated with depth and distance to be evaluated.

1.2 Heat Transport Computer Modeling

Thermal conductivity and heat storage properties of the waste will be determined from the heat extraction studies utilizing both computer modeling and calculations based on simplified relatively homogenous assumptions in the vicinity of the extraction methods. Following these, a larger scale computer model that includes the North Quarry and OU1 areas will be used to predict the potential heat flux to the barrier. The program FEFLOW (DHI-WASY Software) will be utilized to perform 3 dimensional simulations of the South Quarry and North Quarry areas of the Bridgeton Landfill. FEFLOW is a professional software package for modeling heat transport processes in the subsurface. This modeling exercise will consider the following:

- Limits of the current exothermic reaction as defined by the TMPs;
- The geometry of the landfill including the areas up to and beyond (north) the potential barrier alignment;
- The depth of waste;
- The thickness of underlying natural soils;
- The depth to bedrock;
- Conservative estimates of heat conduction and heat capacity will be assigned to the natural materials based on the literature; and
- Thermal conductivity and heat storage properties of the waste derived from heat extraction testing currently being conducted in the South Quarry of the Bridgeton Landfill.

Please note that no assumptions of phase changes or other significant absorptive phenomena will be included within the computer modeling exercise, making the proposed design conservative. It should also be noted that observation of the temperature and rate of temperature changes in the south quarry using the TMPs suggests that an energy absorptive mechanism (other than just raising stored heat energy at higher temperatures) may occur at the heat front. However, this will be ignored for planning purposes in order to achieve a conservative design.

1.3 Historical Heat Front / Heat Flux Predictions

Previously, the rate of heat front progress to the north and the rate of energy flux to the north have been assessed on several dates. Predictions of the amount of heat that could be extracted under steady state conditions from arrays of vertical extraction elements have also been made. The initial results from a single point extraction element (from the first phase of the heat extraction study described above) verified that the heat extraction rates for a single isolated point was within the range predicted.

Heat front migration rates have also been within the ranges predicted. Further refinement of the various heat related properties of the waste, along with improved heat gradient information, will be available from the expanded heat extraction study currently being conducted (as described above). It is anticipated that this information will take approximately 3 to 5 months to obtain with a level of confidence. Estimates of the maximum heat flux in the south quarry have been in the range of 14 Watts/m^2, as of July 2013. Since that time the advance of the reaction to the south has not increased but appears to have slowed.

2.0 DESIGN CRITERIA

Options 1, 3 and 4 for the proposed Isolation Barrier all include active heat extraction systems to prevent possible hypothesized impacts that may occur if radiologically-impacted material (RIM) in Area 1 of OU-1 were to be heated to levels consistent with those observed in conjunction with the exothermic reaction currently being evaluated, and the resulting calculated heat flux at the barrier location. Therefore, the design of the heat extraction system will require design criteria which can be measured and evaluated once the barrier has been constructed.

The heat extraction design criteria will be based upon a compliance location, that is a location along a certain boundary that can be measured, and if the temperature is at or below this temperature, the heat exaction system is deemed effective. The compliance temperature is 175 degrees F. The compliance boundaries are defined as:

- For Options 1 and 3 the compliance boundary will be the north face of the inert barrier. The north face of the inert barrier will be at or below 175 degrees F if an exothermic reaction is south of the barrier.

- For Option 4 the compliance boundary will be a line 15 feet north of the northern row of cooling wells (elements). Therefore, this boundary will be at or below 175 degrees F if an exothermic reaction is south of the southern row of cooling wells.

The heat extraction system will consist of installing a series of vertical metal pipes (or other acceptable materials) with a closed end in the waste (for Option 4) or the inert barrier (for Options 1 and 3). A smaller diameter pipe will be installed in the outer pipe, and will be suspended a certain distance from the bottom of the outer pipe. The smaller diameter pipe will be connected to an incoming cooling liquid header pipe system and the outer pipe will be connected to an outgoing cooling liquid header pipe. The header piping system will be used to convey cooled liquid from the cooling unit which will be pumped into the smaller diameter pipe in the cooling element. This cooled liquid will flow down to the bottom of the outer pipe, and then will flow up the annular space between the two pipes. Circulation of the cooling liquid will remove heat from the system as the liquid is being pumped up to the outgoing header system. The vertical piping system is called individual vertical heat extraction elements. Therefore, the overall heat extraction system will consist of:

- A series of vertical heat extraction elements;

- A header system of pipes which will convey the cooled liquid to the cooling elements and the warmed liquid back to the cooling system;

- A cooling system which will mechanically cool the warmed liquid; and

- A temperature monitoring system.

Each of these components of the heat extraction system will have to be designed based upon the results of the anticipated heat flux expected at the south side of the barrier, and the heat compliance requirements along the north side of the barrier.

2.1 Size and Number of Vertical Heat Extraction Elements

Once the amount of heat required to be removed is calculated, the number and size of the vertical cooling elements will be designed to remove up to two (2) times the predicted heat flux plus a provision to remove more heat if needed. This will provide an adequate factor of safety to ensure the compliance temperatures at the compliance boundaries are maintained. The operators of the heat extraction system will be able to modify the heat extraction rates by either:

- Lowering the inflow temperature in areas needed which would require the addition of a chiller system for the zone identified to need added extraction capacity; and

- Alternatively the array of vertical heat extraction elements can be designed with sufficient space to allow additional extraction elements that could be installed in the future if it becomes evident that higher extraction rates are required.

Please note it is envisioned that a closed loop adiabatic air cooler system will be used which will consist of spraying water on recirculating coils in the cooler unit. However, if necessary, a supplemental chiller may be added during the warmest times of the year if lowering the inflow temperature is necessary beyond what an air cooler can maintain. See Section 2.3 of this memo for further discussions pertaining to the cooling unit(s).

The size of the vertical heat extraction elements will assume the cooler will operate at the average expected summer condition for the St. Louis area to calculate the needed heat extraction needed to maintain compliance boundary temperatures using the predicted heat flux at the boundary.

Both computer modeling and manual calculations will be used to determine the spacing and number of units.

For Option 4, multiple rows will be utilized (two are envisioned at present).

2.2 Vertical Heat Extraction Element Design

For Option 4, the vertical heat extraction elements will not be in an inert wall. Therefore, these elements will be comprised of corrosion resistant metal (low carbon stainless steel) or nonmetallic materials. Element spacing and extraction rate determination will include the thermal conductivity of the element wall.

For Options 1 and 3, the vertical heat extraction elements will be within an inert barrier, therefore the elements may consist of coated steel or other systems, accounting for the protection from corrosion and damage offered by the inert barrier.

Vibratory or helicor pile hammers will be used for installation of the vertical heat extraction elements under Option 4. Installation will use either direct driving of pipes with internal driving mandrels for metal pipes or external mandrels with lost tips for thin wall pipes or non-metallic tubular shapes. No waste excavation is anticipated. If the planned installation methods do not prove to be effective, a rotosonic drill rig could be used as a backup method.

The external portion of the vertical heat extraction element will be designed to withstand down-drag forces associated with standard waste settlement. Grouts that are of limited strength, or other means of reducing stress without negative effects on heat flow, may be utilized to allow thinner wall shapes.

2.3 Distribution and Cooling

The cooling system will utilize a closed loop adiabatic air cooler system which will consist of spraying water on recirculating coils in the cooler unit, typical of commercial HVAC coolers.

This cooler is the type of system being utilized for the heat extraction study in the South Quarry Area of the Bridgeton Landfill. To prevent freezing it will be necessary to use fluid which will allow year-round operations. These systems are readily available and will be sized to provide cooling capacity during the summer month conditions.

The cooler will be designed so that the required heat extraction rate will be maintained during the summer months. It is expected that a cooler system with spray to achieve wet bulb temperatures will be able to cool the returned heated liquid down to an average inflow temperature of approximately 85°F. However, during the design, it may be necessary to have a lower inflow temperature for the cooling liquid to return to the vertical heat extraction elements. If that is so, then lowering the cooling liquid temperature to 40 °F can be expected to increase the heat extraction rate 1.5 times for the boundary conditions intended for compliance. During the summer months, this would require a supplemental chiller, but during the cooler months (approximately 5 months in the St. Louis area), 40 °F is available without a chiller.

Distribution of supply and return liquid will be insulated to prevent unwanted thermal gain. These systems will be above ground HDPE pipe with flex connections to the extraction points.

2.4 Monitoring

In-ground temperature monitoring will also be included as a part of the heat extraction system. It is envisioned that an array of TMPs would be installed using driven methods at the time a heat front is expected to occur within 100 feet to the south of the heat extraction system, based on settlement or gas well temperature data. Since experience shows that the TMPs degrade with settlement, judicious timing of installation of the TMP arrays would be necessary. Each zone to be instrumented would consist of a set of 3 units, one to the south, one within the array zone and one at the point of compliance. It is envisioned that one array per 120 feet would be sufficient.

In addition, temperatures of the circulating liquid (in and out) and flow per vertical heat extraction element location would be used to identify any area that is exhibiting higher temperature or extraction rates that warrant further evaluation or adjustment.

2.5 Design Life

The time required for operation of the heat extraction component is the time needed to reduce energy in order to ensure temperatures at the north side of the barrier location (the compliance boundary) does not rise above 175 °F. The major variables in determination of this time are:

- Overall thickness of the waste mass which governs the heat energy losses to the top and bottom of the landfill surfaces;

- The heat generating capability per unit mass of the reaction constituents within the mass of waste at the end of the operating life; and

- The temperature of the wastes at distance from the barrier location.

The waste mass near the barrier will rise in temperature after the mass of waste south of it has already become heated. This is consistent with the pattern seen in the South Quarry area of the Bridgeton Landfill and at other sites, where the pattern in temperature rise for the large scale heating events has progressed outward from an area of origin. As such, heat extraction at the barrier should result in a receding isotherm as measured from the wall at 175 °F. . It should be noted that the system could be operated intermittently once heat flux toward the barrier drops or could be reactivated if the temperatures rose again after being predicted to not do so.

The rate of reaction and total yield of the reactions (total heat generated per mass of waste) are the defining heat related inputs for the determination of when the heat extraction system can be turned off. At the present time, reasonable estimates of the rate of heat generation per unit mass of waste can be determined from the South Quarry area of the Bridgeton Landfill.

This approximate boundary will be used to assign the approximate limit of heat generation in the modeling to determine long-term heat flux to the chosen barrier location. The rate of heat generation at this boundary and the temperatures at the boundary will be based on the current maximums measured in the South Quarry of Bridgeton Landfill.

At present, based on the experience at other sites, it would appear that reactions in a given area subside within 10 years and what is left is residual heat. Removing this heat eliminates the continuing after-effects and the ability of the heat to spread via conduction to other locations. Therefore, in the absence of other data, it would appear that 15 to 20 years of design life would be a conservative range for irreplaceable components (this is mainly just a physical inorganic barrier should it be chosen as part of the barrier system).

If items are installed significantly in advance of the heat front getting to the barrier location, the operation life of irreplaceable elements would need to be longer. Based on other sites, incubation times between the receipt of wastes and the physical evidence of the reaction has not been greater than 15 years. As such the maximum operating life should be chosen to not exceed the travel time of the reaction to the barrier location (projected) plus 20 years of operating life or 35 years, whichever is greater.

Attachment D

Isolation Barrier Alternative Analysis – Bird Control Issues

Isolation Barriers Alternatives Analysis – Bird Control Issues

Prepared by

Rolph A. Davis, Ph.D.
Executive Chairman
LGL Limited
7 October 2014

The following analyses of bird control issues are keyed to the numbering system in the Isolation Barrier Alternatives Analysis.

3.0 No Action

3.6 Bird Attraction Potential – No change in attractiveness of the site.

4.0 Option 1

4.6 Bird Attraction Potential and Possible Mitigation Measures

It is quite likely that the municipal solid waste (msw) excavated during this option is old enough that the waste will have lost most of its organic content and be unattractive to birds. However, whether that will be the case will not be known until the waste is excavated. To be on the safe side, it is best to assume that the waste will still contain organic matter that is attractive to birds. Therefore, a well-designed bird control program should be in place when the excavation begins. With a bird control program in place at the start of invasive work, the landfill will not become a bird attraction.

The key to a successful control program is to have controllers who are well-trained by experienced professionals and overseen by those professionals. As requested by the Lambert-St. Louis International Airport ("Airport") controllers would take a basic bird mitigation and monitoring course provided by the wildlife professionals at USDA-Wildlife Services. This would ensure that controllers have been advised on issues and approaches of specific interest and concern to the Airport. In addition, the controllers would have specialized training in landfill bird control procedures provided by a biologist from LGL Limited. The biologist from LGL Limited has experience with bird control at many large msw landfills and will focus on the key operational factors that make landfill bird control successful.

The control program would involve continuous coverage with a controller on duty at all times when there is uncovered waste present, including weekends. If any birds appear and attempt to feed on the waste, they will be frightened off using properly-applied procedures using standard pyrotechnics. Because the first arriving birds are always scared away, numbers of birds never increase and never become a problem. These techniques have been used successfully at many major active msw landfills (e.g. Illinois, New Jersey, Texas, Colorado) under the direction of LGL Limited biologists. To insure that control coverage is continuous, a minimum of two controllers would be needed to cover long days and weekends.

The bird species of most concern are Ring-billed Gull, Herring Gull, Turkey Vulture, and European Starling. These are species that feed at landfills and that can pose a hazard to aircraft safety in some situations. Gulls are of most concern because of their well-known propensity to actively feed at landfills. The control program will focus on gulls. Turkey Vultures generally avoid humans and operating equipment and will not attempt to feed under these circumstances. Turkey Vultures are the only birds in this region that have a sense of smell but they do most of their hunting by sight. Starlings can occur in large flocks and are more common in agricultural areas than in landfills.

There will be a seasonal aspect to the bird control program. Most gulls are at nesting areas further north during the late spring though early autumn. Large numbers arrive from the north during late fall and winter. Turkey Vultures leave the area during winter. Flocks of starlings tend to occur at landfills during the fall and winter. Therefore during spring and summer, the main species of concern will be Turkey Vultures and they are easily controlled. During fall and winter, gulls and starlings are present in the area and control efforts will be more intensive. The short days during this period assist in allowing a single controller to cover the excavation and relocation areas. If the waste relocation area is distant from the excavation area, it may be necessary to have an additional controller at the relocation area.

The final details of the bird control plan will be determined in coordination with the Airport during the engineering phase of the project that will occur after the Barrier Option has been selected. During this phase the number of controllers to be used would be determined and the placing of the controllers at the excavation area would be evaluated. Reporting procedures would be determined with at least weekly reports to be prepared and distributed to the Airport and other relevant agencies. Failure criteria would be established to define levels of bird activity at the site that would require notification to the Airport and an intensification of the bird control program. Intensification would involve the addition of bird controllers and possible lethal intervention by USDA personnel. The design phase of the bird control program will be conducted in conjunction with appropriate personnel from the Airport and from USDA – Wildlife Services and will require agreement by the Airport.

In summary, in the unlikely event that the excavated waste contains edible organic material, bird populations can be successfully controlled and there will be not be an increase in risk to aircraft using the Lambert-St. Louis International Airport.

5.0 Option 3

5.6 Bird Attraction Potential and Possible Mitigation Measures

Options 1 and 3 are very similar from a bird control point-of-view. The amounts of msw excavated are similar and the relocation areas are expected to be the same. The construction period for Option 3 is longer (~48 weeks) compared to Option 1 (39 weeks). Because control will have been maintained over the first 39 weeks, it is unlikely that habituation by birds would occur during the final 9 weeks of Option 3. The increased length of Option 3 does not change the effectiveness of the bird control program. The summary description of the proposed control program given for Option 1 applies equally well to Option 3. The two options have the same bird hazard risk which can be well-controlled in either case.

6.0 Option 4

6.6 Bird Attraction Potential and Possible Mitigation Measures

The construction activities involved with this option do not involve excavating previously deposited msw and therefore will not create a possible bird attraction from that source. The drilling and other surface activities should not attract birds any more than many activities that already occur on the site. Option 4 does not provide a bird attraction and does not require a bird control program.

Option 2

Option 2 involves creation of an air barrier achieved by the excavation and relocation of ~500,000 cy of waste. During the excavation, large areas of waste will be left exposed until the final cover is applied. The large amounts of waste to be relocated also increase the difficulty of establishing an effective bird control plan. The key question is whether the waste retains any organic matter that is attractive to birds. This option would disturb the newest waste on the landfill, waste which, based on its age, has the greatest potential to have retained organic matter as compared to the other options. As for the other Options considered, we must take a conservative approach and therefore it is assumed that the waste will be attractive to birds and an appropriate bird control program must be designed.

The bird control program necessary to protect Option 2 is significantly more difficult to design and operate than the programs for Options 1 and 3 given the significantly larger volume of waste and larger impacted areas. The same approach to bird control would be taken for Option 2 as taken for Options 1 and 3, but implementation would be more difficult and the number of controllers on duty at any one time would be higher than for the previous options. The details of the bird control program cannot be determined until the detailed engineering design Option 2 has progressed and operational details determined. A detailed bird control plan would be completed once construction details are known. This would address the need for more controllers, likely increased reporting and the potential for several levels of elevated response in order to minimize risk. The Airport would contribute to the design of the program to insure that it met the requirements of the Airport.

There is a significantly higher bird risk associated with Option 2 and it is less certain that a successful control program could be put in place at a reasonable cost.

Rolph A. Davis, Ph.D.
Executive Chairman, LGL Limited
President, LGL Alaska Research Associates, Inc., Anchorage, Alaska
Director, LGL Ecological Research Associates, Inc., Bryan, Texas
Director, Spectrum Seniors Housing LP

EDUCATION

1972	Ph.D. Animal Ecology, University of Western Ontario.
1964	Graduate courses in Wildlife Biology, University of Guelph.
1963	B.A. Geography, University of Toronto.

PROFESSIONAL EXPERIENCE

2005 -	Executive Chairman, LGL Limited
1979 - 2005	President and CEO of LGL Limited.
1974 - 1979	Vice-President, Operations, and Director, Eastern Region, LGL Limited.
1972	Joined LGL Limited.

Ornithological Studies

- Conducted a five-year review of gull populations associated with the Trail Road Landfill and the Ottawa International Airport.

- Continued for the 17th consecutive year, monitoring of gull control program at the Atlantic County Utilities Authority Landfill near the Atlantic City International Airport and the FAA technical Center.

- Continued monitoring of the gull control program and assessing bird hazard to aircraft safety associated with the Orchard Hills Landfill, near the Chicago-Rockford Airport (14 years).

- Continued monitoring of the gull control program and assessing bird hazard to aircraft safety associated with the Winnebago Landfill near the Chicago-Rockford Airport (9 years).

- Directed a one-year study of gull populations and movements at a landfill near the Edmonton International Airport.

- Conducted an analysis of the potential effects of a proposed landfill on the safety of aviation at a nearby General Aviation Airport in Rockingham County, North Carolina.

- Implemented a gull control program at a major landfill near Houston gaining control of the landfill, turning the control over to landfill staff, and then monitoring the continued success of the control program.

- Assessed the bird hazard to aircraft safety risks associated with a landfill near an airport in central California and designed a bird control program to eliminate potential risks.
- Designed, implemented, conducted and monitored a gull control program at a landfill in Calgary, Alberta (2010-2012).
- Conducted a Stage 1 Safety Assessment of proposed landfill sites near the airstrip in Arviat, Nunavut.
- Provided an independent assessment of a proposed bird control program to be implemented at the Yellowknife Landfill in the Northwest Territories.
- Assessed the potential for disturbance effects from a coastal marina on migrating Red Knots.
- Conducted an assessment of the proposed expansion of the Bracebridge Landfill on the safety of aircraft using the Muskoka Airport.
- Completed a one-year study of bird populations associated with a landfill in the Galveston, Texas area and designed a gull control program to be implemented by landfill staff.
- Reviewed and upgraded a bird control program in place in Lansing, Michigan to insure that it continued to provide protection to aircraft using the Lansing Airport.
- Provided advice on the design and operation of a dredging program in Hamilton Harbour to reduce the effects on colonial nesting birds and migrating waterfowl in the area.
- Conducted a one-year study of bird use of the largest Houston-area landfill to provide a baseline against which the success of a bird control program could be measured. Designed and implemented the bird control program and monitored its success for one year.
- Conducted three-year study of bird populations in support of a proposed new landfill in western Pennsylvania. Assisted with applications to the state regulatory body.
- Conducted a 14-month study of bird use of the Pagel Landfill in Winnebago County, IL, provided input to a permit application, and designed a bird control program to be implemented at the landfill. The activities were in support of an application for a landfill expansion. The success of the bird control program was monitored for 3 years.
- Conducted a study of gull populations at the Atascocita Landfill near the Houston International Airport, provided input to a permit application, and developed a bird control program in support of an application for a landfill expansion. Subsequently implemented the bird control program as part of a permit condition.

- Continued monitoring, through 2012, of bird control program established in Atlantic County, NJ. The program was designed by LGL Limited and began operating in October 1997.

- Provided advice to Transport Canada on land-use zoning regulations (under the federal Aeronautics Act) that were put in place near the Pickering Airport Site to reduce bird hazards to aircraft safety. Project included field studies, determination of safety zones and hazardous land-uses, and mitigation measures that could be put in place to reduce hazards.

- Represented Thurston County, Washington (near Olympia) in a lawsuit about alleged damages caused by birds attracted to their recently closed landfill. The case was settled after "examination for discovery" of Dr. Davis. Subsequently provided testimony for an insurance company involved in a dispute over the settlement.

- Continued monitoring the bird control program initiated at BFI's Tower Landfill in 1993. The control program continued to be highly successful 17 years later.

- Participated in a formal System Safety Review at the Vancouver International Airport to evaluate potential bird hazards arising from land-uses in areas surrounding the airport.

- Evaluated vulture use of a landfill on the coastal plain of the Gulf of Mexico in Texas in relation to a lawsuit. The lawsuit was settled.

- Conducted a full-year study of bird populations at several landfills and bird attractions in western Pennsylvania in preparation for an application to re-open a presently closed landfill. The project involved bird surveys in two subsequent years, research on vulture control at landfills, preparation of permit application materials for the state and for the FAA, and design of a bird control program for use at the site.

- Monitored the bird use of the Orchard Hills Landfill near the Greater Rockford Area Airport in northern Illinois. Project has documented very low gull use of the landfill over 12 years of monitoring. Provide annual bird control training for landfill staff.

- Conducted a Stage 1 Safety Analysis regarding a proposed First Nation landfill at North Spirit Lake in northern Ontario.

- Evaluated bird use of the Anguilla Landfill in St. Croix, U.S. Virgin Islands in response to concerns raised by the FAA about bird hazards to aircraft safety at the adjacent airport, the main international airport on the island. Prepared short-term and long-term bird control plans for the landfill.

- Conducted a study of bird use at a transfer station near the Dover Air Force Base in Delaware and provided expert testimony at regulatory hearings.

- Demonstration of methods to control vultures, crows and starlings at a landfill in western Pennsylvania.

- Assessed potential bird hazards to aircraft safety associated with two proposed sites for a food-waste composting facility in the vicinity of CFB Trenton, the main air transport base for the Canadian Forces.

- Conducted a site assessment and design evaluation of a proposed solid waste transfer station to be constructed near the DuPage Airport in DuPage County, Illinois.

- Conducted Stage 1 Safety Analyses regarding proposed First Nation landfills at Poplar Hill and at Deer Lake in northern Ontario.

- Developed a national model for use by Transport Canada (the regulatory agency) at airports across Canada to control land-use surrounding airports. The model accounts for aircraft flight patterns, altitudes and risk; bird types, numbers and behavior; types of land-uses and their location in relation to high risk safety zones. Wrote guideline material for use by Transport Canada in controlling hazardous land-uses near Canadian airports.

- Conducted Stage 1 and Stage 2 Safety Analyses in conjunction with the proposed Couchiching First Nation Landfill in northwestern Ontario.

- Assessed bird hazards to aircraft safety at the Bluefields Airport, Nicaragua.

- Project Director for a study of fall staging Snow Geese on the Yukon North Slope during the fall of 2001.

- Project Director for a reconnaissance survey of molting waterfowl along the Yukon coast in summer 2001.

- Assessed potential bird hazards to aircraft safety associated with new landfills proposed for Rankin Inlet and Repulse Bay in Nunavut, Canada

- Project Director for an intensive survey of birds in the Mackenzie River Delta and a reconnaissance level survey along the Mackenzie River Valley south to northern Alberta. The studies were in support of an application to construct a natural gas pipeline up the valley.

- On behalf of the Thunder Bay Airport Authority, conducted a risk assessment of bird hazards to aircraft safety at the airport. The report included recommendations for reducing risks that were mostly associated with birds adjacent to the airport.

- Conducted a bird hazard study and associated risk assessment to serve as the basis for aeronautical zoning around the Pickering Airport site northeast of Toronto. Developed a protocol for determination of acceptable mitigation measures to reduce bird attractions at various land-uses near the airport site.

- Provided an independent review of the bird control program for the Tri-County Landfill for the Pennsylvania Department of Environmental Protection, the landfill regulator in Pennsylvania.

- Project Director for a study of bird-use of Ottawa's main landfill (Trail Road Landfill) and the relation of gulls using the landfill to existing bird hazard problems at the Ottawa International Airport. The landfill was granted approval for its expansion.

- Project Director for a three-year study of land-uses around airports in Canada for Transport Canada. Recommended changes to policies controlling these land-uses and improved methods for control of the bird hazard to aircraft safety issue.

- Continuing Consultant to Canada's Department of National Defence on matters relating to potential bird hazards associated with storm water management ponds on lands near the helicopter base at CFB Edmonton.

- Provided advice on the siting of a landfill near a Royal Australian Air Force Base near Brisbane, Australia.

- Assessed gull use of a landfill near Morris, Illinois including night roosting locations, flight lines, and numbers and species at the landfill. Results were related to aircraft safety issues at a nearby General Aviation airport.

- Provided an independent review of a planned bird control program for the proposed Jefferson County Landfill. The review was for the state regulator, the Pennsylvania Department of Environmental Protection.

- Project Director for an assessment of potential bird hazards to aircraft safety associated with a new landfill near the airport at Fort Severn, Ontario along the coast of Hudson Bay.

- Conducted an assessment of potential habitat for Cooper's and Red-shouldered Hawks on a proposed development site in the New Jersey Pinelands.

- Assessed potential bird hazard to aircraft safety issues associated with the site-selection process for a new landfill on lands of the Kasabonika Lake First Nation in Northern Ontario.

- Evaluated bird hazard to aircraft safety issues related to a proposed new landfill at Sachigo Lake on lands of the Windigo First Nation in Northern Ontario.

- Preliminary assessment of bird control issues at the Cedar Hills Landfill near Seattle, Washington.

- Project Director for an assessment of potential bird hazards to aircraft safety associated with a new landfill at Moosonee, Ontario near the coast of James Bay.

- For the Aerodrome Safety Branch of Transport Canada, conducted a critical review of the efficacy of all known bird hazard control techniques available for use on airports.

- Evaluated potential bird hazards to aircraft safety associated with a proposed waste Transfer Station near Logan International Airport at Boston, MA. Provided expert testimony at regulatory hearings.

- On behalf of the Greater Toronto Airports Authority, conducted a critical review of the existing wildlife control program at a major international airport (Lester B. Pearson International Airport) and recommended changes and improvements to be included in the Terms of Reference for renewal of the program. The review was designed to meet forthcoming changes to the airport certification requirements of Transport Canada.

- Evaluated the efficacy of techniques for excluding deer from airports for the Aerodrome Safety Branch of Transport Canada the agency regulating air safety in Canada.

- Designed and implemented a successful gull control program at the Atlantic County, New Jersey, landfill located about 2 miles from the end of the main runway at Atlantic City International Airport. The program is monitored by LGL Limited and the success is overseen by a committee of representatives from the Federal Aviation Administration, U.S. Air Force, Air National Guard, Atlantic City Airport, U.S. Department of Agriculture, State of New Jersey, ACUA, and LGL Limited. Intensive monitoring continues and the program remains successful in its sixth year (2003).

- Conducted a 15 month baseline study of gull populations in the vicinity of the new Denver International Airport in Colorado and then designed, instituted and monitored a gull control program at a nearby landfill. The control program has been monitored for a period of ten years (to 2003) and continues to be successful.

- Prepared the bird monitoring and management plan mandated by the regulatory agency for the Orchard Hills Landfill near Rockford, Illinois. Subsequently conducted the 3-year monitoring program and two additional years to 2003.

- Prepared two chapters for Transport Canada's Bird Control Handbook. Sharing the Skies published in 2001.

- Assessed the potential bird hazard to aircraft impacts of construction of a thoroughbred race track immediately adjacent to the Calgary International Airport.

- Reviewed the potential effects on marine birds of a possible shipping-related oil spill in Placentia Bay and off southern Newfoundland for the Terra Nova Offshore Development Project. Possible rehabilitation of oiled birds and other methods of mitigation were examined.

- Conducted a preliminary evaluation of potential bird hazards to aircraft safety associated with potential expansions of two landfills in San Diego County, California.

- Documented gull population over a one year cycle and assessed potential bird hazards to aircraft associated with proposed landfill sites in Brown County (Green Bay), Wisconsin.

- Monitored the effectiveness of the bird control program at the Niagara Road 12 Landfill, Grimsby, Ontario.

- Conducted studies of bird hazards to aircraft and bird nuisance issues related to a major regional landfill for the Region of York/Metropolitan Toronto area for the Interim Waste Authority Ltd. Fieldwork included full year studies of gull feeding, nesting and roosting locations and flightlines among them.

- Conducted studies on bird hazards to aircraft and bird disease and nuisance issues associated with the site selection process for a major regional landfill near Toronto International Airport in Peel Region for the Interim Waste Authority Ltd. Fieldwork included full year studies of gull behaviour including flightlines, night roosting, landfill use, and nesting areas.

- Provided advice on the location of a food waste composting facility at CFB Cold Lake, Alberta for National Defence Headquarters.

- Evaluated gull use of a small landfill in the western suburbs of Chicago, IL.

- Designed and monitored a bird control program for the new Rosser Landfill north of the Winnipeg International Airport.

- Reviewed the available information about the large bird populations along the Toronto waterfront and assessed the potential bird hazards associated with an expansion of the Toronto City Centre Airport (formerly called the Toronto Island Airport).

- Evaluated bird hazard to aircraft issues at the City of Harlingen, Texas landfill and recommended gull control measures.

- Conducted a 6-month study of gull and crow numbers, movements and behaviour in the Chatham, Ontario area to determine whether a proposed landfill expansion would jeopardize air safety at the Chatham Airport. Safety was improved by eliminating a substantial gull nesting colony at the existing landfill. LGL subsequently designed a bird control program for implementation at the expanded landfill.

- Designed and implemented a gull control program at a sanitary landfill in Biloxi, Mississippi.

- Assessed potential bird hazard to aircraft issues associated with a new landfill near the Rhinelander Airport in Oneida County, north-central Wisconsin and conducted a one year study of gulls in the area.

- Evaluated potential bird nuisance and health effects associated with the proposed expansion of the Ridge Landfill, Chatham, Ontario.

- On behalf of National Defence Headquarters, provided a critical analysis of an environmental assessment and bird control plan for a landfill off the end of the main runway at CFB Trenton. Provided testimony at subsequent hearings conducted by the Ontario Environmental Assessment Board.

- Participated in the development of a revised bird control plan to allow for the safe operation of Vancouver International Airport after the approximate doubling of its runway capacity.

- Designed a bird control plan for an ash and by-pass landfill near the Huntsville (Alabama) International Airport.

- Advised a large waste management company on possible bird hazards to aircraft problems associated with a potential landfill site in the Atlanta, Georgia region.

- Assessed potential bird hazards to aircraft safety associated with the new Gaza International Airport, Palestine.

- Evaluated potential bird hazards to aircraft associated with a landfill expansion near the Shell Lake Municipal Airport, in northwestern Wisconsin.

- Evaluated potential bird hazards to aircraft associated with a landfill expansion near a small airstrip in southeastern Wisconsin.

- Evaluated potential bird hazards to aircraft safety associated with large concentrations of bald eagles along a salmon spawning river near the Squamish, B.C. Airport.

- Conducted a preliminary survey of gull populations and movements in the Kirkland Lake region of Ontario.

- Directed and conducted the field phase and analysis of LGL's 18 month study of bird populations at the proposed new Toronto International Airport (Pickering) for Canada Ministry of Transport. The study in 1972-73 also involved detailed studies of gull movements and radar assessments of bird hazards to aircraft.

- Conducted a one year study of potential bird hazards to aircraft associated with a landfill expansion near Troy, Wisconsin.

- Evaluated potential bird hazards to aircraft associated with a Wet-Dry Recycling Facility near the Guelph Air Park, devised a bird control plan, and monitored the results during construction and operation of the facility. The project included 3 years of gull baseline and monitoring studies.

- Conducted a study of gull numbers and movements in relation to landfills near the Collingwood Municipal Airport for the Town of Collingwood and provided advice on landfill siting to Simcoe County.

- Conducted an 8 month, and a subsequent 2 month, study of bird hazards to aircraft using the Winnipeg (Manitoba) International Airport. The studies and assessments involved two existing landfills and a proposed new landfill.

- Advised L.B. Pearson International Airport (Toronto) on management of stormwater ponds to minimize bird hazards to aircraft.

- Advised Transport Canada on potential hazards from stormwater ponds proposed near Pearson International Airport in Toronto.

- Assessed the potential bird hazards to aircraft safety associated with several proposed sites for new sewage lagoons at Moosonee, ON, at the south end of James Bay.

- Evaluated the potential bird hazard to aircraft concerns associated with a food waste composting facility located near the Oshawa Airport.

- For Transport Canada, documented the need for bird hazard zoning and recommended the extent of zoning restrictions required on lands surrounding L.B. Pearson International Airport (Toronto).

- Advised on the design, conduct and reporting of LGL's 18-month scientific evaluation of the overhead wire system as an effective measure to control gull use of a landfill site in Niagara Falls.

- Supervised LGL's input to the design (overhead wires) and operation of bird control measures at a new landfill operated by the City of Anchorage near a U.S. Army air base.

- Responsible for the design of an operational bird (gull) control management plan to meet FAA specifications at a landfill site near Niagara Falls International Airport.

- Conducted a one year study of bird hazards to aircraft, bird related health hazards, and agricultural damage caused by gulls at landfills in the Essex-Windsor area and reviewed gull control options.

- Revised manual entitled "Airfield Grounds Management - Reduction of Bird Hazards" for Canada Department of National Defence.

- On behalf of Transport Canada, reviewed proposed bird management plan for a federal conservation area adjacent to Vancouver International Airport.

- Evaluated the effectiveness of the taste aversive ReJeX-iT for reducing gull numbers at Metropolitan Toronto's main landfill.

- Conducted gull studies and assessed potential bird hazards to aircraft associated with the expansion of the Ridge Landfill near the Chatham airport in southwestern Ontario.

- Assessed potential bird hazards to aircraft associated with a golf course development and a recreational club near the Oshawa Airport.

- Assessed gull use of athletic fields at Marquette University in Milwaukee, Wisconsin and recommended methods for excluding the gulls.

- Provided an assessment of potential bird hazards to aircraft associated with potential landfill sites in North Simcoe County.

- Assessed potential bird hazards and bird nuisance concerns related to the proposed landfill in an open pit mine near Kirkland Lake in northern Ontario.

- On behalf of Transport Canada, conducted a study of winter gull numbers and movements in St. John's, Newfoundland and assessed the effects of major movements on the safety of aircraft using the St. John's Airport. A second study examined the situation in the June-September period.

- Evaluated bird hazard to aircraft issues associated with the Fall River, Massachusetts airport and adjacent landfill.

- Conducted a one year monitoring program to determine the numbers, movement patterns, and towering behaviour of gulls near the Grimsby Airpark before the approved new Niagara Road 12 Landfill was constructed.

- Assessed the bird hazard to aircraft implications of the re-opening of the Quinte Landfill off the end of the runway at CFB Trenton.

- Advised Canada Department of National Defence on bird hazard issues related to registered airport zoning regulations around CFB Greenwood and CFB Shearwater in Nova Scotia, CFB Trenton in Ontario, CFB Edmonton (Namao) in Alberta, and CFB Comox in BC.

- Designed a bird control plan for an industrial waste treatment facility (WDRF at Guelph) in Southern Ontario.

- Studied bird hazards to aircraft associated with a landfill in northeastern Illinois.

- On behalf of the Vancouver Airport Authority, reviewed bird hazard to aircraft implications of the proposed Sea Island Conservation Area adjacent to the new runway at the Vancouver (B.C.) International Airport.

- Designed a bird management plan for a landfill that was adjacent to a National Wildlife Refuge in SW Louisiana.

- Provided an independent assessment of potential gull problems associated with a proposed landfill near Hamilton at the west end of Lake Ontario and appeared at Joint Board hearings.

- Evaluated gull control options for the proposed Essex-Windsor Regional Landfill in SW Ontario.

- Designed and monitored the effectiveness of a gull control program at the Foothills Landfill in the foothills near Denver, Colorado.

- Conducted a one year monitoring program of the effectiveness of a gull control program at the Britannia Landfill, near Toronto, Ontario.

- Principal investigator on a literature synthesis to determine bird deterrent methods that would be effective at preventing birds from becoming oiled during an oil spill in the Beaufort Sea.

- Evaluated potential bird hazards to aircraft at a proposed new landfill near the Richmond Airport in Virginia. The study included a one year gull monitoring program.

- Advised on a bird control program for a major new landfill in Halton Region, west of Toronto, Ontario.

- Conducted a full year study to document potential bird hazards to aircraft associated with a landfill expansion near the Rockford, Illinois airport. Presented evidence at the associated regulatory hearings.

- Evaluated bird hazards to aircraft at the LaCrosse (Wisconsin) Municipal Airport.

- Evaluated the relative bird hazards to aircraft at several proposed landfill sites in southern Michigan.

- Assessed potential bird populations at a proposed landfill site near a municipal airport in western Pennsylvania.

- Evaluated bird hazards to aircraft and prepared a gull control plan for a waste transfer station near Atlantic City International Airport.

- Studied gull numbers and movements in relation to a proposed landfill near the Dane County Airport at Madison, Wisconsin and prepared a gull control program for the site.

- Evaluated bird hazards to aircraft at a proposed new regional airport in central Ontario.

- Participated in a one year study of gull populations at an airport used by light aircraft near a major new regional landfill site in Halton Region.

- Developed a bird control program for a landfill near the Jacksonville (Florida) International Airport and provided expert testimony at hearings.

- Participated in LGL's studies of bird hazards to aircraft associated with the proposed expansion of the runway system at Vancouver International Airport.

- Prepared a bird control plan for a proposed major regional landfill site near Toronto's Pearson International Airport and assessed gull movements in the vicinity for the Regional Municipality of Peel.

- Provided technical assessment and expert testimony at hearings regarding a landfill site and waste recovery facility adjacent to the FAA Technical Center airport in Atlantic County, N.J.

- Independent monitor of a one year bird control program at a large regional landfill (Britannia) near Toronto's International Airport.

- Provided technical evaluation of bird hazards to piston-engine aircraft using a small airport near a landfill in the Niagara Peninsula of Ontario and conducted a one year baseline study prior to monitoring the effects of a new landfill.

- Evaluation of the effects of road-building on colonies of Great Blue Herons and design of mitigation measures.

- Senior input to three year program to monitor populations of sea-associated birds in the Alaskan Beaufort Sea and in Kasegaluk Lagoon, Chukchi Sea.

- Evaluated the existing gull populations and movements and bird hazards to aircraft at the Niagara Falls International Airport.

- Documented gull use of areas near a proposed landfill site in Peel Region and gull use of major uncontrolled landfills in the vicinity.

- Coauthor of the reports on a series of studies of the effect of aircraft disturbance on bird populations. Component studies included effects on
    - staging Snow Geese,
    - terrestrial bird populations,
    - nesting waterfowl (Brant, Common Eider, Glaucous Gull, and Arctic Tern),
    - moulting sea ducks, and
    - waterfowl in the Mackenzie Valley.

- Co-author of a series of studies on the effects of a fixed noise source (gas compressor simulator) on bird populations. Component studies addressed effects on staging Snow Geese and on terrestrial breeding birds.

- Evaluated the effect of human disturbance on breeding terrestrial birds on the Yukon North Slope and breeding populations of loons, geese and Herring Gulls for three years in the Hudson Bay lowlands.

- Conducted a four year study of the comparative behaviour and ecology of Arctic and Red-throated Loons in the Hudson Bay lowlands and the Labrador Peninsula.

- Studied the molt migration of Canada Geese.

- Studied the reproductive biology of Canada Geese and Snow Geese.

- Conducted studies of bird populations in the Mackenzie Valley and along the Yukon/Alaska North Slope and Brooks Range for assessment of the 'Mackenzie Valley' gas pipeline and later for the Polar Gas Y-Line.

- Conducted studies of bird populations in the Canadian High Arctic, central Arctic, Keewatin District, northern Manitoba and northwestern Ontario for the proposed Polar Gas Project natural gas pipeline.

- Supervised and coauthored LGL's intensive surveys of seabirds and sea-associated birds (including Thayer's Gull, Glaucous Gull and Black-legged Kittiwake) in Lancaster Sound in 1976 for Norlands Petroleums Ltd.

- Directed LGL's major two year study of marine birds in northern Baffin Bay, Lancaster Sound and Jones Sound for the Eastern Arctic Marine Environmental Study (EAMES) conducted for DIAND and funded by Petro-Canada.

- Conducted studies of bird and mammal populations on Melville Island, N.W.T. and adjacent waters in relation to natural gas production and transportation for the Arctic Pilot Project.

- Supervised the conduct and reporting of the two-year Offshore Labrador Studies (OLABS) of seabirds (including gulls) and marine mammals in the Labrador Sea and northern Newfoundland.

- Studied and collected birds in southern Ontario, northern Ontario, James Bay, Northwest Territories, and British Honduras for the Department of Ornithology, Royal Ontario Museum.

Environmental Impact Assessments

- Participated in environmental assessment of the effects of a multiple ship seismic program in Baffin Bay off the coast Greenland.

- Assessed the potential effects of underwater noise from an offshore LNG Terminal in Florida.

- Provided advice on potential effects on marine mammals (bowheads, narwhals, belugas, and seals) of the year-round marine shipment of iron ore from the proposed Mary River Iron Mine on northern Baffin Island and appeared at two sets of Technical and Regulatory Hearings.

- Senior technical advisor on the potential effects of underwater noise on marine mammals for the Deep Panuke Project off the coast of Nova Scotia. The project will become operational in late 2012.

- Prepared environmental assessments and marine mammal monitoring programs for a seismic exploration program in the Canadian Beaufort Sea in 2006, 2007, and 2008 for submission to the Inuvialuit Environmental Screening Committee and the National Energy Board.

- Project Director for an environmental assessment of the potential acoustic effects of an offshore LNG terminal and related sub-sea pipeline on marine mammals and sea turtles in Massachusetts Bay off Boston.

- Assisted with an environmental assessment of the effects offshore seismic research in Baffin Bay, Davis Strait and Lancaster Sound.

- Project Director for Bird and Marine Mammal sections of an application for offshore exploration drilling in the southern Beaufort Sea. The EIS was prepared for submission to the Inuvialuit Impact Review Board and the Canadian Environmental Assessment Agency (CEAA).

- Presentation on the effects of seismic exploration on marine animals to the Royal Society of Canada Expert Panel examining the implications of lifting the moratorium on offshore oil and gas exploration in British Columbia.

- Provided input on marine mammal and bird issues regarding a lawsuit over offshore drilling rights in the Canadian High Arctic.

- Assisted with the preparation of the Environmental Assessment, and subsequent marine mammal monitoring program, of Marathon Oil's 3-D seismic program that was conducted along the Scotian Shelf in 2003.

- Project Director for the bird portions of the Environmental Assessment of the planned Mackenzie Valley gas pipeline from the Mackenzie River delta to northern Alberta.

- Prepared an Environmental Assessment of the effects of seismic exploration on the marine system off Cape Breton Island in the southern Gulf of St. Lawrence. Provided testimony to hearings of the Public Review Commission created by the Governments of Canada and Nova Scotia. Subsequently prepared an update to the EA and participated on a committee of experts providing a technical review of the scientific issues involved.

- Project Director for a series of studies conducted to determine the environmental feasibility of constructing a large diameter natural gas pipeline under the Beaufort Sea from Prudhoe Bay, Alaska to the Yukon Coast of Canada. The studies wer designed to serve as the basis for regulatory filings with the U.S. Federal Energy Regulatory Commission and the Canada National Energy Board.

- Reviewed the potential effects of seismic exploration on marine animals in the Beaufort Sea for the Canada Department of Fisheries and Oceans.

- Prepared an Environmental Assessment of the drilling of an offshore exploration well at the Emma prospect on the Scotian Shelf for Mobil Oil Canada.

- Prepared the descriptive and effects sections for marine mammals and birds in an EIS for offshore exploration drilling in the southeastern Beaufort Sea.

- Presented a half-day seminar on the state-of-the-art knowledge of the effects of offshore seismic exploration surveys on marine mammals to a group of arctic regulators from the Fisheries Joint Management Committee (Canada/Inuvialuit) and Department of Fisheries and Oceans.

- Prepared an Environmental Assessment of the drilling of an offshore exploration well in the French sector of the St. Pierre Bank south of Newfoundland for Mobil Oil Canada.

- Prepared an Environmental Assessment of the drilling of an offshore exploration well at the Adamant N-97 prospect on the Scotian Shelf for Exxon-Mobil Oil Limited.

- Participated in an environmental assessment of a shallow water seismic exploration program on and adjacent to the sensitive Sable Island offshore of Nova Scotia.

- Project Director for a Class Environmental Assessment of the effects of offshore oil and gas exploration on the marine system of the Scotian Shelf, Laurentian Channel and the St. Pierre Bank off eastern Canada.

- Prepared bird, marine mammals, sea turtle and cumulative effects sections of the EIS for the White Rose offshore development on the Grand Bank for Husky Oil Ltd.

- Prepared an environmental assessment of the potential biological effects of seismic exploration on the marine mammals and fisheries resources of Georges Bank off SW Nova Scotia. Appeared before the review panel considering lifting of the drilling moratorium on the Canadian portion of Georges Bank.

- Project Director for a major Class Environmental Assessment of the effects on marine mammals, birds, fish and sea turtles of underwater noise associated with offshore seismic exploration by the oil and gas industry on the Scotian Shelf along Canada's east coast. The study was prepared for the regulatory agency, the Canada/Nova Scotia Offshore Petroleum Board.

- Prepared analyses of the effects of naval training exercises on marine mammals in the Maritime Forces Pacific Ranges of the Canadian Department of National Defence, as part of an overall environmental assessment of the military training exercises.

- Conducted assessment of the environmental effects of the Terra Nova oil development on birds and marine mammals on the Grand Bank, 300 km offshore of Newfoundland for PetroCanada Inc.

- Conducted an environmental review of the potential effects of seismic exploration off the south coast of Newfoundland for Gulf Canada Resources Inc.

- Prepared an assessment of the probable effects on marine mammals of underwater noise and disturbance associated with the Sable Offshore Energy Project which was designed to bring natural gas and condensates ashore from six offshore production platforms on the Scotian Shelf off eastern Canada. Provided expert testimony before a Joint Board representing the National Energy Board, a Canadian Environmental Assessment Act panel, and the Province of Nova Scotia.

- Project Director for an environmental review of the effects of military activities on the tank and artillery range at ATC Meaford. The project included development of measures for the rehabilitation of important vegetative communities and habitats.

- Conducted an Initial Environmental Evaluation (IEE) for the upgrading and potential expansion of the High Arctic Data Communication System on Ellesmere Island, Devon Island, and Cornwallis Island for Canada Department of National Defence.

- Evaluated impact assessment methodologies for use before the Environmental Impact Review Board.

- Involved with the planning and conduct of the Beaufort Region Environmental Assessment and Monitoring (BREAM) project (1990-93).

- Evaluated the effects of operational discharges from ships in waters under jurisdiction of the Canadian Coast Guard.

- Participated in the Initial Environmental Evaluation of the Arctic Subsurface Surveillance System in the High Arctic for Canada Department of National Defence.

- Prepared Initial Environmental Evaluation of the Northern Fleet operation of the Canadian Coast Guard.

- Reviewed environmental assessment procedures used at a regional airport in Ontario.

- Prepared an assessment of potential wildlife restoration techniques for use in the event of an oil spill in the Beaufort Sea.

- Prepared assessment of the feasibility of instituting environmental regulations for arctic shipping.

- Prepared the Initial Environmental Evaluation (IEE) of the Class 8 icebreaker proposed by the Canadian Coast Guard.

- Technical advisor to the Environmental Impact Review Board (EIRB) reviewing winter offshore oil exploration drilling at Isserk in the coastal Beaufort Sea.

- Technical advisor to the Environmental Impact Review Board evaluating open water offshore drilling in the Beaufort Sea.

- Involved with project engineering design and subsequent preparation of the Environmental Impact Statement and Mitigation Plans for birds and marine systems for the Polar Gas Project. Application submitted to DIAND for referral to National Energy Board and Federal Environmental Review Office.

- Prepared the Environmental Impact Statement for the effects of offshore exploratory drilling in Lancaster Sound on populations of seabirds and marine mammals. Defended the EIS at two federal Environmental Assessment Review Panel (EARP) hearings.

- Prepared the bird, mammal, marine system, and countermeasures sections of an Environmental Impact Statement for offshore exploratory drilling in northern Baffin Bay for Petro-Canada. The EIS was not formally submitted because declining oil prices rendered the proposed drilling program uneconomic.

- Prepared and defended the bird and mammal sections of the Environmental Impact Statements at three EARP hearings and at National Energy Board hearings for the Arctic Pilot Project. This project involved the production and pipeline transport of natural gas in the High Arctic, a liquification plant, year-round transport to Europe and the east coast of North America by icebreaking LNG tankers, and potential gasification terminals in Nova Scotia and Quebec.

- Directed and prepared the bird and marine mammal components of the Environmental Impact Statement for oil and gas production in the Beaufort Sea and transportation by pipeline and/or ship through the Northwest Passage or Bering Strait. Appeared as an expert witness at EARP hearings in Resolute and Inuvik.

- Prepared a report on environmental issues and impacts associated with an updated application for offshore drilling in Lancaster Sound for the Consolidex-Magnorth-Oakwood consortium.

- Prepared marine bird and mammal sections of the EIS for offshore oil production from the Endicott field in the Alaskan Beaufort Sea for the U.S. Army Corps of Engineers.

- Major participant on birds and marine mammals in the Beaufort Environmental Monitoring Project (BEMP) for DIAND (1983-87) and the Beaufort Region Environmental Assessment and Monitoring (BREAM) project (1990-91).

Marine Mammal Studies

- Project Supervisor for studies in support of the Baffinland project. Studies included winter and spring surveys of arctic marine mammals in Hudson Strait and Foxe Basin; open water surveys off north Baffin Island; behavioural studies of narwhal responses to arctic shipping; and the design of complex effects monitoring studies regulatory review.

- Invited Expert to a Special Meeting of the Scientific Committee of the International Whaling Commission on Southern Right Whales.

- Project Director for field studies of marine mammals and birds in the southern Beaufort Sea to support an application under CEAA and the Inuvialuit Impact Review Board for exploration drilling in nearshore marine areas.

- Project Director for a two-month field monitoring study of the effects of nearshore seismic exploration on beluga whales and bowhead whales in the southeastern Beaufort Sea. The study involved aerial and ship-based observations and a program of underwater acoustic measurements.

- Project Director for an acoustical measurement and marine mammal monitoring program for the Canadian Hydrographic Service in the Beaufort Sea.

- Participated in an assessment of the potential effects of underwater noise on northern bottlenose whales and sperm whales occupying the proposed marine protected area of the Gully on the Scotian Shelf, off eastern Canada.

- Project Director for a survey of bowhead and beluga whales off the Yukon coast during summer in 2001.

- Technical expert on marine mammal issues providing input to a GAP Analyses of issues related to offshore exploration for natural gas in the southeastern Beaufort Sea for theEnvironmental Studies Research Funds and offshore exploration and development for the Department of Indian and Northern Affairs Canada (2001-02).

- Participated in an assessment of noise issues related to key whale species in the proposed Gully Marine Protected Area off Nova Scotia for Department of Fisheries and Oceans.

- Project Director for a program to measure the underwater noise from pile-driving associated with installation of oil and gas production platforms in offshore waters of the Scotian Shelf.

- Provision of advice on the design and implementation of programs to monitor the effects of the Sable Offshore Energy Project on marine mammals of the Scotian Shelf.

- Conducted a five month study of the responses of whales to the high speed (75 km/h) ferry that began service on the Bar Harbor, ME, to Yarmouth, NS run in 1998. Monitoring was continued for three months in each of 1999, 2000, 2001 and 2002. Subsequent monitoring continued through 2006.

- Review of the effects of underwater noise associated with the Middle Shoal dredging project, Cape Breton, Nova Scotia.

- Evaluated the potential effects of ice-breaking ore carriers, and associated underwater noise, on the ringed seal populations in the Voisey's Bay region of Labrador. Appeared as a technical expert at the regulatory hearings into the project.

- Preparation of a series of scientific papers on arctic marine mammals (beluga whale, narwhal, and Atlantic walrus) in Canadian High Arctic and Greenland waters in collaboration with Danish scientists and other LGL scientists.

- Member of technical panel advising Canada Department of Fisheries and Oceans on its Arctic Science Program.

- Preparation of an international report on the effects of underwater noise on arctic marine mammals for the Greenland Environmental Research Institute, Government of Denmark.

- Determined responses of bowhead whales to an offshore drilling operation in the Alaskan Beaufort Sea for SWEPI.

- Assessment of underwater noise characteristics of an operating drillship and patterns of bowhead migration at the Hammerhead and Corona drilling sites in Camden Bay, Alaska, for Unocal, SWEPI, and the Alaska Oil and Gas Association.

- Evaluation of the responses of migrating bowhead whales to an active drilling operation at an artificial island (Sandpiper Island) in the Alaskan Beaufort Sea.

- Major study of the reproductive biology of bowhead whales in the summering range in 1985 for ten Alaskan oil companies and three government agencies.

- Evaluation of the potential for offshore drilling from Seal Island to influence fall bowhead migration through nearshore Alaskan waters (1984) for Shell Western E & P Inc.

- Retrospective analyses of the relationships of bowhead distribution and oceanographic and hydrographic features in the Canadian Beaufort Sea from 1980-83 for Environmental Studies Revolving Fund.

- Aerial photography study of bowheads to determine distribution, movements, behaviour and residence times in relation to offshore industrial activities in the Canadian Beaufort Sea (1984) for DIAND, DFO and DSS.

- Chairman of NOAA/OCSEAP workshop on marine mammals and offshore oil exploration in the Chukchi Sea.

- Aerial surveys of bowhead whales and other mammals in the SE Beaufort Sea for ESRF in 1983.

- Length distribution and photographic identification of bowhead whales in the Beaufort Sea for U.S. National Marine Fisheries Service (1982).

- Winter distribution of marine mammals in west Greenland, Baffin Bay and Davis Strait for Arctic Pilot Project (1981-82).

- Birds and marine mammals in the Labrador Sea, Strait of Belle Isle, and NE Newfoundland for OLABS (Petro-Canada operator) (1981-83).

- Bowhead whales in the Beaufort Sea and Amundsen Gulf for a consortium of Canadian and Alaskan oil companies (1981).

- Bowhead whales and ringed seals in the SE Beaufort Sea for Dome Petroleum Ltd. (1980).

- White whales in Hudson Strait and eastern Hudson Bay for Canadian Department of Fisheries and Oceans (1980-81).

- Marine mammals, birds and resource harvesting in Baffin Bay, Jones Sound, Lancaster Sound, Prince Regent Inlet and Gulf of Boothia for Petro-Canada EAMES Project (1978-80).

- Birds and marine mammals in Lancaster Sound for Norlands Petroleums Ltd. (1976).

- Marine mammals and birds in the central and High Arctic (1973-1977) and Victoria Island (1980) for Polar Gas Project; Senior author of a comprehensive review of the status and management of arctic marine mammals for NWT Science Advisory Board, and chairman of an international workshop on management of arctic marine mammals for DFO.

- Member Danish/Canadian Working Group on the Arctic Pilot Project (1980-83).

- Invited expert at Scientific Committee of the International Whaling Commission (1979, 1982, 1983, 1986, 1991) to present papers on the behaviour and status of populations of bowhead whales, narwhals and white whales.

PROFESSIONAL MEMBERSHIPS

American Ornithologists Union (Life Member)
Association of Field Ornithologists
British Ornithologists Union
Colonial Waterbird Society
Society for Marine Mammalogy
The Wildlife Society
Arctic Institute of North America (Life Member)
Neotropical Bird Club
Cooper Ornithological Society (Life Member)
Ontario Field Ornithologists (Life)
Wilson Ornithological Society
Australian Ornithologists Union

REPORTS AND PUBLICATIONS

2014 Davis, R.A. Demonstration of the continued effectiveness of the bird control program at the Forward Landfill, Manteca, California – 2012-2013. Rep. by LGL Limited, King City, ON for Forward Landfill Inc., Manteca, CA. 28 p.

2014 Davis, R.A. Effectiveness of the bird control program at the Winnebago Landfill, Rockford, IL, autumn 2013. Rep. by LGL Limited, King City, ON for Winnebago Reclamation Services, Inc., Rockford, IL. 21 p.

2014 Davis, R.A. Monitoring of potential bird hazards to aircraft associated with the Advanced Disposal Services Orchard Hills Landfill in northern Illinois, autumn 2013. Rep. by LGL Limited, King City, ON for Advanced Disposal Services Orchard Hills Landfill, Inc., Davis Junction, IL. 28 p.

2014 Davis, R.A. and B. Hixon. Night disposal of municipal solid waste at the ACUA Landfill – 192 month report: 15 Dec 1997 to 14 December 2013. Rep. by LGL Limited, King City, ON for Atlantic County Utilities Authority, Egg Harbor Twp., NJ. 164 p.

2013 Davis, R.A. Effectiveness of the bird control program at the Winnebago Landfill, Rockford, IL. autumn 2012. Rep. by LGL Limited, King City, ON for Winnebago Reclamation Services, Inc., Rockford, IL. 19 p.

2013 Davis, R.A. Monitoring of potential bird hazards to aircraft associated with the Advanced Disposal Services Orchard Hills Landfill in northern Illinois, Autumn 2012. Rep. by LGL Limited, King City, ON for Advanced Disposal Services Orchard Hills Landfill, Inc., Davis Junction, IL. 28 p.

2013 Davis, A.R. and R.A. Davis. Wildlife risk assessment and management plan for CFB Trenton Air Base (CYTR). Phase 1: Background and Work Plan. Rep. by LGL Limited. King City, ON for CH2M Hill, Kitchener, ON. 14 p.

2013 Davis, A.R. and R.A. Davis. Wildlife risk assessment and management plan for Mountain View Air Base (CPZ3). Phase 1: Background and Work Plan. Rep. by LGL Limited, King City, ON for CH2M Hill, Kitchener, ON. 14 p.

2013 Lewis, S. and R.A. Davis. Discussion of the compatability of airports and landfills. A White Paper. Prep. By Lewis Engineering and LGL Limited for San Joaquin County on behalf of Forward Landfill Inc.

2012 Davis, R.A. Assessment of the effectiveness of the bird control program at the Forward Landfill, Manteca, CA: 2011-2012. Rep. by LGL Limited, King City, ON for Forward Landfill, Republic Services, Inc., Manteca, CA. 24 p.

2012 Davis, R.A. and T.J. Davis. Long-term monitoring of gull control program at Tower Landfill, Denver, Colorado: May 1992 to 31 December 2010 – An Overview Report. Rep. by LGL Limited, King City, ON for Forward Landfill Inc., Manteca, CA. 18 p.

2012 Davis, R.A. and B. Hixon. Night disposal of municipal solid waste at the ACUA Landfill – 168 month report: 15 Dec 1997 to 14 December 2011. Rep. by LGL Limited, King City, ON for Atlantic County Utilities Authority, Egg Harbor Twp., NJ. 167 p.

2011 Davis, R.A. Effectiveness of the bird control program at the Winnebago Landfill, Rockford, IL. autumn 2010. Rep. by LGL Limited, King City, ON for Winnebago Reclamation Services, Inc., Rockford, IL. 17 p.

2011 Davis, R.A. Assessment of the effectiveness of the bird control program at the Forward Landfill, Manteca, CA: 2010-2011. Rep. by LGL Limited, King City, ON for Forward Landfill, Republic Services, Inc., Manteca, CA. 26 p.

2011 Davis, R.A. Monitoring of potential bird hazards to aircraft associated with the Veolia ES Orchard Hills Landfill in northern Illinois, autumn 2010. Rep. by LGL Limited, King City, ON for Veolia ES Orchard Hills Landfill, Inc., Davis Junction, IL. 25 p.

2011 Davis, R.A. Assessment of potential bird hazards to aircraft safety associated with the proposed PBK Landfill in Rockingham County, North Carolina – A Stage 1 Safety Analysis. Rep. by LGL Limited, King City, ON for Brooks, Pierce, McLendon, Humphrey & Leonard, L.L.C., Greensboro, NC. 64 p.

2011 Davis, R.A. and B. Hixon. Night disposal of municipal solid waste at the ACUA Landfill – 168 month report: 15 Dec 1997 to 14 December 2010. Rep. by LGL Limited, King City, ON for Atlantic County Utilities Authority, Egg Harbor Twp., NJ. 174 p.

2010 Davis, R.A. Effectiveness of the bird control program at the Winnebago Landfill, Rockford, IL. autumn 2009. Rep. by LGL Limited, King City, ON for Winnebago Reclamation Services, Inc., Rockford, IL. 16 p.

2010 Davis, R.A. and B. Hixon. Night disposal of municipal solid waste at the ACUA Landfill – 144 month report: 15 Dec 1997 to 14 December 2009. Rep. by LGL Limited, King City, ON for Atlantic County Utilities Authority, Egg Harbor Twp., NJ. 178 p.

2010 Davis, R.A., A.L. Lang, T.J. Davis, and M. Reid. Implementation and monitoring of a bird control program at the Atascocita Recycling and Disposal Facility, Humble, TX. Rep. by LGL Limited, King City, ON for Waste Management of Texas, Inc., Humble, TX. 15 p.

2010 Davis, R.A. Monitoring of potential bird hazards to aircraft associated with the Veolia ES Orchard Hills Landfill in northern Illinois, autumn 2009. Rep. by LGL Limited, King City, ON for Veolia ES Orchard Hills Landfill, Inc., Davis Junction, IL. 25 p.

2009 Davis, R.A. Effectiveness of the bird control program at the Winnebago Landfill, Rockford, IL. autumn 2008. Rep. by LGL Limited, King City, ON for Winnebago Reclamation Services, Inc., Rockford, IL. 15 p.

2009 Davis, R.A. Assessment of potential bird hazards to aircraft safety associated with proposed sites for a landfill at Arviat, Nunavut – A Stage 1 safety Analysis. Rep. by LGL Limited, King City, ON for Nuna Burnside Engineering and Environmental Ltd., Rankin Inlet, NU. 10 p.

2009 Davis, R.A. Monitoring of potential bird hazards to aircraft associated with the Veolia ES Orchard Hills Landfill in northern Illinois, autumn 2008. Rep. by LGL Limited, King City, ON for Veolia ES Orchard Hills Landfill, Inc., Davis Junction, IL. 25 p.

2009 Harris, R.E., T. Thormin and R.A. Davis. Study of bird populations, and risk assessment of bird hazards to aviation safety, at the Leduc and District regional Landfill, Leduc, Alberta. Rep. by LGL Limited, King City, ON for Leduc and District Regional Waste Management Authority, Leduc, AB. 28 p.

2009 Davis, R.A. and B. Hixon. Night disposal of municipal solid waste at the ACUA Landfill – 132 month report: 15 Dec 1997 to 14 December 2008. Rep. by LGL Limited, King City, ON for Atlantic County Utilities Authority, Egg Harbor Twp., NJ. 175 p.

2008 Moulton, V.D. and R.A. Davis. Whale monitoring aboard *The Cat*, summer 2007. Rep. by LGL Limited, St. John's, NL for Bay Ferries Limited, Charlottetown, PEI. 50 p.

2008 Davis, R.A. Effectiveness of the bird control program at the Winnebago Landfill, Rockford, IL. autumn 2007. Rep. by LGL Limited, King City, ON for Winnebago Reclamation Services, Inc., Rockford, IL. 15 p.

2008 Davis, R.A. Monitoring of potential bird hazards to aircraft associated with the Veolia ES Orchard Hills Landfill in northern Illinois, autumn 2007. Rep. by LGL Limited, King City, ON for Veolia ES Orchard Hills Landfill, Inc., Davis Junction, IL. 18 p.

2008 Davis, R.A. Assessment of the effects of underwater noise from the proposed Port Dolphin Energy LNG Deep Water Port Project. Rep. by LGL Limited, King City, ON for CSA International, Inc., Jupiter, FL. 34 p.

2008 Davis, R.A. and B. Hixon. Night disposal of municipal solid waste at the ACUA Landfill – 120 month report: 15 Dec 1997 to 14 December 2007. Rep. by LGL Limited, King City, ON for Atlantic County Utilities Authority, Egg Harbor Twp., NJ. 151 p.

2007 Davis, R.A. Assessment of bird hazards to aircraft safety associated with the expansion of the Rosewarne Drive Landfill, Ontario. Rep. by LGL Limited, King City, ON for the District Municipality of Muskoka, Bracebridge, ON and Dillon Consulting, Toronto, ON. 16 p.

2007 Davis, R.A. Effectiveness of the bird control program at the Winnebago Landfill, Rockford, IL. autumn 2006. Rep. by LGL Limited, King City, ON for Winnebago Reclamation Services, Inc., Rockford, IL. 15 p.

2007 Davis, R.A. Monitoring of potential bird hazards to aircraft associated with the Veolia Orchard Hills Landfill in northern Illinois, 1006. Rep. by LGL Limited, King City, ON for Veolia Orchard Hills Landfill Inc., Davis Junction, IL. 26 p.

2007 Harris, R.E. and R.A. Davis. An overview of concerns related to birds at sanitary landfill sites. Rep. by LGL Limited, King City, ON for EBA Engineering, Calgary, AB. 5 p.

2007 Harris, R.E., T. Elliott and R.A. Davis. Results of mitigation and monitoring program, Beaufort Span 2-D Seismic Program, open-water season 2006. Rep. by LGL Limited, King City, ON for GX Technology Corporation, Houston, TX. 52p.

2006 Davis, R.A. Implementation of a bird control program at the Winnebago Landfill and an assessment of its effectiveness, including changes to potential bird hazards to aircraft safety at the Greater Rockford, IL., Airport, autumn 2005. Rep. by LGL Limited, King City, ON for Winnebago Reclamation Services, Incl, Rockford, IL. 15 p.

2006 Davis, R.A. Monitoring of potential bird hazards to aircraft associated with the Onyx Orchard Hills Landfill in northern Illinois, 2005. Rep. No. TA 2208-9 by LGL Limited, King City, ON for Onyx Orchard Hills Landfill, Inc., Davis Junction, IL. 25p.

2005 Davis, R.A. and G.W. Miller. Assessment of potential bird hazards to aircraft safety associated with the Pagel Landfill in northern Illinois, November 2003-December 2004. Rep. by LGL Limited, King City, ON for Winnebago Reclamation Service, Inc. c/o The Waste Group, Rockford, IL. 15 p.

2005 Davis, R.A., J. Mangino and B. Hixon. Night disposal of municipal solid waste at the ACUA Landfill - 84 month report: 15 December 1997 to 14 December 2004. Rep. by LGL Limited, King City, ON, for the Atlantic County Utilities Authority, Egg Harbor Twp, NJ. 152 p.

2005 Davis, R.A. and G.W. Miller. Monitoring of potential bird hazards to aircraft associated with the Onyx Orchard Hills Landfill in northern Illinois, 2004. rep. by LGL Limited, King City, ON for Onyx Orchard Hills Landfill, Davis Junction, IL. 25 p.

2004 Behavior and control of Turkey Vultures at landfills in western Pennsylvania. Rep. by LGL Limited, King City, ON for Tri-County Landfill, Inc., Grove City, PA and Youchak and Youchak, Pittsburgh, PA. 14 p.

2004 Lang, A.L. and R.A. Davis. Assessment of potential bird hazards to aircraft safety associated with the proposed new landfill at the Poplar Hill First Nation – a Stage 1 Safety Analysis. Rep. by LGL Limited, King City, ON for Enviromental Management Solutions, Inc., Burlington, ON. 11 p.

2004 Davis, R.A. and A.L. Lang. Pickering Airport Site zoning regulations: mitigation of bird hazards arising from particular land-uses. Rep. by LGL Limited, King City, ON for Aerodrome Safety Branch, Transport Canada, Ottawa, ON. 29 p.

2004 Davis, R.A. and G.W. Miller. Assessment of potential bird hazard to aircraft safety risks associated with the proposed expansion of the Tri-County Landfill near Grove City, PA. Rep. by LGL Limited, King City, ON for Tri-County Landfill, Inc., Grove City, PA and Youchak and Youchak, Pittsburgh, PA. 19 p.

2004 Davis, R.A. and G.W. Miller. Monitoring of potentially hazardous bird populations in relation to the proposed expansion of the Tri-County Landfill near Grove City, Pennsylvania. Rep. by LGL Limited, King City, ON for Tri-County Landfill, Inc., Grove City, PA and Youchak and Youchak, Pittsburgh, PA. 56 p.

2004 Dufault, S. and R.A. Davis. Whale monitoring aboard *The Cat*, summer 2003. rep. by LGL Limited, King City, ON for Bay Ferries Limited, Charlottetown, PEI. 48 p.

2004 Lang, A.L. and R.A. Davis. Bird hazard to aircraft safety assessment associated with the proposed new landfill at the Deer Lake First Nation – a Stage 1 Safety Analysis. Rep. by LGL Limited, King City, ON for Enviromental Management Solutions, Inc., Burlington, ON. 12 p.

2004 Davis, R.A. Bird control plan for the Pagel Landfill, Rockford, IL. Rep. by LGL Limited, King City, ON for The Waste Group, Rockford, IL. 13 p.

2004 Miller, G.W. and R.A. Davis. Assessment of potential bird hazards to aircraft safety associated with the Pagel Landfill in northern Illinois, November 2003-April 2004: an interim report. Rep. by LGL Limited, King City, ON for The Waste Group, Rockford, IL. 14 p.

2004 Davis, R.A. and J. Mangino. Night disposal of municipal solid waste at the ACUA Landfill - 72 month report: 15 December 1997 to 14 December 2003. Rep. by LGL Limited, King City, ON, for the Atlantic County Utilities Authority, Egg Harbor Twp, NJ. 129 p.

2004 Lang, A.L. and R.A. Davis. Assessment of potential bird hazards to aircraft safety associated with the proposed sites for a new landfill at the North Spirit Lake First Nation – a Stage 1 Safety Analysis. Rep. by LGL Limited, King City, ON for Keewatin-Aski Ltd., Sioux Lookout, ON. 12 p.

2003 Davis, R.A., T. Kelly, R. Sowden and B. MacKinnon. Risk-based modeling to develop zoning criteria for land-use near Canadian airports. Paper presented at “Bird Strike 2003”. Bird Strike Committee – USA/Canada 5th Annual Meeting, Toronto, ON. 10 p.

2003 Davis, R.A. and G.W. Miller. Bird control plan for the Atascocita Recycling and disposal facility, Humble, Texas. Rep. by LGL Limited, King City, ON for Waste Management of Texas, Inc., Humble, TX. 15 p.

2003 Davis, R.A. and J. Mangino. Night disposal of municipal solid waste at the ACUA Landfill - 60 month report: 15 December 1997 to 14 December 2002. Rep. by LGL Limited, King City, ON, for the Atlantic County Utilities Authority, Egg Harbor NJ. 125 p.

2003 Lang, A.L and R.A. Davis. Bird hazard to aircraft safety associated with the proposed new landfill at the Couchiching First Nation – a Stage 2 Safety Analysis. Rep. by LGL Limited, King City, ON for Neegan Burnside Engineering and Environmental, Orangeville, ON. 9 p.

2003 Dufault, S. and R.A. Davis. Whale monitoring aboard *The Cat*, summer 2002. Rep. by LGL Limited, King City, ON, for Bay Ferries Limited, Charlottetown, PEI. 60 p.

2003 Miller, G.W. and R.A. Davis. Monitoring of potential bird hazards to aircraft associated with the Onyx Orchard Hills Landfill in northern Illinois, 2002. Rep. by LGL Limited, King City, ON for Onyx Orchard Hills Landfill Inc., Davis Junction, IL. 21 p.

2003 Moulton, V.D., R.A. Davis, J.A. Cook, M. Austin, M.L. Reece, S.A. Martin, A. MacGillvray, D. Hannay and M.W. Fitzgerald. Environmental assessment of Marathon Canada Limited's 3-D seismic program on the Scotian Slope, 2003. Rep. by LGL Limited, St. John's, NL for Marathon Canada Ltd., Halifax, N.S. 198 p.

2003 Davis, R.A. Short-term bird control plan for the Anguilla Landfill located near Henry E. Rohlsen Airport, St. Croix, United States Virgin Islands. Rep. by LGL Limited, King City, ON for Government of Virgin Islands, St. Thomas, VI and U.S. Federal Aviation Administration, Orlando, FL. 6 p.

2003 Davis, R.A. Bird mitigation plan for the Anguilla Landfill located near Henry E. Rohlsen Airport, St. Croix, United States Virgin Islands. Rep. by LGL Limited, King City, ON for Government of Virgin Islands, St. Thomas, VI and U.S. Federal Aviation Administration, Orlando, FL. 14 p.

2003 Lang, A.L., R.E. Harris and R.A. Davis. Bird hazard to aircraft safety assessment associated with the proposed new landfill at the Couchiching First Nation – A Stage 1 Safety Analysis. Rep. by LGL Limited, King City, ON for Neegan Burnside, Orangeville, ON. 10 p.

2002 Koski, W.R., R.A. Davis and K.J. Finley. Distribution and abundance of Canadian High Arctic belugas: 1974-1979. NAMMCO Sci. Publ. 4:87-126.

2002 Davis, R.A. and J. Christian. Supplement to Corridor Resources' environmental assessment of a proposed 2-D seismic program in the southeaster Gulf of St. Lawrence. Rep. by LGL Limited, King City, ON for Corridor Resources Inc., Halifax, NS. 27 p.

2002 Davis, R.A., T.F. Kelly, R.J. Sowden and A.L. Lang. Bird use, bird hazard risk assessment, and design of appropriate bird hazard zoning criteria for lands surrounding the Pickering Airport. Rep. by LGL Limited, King City, ON, Safety Management Systems, Ottawa, ON and Avian Aviation Consultants, Guelph, ON for Transport Canada, Ontario Region, Toronto, ON. 32 p + maps.

2002 Lang, A.L. and R.A. Davis. A study to update information on the avifauna of the Pickering federal lands. Rep. by LGL Limited, King City, ON for Public Works and Government Services Canada and Transport Canada, Ontario Region, Toronto, ON. 51 p.

2002 Davis, R.A. and T.J. Davis. Evaluation of gull control program at Tower Landfill, Denver, Colorado: May 1992 – 31 December 2001. Rep. by LGL Limited, King City, ON for BFI Waste Systems of North America, Inc., Commerce City, CO. 17 p.

2002 Miller, G.W., R.A. Davis, V.D. Moulton, A. Serrano and M. Holst. Integration of monitoring results, 2001. p. 6-1 to 6-23 *In:* G.W. Miller and R.A. Davis (eds.) Marine mammal and acoustical monitoring of Anderson Exploration Ltd's open-water seismic program in the southeastern Beaufort Sea. Final Report by LGL Limited, King City, ON and JASCO Research Ltd., Victoria, B.C. for Anderson Exploration Limited, Calgary, AB. 199 p.

2002 Miller, G.W. and R.A. Davis (eds.). Marine mammal and acoustical monitoring of Anderson Exploration Ltd's open-water seismic program in the southeastern Beaufort Sea. Final Report by LGL Limited, King City, ON and JASCO Research Ltd., Victoria, B.C. for Anderson Exploration Limited, Calgary, AB. 199 p.

2002 Davis, R.A. Discussion of issues related to the presence of a waste transfer station near Dover Air Force Base, Dover, DE. Rep. by LGL Limited, King City, ON for Klett Rooney Lieber and Schorling, Wilmington, DE. 12 p.

2002 Lang, A. and R.A. Davis. Field assessment of bird hazard to aircraft safety issues associated with three proposed landfill sites at the Sachigo Lake First Nation. Rep. by LGL Limited, King City, ON for KGS Group, Winnipeg, MB. 6 p.

2002 Harris, R.E. and R.A. Davis. Assessment of potential bird hazards to aircraft safety associated with the proposed new solid waste site – Rankin Inlet, Nunavut. Rep. by LGL Limited, King City, ON for Dept. Community Government and Transportation, Government of Nunavut, Rankin Inlet, NU. 12 p.

2002 Davis, R.A. Assessment of potential bird hazards to aircraft safety associated with two sites for food waste composting facilities in the vicinity of CFB Trenton. Rep. by LGL Limited, King City, ON for Quinte Waste Solutions, City of Quinte West, ON. 6 p.

2002 Harris, R.E. and R.A. Davis. Assessment of potential bird hazards to aircraft safety associated with the proposed new solid waste site – Repulse Bay, Nunavut. Rep. by LGL Limited, King City, ON for Dept. Community Government and Transportation, Government of Nunavut, Rankin Inlet, NU. 12 p.

2002 Harris, R.E., R.A. Davis and S. Morales. Assessment of bird hazards to aircraft safety at the Bluefields Airport, Nicaragua. Rep. by LGL Limited, King City, ON for Proctor and Redfern International, Markham, ON. 19 p.

2002 Davis, R.A. and J. Mangino. Night disposal of municipal solid waste at the ACUA Landfill - 48 month report: 15 December 1997 to 14 December 2001. Rep. by LGL Limited, King City, ON, for the Atlantic County Utilities Authority, Egg Harbor NJ. 107 p.

2002 Miller, G.W. and R.A. Davis. Monitoring of potential bird hazards to aircraft associated with the Onyx Orchard Hills Landfill in northern Illinois, 2001. Rep. by LGL Limited, King City, ON for Onyx Orchard Hills Landfill Inc., Davis Junction, IL. 22 p.

2002 Lang, A.L. and R.A. Davis. Evaluation of the propsed new Moosonee Landfill in relation to bird hazards to aircraft safety at Moosonee Airport, Northern Ontario. Rep. by LGL Limited, King City, ON, for M.F. Tulloch Inc., Thessalon, ON. 10 p.

2002 Dufault, S. and R.A. Davis. Whale monitoring aboard *The Cat*, summer 2001. Rep. by LGL Limited, King City, ON, for Bay Ferries Limited, Charlottetown, PEI. 67 p.

2002 Harris, R.E., R.A. Davis, B. Di Labio and P.A. Hayes. Bird nuisance/health and aviation impact assessments. [Trail Rd. Landfill, Ottawa, ON.] Rep. by LGL Limited, King City, ON, for the City of Ottawa, ON. 27 p.

2001 Thomson, D.H., R.A. Davis, J. Christian, V.D. Mounton and A. Serrano. Environmental assessment of a proposed 2D Seismic Survey in the southeastern Gulf of St. Lawrence, NS. Rep. by LGL Limited, King City, ON, for Corridor Resources Inc., Halifax, N.S. 79 p.

2001 Davis, R.A. Evaluation of the adequacy of the bird control program for the propsed Tri-County Landfill, Pennsylvania and assessment of resulting bird hazard to aircraft safety issues. Rep. by LGL Limited, King City, ON, for Pennsylvania Department of Environmental Protection, Meadville, PA. 33 p.

2001 Dufault, S. and R.Davis. Whale monitoring aboard *The Cat*, summer 2000. Rep. by LGL Limited, King City, ON, for Bay Ferries Limited, Charlottetown, PEI. 32 p.

2001 Thomson, D.H. and R.A. Davis. Review of the potentisl effects of seismic exploration on marine animals in the Beaufort Sea. Rep. by LGL Limited, King City, ON, for Department of Fisheries and Oceans, Yellowknife, Northwest Territories. 81 p.

2001 Davis, R.A. Assessment of bird hazard to aircraft safety issues associated with the proposed new landfill at the Sachigo Lake First Nation. Rep. by LGL Limited, King City, ON, for the Sachigo Lake First Nation and KGS Group, Winnipeg, MB. 10 p.

2001 Davis, R.A. and J. Mangino. Night disposal of municipal solid waste at the ACUA Landfill—36 month report: 15 December to 14 December 2000. Rep. by LGL Limited, King City, ON, for the Atlantic County Utilities Authority, Egg Harbor, NJ. 94 p.

2001 Miller, G.W. and R.A. Davis. Year 2000 monitoring of potential bird hazards to aircraft associated with the Onyx Orchard Hills Landfill in northern Illinois. Rep. by LGL Limited, King City, ON for Onyx Orchard Hills Landfill Inc., Davis Junction, IL. 24 p.

2001 Davis, R.A. and R.E. Harris. Assessment of habitat suitability for nesting Cooper's Hawks and Red-shouldered Hawks on the proposed Shore Toyota property, Hamilton Township, Atlantic County, New Jersey. Rep. by LGL Limited, King City, ON, for Shore Toyota, Egg Harbor Township, NJ. 10 p.

2001 Miller, G.W., D.H. Thomson and R.A. Davis. Impact assessment of proposed marine seismic program in the southeastern Beaufort Sea, 2001-2002. Rep. by LGL Limited, King City, ON, for IEG Inc., Inuvik, NWT and Calgary, AB. 47 p.

2000 Katona, G.Z., R.A. Davis and G.F. Searing. Evaluation of the efficacy of various deer exclusion devices and deterrent techniques for use at airports. Rep. by LGL Limited, King City, ON, for Aerodrome Safety Branch, Transport Canada, Ottawa, ON. 47 p.

2000 Davis, R.A. and T.J. Davis. Evaluation of gull control program at Tower Landfill, Denver, Colorado, May 1992 – 15 May 1999. A summary overview. Rep. by LGL Limited, King City, ON, for BFI of Colorado, Inc., Commerce City, CO. 25 p.

2000 Davis, R.A. Analysis of bird use of the Environtech Landfill, Morris, Illinois. Rep. by LGL Limited, King City, ON, for Environntech, Inc., Morris, IL. 6 p.

2000 Davis, R.A. Assessment of potential bird hazards to aircraft safety associated with the proposed Resortport Development on lands of the Calgary International Airport. Rep. by LGL Limited, King City, ON, for CANA Management Limited, Calgary, AB. 12 p.

2000 Davis, R.A. Assessment and mitigation of potential bird hazards to aircraft safety associated with the proposed Croatian Club site development adjacent to the Oshawa Airport. Report by LGL Limited, King City, ON, for D.G. Biddle and Associates Ltd., Oshawa, ON. 5 p.

2000 Dufault, S. and R.A. Davis. Whale monitoring aboard *The Cat*, summer 1999. Rep. by LGL Limited, King City, ON, for Bay Ferries Ltd., Charlottetown, PEI. 45 p.

2000 Miller, G.W. and R.A. Davis. 1999 monitoring of potential bird hazards to aircraft associated with the Orchard Hills Landfill in northern Illinois. Rep. by LGL Limited, King City, ON, for BFI Waste Systems of North America Inc., Davis Junction, IL. 24 p.

2000 Thomson, D.H., R.A. Davis, V.D. Moulton, R.E. Harris and P. Roussel. Environmental assessment of exploration drilling at the Adamant N-97 site on Sable Bank, Nova Scotia. Rep. by LGL Limited, King City, ON, and Coastal Oceans Associates, Dartmouth, NS, for the Canada/Nova Scotia Offshore Petroleum Board and Mobil Oil Canada Properties, Halifax, NS. 29 p.

2000 Davis, R.A. and T.J. Davis. Evaluation of gull control program at Tower Landfill, Denver, Colorado, May 1992 - 15 May 1999. Rep. by LGL Limited, King City, ON, for BFI of Colorado, Inc., Commerce City, CO. 25 p.

2000 Moulton, V.D., R.A. Davis, J. Christian, D.H. Thomson and M. MacNeil. Environmental assessment of exploration drilling at the Bandol Site on St. Pierre Bank, France. Rep. by LGL Limited, King City, ON, for IFREMER and Mobil Oil Canada Properties, Paris and Halifax. 32 p.

2000 Davis, R. A. Independent evaluation of the adequacy of the bird control program for the proposed Jefferson Landfill, Pennsylvania. Rep. by LGL Limited, King City, ON, for Pennsylvania Department of Environmental Protection, Meadville, PA. 22 p.

2000 Thomson, D.H., R.A. Davis and V.D. Moulton. Environmental assessment of exploration drillig at the Emma site on Sable Bank, Nova Scotia. Rep. by LGL Limited, King City, ON, for Canada/Nova Scotia Offshore Petroleum Board and Mobil Oil Canada Properties, Halifax, NS. 24 p.

2000 Davis, R.A. and J. Mangino. Research, Development and Demonstration Plan, night disposal of municipal solid waste at the ACUA Landfill—24-month report: 15 December 1997 to 14 December 1999. Rep. by LGL Limited, King City, ON, for the Atlantic County Utilities Authority, Egg Harbor, NJ. 194 p.

2000 Harris, R.E. and R.A. Davis. Evaluation of potential bird hazards to aircraft safety associated with a proposed new sanitary landfill site at Fort Severn, Ontario. Rep. by LGL Limited, King City, ON, for the Fort Severn First Nation, Fort Severn, ON. 10 p.

2000 Lawson, J.W., R.A. Davis, W.J. Richardson and C.I. Malme. Assessment of noise issues relevant to key cetacean species (northern bottlenose and sperm whales) in the Sable Gully area of interest. Rep. by LGL Limited, King City, ON, for OceansAct Coordination Office, Dept. Fisheries and Oceans, Dartmouth, NS. 134 p.

2000 Davis, R.A. Assessment of bird hazard to aircraft safety issues associated with the proposed new landfill on lands of the Kasabonika Lake First Nation. Rep. by LGL Limited, King City, ON, for Feherty and Associates Ltd., Newmarket, ON. 8 p.

1999 Davis, R.A., R.E. Harris and J.R. Nisbet. Wildlife control study, Lester B. Pearson International Airport. Rep. by LGL Limited, King City, ON, for the Greater Toronto Airports Authority, Toronto, ON. 52 p.

1999 Thomson, D.H., R.A. Davis, R. Bellore, E. Gonzalez, J. Christian, V. Moulton and R.E. Harris. Environmental assessment of exploration drilling off Nova Scotia. Rep. by LGL Limited, King City, ON, for the Canada-Nova Scotia Offshore Petroleum Board and Mobil Oil Canada Properties Ltd. (on behalf of 7 oil companies). 376 p.

1999 Mactavish, B. and R.A. Davis. Gull numbers and behaviour at the Robin Hood Bay Landfill, St. John's, NF, for the City of St. John's, NF. 10 p.

1999 Davis, R.A. and J. Mangino. Research, development and demonstration plan. Disposal of municipal solid waste at the ACUA Landfill, Full Year Report – 15 December 1997 to 14 December 1998. Rep. by LGL Limited, King City, ON, for the Atlantic County Utilities Authority, Egg Harbor Township, NJ. 116 p.

1999 Miller, G.W. and R.A. Davis. 1998 monitoring of potential bird hazards to aircraft associated with the Orchard Hills Landfill in northern Illinois. Rep. by LGL Limited, King City, ON, for BFI Waste Systems of North America Inc., Davis Junction, IL. 21 p.

1999 Davis, R.A. and D.H. Thomson. Review of potential effects of seismic exploration on Georges Bank. Rep. by LGL Limited, King City, ON, for Chevron Canada Resources and Texaco Canada Petroleum, Inc. 38 p.

1999 Davis, R.A. and R.E. Harris. Bird control plan for the Ridge Landfill, Blenheim, ON. Rep. by LGL Limited, King City, ON, for Browning-Ferris Industries Ltd., Blenheim, ON. 11 p.

1999 Dufault, S. and R.A. Davis. Whale monitoring aboard *The Cat*, final report 1998. Rep. by LGL Limited, King City, ON, for Bay Ferries Limited, Charlottetown, PEI. 26 p.

1998 Christian, J.R., R.A. Buchanan, B.D. Mactavish, D.H. Thomson and R.A. Davis. Biological setting and potential effects of geophysical surveys, offshore St. Pierre and Miquelon and southern Newfoundland. Rep. by LGL Limited, St. John's, NF, for Gulf Canada Resources Ltd., Calgary, AB. 24 p.

1998 Davis, R.A., D.H. Thomson and C.I. Malme. Environmental assessment of seismic exploration on the Scotian Shelf. Rep. by LGL Limited for Canada/Nova Scotia Offshore Petroleum Board, Halifax, NS. 331 p.

1998 Davis, R.A. Assessment of potential bird hazards to aircraft safety associated with the proposed expansion of the Orchard Hills Landfill in northern Illinois. Rep. by LGL Limited, King City, ON, for BFI Waste Systems of North America, Inc., Davis Junction, IL. 74 p.

1998 Malme, C.I., C.R. Greene, Jr. and R.A. Davis. Comparison of radiated noise from pile-driving operations with predictions using the RAM model. Rep. by LGL Limited, King City, ON, for the Sable Offshore Energy Project, Halifax, NS. 10 p.

1998 Harris, R.E. and R.A. Davis. Evaluation of the efficacy of products and techniques for airport bird control. Rep. by LGL Limited, King City, ON for Aerodrome Safety Branch, Transport Canada, Ottawa, ON. 104 p.

1998 Miller, G.W., R.E. Harris, R.A. Davis and C.J. Agnew. Evaluation of bird hazards to aviation in relation to construction and operation of the City of Guelph's Wet-Dry Recycling Centre. Rep. by LGL Limited, King City, ON for the City of Guelph, ON. 75 p.

1997 Davis, R.A. Potential effects on marine mammals of underwater noise from the Sable Offshore Energy Project. Rep. by LGL Limited, King City, ON, for CEF Consultants Limited, Halifax, NS. 21 p.

1997 Davis, R.A. and C.I. Malme. Potential effects on ringed seals of icebreaking ore carriers associated with the Voisey's Bay Nickel Project. Rep. by LGL Limited, King City, ON, for Voisey's Bay Nickel Company, St. John's, NF. 34 p.

1997 Davis, R.A. Review of the effects of underwater noise associated with the Middle Shoal dredging project, Cape Breton, Nova Scotia. Rep. by LGL Limited, King City, ON, for CEF Consultants Limited, Halifax, NS.

1997 Harris, R.E. and R.A. Davis. Marine birds and potential oil spills in the Placentia Bay area, Newfoundland: An initial overview. Rep. by LGL Limited, St. John's, NF, for Terra Nova Development Project, Petro-Canada, Calgary, AB. 18 p.

1997 Davis, R.A. Assessment of background numbers of birds at the Atlantic County, NJ, "Haneman Environmental Park". Rep. by LGL Limited, King City, ON, for Atlantic County Utilities Authority, Egg Harbour Township, NJ. 24 p.

1997 Davis, R.A. Numbers, movements and behaviour of gulls using the Robin Hood Bay waste disposal site: relationship to aircraft safety at the St. John's Airport, Newfoundland - Executive Summary. Rep. by LGL Limited, King City, ON, for Aerodrome Safety Branch, Transport Canada, Ottawa, ON. 16 p.

1997 Davis, R.A., J. Selnø and R.E. Harris. Numbers, movements and behaviour of gulls using the Robin Hood Bay waste disposal site and St. John's Airport, NF - 26 June to 6 October 1996. Rep. by LGL Limited, King City, ON, for Aerodrome Safety Branch, Transport Canada, Ottawa, ON. 45 p.

1997 Harris, R.E. and R.A. Davis. Study of bird hazards to aircraft safety related to waste disposal facilities near the Oshawa Airport. Rep. by LGL Limited, King City, ON, for the Margaree Group, Ajax, ON. 77 p.

1997 Davis, R.A. Bird monitoring plan and contingent bird management plan for the Orchard Hills Landfill. Rep. by LGL Limited, King City, ON, for BFI of Illinois, Inc., Davis Junction, 12. 7 p.

1997 Miller, G.W. and R.A. Davis. Evaluation of the effectiveness of the bird control program at the new Niagara Road 12 Landfill, autumn 1996. Rep. by LGL Limited, King City, ON, for Joint Board of Management, Town of Grimsby, ON. 19 p.

1996 Davis, R.A. and R.E. Harris. Assessment of potential bird hazards to aircraft safety associated with expansion of the Toronto City Centre Airport related to the proposed Fixed Link. Rep. by LGL Limited, King City, ON, for M.M. Dillon Limited, Toronto, ON. 18 p.

1996 Searing, G.F., R.A. Davis and M.W. Demarchi. The wildlife control program at the Vancouver International Airport. Report by LGL Limited, Sidney, BC, for the Vancouver International Airport Authority, Richmond, BC. 42 p.

1996 Davis, R.A. and R.E. Harris. Potential bird hazards to aircraft safety associated with the proposed expansion of the Ridge Landfill, Chatham, ON. Rep. by LGL Limited, King City, ON, for Browning-Ferris Industries Ltd., Etobicoke, ON. 52 p.

1996 Harris, R.E. and R.A. Davis. Evaluation of potential bird nuisance and health effects associated with the proposed expansion of the Ridge Landfill, Chatham, ON. Rep. by LGL Limited, King City, ON, for Browning-Ferris Industries Ltd., Etobicoke, ON. 16 p.

1996 Miller, G.W. and R.A. Davis. Numbers, distribution and behaviour of gulls migrating through the Winnipeg area during Spring 1996. Rep. by LGL Limited, King City, ON, for BFI Waste Systems, Inc., Winnipeg, MB. 32 p.

1996 Davis, R.A. Bird hazards to aircraft safety issues in the environmental assessment of the Aikens Road/Quinte Sanitation Landfill site. Rep. by LGL Limited, King City, ON, for Canada National Defence Headquarters, Ottawa, ON. 10 p.

1996 Davis, R.A. Environmental assessment of potential bird hazards to aircraft safety associated with the new Gaza International Airport. Rep. by LGL Limited, King City, ON, for Marshall Macklin & Monaghan Limited, Toronto, ON. 18 p.

1996 Davis, R.A. Preliminary assessment of populations of gulls and other species in the Kirkland Lake area and the vicinity of the Adams Mine. Rep. by LGL Limited, King City, ON, for Notre Development Corporation, North Bay, ON. 10 p.

1996 Davis, R.A. and G.W. Miller. Evaluation of potential bird hazards to aircraft associated with the proposed Rosser Landfill north of Winnipeg International Airport. Rep by LGL Limited, King City, ON for BFI Waste Systems Inc., Central Canada Division, Winnipeg, MB. 67 p.

1996 Davis, R.A. and P.A. Hayes. Analysis of bird hazard zoning requirements around Lester B. Pearson International Airport, Toronto, ON. Rep. by LGL Limited and Aerocan Aviation Specialists Inc. for L.B. Pearson International Airport, Toronto, ON. 24 p.

1996 Davis, R.A. and P.A. Hayes. Potential bird hazards to aircraft associated with stormwater management ponds at Lester B. Pearson International Airport, Toronto, ON. Rep. by LGL Limited, and Aerocan Aviation Specialists Inc., for L.B. Pearson International Airport, Toronto, ON. 5 p.

1995 Davis, R.A. and B. Mactavish. Gulls associated with the St. John's Airport and the Robin Hood Bay Waste Disposal Site, Newfoundland. Rep. by LGL Limited, St. John's, NF, to Transport Canada, Ottawa. 44 p.

1995 Davis, R.A. Bird control management plan for the City of Guelph's Wet/Dry Recycling Facility adjacent to the Guelph Air Park. Rep. by LGL Limited, King City, ON, for the City of Guelph, ON. 41 p.

1995 Davis, R.A. and R.E. Harris. Studies of the numbers and movements of gulls with respect to potential bird hazards to aircraft safety associated with a proposed landfill near the Collingwood Municipal Airport. Rep. by LGL Limited, King City, ON for the Town of Collingwood, ON. 46 p.

1995 Davis, R.A. Update to assessment of potential bird hazards to aircraft associated with the proposed expansion of the BFI Landfill in Davis Junction, Illinois. Rep. by LGL Limited, King City, ON for BFI of Illinois, Inc., Davis Junction, IL. 5 p.

1995 Davis, T.J. and R.A. Davis. Numbers of waterbirds associated with the newly-constructed mitigation wetland, west of the new Denver International Airport. Rep. by LGL Limited, King City, ON for Denver International Airport, Denver, CO. 17 p.

1995 Davis, R.A. and G.W. Miller. Bird hazard to aircraft safety issues associated with the proposed Rosser Landfill - late April to early September 1995 - An Interim Report. Rep. by LGL Limited, King City, ON to BFI Waste Systems, Inc., Winnipeg, MB. 18 p.

1995 Davis, R.A. Assessment and mitigation of potential bird hazards to aircraft associated with the proposed Coffee Time Donuts restaurant adjacent to Oshawa Airport. Rep. by LGL Limited, King City, ON for D.G. Biddle and Associates Ltd., Oshawa, ON. 4 p.

1995 Davis, R.A. Evaluation of potential bird hazards to aircraft using CFB Shearwater associated with the siting of Front End Processing and Stabilization Facilities in the Halifax region. Rep. by LGL Limited, King City, ON for National Defence HQ, Dept. of National Defence, Ottawa, ON. 6 p.

1995 Richardson, W.J., K.J. Finley, G.W. Miller, R.A. Davis and W.R. Koski. Feeding, social and migration behavior of bowhead whales, *Balaena mysticetus*, in Baffin Bay vs. the Beaufort Sea regions with different amounts of human activity. Marine Mammal Science 11:1-45.

1995 Davis, R.A. and T.J. Davis. Successful gull control at a Colorado landfill. Abstract. Paper presented 5th Meeting, Bird Strike Committee-U.S.A. Dallas, TX.

1995 Miller, G.W. and R.A. Davis. Baseline studies of the numbers and behaviour of gulls in the vicinity of the new Niagara Road 12 Landfill and the need for bird control. Rep. by LGL Limited, King City, ON for Town of Grimsby, ON. 65 p.

1995 Davis, R.A., T.J. Davis and R.E. Harris. Evaluation of the taste aversive, ReJeX-iT for controlling numbers of gulls at the Keele Valley Landfill, a major regional landfill. Rep. by LGL Limited, King City, ON for the Metropolitan Toronto Dept. of Public Works, Maple, ON. 7 p.

1995 Davis, R.A. and G.W. Miller. Initial evaluation of potential bird hazards to aircraft associated with a proposed landfill north of Winnipeg International Airport. Rep. by LGL Limited, King City, ON for BFI Waste Systems Inc., Winnipeg, MB. 28 p.

1995 Davis, R.A. and P.A. Hayes. Analysis of bird hazard zoning around heliports at Canadian Forces Base, Edmonton/Namao, Alberta and Canadian Forces Base Shearwater, NS. Rep. by LGL Limited and Aerocan Aviation Specialists Inc. for Canada Dept. of National Defence, Ottawa, ON. 6 p.

1995 Searing, G.F. and R.A. Davis. A review of the Sea Island Conservation Area management plan from a bird hazard to aircraft perspective. Rep. by LGL Limited, Sidney, BC for Transport Canada, Ottawa, ON. 10 p.

1995 Davis, R.A. and R.E. Harris. Initial evaluation of bird hazards to aircraft associated with a sanitary landfill in Fall River, Massachusetts. Rep. by LGL Limited, King City, ON for Browning-Ferris Industries, Inc., Fall River, MA. 8 p.

1995 Davis, R.A. Evaluation of potential bird hazards to aircraft associated with a proposed golf facility adjacent to the Oshawa Airport. Rep. by LGL Limited, King City, ON for The Greer Galloway Group, Courtice, ON. 4 p.

1995 Davis, R.A. Assessment of gull problems and recommendations for gull control at Marquette University, Milwaukee, Wisconsin. Rep. by LGL Limited, King City, ON for MK Associates, LaGrange, IL and Marquette University, Milwaukee, WI. 5 p.

1994 Davis, R.A. Review of bird hazard to aircraft safety issues related to the re-opening of the Quinte Landfill near CFB Trenton, ON. Rep. by LGL Limited, King City, ON for Canada Department of National Defense, Astra, ON. 7 p.

1994 Davis, R.A. and T.J. Davis. Studies of the numbers and behavior of gulls, and the effectiveness of a gull control program at Tower Landfill, near Denver, Colorado. Rep. by LGL Limited, King City, ON for BFI of Colorado, Inc., Commerce City, CO. 156 p.

1994 Davis, R.A. and G.W. Miller. Assessment of potential bird hazards to aircraft associated with the proposed expansion of the Ogle County (Illinois) Landfill. Rep. by LGL Limited, King City, ON for Browning-Ferris Industries of Illinois, Inc., Davis Junction, IL. 45 p.

1994 Davis, R.A. Technical review, gull hazard reduction program, John F. Kennedy International Airport, Draft Environmental Impact Statement. Rep. by LGL Limited, King City, ON for Browning-Ferris Industries, Inc., Washington, D.C. 5 p.

1994 Miller, G.W. and R.A. Davis. Assessment of potential bird hazards to aircraft associated with the proposed expansion of the Troy Area Landfill in SE Wisconsin. Rep. by LGL Limited, King City, ON for Troy Area Landfill, Inc., East Troy, WI. 45 p.

1994 Koski, W.R. and R.A. Davis. Distribution and numbers of narwhals in Baffin Bay and Davis Strait. Meddelelser om Grønland Bioscience 39:15-40. Copenhagen.

1994 Miller, G.A. and R.A. Davis. Assessment of potential hazards to aircraft associated with the proposed relocation of the Oneida County (Wisconsin) Landfill. Rep. by LGL Limited, King City, ON for Planning and Zoning Committee, Oneida County, WI. 42 p.

1994 Miller, G.W. and R.A. Davis. Gull populations in the Regional Municipality of Peel, ON, 1992-93. Rep. by LGL Limited, King City, ON for the Interim Waste Authority Ltd., Toronto, ON. 60 p.

1994 Searing, G.F. and R.A. Davis. A review of the bird hazards to aircraft concerns at Vancouver International Airport from implementation of the Sea Island Conservation Area Management Plan. Rep. by LGL Limited, Sidney, BC for the Vancouver International Airport Authority, Richmond, BC. 15 p.

1994 Harris, R.E. and R.A. Davis. Gull populations in Metropolitan Toronto and the Regional Municipality of York, ON, August 1992-December 1993. Rep. by LGL Limited, King City, ON for the Interim Waste Authority, Toronto, ON. 109 p.

1994 Born, E.W., M.P. Heide-Jørgensen and R.A. Davis. The Atlantic walrus (*Odobenus rosmarus rosmarus*) in West Greenland. Meddelelser om Grønland, Bioscience 40:3-33.

1993 Davis, R.A. Present situation and work plan for gull monitoring and control at the landfill in the City of Harlingen, TX. LGL Rep. No. TA 2034-1 for City of Harlingen, TX. 10 p.

1993 Davis, R.A. Bird control plan for Tower Road Landfill, Commerce City, Colorado. Rep. by LGL Limited, King City, ON, for BFI of Colorado, Inc., Commerce City, CO. 7 p.

1993 Davis, R.A., R.E. Harris, J.R. Nisbet and L. Hellas. Potential nuisance and health issues associated with birds attracted to proposed IWA Landfill Sites in the Greater Toronto Area. Rep. by LGL Limited and Bird and Hale Limited for Interim Waste Authority, Toronto, ON. 37 p.

1993 Heide-Jørgensen, M.P., H. Lassen, J. Teilmann and R.A. Davis. An index of relative abundance of wintering belugas (*Delphinapterus leucas*) and narwhals (*Monodon monoceros*) off West Greenland. Can. J. Fish. Aquat. Sci. 50:2323-2335.

1993 Miller, G.W. and R.A. Davis. Assessment of the 1992-93 gull control program at Britannia Sanitary Landfill, Peel Region. Rep. by LGL Limited, King City, ON for Regional Municipality of Peel, Mississauga, ON. 23 p.

1993 Koski, W.R., R.A. Davis, G.W. Miller and D.E. Withrow. Reproduction. p. 239-274 *In*: J.J. Burns, J.J. Montague and C.J. Cowles (eds.), The bowhead whale. Spec. Publ. No. 2, Society for Marine Mammalogy, Lawrence, KS. 787 p.

1993 Davis, R.A. Petit Bois Landfill bird management plan to protect National Wildlife Mini-Refuge, Calcasieu Parish, Lousiana. LGL Limited Rep. No. TA 2030 for Browning-Ferris Industries of Lousiana, Inc., Sulphur, LA. 19 p.

1993 Davis, R.A. and T.J. Davis. Design and evaluation of the gull control program at the RPS Landfill, Colorado. LGL Rep. No. TA 2004-1, King City, ON, for BFI Waste Systems of Colorado, Inc., Commerce City, CO. 14 p.

1993 Davis, R.A. Baling of waste at Essex-Windsor Regional Landfill: potential effects on gull numbers and gull control methods and costs. LGL Ltd. Rep. No. TA 2020-3 for Essex-Windsor Waste Management Committee, Essex, ON. 5 p.

1993 Davis, R.A. Independent review of potential gull problems associated with the proposed South Quarry Landfill, Hamilton-Wentworth. Rep. by LGL Limited, King City, for Steetley Quarry Products, Inc., Hamilton, ON. 31 p.

1993 Davis, R.A. Bird control options for the proposed Essex-Windsor Regional Landfill. LGL Ltd. Rep. No. TA 2020-2, King City, for Essex-Windsor Waste Management Committee, Essex, ON. 10 p.

1993 Davis, R.A. Evaluation of environmental assessment methods for use before the Environmental Impact Review Board. Rep. by LGL Limited, King City, ON, for Environmental Impact Review Board, Inuvik, N.W.T. 20 p.

1993 Davis, R.A. Bird control program and issues for the proposed ash monofill at the Wall Street Site, Limestone County, Alabama. Rep. by LGL Limited, King City, ON, for the Solid Waste Disposal Authority, Huntsville, AL. 17 p.

1993 Davis, R.A. Evaluation of air safety issues associated with the expansion of the Mallard Ridge Recycling and Disposal Facility, WI. Rep. by LGL Ltd., King City, ON, for Waste Management of Wisconsin, Inc., Delavan, WI. 37 p.

1993 Davis, R.A. Review of environmental aspects of Hunstville International Airport Landfill Impact Study. Rep. by LGL Ltd., King City, ON, for Solid Waste Disposal Authority, City of Hunstville, Alabama. 9 p.

1993 Davis, R.A. Evaluation of potential bird hazards to aircraft associated with a landfill expansion near Shell Lake, Wisconsin. Rep. by LGL Ltd., King City, ON., for Lake Area Disposal Landfill Inc., Rice Lake, WI. 17 p.

1993 Davis, R.A. and G.W. Miller. Proposed Essex-Windsor Regional Landfill Site, Site-specific Investigations - Evaluation of bird use of the site, related bird hazards to aircraft, and potential bird problems. Rep. by LGL Ltd., King City, ON, for Proctor and Redfern Ltd. 65 p.

1993 Miller, G.W. and R.A. Davis. Potential bird hazards to aircraft associated with proposed new landfill sites for Brown County, Wisconsin. Rep. by LGL Ltd., King City, ON, for Robert E. Lee and Associates, Green Bay, Wisconsin. 68 p.

1992 Davis, R.A. Evaluation of the effects of an artificial cover material (Fabrisoil) on the numbers of gulls using a sanitary landfill in Essex County, ON. Rep. by LGL Limited, King City, Ont. for Proctor and Redfern Ltd., Windsor, Ont. 4 p.

1992 Miller, G.W. and R.A. Davis. Gull distribution and numbers near the proposed Niagara Road 12 landfill, November 1991-July 1992, and an assessment of potential nuisance concerns. Rep. by LGL Limited, King City, Ont. for Proctor and Redfern Ltd., Hamilton, Ont. 17 p.

1992 Heide-Jorgensen, M.P., H. Lassen, J. Teilmann and R.A. Davis. An index of the relative abundance of wintering belugas, *Delphinapterus leucas*, off West Greenland. Working Paper. Scientific Working Group, Joint Commission on the Conservation and Management of Narwhal and Beluga. Iqaluit, N.W.T. 36 p.

1992 Thomson, D.H., R.A. Davis and S.R. Johnson. Ecological issues related to a marine transportation system servicing Coronation Gulf, N.W.T. Rep. by LGL Limited, King City, Ont. for Canarctic Shipping Company Ltd., Ottawa, Ont. 126 p.

1992 Miller, G.W., R.A. Davis, W.R. Koski, M.J. Crone, D.J. Rugh, D.E. Withrow and M.A. Fraker. Calving intervals of bowhead whales-an analysis of photographic data. Rep. Int. Whal. Comm. 42:501-506.

1992 Koski, W.R., R.A. Davis, G.W. Miller and D.E. Withrow. Growth rates of bowhead whales as determined from low-level aerial photogrammetry. Rep. Int. Whal. Comm. 42:491-499.

1992 Raftery, A. and R.A. Davis. Bowhead whale calving intervals. Appendix 2, Report of the Bowhead Whale Assessment Meeting, Scientific Committee, International Whaling Commission, Reykjavik, Iceland. May 1991. Rep. Int. Whal. Comm. 42:153.

1992 Davis, R.A. Bird control program for the proposed Solid Waste Disposal Authority landfill, City of Huntsville, Limestone County, Alabama. Rep. by LGL Limited, King City, ON, for Solid Waste Disposal Authority, Huntsville, Alabama. 42 p.

1992 Davis, R.A. Bird control program and documentation for the Gulf Pines Landfill, Biloxi, Mississippi. Rep. by LGL Limited, King City, ON, for Browning-Ferris Industries of Mississippi, Inc., Biloxi, MS. 16 p.

1992 Miller, G.W. and R.A. Davis. Spring studies of gull distribution and numbers in Dane County, Wisconsin, 1992. Rep. by LGL Limited, King City, ON, for Browning-Ferris Industries of Wisconsin, Inc., Madison, WI. 20 p.

1992 Davis, R.A. Evaluation of potential bird hazards to aircraft safety associated with the City of Guelph's proposed wet/dry recycling facility adjacent to the Guelph Air Park. Rep. by LGL Ltd., for the City of Guelph, ON. 23 p.

1992 Miller, G.W. and R.A. Davis. Evaluation of bird use of the Maidstone sanitary landfill site (Landfill Site No. 3) and related bird hazards to aircraft and other potential bird problems. Rep. by LGL Limited for Proctor and Redfern Ltd., Windsor, ON. 27 p.

1991 Harris, R.E., G.B. Cameron and R.A. Davis. Report on surveys for Great Blue Heron Nesting Colonies and other wildlife species and habitats of concern for the proposed Steeles Avenue East widening project. Rep. by LGL Limited, King City, for Totten Sims Hubicki Associates Ltd., Whitby, ON. 24 p.

1991 Davis, R.A. Review of gull movements in relation to the County Landfill and Municipal Airport at LaCrosse, Wisconsin. Rep. by LGL Limited, King City, ON for Browning-Ferris Industries of Wisconsin, Inc., Sun Prairie, WI. 9 p.

1991 Davis, R.A. Early autumn studies of gull numbers and movements in Dane County, Wisconsin, 1991. Rep. by LGL Ltd., King City, ON for Browning-Ferris Ind. of Wisconsin, Sun Prairie, WI. 19 p.

1991 Davis, R.A. Gull control program for the Madison Prairie Landfill in Wisconsin. Rep. by LGL Limited, King City, ON for Browning-Ferris Industries of Wisconsin, Inc., Sun Prairie, WI. 44 p.

1991 Davis, R.A. Plan to control gulls at the Cardiff Transfer Station, Atlantic County, New Jersey. Rep by LGL Limited, King City, ON to Chambers Waste Systems of NJ, Inc., Pleasantville, NJ. 17 p.

1991 Davis, R.A., W.J. Richardson, L. Thiele, R. Dietz and P. Johnson. Report on underwater noise. p. 154-269 *In*: The State of the Arctic Environment. University of Lapland, Arctic Centre Publication No. 2, Rovaniemi, Finland. 405 p.

1991 Miller, G.W., R.A. Davis, W.R. Koski, M.J. Crone, D.J. Rugh and M.A. Fraker. Calving intervals of bowhead whales--a preliminary analysis. Paper SC/43/PS27 presented to Scientific Committee, International Whaling Commission, Reykjavik, Iceland. May 1991. 13 p.

1991 Davis, R.A. and G.W. Miller. Bird hazards to aircraft associated with the proposed Madison Prairie Sanitary landfill near Madison, Wisconsin. Rep. by LGL Limited, King City, ON for Browning-Ferris Industries, Inc., Sun Prairie, WI. 35 p.

1991 Davis, R.A. and M.G. Foy. Analysis of the Initial Environmental Evaluation for the Oro-Barrie-Orillia airport. Rep. by LGL Limited, King City, ON, for the Central Oro Ratepayer's Association, Oro Station, ON. 15 p.

1991 Miller, G.W., R.A. Davis and W.J. Richardson. Behavior of bowhead whales of the Davis Strait and Bering/Beaufort Stocks vs. regional differences in human activities. Rep. by LGL Limited, King City, ON, for U.S. Minerals Manage. Serv., Herndon, VA. OCS Study MMS 91-0029. 121 p.

1991 Thomson, D.H., R.A. Davis and T. Hillis. Effects of operational discharges from ships on marine life. Rep. by LGL Limited, King City, ON, for Canadian Coast Guard, Ottawa, Ont. 30 p.

1991 Davis, R.A. and G.W. Miller. Evaluation of gull populations expected to use the proposed Niagara Road 12 Landfill and potential hazards to aircraft using Grimsby Airpark. Rep. by LGL Ltd., King City, ON to Proctor and Redfern Ltd., Hamilton, ON. 24 p.

1991 Cross, W.E., T.L. Hillis and R.A. Davis. Wildlife and habitat restoration in the event of an oil spill in the Beaufort Sea. Rep. by LGL Ltd., King City, ON for the Beaufort Sea Steering Committee, Hull, PQ. 32 p.

1990 Finley, K.J., G.W. Miller, R.A. Davis and C.R. Greene. Reactions of belugas, *Delphinapterus leucas*, and narwhals, *Monodon monoceros*, to ice-breaking ships in the Canadian High Arctic. p. 97-117 *In*: T.G. Smith, D.J. St. Aubin and J.R. Geraci (eds.), Advances in research on the beluga whale, *Delphinapterus leucas*. Can. Bull. Fish. Aquat. Sci. 224.

1990 Miller, G.W. and R.A. Davis. Independent monitoring of the 1990 gull control program at Britannia Sanitary Landfill Site. Rep. by LGL Limited, King City, ON for Regional Municipality of Peel, Mississauga, ON. 16 p.

1990 Davis, R.A. Gull control at Brampton Landfill Site VIB. Rep. by LGL Limited, King City, ON for Regional Municipality of Peel, Brampton, ON. 57 p.

1990 Davis, R.A. and M.G. Foy. A review of the environmental assessment of the Oro-Barrie-Orillia airport. Rep. by LGL Limited, for Central Oro Ratepayer's Association, Oro Station, ON. 43 p.

1990 Davis, R.A., W.J. Richardson, L. Thiele, R. Dietz and P. Johansen. State of the arctic environment: Report on underwater noise. Finnish initiative on the protection of the arctic environment. Rep. by Greenland Environmental Research Institute, Copenhagen. 151 p.

1990 Koski, W.R., G.W. Miller and R.A. Davis. Growth rates and morphology of bowhead whale calves: photogrammetric evidence. Extended abstract presented at the 5th Conference on the Biology of the Bowhead Whale, *Balaena mysticetus*, April 1990, Anchorage, Alaska.

1990 Miller, G.W. and R.A. Davis. Monitoring of a gull control program at Britannia Sanitary Landfill Site: autumn 1989. Rep. by LGL Limited, King City, ON for Regional Municipality of Peel, Mississuaga, ON. 26 p.

1990 Davis, R.A., S.R. Johnson and W.R. Koski. Reactions of bowhead whales to a drillsite along their autumn migration corridor through the Alaskan Beaufort Sea, fall 1986. Paper presented 5th Conf. Biol. Bowhead Whale, 1-3 April 1990, Anchorage, AK.

1990 Davis, R.A., K.J. Finley and W.J. Richardson. Can a comparison of the behavior of two stocks (Western Arctic and Davis Strait) of bowhead whales help in assessing long-term effects of human activities? Paper presented 5th Conf. Biol. Bowhead Whale, 1-3 April 1990, Anchorage, AK.

1989 Davis, R.A. Technical assessment of the bird deterrent plan for the proposed Doughty Road Solid Waste Facility Site, Atlantic County, NJ. Rep. by LGL Limited, King City, ON, for Gordon, Gordon & Haley, West Orange, NJ. 14 p.

1989 Davis, R.A. Technical review of the Supplemental Operations Study and bird control experiments for the proposed Doughty Road Landfill Site, Atlantic County, New Jersey. Rep. by LGL Limited, King City, ON for Sills Cummis, Atlantic City, NJ. 11 p.

1989 Davis, R.A. Review of bird control techniques and design of a gull control program for Site VI in Peel Region. Rep. by LGL Limited, King City, ON for Regional Municipality of Peel, Brampton, ON. 31 p.

1989 Davis, R.A. Technical assessment of bird hazard risk associated with experimental landfilling near Niagara Falls International Airport. Rep. by LGL Limited, King City, ON to Browning-Ferris Industries, Buffalo, NY. 14 p.

1989 Davis, R.A. and G.W. Miller. Status of gulls in relation to potential landfill sites north of Toronto's Pearson International Airport, autumn 1988. Rep. by LGL Limited to Regional Municipality of Peel, Brampton, ON. 21 p.

1989 Davis, R.A. and C. Risley. Status and future of a Great Blue Heron colony near the proposed Taunton Road extension. Rep. by LGL Limited, King City, ON for Regional Municipality of Durham, Whitby, ON. 12 p.

1989 Koski, W.R., C.R. Greene and R.A. Davis. Potential effects of exploratory drilling in nearshore waters of Camden Bay, Alaska on bowhead whales. Rep. by LGL Limited and Greeneridge Sciences Inc. for ARCO Alaska, Anchorage, AK. 58 p.

1989 Johnson, S.R., J.J. Burns, C.T. Malme and R.A. Davis. Synthesis of information on the effects of noise and disturbance on major haulout concentrations of Bering Sea pinnipeds. Rep. by LGL Alaska Res. Assoc., Anchorage, AK, for Minerals Management Service, Anchorage, AK. 267 p.

1989 Richardson, W.J., C.R. Greene, J.P. Hickie, R.A. Davis and D.H. Thomson. Effects of offshore petroleum operations on cold water marine mammals: a literature review. 2nd Edition. Rep. by LGL Limited to Amer. Petrol. Inst., Washington, D.C. 385 p.

1988 Davis, R.A. Analysis of bird/aircraft collisions at major airports in the New York State area, 1977-1987. Rep. by LGL Limited, King City, ON for Browning-Ferris Industries, Buffalo, NY. 7 p.

1988 Davis, R.A. and R.H. Harris. Gull populations and bird hazards to aircraft in the Niagara Falls, N.Y. area, September 1988. Rep. by LGL Ltd., King City, ON for Browning-Ferris Industries, Inc., Buffalo, NY. 35 p.

1988 Koski, W.R., G.W. Miller and R.A. Davis. The potential effects of tanker traffic on the bowhead whale in the Beaufort Sea. Rep. by LGL Ltd., King City, ON for Canada Dept. Indian Affairs and Northern Development, Ottawa, ON. 150 p.

1987 Finley, K.J., J.P. Hickie and R.A. Davis. Status of the beluga, *Delphinapterus leucas*, in the Beaufort Sea. Can. Field-Naturalist 101:271-278.

1987 Richardson, W.J., R.A. Davis, C.R. Evans, D.K. Ljungblad and P. Norton. Summer distribution of bowhead whales, *Balaena mysticetus*, relative to oil industry activities in the Canadian Beaufort Sea, 1980-84. Arctic 40:93-104.

1987 Davis, R.A. Responses of bowhead whales to an offshore drilling operation in the Alaskan Beaufort Sea; autumn 1986: Integration and summary report. Rep. by LGL Ltd., King City, ON for Shell Western E & P Inc., Anchorage, AK. 51 p.

1987 Davis, R.A., W.R. Koski and G.W. Miller. Size composition and age segregation of bowhead whales in the Canadian Beaufort Sea. Paper presented 4th Conf. Biol. Bowhead Whale, 4-6 Mar 1987, Anchorage, AK.

1987 Davis, R.A., W.R. Koski and G.W. Miller. Site fidelity and growth rates of bowhead whales in the Beaufort Sea. Paper presented 4th Conf. Biol. Bowhead Whale, 4-6 Mar 1987, Anchorage, AK.

1987 Nerini, M., J. Cubbage, R. Davis, J. Calambokidis, W. Koski and D. Rugh. Length-frequency distribution of bowhead whales in the Canadian Beaufort Sea, 1982-1984. Paper (SC/37/PS23) tabled at Scientific Committee of Int. Whal. Comm., Cambridge. 14 p.

1986 McLaren, P.L., C.R. Greene, W.J. Richardson and R.A. Davis. Bowhead whales and underwater noise near a drillship operation in the Alaskan Beaufort Sea, 1985. Rep. for UNOCAL Corp., Anchorage, AK. 137 p.

1986 Davis, R.A., W.R. Koski, G.W. Miller, P.L. McLaren and C.R. Evans. Reproduction in the bowhead whale, Summer 1985. Rep. by LGL Ltd., King City, ON for Standard Alaska Production Company et. al. 176 p.

1986 Johnson, S.R., C.R. Greene, R.A. Davis and W.J. Richardson. Bowhead whales and underwater noise near the Sandpiper Island drillsite, Alaskan Beaufort Sea, Autumn 1985. Rep. by LGL Ltd., King City, ON and Greeneridge Sciences Inc., Santa Barbara, CA, for Shell Western E & P Inc., Anchorage, AK. 130 p.

1986 Davis, R.A., W.R. Koski and G.W. Miller. Experimental use of aerial photogrammetry to assess the long-term responses of bowhead whales to offshore industrial activities in the Canadian Beaufort Sea. Rep. by LGL Ltd., King City, ON to Canada Dept. Indian and Northern Affairs, Ottawa, ON. 157 p.

1986 Finley, K.J., L.D. Murison, C.R. Evans and R.A. Davis. An investigation of Isabella Bay, Baffin Island, as critical habitat for the eastern arctic bowhead whale (*Balaena mysticetus*), 1983-1985. Rep. by LGL Ltd., Sidney, BC for World Wildlife Fund (Canada), Toronto, ON. 77 p.

1986 Thomson, D.H., D.B. Fissel, J.R. Marko, R.A. Davis and G.A. Borstad. Distribution of bowhead whales in relation to hydrometeorological events in the Beaufort Sea. Environmental Studies Revolving Funds Report No. 028. Ottawa. 119 p.

1985 Davis, R.A., C.R. Greene and P.L. McLaren. Studies of the potential for drilling activities on Seal Island to influence fall migration of bowhead whales through Alaskan nearshore waters. Rep. by LGL Ltd., King City, ON for Shell Western E & P Inc., Anchorage, AK. 69 p.

1985 Davis, R.A., R.N. Jones, C.D. MacInnes and A.J. Pakulak. Molt migration of large Canada geese on the west coast of Hudson Bay. Wilson Bull. 97:296-305.

1985 Davis, R.A. and W.J. Richardson. Observations on the variable distribution of bowhead whales, *Balaena mysticetus*, in the vicinity of the 'industrial area' of the Canadian Beaufort Sea, 1976-1984. Extended abstract of paper presented at Third Conference on the biology of the bowhead whale, *Balaena mysticetus*, January 21-23, 1985. Anchorage, AK.

1985 Richardson, W.J., R.A. Davis, C.R. Evans and P. Norton. Distribution of bowheads and industrial activity, 1980-84. p. 255-306 *In*: W.J. Richardson (ed.), Behavior, disturbance responses and distribution of bowhead whales *Balaena mysticetus* in the eastern Beaufort Sea, 1980-84. Rep. by LGL Ecol. Res. Assoc., Inc., Bryan, TX for U.S. Minerals Management Service, Reston, VA. 306 p.

1984 Davis, R.A. Fall migration of the bowhead whale through the Alaskan Beaufort Sea: implications for exploratory drilling. Rep. by LGL Limited, King City, ON for D.F. Dickins Associates Ltd., Vancouver, BC. 18 p.

1984 Davis, R.A. and D.H. Thomson. Marine Mammals. 76 p. *In*: J. Truett (ed.). Barrow Arch environment and possible consequences of planned offshore oil and gas development. Rep. by LGL Ecological Research Associates, Texas, to U.S. NOAA, Juneau, Alaska.

1984 Finley, K.J., G.W. Miller, R.A. Davis and C.R. Greene. Responses of narwhals (*Monodon monoceros*) and belugas, (*Delphinapterus leucas*) to ice-breaking ships in Lancaster Sound - 1983. Rep. by LGL Limited, King City, ON to Canada Dept. Indian Affairs and Northern Development, Ottawa, ON. 117 p.

1984 Finley, K.J. and R.A. Davis. Reactions of beluga whales and narwhals to ship traffic and ice-breaking along ice edges in the eastern Canadian high arctic: 1982-1984. An overview. Rep. by LGL Limited, King City, ON for Canada Dept. Indian Affairs and Northern Development, Ottawa, ON. 41 p.

1984 Finley, K.J., C.R. Evans and R.A. Davis. Evaluation of the importance of Isabella Bay, Baffin Island, as summer habitat for the endangered bowhead whale. Progress report of 1984 studies. Rep. by LGL Limited, King City, ON for World Wildlife Fund (Canada), Toronto, ON. 30 p.

1984 McLaren, P.L. and R.A. Davis. Distribution of bowhead whales and other marine mammals in the southeast Beaufort Sea, August-September 1983. Rep. by LGL Ltd., Toronto, to the Environmental Studies Revolving Funds, Ottawa, ON. 63 p.

1984 Miller, G.W. and R.A. Davis. Distribution and movements of narwhals and beluga whales in response to ship traffic at the Lancaster Sound ice edge - 1984. Rep. by LGL Limited, King City, ON for Canada Dept. of Indian Affairs and Northern Development, Ottawa, ON. 34 p.

1983 Davis, R.A., P.L. McLaren and R.A. Buchanan. Environmental issues and impacts associated with exploratory drilling in Lancaster Sound. Rep. by LGL Ltd., Toronto to The Consolidex Magnorth Oakwood Lancaster Sound Joint Venture and Pallister Resource Management Ltd., Calgary, AB. 171 p.

1983 Davis, R.A., W.R. Koski and G.W. Miller. Preliminary assessment of the length-frequency distribution, life history and gross annual reproductive rate of the western arctic bowhead whale as determined with low-level aerial photography. Rep. by LGL Limited to U.S. National Marine Mammal Laboratory, Seattle, WA. 93 p. (Paper SC/35/PS5 at Scientific Committee, International Whaling Commission, Cambridge, July 1983.)

1983 Davis, R.A. and W.J. Richardson. Bowhead whale population estimates and distribution from aerial survey efforts in the Canadian Beaufort Sea. Extended Abstract. 2nd Conference on Biology of the Bowhead Whale, Anchorage, AK. 5 p.

1983 Finley, K.J., C.R. Evans and R.A. Davis. Evaluation of the importance of Isabella Bay, Baffin Island, as summer habitat for the endangered bowhead whale. Rep. by LGL Ltd., Toronto, to World Wildlife Fund, Toronto, ON. 72 p.

1983 Finley K.J., C.R. Greene, and R.A. Davis. A study of ambient noise, ship noise, and the reactions of narwhals and belugas to the MV *Arctic* breaking ice in Admiralty Inlet, N.W.T. 1982. Rep. by LGL Ltd., to Canada Dept. of Indian Affairs and Northern Development, Ottawa, ON. 108 p.

1983 Finley, K.J., J.P. Hickie and R.A. Davis. Status report on the white whale in the Beaufort Sea. Rep. by LGL Ltd., Toronto for Comm. on status of endangered wildlife in Canada. Dept. Fisheries and Oceans, Ottawa, ON. 25 p.

1983 Richardson, W.J., R.A. Davis, C.R. Evans and P. Norton. Distribution of bowheads and industrial activity, 1980-82. *In*: W.J. Richardson (ed.), Behavior, disturbance responses and distribution of bowhead whales *Balaena mysticetus* in the eastern Beaufort Sea, 1982. Rep. for U.S. Minerals Management Service, Reston, VA.

1983 Hickie, J. and R.A. Davis. Distribution and movements of bowhead whales and other marine mammals in the Prudhoe Bay region, Alaska, 26 September-13 October 1982. Rep. by LGL Ecological Research Associates Inc. to Shell Oil Company Inc., Houston, TX.

1983 McLaren, P.L. and R.A. Davis. Marine mammal distribution off West Greenland and in southern Baffin Bay and northern Davis Strait, March 1982. Rep. by LGL Limited, Toronto, to Arctic Pilot Project, Calgary, AB. 98 p.

1983 Finley, K.J., G.W. Miller, R.A. Davis and W.R. Koski. A distinctive large breeding population of ringed seals (*Phoca hispida*) inhabiting the Baffin Bay pack ice. Arctic 36:162-173.

1983 Richardson, W.J., C.R. Greene, J.P. Hickie and R.A. Davis. Review of the effects of offshore petroleum operations on cold water marine mammals. Rep. by LGL Limited, to American Petroleum Institute, Washington. 248 p.

1982 Davis, R.A. and C.R. Evans. Offshore distribution and numbers of white whales in the eastern Beaufort Sea and Amundsen Gulf, summer 1981. Rep. by LGL Limited, Toronto, to Sohio Alaska Petroleum Company, Anchorage, AK and Dome Petroleum Ltd., Calgary, AB. 78 p.

1982 McLaren, P.L. and R.A. Davis. Winter distribution of arctic marine mammals in ice-covered waters of eastern North Amercia. Rep. by LGL Limited, Toronto to Petro-Canada Exploration, Inc., Calgary, AB. 151 p.

1982 Miller, G.W., R.A. Davis and K.J. Finley. Ringed seals in the Baffin Bay region: habitat use, population dynamics and harvest levels. Rep. by LGL Limited, Toronto, to Arctic Pilot Project, Calgary, AB. 93 p.

1982 Finley, K.J., G.W. Miller, R.A. Davis and W.R. Koski. Status of ringed seals (*Phoca hispida*) of the Baffin Bay pack ice. Rep. by LGL Limited, Toronto to Petro-Canada Exploration, Inc., Calgary, AB. 39 p.

1982 Finley, K.J., G.W. Miller, M. Allard, R.A. Davis and C.R. Evans. The belugas (*Delphinapterus leucas*) of northern Quebec: distribution, abundance, stock identity, catch history and management. Can. Tech. Rep. Fish. Aquat. Sci. 1123. 57 p.

1982 Davis, R.A., W.R. Koski, W.J. Richardson, C.R. Evans and W.G. Alliston. Distribution, numbers and productivity of the Western Arctic stock of bowhead whales in the eastern Beaufort Sea and Amundsen Gulf, summer 1981. Rep. by LGL Ltd., Toronto, to Sohio Alaska Petroleum Co. and Dome Petroleum Ltd. (Co-managers). 134 p.

1981 Davis, R.A. Summary of marine mammal distribution in arctic portions of the proposed Arctic Pilot Project shipping route. p. 78-89 *In*: N.M. Peterson (ed.). The question of sound from icebreaker operations: Proceedings of a workshop. Arctic Pilot Project/Petro-Canada, Calgary, AB. 340 p.

1981 Davis, R.A. Environmental research in frontier regions. p. 35-43 *In*: Frontier oil and gas development--The decade ahead. Spec. Publ. Arctic Institute of N. Am., Univ. of Calgary, AB. 233 p.

1981 McLaren, P.L. and R.A. Davis. Distribution of wintering marine mammals in southern Baffin Bay and northern Davis Strait, March 1981. Rep. by LGL Ltd., Toronto for Arctic Pilot Project, Calgary, AB. 92 p.

1981 Renaud, W.E. and R.A. Davis. Aerial surveys of bowhead whales and other marine mammals off the Tuktoyaktuk Peninsula, N.W.T., August-September 1980. Rep. by LGL Ltd., Toronto for Dome Petroleum Ltd., Calgary, AB. 55 p.

1981 Davis, R.A. Report of a workshop on arctic marine mammals. Can. Tech. Rep. Fish. Aquatic Sci. 1005:iv + 13 p.

1981 Davis, R.A. Notes on bird habitat along the proposed "Miisi Falls" pipeline route. Rep. by LGL Ltd., to Polar Gas Project, Toronto, ON.

1980 Davis, R.A. Issues in arctic marine mammal management. Paper presented to Can. Soc. Environmental Biologists. Ottawa, Jan. 1980.

1980 Davis, R.A., K.J. Finley and W.J. Richardson. The present status and future management of arctic marine mammals in Canada. Sci. Advis. Board of the Northwest Territories Rep. No. 3. 93 p.

1980 Davis, R.A. and W.R. Koski. Recent observations of the bowhead whale in the eastern Canadian high arctic. Rep. Int. Whal. Comm. 30:439-444.

1980 Koski, W.R. and R.A. Davis. Studies of the late summer distribution and fall migration of marine mammals in NW Baffin Bay and E Lancaster Sound, 1979. Rep. by LGL Ltd. for Petro-Canada Exploration Inc., Calgary, AB. 214 p.

1980 Finley, K.J., R.A. Davis and H.B. Silverman. Aspects of the narwhal hunt in the eastern Canadian arctic. Rep. Int. Whal. Comm. 30:459-464.

1979 Davis, R.A. and K.J. Finley. Distribution, migration, abundance and stock identity of eastern arctic white whales. Working paper SC/31/SM10, 31st Ann. Meeting, International Whaling Commission, Cambridge, England, June 1979. 49 p.

1979 Koski, W.R. and R.A. Davis. Distribution of marine mammals in northwest Baffin Bay and adjacent waters, May-October 1978. Rep. by LGL Ltd. to Petro-Canada, Calgary, AB. 305 p. + Map Appendix (223 p.).

1979 Davis, R.A. and A.D. Sekerak. Notes on birds, marine mammals and marine ecology made during reconnaissance flights over Polar Gas Project's Y-Line and associated route options, July 1979. Rep. by LGL Ltd. to Polar Gas Project, Toronto, ON. 11 p.

1978 Davis, R.A., W.R. Koski and K.J. Finley. Numbers and distribution of walruses in the central Canadian high arctic. Rep. by LGL Ltd., to Polar Gas Project, Toronto, ON. 50 p.

1978 Davis, R.A., W.J. Richardson, S.R. Johnson and W.E. Renaud. Status of the Lancaster Sound narwhal population in 1976. Rep. Int. Whal. Comm. 28:209-215.

1977 Davis, R.A. and A.D. Sekerak. Ecological significance of northwest Baffin Bay and Lancaster Sound. An overview report. Rep. by LGL Ltd. for Petro-Canada, Calgary, AB. 25 p.

1977 McLaren, M.A., W.E. Renaud, R.A. Davis and J.C. Truett. Studies of terrestrial mammals on eastern Melville Island, July-August 1977. Rep. by LGL Ltd. for Petro-Canada, Calgary, AB. 111 p.

1976 Johnson, S.R., W.E. Renaud, R.A. Davis and W.J. Richardson. Marine mammals recorded during aerial surveys of birds in eastern Lancaster Sound, 1976. Rep. by LGL Ltd. for Norlands Petroleums Ltd., Calgary, AB. 180 p.

1976 Johnson, S.R., W.E. Renaud, W.J. Richardson, R.A. Davis, C. Holdsworth and P.D. Hollingdale. Aerial surveys of birds in eastern Lancaster Sound. Rep. by LGL Ltd. for Norlands Petroleums Ltd., Calgary, AB. 365 p. + Appendix, 342 p.

1976 McLaren, P.L., R.A. Davis, W.E. Renaud and C. Holdsworth. Studies of the numbers and distribution of birds in the District of Keewatin, N.W.T., June-August 1975. Rep. by LGL Ltd. for Polar Gas Project, Toronto, ON. 591 p.

1976 Alliston, W.G., M.S.W. Bradstreet, M.A. McLaren, R.A. Davis and W.J. Richardson. Numbers and distribution of birds in the central District of Franklin, NWT, June-August 1975. Rep. by LGL Ltd. for Polar Gas Project, Toronto, ON. 588 p.

1975 Davis, R.A., K.J. Finley, M.S.W. Bradstreet, C. Holdsworth and M. McLaren. Studies of the numbers and distribution of birds and marine mammals in the central Canadian arctic, 1974: A supplement. Rep. by LGL Ltd. for Polar Gas Project, Toronto, ON. 205 p.

1974 MacInnes, C.D., R.A. Davis, R.N. Jones, B.C. Lieff and A.J. Pakulak. Reproductive efficiency of McConnell River small Canada Geese. J. Wildl. Manage. 38:686-707.

1974 Davis, R.A., M.S.W. Bradstreet, C. Holdsworth, M.A. McLaren and W.J. Richardson. Studies of the numbers and distribution of birds in the central Canadian arctic - 1974: A preliminary report. Rep. by LGL Ltd. for Polar Gas Project. 238 p.

1974 Davis R.A. Aerial surveys of bird populations along the route of the proposed gas pipeline in the Mackenzie District, Northwest Territories, summer, 1972. Arctic Gas Biol. Rep. Ser., 11(1). 156 p.

1974 Davis, R.A. and A.N. Wiseley. Normal behaviour of snow geese on the Yukon-Alaska North Slope and the effects of aircraft-induced disturbance on this behaviour, September 1973. Arctic Gas Biol. Rep. Ser., 27(2). 85 p.

1974 Davis, R.A., W.J. Richardson, D.V. Wesloh and J.F. Barr. Bird populations and movements associated with the proposed site of the new Toronto International Airport. Rep. by LGL Ltd. for Canada Ministry of Transport. 333 p. + Appendix.

1974 Davis, T.J., J. Ward, W.J. Richardson, W.W.H. Gunn and R.A. Davis. Dispersal and rehabilitation of waterbirds: review of current knowledge and recommendations for reducing bird mortality associated with oil spills. Rep. by LGL Ltd. for Petroleum Association for Conservation of the Canadian Environment (PACE), Toronto, ON. 103 p.

1974 Gollop, M.A. and R.A. Davis. Studies of bird populations and productivity on lakes on the Yukon North Slope, July, 1972. Arctic Gas Biol. Rep. Ser., 12(1). 35 p.

1974 Gollop, M.A. and R.A. Davis. Autumn bird migration along the Yukon arctic coast, July, August, September, 1972. Arctic Gas Biol. Rep. Ser., 13(3). 80 p.

1974 Gollop, M.A. and R.A. Davis. Gas compressor noise simulator disturbance to Snow Geese, Komakuk Beach, Yukon Territory, September, 1972. Arctic Gas Biol. Rep. Ser., 14(8). 25 p.

1974 Gollop, M.A., R.A. Davis, J.P. Prevett and B.E. Felske. Disturbance studies of terrestrial breeding bird populations: Firth River, Yukon Territory, June, 1972. Arctic Gas Biol. Rep. Ser., 14(3). 56 p.

1974 Gollop, M.A., J.E. Black, B.E. Felske and R.A. Davis. Disturbance studies of breeding black brant, common eiders, glaucous gulls and arctic terns at Nunaluk Spit and Phillips Bay, Yukon Territory, July, 1972. Arctic Gas Biol. Rep. Ser., 14(4). 51 p.

1974 Gollop, M.A., J.R. Goldsberry and R.A. Davis. Aircraft disturbance to moulting sea ducks, Herschel Island, Yukon Territory, August, 1972. Arctic Gas Biol. Rep. Ser., 14(5). 30 p.

1974 Gollop, M.A., J.R. Goldsberry and R.A. Davis. Effects of gas compressor noise simulator disturbance to terrestrial breeding birds, Babbage River, Yukon Territory, June, 1972. Arctic Gas Biol. Rep. Ser., 14(2). 48 p.

1974 Salter, R.E. and R.A. Davis. Preliminary waterfowl disturbance studies, Mackenzie Valley, August, 1972. Arctic Gas Biol. Rep. Ser., 14(6). 26 p.

1974 Salter, R.E. and R.A. Davis. Surveys of terrestrial bird populations in Alaska, Yukon Territory, Northwest Territories, and northern Alberta, May, June, July, 1972. Arctic Gas Biol. Rep. Ser., 12(2). 349 p.

1973 Davis, R.A., C. Holdsworth and W.J. Richardson. Present ornithological knowledge and suggested research programs for the Polar Gas Pipeline Project. Rep. by LGL Ltd. for Polar Gas Project, Toronto, ON. 245 p. + Map Appendix.

1972 Davis, R.A. A comparative study of the use of habitat by arctic loons and red-throated loons. Ph.D. thesis, University of Western Ontario, London, Canada. 288 p.

1971 Davis, R.A. Flight speed of arctic and red-throated loons. Auk 88:169.

1971 Davis, R.A. and R.N. Jones. Notes on summer birds along the northshore of the Gulf of St. Lawrence. Canadian Field Naturalist 85:191-192.

1969 Barlow, J.C., J.A. Dick, D.H. Baldwin and R.A. Davis. New records of British Honduras. Ibis 111:399-402.

1967 Davis, R.A. Bird notes from James Bay in late November. Canadian Field-Naturalist 81:229-230.

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