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December 15, 2021 ***TRANSMITTAL VIA EMAIL 12/15/2021***

Mr. Phil Roycraft
Michigan Department of Environment, Great Lakes, and Energy
Materials Management Division
Saginaw Bay District Office
401 Ketchum St, Suite B
Bay City, Michigan 48708

TRANSMITTAL KARN LANDFILL REMEDIAL ACTION PLAN (RAP), ESSEXVILLE, MICHIGAN; WASTE DATA SYSTEM NUMBER 392503

Dear Mr. Roycraft,

Please find the enclosed remedial action plan to address arsenic-impacted groundwater adjacent to Saginaw Bay at the Karn Landfill monitored under the Hydrogeological Monitoring Plan, Rev. 3 dated December 19, 2017. This remedial action plan builds on the feasibility study submitted to the Department on March 3, 2021 and the responses to feedback provided by the Remediation Advisory Team (RAT) from presentations of the study and results on April 12, 2021 and September 29, 2021.

Consumers Energy requests initial review responses by March 31, 2022. Please feel free to contact me with any questions or clarifications.

Sincerely,

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Remedial Action Plan

Groundwater Impacts from the D.E. Karn Landfill

Prepared for
Consumers Energy Company

December 2021

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Remedial Action Plan: Groundwater Impacts from the D.E. Karn Landfill

December 2021

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Certifications

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a licensed Professional Engineer under the laws of the state of Michigan.

Kathleen Lindstrom

Kathleen Lindstrom
PE license #: 6201061370

December 15, 2021
Date

STATE OF MICHIGAN
KATHLEEN LINDSTROM
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Abbreviations

µg/L	micrograms per liter
µM	micrometer
3D	three-dimensional
Barr	Barr Engineering Co.
bay	Saginaw Bay
CCR	coal combustion residuals
Consumers	Consumers Energy Company
CQA	construction quality assurance
CSBR	continuously stirred batch reactor
CSM	conceptual site model
EBCT	empty bed contact time
EGLE	Michigan Department of Environment, Great Lakes, and Energy
EVS	Earth Volumetric Studio
feet/day	feet per day
FS	feasibility study
generating facility	D.E. Karn Electrical Power Generating Facility
Geosyntec	Geosyntec Consultants
groundwater model	groundwater flow model
GSI	groundwater-surface water interface
Hach® Test	Hach® low-range arsenic field test
HMP	Hydrogeological Monitoring Plan
MDEQ	Michigan Department of Environmental Quality
MDOT	Michigan Department of Transportation
mg/kg	milligrams per kilogram
mL	milliliter
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
PRB	permeable reactive barrier
psf	pounds per square foot
QA/QC	Quality Assurance/Quality Control
RAP	Remedial Action Plan
river	Saginaw River
SESC	Soil Erosion and Sedimentation Control
s.u.	standard units
TOC	total organic carbon
ZVI	zero-valent iron

Executive Summary

This Remedial Action Plan (RAP) describes the remedial response proposed to address arsenic-impacted groundwater venting to the Saginaw Bay (bay) from the 171-acre, Type III, low-hazard industrial landfill (i.e., Karn Landfill) at Consumers Energy Company's (Consumers') D.E. Karn Electrical Power Generating Facility (generating facility). The closed Karn Landfill in proximity to the generating facility is shown on Figure 1. This RAP is being pursued to fulfill Consumers' obligations related to the monitoring conducted in accordance with Hydrogeological Monitoring Plan, Rev. 03 (Karn Landfill HMP) (reference (1)) pursuant to Part 115 ("Solid Waste Management") and Part 201 ("Environmental Remediation") of Michigan's Natural Resources and Environmental Protection Act, Public Act 451 of 1994, as amended (Parts 115 and 201, respectively, of Act 451), and the administrative rules promulgated pursuant thereto. This RAP is being pursued under R 299.4319(7) of the Part 115 Rules and in compliance with the provisions of section 20114b of Part 201.

Previous closure and response activities that Consumers has completed specific to the Karn Landfill have included:

- completing the construction of a final cover over the Karn Landfill in five partial closure phases; and
- installing a system of six groundwater extraction wells in December 2017 to mitigate venting of impacted groundwater to the bay and operating from December 2017 to date.

The remedial action described in this RAP addresses potential migration of contaminants from the Karn Landfill to surface water via the groundwater-surface water interface (GSI) exposure pathway – specifically, where groundwater from the Karn Landfill enters the bay along the northern perimeter embankment dike. The drinking water exposure pathway for the Karn Landfill is not complete and will be addressed through institutional controls. This RAP has not evaluated or addressed any other groundwater pathways because they were deemed irrelevant to the Karn Landfill.

Observations from previous investigations performed at the Karn Landfill were used to develop the conceptual site model (CSM). The CSM includes a description of the current understanding of geologic, geotechnical, hydrologic, groundwater quality, and constraints.

A remedial response options assessment was completed to screen potential remedial response options and recommended three options to carry forward for further evaluation in a detailed feasibility study (FS): 1) a groundwater extraction and treatment system; 2) an air sparging system; and 3) a permeable reactive barrier (PRB) employing zero-valent iron (ZVI). Relative advantages and disadvantages, implementability, effectiveness at meeting remedial response objectives, estimated costs, schedule, and data gaps were compared for each remedial response option. The recommended option from the FS that was further refined in the FS Addendum was a ZVI-containing PRB installed in the revised remedial response area (i.e., the entire extent along the northern alignment of the perimeter embankment dike adjacent to the bay [Figure 2]). The FS and FS Addendum concluded that implementation of a ZVI-containing PRB was feasible in the revised remedial response area and recommended that a PRB installed along the length of the revised remedial response area be carried forward to the RAP.

This RAP includes a discussion of the CSM, a summary of the FS and FS Addendum completed for the Karn Landfill, anticipated permit requirements and approvals for implementation of a PRB, preparation activities and general requirements for the Karn Landfill, the design and construction of the PRB, the anticipated schedule for implementation, and a summary of the monitoring and maintenance plan that will be developed to maintain the effectiveness and integrity of the remedial response after construction.

1 Introduction

This Remedial Action Plan (RAP) has been prepared to address arsenic-impacted groundwater venting to Saginaw Bay (bay) from the Type III, low-hazard industrial landfill (i.e., Karn Landfill) at the Consumers Energy Company's (Consumers') D.E. Karn Electrical Power Generating Facility (generating facility). The remedy proposed herein is intended to fulfill Consumers' obligations related to monitoring conducted in accordance with Hydrogeological Monitoring Plan, Rev. 03 (Karn Landfill HMP) (reference (1)) under Parts 115 and 201 of the Michigan Natural Resources and Environmental Protection Act of 1994 (Michigan Public Act 451), as amended, and the administrative rules respectively promulgated pursuant thereto. The generating facility is located at 2742 N. Weadock Highway in Essexville, Michigan, east of the Saginaw River (river) on the south end of the bay (Figure 1). Adjacent to the Karn Landfill, but not evaluated for remedial responses, are:, the former Karn Bottom Ash Pond, the Karn Lined Impoundment, and the former Karn 1&2 Chemical Treatment Ponds (Figure 2). This RAP is being pursued under R 299.4319(7) of the Part 115 Rules and in compliance with the provisions of section 20114b of Part 201.

Consumers performs routine groundwater monitoring pursuant to the Karn Landfill HMP (reference (1)). Groundwater monitoring at the Karn Landfill commenced in 1983 when the first monitoring wells were installed (reference (2)). The Michigan Water Resources Commission issued a Determination of Permit Exemption No. GWE – 0005 on August 21, 1986 (reference (3)) that determined: 1) groundwater at the site overlies an unusable aquifer and 2) discharges were adequately regulated by the National Pollutant Discharge Elimination System (NPDES) permit and solid waste operating licenses issued under Act 641 of Public Act of 1978. Monitoring wells MW-18 and MW-19 (formerly MW-10 and MW-11) continue to be sampled on a quarterly basis to validate the no change in discharge standard under the exemption.

In February 2002, the Michigan Department of Environmental Quality (MDEQ, since renamed to the Michigan Department of Environment, Great Lakes, and Energy [EGLE]) issued a Letter of Warning raising concerns related to possible water quality issues associated with coal ash materials, including arsenic, venting into the bay. Consumers completed a detailed investigation and characterization in September 2005 (reference (4)) of the discharge, culminating in a determination that the groundwater-surface water interface (GSI) pathway was relevant and could be protected through an authorized groundwater mixing zone monitored at alternative monitoring points. Consumers Energy applied for a groundwater mixing zone authorization in 2007 that was ultimately approved on August 26, 2009 (reference (5)). The approval of the mixing zone provided updated GSI criteria, accepted the GSI compliance monitoring approach to verify ongoing compliance with GSI criteria, and required a detailed HMP to be submitted as a condition of the solid waste operating license (reference (6)).

Consumers submitted a Karn Landfill HMP Rev. 01 that was approved by EGLE on March 1, 2010 (reference (7)). The Karn Landfill HMP Rev. 01 included a potentiometric monitoring program, a porewater monitoring program, a leachate monitoring program, and a GSI Compliance Monitoring Program consistent with the requirements set forth in a 2009 letter from EGLE (reference (5)). Updates to Karn Landfill HMP Rev. 01 were completed after the mixing zone reauthorization request was submitted in February 2014 (reference (8)) to document replacement of GSI compliance monitoring wells on the northern perimeter embankment dike and studies completed validating the mass flux-based methodology in Karn Landfill HMP Rev. 02 based on findings from a groundwater flux investigation (reference (9)). The refined characterization of the venting groundwater plume and the mass flux-based methodology for calculating compliance with the mixing zone was incorporated into the mixing zone reauthorization memo for implementation (reference (10)). Finally, the Karn Landfill HMP Rev. 02 was updated again in December 2017 to incorporate groundwater monitoring wells installed for the Karn Bottom Ash Pond into the potentiometric monitoring program and document the implementation of an interim system of six groundwater extraction wells on the northern border of the Karn Landfill near the bay in late 2016 where the greatest groundwater quality concerns have historically been observed (reference (1)).

Results from the GSI Compliance Monitoring Program documented since 2016 have reported arsenic, boron, chromium (based on the GSI criterion for hexavalent chromium), molybdenum, and selenium detected in groundwater above Part 201 generic GSI criteria from at least one sampling event. Arsenic and boron are the two parameters that are most consistently detected at concentrations above generic GSI criteria, and arsenic is the parameter that exceeds chronic mixing zone-based concentration values in monitoring wells upgradient of the bay. Monitoring wells upgradient of the river are consistently below the chronic mixing zone-based concentration values, so remedial response evaluations have been focused on groundwater venting to the bay. While the existing groundwater extraction system provides a measure of hydraulic containment, Barr Engineering Co. (Barr) assisted Consumers with an evaluation of remedial response options and recommended a long-term solution for maintaining compliance at the Karn Landfill.

The remedial response described in this RAP addresses the GSI pathway – specifically, where groundwater from the Karn Landfill enters the bay along the northern perimeter embankment dike. The drinking water pathway is expected to be addressed through a restrictive covenant in addition to the executed restrictive covenant that states that the Karn Landfill has been used as a landfill and that filling, grading, excavating, drilling, or mining are not allowed within the restricted area for at least fifty years following the completion of the Karn Landfill (Attachment A). This RAP has not evaluated or addressed any other groundwater pathways since they were deemed not to be relevant.

1.1 Overview of Material Management

Materials subject to state solid waste requirements have been managed in four different locations in and adjacent to the Karn Landfill. In addition to the Karn Landfill, other waste management units include the Karn Bottom Ash Pond, the Karn Lined Impoundment, and the former Karn 1&2 Chemical Treatment Ponds.

1.1.1 Karn Landfill

The Karn Landfill received sluiced bottom ash and fly ash from the coal-fired units at the generating facility starting in the late 1950s. Construction Permit No. 0195 (Construction Permit) authorized the Karn Landfill construction consisting of breakwater dikes from the shoreline at the plant lakeward to enclose shallow, submerged, bay-bottom land (reference (11)). The perimeter embankment dikes were constructed using native materials ranging from silty clay to coarse sand, were topped with bottom ash, and are armored on the shoreward and channel side with riprap (reference (4)). The Construction Permit also established the engineering and operational conversion of hydraulic deposition to controlled moisture placement to achieve maximum density deposition. The conversion to dry fly ash handling operations was completed in February 2009 (reference (12)).

Consumers started to close portions of the Karn Landfill in 2012 after EGLE approved revisions to the final closure plan incorporating a geomembrane cover (reference (13)). Subsequent revisions of the closure plan were submitted in 2014 that included a revised final cover grading plan to optimize regrading of material within the Karn Landfill and the construction of a final cover system to promote positive drainage (reference (14)). Consumers Energy certified the final phase of closure (reference (15)) in 2019, culminating in approval of all phases of Karn Landfill closure by EGLE on June 24, 2020, and initiating the 30-year post-closure care period.

1.1.2 Karn Bottom Ash Pond

The Karn Bottom Ash Pond was a treatment unit (settling basin) within the NPDES system that settled commingled plant process waters and bottom ash within a defined area (reference (16)). The materials collected in this unit were defined as "other wastes regulated by statute" under state solid waste rules, exempting the management of liquid industrial waste from solid waste licensing in lieu of the NPDES Permit. However, sludges and residues generated from disposal would be subject to applicable solid waste requirements. Therefore, this treatment and storage area was closed in 2018 by excavating coal ash to an extent where health-based criteria were met, which was certified through multiple lines of evidence (reference (17)). EGLE accepted the closure of the Karn Bottom Ash Pond on November 30, 2020 (reference (18)).

1.1.3 Karn Lined Impoundment

The Karn Lined Impoundment is a double-lined, double-composite storage pond (reference (19)) that includes a leachate collection system that went into service in June 2018 to replace the Karn Bottom Ash Pond. The Karn Lined Impoundment is licensed to receive coal ash materials after December 28, 2020, authorized by Solid Waste Operating License No. 9629. The bottom ash is periodically excavated, and the removed coal ash materials are stacked and allowed to dewater prior to being loaded and hauled for disposal.

1.1.4 Karn 1&2 Chemical Treatment Facility

The Karn 1&2 Chemical Treatment Facility consisted of two treatment basins: an equalization basin (south pond) and a treatment basin (north pond). This treatment facility was constructed in 1978 (reference (20)) based on changes in the NPDES system that required treatment and characterization of boiler chemical cleaning wastes prior to discharge. The materials collected in this unit were defined as "other wastes regulated by statute" under state solid waste rules, exempting the management of liquid industrial waste from solid waste licensing in lieu of the NPDES Permit. However, sludges and residues generated from disposal would be subject to applicable solid waste requirements. These ponds were closed in 2014 by removing all liquid and solid waste residues and documenting the excavation of the liner systems to native soil.

1.2 Remedial Response Objectives

The GSI pathway is the primary, relevant exposure pathway of concern; therefore, the primary remedial response objective is to meet and maintain long-term compliance during post-closure care of the Karn Landfill with mixing zone-based GSI criteria for arsenic in groundwater venting from the Karn Landfill to the bay. Site-specific chronic and acute mixing zone-based concentration values for arsenic are 100 micrograms per liter (µg/L) and 680 µg/L, respectively.

Drinking water and volatilization to indoor air are not exposure pathways of concern for the Karn Landfill. There are no water supply wells at the property, and potable water is municipally-supplied through the Bay County Department of Water and Sewer, which purchases Lake Huron water from the Saginaw-Midland Municipal Water Supply Corporation, sourced near Au Gres, Michigan. Groundwater beneath the Karn Landfill discharges to the river and bay; therefore, there are no down-gradient, off-site drinking water wells. To control future exposure via the drinking water pathway, drilling is restricted as discussed in Section 2.3, thereby preventing future construction of water supply wells, and additional restrictive covenants may be pursued in the future to more explicitly restrict the use of wells to extract groundwater for consumption or irrigation. Exposure risks related to the volatilization to indoor air pathway are not relevant to the Karn Landfill because coal combustion residual (CCR) materials do not provide a source of vapors.

1.3 Report Organization

This RAP is organized as follows:

Section 2 Completed Response Activities: This section includes a summary of response activities to address groundwater impacts completed to date.

Section 3 Conceptual Site Model: This section includes a summary of the current CSM, including a description of the geologic, geotechnical, hydrologic, and hydrogeologic conditions, groundwater quality, and constraints for remedial response implementation.

Section 4 Options Assessment and Feasibility Study Summary: This section summarizes the options assessment, FS (reference (21)), and FS addendum (reference (22)) that were completed to identify a recommended remedial action for inclusion in this RAP.

Section 5 Design and Implementation Summary: This section provides a summary of the remedial response design and the key steps for remedial response implementation.

Section 6 Monitoring and Maintenance Plans: This section describes the monitoring, operation, and maintenance actions that will be implemented to maintain the effectiveness and integrity of the remedial response, including plans for contingent actions in the event of insufficient effectiveness of the remedial response.

Section 7 Implementation Schedule: This section provides a high-level overview of the schedule for implementing the remedial response.

Section 8 References

2 Completed Response Activities

In 2002, the MDEQ (now known as EGLE) issued a Letter of Warning raising concerns regarding groundwater quality issues at the Karn Landfill associated with coal ash constituents, including arsenic, venting to the bay (reference (11)). Consumers has since conducted the following activities in response to that inquiry:

- Completed a detailed hydrogeological characterization submitted in September 2005 (reference (4)) that determined that compliance for the GSI pathway could be achieved through an authorized groundwater mixing zone monitored at alternative monitoring points
- Discontinued hydraulic fly ash sluicing at the Karn Landfill in February 2009
- Received authorization for groundwater mixing zone on August 26, 2009 (reference (5))
- Received authorization for integrated solid waste landfill and GSI Compliance Monitoring Program (reference (5)) approved on March 1, 2010 (reference (7))
- Completed the closure (through removal) of the unlined Karn Bottom Ash Pond in October 2019
- Constructed and began operating the Karn Lined Impoundment in June 2018
- Improved the design of the final Karn Landfill cover through incorporation of geosynthetics and grading to promote drainage
- Completed the construction of the final cover in five partial closure phases
- Received authorization for an interim system of six groundwater extraction wells in December 2017

Of these response activities, those specific to the Karn Landfill (i.e., cover and groundwater extraction) are described in Sections 2.1 and 2.2. A restrictive covenant filed for the generating facility that includes the Karn Landfill constitutes a response activity and is described in Section 2.3.

2.1 Landfill Final Cover

Consumers submitted an initial, revised closure plan for the Karn Landfill pursuant to Special License Condition 20.d of Solid Waste Disposal Area License No. 9234 on December 20, 2011 (reference (23)). The revised closure plan emphasized improvements to the final cover to minimize infiltration from precipitation and reduce the influence of former hydraulic operations on the migration of constituents. After amendments to the final cover design in response to MDEQ comments (reference (13)), MDEQ approved the final cover design on August 27, 2012 (reference (24)). Consumers submitted the first partial, final cover construction certification documentation report for Ponds B and C1 on September 23, 2013 and this documentation was approved by MDEQ on January 17, 2014 (reference (25)). Installation of the final cover was completed in December 2019. Consumers received EGLE’s approval of the Karn Landfill final closure certification on June 23, 2020 (reference (26)). The Karn Landfill has entered into the required 30-year post-closure care period.

2.2 Groundwater Extraction System

A groundwater flow model (groundwater model) was developed by NTH Consultants, Ltd. in 2011 to provide a numerical representation of the hydrogeologic conditions at the Karn Landfill and the surrounding area. The groundwater model was originally built using the modular three-dimensional finite difference groundwater model developed by the U.S. Geological Survey (reference (27)). This groundwater model was updated by Geosyntec Consultants (Geosyntec) in 2016 (Attachment B of reference (1)) to reflect 2016 conditions following closure of Ponds B and C1 in 2012 (reference (28)), closure of Pond A West 1 in 2014 (reference (29)), and closure of part of Pond A West 2 in 2015 (reference (30)). Six groundwater extraction wells were installed in 2017 along the northern perimeter embankment dike using the groundwater model as the basis of design (Attachment B of reference (1)).

The extraction system was installed to maintain compliance according to the Karn Landfill HMP by: 1) limiting groundwater discharge to porewater within the bay for a portion of the Karn Landfill 2) removing arsenic from the subsurface within the capture zone and precipitating it *ex situ* by ferric chloride injection prior to discharge through the NPDES-permitted outfall; and 3) depressing the water table within the capture zone to induce a more positive oxidation reduction potential with oxygenated water for *in situ* attenuation of available arsenic. The system runtime and total pumping rate have been lower than anticipated, in part due to the relatively small, saturated thickness of the upper native sand unit. While the system is maintaining compliance today, Consumers is looking for a longer-term, less maintenance-intensive solution.

2.3 Restrictive Covenants

A Declaration of Restrictive Covenant for the Karn Landfill dated September 1, 1979, was recorded with the Bay County Register of Deeds on March 9, 1980. The 1979 Restrictive Covenant included a legal description for 152 acres of land to be used as a sanitary landfill for ash disposal and stipulated that this land could not be filled, graded, excavated, drilled, or mined for 15 years after completion of landfill activity without written authorization from the State of Michigan.

Another Declaration of Restrictive Covenant for the Karn Landfill dated June 1, 1982, was recorded with the Bay County Register of Deeds on October 6, 1982, for the purpose of correcting the description of land intended to be restricted. The 1982 Restrictive Covenant included a legal description for 174 acres of land to be used for the Karn Landfill.

An Amended Declaration of Restrictive Covenant for the Karn Landfill dated and recorded with the Bay County Register of Deeds on March 15, 1990, stipulated that the restricted land could not be filled, graded, excavated, drilled, or mined for 50 years after completion of landfill activity without written authorization from the State of Michigan. Copies of these Restrictive Covenants are provided in Attachment A.

Future land use restrictions will be considered following implementation of the remedial response and are likely to include more explicit restrictions on the use of wells to extract groundwater for consumption or irrigation and to protect the integrity of the PRB.

3 Conceptual Site Model

This section provides a summary of the geologic, geotechnical, hydrologic, and hydrogeologic conditions, groundwater quality, and constraints for remedial response implementation.

3.1 Geology

The primary geologic units under the Karn Landfill are coal ash and other fill materials, sand, an intermediate silt/clay unit, and clay. A three-dimensional (3D) model of stratigraphy was created using Earth Volumetric Studio software, developed by C Tech Development Corporation. Lithology data from select borings compiled from hydrogeologic investigations completed at the D.E. Karn and J.C. Weadock Generating Complex were used to interpolate stratigraphic contacts across the model extent, and cross sections along the northern perimeter embankment dike, shown on Figure 3, depicting features and stratigraphy from the 3D model are included on Figure 4 and Figure 5. The fill/native sand unit is the primary conduit of impacted groundwater flow. Native sands are present as two units separated by an intermediate silt/clay layer on the west side of the Karn Landfill, but the lower sand pinches out to zero thickness toward the east. The upper sand ranges in thickness from approximately 33 feet on the west side of the Karn Landfill to less than 10 feet on the east side. A continuous, native, hard silty clay unit, deposited as glacial till, exists beneath the sand and intermediate silt/clay units. The top of this unit is relatively flat throughout the eastern portion of the Karn Landfill, at an elevation of approximately 575 feet, but slopes downward to the west under the river to an elevation of 515 feet, and the unit extends to bedrock at an elevation of approximately 500 to 520 feet.

3.2 Geotechnical Conditions

Multiple geotechnical investigations have previously been completed at the Karn Landfill, and one investigation of note was a slope stability analysis conducted in 2010 by NTH that stated that further slope stabilization to the perimeter embankment dikes would likely be required prior to installing a soil-bentonite wall (reference (31)). Based on this evaluation and previous recommendations, Consumers regraded the perimeter embankment dike slopes along the intake channel and installed a geotextile liner and riprap on the perimeter embankment dike slope bordering the discharge channel in 2011 (reference (32)). Consumers also implemented a long-term monitoring plan for the perimeter embankment dike following the intake and discharge channel slope improvements (reference (33)).

A geotechnical evaluation was performed by Barr as part of the FS to assess the long-term stability of the northern perimeter embankment dike along the bay approximately between MW-8 and MW-16 under construction equipment loading assumed for implementation of the remedial response. The geotechnical evaluation of the perimeter embankment dike was performed by developing a geotechnical model in SLOPE/W, a two-dimensional slope stability modeling software (reference (34)), using data from previous geotechnical investigations ((reference (35)) (reference (36)), (reference (37)), (reference (38)).

Two sections were evaluated for construction (undrained) and long-term (drained) conditions. The two sections selected as critical sections for the geotechnical evaluation were along Transect 4, where there is a steep slope into the bay with a limited area between the toe of the slope and the bay, and through

Pond A East (consistent with Section I-I' from a prior report (reference (38)) where there is a shallower overall slope but a wider area between the toe of the slope and the bay and greater overall elevation change. Cross section locations are included in Attachment B. Initial stratigraphic information for the geotechnical model was generated from the existing EVS model for the Karn Landfill. The initial stratigraphy was refined based on information in previous evaluations (references (39) and (38)).

Conservative values for the bay surface water elevation were used in the geotechnical model. Recent low lake levels (reference (40)) were used for the downstream condition at Transect 4, where a low water condition is critical due to the lack of water buttressing the toe of the slope in the water. At Pond A East, the water level at the downstream toe was set at the beach elevation (581 feet) rather than the recent low lake level (576 feet), because dropping the water lower than the beach would result in less conservative conditions (i.e., a higher effective stress at the toe). For both model sections, the bay elevation is within the historical range recorded by National Oceanic and Atmospheric Administration (NOAA) Great Lakes Environmental Research Laboratory (576 ft [January 2013] to 582 ft [July 2020] (reference (40)).

Simulated loading at the two sections consisted of two discrete surcharge loads to represent tracks of either one-pass trenching equipment or a conventional long-arm excavator using discrete strip loads at the maximum dynamic loading conditions for a one-pass trencher, approximately 2,300 psf (16 pounds per square inch). With this loading, the factor of safety for both the construction loading (undrained) and long-term (drained) cases were acceptable. The factor of safety was found to be greater than 2.00 for all examined cases, which is greater than the recommended minimum factor of safety of 1.30 and 1.50 for construction and long-term conditions, respectively; therefore, the proposed construction activities are not anticipated to result in destabilization of the dike or slope failure.

Following completion of the FS, the extent of the remedial response area was revised to include the entire northern boundary of the Karn Landfill immediately upgradient of GSI, as shown on Figure 2. Therefore, it was necessary to evaluate the stability of the extended portion of the PRB due to presence of a stratigraphic unit that was not evaluated in the geotechnical model for the FS – the intermediate silt/clay unit. The intermediate silt/clay was previously studied by Golder (reference (38)) and was found to be sensitive based on field vane testing, possibly because of calcium carbonate cement. A geotechnical evaluation was performed to evaluate stability of the extended portion by developing a geotechnical model in SLOPE/W® software. Material parameters were assigned using data from previous geotechnical investigations.

A section was evaluated through Pond A into the bay at the northern portion of the northern perimeter embankment dike, as shown on Figure 3 of Attachment C, which represents the area with the greatest elevation change from the Karn Landfill to the bay, while intersecting the intermediate silt/clay unit. The intermediate silt/clay unit is generally a low-plasticity organic silt/clay, OL in the United Soil Classification System (reference (41)). Barr conducted an additional model scenario to evaluate the consequences of disturbing the cemented structure of the intermediate silt/clay through the PRB excavation process. In that model scenario, remolded strength values were selected for the intermediate silt/clay to represent the strength of the material in the absence of cementation. The remolded strength of the intermediate silt/clay was conservatively selected as the 25th percentile remolded strength from the field vane tests conducted by Golder in the ponds (reference (38)), 500 pounds per square foot (psf).

The phreatic surface in the stability model was set at approximately 582 feet based on results from the groundwater model. Construction loading during trenching activities was modeled consistent with the FS (Attachment B), using discrete strip loads at the maximum dynamic loading conditions for a one-pass trencher, approximately 2,300 psf (16 pounds per square inch), roughly centered on the dike alignment.

Results for drained and undrained loading were generally similar to those for Pond A East as described in the FS and are summarized in Table 3 of Attachment C. The results showed acceptable factors of safety relative to the threshold factors of safety of 1.30 for undrained loading and 1.50 for drained loading (40 CFR § 257.74(e)(1)). Remolded cases also had acceptable factors of safety relative to the 1.30 undrained threshold and the alternative 1.20 liquefaction threshold from 40 CFR § 257.74(e)(1), which was taken to be the nearest approximation of the remolded case. These results indicate no new conclusions for the geotechnical stability of the dike relative to what was previously identified; therefore, construction activities for a PRB across the extent of the northern perimeter embankment dike are not anticipated to cause dike or slope failure.

Additional details about the geotechnical models and input assumptions, such as hydraulic conditions, material parameters, and model results are in Attachment B and Attachment C.

3.3 Hydrogeology

Groundwater flows radially outward towards the bay, river, intake channel, and discharge channel (Figure 6). Following the closure of the Karn Bottom Ash Pond and the installation of final cover over the Karn Landfill, a reduction in hydraulic gradients and groundwater elevations has been observed in monitoring conducted under the Karn Landfill HMP. However, a groundwater potentiometric mound persists with the highest groundwater elevations near monitoring wells OW-11, DEK-MW-15003, and DEK-MW-18001. An NPDES surface conveyance ditch located just south of the Karn Landfill appears to be contributing to the groundwater mound. Groundwater elevations are expected to decrease once the Karn Generating Complex ceases operations, which is anticipated to occur in mid-2023; however, some degree of groundwater mounding may remain due to groundwater recharge south of the Karn Landfill.

Currently, the thickness of saturated ash ranges from approximately 0 to 13 feet based on water level measurements recorded approximately two years after the final portion of the final cover was constructed. As noted in Section 2.2, a system of six groundwater extraction wells, were installed to capture arsenic-impacted groundwater for treatment and discharge. The system experiences intervals of downtime due to maintenance issues, and the system runtime and total pumping rate have been lower than anticipated.

Hydraulic conductivity has been estimated based on site-specific slug testing and laboratory testing of soil samples from 62 locations at the Karn Landfill and 22 locations at the adjacent Weadock Landfill. Hydraulic conductivities are comparable for materials tested at both landfills; therefore, the presented values include data from both landfills. The horizontal hydraulic conductivity estimates for ash, the upper native sand unit (Figure 7), and the clay layer range from 7.1×10^{-2} to 28 feet per day (feet/day), 1.2×10^{-2}

to 54 feet/day, and 2.2 x 10^{-2} to 0.17 feet/day, respectively. Samples were collected from the northern perimeter embankment dike, native clay, and intermediate silt/clay unit for use in laboratory falling head tests to estimate vertical hydraulic conductivity at the Karn and Weadock Landfills (references (22) (42)). Vertical hydraulic conductivity of the clay is consistently lower than horizontal hydraulic conductivity, and the vertical hydraulic conductivity of the intermediate silt/clay was measured at 10 x 10^{-2} and 1.78 x 10^{-2} feet/day.

3.4 Surface Water Hydrology

As of July 2021, average surface water elevations at the NOAA Essexville gauge station increased by approximately four feet since 2013 when record low elevations were recorded following an approximately 24-year-long trend of decreasing surface water elevations. Great Lake water levels fluctuated over a range of 3 to 6 feet since the nineteenth century and, in the future, more rapid fluctuations between extreme low and extreme high water levels are expected, due to increasingly volatile trends in regional precipitation and temperature attributed to climate change (reference (43)). Flood control at the Karn Landfill is maintained with the perimeter embankment dike system to prevent inflow from the river and bay, and a series of lined drainage ditches to control runoff from precipitation that falls within the closed area of the Karn Landfill.

3.5 Groundwater Quality

Coal ash-related constituents are detected in groundwater based on routine monitoring performed pursuant to the Karn Landfill HMP (reference (1)). The Karn Landfill HMP Rev. 03 prescribes a GSI Compliance Monitoring program that consists of quarterly groundwater samples collected from 10 monitoring wells, quarterly porewater samples collected along 6 transects (Figure 2) in the bay, and annual field leachate samples collected from two leachate head wells screened in ash. It is expected that field leachate sampling under the Karn Landfill HMP will be discontinued during the 30-year post-closure care period, and groundwater and porewater monitoring frequency under the Karn Landfill HMP may be reduced in the future.

Groundwater from the Karn Landfill vents into the bay, and the GSI is the primary exposure pathway associated with the Karn Landfill. Since 2016, arsenic, boron, chromium (based on the GSI criterion for hexavalent chromium), molybdenum, and selenium have been detected in groundwater above Michigan generic GSI criteria, and arsenic and boron are the two parameters that are most consistently detected at concentrations above generic GSI criteria at the Karn Landfill. Site-specific mixing zone criteria for arsenic, boron, and selenium have been established (reference (44)). Of these parameters, arsenic is the primary coal ash parameter of interest, because it has been observed above the acute mixing zone-based concentration criteria (680 µg/L) in northern perimeter embankment dike monitoring wells upgradient of where the GSI is monitored for compliance at Transects 3 and 5. Selenium and boron concentrations are regularly observed above generic GSI criteria but not above chronic or acute site-specific mixing zone criteria.

Figure 8 shows arsenic concentrations measured in July and August 2021, and concentrations in monitoring wells upgradient of the bay exceed site-specific mixing zone criteria. Compliance with applicable mixing zone-based GSI criteria has been documented to be achieved on a quarterly basis since 2010, consistent with the requirements set forth in the Revisions to GSI Criteria and Facility Relicensing for Consumers Energy's Weadock and Karn Landfills, Bay County letter sent by EGLE on August 26, 2009 (reference (5)), but arsenic levels have been observed above the chronic mixing zone-based concentration value of 100 µg/L at the alternative monitoring points for compliance (i.e., GSI transect point at water's edge) at Transects 3 through 5. Therefore, Consumers has demonstrated compliance by evaluating the total chronic loading based on contribution from each compliance monitoring location with respect to the total flux observed in the mixing zone (reference (10)

3.6 Constraints

Potential constraints at the Karn Landfill that were considered and incorporated into the remedial response design summary in Section 5 are:

- Access Roads
- Perimeter embankment dikes
- Infrastructure, including high voltage power transmission lines and towers, monitoring wells and piezometers, stormwater culverts, and the existing groundwater extraction system
- Final cover system

Approximate locations of these potential constraints are shown on Figure 9.

4 Options Assessment and Feasibility Study Summary

A corrective action options assessment and FS were conducted to assess potential corrective actions and identify a remedial response to address arsenic-impacted groundwater venting to the bay from the Karn Landfill. Following the expansion of the remedial response area to be inclusive of the entire northern boundary of the Karn Landfill, an addendum to the FS was completed to evaluate the feasibility of remedial response in the northwest portion of the northern perimeter embankment dike. Additionally, an accelerated flow-through column test was conducted to further assess the technology by more fully replicating conditions associated with full-scale implementation of a PRB, including use of an actively supplied source of groundwater collected under the Karn Landfill to feed the columns. The FS, FS addendum, and column testing summary are included as Attachment B, Attachment C, and Attachment D to this document, respectively, and summary of each is included below.

4.1 Options Assessment Summary

A remedial response options assessment (options assessment) was completed to evaluate potential remedial response options for addressing arsenic-impacted groundwater related to the Karn Landfill from Transects 2 through 6 and recommend remedial response options to be carried forward for further assessment in the feasibility study (FS). The five remedial response options evaluated in the options assessment were 1) installing a low-permeability subaqueous cap; 2) excavating coal ash material from the Karn Landfill; 3) optimizing the existing groundwater extraction and treatment system and installing a barrier wall; 4) installing an air sparging system; and 5) installing a permeable reactive barrier (PRB) containing zero-valent iron (ZVI). Relative advantages and disadvantages, implementability, effectiveness at meeting remedial response objectives, estimated cost relative to other remedial response options, schedule, and data gaps were compared for each remedial response option.

Installation of a subaqueous cap was not retained for further evaluation, because short-term and long-term effectiveness was uncertain, and it would have a relatively high cost to the other technologies without providing source control or treatment at the solid waste boundary. Excavating coal ash material from the Karn Landfill was not retained for further evaluation because the construction duration would delay effective source control by at least four years, and source control through excavation was expected to have a relatively high cost to the other technologies without the benefit of improving short-term protection until construction was completed.

Optimization of the groundwater extraction system detailed in the Karn Landfill HMP, along with installation of a barrier wall, an air sparging system, and a PRB were carried forward for further assessment in the FS.

4.2 Feasibility Study Summary

In the FS, the remedial response options were evaluated in greater detail on the basis of effectiveness, implementability, advantages, disadvantages, permitting considerations, community considerations, schedule, and feasibility-level costs, and in general accordance with section 20120 of Part 201. The FS concluded that the preferred remedial response option to meet the remedial response objective is a PRB based on:

- Bench testing results show that ZVI is effective in treating arsenic in groundwater within the remedial response area.
- Groundwater modeling results, further detailed in Attachment B, indicate that a fully permeable PRB is preferred to a funnel-and-gate design utilizing low-permeability walls to funnel groundwater through the permeable reactive sections of the PRB, to capture and treat groundwater flow to the bay.
- It is expected to provide short- and long-term effectiveness in reduction of arsenic concentrations in groundwater.
- It is expected to be implementable with low operation and maintenance requirements relative to other remedial response options.
- There are few permitting and community considerations.
- The schedule for construction following finalization of design and selection of a contractor would likely be equal to or shorter than other remedial response options.
- The cost appears favorable relative to other remedial response options.

Additional detail on the bench testing and groundwater modeling conducted to evaluate the feasibility of a PRB as part of the FS is included below. Additional detail on the balancing criteria and schedule and relative costs is included in the FS (see Attachment B).

4.2.1 PRB Bench-Scale Testing Results

Barr completed bench-scale testing to evaluate the effectiveness of a ZVI-containing PRB for treatment of arsenic and the potential treatment lifespan of a PRB. Bench-scale testing also identified certain design data collection needs for a PRB.

Work performed by others in 2014 evaluated the ability of ZVI, activated alumina, and ferric sulfide coated activated alumina to mitigate arsenic concentrations in sodium arsenite-spiked porewater. The spiked porewater, soils from the Karn Landfill, and varying masses of the amendments were allowed to react in continuously stirred batch reactors (CSBRs). Results indicated that all three amendments were capable of removing arsenic from solution, the ZVI most effectively removed arsenic, and there were not major concerns identified regarding adverse effects from the installation of a ZVI-containing PRB at the Karn Landfill (reference (45)).

The results of this work were used by Barr to design two bench testing experiments. The first experiment was performed to evaluate the rate of the reaction between arsenic in Karn Landfill groundwater and ZVI by varying the amount of time that reaction was allowed to occur. The second experiment used CSBRs to assess the effectiveness and treatment capacity of ZVI exposed to Karn Landfill groundwater by reacting two masses of ZVI with successive batches of Karn Landfill groundwater.

Groundwater used in the experiments was collected from MW-10 using low-flow sampling methods and was transported and stored under a nitrogen blanket to limit aeration and a potential associated shift in oxidation state of arsenic in the groundwater. The ZVI used was for both tests was Peerless Metal Inc. 8/50 ZVI, which is a pure, oil-free ZVI designed for implementation in PRBs. The kinetic rate experiment and CSBR experiments are detailed below.

4.2.1.1 Kinetic Rate Evaluation Experiment

The kinetic rate evaluation experiment was designed to evaluate reaction kinetics between ZVI and arsenic in Karn Landfill groundwater and inform the design of the CSBR experiment. During the kinetic rate experiment, six vials containing groundwater and ZVI were placed on a vial spinner and allowed to react for varying times (i.e., 1, 3, 5, 9, or 12 hours). Five vials contained 47.5 milliliters (mL) of groundwater and 2.5 grams of ZVI, and the sixth vial acted as a control, containing only Karn Landfill groundwater. At each designated time interval, effluent water was collected from the appropriate vial for laboratory analysis of dissolved arsenic and dissolved arsenic analysis by a Hach® low-range arsenic field test (Hach® test). Due to limited sample volume, the Hach® tests were performed with a 2:1 dilution of two parts de-ionized water and one part effluent sample water.

Tabulated analytical results, the laboratory analytical report, and photos documenting Hach® test results are included in Attachment B. Analytical results indicate that at each interval, the reacted water was non-detect for dissolved arsenic; however, the analytical results for this test were likely affected by the formation of a precipitate in the samples. During sample collection, the samples were filtered through a 45 micrometer (μM) filter and initially appeared clear, but after storage overnight, a reddish-brown precipitate formed. It is believed that this precipitate is likely an iron compound due to its coloration and because it was not observed in the control vial (which was not reacted with ZVI). This indicates that dissolved iron and arsenic continued to react after the sample was collected, and additional arsenic was precipitated out of solution after sample collection. Because of this potential qualification to the analytical sample results, the Hach® tests were relied on for evaluation of arsenic concentrations. Hach® test results were obtained immediately after sample collection, so results are more representative of conditions compared to analytical sample results, and results from the Hach® test generally agree with available literature on similar experimental setups (reference (46)).

Results of the experiment indicated:

- The Hach® tests collected during the experiment suggest that the ZVI is capable of reducing dissolved arsenic concentrations from greater than 300 μg/L to approximately 10 to 30 μg/L within one hour of reaction time.
- Arsenic concentrations in the effluent water were less than analytical detection limits within nine hours of reaction time.

- Arsenic concentrations were not significantly reduced in the control sample indicating that the reaction with ZVI was the main method of arsenic removal.
- Hach® test results and analytical results for the control sample generally agree.

4.2.1.2 Continuously Stirred Batch Reactor Experiment

A CSBR experiment was performed by Barr to evaluate the potential treatment capacity of the ZVI and treatment lifespan of a ZVI-containing PRB at the Karn Landfill. Two different batch reactors were operated during the experiment, one containing 5 grams of ZVI and one containing 10 grams of ZVI. Fourteen batches for each mass of ZVI were run by allowing 4,000 mL of groundwater to react with the ZVI for 12 hours while being constantly mixed by overhead stirrers in vessels that were open to the atmosphere.

The 5-gram and 10-gram ZVI masses used in the experiment were chosen based on the ratio of an obtainable volume of groundwater for the experiment to masses of ZVI that would allow for simulating decades of groundwater flow through a PRB. Assumptions for the simulated PRB design were based on the evaluation performed in the corrective action options assessment, which assumed a 1.5-foot thick PRB, containing 30% ZVI by mass. A groundwater flux through the proposed location of the PRB of 370 gallons per square foot per year was assumed based on the groundwater flux evaluation performed by others as part of the first quarter 2020 Groundwater Monitoring Report (reference (47)). A residence time of groundwater in the PRB was calculated based on the groundwater flux and PRB thickness, and the mass loading of ZVI within the PRB was used to estimate a volumetric flow of groundwater per unit mass of ZVI per year. The results of this evaluation indicated that each 4,000 mL batch of groundwater would represent approximately 5.6 years of *in situ* groundwater flow in a 10-gram ZVI CSBR, and 11.2 years in a 5-gram ZVI CSBR. These values are directly related to the mass loading of ZVI and thickness of the PRB (e.g., doubling the assumed PRB thickness would double the time simulated by each batch) and the values are inversely related to the groundwater flux.

The 12-hour reaction time used in the experiment was based on the kinetic rate experiment, which suggests that a reaction time of nine hours or more is sufficient to reach equilibrium in the reaction between the groundwater and ZVI under mixing conditions, and literature documenting similar experiments (reference (46)).

After 12 hours, effluent samples were collected from each batch through a 45 µM filter, Hach® tests were performed on the reacted water, and water quality field parameters of the reacted water were measured with a YSI Pro DSS® water quality meter. The batch reactors were then drained while retaining the ZVI, and 4,000 mL of unreacted groundwater was added to begin the next batch. The ZVI in the batch reactors was not replaced or supplemented with fresh ZVI during the experiment.

Analytical results, field parameters, and an image showing the Hach® field test results are in Attachment B. The Quality Assurance/Quality Control (QA/QC) data were reviewed to assess the validity of the analytical results, and the QA/QC data evaluations are included in Attachment B. The results of the CSBR experiment suggest that a PRB containing ZVI has the potential to attenuate arsenic in groundwater at the Karn Landfill for an extended period of time before needing refreshment based on the following observations:

- Groundwater collected from MW-10 had an arsenic concentration of approximately 450 µg/L, and arsenic was primarily in the arsenite (As^{+3}) form.
- Some arsenite was oxidized to arsenate (As^{+5}) during collection, transport, and storage of the groundwater despite the use of nitrogen blanketing, and the dissolved arsenic concentration was reduced to approximately 385 µg/L. Literature suggests that arsenite and arsenate are both effectively removed by a ZVI-containing PRB (reference (48)), and results from the CSBR experiment are expected to be adequately representative of in-situ ZVI-driven arsenic attenuation, despite the oxidation of the groundwater.
- The ZVI in both the 5-gram and 10-gram batches was capable of reducing influent arsenic concentrations by approximately 90% or more over the course of 4 and 8 batches, respectively, representing approximately 45 years of treatment for both masses of ZVI tested.
- Effluent water quality observations did not present concerns for adverse changes to groundwater downgradient of the PRB based on the following:
    - Effluent iron concentrations were below the influent iron concentration of 22 µg/L in all samples except one where an effluent iron concentration of 33 µg/L was reported, which is approximately an order of magnitude below groundwater quality standards.
    - The pH of the effluent water did rise from approximately 7.3 standard units (s.u.) to an average of approximately 8.0 s.u. and maximum observed value of approximately 8.7 s.u. during the experiment. An increase of pH is expected from treatment with ZVI, and is exaggerated by CSBR testing due to the relative high availability of oxygen in a CSBR, but treated water was not observed to exceed groundwater quality criteria of 9.0 s.u.
- Both batches of ZVI treated 56 L of water during the course of the experiment and did not reach exhaustion of their treatment capacity; however, the treatment capacity of the ZVI was reduced over the course of the experiment, indicating refreshment of the ZVI media during the post-closure period would likely be required to maintain compliance with the mixing zone-based value arsenic.

Groundwater used in the experiment had an arsenic concentration of approximately 385 µg/L after transportation and storage, but concentrations of greater than 1,000 µg/L have been observed within the remedial response area. To estimate the potential treatment lifespan of the PRB, the percent-removal of arsenic by ZVI in the experiment was used to estimate a conservative treatment lifespan of the ZVI (i.e., an upper estimate based on relatively ideal conditions in the CSBR). To treat groundwater to below the mixing zone-based concentration criteria of 100 µg/L for arsenic, a PRB must provide at least 90% attenuation of arsenic in the most impacted areas of the remedial response area. A removal efficiency of approximately 90% was observed through the first four batches in the 5-gram CSBR, and first eight batches in the 10-gram CSBR, representing approximately 45 years of treatment by both masses of ZVI.

Due to the constraints of a batch testing experiment in evaluating PRB performance, these results are meant only to represent a proof of concept for groundwater treatment by ZVI and demonstrate a treatment capacity of ZVI under experimental conditions. Other *in situ* conditions such as plugging and fouling of the PRB by mineral precipitation and reaction kinetics under non-mixed conditions may reduce the treatment lifespan of the PRB relative to the conservative estimate of 45 years. These factors were further evaluated during a flow-through column study performed by Barr between December 2020 and March 2021.

4.2.2 Groundwater Modeling

A groundwater flow model was developed to represent groundwater flow directions near the landfill in support of the FS. The Karn Landfill was previously represented in groundwater flow models by others in 2011 and 2016 (reference (49); Attachment B of Appendix F of reference (50)). Hydrologic conditions have changed at the Karn Landfill since 2016 due to the clean-closure of the Karn Bottom Ash Pond and Karn Landfill; therefore, the groundwater flow model was updated to simulate hydrologic conditions in June 2010, March 2016, and October 2019. Additionally, a geologic model was developed in EVS software (reference (51)), and the geologic model provided an up-to-date and comprehensive understanding of Karn Landfill geology for use in an updated groundwater flow model. Additional details about the groundwater flow model and input assumptions, such as the model domain, layers, and boundary conditions, are included in Attachment B. A fully permeable PRB was not initially simulated using the groundwater model for the FS, because implementation of that design is not expected to alter groundwater flow at the Karn Landfill until fouling of the PRB has occurred. The magnitude and rate of fouling was not estimated during FS development, but subsequent modeling efforts during the FS Addendum development included groundwater modeling with assumed hydraulic conductivity reductions through the PRB due to fouling.

During FS development, a simulation was performed to assess the feasibility of a funnel-and-gate PRB. A funnel-and-gate PRB is constructed by installing low-permeability barrier walls (e.g., soil-bentonite cutoff walls) with strategically placed permeable sections containing reactive materials. The goal of the low-permeability barrier walls is to direct groundwater flow through the reactive gates, which can have advantages including:

- Lowering the total amount of reactive materials required to address groundwater concerns.
- Reducing the level of effort required to replace the PRB.

Potential disadvantages of a funnel-and-gate design compared to a fully permeable PRB include:

- Requiring a greater overall footprint to adequately capture groundwater flow.
- Causing greater changes to groundwater flow patterns at the Karn Landfill, adding greater uncertainty of system performance during the design phase.

- Accelerating groundwater flux through the permeable sections of the PRB which potentially decreases treatment effectiveness and increases the rate of PRB material aging, necessitating more frequent replacement.

- Increasing the costs of the initial construction.

The funnel-and-gate PRB was modelled as single 1,500-foot permeable reactive gate between two low-permeability cutoff walls with a combined length of approximately 2,800 feet. Modeling results for the PRB option are shown in Figure 12 of Attachment B, and indicate the following:

- The low-permeability cutoff walls would potentially need to extend beyond the remedial response area to provide complete treatment of impacted groundwater in the remedial response area due to groundwater flow around the impermeable cutoff walls.

- The low-permeability cutoff walls could increase groundwater elevations upgradient of the PRB and could cause daylighting of groundwater along sections of the PRB.

- Some groundwater would flow through the low-permeability barrier as indicated by the particle flow paths that pass through the low-permeability barrier in the northwest portion of the barrier shown on Figure 12 of Attachment B.

- Groundwater flow would be accelerated at the interfaces of the impermeable cutoff walls and reactive gate, which would reduce the residence time of the groundwater in the reactive media and potentially accelerate aging of portions of the permeable reactive gates.

Based on these modeling results and the estimated PRB treatment lifespan, a funnel-and-gate design was not considered cost effective compared to a fully permeable PRB, and a fully permeable PRB was assumed for the FS. A fully permeable PRB was further evaluated with groundwater modeling in the FS addendum and is described in Section 4.3.1.

4.3 Feasibility Study Addendum Summary

Following completion of the FS, the extent of the remedial response area was revised to include the entire northern boundary of the Karn Landfill immediately upgradient of GSI, as shown on Figure 2. The geology in the northwest portion of the northern perimeter embankment dike is different than in the FS remedial response area (i.e., the northern landfill boundary approximately between MW-8 and MW-16).. Specifically, the depth to the glacial till clay is significantly deeper, and a lower native sand unit is present and separated from the upper native sand unit by an intermediate silt/clay unit (Figure 4). Therefore, an addendum to the FS was completed to evaluate the feasibility of a PRB in the revised remedial response area.

Additional investigation activities conducted during the FS Addendum development were monitoring well installations, soil and groundwater sampling, slug testing, and pump testing. Nine temporary monitoring wells were installed at five locations shown in Attachment C, which includes two locations where monitoring wells were screened below the intermediate silt/clay layer in the lower native sand unit.

Monitoring well installation activities included analysis of soil samples collected above and below the intermediate silt/clay unit and laboratory flexible wall permeameter testing of two Shelby tube samples collected from the intermediate silt/clay layer. Slug testing was performed at four temporary well locations to evaluate the hydraulic conductivity of the upper and lower native sand units, and a pumping test was performed to evaluate the competency of the intermediate silt/clay layer. The results of the investigation activities are contained in Attachment C and are further discussed in Sections 4.3.1 through 4.3.3.

Based on data collected as part of the FS addendum, the remedial response is not needed within the lower sand unit (i.e., the native sand layer below the intermediate silt/clay layer) in the revised remedial response area because documented arsenic concentrations are below mixing zone-based GSI criteria and the intermediate silt/clay layer appears to be consistently confining. Therefore, the PRB in this area can be keyed into the intermediate silt/clay layer.

The feasibility of constructing a PRB in the revised remedial response area was based on hydrogeological, geotechnical, and constructability evaluations; a reevaluation of FS balancing criteria (i.e., short- and long-term effectiveness; implementability; and permitting and community considerations); and reassessment of schedule and range of costs. Results from evaluations in the FS addendum suggested that installing a PRB in the revised remedial response area is feasible and could accomplish the remedial action objectives based on the following:

- Groundwater quality, soil quality, and hydrogeologic conditions within the additional remedial response area (i.e., the remedial response area that is outside of the extent considered in the FS) are generally consistent with conditions observed within the FS remedial response area extent. Bench and column testing completed during the FS indicated a PRB containing ZVI would mitigate arsenic impacts; therefore, the consistent groundwater quality, soil quality, and hydrogeologic conditions indicate the PRB will also be effective in the additional remedial response area.

- Based on groundwater modeling results, it is not anticipated that a PRB installed along the length of the revised remedial response area and keyed into the uppermost confining unit (i.e., the intermediate silt/clay unit to the northwest and the glacial till to the southeast) would alter groundwater flow directions in a manner that would significantly reduce the effectiveness of a PRB. A PRB installed in this manner is expected to mitigate arsenic-impacted groundwater that is currently venting from the Karn Landfill into the bay.

- Based on geotechnical and constructability evaluations, a PRB is implementable within the additional remedial response area.

A summary of the soil and groundwater data comparison, groundwater modeling, and PRB constructability evaluation performed as part of the FS Addendum is below. Additional detail on these items and the FS balancing criteria revaluated for the revised remedial response area are included in Attachment C.

4.3.1 Groundwater and Soil Quality Comparisons

Bench testing conducted as part of the FS and the flow-through column study assumed a PRB would be installed in the FS remedial response area. To assess effectiveness of a PRB installed across the entire northern boundary of the Karn Landfill, groundwater and soil quality data from the FS remedial response area extent were compared to groundwater and soil quality data collected from the additional remedial response area extent to assess differences in groundwater and soil quality data between these two areas and potential implications differences may have on the effectiveness of a PRB.

4.3.1.1 Groundwater Quality Comparison

Groundwater quality will primarily influence the effectiveness of a PRB based on: 1) the ability of a PRB containing ZVI to provide long-term attenuation of arsenic to below site-specific mixing zone-based criteria, 2) the rate and magnitude of plugging/fouling of the PRB, and 3) the potential for adverse changes to non-arsenic parameters.

Groundwater samples were collected in July 2021 at nine temporary monitoring wells in the additional remedial response area, including two locations screened below the intermediate silt/clay layer in the lower native sand unit. Results from July 2021 sampling in the additional and FS remedial response areas are shown on Figure 10. Arsenic concentrations in monitoring wells below the intermediate silt/clay unit were less than the site-specific chronic and acute mixing zone-based GSI criteria for arsenic. Therefore, remedial response is not needed in the lower native sand unit and data collected from the lower native sand unit are not compared to groundwater data from the FS remedial response area in this section.

Groundwater quality data collected from wells screened in the upper sand unit in the additional remedial response area in July 2021 (included in Attachment C) were compared to data collected from wells screened in the upper sand unit in the FS remedial response area (i.e., MW-8, MW-10, MW-12, and MW-14) in August 2020, October 2020, and July 2021 (included in Attachment C). For each location, the most recent data available for each parameter was used in the comparison. A comparison of the average values for select parameters in each extent is included in Table 1.

Table 1 Feasibility Study Area and Additional Area Groundwater Quality Comparison

Parameter	Units	Average Value	
		FS Remedial Response Area	Additional Remedial Response Area
Alkalinity, total, as $CaCO_3$	µg/L	447,500	331,286
Total Arsenic	µg/L	276	338
Total Calcium	µg/L	223,750	136,600
Total Iron	µg/L	3,769	1,495
Total Magnesium	µg/L	64,300	27,814
Total Manganese	µg/L	557	407
Oxidation reduction potential	millivolts	-52.0	-123
pH	s.u.	7.2	8.3
Total Potassium	µg/L	12,775	6,883
Sulfate, as SO_4	µg/L	452,225	154,729

Key observations from this evaluation are as follows:

- The data do not suggest that iron concentrations will be higher downgradient of the additional remedial response area than downgradient of the FS remedial response area.
- The oxidation reduction potential within the additional remedial response area suggests that the aquifer is a reducing environment consistent with conditions observed within the FS remedial response area. This indicates that arsenic speciation will be similar between the two areas, and arsenic will primarily be in the more soluble arsenite form (As^{3+}).
- The average pH observed within the additional remedial response area was higher than the average pH observed within the FS remedial response area.
    - Higher groundwater pH can lead to greater mineral deposition within the PRB and/or localized areas where groundwater pH may approach a relevant criterion immediately downgradient of the PRB.
    - Observations included in the FS of ZVI's propensity to increase the pH of Karn Landfill groundwater suggest that ZVI at a 5% amendment ratio will likely not increase groundwater pH above 9.0 s.u. under in-situ conditions.
- Groundwater quality minerals and parameters that may affect the rate and magnitude of plugging and fouling of a PRB, which include calcium, magnesium, manganese, alkalinity, and sulfate, have lower concentrations within the additional remedial response area than within the FS remedial response area. However, the rate of plugging and fouling within the

additional remedial response area extent is expected to be similar to the FS remedial response area extent due to the higher pH observed within the additional remedial response area extent.

Together, these observations suggest that a PRB installed in the additional remedial response area would have the ability to provide effective, long-term removal of arsenic to below site-specific mixing-zone based GSI criteria, consistent with findings from the FS for a PRB installed in the FS remedial response area. Changes to groundwater quality downgradient of a PRB are anticipated to be consistent between the two areas based on this evaluation.

4.3.1.2 Soil Quality Comparison

Soil quality in the upper sand unit was compared between the additional and FS remedial response areas based on soil samples collected from the TW-21-009 through TW-21-013 borings installed in July 2021 and the DEK-SB-20001 through DEK-SB-20010 borings installed in July 2020. The locations and analytical results from the 2020 and 2021 soil samples are included in Attachment C.

Field observations of the upper sand unit were similar in both areas. The saturated soils in these areas were primarily classified as poorly graded, fine to medium grained, tan to dark gray sands. A comparison of analytical data from each area included concentrations of total organic carbon (TOC), arsenic, and iron. A comparison of the average values in each extent for each parameter is included in Table 2.

Table 2 Feasibility Study Extent and Additional Remedial Response Area Extent Soil Quality Comparison

Parameter	Units	Average Value	
		FS Remedial response area	Additional Remedial response area
Carbon, total organic	milligrams per kilogram (mg/kg)	2,380	1,590
Moisture	%	15.9	19.2
Solids, percent	%	84.0	80.0
Arsenic	mg/kg	7.73	7.39
Iron	mg/kg	4,080	3,450

For each of these parameters, average concentrations in the two areas were generally consistent. Average arsenic and iron concentrations were approximately 4% and 15% lower, respectively, between the additional and FS remedial response areas. The average TOC concentration was approximately 33% lower within the additional remedial response area compared to the FS remedial response area. High TOC concentrations can result in biofouling of PRBs, but literature suggests that biofouling is not a concern for ZVI-containing PRBs (reference (48)), and so the differences in TOC between the two areas does not affect this evaluation. A comparison of field observations and analytical data collected between these two areas suggests that performance of a PRB would be similar between the additional and FS remedial response areas.

4.3.2 Groundwater Modeling

The groundwater model for the Karn Landfill, as described in Attachment B, was updated with hydraulic conductivity estimates from additional investigation activities, described in Attachment C, to evaluate the potential for groundwater to bypass (by going around or under) a PRB in the revised remedial response area before discharging to the bay. Groundwater model files, including from scenarios run for the FS, are included in Attachment C.

The vertical hydraulic conductivity of the intermediate silt/clay unit was updated in the groundwater model based on the lab permeability test results. Pumping test results corroborated the lab permeability test results but were not used directly because the lab permeability test was a more direct measurement of the vertical hydraulic conductivity. Horizontal hydraulic conductivity of the intermediate silt/clay unit remained at the calibrated value (1.86 feet/day). The horizontal hydraulic conductivity of the lower native sand unit was updated in the groundwater model based on the results of slug tests completed at TW-21-011D and TW-21-012D and the pump test completed at TW-21-012D. The vertical hydraulic conductivity of the lower native sand unit was updated to maintain anisotropy of 10, consistent with the calibrated model. A summary of groundwater model hydraulic conductivity updates is shown in Attachment C.

The calibrated horizontal hydraulic conductivity of the upper native sand unit was reviewed against the results of slug tests completed in the additional remedial response area and against previously collected data. Instead of updating and recalibrating the groundwater model, a sensitivity analysis of the upper native sand hydraulic conductivity was performed with predictive scenarios described in Attachment C.

The groundwater model was used to simulate the “existing” Karn Landfill conditions (i.e., October 2019 conditions with no PRB) (Figure 11) and for three predictive scenarios which included a PRB with assumed hydraulic characteristics under initial, moderately fouled, and highly fouled conditions. Data from October 2019 is expected to be reasonably representative of future conditions because the remaining landfill cells were closed with final cover and CCR materials in the Karn Bottom Ash Pond had been dredged out and the area backfilled with clay. As discussed in Section 3.3, groundwater elevations are expected to decrease once the Karn Generating Complex ceases operations and groundwater flow rates may be reduced. This will be evaluated during final design.

Three sensitivity scenarios were completed using PRB hydraulic conductivity values listed in Table 3, which were based on available literature data.

Table 3 Summary of PRB Fouling Characteristics

PRB Condition Represented in Model Scenario	Porosity	Hydraulic Conductivity (feet/day)
Initial condition[1]	0.32	12.1
Moderately fouled[2]	0.17	1.21
Highly fouled[2]	0.02	1.42×10^{-3}

[1] Values assumed from literature data (reference (52))
[2] Values calculated from initial condition values as well as literature methods for porosity reduction and estimating hydraulic conductivity from porosity (reference (53))

The existing Karn Landfill conditions scenario served as a basis of comparison for the effects of installing a PRB and PRB fouling on groundwater flow through the remedial response area. The initial and moderately fouled PRB scenarios resulted in negligible flow differences through the remedial response area compared to the existing conditions, indicating groundwater flow through the PRB will occur and groundwater bypassing the PRB is not expected under initial or moderately fouled conditions. Groundwater modeling results for the moderately fouled scenario are shown on Figure 12. For the highly fouled scenario, 3% of the particle traces that flowed through the PRB under initial and moderately fouled conditions (and, therefore, through the PRB area under existing conditions), bypassed the PRB to the northwest, indicating some bypass could occur under highly fouled conditions and PRB media refreshment should occur before the PRB becomes highly fouled. Additional detail for the groundwater modeling conducted as part of the FS Addendum can be found in Section 5.3 and Attachment C.

4.3.3 Constructability

A constructability evaluation was performed to assess the feasibility of installing a PRB within the revised remedial response area (i.e., the entire northern boundary of the Karn Landfill). Constructability considerations evaluated were the existing remedial response area constraints, the anticipated PRB geometry, and the anticipated PRB design parameters. These considerations were evaluated for a one-pass trenching technology; however, this construction is likely feasible with multiple PRB installation technologies.

Constraints including the landfill final cover system, perimeter embankment dike geometry, existing infrastructure, and existing stratigraphy were evaluated for assessing the PRB constructability. The landfill final cover system will restrict the PRB work platform width to the perimeter embankment dike crest, but the perimeter embankment dike crest width of approximately 24 feet should be sufficient for one-pass trenching. However, the perimeter embankment dike crest slopes may require grading to create a level work platform. Locations of utilities and other existing infrastructure will need to be verified during remedy design, and the final design will include provisions to prevent damage to existing infrastructure. The remedial response area stratigraphy is not anticipated to include large cobble seams or boulders that would obstruct the operation of a one-pass trenching technology. Thickness of the intermediate silt/clay unit was observed to be approximately 9.5 and 5.0 feet at TW-21-011D and TW-21-012D, respectively, and those observations generally agree with observations from other deep borings in the vicinity and the modeled thickness of the layer from the EVS model previously completed by Barr. A minimum embedment depth requirement of 2 feet to 3 feet is anticipated in this unit, which is achievable for the thicknesses observed, while an embedment of 5 feet is anticipated in areas where the PRB would be embedded into the glacial till.

PRB geometry assumptions for depth, width, alignment, and continuity were evaluated for assessing the PRB constructability. The depth of the PRB is anticipated to range from 25 feet to 45 feet and reaching this design depth range is achievable by the one-pass trenching technology. One-pass trenching methods typically minimize the number of depth changes for production efficiency; however, the technology does have the capability to install to a variable design depth profile as needed. A minimum width of 1.5 feet is anticipated for the remedy design and is achievable with the one-pass trenching technology (standard machine widths are 1.5 feet, 2 feet, and 2.5 feet). The one-pass trenching operation will likely require the alignment be offset from the centerline of the dike crest to allow for traffic and material staging on the crest, which will serve as the working platform, however this should not create a constructability concern.

PRB parameter assumptions of strength, permeability, uniformity, continuity, and ZVI amendment rate were evaluated for assessing the PRB constructability. Industry standard strength and permeability ranges are anticipated for the remedy design and are achievable by the one-pass trenching technology. Uniformity and continuity requirements are achievable with the one-pass trenching operation which is able to construct a well-mixed final barrier through the subsurface layers and achieve a consistent ZVI amendment rate.

Results of the constructability evaluation indicate that it is feasible to construct the extended PRB with one-pass trenching technology. It is likely that other common PRB installation technologies could achieve the anticipated remedy design; however, one-pass trenching is anticipated to be the more efficient, lower cost, and effective installation method.

4.4 Flow-Through Column Testing Summary

Bench testing completed as part of the FS indicated that attenuation through direct contact with ZVI was an effective means to remove arsenic from impacted groundwater. Barr completed accelerated flow-through column testing to further assess the technology by more fully replicating conditions associated with full-scale implementation of a PRB, including use of an actively supplied source of groundwater collected from the Karn Landfill to feed the columns.

The column test was conducted from December 1, 2020 through March 2, 2021, which allowed for a pore-volume throughput equivalent to approximately 30 years of service life of a full-scale PRB that is under consideration for use at the Karn Landfill. The number of pore water volume flushes a full-scale PRB would experience over 30 years was estimated based on the assumptions that a full-scale PRB would have a width of 1.5 feet, a porosity of 0.3, and the average groundwater velocity of 0.027 feet/day, which is based on the velocity predicted by Barr's groundwater modeling results in the area of installation. These assumptions suggest that a PRB of above-referenced characteristics would experience approximately 660 pore water volume exchanges during a 30-year service life. That number of pore water volume exchanges was used to establish the test duration based on flow rate through the column.

An empty bed contact time (EBCT) of 9 hours was selected based on previous kinetic rate testing, which suggested a reaction time of less than 9 hours was adequate to achieve acceptable reductions in arsenic concentrations (i.e., concentrations of arsenic were 0 to 10 µg/L after 9 hours).

Selecting an EBCT of 9 hours established the flow rate based on the volume of the test columns. Consistent with design guidance for accelerated column tests design (reference (54)), replicating the number of pore water volume exchanges in a column study that would be realized in full-scale implementation, while passing groundwater at a faster rate through the column than what would occur in full-scale implementation, is an efficient means of evaluating the longevity of a reactive medium.

The column test was conducted using four columns, designated C1 through C4. The columns were each four-inch diameter by approximately 54-inches high and constructed of solvent-welded polyvinyl chloride pipe. Each column was constructed with intermediate sampling ports located approximately one-third and two-thirds of the height of the column, referred to as the 33% and 66% sampling ports respectively, and an effluent sampling port. Groundwater from the existing groundwater extraction system was fed to the columns from the influent line in the existing on-site groundwater treatment building. Groundwater flow to each column was regulated through periodic adjustment of a needle valve on a dedicated rotameter.

The control column, C1, contained site sands without ZVI. The experimental columns C2, C3 and C4 contained MDOT Class II sand with ZVI at ZVI/sand mass ratios of 5%/95%, 15%/85%, and 30%/70% respectively.

ZVI amendment rates were based on results from batch testing which suggested that, from a stoichiometric standpoint, a 1.5-foot thick PRB containing 30% ZVI by mass could reduce arsenic concentrations in groundwater by approximately 90% or more over a 45-year service life. Because the 30% ZVI content used in the batch testing was anticipated to maintain treatment effectiveness for a period longer than the post-closure period for the corrective action, a ZVI content of 30% was established as the high-end ZVI content for use in the column testing. Lesser ZVI contents of 5% and 15% were based on anticipated effectiveness at lower amendment rates and industry-standard amendment rates (references (46); (48)).

Sampling was conducted throughout the test to assess the efficacy of arsenic removal and also to assess other ramifications of ZVI treatment of extracted groundwater. More frequent sampling occurred during the first five weeks of the column test and less frequent sampling occurred for the remaining eight weeks. Generally, samples collected for laboratory analysis were analyzed for alkalinity, hardness, pH, sulfate, arsenic, calcium, iron, and magnesium, and select samples were analyzed for arsenic speciation. In addition to laboratory analyses, field parameters (dissolved oxygen, pH, oxidation reduction potential, specific conductance, temperature, turbidity, and pressure drop across the columns) were recorded during each event and a Hach® field test kit for arsenic was used to evaluate real-time arsenic concentrations, which allowed for timely results evaluation and adjustments to the experimental procedure based on real-time results.

One sample was collected from the source water immediately prior to bench testing for laboratory analysis. Sampling protocols for the first five weeks included collecting samples from each sampling port (effluent and intermediate sampling ports) on all columns on a weekly basis. At each sampling event, a sample was collected from each of three sample ports located at equal intervals along the column's treatment path (i.e., 33% of its length, 66% of its length, and the effluent).

During the remaining eight weeks of the test, sampling was conducted every-other week and was focused on column C2 (containing a 5%/95% ratio of ZVI/sand). Sampling was limited to this column because that amendment ratio was considered most probable for full-scale PRB implementation.

Influent dissolved arsenic concentrations varied over the duration of the experiment from 69 µg/L to 760 µg/L. C1 (i.e., the control column) effluent arsenic concentrations were generally consistent with influent arsenic concentrations which indicates that the control column did not attenuate arsenic, and therefore, attenuation of arsenic in the experimental columns should be considered a result of the ZVI within those columns. Attachment D includes figures which show the dissolved arsenic effluent concentrations over the duration of the column test as a percentage of the influent concentrations.

In columns containing ZVI (i.e., the experimental columns – C2, C3, and C4), analytical results indicate that concentrations of total arsenic were similar to results for dissolved arsenic, suggesting that ZVI is effective at sequestering arsenic in both the dissolved and suspended phases. These results generally agree with the continuously stirred batch reactor experiment conducted as part of the FS (Section 4.2 and Attachment B).

Experimental columns consistently removed arsenic to below site-specific chronic mixing zone-based concentration values of 100 µg/L for the duration of the test. A comparison of analytical results to GSI criteria is included in Attachment D. The experimental column C2 had the lowest ZVI-to-sand mass ratio (5% to 95%) of the three columns evaluated during the testing and therefore, would represent the most cost-effective amendment ratio evaluated for use in a full-scale PRB. A ZVI-to-sand mass ratio of 5% to 95% is recommended for further evaluation in final design.

Results from the column test suggest that the preliminary 10-year design life assumed in the FS was conservative, and a longer service life is reasonable to assume from the perspective of the PRB's ability to reduce arsenic concentrations in groundwater to less than its site-specific chronic mixing zone-based GSI criterion. Based on literature and observations from the column testing, factors other than ZVI oxidation or passivation (e.g., fouling/decreased barrier permeability) may drive the lifespan of a full-scale PRB. Geochemical modeling, to be completed in final design, should be employed to assess these factors in detail.

Visual observations during column deconstruction indicated fouling occurred in the column media; however, flow through the column was maintained during testing. Fouling is partially attributable to the corrosion products of the ZVI spalling from the surface of the ZVI or forming in solution, along with adsorbed or co-precipitated arsenic. Retention of sulfur-bearing compounds in the ZVI also contributed to the visually observed fouling. Characterization of solids subsequent to the column testing confirmed the presence of arsenic removed from groundwater in the sand/ZVI matrix.

Additional detail on the flow-through column study is included in Attachment D.

5 Design and Implementation Summary

The remedial response strategy is to remove arsenic from groundwater by installing a PRB containing ZVI perpendicular to groundwater flow along the northern perimeter embankment dike. For the purpose of this RAP, this design concept is discussed and is shown on Figure 13. Design details will be finalized at a later date, and the final design (e.g., exact PRB dimensions) may differ from the concepts presented in this RAP.

The following sections provide a summary of the design and implementation plan, including permit requirements and approvals that will be obtained prior to construction; site preparation activities and general requirements; the design and construction of a PRB along the northern perimeter embankment dike; and site restoration.

5.1 Permit Requirements and Approvals

Anticipated permit requirements and approvals to implement the RAP are described in Sections 5.1.1 and 5.1.2.

5.1.1 Soil Erosion and Sedimentation Control Permit

Pursuant to Part 91 (Soil Erosion and Sedimentation Control) of Act 451, a Soil Erosion and Sedimentation Control (SESC) permit is required, because the proposed construction area is within 500 feet of a lake or a stream and construction will disturb more than 1 acre of land. An SESC permit application will be submitted to the Bay County Drain Commissioner, the local SESC enforcement agency, for review and permit issuance. A Notice of Coverage will not be required under the Permit-by-Rule pursuant to Part 31 of Act 451 because the construction will not disturb more than 5 acres of land.

The SESC plan, included with the local SESC permit application, will include the physical limits of the earth change, a description and location of onsite drainage facilities, if needed, and a description of temporary SESC control measures that will be implemented to mitigate potential soil erosion and sedimentation issues. To fulfill these requirements, details regarding temporary and permanent SESC measures, such as installing silt fence and a site restoration plan, will be included in the SESC plan. Erosion control measures will be inspected and maintained according to the SESC permit until construction is complete, the disturbed earth surface has stabilized, and the SESC permit has been terminated.

5.1.2 Michigan Department of Environment, Great Lakes, and Energy/U.S. Army Corps of Engineers Joint Permit

An EGLE/U.S. Army Corp of Engineers Joint Permit is not necessary for this project based on:

- Part 315 of Michigan Public Act 451, Dam Safety Regulations, provides an exemption for Part 115 Impoundments under § 324.31506(2)(c).

- The proposed location of the PRB is not subject to Part 323 of Michigan Public Act 451, Shorelands Protection and Management, or Part 303 of Michigan Public Act 451, Wetlands

Protection, because it does not include wetlands, bottomlands, designated high-risk erosion areas, or designated environmental areas (the work limits are anticipated to be approximately 100 feet landward from the bay).

- The proposed location of the PRB is not subject to Part 31 of Michigan Public Act 451, Water Resources Protection, because it is not within a Federal Emergency Management Agency 100-year flood zone.

- The PRB construction is not subject to Title 33 of the Code of Federal Regulations Part 322, Permits for Structures or Work in or Affecting Navigable Waters of the United States, because construction will not affect the navigable capacity of the bay by affecting its course, location, or condition.

If the anticipated construction activities change, the need for a Joint Permit will be reevaluated.

5.2 Site Preparation and General Requirements

Implementation of the remedial response will begin with site preparation. The site preparation activities and general requirements are described below in more detail.

5.2.1 Extraction System Demolition and Abandonment

The existing groundwater extraction system, shown on Figure 9, will be abandoned prior to PRB construction. The extraction wells will be decommissioned by disconnecting the wells from the power source, removing pumps, and plugging the wells and abandoning them in place. The section of the extraction well transmission piping that crosses the northern perimeter embankment dike will be removed to allow for PRB construction. Extraction transmission piping that is not removed for PRB construction will be abandoned in place by sealing the pipe ends or plugging the pipes.

5.2.2 Protection of Utilities and Other Infrastructure

Existing utilities and infrastructure are shown on Figure 9. The design will mitigate or rectify impacts to existing utilities and infrastructure by relocating or replacing them, as summarized below. Utilities and infrastructure that are not expected to be disturbed during remedial response implementation (e.g., the Karn Lined Impoundment, the closed Karn Bottom Ash Pond, the drainage ditches, etc.) are not discussed.

- **Access Roads** –During site preparation and construction activities, the northern perimeter access road will be disturbed for PRB construction. Additionally, heavy construction traffic will use access roads outside of the remedial response area to access the northern perimeter embankment dike. During site restoration, the access road along the northern perimeter embankment dike and portions of other access roads that may be damaged by construction traffic will be restored to pre-construction conditions.

- **Stormwater Culverts** – Six stormwater culverts cross under the access road along the northern perimeter embankment dike to the bay. PRB construction will require that these culverts be temporarily removed. The final design will include measures to manage stormwater flows (e.g., a pump or a series of pumps along the drainage ditch to convey stormwater from the ditch to the bay) until the stormwater culverts are replaced during site restoration activities.

- **Monitoring Wells and Piezometers** – Monitoring wells and piezometers in and near the northern perimeter embankment dike are used to monitor groundwater elevations and groundwater quality (Figure 9). Some of the instruments are located in the proposed remedial response area and may be impacted by construction activities depending on the final PRB dimensions and placement. If monitoring wells or piezometers must be removed to facilitate PRB construction, they will be replaced as needed, based on existing groundwater monitoring programs and the post-remediation groundwater monitoring program pursuant to the Karn Landfill HMP.

- **Karn Landfill Cover System** – A landfill final cover system is installed over the Karn Landfill and extends to the landward side of the access road along the northern perimeter embankment dike. The potential and extent which PRB construction will impact the final cover system will be evaluated during final design, and if the final cover system will be disturbed during construction, the final design will include provisions to make necessary repairs to the cover system, pursuant to the closure plan (reference (13)).

- **Perimeter Embankment Dikes** – Perimeter embankment dikes surround the Karn Landfill and prevent surface water flooding into the Karn Landfill. The PRB will be installed using heavy construction vehicles and equipment in the northern perimeter embankment dike. Geotechnical modeling performed as part of the FS (Attachment B and Attachment C) and FS addendum (Attachment C), and as described in Section 3.2, simulated conditions during and after constructing a PRB and suggested that the northern perimeter embankment dike will maintain a sufficient factor of safety during and after construction using conservative modeling scenarios (e.g., historic low bay surface water levels). Periodic inspections of the northern perimeter embankment dike will be conducted during construction to monitor for slope stability concerns.

5.2.3 Site Controls

Temporary and permanent SESCs will be installed and maintained prior to and during construction in accordance with the project's SESC plan (Section 5.1.1). SESC measures may include installing a silt fence downgradient of disturbed areas and check dams to help manage stormwater runoff and mitigate soil erosion.

Earth work activities, such as excavating a temporary work bench, mixing PRB materials, installing the PRB, spoil loading and transportation, and other construction operations have the potential to emit fugitive dust. Controls and mitigation measures (e.g., water application) will be implemented during construction to control fugitive dust emissions from these activities.

5.2.4 Project Health and Safety

A project health and safety plan will be developed for this work to provide worker protection throughout remedial response implementation. The project health and safety plan will describe the site layout, project hazards, mitigation measures, emergency response procedures, project contact information, site- and project-specific safety requirements, and safety documentation requirements.

5.2.5 Construction Quality Assurance

A construction quality assurance (CQA) plan will be developed as part of the final design. The purpose of the CQA plan is to develop a process to document that the remedial response is being implemented in accordance with the approved project plans and specifications. The CQA plan will describe the approach for documenting the lines of evidence needed to verify the PRB installation depth, composition and distribution of materials, and hydrogeologic characteristics are within design specifications along with providing a description of other minimum requirements for construction observation, testing, surveying, and documentation activities.

5.3 Permeable Reactive Barrier Design and Construction

Remedial response implementation will include installing a ZVI-containing PRB along the length of the northern perimeter embankment dike in response to elevated arsenic groundwater concentrations in the upper native sand unit within the remedial response area. The proposed PRB design and construction activities are summarized in Sections 5.3.1 through 5.3.4. The feasibility-level PRB design is shown in cross section on Figure 14. The composition, dimensions, and placement of the PRB will be finalized during final design.

5.3.1 PRB ZVI/Aggregate Mixture

The ZVI and aggregate mixture will be established to provide a PRB hydraulic conductivity that promotes groundwater flow through, rather than around, the PRB and a ZVI content that is adequate to provide for long-term PRB efficacy. Work completed as part of the FS and FS addendum, including a batch testing experiment, a flow-through column test, and groundwater modeling, demonstrated the feasibility of constructing a PRB using a sand and/or pea gravel mixture and a ZVI concentration of approximately 5%; however, mineral fouling of the PRB was not able to be evaluated through these activities and will need to be further evaluated with geochemical modeling during final design.

The groundwater model was used to evaluate groundwater flow through a PRB, as described in the FS (reference (21)) and FS addendum (reference (22)). Groundwater modeling included running an existing conditions scenario (i.e., no PRB) with particle tracking to evaluate flow through the proposed area for the PRB under existing conditions, and particle traces from that scenario are shown on Figure 11.

In the existing conditions scenario, approximately 65% of particles were simulated to pass through the area proposed for the PRB. The potential effects of a PRB on groundwater flow were evaluated by comparing the number of particles passing through the proposed area for the PRB under the existing conditions scenario to scenarios that assumed a PRB with different hydraulic conductivity values representing initial, moderately fouled, and highly fouled PRB conditions. As fouling occurs, the porosity and, therefore, hydraulic conductivity of the PRB will be reduced. The hydraulic conductivity for the modeled PRB was based on literature-derived values for porosity of an initial, moderately fouled, and highly fouled PRB, which was then translated into hydraulic conductivity as discussed in the FS addendum (reference (22)). Modeling results suggest a difference of less than 1% between the number of particles passing through the proposed area for the PRB under scenarios assuming no PRB (the existing conditions scenario), an initial PRB, and a PRB with moderate fouling. Groundwater modeling results for the moderate fouling scenario are shown on Figure 12. Groundwater modeling results for a highly fouled PRB showed that approximately 3% of the particles bypassed the highly fouled PRB, indicating that if a high degree of fouling occurs, some flow around the PRB could occur..

Groundwater modeling results for the highly-fouled PRB conditions will be used to establish a minimum acceptable PRB permeability prior to refreshment. The rate of pore volume reduction estimated by geochemical modeling and available literature will be used to work backwards from the established minimum hydraulic conductivity to derive an initial minimum permeability based on the minimum acceptable service life of the PRB. Geochemical modeling will be used to estimate the rate of pore volume reduction by predicting the volume of minerals that are expected to precipitate as ZVI reacts with groundwater, as a function of pore volume of groundwater flow and temporal changes in chemistry as understood by the column tests, and the increase in mineral volume will be used to estimate changes in porosity and effects upon hydraulic conductivity. The minimum initial hydraulic conductivity derived from this exercise will then be used in the design of the ZVI/aggregate mixture. Grain-size distribution data and hydraulic conductivity data from the northern perimeter embankment dike will also be evaluated during the ZVI/aggregate mixture design to prevent migration of fines into the PRB within the northern perimeter embankment dike. Design of the aggregate mixture will also consider if standard Michigan Department of Transportation (MDOT) aggregate mixtures would be suitable for the PRB because they are widely available and standardized.

The ZVI content of the PRB will be further evaluated during final design based on results from a flow-through column test (Attachment D) and geochemical modeling. The flow-through column test was performed using groundwater collected from Karn Landfill monitoring wells and included testing three columns of MDOT Class II sand containing ZVI at concentrations of 5, 15, and 30% by mass, along with a control column composed of soils collected nearby. Results from the column test showed that each experimental column consistently removed arsenic to below the site-specific GSI criterion of 100 µg/L for the duration of the test, which was designed to simulate approximately 30 years of full-scale implementation. The recommendation based on column testing results was to move forward with a ZVI content of 5% by mass, because it achieved the remedial response objectives and represented the most cost-effective ZVI content of the three mixes evaluated during the test. The ZVI content may be modified if results from geochemical modeling show unacceptable mineral deposition rates for a PRB with a ZVI content of 5%. The designed ZVI content may vary along the length of the PRB due to differences in groundwater quality and hydraulics along the northern perimeter embankment dike.

5.3.2 PRB Dimensions and Location

The PRB will be installed along the length of the northern perimeter embankment dike in the upper sand unit. The PRB will be installed underlying the access road in an alignment that allows for access by the construction equipment while reducing potential impacts to the Karn Landfill cover system and existing instruments associated with management of environmental conditions on the property. The PRB is expected to be approximately 6,000-feet long, 1.5-feet wide, and 25 to 40 feet deep.

It is not expected that ZVI-containing portions of the PRB will extend to the ground surface. The height that ZVI-containing portions of the PRB will extend from the confining units will be based on historic groundwater elevations documented in the groundwater monitoring program, and it is anticipated that the ZVI-containing portion of the PRB will extend to at least 1 foot above the highest groundwater elevation recorded along the northern perimeter embankment dike since 2018 which was when the Karn Bottom Ash Ponds ceased receipt of NPDES wastewater streams.

The width of the PRB, which is conceptually anticipated to be 1.5 feet based on hydraulic data and the results of the flow-through column study, will be established during final design and will be balanced with other design parameters, such as the aggregate mixture and ZVI content, to meet the remedial response objectives and fit within constructability constraints (e.g., available one-pass trencher widths). The design width of the PRB may vary along the length of the PRB.

The PRB will be keyed into a competent confining geologic unit underlying the northern perimeter embankment dike. This confining unit is the glacial till layer in the southeast portion of the remedial response area and the intermediate silt/clay layer in the northwest portion of the remedial response area as shown on Figure 14. The depth to these confining layers is expected to range from 25 to 40 feet below ground surface, based on existing soil boring data. Additional investigation activities, such as soil borings, hydraulic profiling borings, and surveying may be conducted prior to construction based on direction of design engineer to refine the depth to the confining layers in areas of less dense subsurface data (e.g., where existing soil boring data is more than approximately 100 feet apart) along the PRB alignment.

5.3.3 Permeable Reactive Barrier Construction

Following the general site preparation activities previously described, initial construction activities will likely include creating a work bench to receive spoils from the PRB installation. The expected construction method is one-pass trenching because the anticipated PRB dimensions and composition can be achieved by one-pass trenching, and because it is anticipated that one-pass trenching will be the most efficient construction method. The final design will be accommodating to other construction methods (e.g., open excavation), and the method of implementation will depend on the contractor’s preferred method and economic considerations. Installation by one-pass trenching methods would not require stabilization of the PRB trench, but traditional excavation methods could require shoring the PRB trench during construction. Shoring methods (e.g., biopolymer slurry, sheet piling) will be evaluated prior to construction.

PRB construction will involve excavating material above and below the water table. The dry materials excavated during work bench construction may be stockpiled for use during site restoration activities. Saturated materials will be dewatered before they are hauled along with overburden dry material not needed for site restoration to the Weadock Landfill for disposal. It is anticipated that saturated soils will be placed on the work bench for dewatering. They will be placed for a sufficient period of time to allow water from the soils to percolate back to groundwater. The dewatering approach will be refined during final design and construction.

5.3.4 Restoration

Stormwater culverts will be reinstalled in the excavated areas of the northern perimeter embankment dike access road, and the work bench will be backfilled with clean material (e.g., sand) to a grade that allows for a suitable coarse aggregate layer to restore the access road. The northern perimeter embankment dike access road and other access roads impacted by construction will be restored to pre-construction conditions. Monitoring wells or piezometers removed or damaged during construction will be replaced if required for the Karn Landfill HMP and/or monitoring plan developed for the remedial response.

6 Monitoring and Maintenance Plans

A monitoring and maintenance plan will be developed during final design and will describe the groundwater monitoring program that will be implemented to evaluate PRB performance, plans to maintain the effectiveness and integrity of the remedial response after construction, and contingency planning. These monitoring and maintenance plans will be incorporated into the Karn Landfill HMP. The components of this plan are described in Sections 6.1 through 6.3.

6.1 Permeable Reactive Barrier Performance Monitoring

Groundwater conditions will be monitored before, during, and after construction to assess PRB performance. A monitoring well network will be developed for this program and will include both existing and new monitoring locations. The monitoring well network will likely include points of compliance, monitoring wells along the discharge channel and the river, and monitoring wells within, upgradient, and downgradient of the PRB. Groundwater samples will be analyzed for select constituents consistent with the Karn Landfill HMP and will be established in the monitoring plan. Groundwater elevations will be used to evaluate the hydraulic gradient across the PRB and monitor for changes to the hydraulic characteristics of the Karn Landfill and the remedial response area.

Initially, groundwater monitoring will be conducted on a quarterly basis, pursuant to the Karn Landfill HMP and consistent with PRB performance monitoring frequency recommended by the Interstate Technology and Regulatory Council (reference (48)). However, the monitoring frequency may be reduced if compliance with applicable GSI criteria (Section 1.2) is achieved, pursuant to Part 115 R 299.4445.

Should monitoring indicate plugging/fouling may be occurring, which may be indicated by changes to groundwater flow patterns in the vicinity of the PRB or increasing arsenic concentrations downgradient of the PRB, core sampling may be conducted to evaluate mineral buildup within the PRB and the PRB's reactivity and compositional consistency.

6.2 Permeable Reactive Barrier Maintenance

The PRB may require refreshment or replacement of reactive media during the 30-year post-closure care period due to exhaustion of the reactive materials or plugging/fouling of the PRB. PRB performance will be monitored in accordance with the monitoring and maintenance plan developed during final design, and the PRB will be refreshed as needed to mitigate groundwater flow around the PRB or arsenic concentrations above chronic mixing zone-based GSI criteria downgradient of the PRB. An estimated refreshment interval and the performance criteria that triggers refreshment will be evaluated during the final design.

Refreshment by excavation and replacement of the existing PRB is the assumed method to address declining PRB performance. Other ZVI-containing PRB refreshment methods (e.g., ultrasonic precipitate cracking, deep mixing) may be considered if demonstrated to be feasible during operation of the PRB prior to refreshment. PRB replacement is assumed to be in-kind and consistent with the methods presented in this RAP, but performance monitoring data and advances in PRB technology will be evaluated before refreshment to assess if modifications to the replacement PRB's design are appropriate or if other refreshment methods are feasible.

6.3 Contingency Planning

General contingency plans will be developed and incorporated as part of the monitoring and maintenance plan and implemented as needed if the remedial response does not meet the remedial response objectives. The estimate of the time to achieve remedial response objectives is dependent on the time required for reactive materials in the PRB to ripen and the time for groundwater to flow from the PRB to the GSI. Bench testing conducted as part of the FS suggests that the PRB will provide sufficient arsenic treatment within a period of days or weeks following installation.

Groundwater flow through the remedial response area to the GSI is variable and dependent on the heterogeneity of the remedial response area lithology and the temporal variability of groundwater and surface water conditions in the vicinity of the remedial response area. Based on the average groundwater velocity along the northern perimeter embankment dike and the distance from the proposed PRB location to the GSI, it is anticipated that it will take at least one to two years for groundwater treated by the PRB to be observed at the GSI compliance monitoring locations. However, changes in future surface water elevations, effects of the cessation of operations at the generating facility, and local heterogeneity in hydrogeologic conditions upgradient of the GSI result in uncertainty in the time to observe improvements to water quality at compliance points.

The timing for implementing contingency plans will be developed during final design and included in the monitoring and maintenance plan. In general, if groundwater monitoring activities indicate that groundwater quality is not meeting the remedial response objectives within the expected amount of time following construction, additional evaluation will be completed to identify potential contingency actions. Specific contingency actions will be dependent on the mechanism of failure.

7 Implementation Schedule

The schedule for implementing the remedial response is dependent on timing of approval of this RAP, including public participation; contractor availability for design data collection; and contractor availability for contracting and conducting construction activities. While the schedule is subject to change based on these variables, the anticipated schedule is:

Anticipated Timeframe	Implementation Component
December 2021	Submit RAP to EGLE
May 2022	EGLE approval of RAP
June 2022 through first quarter 2023	Design data collection, final design, and engineering plans
First and second quarter 2023	Permitting and contractor selection
Third quarter 2023	Site preparation; begin remedial response implementation
Third and fourth quarter 2023	Remedial response implementation followed by site restoration and demobilization
2023 through 2053 (assumed)	Post-construction maintenance and monitoring

Remedial response construction is expected to take approximately four to six months to complete, following final design and contractor selection and mobilization. For the purpose of this RAP, it was assumed that construction would take six months, but the actual construction duration may differ from this and further impact this proposed timeline. As this schedule is further refined during final design and contractor selection, EGLE will be notified of changes.

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Figures

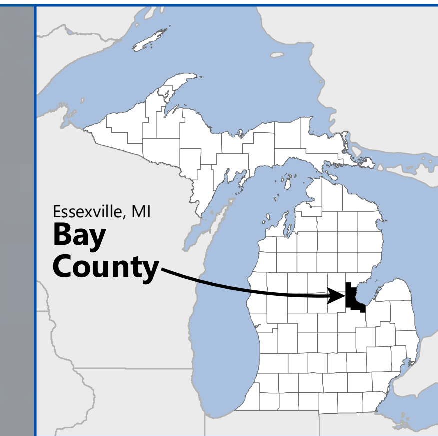
SITE LOCATION
D.E. Karn Generating Facility
Consumers Energy Company
Essexville, MI

FIGURE 1

Aerial Image: USDA NAIP 2020

SITE LAYOUT
D.E. Karn Generating Facility
Consumers Energy Company
Essexville, MI

FIGURE 2



Boring Included in 3D Model

2021 Temporary Well Installed for PRB Extension Evaluation

Section Locations

Karn Landfill

Weadock Landfill

Closed Bottom Ash Pond

Karn Lined Impoundment

Notes:
- Only borings included in development of the three-dimensional (3D) geologic model are shown on this figure, except for temporary wells installed in 2021, which are shown on this figure and cross sections for location purposes only. Geologic data from those borings were not used to inform the geologic model.
- Years included in parentheses indicate the year a boring was completed, if multiple borings with the same name have been completed on site.

N

0 500 1000

Feet

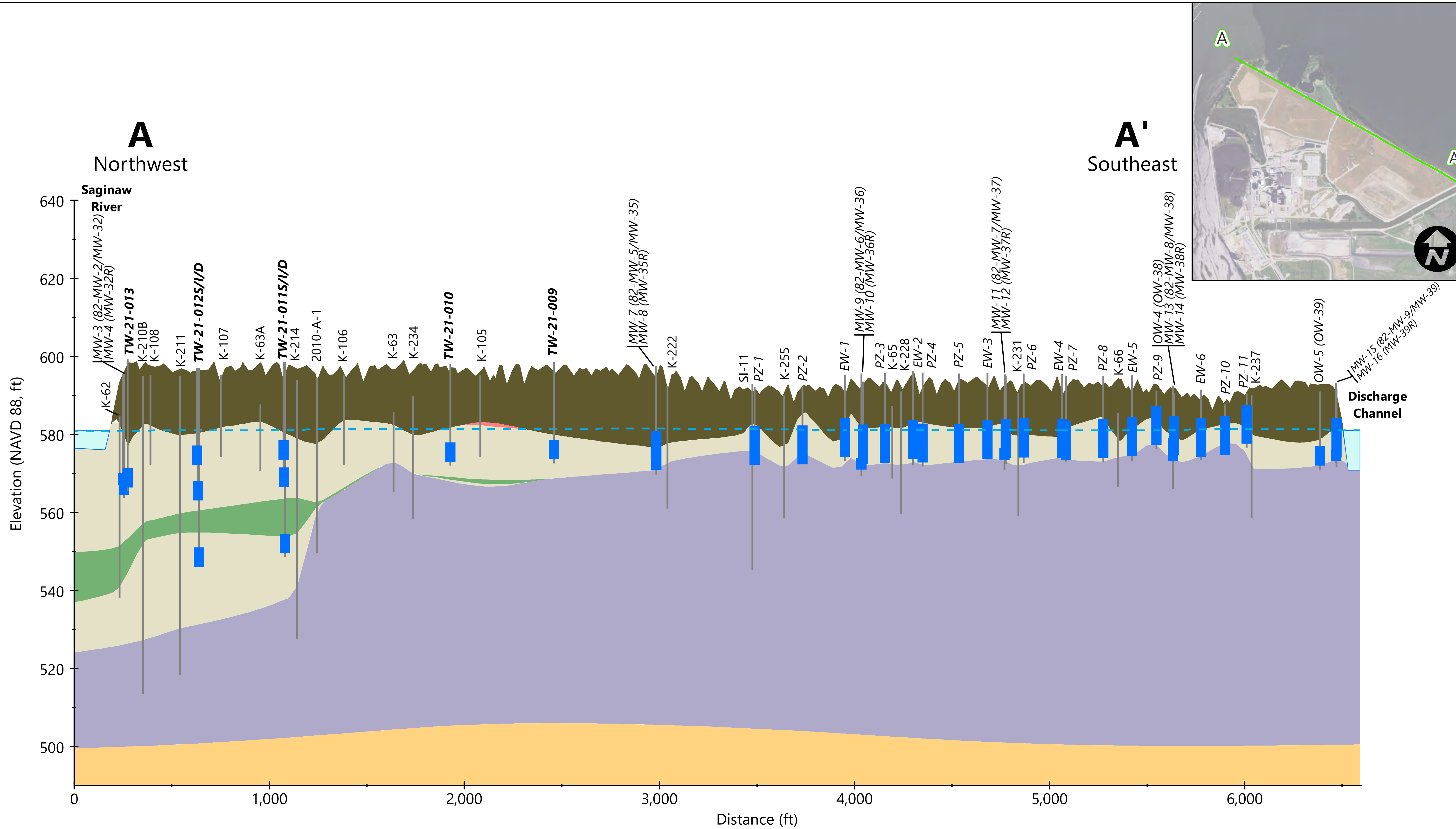
Aerial Image: USDA NAIP 2020

CROSS SECTION LOCATIONS

D.E. Karn Generating Facility
Consumer Energy Company
Essexville, MI

FIGURE 3

Barr Footer: ArcGIS 10.8.1, 2021-11-22 09:29 File: I:\Projects\22\09\1015\Maps\Reports\RAP 2021 Update\Figure3_CrossSectionLocations.mxd User: cml3



Stratigraphy

- Ash/Fill
- Peat/Organics
- Sand
- Intermediate Silt/Clay with Organics
- Clay
- Bedrock

Water Table (July 2021)

Well/Piezometer Screen
Italicized If Active
Bold if Installed in 2021

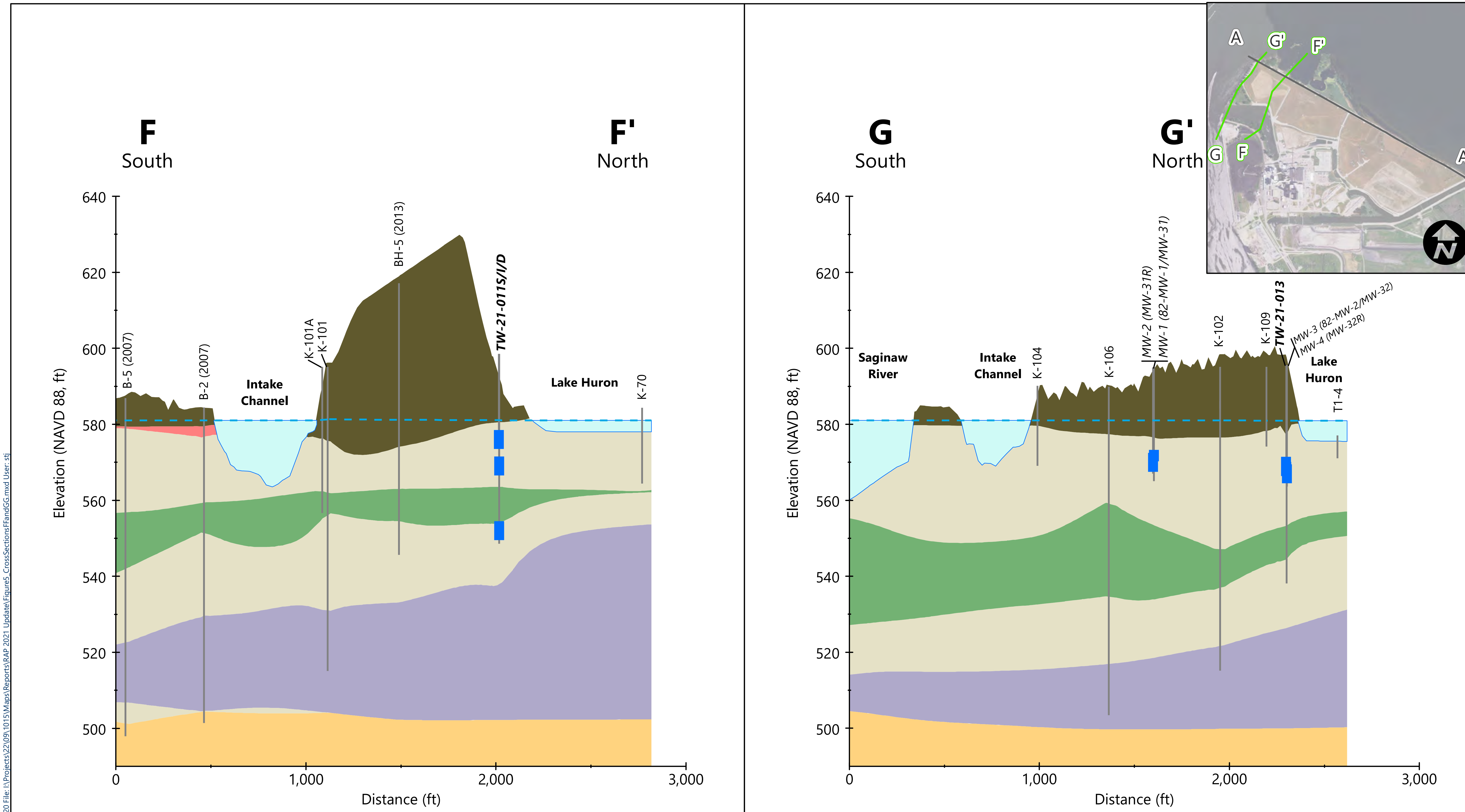
Boring

NOTES
- The cross section is a two-dimensional slice through a three-dimensional interpolation of available site data.
- Stratigraphy shown in the cross section is consistent with EVS modeling results included in the February 2021 Feasibility Study and does not account for soil observations from borings completed in 2021 because the existing modeling results generally agreed with borings completed in 2021.
- Borings within 50 feet of the cross section line are projected onto this cross section. Due to the projection, the surveyed ground surface at a boring may not match the ground surface shown on the cross section.
- Water table is approximate and based on water levels measured in July 2021.
- Grid based modeling has inherent limitations to accurately represent steep slopes. Constructed slopes are approximate and may not exactly match constructed grades.

BARR

CROSS SECTION A-A'
D.E. Karn Generating Facility
Consumers Energy Company
Essexville, MI

FIGURE 4



Stratigraphy

- Ash/Fill
- Peat/Organics
- Sand
- Intermediate Silt/Clay with Organics
- Clay
- Bedrock

Water Table (July 2021)

Well/Piezometer Screen
Italicized If Active
Bold if Installed In 2021

Boring

NOTES
- The cross section is a two-dimensional slice through a three-dimensional interpolation of available site data.
- Stratigraphy shown in the cross section is consistent with EVS modeling results included in the February 2021 Feasibility Study and does not account for soil observations from borings completed in 2021 because the existing modeling results generally agreed with borings completed in 2021.
- Borings within 50 feet of the cross section line are projected onto this cross section. Due to the projection, the surveyed ground surface at a boring may not match the ground surface shown on the cross section.
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- Grid based modeling has inherent limitations to accurately represent steep slopes. Constructed slopes are approximate and may not exactly match constructed grades.

BARR

CROSS SECTIONS F-F' AND G-G'
D.E. Karn Generating Facility
Consumers Energy Company
Essexville, MI

FIGURE 5

Monitoring/ Observation Well
Extraction Well
Stilling Well
Temporary Monitoring Well
Piezometer
NOAA Gauge Station
Groundwater Elevation Contour (feet, MSL) *(Dashed where inferred)*
Karn Landfill
Closed Karn Bottom Ash Pond
Karn Lined Impoundment
Former Karn 1&2 Chemical Treatment Ponds
(577.53) Indicates groundwater elevation not used for contouring

Notes:
- Water levels for TW-21-009 through TW-21-013 were measured on 7/6/21 and 7/7/21. All other elevations were measured on 7/26/21.
- Groundwater extraction wells were not operating on 7/26/2021.
- TW-21-012S water level was not used in contouring due to difference in water level and measurement date with MW-6.
- Saginaw Bay elevation (NAVD88) measured at NOAA Essexville, MI Gauge Station (9075035) on 7/26/21.

N

0 500 1000
Feet

Aerial Image: USDA FSA NAIP 2020

GROUNDWATER ELEVATION JULY 2021
D.E. Karn Generating Facility
Consumers Energy Company
Essexville, MI

FIGURE 6

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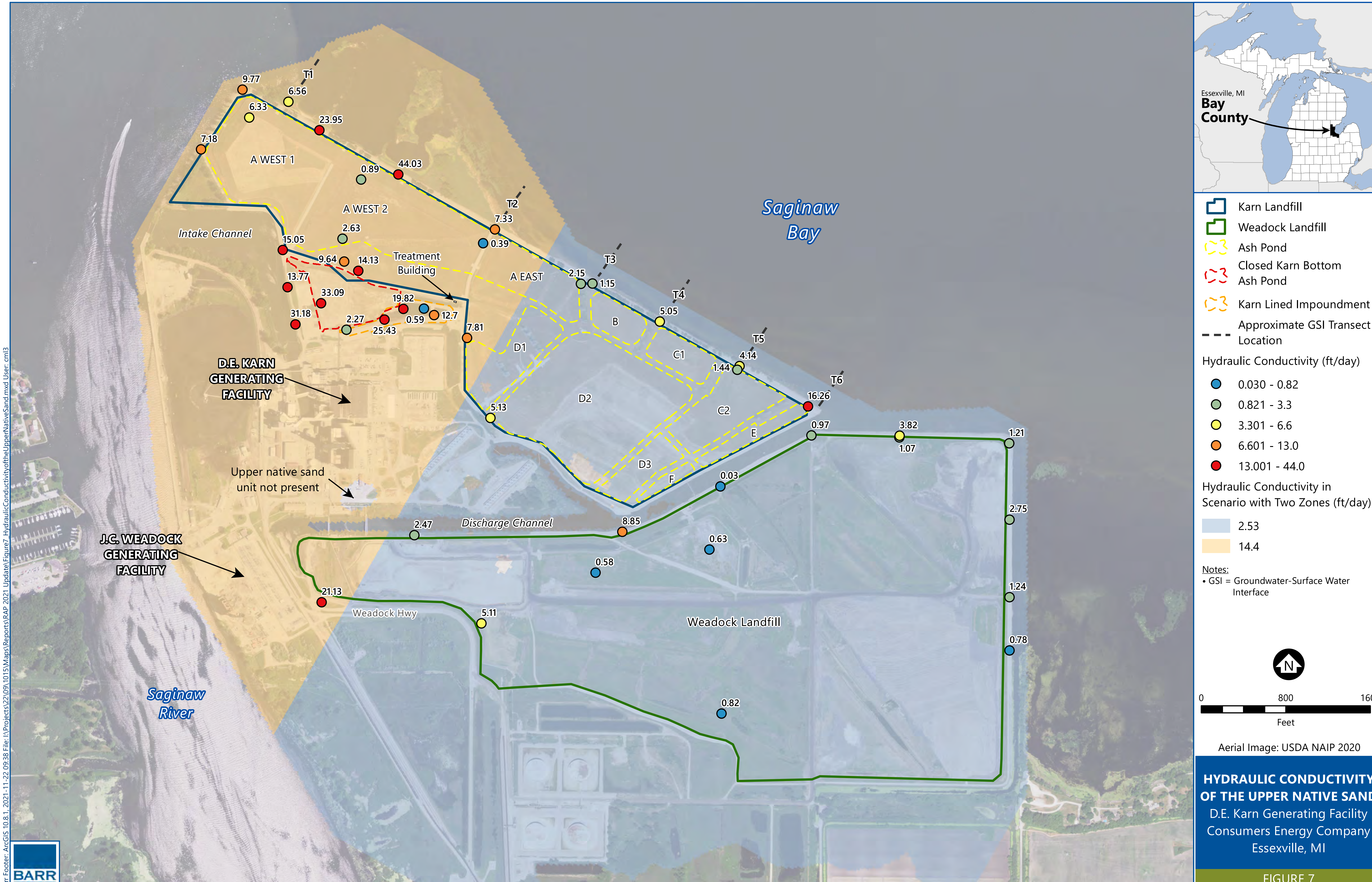
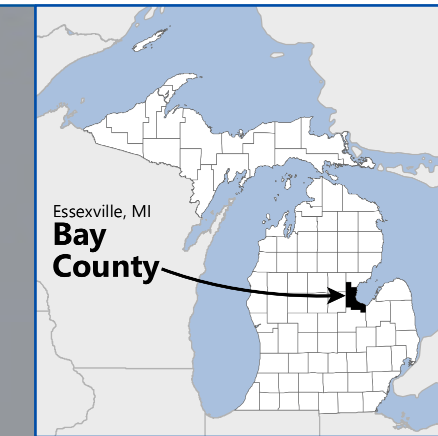


HYDRAULIC CONDUCTIVITY OF THE UPPER NATIVE SAND
D.E. Karn Generating Facility
Consumers Energy Company
Essexville, MI

FIGURE 7



Monitoring/ Observation Well

Porewater Sample Location

Temporary Monitoring Well

Exceeds Chronic Mixing Zone-Based GSI Value (100 ug/L)

Approximate GSI Transect Location

Notes:
- Concentrations displayed in ug/L.
- Samples were collected from TW-21-009 through TW-21-013 on July 6 and 7, 2021, and at all other locations between July 26 and August 2, 2021.
- GSI = Groundwater-Surface Water Interface

* Porewater sampling location; concentration not representative of groundwater conditions.

** Well is screened in ash; concentration is not representative of groundwater conditions in upper native sand.

*** Well is screened in a different hydrogeologic unit than the other monitoring locations; concentration is not representative of groundwater conditions in upper native sand.

N

0 500 1000

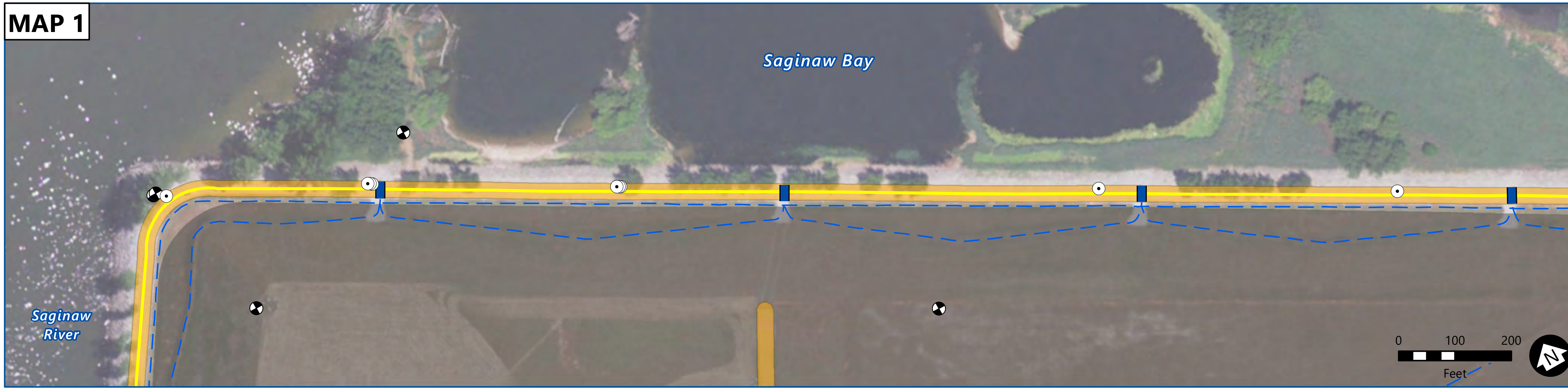
Feet

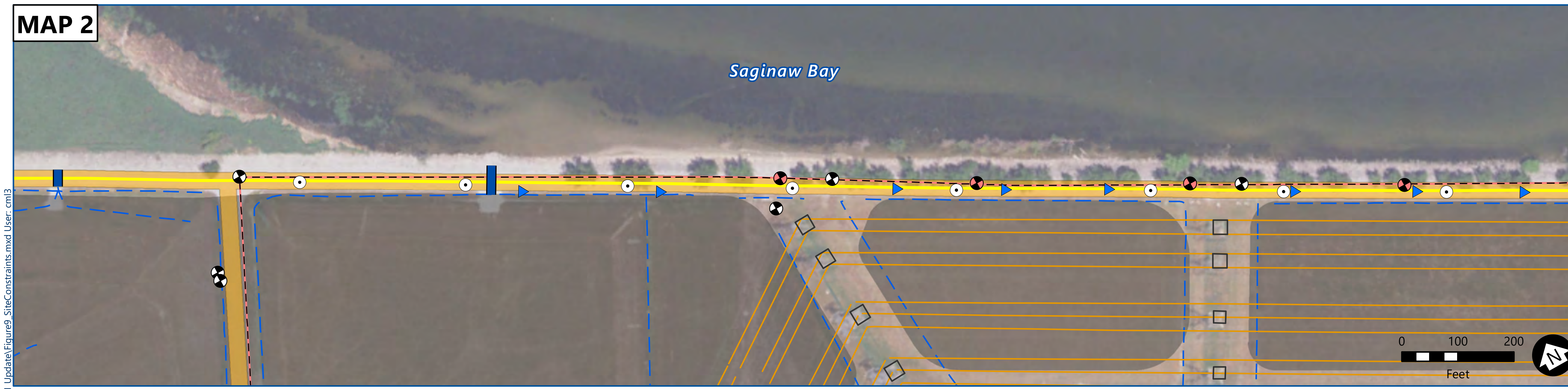
Aerial Image: USDA NAIP 2020

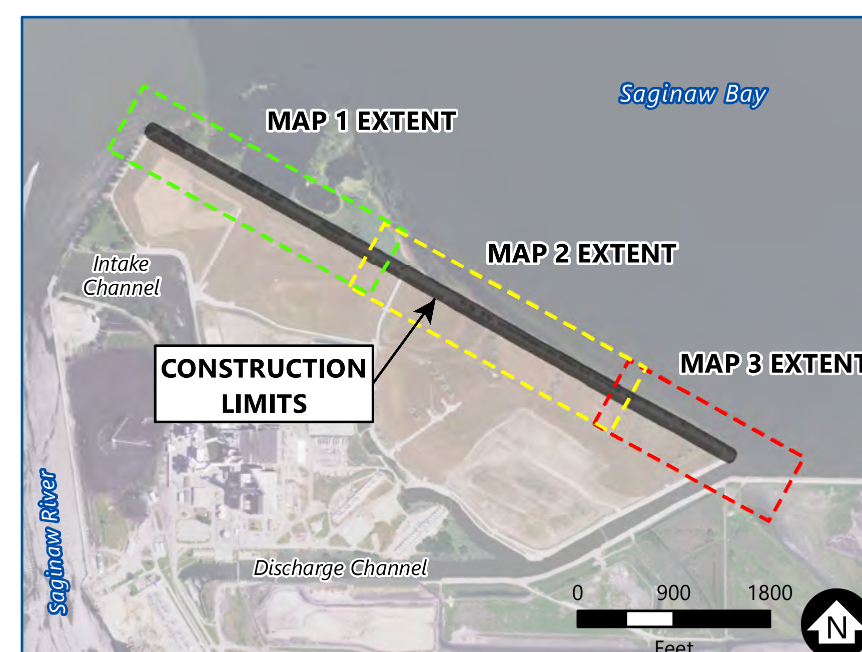
TOTAL ARSENIC CONCENTRATIONS JULY 2021

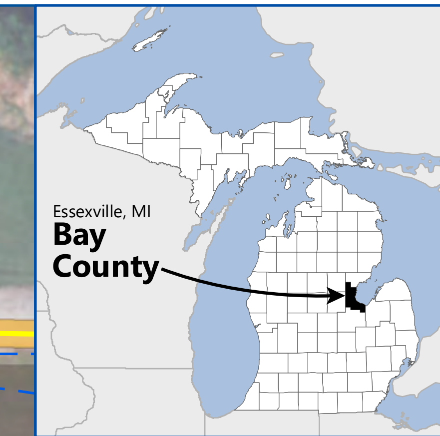
D.E. Karn Generating Facility
Consumers Energy Company
Essexville, MI

FIGURE 8









Monitoring/ Observation Well

Existing Extraction Well

Temporary Monitoring Well

Piezometer

Karn Landfill Final Cover System

Access Road

Perimeter Embankment Dike

Stormwater Culvert

Drainage Ditch

Extraction Well Transmission Piping

Utilities

Overhead Electric

Overhead Electric Tower

Notes:
- All utility locations are approximate. Utilities shown on this figure may not represent all utilities present at the site.
- Karn Landfill Final Cover System extent based on construction drawings submitted to EGLE as part of the DE Karn Landfill Final Closure Certification

Aerial Image: USDA NAIP 2020

POTENTIAL SITE CONSTRAINTS
D.E. Karn Generating Facility
Consumers Energy Company
Essexville, MI

FIGURE 9

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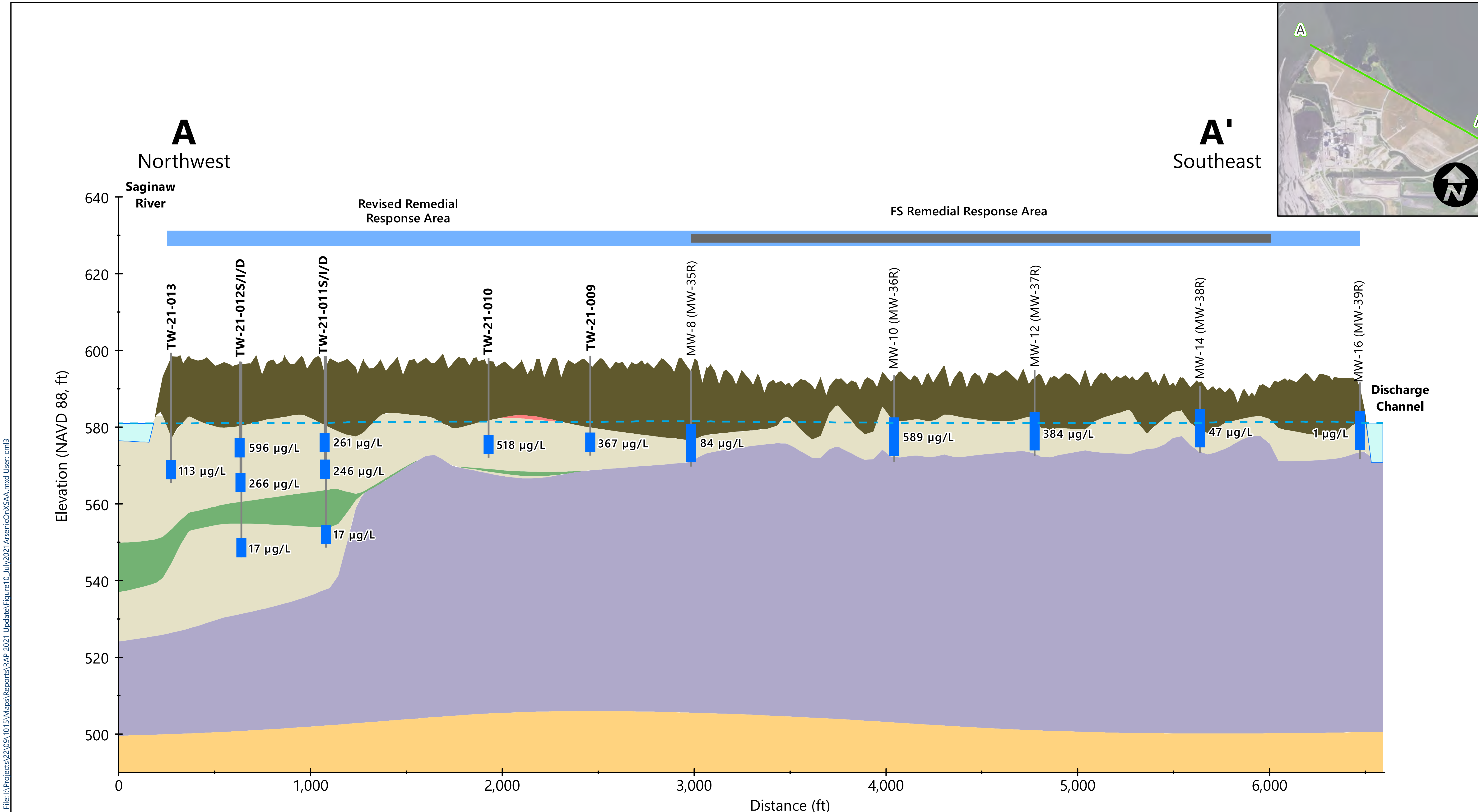


Stratigraphy

- Ash/Fill
- Peat/Organics
- Sand
- Intermediate Silt/Clay with Organics
- Clay
- Bedrock

Water Table (July 2021)

113 µg/L — Well/Piezometer Screen and July 2021 Total Arenic Concentration (**Bold** If Installed in 2021)

Boring

FS Remedial Response Area

Revised Remedial Response Area

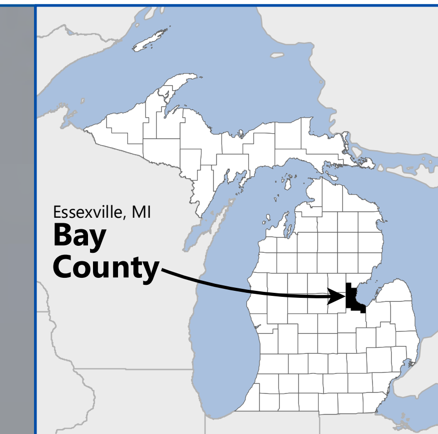
NOTES
- Select borings shown are located along the norther perimeter embankment dike and were used to evaluate the potential effectiveness of the extended PRB footprint.
- Stratigraphy shown in the cross section is consistent with EVS modeling results included in the February 2021 Feasibility Study and does not account for soil observations from borings completed in 2021 because the existing modeling results generally agreed with borings completed in 2021.
- Water table is approximate and based on water levels measured in July 2021.
- Grid based modeling has inherent limitations to accurately represent steep slopes. Constructed slopes are approximate and may not exactly match constructed grades.
- Groundwater sampling was performed at TW-21-009 through TW-21-013 on July 6 and 7, 2021. Groundwater sampling was performed at all other locations shown on July 27, 2021.

BARR

JULY 2021 TOTAL ARSENIC CONCENTRATIONS FOR SELECT WELLS ALONG THE NORTHERN PERIMETER EMBANKMENT DIKE

D.E. Karn Generating Facility
Consumers Energy Company
Essexville, MI

FIGURE 10



- Karn Landfill
- Weadock Landfill
- Ash Pond
- Closed Karn Bottom Ash Pond
- Karn Lined Impoundment
- Former Karn 1&2 Chemical Treatment Ponds
- Approximate GSI Transect Location
- Particle Trace In Existing Conditions

Notes:
- GSI = Groundwater-Surface Water Interface

N

0 500 1000
Feet

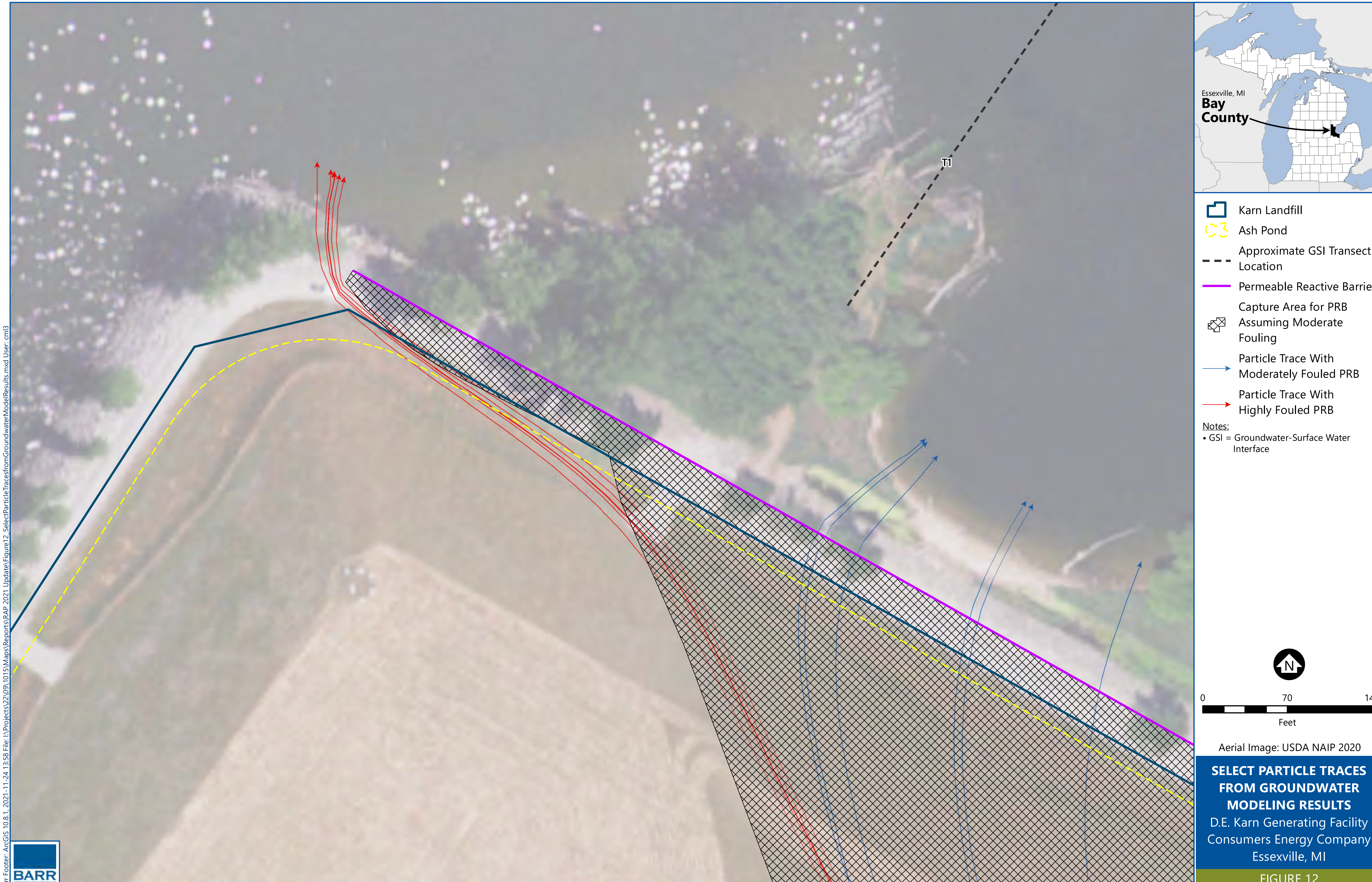
Aerial Image: USDA NAIP 2020

EXISTING CONDITIONS GROUNDWATER MODEL RESULTS

D.E. Karn Generating Facility
Consumers Energy Company
Essexville, MI

FIGURE 11

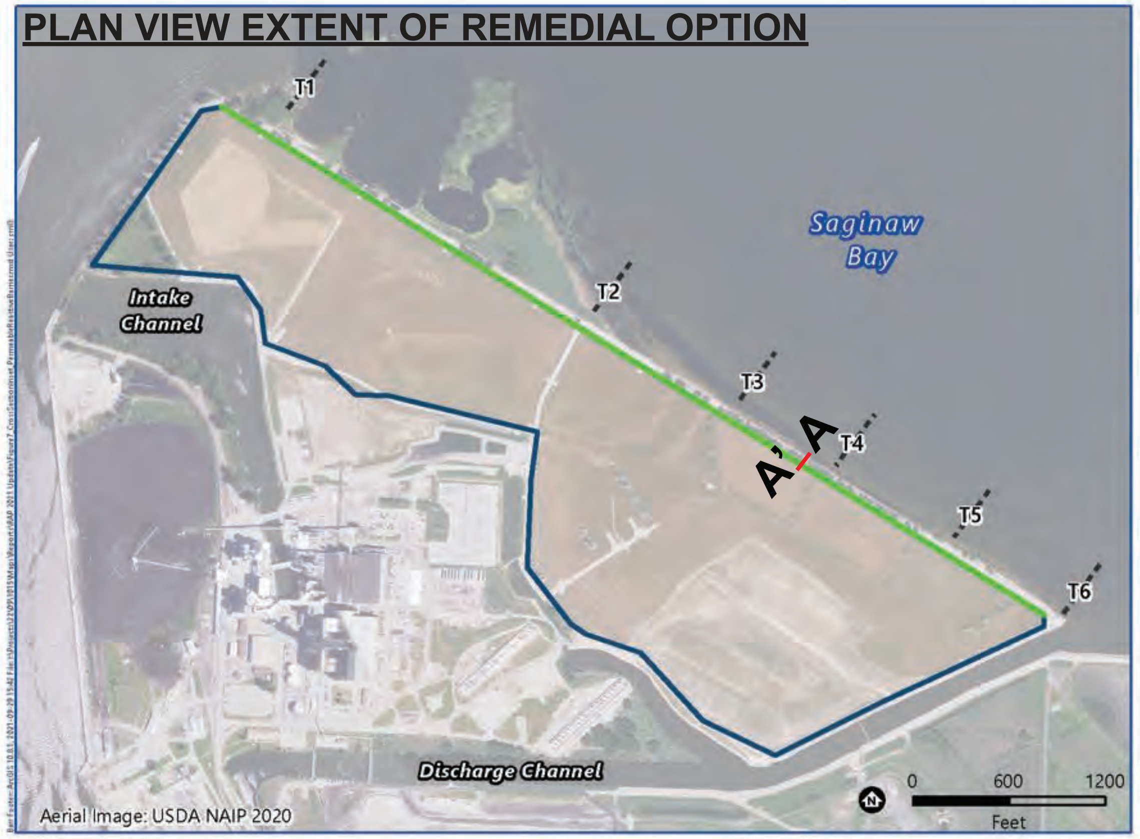
BARR



SELECT PARTICLE TRACES FROM GROUNDWATER MODELING RESULTS

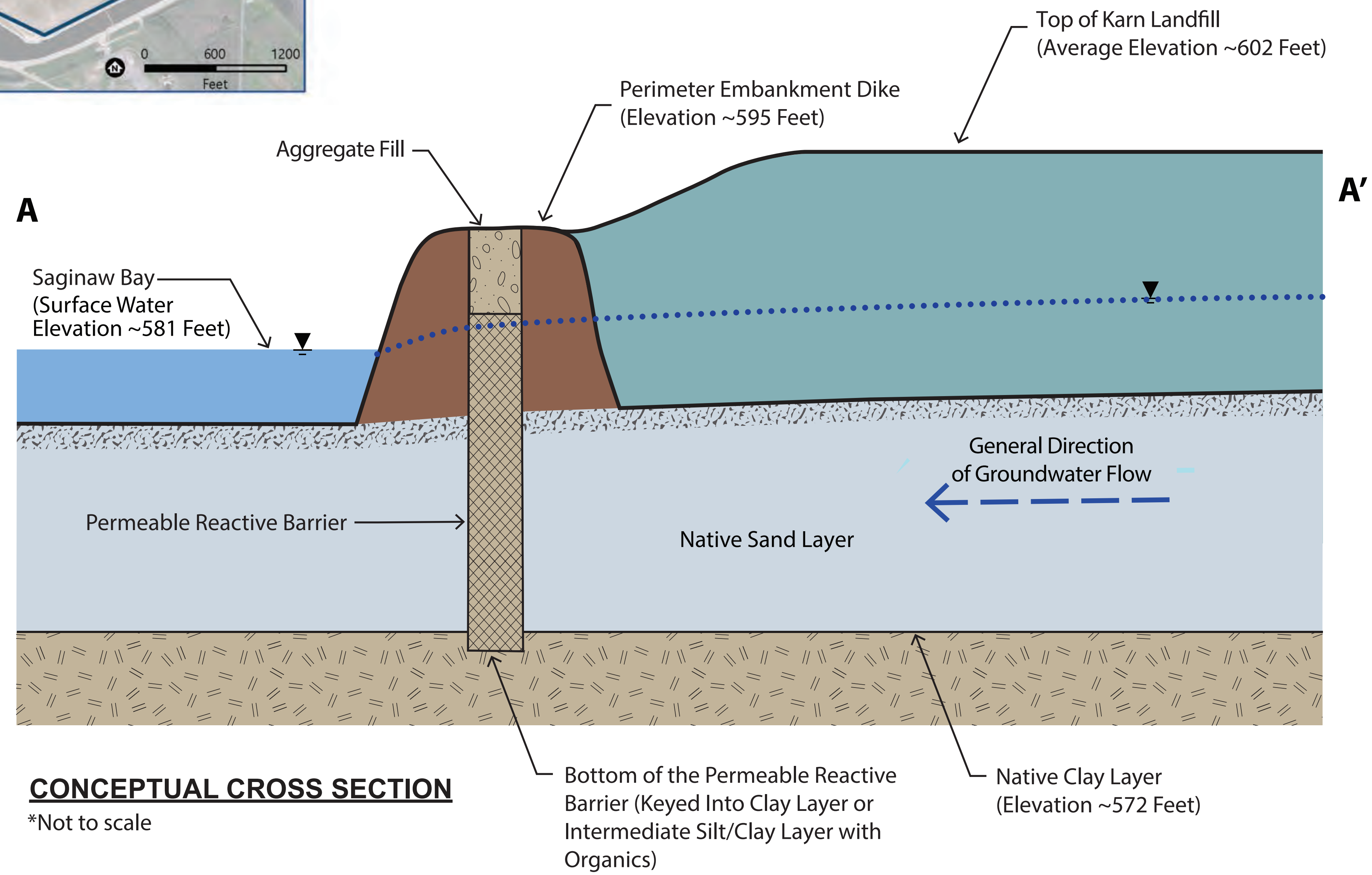
D.E. Karn Generating Facility
Consumers Energy Company
Essexville, MI

FIGURE 12



Plan View Legend

- Karn Landfill
- Permeable Reactive Barrier
- Approximate GSI Transect Location



CONCEPTUAL CROSS SECTION

*Not to scale

PERMEABLE REACTIVE BARRIER OVERVIEW
D.E. Karn Generating Facility
Consumers Energy Company
Essexville, MI

FIGURE 13

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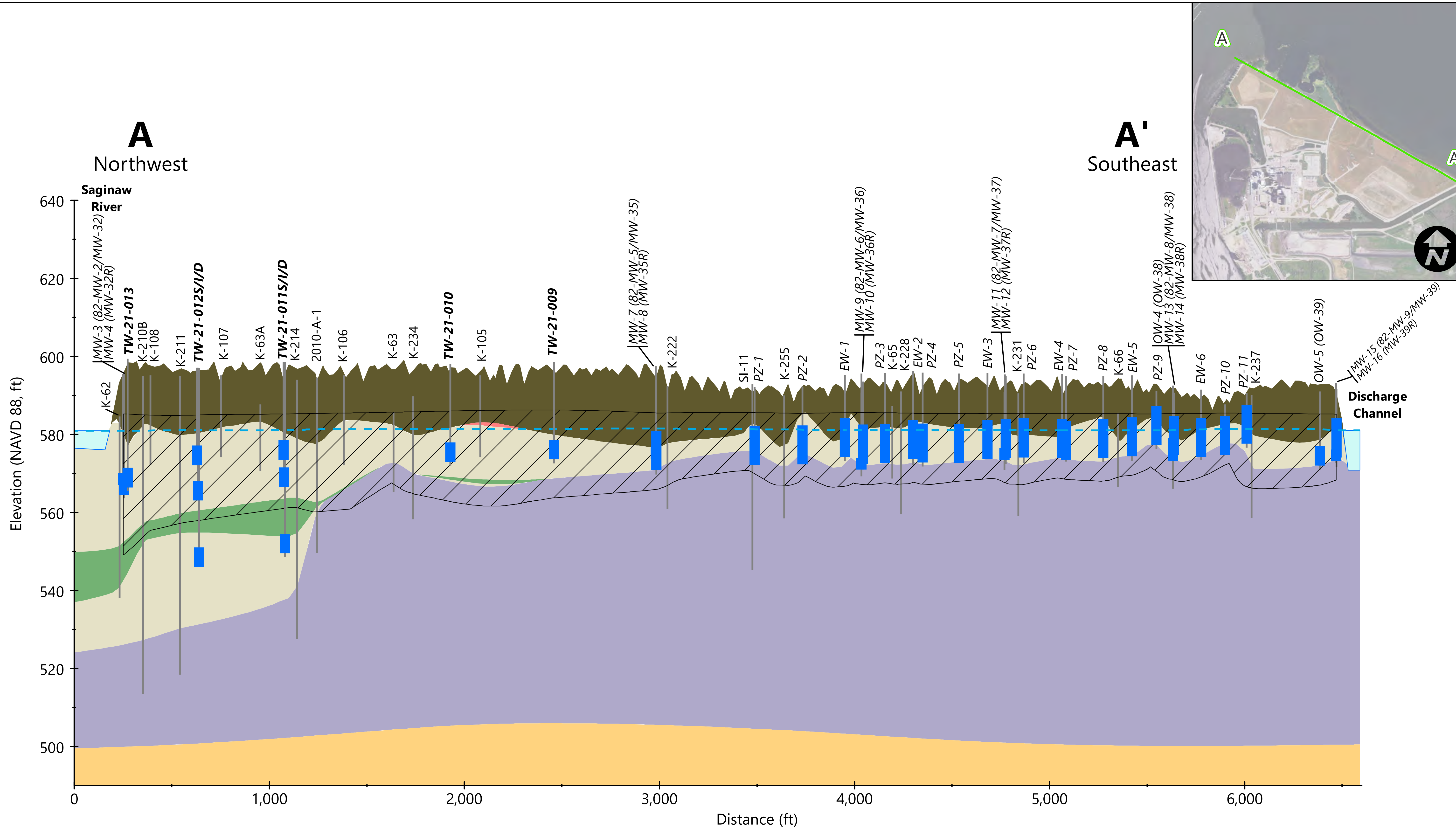

Stratigraphy

- Ash/Fill
- Peat/Organics
- Sand
- Intermediate Silt/Clay with Organics
- Clay
- Bedrock

Water Table (July 2021)

Well/Piezometer Screen
Italicized If Active
Bold if Installed in 2021

Boring

Potential PRB Extent

NOTES
- The cross section is a two-dimensional slice through a three-dimensional interpolation of available site data.
- Stratigraphy shown in the cross section is consistent with EVS modeling results included in the February 2021 Feasibility Study and does not account for soil observations from borings completed in 2021 because the existing modeling results generally agreed with borings completed in 2021.
- Borings within 50 feet of the cross section line are projected onto this cross section. Due to the projection, the surveyed ground surface at a boring may not match the ground surface shown on the cross section.
- Water table is approximate and based on water levels measured in July 2021.
- Grid based modeling has inherent limitations to accurately represent steep slopes. Constructed slopes are approximate and may not exactly match constructed grades.

CROSS SECTION A-A' WITH POTENTIAL PRB INSTALLATION DEPTHS
D.E. Karn Generating Facility
Consumers Energy Company
Essexville, MI

FIGURE 14

BARR