BURNS McDONNELL

DTE ELECTRIC COMPANY

FLY ASH BASIN CLOSURE PLAN

MONROE POWER PLANT

PROJECT NO. 151630

REVISION 2

JANUARY 4, 2024

CONTENTS

FIGURES

TABLES

List of Abbreviations

Abbreviation	Term/Phrase/Name
CCR	Coal Combustion Residuals
CFR	Code of Federal Regulations
cm/sec	centimeters per second
DTE	DTE Electric Company
EGLE	Michigan Department of Environment, Great Lakes, and Energy
EPA	Environmental Protection Agency
FAB	Fly Ash Basin
FML	Flexible membrane liner
HDPE	High-density polyethylene
MAC	Michigan Administrative Code
Monroe	Monroe Power Plant
RCRA	Resource Conservation and Recovery Act
U.S.C.	United States Code
USACE	United State Army Corps of Engineers
VEL	Vertical Extension Landfill

Index and Certification

DTE Electric Company
Fly Ash Basin Closure Plan
Project No. 151630

Report Index

Chapter Number	Chapter Title	Number of Pages
1.0	Introduction	1
2.0	Details of Closure	6
3.0	Revisions and Amendments	1
4.0	Record of Revisions and Updates	1
Appendix A	Conceptual Closure Design	2
Appendix B	Alternative Final Cover System Equivalency Demonstration	172

Certification

I hereby certify, as a Professional Engineer in the state of Michigan, that the information in this document was assembled under my direct personal charge and meets the requirements of 40 CFR § 257.102. This report is not intended or represented to be suitable for reuse by the DTE Electric Company or others without specific verification or adaptation by the Engineer.

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Date: January 4, 2024

1.0 Introduction

On April 17, 2015, the Environmental Protection Agency (EPA) issued the final version of the federal Coal Combustion Residuals (CCR) Rule to regulate the disposal of coal combustion residual materials generated at coal-fired electric generating units. The rule is administered as part of the Resource Conservation and Recovery Act (RCRA, 42 United States Code [U.S.C.] §6901 et seq.), under Subtitle D. DTE Electric Company (DTE) is subject to the CCR Rule. As such, DTE must develop a Closure Plan for the CCR units at Monroe Power Plant (Monroe) per 40 Code of Federal Regulations (CFR) §257.102. This document serves as DTE's revised Closure Plan for the Fly Ash Basin (FAB), also referred to as the Fly Ash Impoundment.

According to §257.102(b)(1), the Closure Plan must contain the following:

- A description of how the CCR unit will be closed.
    - For in-place closure: A description of the final cover system, the methods for installing the final cover system, and the methods for achieving compliance with the standards outlined in §257.102(d).
    - For closure by removal: A description of the procedures to remove the CCR and decontaminate the CCR unit in accordance with §257.102(c).
- An estimate of the maximum amount of material ever stored in the CCR unit over its active life.
- An estimate of the largest area of the CCR unit ever requiring a final cover as required by §257.102(d) at any time during the CCR unit's active life.
- A schedule for completing closure activities, including the anticipated year of closure and major milestones for permitting and construction activities.

The seal on this report certifies that this document meets the requirements of 40 CFR §257.102. This closure plan is in addition to, not in place of, any other applicable site permits, environmental standards, or work safety practices.

2.0 Details of Closure

2.1 Impoundment Description

DTE owns and operates Monroe Power Plant, a four-unit, 3,300-megawatt coal-fired facility located in Monroe, Michigan. Monroe has one active CCR surface impoundment, known as the Fly Ash Basin (FAB), and one active CCR landfill known as the Vertical Extension Landfill (VEL). This CCR closure plan outlines the plan to close the FAB by leaving CCR in place. Note, this document is a revision to the original "Monroe Ash Basin Closure Plan for Monroe Power Plant," which was prepared by Geosyntec Consultants in October of 2016.

2.1.1 CCR Inventory and Extent

The original footprint of the FAB was approximately 410 acres but was reduced to 331 acres after construction of the VEL. The VEL was constructed over existing CCR material within the FAB. . CCR material stored within the VEL will be removed to the underlying ash subgrade and consolidated within the FAB to achieve closure grades prior to installing the final cover system. An alternative final cover system will be placed over the re-graded CCR material as described in Section 2.2.2.

The maximum storage capacity of the FAB was calculated to be 29.4 million cubic yards per the 2022 annual inspection report prepared by Geosyntec Consultants. This volume is also an estimate of the maximum inventory of material that could potentially be stored in the FAB over its active life. Neither the maximum storage capacity nor maximum fill elevation for the VEL will be exceeded as part of the closure design.

2.2 Closure Method

The rule allows for CCR units to be closed through removal of CCR or by leaving CCR material in-place. The FAB will be closed in place and will receive an alternative cover system in accordance with 40 CFR 257.102(d)(3)(ii). Per Michigan Administrative Code (MAC) R.299.4309(7), to close the impoundment the owner or operator must also complete the following:

- Eliminate free liquids by removing liquid wastes or solidifying the remaining wastes and waste residues.
- Stabilize remaining wastes to a bearing capacity that is sufficient to support final cover.
- Cover the surface impoundment with a final cover that is in compliance with the requirements of R 299.4304.
- Conduct groundwater monitoring and postclosure maintenance in accordance with rules applicable to type III landfills.

To meet the applicable requirements, closure activities will require drainage (unwatering of free water and dewatering of separable pore water) to allow for stabilization of the existing CCR material, grading of the CCR material to drain, and installation of the final cover system over the CCR material to minimize erosion and infiltration. Unwatering and dewatering activities will be performed throughout construction, as necessary, to manage water within the FAB. The in-place closure design for the FAB is discussed in more detail in the following sections. A figure showing the conceptual closure design is included in Appendix A.

2.2.1 Unwatering and Dewatering

Unwatering of the FAB will be completed during the dewatering process. It is anticipated that an engineered dewatering system, such as wells or wellpoints, will be used to remove separable pore water from the impounded CCR material. Water removed during the dewatering process will be discharged through the existing outfall (Outfall 001F) in accordance with the site NPDES discharge permit number MI0001848. The dewatering system will be maintained around the clock during the closure construction until separable pore water has been removed, at which point the dewatering system will be removed. Where possible, construction stormwater will be managed by using ditches and sumps with water pumped to Outfall 001F.

2.2.2 Final Cover System

Pursuant to §257.102(d)(3)(i), the final cover system must be designed and constructed to meet the following criteria:

- Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present, or a permeability no greater than $1x10^{-5}$ centimeters per second (cm/sec), whichever is less.
- The infiltration of liquids through the closed CCR unit must be minimized by use of an infiltration layer that contains a minimum of 18 inches of earthen material.
- The erosion of the final cover system must be minimized by use of an erosion layer that contains a minimum of six inches of earthen material capable of sustaining native plant growth.
- The disruption of the integrity of the final cover system must be minimized through a design that accommodates settling and subsidence.

Alternatively, the owner or operator may select an alternative final cover system design pursuant to §257.102(d)(3)(ii), provided the alternative final cover system meets the following criteria:

- The design of the final cover system must include an infiltration layer that achieves an equivalent reduction in infiltration as the infiltration layer specified in paragraphs §257.102 (d)(3)(i)(A) and (B).
- The design of the final cover system must include an erosion layer that provides equivalent protection from wind or water erosion as the erosion layer specified in paragraph §257.102 (d)(3)(i)(C) of this section.
- The disruption of the integrity of the final cover system must be minimized through a design that accommodates settling and subsidence.

Note that the permeability of the natural subsoils present range from 1.66×10^{-7} cm/sec to 3.29×10^{-8} cm/sec as noted in the Alternative Liner Demonstration for the Fly Ash Basin prepared by Geosyntec Consultants in April of 2023.

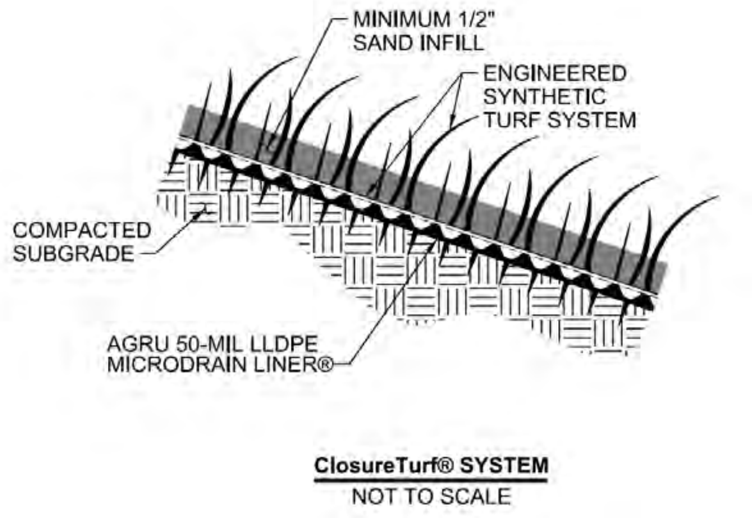
The FAB is being closed as a Type III landfill under Michigan Public Act 451, Part 115 Rules, §324.11506(12). MAC R.299.4304 addresses final cover design requirements for Type III landfills. This standard flexible membrane liner (FML) cover system has the following requirements:

- The system is designed to minimize erosion and infiltration to the extent necessary to protect public health and the environment [see R.299.4304(1)].
- The system must contain a lower component of an infiltration layer which has a flexible membrane liner and 2' minimum of protective soil [see R.299.4304(6)(a)(ii)]. This depth is inclusive of the erosion layer.
- The system must contain an upper component including a 6" erosion layer which can support native plants [see R.299.4304(6)(b)]

R.299.4304(6)(a)(iii) allows approved alternative materials if equivalent protection is provided.

An alternative final cover system, as shown in Figure 2-1, will be utilized in lieu of a typical clay final cover system. This ClosureTurf® system includes a geomembrane liner component to achieve the minimum permeability requirements of the CCR Rule, rather than relying on the permeability of the 18-inches of clay infiltration material. The geomembrane liner will meet the requirements of R.299.4915 per R.299.4304(6)(a)(ii). In lieu of the erosion layer required by both the CCR Rule and R.299.4304(6)(b), a synthetic turf is used. The synthetic turf consists of a woven geotextile fabric with HDPE synthetic grass blades and is ballasted by a ½" layer of sand infill. An Equivalency Demonstration report for this alternative cover system is provided in Appendix B.

Figure 2-1: Alternative Final Cover System



CCR material within the FAB will be graded to drain prior to receiving the final cover system, as described in Section 2.2.2.1. When complete, the FAB will have two stormwater discharge locations, including the existing discharge channel which discharges to the Monroe plant discharge canal, and a new discharge channel which will outfall to Lake Erie to the east of the FAB.

2.2.2.1 Geometry and Stormwater Management

The geometry and stormwater management controls of the closed impoundment will allow the CCR unit to meet the following requirements as outlined in §257.102(d) of the CCR Rule:

- Control, minimize or eliminate, to the maximum extent feasible, post-closure infiltration of liquids into the waste and releases of CCR, leachate, or contaminated run-off to the ground or surface waters or to the atmosphere.
- Prevent the probability of future impoundment of water, sediment or slurry.

Similarly, R. 299.4304(5) requires the following:

- To prevent the ponding of water on completed fill surfaces, the grading contours shall tend to forestall development of local depressions due to post-construction settlement. Slopes of the final cover shall not exceed 1 vertical on 4 horizontal or as necessary to permit the establishment of vegetative cover.

The final closure system grade will slope at a minimum of 1.0 percent over the capped CCR surface to prevent the collection of standing water and limit the velocity of storm water runoff to reduce the potential for erosion of the sand infill and will slope at a minimum of 0.5 percent within ditch flow lines. Intermediate swales will be utilized to limit the maximum overland flow distance, thereby limiting the chance for ponding water, as well as limiting the infiltration of run-off. The intermediate swales will collect area runoff and convey it to stormwater pipes which flow to open channels which discharge to the discharge canal and Lake Erie. Slopes within the closure footprint will be limited to 4H:1V. Because the cover system does not contain a soil component, erosion of the final cover system during construction will be limited to the very limited displacement of the sand infill material.

As described in the History of Construction prepared by Geosyntec Consultants (updated October 2021), the FAB was constructed above grade with a perimeter embankment. There is adequate separation between the bottom of the FAB and the uppermost aquifer per the Locations Restrictions Demonstrations prepared by TRC (October 2018). Based on these factors and the low permeability of the underlying soils noted in section 2.2.2, the siting of the FAB will minimize post-closure infiltration of liquids from the sides and bottom of the unit.

2.2.2.2 Integrity of the Final Cover

Requirements related to the integrity of the final cover system include the following:

- Provide for major slope stability to prevent sloughing or movement of the final cover system during closure and post-closure periods.
- The disruption of the integrity of the final cover system must be minimized through a design that accommodates settling and subsidence.

Engineering calculations will be performed during final design to confirm the final cover system meets both of these requirements.

Settling and subsidence of the final cover system is expected to be minimal. Settlement would potentially be caused by consolidation of the CCR material, general fill material, or underlying natural subsoils under new loads from construction activities; however, the majority of this settlement is expected to occur during dewatering and site grading activities and is expected to be minimal after the cover is installed. Based on the known properties of CCR, settlement associated with dewatering and grading will occur during construction activities. General fill and relocated CCR material from within the FAB will be installed in a controlled manner to minimize post-fill installation settlement. The underlying natural subsoils at the site will exhibit time dependent consolidation from an increase in effective stresses caused by dewatering of the CCR and grading activities. Effective stress is the soil particle-to-particle stress including buoyancy effects on the particles from saturation. Dewatering will decrease buoyancy of natural subsoils, and thus increase effective stress. However, based on the depth of natural subgrade beneath the final cover and consistent increase in effective stress, any settlement is not expected to disrupt the integrity of the final cover system.

Slope stability of the overall system will also be performed including mass stability of the CCR and existing embankments and cover stability. Based on the current stability of the FAB and minor grading to be performed of the CCR, slope stability is not considered a significant concern. If slope stability factors of safety are found to not meet minimum standards, mitigations to increase stability will be determined and implemented.

2.2.3 Final Cover Schedule

According to §257.102 of the CCR Rule, closure of FAB must commence no later than 6 months following the date on which a closure event is triggered, or no later than 30 days following the last known receipt of CCR or non-CCR wastestream by the FAB. Similarly, §324.11519b(6) requires the following:

> The owner or operator of a coal ash impoundment shall begin to implement closure as described in R 299.4309(7) of the MAC not more than 6 months after the final placement of coal ash within the impoundment and shall diligently pursue the closure. The closure shall be completed in compliance with 40 CFR 257.102(f)(1) and (2).

A notification of intent to initiate closure of the FAB will be placed in the facility's CCR Operating Record and on DTE's CCR public website prior to commencing closure. Pre-closure construction activities, including closure design and permitting, are underway. Closure construction for the FAB is anticipated to commence in the second quarter of 2024, or whenever permit documents are reviewed and approved by Michigan Department of Environment, Great Lakes, and Energy (EGLE). Closure construction is anticipated to be completed in phases and take a minimum of five years. The construction schedule will likely include breaks for winter periods (roughly between the months of December through February). The estimated closure schedule is as indicated in Table 2-1.

Table 2-1: Closure Schedule

Activity	Schedule
Anticipated date of last known receipt of CCR or non-CCR wastestream	Q4 2023
Begin closure construction	Q2 2024
Pond unwatering / dewatering (bulk removal, water handling activities will continue throughout construction)	Q2 2024 – Q3 2026
Grading of CCR material (will occur in phases across the 410-acre footprint)	Q3 2024 – Q4 2028
Installation of final cover system (will occur in phases following grading activities and removal of separable pore water)	Q3 2024 – Q2 2029
Target to complete closure	Q2 2029

2.2.3.1 Closure Completion

The federal CCR rule requires that closure of the FAB be completed within five years of commencing closure activities. The rule also allows the timeframe for completing closure of the CCR unit to be extended by multiple two-year extensions if DTE can substantiate the factual circumstances demonstrating the need for the extension. If needed, a demonstration for an extension of the closure timeframe shall be completed pursuant to §257.102(f)(2).

The CCR Rule does not define “closure complete” for CCR units. For the purposes of this Closure Plan, closure of the FAB is considered complete when the final cover system is installed, and the applicable construction completion documentation is finalized.

Within 30 days of completion of closure of the FAB, DTE must prepare a notification of closure of the FAB and place it in the facility’s CCR Operating Record and on DTE’s CCR public website. This notification shall include certification by a qualified professional engineer in the State of Michigan verifying that closure has been completed in accordance with this Closure Plan and the requirements of §257.102. Additionally, DTE must record a notation on the deed to the property following completion of closure of the FAB in accordance with §257.102(i). The purpose of this notation is to inform any potential future owner of the property of the previous use of the land, and that the land is restricted by post-closure care requirements.

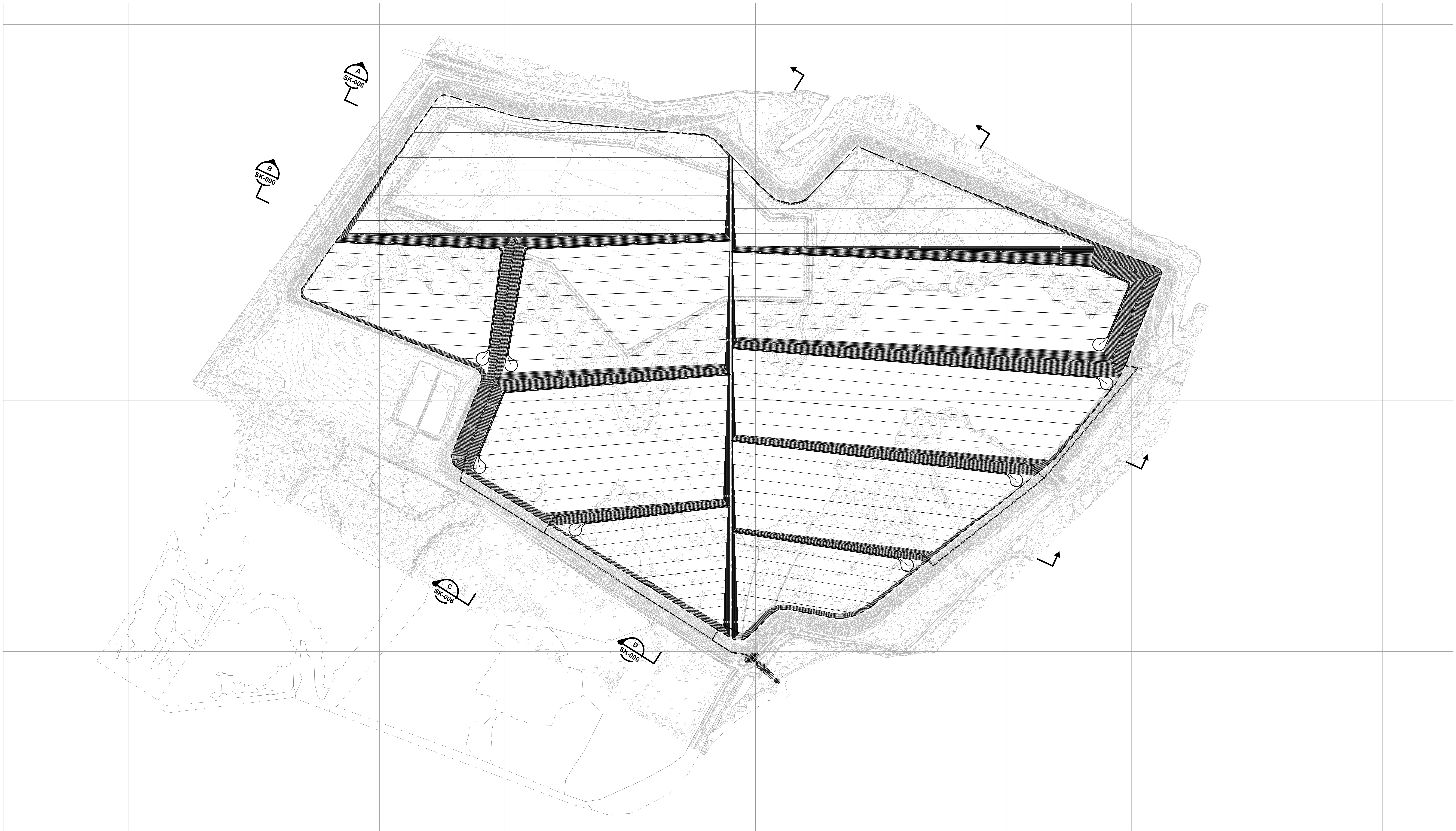
3.0 Revisions and Amendments

The initial Closure Plan for the FAB was placed in the CCR Operating Record in October of 2016. This update replaces the initial Closure Plan. If the Closure Plan is further revised, the written Closure Plan will be amended no later than 30 days following the triggering event. Additionally, the written Closure Plan will be amended at least 60 days prior to a planned change in the operation of the FAB, or no later than 60 days after an unanticipated event. The initial Closure Plan and any amendment will be certified by a qualified professional engineer in the State of Michigan for meeting the requirements of §257.102 of the CCR Rule. All amendments and revisions must be placed on the CCR public website within a reasonable amount of time following placement in the facility's CCR Operating Record. A record of revisions made to this document is included in Section 4.0 of this document.

4.0 Record of Revisions and Updates

Revision Number	Date	Revisions Made	By Whom
0	October 2016	Initial Issue	Geosyntec Consultants
1	October 2023	Redesign of closure	Burns & McDonnell
2	January 2024	Revisions to Appendix B – Alt. Final Cover Equivalency Demonstration	Burns & McDonnell

APPENDIX A – CONCEPTUAL CLOSURE DESIGN



NOTES:

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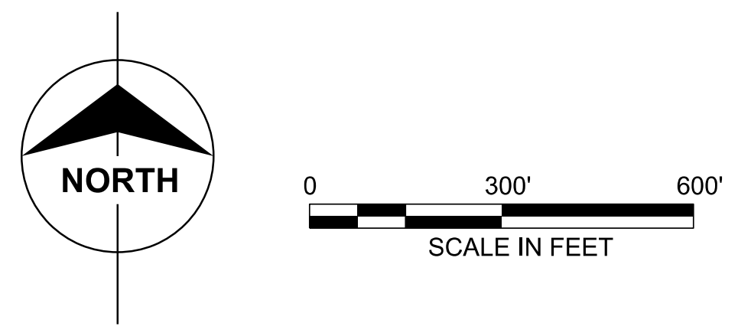
   VERTICAL DATUM IS NGVD 29.



PRELIMINARY - NOT FOR CONSTRUCTION

Millimeters
Scale For Microfilming
Inches

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BURNS McDONNELL

2111 WOODWARD AVENUE, SUITE 202
DETROIT, MI 48201
313-309-5711
Burns & McDonnell Michigan, Inc.

designed --------
detailed --------

DTE

MONROE COUNTY, MICHIGAN

MONROE FLY ASH BASIN CLOSURE
OPTION 3 CONCEPTUAL GRADING PLAN
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project 151630
contract 8120
drawing **SK-003**
rev. **A**
sheet of sheets
file 151630 SK-003.DGN

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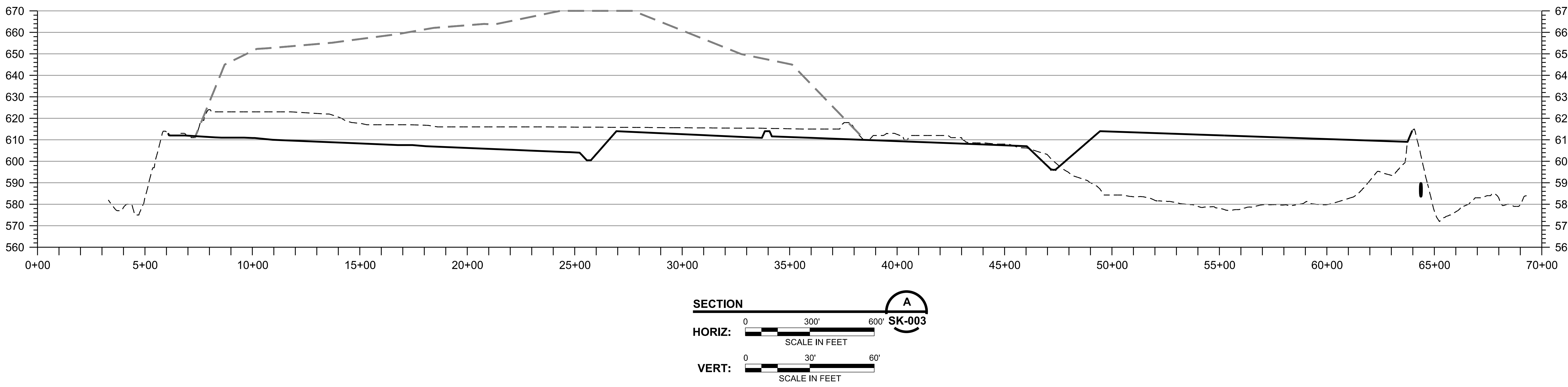
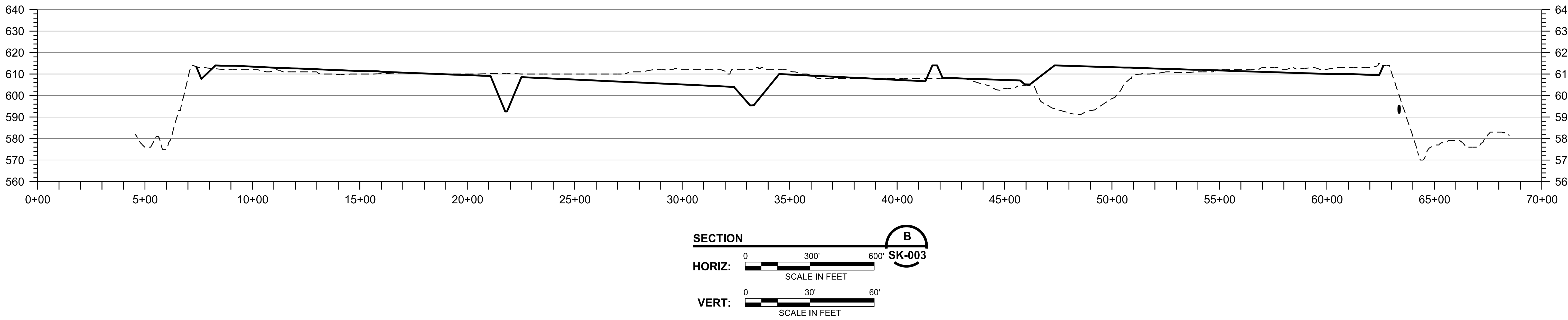
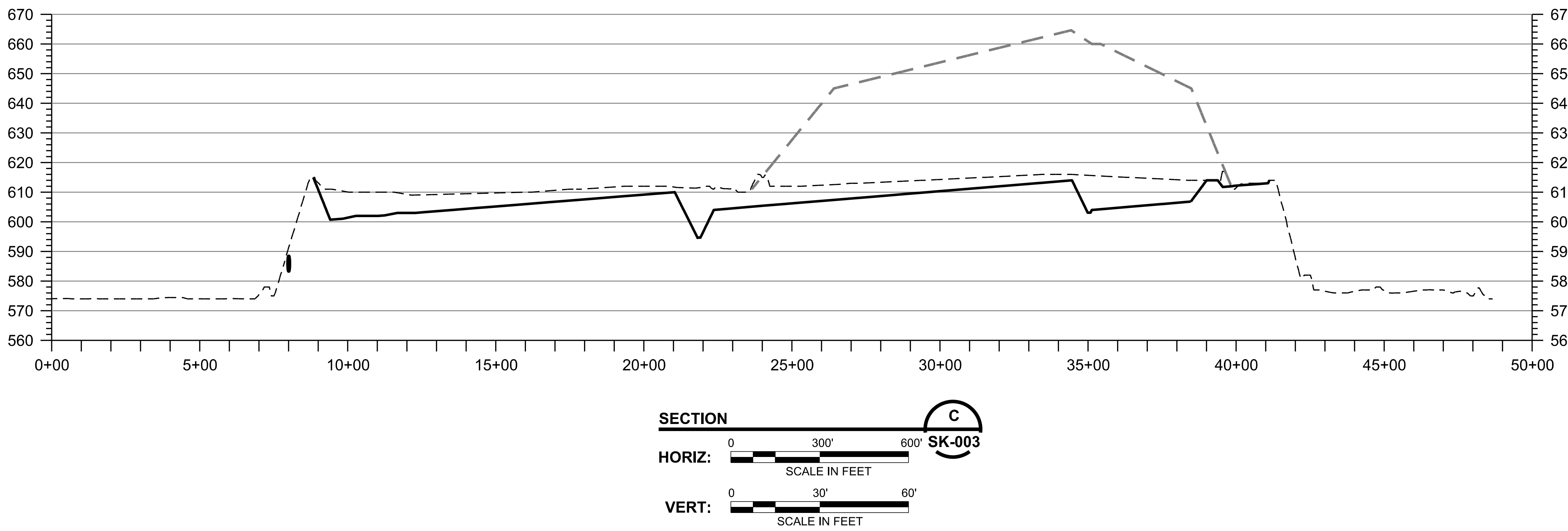
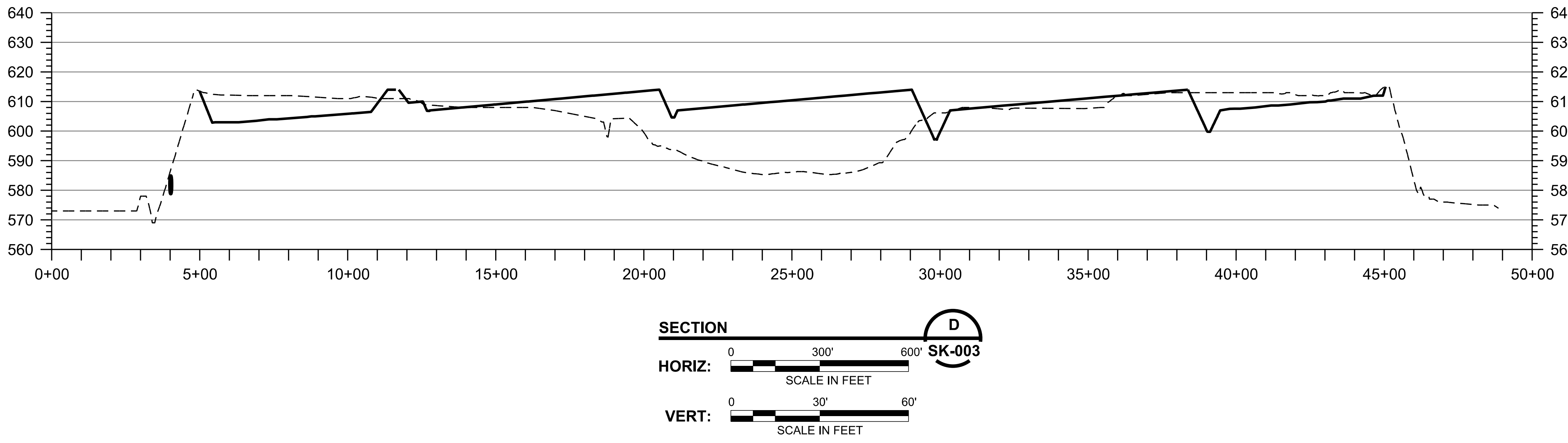
8/25/2023









Millimeters

Scale For Microfilming

Inches

PRELIMINARY - NOT FOR CONSTRUCTION

no.	date	by	ckd	description	no.	date	by	ckd	description

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designed
detailed

DTE

MONROE COUNTY, MICHIGAN

MONROE FLY ASH BASIN CLOSURE
OPTION 3 CONCEPTUAL GRADING SECTIONS

project 151630
contract 8120
drawing **SK-006**
rev. **A**
sheet
of
sheets
file 151630 SK-006.DGN

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8/25/2023

APPENDIX B – ALTERNATIVE FINAL COVER SYSTEM EQUIVALENCY DEMONSTRATION

DTE ELECTRIC COMPANY

ALTERNATIVE FINAL COVER SYSTEM EQUIVALENCY DEMONSTRATION

MONROE FLY ASH BASIN CLOSURE

PROJECT NO. 151630

REVISION 1
JANUARY 4, 2024

CONTENTS

List of Abbreviations

Abbreviation	Term/Phrase/Name
Burns & McDonnell	Burns and McDonnell Michigan, Inc.
CFR	Code of Federal Regulations
cfs	Cubic feet per second
DTE	DTE Energy
FAB	Fly Ash Basin
FML	Flexible Membrane Liner
fps	Feet per second
ft	Feet
EGLE	Michigan Department of Environment, Great Lakes, and Energy
GSI	Geosynthetic Institute
HDPE	High Density Polyethylene
HELP	Hydraulic Evaluation of Landfill Performance
LLDPE	Linear Low-Density Polyethylene
MAC	Michigan Administrative Code
MDEQ	Michigan Department of Environmental Quality
NOAA	National Oceanic and Atmospheric Administration
psf	Pounds per Square Foot

Index and Certification

DTE Electric Company
ALTERNATIVE FINAL COVER SYSTEM EQUIVALENCY DEMONSTRATION
Project No. 151630

Report Index

Chapter Number	Chapter Title	Number of Pages
1.0	Introduction	2
2.0	State and Federal Cover System Requirements	3
3.0	Infiltration Equivalency	3
4.0	Erosion Mitigation	2
5.0	Settlement and Subsidence	1
6.0	Resiliency and Longevity	3
7.0	Conclusion	1
Appendix B	Infiltration Calculations	45
Appendix C	Hydraulic Shear Calculations	15
Appendix F	Stormwater Calculations	40

Certification

I hereby certify, as a Professional Engineer in the state of Michigan, that the information in this document was assembled under my direct personal charge and the final closure system meets the requirements for 40 CFR §257.102. This report is not intended or represented to be suitable for reuse by the DTE Electric Company or others without specific verification or adaptation by the Engineer.

Allyson Myers

Allyson Myers, P.E.
(Michigan License No. 6201312005)

Date: January 4, 2024

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01/04/2024

1.0 Introduction

On behalf of DTE Energy (DTE), Burns & McDonnell Michigan, Inc. (Burns & McDonnell) has prepared this Alternative Final Cover Equivalency Demonstration (Demonstration) for the proposed alternative final cover system to be used in the closure of the Monroe Fly Ash Basin (FAB). This Demonstration will seek to show that the proposed alternative final cover system provides equivalent or greater performance than the cover system prescribed by Michigan Administrative Code R 299.4304(6), and that it meets the alternative final cover design and construction requirements of 40 CFR §257.102(d)(3)(ii).

The FAB is located at 7955 East Dunbar Road, Monroe, MI 48162. The FAB is within Section 16, Township 7 South, Range 9 East, of Monroe Township, Michigan and is comprised of approximately 410-acres (the 331-acre FAB plus the 79-acre Vertical Extension Landfill). The FAB and Vertical Extension Landfill (VEL) operate under the Michigan Department of Environment, Great Lakes, and Energy (EGLE) Solid Waste Operating License (Facility No, 397800, License No. 9579) which will expire in December of 2024. However, the VELis proposed to be closed by removal of CCR, which includes all CCR above the base elevation of the VEL when the unit was initially constructed. Once closed, the VEL will cease to exist as an independent unit. Closure of the VEL is scheduled to be complete prior to the installation of the final cover within the footprint of the VEL; therefore, the FAB will be the only unit to receive final cover.

The FAB is subject to the Solid Waste Management section (Part 115) of the Natural Resources and Environmental Protection Act (NREPA), Act 451 of 1994, as amended, the rules of the Michigan Administrative Code (MAC), and the Federal Coal Combustion Residuals (CCR) Rule issued by the Environmental Protection Agency in 2015 (CCR Rule), as amended. Therefore, compliance with the alternative final cover system requirements of both the state and federal regulations shall be the primary topic of this Demonstration. This Demonstration also addresses specific requests from EGLE's Materials Management Division (MMD) pertaining to the resiliency and longevity of the proposed final cover system.

The FAB is defined as a Type III landfill under Michigan Public Act 451, Part 115 Rules, R 324.11506(12). Specifically, the FAB is defined as a coal ash surface impoundment where coal ash will remain after closure and will be closed in place as a landfill pursuant to R 299.4309 of the MAC.

ClosureTurf® was selected as the flexible membrane liner (FML) component of the alternative cover system. This is a combined artificial turf and geosynthetic material manufactured by Watershed Geo®. The selected option includes the synthetic turf ballasted by sand infill underlain by 50-mil linear low-density polyethylene (LLDPE) geomembrane and a drainage layer (see Figure 1-1). This alternative final cover system is being proposed because:

- It meets or exceeds the regulatory requirements or constitutes an adequate alternative. This is demonstrated in the following sections.
- It would eliminate approximately 1.3 million cubic yards of imported cover soil (assuming 2 feet of clean soil capable of supporting vegetation).
- It would reduce the long-term maintenance needs associated with natural vegetation.

- It would allow the possibility to use PowerCap™ technology for potential future projects that could incorporate solar energy production during the post-closure period of the FAB (following completion of this project). PowerCap™ is a racking system for solar power attached directly to ClosureTurf® without penetrations.

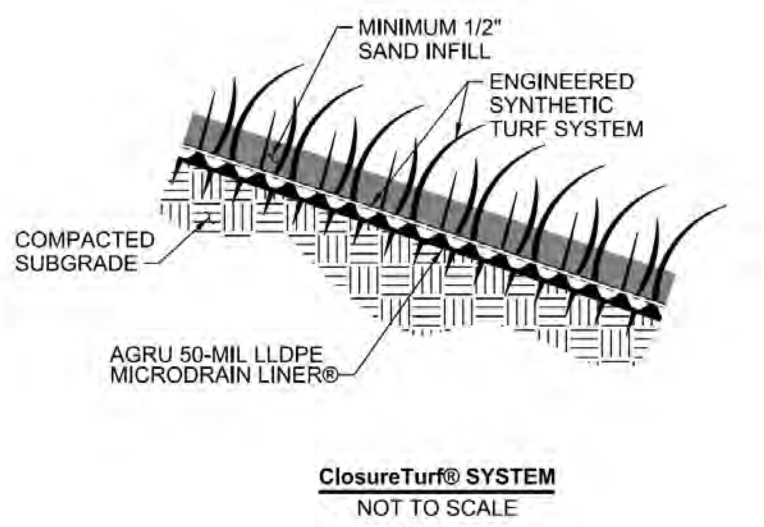

Figure 1-1: Profile view of ClosureTurf®

On February 8th, DTE met with EGLE to discuss the use of ClosureTurf® as the primary component of the Monroe FAB final cover system. ClosureTurf® is not new to the state of Michigan as it has been approved for the South Kent Landfill as a final cover material for the Ash Incinerator Basin but has yet to be installed. EGLE agreed that ClosureTurf® would be approved as an alternative final cover system if DTE demonstrates that ClosureTurf® is equivalent to the FML final cover system prescribed in the Part 115 Rules, is constructable, and is resilient to several specific climatic challenges. In particular, EGLE requested that DTE evaluate the proposed alternative cover system's resilience to freeze-thaw cycles, the longevity of the material, erosivity of the sand ballast material, and ClosureTurf's® compatibility with the proposed stormwater system. For reference, minutes for all relevant meetings with EGLE are provided in Appendix A.

On July 6th, a pre-application meeting was held between DTE and EGLE. In this meeting, EGLE confirmed that the general format of this Demonstration is an acceptable mechanism to request approval of an alternative final cover system. As discussed in the meeting, the key points of this Demonstration are:

- Demonstrate infiltration equivalency.
- Demonstrate erosion resistance.
- Demonstrate adequate sizing of the stormwater system.
- Demonstrate adequate UV resistance.
- Demonstrate adequate resiliency to freeze-thaw conditions.
- Demonstrate that settlement and subsidence will not be detrimental.

These items are addressed in the following sections.

2.0 State and Federal Standard Cover System Requirements

The proposed final cover system shall consist of the following layers (from top to bottom):

- Specified Infill that meets the criteria for use with ClosureTurf® (13 mm or 0.5 inches of sand)
- ClosureTurf® Synthetic Turf (32 mm or 1.25 inches high typical)
- 50-mil Geomembrane with Microdrain® providing a lateral drainage layer

Although a large number of solid waste facilities, including CCR storage facilities, have successfully utilized final cover systems consisting of synthetic turf, neither the Michigan Part 115 Regulations or the Federal CCR Rules contain detailed requirements for these types of systems, unlike compacted soil and FML systems. Instead, final cover systems utilizing alternative materials shall demonstrate equivalency with the rules and regulations. Sections 2.1 and 2.2 shall establish the rules that serve as the basis for the comparisons made in this Demonstration.

2.1 Michigan Admin. Code, Part 115

The CCR Unit is defined as a Type III landfill under Part 115 324.11506(12). Type III Landfill final cover design requirements are provided in Michigan's Administrative Code R.299.4304, which has depth requirements for compacted soil final cover systems [R299.4304(6)(a)(i)] and FML final cover systems [R299.4304(6)(a)(ii)]. As the proposed alternative final cover system is closest in nature to this traditional FML final cover system, this shall be the basis for the equivalency demonstration, and hereby referred to as the Part 115 standard FML cover system in this Demonstration. This standard FML cover system has the following requirements that are applicable to the CCR Unit. For each requirement, the approach this Demonstration will use to show equivalency is listed below.

A. The system is designed to minimize erosion and infiltration to the extent necessary to protect public health and the environment [see R299.4304(1)].

    - The minimization of infiltration shall be demonstrated in Section 3.0
    - The minimization of erosion shall be demonstrated in Section 4.0

B. The system must contain a lower component of an infiltration layer which has a flexible membrane liner and 2' minimum of protective soil [see R299.4304(6)(a)(ii)]. This depth is inclusive of the erosion layer.

    - The proposed alternative final cover system has a LLDPE geomembrane. However, it does not have 2 feet of protective soil. Alternatively, the synthetic turf functions as a protective layer to the geomembrane. The synthetic turf's ability to withstand erosion shall be demonstrated in Section 4.0.

C. The system must contain an upper component including a 6” erosion layer which can support native plants [see R299.4304(6)(b)]

  - The proposed alternative final cover system does not contain a component capable of supporting native plant growth because the synthetic turf is intended to provide the protective role of vegetation and stabilize the sand infill, which protects the geosynthetic layers below.

MAC R.299.4304(6)(a)(iii) allows approved alternative materials if equivalent protection is provided. This demonstration establishes the equivalency of the proposed alternative final cover system that is listed at the beginning of Section 2.0.

Additionally, MAC R.299.4915 sets forth requirements for the durability and longevity of FML. The FML component of the alternative final cover system adheres to the same manufacturer specifications as traditional HDPE or LLDPE liners with respect to tensile strength, elasticity, chemical resistance, and other physical properties. However, it is important to address the climate exposure resistance requirements of R.299.4915(1)(c)(i):

- (A FML shall) be sufficiently durable so that the properties of the liner are not significantly impaired by any of the following during the active life of the landfill and the postclosure period: Exposure to sunlight, precipitation, or anticipated temperature variations.

Section 6.0 provides detail on the behavior of the alternative final cover system when exposed to UV light and cold weather (i.e., specifically freeze/thaw) conditions. This section also addresses the incorporation of the ClosureTurf® material into the stormwater system design. Note that erosion resistance due to precipitation is addressed in Section 4.0.

2.2 Federal CCR Rules

The cover system prescribed by 40 CFR 257 (Federal CCR Rules) contains an erosion layer component and an infiltration layer component, similar to Michigan’s Part 115 Rules on Type III landfills. More specifically, the final cover system design and construction requirements for an alternative system are described in 40 CFR §257.102(d)(3)(ii). The applicable final cover system requirements of 40 CFR §257.102(d)(3)(ii) are listed below, followed by the approach this Demonstration will use to show equivalency or compliance.

A. The design of the final cover system must include an infiltration layer that achieves an equivalent reduction in infiltration as the infiltration layer specified in paragraphs §257.102 (d)(3)(i)(A) and (B) of this section.

  - §257.102 (d)(3)(i)(A) states - The permeability of the final cover system must be less than or equal to the permeability of any bottom liner system or natural subsoils present, or a permeability no greater than 1 × 10−5 cm/sec, whichever is less.
    - A comparison of hydraulic conductivities and overall infiltration of the natural subsoil to the alternative final cover infiltration shall be provided in Section 3.0.

- (d)(3)(i)(B) states - The infiltration of liquids through the closed CCR unit must be minimized by the use of an infiltration layer that contains a minimum of 18 inches of earthen material.
    - This prescriptive requirement is less robust than the requirement of the Michigan Part 115 Rules, which requires a FML plus 24 inches of earthen material [see R299.4304(6)(a)(ii)]. It is assumed that a comparison to the standard Part 115 cover system shall also satisfy a comparison with this infiltration layer requirement. Section 3.0 provides the infiltration equivalency demonstration.

B. The design of the final cover system must include an erosion layer that provides equivalent protection from wind or water erosion as the erosion layer specified in paragraph (d)(3)(i)(C) of this section.

- (d)(3)(i)(C) states - The erosion of the final cover system must be minimized by the use of an erosion layer that contains a minimum of six inches of earthen material that is capable of sustaining native plant growth.
    - The proposed alternative final cover system does not contain a component capable of supporting native plant growth because the synthetic turf is intended to provide the protective role of vegetation and stabilize the sand infill, which protects the geosynthetic layers below. The synthetic turf functions as a protective layer to the geomembrane. The synthetic turf's ability to withstand erosion is demonstrated in Section 4.0.

C. The disruption of the integrity of the final cover system must be minimized through a design that accommodates settling and subsidence.

    - The accommodation of settling and subsidence is discussed in Section 5.0.

3.0 Infiltration Equivalency

A comparison of final cover and natural liner systems was performed to demonstrate compliance with the following State and Federal rules:

- MI Administrative Code R299.4304(1): *The owner and operator of a type III landfill unit shall install a final cover system which is designed to minimize erosion and infiltration to the extent necessary to protect the public health and the environment.*
- 40 CFR §257.102(d)(3)(ii)(A): *The design of the final cover system must include an infiltration layer that achieves an equivalent reduction in infiltration as the infiltration layer specified in paragraphs (d)(3)(i)(A) and (B) of this section.*
    - 40 CFR §257.102(d)(3)(i)(A): *The permeability of the final cover system must be less than or equal to the permeability of any bottom liner system or natural subsoils present, or a permeability no greater than* 1×10^{-5} *cm/sec, whichever is less.*
    - 40 CFR §257.102(d)(3)(i)(B): *The infiltration of liquids through the closed CCR unit must be minimized by the use of an infiltration layer that contains a minimum of 18 inches of earthen material.*

The permeability of the natural subsoil liner of the CCR Unit was obtained from the Alternative Liner Determination for the FAB, dated April 2023 (Page 2-5). The permeability (hydraulic conductivity) of the soil ranges from 1.66×10^{-7} cm/sec to 3.29×10^{-8} cm/sec, which shall be used for the basis of the comparison described in 40 CFR §257.102(d)(3)(i)(A). The hydraulic conductivity of the ClosureTurf® LLDPE FML is 4×10^{-13} cm/sec, which is less than that of the natural subsoils. However, the intent of the rule is to minimize infiltration, which is also primarily dependent on depth, among other factors. Therefore, the infiltration of the alternative final cover system was compared to that of the natural subsoils of the CCR Unit.

To demonstrate equivalency with MI Administrative Code R299.4304(1) and 40 CFR §257.102(d)(3)(i)(B), infiltration of the alternative final cover system was also compared to that of the prescribed FML final cover system [see R299.4304(6)(a)(ii) and R299.4304(6)(b)], which is more robust when compared to the federal prescribed infiltration layer because it also contains a FML. By demonstrating that the proposed system yields a lower infiltration than the Part 115-prescribed FML cover system, it is evident that the system minimizes infiltration to the extent necessary to protect the public health and the environment.

The Hydraulic Evaluation of Landfill Performance (HELP) model was used to determine the two-dimensional movement of water flowing through the alternative final cover system and the systems used as a comparison. Attachment B includes the HELP Model results, inputs, and discussion that expands beyond the summary provided in this Section.

3.1 HELP Model Methodology

A 100-year period was used to model infiltration of the various final cover systems. Climate and weather data was compiled for a 100-year period in the Detroit area using data from national databases defined in the HELP Model User Manual along with the synthetic weather generator in the HELP software. The evaporative zone depth was chosen to be the depth to geosynthetic, or up to 12 inches, which is typical of southeast Michigan. The modeling parameters of the various final cover/natural soils layers were obtained using HELP default values, supplemented by product-specific data by Watershed Geo® and site-specific data for the CCR Unit.

The HELP Model layers representing the ClosureTurf® alternative final cover system are as follows. Details on the hydraulic conductivity and other parameters for each layer are provided in the cover sheet of the HELP Model calculation and corresponding HELP model reports (Attachment B).

- Engineered Turf with Specified Infill (13 mm of 0.5 inches of sand)
- Microdrain® Lateral Drainage Layer (130 mil thickness)
- LLDPE Geomembrane (50 mil thickness)

Prior to comparing the alternative final cover system to the other two infiltration barrier systems (standard Part 115 geomembrane cover and the natural subsoils), a critical area was selected so that consistent values could be used for each model for slope, area, and drainage length. This was required because the proposed grading plan utilizes slopes of 0.5%, 1.0% and 25%, and surface slope and runoff affect infiltration quantities through any given system. Using the proposed grading plan for the Monroe FAB, the largest contiguous areas corresponding to each slope (0.5%, 1% and 25%) were obtained. Each area, all using the alternative final cover system, was modeled for infiltration using the HELP Model, and the area resulting in the highest infiltration was used in the comparison of cover system types. The critical area of the final cover that is most susceptible to infiltration is the largest 0.5% slope area (0.64 acres). This critical area was used in the comparison of the alternative final cover system to the following infiltration barrier systems.

The HELP Model layers representing the Part 115-prescribed FML final cover system, meeting both the state and federal requirements, is as follows. Part 115 does not require that the protective cover soil be clay, however, clay was selected for use in this comparison system to conservatively decrease the hydraulic conductivity of the system.

- Vegetated Erosion Layer (6 inches of loamy soil)
- Protective Soil Cover (18 inches of clay soil)
- LLDPE Geomembrane (40 mil thickness)

The HELP Model layers representing the natural subsoil of the CCR Unit are as follows. To properly model the behavior of liquid movement through the CCR Unit, a layer of waste was also included. Attachment B provides more information on the selection of these layers.

- Dense fly ash waste (10 feet)
- Soil matching actual Monroe FAB properties (34 feet of clay)

3.2 Results and Conclusions

The resulting infiltration determined by the HELP Model is provided in Table 3-1, below.

Table 3-1: HELP Model Infiltration Results

Infiltration Barrier System	Slope (%)	Area (acres)	100-Year Avg. Annual Infiltration (in)	100-Year Avg. Annual Infiltration (ft^3)	100-Year Avg. Annual Infiltration (%)
Alternative Final Cover System (ClosureTurf®)	**0.5%**	**0.64**	**0.37**	**863**	**1.17**
Standard MI Part 115 Geomembrane Cover	0.5%	0.64	0.59	1370	1.86
Monroe FAB Natural Subsoil Liner	0.5%	0.64	0.53	1228	1.67

According to the HELP model results, the lowest annual average infiltration was from the alternative ClosureTurf® final cover system, thus exceeding the infiltration performance of the Part 115-prescribed FML final cover system, which meets the requirements of the federal and state rules. Therefore, requirement R299.4304(1) is satisfied. As shown in Table 3-1, the alternative final cover system also yields less infiltration than the natural subsoils of the CCR Unit. Therefore, 40 CFR §257.102(d)(3)(i)(A) is satisfied. Based on these results, the ClosureTurf® alternative final cover system has more restrictive infiltration properties than what is required by state and federal requirements.

4.0 Erosion Mitigation

An analysis of the ClosureTurf® sand infill material was performed as part of the final cover design process and to demonstrate compliance with the following State and Federal rules:

- MI Administrative Code R299.4304(1): *The owner and operator of a type III landfill unit shall install a final cover system which is designed to minimize erosion and infiltration to the extent necessary to protect the public health and the environment.*
- MI Administrative Code R299.4304(6)(b): *The erosion layer shall consist of a minimum of 6 inches of earthen material that is capable of supporting native plant growth.*
- 40 CFR §257.102(d)(3)(ii)(B): *The design of the final cover system must include an erosion layer that provides equivalent protection from wind or water erosion as the erosion layer specified in paragraph (d)(3)(i)(C) of this section.*
    - 40 CFR §257.102 (d)(3)(i)(C): *The erosion of the final cover system must be minimized by the use of an erosion layer that contains a minimum of six inches of earthen material that is capable of sustaining native plant growth.*

The proposed alternative final cover system does not contain a component capable of supporting native plant growth, nor does it contain an erosion layer consisting of six inches of earthen material. However, the synthetic turf component of ClosureTurf® is intended to provide the protective role of vegetation and stabilize the sand infill, which protects the geosynthetic layers below. This is an alternative material used to accomplish the same goal as the erosion layer required by the state and federal rules. However, to be considered a suitable substitute for the six-inch layer capable of supporting native plant growth, the erosivity of the sand infill shall be analyzed to understand the longevity of the material and its ability to serve as a reliable protective cover for the geomembrane.

The CCR Unit's final cover system is designed in a manner that mitigates erosion of the sand infill within the synthetic turf component of ClosureTurf®. To mitigate erosion of the sand infill, the hydraulic shear stress shall be managed via the proper configuration of slopes and maximum flow lengths throughout the final cover system. The final cover system was designed with a network of swales to intercept runoff and limit the maximum flow lengths in any given area. Using the ClosureTurf® Design Guidelines Manual (Watershed Geo, 2023), the hydraulic shear stress was calculated for various critical scenarios. Each critical shear stress was compared to the manufacturer's recommended maximum shear stress to evaluate the likelihood of erosion.

Additionally, erosion of the sand infill as a result of wind forces is explored in Section 4.3.

4.1 Hydraulic Shear Stress Calculation

Hydraulic shear stress calculations were prepared using the methodologies in Watershed Geo®'s ClosureTurf® Design Guidance Manual. Using independent third-party laboratory testing of ClosureTurf®, Watershed Geo® has determined that erosion of sand infill occurs when the material experiences a hydraulic shear stress of 1.5 lb/ft^2 and above. Furthermore, the critical shear stress for design purposes was managed to stay below this value with a factor of safety of 1.5, which was selected for this particular design. Therefore, the critical hydraulic shear stress for the design of the CCR Unit is 1.0 lb/ft^2.

The hydraulic shear stress calculations and a more-detailed explanation of methodology and inputs is provided in Attachment C. A 100-yr, 60-min storm event was selected for the calculation, and the National Oceanic and Atmospheric Administration (NOAA) database was used to predict rainfall for the selected event.

Two critical scenarios were selected for a comparison of actual shear stress to the critical shear stress of 1.0 lb/ft^2. Both scenarios considered flow paths over 1% and 25% slopes where sheet flow and shallow concentrated flows are expected to occur. Scenario 1 included the maximum length of the steepest slope. Scenario 2 consisted of the longest overall flow path. Attachment C includes a figure illustrating these flow paths. The hydraulic shear calculated for each flow path scenario was compared to the critical hydraulic shear stress for the design of the CCR Unit.

4.2 Results and Conclusions for Water Erosivity

For Scenario 1, stormwater runoff flows over the 668-ft “top deck” with 1% then over 79 feet of 25% slope before terminating in a reinforced channel. For this scenario, the hydraulic shear stress reaches a maximum value of 0.702 lb/ft^2. For Scenario 2, stormwater runoff flows over the 1072-ft “top deck” with 1% then over 32 feet of 25% slope before terminating in a reinforced channel. For this scenario, the hydraulic shear stress reaches a maximum value of 0.921 lb/ft^2. Neither scenario exceeds the critical hydraulic shear stress of 1.0 lb/ft^2. Therefore, it is not expected that erosion of the sand infill will occur during the 100-yr, 60-min storm event.

It has been demonstrated that the ClosureTurf® component of synthetic turf paired with sand infill provides adequate resistance to erosion for the CCR Unit design. Therefore, it can be derived that the component covering the geomembrane will remain in place when faced with the erosive forces of a major storm event. Furthermore, an increased soil depth and native vegetation offer no additional benefits beyond what is provided by the proposed alternative final cover system with regard to erosion mitigation. MI Administrative Code R299.4304(1) is satisfied for the material’s ability to mitigate erosion.

4.3 Results and Conclusions for Wind Erosivity

The ability of the sand infill component of ClosureTurf® to resist erosion due to wind has been investigated by Watershed Geo®. This investigation was qualitative and has not been published formally, but the results demonstrate that high winds directed in a near-parallel orientation with respect to the final cover system did not displace sand infill particles significantly. The experiment was performed using a blower producing winds of approximately 145 mph. Following this investigation, Watershed Geo® determined that the synthetic grass blades adequately deflected winds from a near-parallel direction. The degree and orientation of slopes for the FAB design will resemble the conditions of this experiment, as most slopes are 1-percent or less. It should be noted that 4:1 slopes will be present in the drainage channels but are also partially shielded from winds due to the “sunken” orientation of channels. The investigation by Watershed Geo® does not raise concerns about this type of exposure.

5.0 Settlement and Subsidence

40 CFR §257.102(d)(3)(ii)(C) states that *the disruption of the integrity of the final cover system must be minimized through a design that accommodates settling and subsidence* when considering an alternative final cover system.

Settling and subsidence of the final cover system is expected to be minimal such that the final design will not result in a reversal of grade due to localized or differential settlement the FAB. Settlement would potentially be caused by consolidation of the CCR material, general fill material, or underlying natural subsoils under new loads from construction activities; however, the majority of this settlement is expected to occur during dewatering and site grading activities and is expected to be minimal after the cover is installed. Based on the known properties of CCR, settlement associated with dewatering and grading will occur during construction activities. General fill and relocated CCR material from within the FAB will be installed in a controlled manner to minimize post-fill installation settlement. The preliminary grading plan includes an efficient design that limits fill heights while still maintaining required slopes for drainage.

The underlying natural subsoils at the site will exhibit time dependent consolidation from an increase in effective stresses caused by dewatering of the CCR and grading activities. Effective stress is the soil particle-to-particle stress including buoyancy effects on the particles from saturation. Dewatering will decrease buoyancy of natural subsoils, and thus increase effective stress. However, based on the depth of natural subgrade beneath the final cover and consistent increase in effective stress, any settlement is not expected to disrupt the integrity of the final cover system.

Although it is expected to be minimal, settlement of the final cover system poses a risk of rupture to the components of the alternative final cover system if it causes strain to increase beyond what is allowable for the material. If settlement does occur, it would be maximized beneath the new fill, leading to a slight decrease in the fill height. Therefore, settlement of high points will lead to a slightly negative strain being imparted on the final cover system and thus there is no risk of rupturing the final cover system. Settlement depths, final fill height and associated final cover slope will be evaluated during final design, with attention paid to locations where there are penetrations through the final cover system for the storm drainage culverts. Evaluations will also confirm that the slope is adequate for drainage accounting for possible settling and subsidence.

Areas of low strength material may be present which could pose the risk of localized settling and subsidence that could cause pooling of water on the final cover system. To mitigate this risk, requirements in the final design specifications will include inspection of the final cover subgrade prior to placement of the final cover. This will confirm the final cover is placed on a firm, stable subgrade. Additionally, the minimal weight of the proposed final cover will also limit the possibility of further localized settlement and subsidence.

6.0 Resiliency and Longevity

R299.4915(1)(c)(i) states that the FML must *be sufficiently durable so that the properties of the liner are not significantly impaired by any of the following during the active life of the landfill and the postclosure period: exposure to sunlight, precipitation, or anticipated temperature variations.* This section shall address the resiliency of the alternative final cover to these conditions (the erosion component of precipitation durability is addressed in Section 2.0). During the discussions with EGLE, referenced in Section 1.0 of this Demonstration, EGLE expressed interest in several items concerning ClosureTurf's® ability to withstand forces that may affect the material's longevity. EGLE and DTE also discussed ClosureTurf's® unique runoff properties and whether the design of the stormwater management system will properly accommodate ClosureTurf®. The following sections discuss these considerations and those of MAC R299.4915(1)(c)(i).

6.1 UV Degradation

This topic is being considered to demonstrate that ClosureTurf® has an adequate degree of resiliency to UV degradation. The effect of UV exposure is a concern for geosynthetic materials that are exposed to the elements. With the synthetic turf component of the alternative final cover system providing a critical role in the preservation of the underlying LLDPE, the longevity of the material is critical to the minimization of erosion and infiltration.

The UV degradation of ClosureTurf® has been studied extensively to get an understanding of how the cover system reacts to prolonged UV exposure. Attachment D includes the 2022 Assessment of UV Longevity that was prepared by a third-party consultant for Watershed Geo®, which is an Appendix to the ClosureTurf® Design Guidance Manual (Watershed Geo®, 2023). This document includes a series of tests performed at five facilities throughout the United States and utilizes tensile strength measurements to obtain the half-life of the HDPE grass blades. One such series of tests was performed in New River, Arizona for a duration of 10 years. Tests were conducted after 1, 5, 7, and 10 years of use. Using these results, Geosyntec Consultants were able to estimate the material's half-life (50% tensile strength time) and the time to degrade to 12.5% of the original tensile strength. This latter value represents the stage at which the HDPE grass blades will become susceptible to damage by vehicular traffic and the force exerted by stormwater runoff.

Results from the New River, Arizona testing found that the expected half-life of ClosureTurf® will be between 75-93 years. For a 12.5% remaining tensile strength on this site, Watershed Geo® estimates ClosureTurf® will be between 181-216 years. In other words, the HDPE blades are expected to degrade to half of the original tensile strength after 75 years and become susceptible to damage by vehicular traffic and the force exerted by stormwater runoff after 181 years. This length of time demonstrates the longevity of the material, but it is also important to note that ClosureTurf® undergoing testing at the New River, Arizona laboratory experiences far greater UV exposure than areas in the Midwest. Therefore, it can be predicted that the half-life of ClosureTurf® for the Monroe DTE site will be greater.

6.2 Freeze/Thaw Effect

This topic is being considered to demonstrate that the LLDPE component of ClosureTurf® will not be adversely affected by the increased frequency of freeze-thaw cycles that may result from the lack of the 2-foot-thick cover soil layer prescribed by R299.4304(6)(a)(ii) and 40 CFR §257.102(d)(3)(i)(B). The alternative final cover system has a ½-inch thick sand infill layer and textile component of the synthetic turf insulating the LLDPE layer from the ambient air temperatures. Both the prescribed final cover systems and the alternative final cover system are thinner than the frost depth in Michigan and therefore susceptible to freeze-thaw cycles. However, the thinner layer of cover component of ClosureTurf® may mean that the freeze-thaw cycling of the HDPE will occur more frequently in the case of the alternative final cover system.

In White Paper #28 by Geosynthetic Institute (GSI), a freeze-thaw cycling behavior test on geomembrane seams by Comer and Hsuan in 1994 is summarized and evaluated. This White Paper is provided in Attachment E. In the study, Comer and Hsuan tested 31 different seams on 19 different geomembrane sheet materials with 7 resin types. In the study, tensile strength results were obtained from the material which would undergo cyclic temperatures ranging from -20℃ to +20℃. In all parts of the study, tensile strength was taken after 1, 5, 10, 20, 50, 100 and 200 cycles. In the first part of the study, tensile strength was taken at +20℃. In the second part of the study, tensile strength was taken at -20℃. In the third part of the study tensile strength was taken at +20℃ but unlike the first two test, during the freeze-thaw cycles, there was constant strain tensioned.

For all three parts of the study, the results showed that tensile strength, shear strength, and peel strength show no indication of change of the tested materials or their seams (Attachment E). The overall conclusion from this study is that geomembrane sheets and seams will not be affected by freeze-thaw conditions. Therefore, any increased frequency of freeze-thaw cycles should not affect the LLDPE component of ClosureTurf® used in the alternative final cover system.

6.3 Compatibility with the Stormwater System

This topic is being considered to demonstrate that ClosureTurf® has been properly incorporated into the stormwater management system of the CCR Unit closure. ClosureTurf® has a notably high curve number, which impacts the runoff flow rates and the system design.

The final cover system of the CCR Unit was modeled in HydroCAD to determine adequate sizing of the stormwater conveyance features, which consist of drainage ditches and culverts which ultimately discharge into new and existing discharge channels connected to Lake Erie via the Monroe Power Plant's discharge channel. The purpose of performing these calculations is to determine the sizing of these stormwater features and to verify the flow velocities are not detrimental to the final cover or the features themselves. Peak flows for 25-year, 24-hour rainfall event were used to accomplish this. The stormwater calculations are provided in Attachment F.

ClosureTurf® has a curve number (CN) of 95, which is higher than the CN of typical landfill vegetation. In fact, this CN more closely resembles gravel driving surfaces. Therefore, the runoff flow rates are notably high per acre. However, using a CN of 95 for the CCR Unit's top deck and slopes (as shown in Attachment F), adequate freeboard and flow velocities are maintained for the critical design channels. These critical design channels were selected because they represent the only two discharge locations for the entire final cover system. The first channel, labeled as 31R in Attachment F, has a channel capacity of 373.05 cfs, a maximum velocity of 7.85 fps, an average velocity of 3.10 fps and a freeboard of 0.8 ft. The second channel, labeled as 32R in Attachment F has a channel capacity of 240.5 cfs, a maximum velocity of 3.79 fps, an average velocity of 1.24 fps, and a freeboard of 0.6 ft. The flow velocities are not expected to erode the concrete channel lining of these major discharge points.

7.0 Conclusion

Burns & McDonnell has prepared this Equivalency Demonstration to convey our understanding that the alternative final cover system presented herein meets the state and federal requirements for a Type III landfill and CCR Unit, or constitutes an acceptable alternative. As demonstrated in the Demonstration, the alternative final cover system allows lower levels of infiltration (see Section 3.0), provides an erosion layer that minimizes erosion while protecting the LLDPE geomembrane (see Section 4.0), and accommodates settling and subsidence (see Section 5.0). This Demonstration addresses all applicable requirements of 40 CFR §257.102(d)(3)(ii) and Michigan Administrative Code R.299.4304. Additionally, ancillary considerations such as UV degradation, freeze-thaw effect, and compatibility with the stormwater system design have been addressed for the sake of engineering best practice, to provide confidence in the overall performance of the system.

ATTACHMENT A – EGLE MEETING MINUTES: FEB. 8TH & JULY 6TH

Meeting Minutes

BURNS McDONNELL

Project Name:	DTE Monroe Fly Ash Basin Closure Project
Meeting Subject:	Alternative Closure Concepts with EGLE Materials Management Division
Meeting Date:	February 8, 2023, 1:00 PM (eastern)
Location	Constitution Hall, Lansing MI
BMcD Project No.:	151630

Name	Company	Role	Attendance
Margie Ring	EGLE MMD	Solid Waste Engineering Coordinator	x
Gary Schwerin	EGLE MMD	District Engineer	x
Brett Coulter	EGLE MMD	Geologist	x
Chris Scieszka	DTE	Environmental	x
Robert Lee	DTE	Environmental	x
Mark Rokoff	BMcD	CCR Specialist	x
Tyler Schmidt	BMcD	Environmental Engineer	x

1. Introduction
    a. Chris gave a high-level project overview: The FAB/VEL closure is in early design phase (conceptual design). Both units will be closed. DTE is considering solar. ClosureTurf (CT) is a potential option being considered for a number of positive reasons.
    b. Margie is familiar with CT. This alternative cover was approved for use at the Kent County Landfill in their incinerator ash disposal area (although not yet installed). This unit is also a Type III landfill.
2. Timelines for Closure
    a. Gary asked about timelines. Chris said it will be in line with EPA Part B determination and noted that they are actively converting to dry handling. Later in the meeting, Margie asked if DTE would be pushing the operation of the pond/VEL longer. Rob replied that DTE will move forward with closure once the dry handling conversion is complete.
    b. Margie pointed out that the MI Type III rules dictate closure must be complete in 1 year from ceasing operation. However, she recognized the magnitude of the project and that extensions could be granted via a formal variance procedure.
    c. Rob asked what an appropriate assumption would be. Would EGLE be opposed to them conservatively assuming the entire 15 year period would be necessary? Margie said that would be okay if we made a reasonable case. She encouraged being conservative since this is one of the largest closure projects and the variance process is not an activity you want to repeat regularly.
3. Mark presented the CT Slideshow, prepared by BMcD and DTE (see attached).
    a. EGLE is open to the use of CT if the proper variance procedure is followed.
    b. EGLE is open to the use of PowerCap. Margie indicated that she like the concept of solar over a landfill.
4. Procedure for CT approval—EGLE said:
    a. DTE needs to provide design documents and closure plan to Gary to review.
    b. DTE needs to pass licensing process to receive a variance to the prescribed Type III cover system (note this includes calculations and a formal demonstration).
5. Freezing liquids in the CT system (Gary initiated conversation).

   a. Gary believes the "flat" slope and the thin sand layer may be conducive to freezing water on the liner after saturating the sand infill as well as a freeze-thaw effect within the sand layer.
   b. Mark said we can address that concern. CT has been successfully used in cold climates.
6. Slopes under 2% (minimum per MI Part 115).
   a. Gary said a variance would be required if a slope shallower than this was to be used AND this includes grades for drainage lines/swales.
   b. Gary said a variance has been granted before but it's difficult/rare as the level of demonstration is notable. DTE would need to demonstrate that >2% slopes are not feasible.
   c. Gary also said that the 2% minimum slope applies to internal ditches, swales, etc.
   d. Gary prefers that proper slopes and drainage is achieved by use of sawtooth/herringbone grading.
   e. Gary is concerned about concrete-lined channels (both for CT and traditional covers) largely due to maintenance and lifespan. Mark said CT requires a strengthened sand infill in flowlines (Hydrobinder).
7. Maximum Height Variance
   a. Chris asked EGLE if they would allow us to build the top of final cover beyond the design elevation of the FAB/VEL. Mark said it may be necessary for drainage.
   b. Margie cited the rule that allowed a change in landfill elevation (if it doesn't result in an increase in disposal capacity).
   c. The most that would need to be done is a Construction Permit Modification, although an easier path may be possible.
   d. If DTE can prove that an increased height is required to comply with rules, a design change may be the route to approval (not a permit mod).
   e. DTE clarified that max VEL height is not a concern, just FAB. Margie said she'd need to think about the approval process for the FAB design, since the VEL is the only unit with a construction permit.
8. Lifespan of CT materials (Margie initiated conversation)
   a. Chris said 100+ years is what the manufacturer projects. Mark said that projection is conservative. Margie found that news acceptable.
   b. Margie said that they added a condition when CT was approved for Kent County: to retain financial assurance budget for a specified time beyond post-closure period. Margie said EGLE may consider a similar condition in the FAB/VEL license if CT is selected.
9. Post Closure Period Timeline Modifications
   a. Chris asked for clarification on the Part 115 rule.
   b. Margie confirmed that the post closure care period can be reduced if certain criteria is met (no odors, no leachate issues, etc).
   c. Margie said failure to meet criteria can also extend the period.
10. Additional discussion items
   a. Rob said DTE would prefer to have a decision from EGLE on the maximum height approval process and likelihood for approval before pulling together a 30% design. Margie said they would need to discuss internally.

   i. **ACTION: EGLE is considering the appropriate process to pursue this change and will contact DTE when complete (although no formal date was assigned).**

b. BMcD described the PowerCap racks and system. No concerns from EGLE.
c. The Carleton Farms Type II landfill has similar material. It's believed this is the site in Michigan that has Versacap (another Watershed Geo product), EGLE recognizes the durability differences between the two products. Note that Versacap (essentially CT without the sand infill) is being deployed as intermediate cover (not final cover) and helps with some geometric limitations at the site (it is thinner than the traditional cap system).
d. Gary said if CT is used, DTE needs to revise the post closure care plan.
e. Mark clarified that the berms that are in pace would not obstruct runoff. They may be graded to allow drainage.
f. Gary prefers an iterative review process. Mark clarified that it's our goal to have permit compliance addressed in the 30% design review, and the preceding designs would adhere to the conceptual design framework (reducing the role of regulatory review after the 30% design stage).
   i. **ACTION: DTE/BMcD to schedule a follow up meeting to present the intended design and regulatory variances or "tight spots" with EGLE early in the process (prior to the 30% design) to continue to improve the understanding on regulatory approach (this was always our intention). No date was set.**
g. Rob offered to host EGLE (Gary and/or their new hire) to come to the site and better understand the site conditions. No specifics were determined.

Meeting Minutes

BURNS McDONNELL

Project Name:	DTE Monroe Fly Ash Basin Closure Project
Meeting Subject:	Operating License Pre-Application Meeting with EGLE Materials Management Division
Meeting Date:	July 6, 2023, 1:00 PM (eastern)
Location	Constitution Hall, Lansing MI
BMcD Project No.:	151630

Name	Company	Role	Attendance
Margie Ring	EGLE MMD	Solid Waste Engineering Coordinator	x
Gary Schwerin	EGLE MMD	District Engineer	x
Brett Coulter	EGLE MMD	Geologist	x
Richelle Ozoga	EGLE MMD	District Engineer	x
Chris Scieszka	DTE	Environmental	x
Robert Lee	DTE	Environmental	x
Dan Sand	DTE	Project Manager	x
Mark Rokoff	BMcD	CCR Specialist	x
Tyler Schmidt	BMcD	Environmental Engineer	x

1. Introduction and summary of previous meeting
    a. Safety Moment: 9PM Rule for home/vehicle security.
    b. Mark summarized Feb 8th meeting. Main topics were ClosureTurf, final cover slopes, project timeline, CCR unit design elevations, and potential submittals (permit/license/design change). DTE agreed that the summary covered main discussion points.
    c. Margie said EGLE is working on revisions to Part 115 to better align with Federal CCR rule although they may not be finalized prior to submittal of the updated operating license for the FAB.
2. Project overview:
    a. Project is currently between conceptual-level and 30%.
    b. Significant grading is required to convey stormwater runoff from site. Lake Erie elevation is a downstream constraint.
    c. Closure Plan will be revised to align with current project planning.
    d. Margie asked, Where ash is being placed now?
        i. Chris: Fly Ash Basin (FAB) and Vertical Extension Landfill (VEL). DTE's Dry Fly Ash Project is intended to use Sibley site as a future disposal location.
    e. Gary asked about closure duration.
        i. Mark: estimated 6 years minimum. Dewatering may prolong that the schedule.
        ii. Margie said a variance to the Operating License will be required.
3. Variance timeline
    a. Margie read Part 115 rule on closure timelines
        i. For Landfills, it's 6 months following last receipt of waste.
        ii. For surface impoundments (FAB), Part 115 defers to timelines specified in the Federal Rule (257.102). No variance is needed for FAB.
    b. There are some options to expedite approval for activities only reliant on the timeline variance given the site-specific configuration with the FAB and VEL. Margie said (note that this is discussed in more detail under item #4):

        i. Consideration 1: apply for two operating licenses, one for VEL and one for FAB, so the VEL closure can start before all FAB variances are approved.
            1. Multiple Operating Licenses is accompanied by multiple fees.
        ii. Consideration 2: EGLE enforcement (Chris said DTE will not pursue this one)

4. VEL closure by removal (CbR)
    a. Mark described this process as a way to close the operating license and remove the VEL from state jurisdiction, which is DTE's preferred approach.
    b. Margie asked, Is ash being removed and disposed offsite?
        i. Chris: No—will be disposed of in FAB. Quantity is 200-300K CY.
    c. Gary asked, is the top of VEL below final design grades?
        i. Mark said yes, fill is required to achieve slopes in the current site design for stormwater flow.
    d. Margie asked, Is there a barrier at the bottom of VEL?
        i. Chris: No. The layer between the VEL and FAB is permeable.
    e. Mark/Chris asked if the CbR can be approved without physically moving the ash and returning same or similar material in it's place (as part of the FAB closure)?
        i. Margie said it is a unique proposal and agreed with DTE that there may be a better way to close out the VEL license compared to the double handling of the CCR. If the VEL were to no longer be treated as a separate unit, EGLE would need to find a way to justify it.
        ii. Mark: Part 115 does not describe closure by removal for a landfill as this is not a typical approach.
        iii. ACTION: EGLE to review Part 115 and provide options to administratively close the VEL, and how to characterize the VEL at time of closure. DTE to seek resolution by July 20, 2023.
            1. Chris and Margie discussed on 7/14 – EGLE determined there is not a path forward for the VEL to administratively close by removal, however we could close the VEL by physically removing the landfill and certifying the removal.
                a. DTE and Burns & Mac to discuss this in context of timing for CbR and operating license renewal

5. Operating License Application Process
    a. Mark explained the structure of the proposed license application, explained what unique design features are categorized as variances (and which are equivalency demonstrations/design changes) and asked if EGLE agreed with the approach.
        i. EGLE concurred.
    b. Mark asked, Which application form to use (most recent form or CCR-specific form)?
        i. Margie said, use most recent because it reflects Part 115 updates.
        ii. ACTION: BMcD to compare new application form to the one submitted with previous application in 2019, to identify major changes.

      iii. Financial Assurance for CCR Landfills did not change (maximum is still $1 million). Financial Assurance for Type III landfills rose from $1 to 2 million (max.).
   c. Margie asked, Does the landfill have a permanent marker?
      i. Chris/Dan: yes

6. Alternative Cover: ClosureTurf
   a. Mark: demonstration will be modeled after Kent County
      i. Margie said that Kent County was an ash monofill, not a landfill. Several MSW landfills have asked for ClosureTurf and been denied.
   b. Kent county had stipulations in their permit:
      i. Increased financial assurance.
      ii. Agreement to replace with a traditional cover system if ClosureTurf fails.
         1. Chris asked for clarification. Are occasional repairs acceptable?
            a. Margie: Yes. The stipulation was intended for large-scale repeated failures. A maintenance plan would address this concern.
   c. Margie asked if ClosureTurf has been approved for other sites
      i. Mark: Yes. Not in MI but all around U.S. This data was shared in our last presentation to EGLE (in February), but generally there is over 3,000 acres placed in the US as of late 2022.
   d. EGLE agreed that the Closure Plan was the correct location to include the Equivalency Demonstration, within overall Application.
7. Elevation of the FAB:
   a. Mark explained that based on the current design, the difference in height is approximately 1 ft.
   b. Margie recommends emphasizing that the increased height does not affect disposal capacity.
   c. Margie: EGLE is primarily interested in changes to maximum elevation.
   d. Margie said DTE will need to evaluate the stability of the slopes wherever the outer berm is cut down.
      i. Mark: DTE plans to evaluate. However, given the proposed changes to the pond, this is not anticipated to be a big concern (i.e., because of dewatering, removal of driving forces, and shallow grades within the FAB footprint).
8. Final Cover Slope Variance
   a. Mark: Monroe is unique because it's a pond, not a landfill. This CCR pond is one of the largest in the U.S. The waste is homogeneous in type (in that it is all CCR materials) and there are no groundwater impacts.
   b. Mark asked, Are the demonstrations/calculations identified on the slide adequate? Anything else EGLE would like to see?
      i. Gary: We would need to minimize maintenance concerns (look at rules) such as concrete on the final cover.
      ii. Mark said ClosureTurf is commonly used with hydrobinder in ditches and we would address this in the operating license.

- c. For maintenance mitigation, Gary requests that DTE includes a Maintenance Plan with discussion on procedures/precautions influenced by shallow slopes.
- d. Mark asked if there are major "Red Flags."
    - i. Gary said there may be back and forth but if there was no chance at approval, he would tell DTE and not wait until a full application was submitted. He thinks the approach stands a solid chance of being approved.

9. Timeline:
    - a. Mark reviewed durations for EGLE approval.
    - b. Margie clarified some things about the 120-day extensions.
        - i. The first 120-day extension, if requested by applicant, is always granted.
        - ii. Subsequent 120-day extensions MAY be granted by EGLE. If no chance at approval, EGLE will not grant it.
    - c. Mark asked EGLE about the likelihood of this Application being approved early.
        - i. Gary said, due to the slope variance, the complexity around CbR of the VEL, and use of ClosureTurf, there is a good chance review will exceed 120 days.
    - d. Mark asked about ways to expedite process.
        - i. EGLE is in favor of the in-person meeting at the time of submittal to present the content and details in the operating license (and answer questions).
        - ii. Gary recommends contacting the Monroe County Clerk prior to the Application submittal to assist them with understanding the submittal. This will ease potential questions by the municipality including the need for public meeting.
    - e. Mark noted that while final schedule is dependent on other factors, it is the current project understanding to submit the new operating license mid to late August.
10. Additional discussion items
    - a. Gary asked DTE to further describe the dewatering process.
        - i. Mark: While the design and investigation associated with this step is not complete and changes may occur, current project plan is for the use of deep wells to be installed over the FAB footprint to satisfy the requirements in 257.102.
        - ii. Brett: How deep are the "deep wells?" Mark clarified that they are called deep wells because of how they're constructed, but are only as deep as the CCR in the pond (they would not penetrate through the base of the FAB).

ATTACHMENT B – INFILTRATION CALCULATIONS

DTE Monroe Power Plant
Fly Ash Basin and Vertical Extension Landfill
HELP MODEL INFILTRATION CALCULATIONS

BURNS & McDONNELL

PROJECT: DTE Monroe Fly Ash Basin
SUBJECT: Infiltration Modeling of Final Cover Systems Using HELP Model
PROJECT NUMBER: 151630
DATE: 8/21/2023 Page 1 of 3

Purpose: 1) To demonstrate the infiltration equivalency of the alternative final cover system, compared to the cover system prescribed by Part 115 of the Michigan Administrative Code [R299.4304(6)(a)] and
2) To demonstrate that the alternative final cover system meets the intent of 40 CFR §257.102(d)(3)(i)(A), which states that the permeability of the final cover system must be less than or equal to the permeability of any bottom liner system or natural subsoils present, or a permeability no greater than 1 × 10−5 cm/sec, whichever is less. Modeling infiltration of both the cover system and the liner is the typical approach to demonstrate complaince with this requirement.

Background: DTE Energy plans on closing the Monroe Fly Ash Basin (FAB) using an alternative final cover system. ClosureTurf was selected to be the primary component of the design, consisting of geomembrane overlayed by sand-ballasted synthetic turf and a lateral drainage system.

Methodology: Infiltration through selected cover systems was estimated using the Hydrologic Evaluation of Landfill Performance (HELP) Model, Version 4. A 100-year modeling period was used. Inputs were selected using guidance provided by Watershed Geo, the manufacturer of ClosureTurf, and the EPA HELP User Manual.

Part 1: Select the critical area to use in the alternative final cover system infiltration comparison.
The grading plan (Attachment 1) for the Monroe FAB was used identify the largest contiguous areas corresponding to each slope (0.5%, 1% and 25%). These areas are shown on Figure 1. The final closure condition for each area, all using the alternative final cover system, were modeled for infiltration using the HELP Model, and the area resulting in the highest infiltration was used in the comparison of cover system types. The HELP Model Results are provided for Areas 1-3 in Attachments 2-4, respectively. Table 1, below, summarizes the selection of the critical area.

Table 1 - Critical Area Analysis Results

Area ID	Cover System[1]	Slope (%)	Max. Drainage Length (feet)	Area (acres)	Curve Number	100-Year Avg. Annual Infiltration (in)
1	Alt. Final	0.5%	3473	0.64	95	0.37
2	Alt. Final	1%	1072	55.7	95	0.23
3	Alt. Final	25%	113	24.9	95	0.013

Note: 1. The layers of the Alternative Final Cover System are described on Page 2.

Area 3 (0.5% slopes) has the highest annual infiltration of the selected areas, 0.37 inches of the total annual rainfall of 31.5 inches. Therefore, Area 3 is the critical area and was used for the infiltration comparison of the alternative final cover system to the Michigan Part 115 cover system and the in-situ soil liner at the FAB. Table 2 provides the results of the comparison using a constant slope, area, and flow length.

Prepared By: Tyler J. Schmidt, PE Date: 8/21/2023
Checked By: Allyson Myers, PE Date: 8/23/2023
Approved By: Allyson Myers, PE Date: 8/23/2023

PROJECT: DTE Monroe Fly Ash Basin
SUBJECT: Infiltration Modeling of Final Cover Systems Using HELP Model
PROJECT NUMBER: 151630
DATE: 8/21/2023

Methodology: cont.

Part 2: Use the critical area of 0.63 acres at 0.5% slopes to compare the alternative final cover system to the cover system prescribed by Part 115 of the Michigan Administrative Code [R299.4304(6)(a)].

Table 2 - Alternative Final Cover Profile (from top to bottom, see Attachment 2):

Layer Description	Thickness (in)	Hydraulic Conductivity (cm/sec)
Engineered Turf with Sand Infill	0.5	$2.5x10^{-2}$
Microdrain® Lateral Drainage Layer	0.13	$5.64x10^{-2}$ (lateral)[1]
50-mil LLDPE Geomembrane	0.05	$4.0x10^{-13}$

Note:
1. Saturated hydraulic conductivity for the drainage layer is calculated based on slope. See Supplemental Calculations.

Table 3 - Standard MI Part 115 Geomembrane Cover Profile (from top to bottom)

Layer Description	Thickness (in)	Hydraulic Conductivity (cm/sec)
Vegetated Erosion Layer	6	$3.7x10^{-4}$ (see Note 1)
Protective Cover Soil	18	$3.3x10^{-5}$ (see Note 2)
40-mil LLDPE Geomembrane	0.04	$4.0x10^{-13}$ (see Note 3)

Note:
1. Hydraulic conductivity is the default for Loam (HELP Material Texture 8).
2. Hydraulic conductivity is the default for Sandy Clay (HELP Material Texture 13).
3. Hydraulic conductivity is the default for Linear Low Density Polyethelene Liner (LLDPE) (HELP Material Texture 13).

The summary of the HELP Model for Standard MI Part 115 Geomembrane Cover (on 0.5% slopes) is provided as Attachment 5. The results for the infiltration comparison can be found in Table 5.

Part 3: Use the critical area of 0.63 acres to compare the alternative final cover system to the site-specific natural subsoils.

In the HELP Model for the natural subsoils (Attachment 6), the in-situ clay liner was isolated aside from an assumed 10-foot layer of ash waste overlaying it (which was included to accurately model head on liner). The inclusion of this 10-foot waste layer is conservative because it adds an additional barrier layer to the comparison scenario that the Alternative Final Cover must overcome. The in-situ clay liner depth and hydraulic conductivity was obtained from the Alternative Liner Determination for the FAB, dated April 2023 (Pages 2-3 and 2-5). In this report, the depth and hydraulic conductivity of the soil is presented in a range. For this comparison, the highest depth and lowest hydraulic conductivity was selected, which can be found in Table 4.

Table 4 - Monroe FAB Natural Subsoil Profile (from top to bottom, see Attachment 6):

Layer Description	Thickness (in)	Hydraulic Conductivity (cm/sec)
Ash Waste	120 (10 feet)	$1x10^{-2}$ (See Note 1)
Clay Soils	408 (34 feet)	$3.29x10^{-8}$

Note:
1. Hydraulic conductivity is the default for High-Density MSW Fly Ash (HELP Material Texture 32).

Prepared By: Tyler J. Schmidt, PE Date: 8/21/2023
Checked By: Allyson Myers, PE Date: 8/23/2023
Approved By: Allyson Myers, PE Date: 8/23/2023

DTE Monroe Power Plant
Fly Ash Basin and Vertical Extension Landfill
HELP MODEL INFILTRATION CALCULATIONS

BURNS & McDONNELL

PROJECT: DTE Monroe Fly Ash Basin
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PROJECT NUMBER: 151630
DATE: 8/21/2023 Page 3 of 3

Results: The resulting 100-year average annual infiltration for the three final cover/liner systems modeled (see Attachments 2, 5 and 6) is presented in Table 5. The lowest infiltration values come from the Alternative Final Cover System.

Table 5 - Average Annual Infiltration Comparison

Infiltration Barrier System	Slope (%)	Area (acres)	100-Year Avg. Annual Infiltration (in)	100-Year Avg. Annual Infiltration (ft^3)	100-Year Avg. Annual Infiltration (%)
Alternative Final Cover System	**0.5%**	**0.64**	**0.37**	**863**	**1.17**
Standard MI Part 115 Geomembrane Cover	0.5%	0.64	0.59	1370	1.86
Monroe FAB Natural Subsoil Liner	0.5%	0.64	0.53	1228	1.67

Supplemental Calculations: A geosynthetic lateral drainage layer was modeled for the Alternative Final Cover System. For the corresponding HELP Models (see Attachments 2-4), the drainage layer's hydraulic conductivity was calculated using the methodology described in Attachment 7 (see References, below). That calculation is shown below. The following results were included in the HELP model inputs.

Hydraulic Conductivity = Transmissivity (ϴ) divided by Thickness (T, for 130 mil MicroDrain)

$$\theta = 0.00020697\left(\frac{12.28 \times i^{0.624}}{i}\right)$$

For i = 0.005, ϴ = 186.3 cm2/sec and T = 0.33 cm, Therefore, Hydraulic Conductivity is 564.3 cm/sec
For i = 0.01, ϴ = 143.6 cm^2/sec and T = 0.33 cm, Therefore, Hydraulic Conductivity is 434.8 cm/sec
For i = 0.25, ϴ = 42.80 cm^2/sec and T = 0.33 cm, Therefore, Hydraulic Conductivity is 129.6 cm/sec

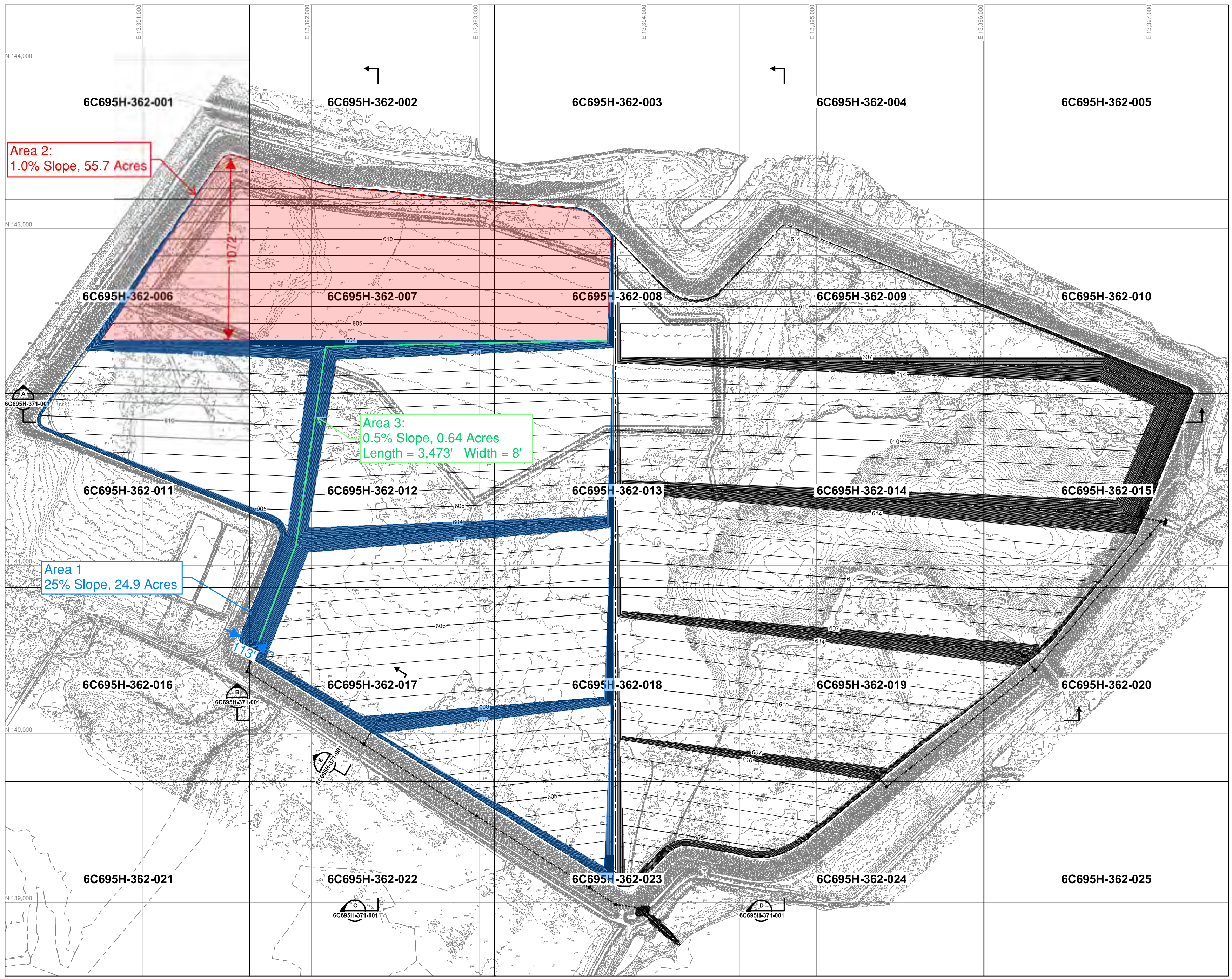
References:

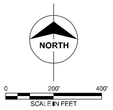
1. Figure 1: Grading Plan with Infiltration Areas **(Attachment 1)**
2. HELP Model Results for Alt. Final Cover and Largest 0.5% Slope Area **(Attachment 2)**
3. HELP Model Results for Alt. Final Cover and Largest 1% Slope Area **(Attachment 3)**
4. HELP Model Results for Alt. Final Cover and Largest 25% Slope Area **(Attachment 4)**
5. HELP Model Results for Standard MI Part 115 Geomembrane Cover **(Attachment 5)**
6. HELP Model Results for Monroe FAB Natural Subsoils **(Attachment 6)**
7. Hydrologic Performance of Synthetic Turf Cover Systems and Their Equivalency to Prescriptive Cover Systems, Carlson, 2019 **(Attachment 7)**
8. HELP User Guide
9. ClosureTurf Design Guidance Manual, 2023 **(Attachment 8)**

Prepared By:	Tyler J. Schmidt, PE	Date:	8/21/2023
Checked By:	Allyson Myers, PE	Date:	8/23/2023
Approved By:	Allyson Myers, PE	Date:	8/23/2023

Attachment 1 - Figure 1: Grading Plan with Infiltration Areas

ATTACHMENT 1
GRADING PLAN WITH
INFILTRATION AREAS





6C695H-362
LATEST REVISION "0"

NO.	DATE	ISSUED FOR	DISPLN/RSP ENG	PRJ ENG
6				
5				
4				
3				
2				
1	30JUN23	ISSUED FOR 30% REVIEW	ENR AMM	–

PROJECT ENGINEER: –
APPROVALS
PRECONSTRUCTION REVISION BLOCK - REV. 0

Vendor:

BURNS McDONNELL
2111 Woodward Avenue, Suite 202
Detroit, MI 48201
313-309-5711
Burns & McDonnell Michigan, Inc.

DTE ELECTRIC COMPANY

TITLE
FLY ASH BASIN CLOSURE PROJECT
FINISH GRADING PLAN
KEY PLAN

LOCATION NAME: MONROE POWER PLANT
UNIT NUMBER: 1
ORIGINATING SOURCE: BURNS & MCDONNELL MICHIGAN, INC.
SCALE: AS SHOWN
USE DIMENSIONS ONLY DO NOT SCALE
DTE ELECTRIC COMPANY DRAWING NUMBER: 6C695H-362

DESIGN FILE NAME: 0695-C-H-0362.dgn

PRELIMINARY - NOT FOR CONSTRUCTION

THIS IS A CAD PRODUCED DRAWING. ANY CHANGES OR REVISIONS TO THIS DRAWING MUST BE COMPLETED USING THE CAD SYSTEM

DTE ELECTRIC APPROVALS		DATE
ENS TECH DRG	–	–
	–	–
ENS PLANT ENG	–	–
	–	–
DIST OPR	–	–
	–	–
PROJECT ENG	–	–
ENG COMP	–	–

OTHER APPROVALS		DATE
VERIFYER	–	–
ARCH	–	–
CIVIL	–	–
MECH	–	–
	–	–
ELEC	–	–
	–	–
I&C	–	–

DESIGNED BY	DATE
A. MYERS	18MAY23
DRAWN BY	DATE
J. RIDDER	18MAY23
CHECKED BY	DATE
APPROVED BY	DATE
PROJECT ENGINEER	DATE
PROJECT MANAGER	DATE

J	PROJ. ENG.	PROJ. MGR.		MADE BY	DATE	I&C	ELECT.
				CH'K BY	DATE	MECH.	APPROVED BY
H	PROJ. ENG.	PROJ. MGR.		MADE BY	DATE	I&C	ELECT.
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Attachment 2 - HELP Model Results for Alt. Final Cover and Largest 0.5% Slope Area

HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE
HELP MODEL VERSION 4.0 BETA (2018)
DEVELOPED BY USEPA NATIONAL RISK MANAGEMENT RESEARCH LABORATORY

Title: Infiltration - Alternative Fin… **Simulated On:** 8/21/2023 18:06

Layer 1

Type 1 - Vertical Percolation Layer (Cover Soil)
Engineered Turf
Material Texture Number 43

Thickness = 0.5 inches
Porosity = 0.437 vol/vol
Field Capacity = 0.062 vol/vol
Wilting Point = 0.024 vol/vol
Initial Soil Water Content = 0.1092 vol/vol
Effective Sat. Hyd. Conductivity = 2.50E-02 cm/sec

Layer 2

Type 2 - Lateral Drainage Layer
Studded Geomembrane Drainage Layer
Material Texture Number 44

Thickness = 0.13 inches
Porosity = 0.85 vol/vol
Field Capacity = 0.01 vol/vol
Wilting Point = 0.005 vol/vol
Initial Soil Water Content = 0.01 vol/vol
Effective Sat. Hyd. Conductivity = 5.64E+02 cm/sec
Slope = 1 %
Drainage Length = 3473 ft

Layer 3

Type 4 - Flexible Membrane Liner
LDPE Membrane
Material Texture Number 36

Thickness = 0.05 inches
Effective Sat. Hyd. Conductivity = 4.00E-13 cm/sec
FML Pinhole Density = 1 Holes/Acre
FML Installation Defects = 1 Holes/Acre
FML Placement Quality = 3 Good

Note: Initial moisture content of the layers and snow water were computed as nearly steady-state values by HELP.

General Design and Evaporative Zone Data

SCS Runoff Curve Number = 95
Fraction of Area Allowing Runoff = 100 %
Area projected on a horizontal plane = 0.64 acres
Evaporative Zone Depth = 0.5 inches
Initial Water in Evaporative Zone = 0.055 inches
Upper Limit of Evaporative Storage = 0.218 inches
Lower Limit of Evaporative Storage = 0.012 inches
Initial Snow Water = 0.171063 inches
Initial Water in Layer Materials = 0.056 inches
Total Initial Water = 0.227 inches
Total Subsurface Inflow = 0 inches/year

Note: SCS Runoff Curve Number was User-Specified.

Evapotranspiration and Weather Data

Station Latitude = 41.91 Degrees
Maximum Leaf Area Index = 4.5
Start of Growing Season (Julian Date) = 128 days
End of Growing Season (Julian Date) = 259 days
Average Wind Speed = 11 mph
Average 1st Quarter Relative Humidity = 70 %
Average 2nd Quarter Relative Humidity = 65 %
Average 3rd Quarter Relative Humidity = 74 %
Average 4th Quarter Relative Humidity = 75 %

Note: Evapotranspiration data was obtained for Monroe, Michigan

Normal Mean Monthly Precipitation (inches)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
1.88514	1.69133	2.363089	2.880845	3.136959	3.246387
3.058041	3.406246	2.984792	2.293588	2.481272	2.31871

Note: Precipitation was simulated based on HELP V4 weather simulation for:
Lat/Long: 41.91/-83.47

Normal Mean Monthly Temperature (Degrees Fahrenheit)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
28.3	33.3	42.5	54.5	68.5	78.2

82.5	79.3	70.1	56.5	42.6	34.1

Note: Temperature was simulated based on HELP V4 weather simulation for:
Lat/Long: 41.91/-83.47
Solar radiation was simulated based on HELP V4 weather simulation for:
Lat/Long: 41.91/-83.47

Average Annual Totals Summary

Title: Infiltration - Alternative Final Cover, 0.5% slopes
Simulated on: 8/21/2023 18:10

	Average Annual Totals for Years 1 - 100*			
	(inches)	[std dev]	(cubic feet)	(percent)
Precipitation	31.75	[3.66]	73,753.2	100.00
Runoff	6.235	[2.006]	14,485.3	19.64
Evapotranspiration	9.520	[1.267]	22,116.3	29.99
Subprofile1				
Lateral drainage collected from Layer 2	15.6195	[1.6549]	36,287.3	49.20
Percolation/leakage through Layer 3	0.371435	[0.034951]	862.9	1.17
Average Head on Top of Layer 3	0.0048	[0.0005]	---	---
Water storage				
Change in water storage	0.0006	[0.6443]	1.4108	0.00

* Note: Average inches are converted to volume based on the user-specified area.

Peak Values Summary

Title: Infiltration - Alternative Final Cover, 0.5% slopes
Simulated on: 8/21/2023 18:10

	Peak Values for Years 1 - 100*	
	(inches)	(cubic feet)
Precipitation	2.88	6,691.1
Runoff	2.202	5,115.2
Subprofile1		
Drainage collected from Layer 2	0.8194	1,903.7
Percolation/leakage through Layer 3	0.010583	24.6
Average head on Layer 3	0.0955	---
Maximum head on Layer 3	0.1775	---
Location of maximum head in Layer 2	9.68	(feet from drain)
Other Parameters		
Snow water	5.1650	11,999.3
Maximum vegetation soil water	0.4370	(vol/vol)
Minimum vegetation soil water	0.0240	(vol/vol)

Final Water Storage in Landfill Profile at End of Simulation Period

Title: Infiltration - Alternative Final Cover, 0.5% slopes
Simulated on: 8/21/2023 18:10
Simulation period: 100 years

	Final Water Storage	
Layer	(inches)	(vol/vol)
1	0.0143	0.0286
2	0.0013	0.0100
3	0.0000	0.0000
Snow water	0.2721	---

Attachment 3 - HELP Model Results for Alt. Final Cover and Largest 1% Slope Area

```
----------------------------------------------------------------------------------------------------------------
                  HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE
                         HELP MODEL VERSION 4.0 BETA (2018)
      DEVELOPED BY USEPA NATIONAL RISK MANAGEMENT RESEARCH LABORATORY
----------------------------------------------------------------------------------------------------------------
     Title:      Infiltration - Alternative Fin…          Simulated On:      8/21/2023 16:48
----------------------------------------------------------------------------------------------------------------

                                   Layer 1
                 Type 1 - Vertical Percolation Layer (Cover Soil)
                                Engineered Turf
                          Material Texture Number 43
     Thickness                                  =          0.5  inches
     Porosity                                   =        0.437  vol/vol
     Field Capacity                             =        0.062  vol/vol
     Wilting Point                              =        0.024  vol/vol
     Initial Soil Water Content                 =       0.1129  vol/vol
     Effective Sat. Hyd. Conductivity           =     2.50E-02  cm/sec

                                   Layer 2
                        Type 2 - Lateral Drainage Layer
                     Studded Geomembrane Drainage Layer
                          Material Texture Number 44
     Thickness                                  =         0.13  inches
     Porosity                                   =         0.85  vol/vol
     Field Capacity                             =         0.01  vol/vol
     Wilting Point                              =        0.005  vol/vol
     Initial Soil Water Content                 =         0.01  vol/vol
     Effective Sat. Hyd. Conductivity           =     4.35E+02  cm/sec
     Slope                                      =            1  %
     Drainage Length                            =         1072  ft

                                   Layer 3
                       Type 4 - Flexible Membrane Liner
                                LDPE Membrane
                          Material Texture Number 36
     Thickness                                  =         0.05  inches
     Effective Sat. Hyd. Conductivity           =     4.00E-13  cm/sec
     FML Pinhole Density                        =            1  Holes/Acre
     FML Installation Defects                   =            1  Holes/Acre
     FML Placement Quality                      =            3  Good
     ----------------------------------------------------------------------------------------------------------------
     Note:       Initial moisture content of the layers and snow water were
                 computed as nearly steady-state values by HELP.
```

General Design and Evaporative Zone Data

SCS Runoff Curve Number	=	95	
Fraction of Area Allowing Runoff	=	100	%
Area projected on a horizontal plane	=	55.7	acres
Evaporative Zone Depth	=	0.5	inches
Initial Water in Evaporative Zone	=	0.056	inches
Upper Limit of Evaporative Storage	=	0.218	inches
Lower Limit of Evaporative Storage	=	0.012	inches
Initial Snow Water	=	0.171063	inches
Initial Water in Layer Materials	=	0.058	inches
Total Initial Water	=	0.229	inches
Total Subsurface Inflow	=	0	inches/year

Note: SCS Runoff Curve Number was User-Specified.

Evapotranspiration and Weather Data

Station Latitude	=	41.91	Degrees
Maximum Leaf Area Index	=	4.5	
Start of Growing Season (Julian Date)	=	128	days
End of Growing Season (Julian Date)	=	259	days
Average Wind Speed	=	11	mph
Average 1st Quarter Relative Humidity	=	70	%
Average 2nd Quarter Relative Humidity	=	65	%
Average 3rd Quarter Relative Humidity	=	74	%
Average 4th Quarter Relative Humidity	=	75	%

Note: Evapotranspiration data was obtained for Monroe, Michigan

Normal Mean Monthly Precipitation (inches)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
1.88514	1.69133	2.363089	2.880845	3.136959	3.246387
3.058041	3.406246	2.984792	2.293588	2.481272	2.31871

Note: Precipitation was simulated based on HELP V4 weather simulation for:
Lat/Long: 41.91/-83.47

Normal Mean Monthly Temperature (Degrees Fahrenheit)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
28.3	33.3	42.5	54.5	68.5	78.2

```
    82.5       79.3       70.1       56.5       42.6       34.1
-----------------------------------------------------------
Note:      Temperature was simulated based on HELP V4 weather simulation for:
           Lat/Long: 41.91/-83.47
           Solar radiation was simulated based on HELP V4 weather simulation for:
           Lat/Long: 41.91/-83.47
```

Average Annual Totals Summary

Title: Infiltration - Alternative Final Cover, 1% slopes
Simulated on: 8/21/2023 16:52

	Average Annual Totals for Years 1 - 100*			
	(inches)	[std dev]	(cubic feet)	(percent)
Precipitation	31.75	[3.66]	6,418,836.0	100.00
Runoff	6.024	[1.97]	1,217,983.2	18.98
Evapotranspiration	9.655	[1.265]	1,952,117.3	30.41
Subprofile1				
Lateral drainage collected from Layer 2	15.8295	[1.698]	3,200,577.2	49.86
Percolation/leakage through Layer 3	0.237594	[0.022975]	48,039.4	0.75
Average Head on Top of Layer 3	0.0019	[0.0002]	---	---
Water storage				
Change in water storage	0.0006	[0.6445]	118.8	0.00

* Note: Average inches are converted to volume based on the user-specified area.

Peak Values Summary

Title: Infiltration - Alternative Final Cover, 1% slopes
Simulated on: 8/21/2023 16:52

	Peak Values for Years 1 - 100*	
	(inches)	(cubic feet)
Precipitation	2.88	582,338.6
Runoff	2.202	445,179.3
Subprofile1		
Drainage collected from Layer 2	0.8787	177,669.8
Percolation/leakage through Layer 3	0.006864	1,387.8
Average head on Layer 3	0.0382	---
Maximum head on Layer 3	0.0761	---
Location of maximum head in Layer 2	3.99	(feet from drain)
Other Parameters		
Snow water	5.1650	1,044,314.8
Maximum vegetation soil water	0.4370	(vol/vol)
Minimum vegetation soil water	0.0240	(vol/vol)

Final Water Storage in Landfill Profile at End of Simulation Period

Title: Infiltration - Alternative Final Cover, 1% slopes
Simulated on: 8/21/2023 16:53
Simulation period: 100 years

	Final Water Storage	
Layer	(inches)	(vol/vol)
1	0.0141	0.0283
2	0.0013	0.0100
3	0.0000	0.0000
Snow water	0.2721	---

Attachment 4 - HELP Model Results for Alt. Final Cover and Largest 25% Slope Area

```
------------------------------------------------------------------------------------------------------------------
                    HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE
                          HELP MODEL VERSION 4.0 BETA (2018)
      DEVELOPED BY USEPA NATIONAL RISK MANAGEMENT RESEARCH LABORATORY
------------------------------------------------------------------------------------------------------------------
      Title:        Infiltration - Alternative Fin…            Simulated On:       8/21/2023 16:33
------------------------------------------------------------------------------------------------------------------

                                        Layer 1
                     Type 1 - Vertical Percolation Layer (Cover Soil)
                                    Engineered Turf
                               Material Texture Number 43
      Thickness                                    =              0.5  inches
      Porosity                                     =            0.437  vol/vol
      Field Capacity                               =            0.062  vol/vol
      Wilting Point                                =            0.024  vol/vol
      Initial Soil Water Content                   =            0.085  vol/vol
      Effective Sat. Hyd. Conductivity             =         2.50E-02  cm/sec

                                        Layer 2
                              Type 2 - Lateral Drainage Layer
                          Studded Geomembrane Drainage Layer
                               Material Texture Number 44
      Thickness                                    =             0.13  inches
      Porosity                                     =             0.85  vol/vol
      Field Capacity                               =             0.01  vol/vol
      Wilting Point                                =            0.005  vol/vol
      Initial Soil Water Content                   =             0.01  vol/vol
      Effective Sat. Hyd. Conductivity             =         1.30E+02  cm/sec
      Slope                                        =               25  %
      Drainage Length                              =              113  ft

                                        Layer 3
                            Type 4 - Flexible Membrane Liner
                                     LDPE Membrane
                               Material Texture Number 36
      Thickness                                    =             0.05  inches
      Effective Sat. Hyd. Conductivity             =         4.00E-13  cm/sec
      FML Pinhole Density                          =                1  Holes/Acre
      FML Installation Defects                     =                1  Holes/Acre
      FML Placement Quality                        =                3  Good
      ------------------------------------------------------------------------------------------------------------
      Note:        Initial moisture content of the layers and snow water were
                   computed as nearly steady-state values by HELP.
```

General Design and Evaporative Zone Data

SCS Runoff Curve Number	=	95	
Fraction of Area Allowing Runoff	=	100	%
Area projected on a horizontal plane	=	24.9	acres
Evaporative Zone Depth	=	0.5	inches
Initial Water in Evaporative Zone	=	0.042	inches
Upper Limit of Evaporative Storage	=	0.218	inches
Lower Limit of Evaporative Storage	=	0.012	inches
Initial Snow Water	=	0.171063	inches
Initial Water in Layer Materials	=	0.044	inches
Total Initial Water	=	0.215	inches
Total Subsurface Inflow	=	0	inches/year

Note: SCS Runoff Curve Number was User-Specified.

Evapotranspiration and Weather Data

Station Latitude	=	41.91	Degrees
Maximum Leaf Area Index	=	4.5	
Start of Growing Season (Julian Date)	=	128	days
End of Growing Season (Julian Date)	=	259	days
Average Wind Speed	=	11	mph
Average 1st Quarter Relative Humidity	=	70	%
Average 2nd Quarter Relative Humidity	=	65	%
Average 3rd Quarter Relative Humidity	=	74	%
Average 4th Quarter Relative Humidity	=	75	%

Note: Evapotranspiration data was obtained for Monroe, Michigan

Normal Mean Monthly Precipitation (inches)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
1.88514	1.69133	2.363089	2.880845	3.136959	3.246387
3.058041	3.406246	2.984792	2.293588	2.481272	2.31871

Note: Precipitation was simulated based on HELP V4 weather simulation for:
Lat/Long: 41.91/-83.47

Normal Mean Monthly Temperature (Degrees Fahrenheit)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
28.3	33.3	42.5	54.5	68.5	78.2

82.5	79.3	70.1	56.5	42.6	34.1

\---

Note: Temperature was simulated based on HELP V4 weather simulation for:
Lat/Long: 41.91/-83.47
Solar radiation was simulated based on HELP V4 weather simulation for:
Lat/Long: 41.91/-83.47

Average Annual Totals Summary

Title: Infiltration - Alternative Final Cover, 25% slopes
Simulated on: 8/21/2023 16:40

	Average Annual Totals for Years 1 - 100*			
	(inches)	[std dev]	(cubic feet)	(percent)
Precipitation	31.75	[3.66]	2,869,461.7	100.00
Runoff	5.834	[1.93]	527,313.4	18.38
Evapotranspiration	9.759	[1.273]	882,042.3	30.74
Subprofile1				
Lateral drainage collected from Layer 2	16.1406	[1.7403]	1,458,902.6	50.84
Percolation/leakage through Layer 3	0.012577	[0.001176]	1,136.8	0.04
Average Head on Top of Layer 3	0.0001	[0]	---	---
Water storage				
Change in water storage	0.0007	[0.6445]	66.7	0.00

* Note: Average inches are converted to volume based on the user-specified area.

Peak Values Summary

Title: Infiltration - Alternative Final Cover, 25% slopes
Simulated on: 8/21/2023 16:40

	Peak Values for Years 1 - 100*	
	(inches)	(cubic feet)
Precipitation	2.88	260,327.3
Runoff	2.202	199,012.0
Subprofile1		
Drainage collected from Layer 2	0.9462	85,528.5
Percolation/leakage through Layer 3	0.000476	43.0
Average head on Layer 3	0.0026	---
Maximum head on Layer 3	0.0012	---
Location of maximum head in Layer 2	0.00	(feet from drain)
Other Parameters		
Snow water	5.1650	466,848.1
Maximum vegetation soil water	0.4370	(vol/vol)
Minimum vegetation soil water	0.0240	(vol/vol)

Final Water Storage in Landfill Profile at End of Simulation Period

Title: Infiltration - Alternative Final Cover, 25% slopes
Simulated on: 8/21/2023 16:41
Simulation period: 100 years

	Final Water Storage	
Layer	(inches)	(vol/vol)
1	0.0152	0.0304
2	0.0013	0.0100
3	0.0000	0.0000
Snow water	0.2721	---

Attachment 5 - HELP Model Results for Standard MI Part 115 Geomembrane Cover

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HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE
HELP MODEL VERSION 4.0 BETA (2018)
DEVELOPED BY USEPA NATIONAL RISK MANAGEMENT RESEARCH LABORATORY

Title: Infiltration - Standard Final … **Simulated On:** 8/21/2023 22:26

Layer 1

Type 1 - Vertical Percolation Layer (Cover Soil)
L - Loam
Material Texture Number 8

Thickness = 6 inches
Porosity = 0.463 vol/vol
Field Capacity = 0.232 vol/vol
Wilting Point = 0.116 vol/vol
Initial Soil Water Content = 0.463 vol/vol
Effective Sat. Hyd. Conductivity = 3.70E-04 cm/sec

Layer 2

Type 1 - Vertical Percolation Layer
SC - Sandy Clay
Material Texture Number 13

Thickness = 18 inches
Porosity = 0.43 vol/vol
Field Capacity = 0.321 vol/vol
Wilting Point = 0.221 vol/vol
Initial Soil Water Content = 0.4299 vol/vol
Effective Sat. Hyd. Conductivity = 3.30E-05 cm/sec

Layer 3

Type 4 - Flexible Membrane Liner
LDPE Membrane
Material Texture Number 36

Thickness = 0.04 inches
Effective Sat. Hyd. Conductivity = 4.00E-13 cm/sec
FML Pinhole Density = 1 Holes/Acre
FML Installation Defects = 1 Holes/Acre
FML Placement Quality = 3 Good

Note: Initial moisture content of the layers and snow water were computed as nearly steady-state values by HELP.

General Design and Evaporative Zone Data

SCS Runoff Curve Number	=	74	
Fraction of Area Allowing Runoff	=	100	%
Area projected on a horizontal plane	=	0.64	acres
Evaporative Zone Depth	=	12	inches
Initial Water in Evaporative Zone	=	5.358	inches
Upper Limit of Evaporative Storage	=	5.358	inches
Lower Limit of Evaporative Storage	=	2.022	inches
Initial Snow Water	=	0.171063	inches
Initial Water in Layer Materials	=	10.516	inches
Total Initial Water	=	10.687	inches
Total Subsurface Inflow	=	0	inches/year

Note: SCS Runoff Curve Number was User-Specified.

Evapotranspiration and Weather Data

Station Latitude	=	41.91	Degrees
Maximum Leaf Area Index	=	4.5	
Start of Growing Season (Julian Date)	=	128	days
End of Growing Season (Julian Date)	=	259	days
Average Wind Speed	=	11	mph
Average 1st Quarter Relative Humidity	=	70	%
Average 2nd Quarter Relative Humidity	=	65	%
Average 3rd Quarter Relative Humidity	=	74	%
Average 4th Quarter Relative Humidity	=	75	%

Note: Evapotranspiration data was obtained for Monroe, Michigan

Normal Mean Monthly Precipitation (inches)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
1.88514	1.69133	2.363089	2.880845	3.136959	3.246387
3.058041	3.406246	2.984792	2.293588	2.481272	2.31871

Note: Precipitation was simulated based on HELP V4 weather simulation for:
Lat/Long: 41.91/-83.47

Normal Mean Monthly Temperature (Degrees Fahrenheit)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
28.3	33.3	42.5	54.5	68.5	78.2
82.5	79.3	70.1	56.5	42.6	34.1

Note: Temperature was simulated based on HELP V4 weather simulation for:
Lat/Long: 41.91/-83.47
Solar radiation was simulated based on HELP V4 weather simulation for:
Lat/Long: 41.91/-83.47

Average Annual Totals Summary

Title: Infiltration - Standard Final Cover, 0.5% slopes
Simulated on: 8/21/2023 22:29

	Average Annual Totals for Years 1 - 100*			
	(inches)	[std dev]	(cubic feet)	(percent)
Precipitation	31.75	[3.66]	73,753.2	100.00
Runoff	3.181	[2.087]	7,390.2	10.02
Evapotranspiration	27.975	[2.884]	64,992.5	88.12
Subprofile1				
Percolation/leakage through Layer 3	0.589751	[0.027653]	1,370.1	1.86
Average Head on Top of Layer 3	15.7122	[1.2264]	---	---
Water storage				
Change in water storage	0.0002	[1.2972]	0.4038	0.00

* Note: Average inches are converted to volume based on the user-specified area.

Peak Values Summary

Title: Infiltration - Standard Final Cover, 0.5% slopes
Simulated on: 8/21/2023 22:30

	Peak Values for Years 1 - 100*	
	(inches)	(cubic feet)
Precipitation	2.88	6,691.1
Runoff	1.929	4,482.5
Subprofile1		
Percolation/leakage through Layer 3	0.002132	4.9533
Average head on Layer 3	23.9998	
Other Parameters		
Snow water	5.1650	11,999.3
Maximum vegetation soil water	0.4465 (vol/vol)	
Minimum vegetation soil water	0.1685 (vol/vol)	

Final Water Storage in Landfill Profile at End of Simulation Period

Title: Infiltration - Standard Final Cover, 0.5% slopes
Simulated on: 8/21/2023 22:30
Simulation period: 100 years

	Final Water Storage	
Layer	(inches)	(vol/vol)
1	2.6957	0.4493
2	7.7370	0.4298
3	0.0000	0.0000
Snow water	0.2721	---

Attachment 6 - HELP Model Results for Monroe FAB Natural Subsoils

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HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE
HELP MODEL VERSION 4.0 BETA (2018)
DEVELOPED BY USEPA NATIONAL RISK MANAGEMENT RESEARCH LABORATORY

Title: Infiltration - Monroe FAB Clay… **Simulated On:** 8/21/2023 23:18

Layer 1

Type 1 - Vertical Percolation Layer (Cover Soil)
High-Density MSW Fly Ash
Material Texture Number 32

Thickness	=	120	inches
Porosity	=	0.45	vol/vol
Field Capacity	=	0.116	vol/vol
Wilting Point	=	0.049	vol/vol
Initial Soil Water Content	=	0.33	vol/vol
Effective Sat. Hyd. Conductivity	=	1.00E-02	cm/sec

Layer 2

Type 3 - Barrier Soil Liner
Native Clay - Monroe FAB
Material Texture Number 45

Thickness	=	408	inches
Porosity	=	0.452	vol/vol
Field Capacity	=	0.411	vol/vol
Wilting Point	=	0.311	vol/vol
Initial Soil Water Content	=	0.452	vol/vol
Effective Sat. Hyd. Conductivity	=	3.29E-08	cm/sec

Note: Initial moisture content of the layers and snow water were computed as nearly steady-state values by HELP.

General Design and Evaporative Zone Data

SCS Runoff Curve Number	=	74	
Fraction of Area Allowing Runoff	=	0	%
Area projected on a horizontal plane	=	0.64	acres
Evaporative Zone Depth	=	0.5	inches
Initial Water in Evaporative Zone	=	0.057	inches
Upper Limit of Evaporative Storage	=	0.225	inches
Lower Limit of Evaporative Storage	=	0.024	inches
Initial Snow Water	=	0.171063	inches
Initial Water in Layer Materials	=	224.012	inches

Total Initial Water	=	224.183	inches
Total Subsurface Inflow	=	0	inches/year

Note: SCS Runoff Curve Number was User-Specified.

Evapotranspiration and Weather Data

Station Latitude	=	41.91	Degrees
Maximum Leaf Area Index	=	4.5	
Start of Growing Season (Julian Date)	=	128	days
End of Growing Season (Julian Date)	=	259	days
Average Wind Speed	=	11	mph
Average 1st Quarter Relative Humidity	=	70	%
Average 2nd Quarter Relative Humidity	=	65	%
Average 3rd Quarter Relative Humidity	=	74	%
Average 4th Quarter Relative Humidity	=	75	%

Note: Evapotranspiration data was obtained for Monroe, Michigan

Normal Mean Monthly Precipitation (inches)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
1.88514	1.69133	2.363089	2.880845	3.136959	3.246387
3.058041	3.406246	2.984792	2.293588	2.481272	2.31871

Note: Precipitation was simulated based on HELP V4 weather simulation for:
Lat/Long: 41.91/-83.47

Normal Mean Monthly Temperature (Degrees Fahrenheit)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
28.3	33.3	42.5	54.5	68.5	78.2
82.5	79.3	70.1	56.5	42.6	34.1

Note: Temperature was simulated based on HELP V4 weather simulation for:
Lat/Long: 41.91/-83.47
Solar radiation was simulated based on HELP V4 weather simulation for:
Lat/Long: 41.91/-83.47

Average Annual Totals Summary

Title: Infiltration - Monroe FAB Clay Liner
Simulated on: 8/21/2023 23:20

	Average Annual Totals for Years 1 - 100*			
	(inches)	[std dev]	(cubic feet)	(percent)
Precipitation	31.75	[3.66]	73,753.2	100.00
Runoff	0.000	[0]	0.0000	0.00
Evapotranspiration	30.283	[16.952]	70,352.9	95.39
Subprofile1				
Percolation/leakage through Layer 2	0.528805	[0.001516]	1,228.5	1.67
Average Head on Top of Layer 2	119.8328	[1.3452]	---	---
Water storage				
Change in water storage	0.9349	[17.1672]	2,171.9	2.94

* Note: Average inches are converted to volume based on the user-specified area.

Peak Values Summary

Title: Infiltration - Monroe FAB Clay Liner
Simulated on: 8/21/2023 23:20

	Peak Values for Years 1 - 100*	
	(inches)	(cubic feet)
Precipitation	2.88	6,691.1
Runoff	0.000	0.0000
Subprofile1		
Percolation/leakage through Layer 2	0.001448	3.3646
Average head on Layer 2	119.9998	
Other Parameters		
Snow water	132.4858	307,791.0
Maximum vegetation soil water	0.4500 (vol/vol)	
Minimum vegetation soil water	0.0490 (vol/vol)	

Final Water Storage in Landfill Profile at End of Simulation Period

Title: Infiltration - Monroe FAB Clay Liner
Simulated on: 8/21/2023 23:20
Simulation period: 100 years

	Final Water Storage	
Layer	(inches)	(vol/vol)
1	53.9999	0.4500
2	184.4160	0.4520
Snow water	79.2528	---

Attachment 7 - Hydrologic Performance of Synthetic Turf Cover Systems and Their Equivalency to Prescriptive Cover Systems, Carlson, 2019

IFAI Geosynthetics Conference
Feb. 10-13, 2019 | Houston, TX USA

Hydrologic Performance of Synthetic Turf Cover Systems and Their Equivalency to Prescriptive Cover Systems

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ABSTRACT

Synthetic turf cover systems have gained popularity as a viable final cover system alternative to traditional soil-geosynthetic cover systems for various reasons (e.g., less material required, quicker installation, and less maintenance). Federal and state regulations commonly require that the design engineers demonstrate alternative cover systems perform equivalently with the prescribed traditional cover system. This paper presents a comparison between the calculated hydrologic performance of traditional and synthetic turf cover systems for two state regulations; one for municipal solid waste (MSW) landfills and one for hazardous waste landfills. The results of these analyses showed that synthetic turf cover systems have larger annual runoff and drainage collection with similar or smaller annual infiltration through the geomembrane when compared to the traditional cover systems. Therefore, the synthetic turf cover systems perform similar to or better than the prescribed traditional cover systems in terms of infiltration.

INTRODUCTION

Synthetic turf cover systems are a relatively new geosynthetic product that typically consist of the following layers (from bottom to top) [WatershedGeo, 2018]: (i) a structured linear-low density polyethylene (LLDPE) or high density polyethylene (HDPE) geomembrane, which includes studs on the top to act as a drainage layer and spikes on the bottom to increase the interface shear strength of the system; (ii) an engineered turf protective layer, consisting of HDPE grass blades attached to woven geotextiles; and (iii) a thin layer (12.5-mm. thick minimum) of specified infill, which is usually clean sand primarily used for ballasting and protecting the engineered turf and the structured geomembrane. Figure 1 shows a typical detail for a synthetic turf cover system.

Because synthetic turf cover systems typically require less material, are generally quicker to install, and are expected to require less maintenance after installation [WatershedGeo, 2018], they have gained popularity as a viable alternative to the traditional soil-geosynthetic cover system. Federal and state regulations commonly require that the design engineers demonstrate alternative cover systems perform equivalently in terms of infiltration compared to the prescribed traditional cover system. This paper presents a comparison between the calculated hydrologic performance cover system components correspond to either prescribed limits, typical values, or manufacturer-specified values. Case Study 2 considers long-term site conditions and thus, the hydraulic conductivities of the drainage layers are expected to decrease due to degradation, clogging, and/or creep of the drainage layers. Therefore, the hydraulic conductivities in Case Study 2 have been reduced by a factor of 2.4 to account for some creep, delayed intrusion, particulate clogging, and biological clogging and a factor of safety of 1.5. The reduction factor of 2.4 was developed from available technical literature [Giroud et al., 2000] and is typical for cover systems. Although a reduction factor could also be used for the granular drainage layer in Case Study 1, it was not considered for the analyses presented in this paper.

The geomembrane components of the prescribed and alternative cover systems were modeled to contain one hole per 0.004 km^2 and have good installation quality. For the calculations, each hole was modeled with an area of 1 cm^2 as recommended by Giroud and Bonaparte [1989]. A 100 percent runoff from precipitation on the cover systems was allowed in the HELP models; however, it should be controlled to prevent excessive erosion of the final cover system.

See Supplemental Calculations
Section of HELP Model Cover

Table 1. Cover system properties used in HELP models

Component	Case Study (1)	Layer Thickness	Total Porosity (2)	Field Capacity (2)	Wilting Point (2)	Saturated Hydraulic Conductivity (cm/sec)	HELP Material Texture # (2)	HELP Layer Type
Vegetative Cover Layer	1, 2	0.15 m	0.471	0.342	0.210	1.0×10^{-4} (3)	12	Vertical Percolation
Protective Soil Layer	1, 2	0.45 m	0.471	0.342	0.210	5.0×10^{-5} (3)	12	Vertical Percolation
Granular Drainage Layer (4)	1	0.3 m	0.457	0.083	0.033	1.0×10^{-3} (5)	3	Drainage Layer
Double-Sided Geocomposite Drainage Layer	2	7.6 mm	0.850	0.010	0.005	11.84 (4.93) (6)(7)	20	Drainage Layer
HDPE Geomembrane	1, 2	1.5 mm	-	-	-	2.0×10^{-13} (7)	35	Geomembrane
Engineered Turf (8)	1	25 mm	0.437	0.062	0.024	2.5×10^{-2}	2	Vertical Percolation
	2	12.5 mm						
Woven Geotextile (8)	1, 2	-	-	-	-	-	-	Not Modeled
Studded Drainage Layer for Textured HDPE Geomembrane (8)	1, 2	3.3 mm	0.850	0.010	0.005	~~75.76 (31.57) (6)~~	20	Drainage Layer
Textured HDPE Geomembrane (with spike down) (8)	1, 2	1.5 mm	-	-	-	~~2.0×10^{-13} (7)~~	35	Geomembrane
Soil Barrier Layer (9)	1	0.6 m	0.427	0.418	0.367	1.0×10^{-6} (5)	16	Barrier Soil
Methane Gas Venting Layer (4)	1	0.3 m	0.457	0.083	0.033	1.0×10^{-3} (5)	3	Vertical Percolation
Compacted Clay Liner	2	0.6 m	0.427	0.418	0.367	1.0×10^{-7} (5)	16	Barrier Soil
Geosynthetic Clay Liner	2	7.6 mm	0.750	0.747	0.400	5.0×10^{-9} (7)	17	Barrier Soil
Daily/Intermediate Cover (9)	2	0.15 m	0.427	0.418	0.367	5.0×10^{-5} (3)	16	Vertical Percolation

LLDPE has a different hydraulic
conductivity. See HELP Model.

Notes:

(1) Case study identifies for which case study or studies the cover system component was used.
(2) Values shown for total porosity, field capacity, and wilting point correspond to the default values for the selected HELP material texture number.
(3) Hydraulic conductivity values selected based on typical values.
(4) Drainage and methane gas venting layers are modeled with properties typical of filter sands.
(5) Hydraulic conductivity values selected based on minimum design requirements.
(6) Hydraulic conductivity values within the parentheses represent the long-term hydraulic conductivities with a reduction factor of 2.4 applied.
(7) Hydraulic conductivity values selected based on typical values from manufacturers.
(8) Properties for synthetic turf cover system layers were selected based on manufacturers design guidelines [WatershedGeo, 2018].
(9) Soil barrier layer and daily/intermediate cover are modeled with properties typical of compacted clays.

Output Data. The HELP program calculated and output the average annual rates for surface runoff, stormwater collected through the drainage layer, and infiltration through the geomembrane and the average hydraulic head over the geomembrane during the peak daily rainfall event. The

Attachment 8- ClosureTurf Design Guidance Manual, 2023

ClosureTurf®

DESIGN GUIDANCE MANUAL

ClosureTurf® Final Cover System

February 10th, 2023

WatershedGeo®
Unearthing Solutions

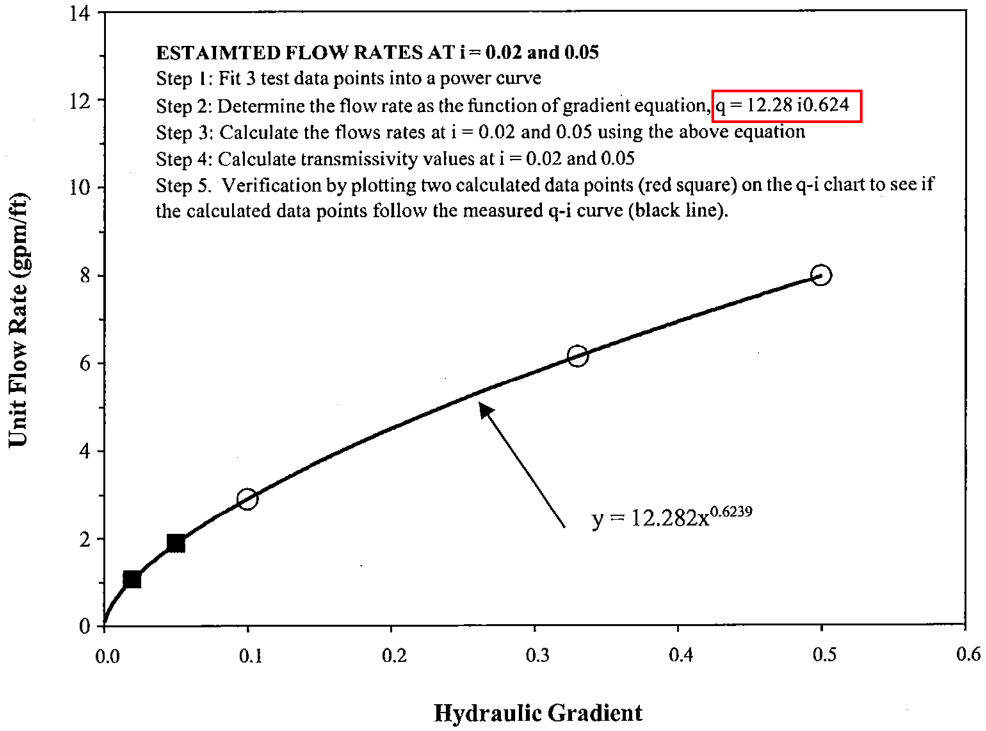
ClosureTurf® is a US registered trademark which designates a product from Watershed Geosynthetics LLC. The ClosureTurf product is the subject of issued US and foreign patents and US and foreign patent-pending applications. PowerCap™ is a US trademark that designates a product from Watershed Solar LLC which is licensed to Watershed Geosynthetics LLC. The PowerCap product is the subject of issued US patents and US and foreign patent-pending applications.

All information provided herein by Watershed Geosynthetics LLC concerning these products are based upon data derived from independent third-party testing. This information, however, should not be used or relied upon for any specific use without first consulting with an independent professional engineer licensed in the geographic area in which a project is located. Since the actual site conditions, and the installation and use of these products are beyond our control, no guaranty or warranty of any kind, expressed or implied, is made by Watershed Geosynthetics LLC with respect to these products.

v.23041

CLOSURETURF LLC -LANDFILL COVER SYSTEM
HYDRAULIC TRANSMISSIVITY TESTING (ASTM D 4716)

Test Configuration (from Top to Bottom): Sand Layer/Polytex Artificial Grass with Geotextile Side Down/
Agru 50-mil Super Gripnet LLDPE Geomembrane with Studs Side Up



ESTAIMTED FLOW RATES AT i = 0.02 and 0.05

Step 1: Fit 3 test data points into a power curve

Step 2: Determine the flow rate as the function of gradient equation, $q = 12.28\,i^{0.624}$

Step 3: Calculate the flows rates at i = 0.02 and 0.05 using the above equation

Step 4: Calculate transmissivity values at i = 0.02 and 0.05

Step 5. Verification by plotting two calculated data points (red square) on the q-i chart to see if the calculated data points follow the measured q-i curve (black line).

Test No.	Flow Direction	Specimen Size Width x Length	Total Normal Stress[(1)]	Seating Time	Hydraulic Gradient	Transmissivity	Flow Rate	
			σ_n	t	i	$\theta = 0.00020697(q/i)$	$q = 12.28i^{0.624}$	q'
		(in. x in.)	(psf)	(hour)	(-)	(m^2/sec)	(gpm/ft)	(l/min/m)
					0.02	1.11E-02	1.07	
					0.05	7.84E-03	1.89	
1	MD	12 x12	47	0.25	0.10	6.04E-03	2.92	36.3
2	MD	12 x12	47	0.25	0.33	3.86E-03	6.15	76.4
3	MD	12 x12	47	0.25	0.50	3.30E-03	7.97	99.0

NOTE:

Total normal stress = total weight (sand + steel plate + surcharge) divided by the plan area of test specimen (1 square ft). A normal stress of 47 psf is approximately the minimum total stress required to keep the specimen from uplifting.

DATE TESTED:	1/11/2013
FIGURE NO.	A-1
PROJECT NO.	SGI10007
DOCUMENT NO.	
FILE NO.	

SGI TESTING SERVICES, LLC

ATTACHMENT C – HYDRAULIC SHEAR CALCULATIONS

DTE Monroe Power Plant
Fly Ash Basin and Vertical Extension Landfill
HYDRAULIC SHEAR STRESS DESIGN CALCULATIONS

PROJECT: DTE Monroe Fly Ash Basin
SUBJECT: Hydraulic Shear Stress Calculations for Erosion Mitigation
PROJECT NUMBER: 151630
DATE: 8/21/2023 Page 1 of 5

Purpose: To mitigate erosion of the sand infill within ClosureTurf, the hydraulic shear stress shall be calculated at various critical scenarios and compared to the manufacturer's recommended maximum shear stress.

Background: DTE Energy plans on closing the Monroe Fly Ash Basin (FAB) using an alternative final cover system. ClosureTurf was selected to be the primary component of the design, consisting of geomembrane overlayed by sand-ballasted synthetic turf and a lateral drainage system.

Methodology: Burns & McDonnell performed hydraulic shear stress calculations using methods from the WatershedGEO ClosureTurf Design Guidance Manual. Based on third-party testing, WatershedGEO concluded that Minimal sand infill mobilization will happen at hydraulic shear values which are greater than 1.5 lb/ft^2. A 1.5 factor of safety will be used for the critical hydraulical shear stress therefore will we be using 1 lb/ft^2 as the critical hydraulic shear stress. Hydraulic shear for the cover system was estimated for critical scenarios determined by the engineering team based on drainage length and slope angles. Then, the hydraulic shear for these critical scenarios were compared to the suggested design value of 1 lb/ft^2 (the critical hydraulic shear).

References:
1. ClosureTurf Design Guidance Manual, 2023 **(Attachment 1)**
2. Atlas 14 Rainfall Distribution Table for Detroit MI **(Attachment 2)**
3. Design Drawings **(Attachment 3)**

7222 = Data Input
7222 = Calculated and/or Referenced Cell

Conclusions: Critical hydraulic shear stress (τc) is suggested to be 1 lb/ft^2, which is greater than the various hydraulic shear stresses (τ) calculated for the various critical design scenarios presented in the calculation. The actual hydraulic shear stresses are below the values for which WatershedGEO indicates minimal sand infill mobilization is expected to occur.

Prepared By: Alexis A. Nesbitt Date: 8/4/2023
Checked By: Tyler Schmidt, PE Date: 8/21/2023
Approved By: Allyson Myers, PE Date: 8/22/2023

DTE Monroe Power Plant
Fly Ash Basin and Vertical Extension Landfill
HYDRAULIC SHEAR STRESS DESIGN CALCULATIONS

Prepared by: AAN Date: 8/4/2023
Checked by: TJS Date: 8/21/2023

Hydraulic Shear Stress - Scenario 1

Hydraulic shear stress greater than critical shear stress?				**REFERENCE**
Critical Hydraulic Shear Stress	τ_c=	1.5	lb/ft^2	Attachment 1-5
Critical Hydraulic Shear Stress with 1.5 factor of safety	τ_c=	**1**	lb/ft^2	

Scenario 1: 693' Top Deck (1%), 79' Slope (4:1)

Step 1: Calculate the maximum hydraulic shear stress of flow on the top deck:

Rainfall intensity	R=	0.219	ft/hr	Attachment 2-1
ClosureTurf Drainage Layer Type		Microdrain		Given (Design Parameter)
Drainage Length	L_1	693	ft	Attachment 3-1
Slope	S_1=	1.0	%	Attachment 3-1
Slope Angle	α_1=	**0.573**	degrees	
Hydraulic Gradient	i_1=	**0.010**		
Manning's roughness Coefficient	n_1=	0.220		Attachment 1-1

Flow Rate	$q = 12.28 * i^{0.624}$	q=	**0.69**	gpm/ft	Attachment 1-6
Transmissivity	$\theta_{i=0.01} = 0.00020697 \times \frac{q}{i}$	$\theta_{i=0.01}$ =	**0.01436**	m^2/sec	Attachment 1-6

Flow rate on the slope under the design rainfall intensity

$$q_1 = L_1 \times R \times cos\alpha_1$$

q_1= **151.8** ft^2/hr Attachment 1-7

Internal Flow Capacity of ClosureTurf with Microdrain

$$q_{int} = \theta_{i=0.01} \times i_1$$

q_{int}= **5.561** ft^2/hr Attachment 1-8

Remaining flow through turf and sand infill

$$q'_{total} = q_{total} - q_{int}$$

146.198 ft^2/hr Attachment 1-8

q'_{total}= **0.041** ft^2/s Attachment 1-8

Mannings Equation with the assumptions that:

Hydraulic radius is equal to the flow depth

$$V_1 = \frac{1.486}{n1} H_1{}^{2/3} S_o{}^{1/2}$$

H_1 = **0.185** ft Attachment 1-7

Maximum Hydraulic Shear Stress: τ_1= **0.115** psf Attachment 1-7

$$\tau_1 = \gamma_w \times H_1 \times S_1, \quad where \quad \gamma_w = 62.4\ lb/ft^3$$

Compare Max. Hydraulic Shear Stress to Critical Hydraulic Shear Stress (τc) **$\tau_1 < \tau_c$** Attachment 1-7

DTE Monroe Power Plant
Fly Ash Basin and Vertical Extension Landfill
HYDRAULIC SHEAR STRESS DESIGN CALCULATIONS

Step 2: Calculate the maximum hydraulic shear stress of flow on the slope:

Rainfall intensity	R=	0.219	ft/hr	Attachment 2-1
ClosureTurf Drainage Layer Type		Microdrain		Given (Design Parameter)
Drainage Length	L_2	79	ft	Attachment 3-1
Slope	S_2=	25.0	%	Attachment 3-1
Slope Angle	α_2=	14.036	degrees	
Hydraulic Gradient	i_2=	0.250		
Manning's roughness Coefficient	n_2=	0.120		Attachment 1-2

Flow Rate $q = 12.28 * i^{0.624}$ q= 5.17 gpm/ft Attachment 1-6

Transmissivity $\theta_{i=0.012} = 0.00020697 \times \frac{q}{i}$ $\theta_{i=0.012} =$ 0.00428 m^2/sec Attachment 1-6

Flow rate on the slope under the design rainfall intensity

(Note that flow from the top deck, q_1, will flow onto the side slope)

$$q_2 = q_1 + (L_2 \times R \times cos\alpha_2)$$

q_2= 168.5 ft^2/hr Attachment 1-8

Internal Flow Capacity of ClosureTurf with Microdrain

$$q_{int} = \theta_{i=0.01} \times i_2$$

q_{int}= 41.445 ft^2/hr Attachment 1-8

Remaining flow through turf and sand infill

$$q'_{total} = q_{total} - q_{int}$$

127.099 ft^2/hr Attachment 1-8

q'_{total}= 0.035 ft^2/s Attachment 1-8

Mannings Equation with the assumptions that:

Hydraulic radius is equal to the flow depth

$$V_1 = \frac{1.486}{n1} H_1^{2/3} S_o^{1/2}$$

H_2 = 0.045 ft Attachment 1-8

Maximum Hydraulic Shear Stress: τ_2= 0.702 psf Attachment 1-8

$$\tau_1 = \gamma_w \times H_1 \times S_1, \quad where \ \ \gamma_w = 62.4\ lb/ft^3$$

Compare Max. Hydraulic Shear Stress to Critical Hydraulic Shear Stress (τc) $\tau_2 < \tau_c$ Attachment 1-8

DTE Monroe Power Plant
Fly Ash Basin and Vertical Extension Landfill
HYDRAULIC SHEAR STRESS DESIGN CALCULATIONS

Prepared by:	AAN	Date:	8/4/2023
Checked by:	TJS	Date:	8/21/2023

Hydraulic Shear Stress - Scenario 2

Hydraulic shear stress greater than critical shear stress?

				REFERENCE
Critical Hydraulic Shear Stress	τ_c=	1.5	lb/ft^2	Attachment 1-5
Critical Hydraulic Shear Stress with 1.5 factor of safety	τ_c=	1	lb/ft^2	

Scenario 1: 1072' Top Deck (1%), 32' Slope (4:1)

Step 1: Calculate the maximum hydraulic shear stress of flow on the top deck:

Rainfall intensity	R=	0.219	ft/hr	Attachment 2-1
ClosureTurf Drainage Layer Type		Microdrain		Given (Design Parameter)
Drainage Length	L_1	1072	ft	Attachment 3-1
Slope	S_1=	1.0	%	Attachment 3-1
Slope Angle	α_1=	0.573	degrees	
Hydraulic Gradient	i_1=	0.010		
Manning's roughness Coefficient	n_1=	0.220		Attachment 1-1

Flow Rate	$q = 12.28 * i^{0.624}$	q=	0.69	gpm/ft	Attachment 1-6
Transmissivity	$\theta_{i=0.01} = 0.00020697 \times \frac{q}{i}$	$\theta_{i=0.01}$ =	0.01436	m^2/sec	Attachment 1-6

Flow rate on the slope under the design rainfall intensity

$$q_1 = L_1 \times R \times cos\alpha_1$$

q_1=	234.8	ft^2/hr	Attachment 1-7

Internal Flow Capacity of ClosureTurf with Microdrain

$$q_{int} = \theta_{i=0.01} \times i_1$$

q_{int}=	5.561	ft^2/hr	Attachment 1-8

Remaining flow through turf and sand infill

$$q'_{total} = q_{total} - q_{int}$$

	229.195	ft^2/hr	Attachment 1-8
q'_{total}=	0.064	ft^2/s	Attachment 1-8

Mannings Equation with the assumptions that:

Hydraulic radius is equal to the flow depth

$$V_1 = \frac{1.486}{n1} H_1{}^{2/3} S_o{}^{1/2}$$

	H_1 =	0.242	ft	Attachment 1-7
Maximum Hydraulic Shear Stress:	τ_1=	0.151	psf	Attachment 1-7

$$\tau_1 = \gamma_w \times H_1 \times S_1, \quad where \quad \gamma_w = 62.4\ lb/ft^3$$

Compare Max. Hydraulic Shear Stress to Critical Hydraulic Shear Stress (τc)	$\tau_1 < \tau_c$	Attachment 1-7

Step 2: Calculate the maximum hydraulic shear stress of flow on the slope:

Rainfall intensity	R=	0.219	ft/hr	Attachment 2-1
ClosureTurf Drainage Layer Type		Microdrain		Given (Design Parameter)
Drainage Length	L_2	32	ft	Attachment 3-1
Slope	S_2=	25.0	%	Attachment 3-1
Slope Angle	α_2=	14.036	degrees	
Hydraulic Gradient	i_2=	0.250		
Manning's roughness Coefficient	n_2=	0.120		Attachment 1-2

Flow Rate	$q = 12.28 * i^{0.624}$	q=	5.17	gpm/ft	Attachment 1-6
Transmissivity	$\theta_{i=0.012} = 0.00020697 \times \frac{q}{i}$	$\theta_{i=0.012}$ =	0.00428	m^2/sec	Attachment 1-6

Flow rate on the slope under the design rainfall intensity

(Note that flow from the top deck, q_1, will flow onto the side slope)

$$q_2 = q_1 + (L_2 \times R \times cos\alpha_2)$$

q_2= 241.6 ft^2/hr Attachment 1-8

Internal Flow Capacity of ClosureTurf with Microdrain

$$q_{int} = \theta_{i=0.01} \times i_2$$

q_{int}= 41.445 ft^2/hr Attachment 1-8

Remaining flow through turf and sand infill

$$q'_{total} = q_{total} - q_{int}$$

	200.110	ft^2/hr	Attachment 1-8
q'_{total}=	0.056	ft^2/s	Attachment 1-8

Mannings Equation with the assumptions that:

Hydraulic radius is equal to the flow depth

$$V_1 = \frac{1.486}{n1} {H_1}^{2/3} {S_o}^{1/2}$$

Maximum Hydraulic Shear Stress:

$$\tau_1 = \gamma_w \times H_1 \times S_1, \quad where \quad \gamma_w = 62.4\ lb/ft^3$$

H_2 =	0.059	ft	Attachment 1-8
τ_2=	0.921	psf	Attachment 1-8

Compare Max. Hydraulic Shear Stress to Critical Hydraulic Shear Stress (τc)

$\tau_2 < \tau_c$ Attachment 1-8

ATTACHMENT 1-1

ClosureTurf®

DESIGN GUIDANCE MANUAL

ClosureTurf® Final Cover System

February 10th, 2023

WatershedGeo®
Unearthing Solutions

ClosureTurf® is a US registered trademark which designates a product from Watershed Geosynthetics LLC. The ClosureTurf product is the subject of issued US and foreign patents and US and foreign patent-pending applications. PowerCap™ is a US trademark that designates a product from Watershed Solar LLC which is licensed to Watershed Geosynthetics LLC. The PowerCap product is the subject of issued US patents and US and foreign patent-pending applications.

All information provided herein by Watershed Geosynthetics LLC concerning these products are based upon data derived from independent third-party testing. This information, however, should not be used or relied upon for any specific use without first consulting with an independent professional engineer licensed in the geographic area in which a project is located. Since the actual site conditions, and the installation and use of these products are beyond our control, no guaranty or warranty of any kind, expressed or implied, is made by Watershed Geosynthetics LLC with respect to these products.

ATTACHMENT 1-2

5. Surface Water Management

This chapter provides guidance on the design of open channels with ClosureTurf to manage surface water. The chapter addresses landfill hydrology, final cover conveyance channels, infill materials, and downstream considerations related to energy dissipation systems and sediment storage volumes in ponds.

5.1. Hydrology, Channel Sizing, and Channel Infill Selection

Table 5-1 presents parameters for defining site hydrology when applying the Rational Method or the Soil Conservation Service Unit Hydrograph Method to evaluate hydrologic performance of ClosureTurf. These parameters are used for sizing conveyance channels using Manning's Equation and selecting infill materials as a function of permissible and computed flow velocities.

Table 5-1. Hydrology and Hydraulics Parameter Recommendations for ClosureTurf-lined Areas

Runoff Process	Parameter	Value
Rainfall to Runoff	Curve Number	92 - 95, or as selected by the design engineer
	Rational "C"	0.74 - 0.78, or as selected by the design engineer
Sheet Flow	Manning's Roughness	0.22 (when land slope $\leq$ 10%) 0.12 (when land slope > 10%)
	Maximum Flow Length	Selected such that flow depth is $\leq$ 0.1 foot, or as required
Shallow Concentrated Flow	Average Velocity (1) (feet/second)	TR-55 unpaved condition (calculated as 16.135 x $(S)^{0.5}$, where S is the surface slope in feet/foot), or as selected by the design engineer
Concentrated Flow (2)	Manning's Roughness	0.02 (when using HydroBinder)

Notes:

1. The suggested value is based on Part 630 Hydrology, National Engineering Handbook (NRCS 2010) for shallow concentrated flow over an unpaved surface or grassed waterway of a given slope. Check local requirements for suitability.
2. Hydraulically stable stone (gravel/riprap) or HydroBinder other than the granular infill should be used in concentrated flow locations.

6. Hydraulic Stability of Granular Infill

The specified granular infill is one of the three components of ClosureTurf. The infill serves as a protective layer for the turf and geomembrane components. While the turf and geomembrane components are not directly sensitive to hydraulic forces, washout of the sand layer can increase exposure of the turf and geomembrane to puncture stresses, ultraviolet (UV) degradation, and wind uplift.

Washout of the granular infill can occur when raindrops dislodge individual sand particles (i.e., splash erosion), when planar flow concentrations during a storm impose hydraulic shear stresses high enough to mobilize the infill (i.e., sheet erosion), or when a combination of the two mechanisms occurs.

This chapter presents evaluation methods and performance requirements for the granular infill based on an extensive testing program to establish allowable shear stresses, material specification requirements, recommended design methods to compare calculated shear stresses with allowable ones, and the selection of an alternative infill in case calculated shear stresses exceed allowable ones.

This chapter is limited in scope to areas of a ClosureTurf installation that receive sheet flow or shallow concentrated flow. It is considered best practice to use supplemental/alternative infill materials in ClosureTurf concentrated flow channels, as discussed in Section 5.2.3.

6.1. Hydraulic Testing and Performance Specifications

Hydraulic stability of granular (sand) infill has been independently tested by TRI Environmental (TRI), a third-party laboratory, in general accordance with ASTM D 6460, *Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Earthen Channels from Stormwater-Induced Erosion*, and ASTM D 6459, *Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Hillslopes from Rainfall-Induced Erosion*. A summary of the sand infill testing program and results and the development of the sand infill specification based on the test results is provided as Appendix F.

The ClosureTurf Sand Infill Specification is available at Watershed Geo's online technical library. The sand infill must meet criteria for fine aggregate angularity, specific gravity, and particle size distribution. When the sand infill material specifications are met, the permissible hydraulic shear stress of the sand infill is suggested to be 0.8 psf.

6.2. Suggested Method for Calculating Hydraulic Shear Stress

For design, the calculated hydraulic shear stresses for a ClosureTurf installation should be less than the suggested permissible hydraulic stress of 0.8 psf for the sand infill. The example calculations included as Appendix G provide a suggested method to estimate the hydraulic shear stress on ClosureTurf using typical engineering methods such as those presented in HEC 22, Urban Drainage Design Manual (FHWA 2009). Two different hydraulic shear stress calculations are presented in the appendix, differentiated by location and the choice of geomembrane used in ClosureTurf. Typically, multiple drainage paths are evaluated to establish a maximum anticipated hydraulic shear stress for design. If the calculated maximum hydraulic shear stress exceeds the permissible value, mitigation options include flattening the slope, shortening drainage lengths (e.g., addition of a drainage bench), and using infill with a higher permissible shear stress (e.g., HydroBinder, as discussed in Chapter 5).

Based on Watershed Geo's experience, it is suggested that the maximum drainage length on a typical landfill slope (e.g., 3H:1V or 4H:1V) be limited to the drainage length calculated using the permissible sand infill hydraulic shear stress of 0.8 psf or 350 ft, whichever is smaller, or an alternative length as determined appropriate by the design engineer. Depending on the size of drainage area of the landfill top deck, a stormwater diversion berm is also suggested to separate top deck runoff and the runoff from the side slope in order to mitigate potential localized sand infill movement resulting from surface irregularities due to imperfections during construction and differential landfill settlement along the crest line.

ATTACHMENT 1-5

WatershedGeo®
Unearthing Solutions

Technical Note

EXAMPLE SAND INFILL HYDRAULIC SHEAR CALCULATIONS

INTRODUCTION

Sand infill hydraulic stability in ClosureTurf® has been independently tested by the third-party laboratory, TRI Environmental. Test results demonstrate minimal sand infill mobilization at hydraulic shear values exceeding 1.5 lb/ft^2. The suggested design value for evaluating the potential for infill mobilization is 0.8 lb/ft^2.

An example set of calculations utilizing site specific parameters to estimate hydraulic shear from rainfall runoff are provided. The purpose of the calculations is to evaluate whether the calculated maximum hydraulic shear stress in the sand infill of ClosureTurf exceeds the suggested critical hydraulic shear stress. The calculations that follow are meant to serve as a suggested method to estimate the maximum hydraulic shear stress possible at potential ClosureTurf installations.

Two different hydraulic shear calculations are evaluated, differentiated by location and the choice of geomembrane liner used in the ClosureTurf system. The drainage length details are as follows, and the calculation results are summarized in Table 1.

1. Top deck with MicroSpike® + side slope with Super Gripnet® or MicroDrain®.
2. Side slope with Super Gripnet® or MicroDrain®.

Table 1. Summary of Hydraulic Shear Calculation Results

Drainage Path No.	Segment No.	Slope (%)	Length (ft)	Geomembrane Liner	Calculated Maximum Hydraulic Shear Stress (psf)	Suggested Critical Hydraulic Shear Stress (psf)	Hydraulic Shear Stress (Meets or Does Not Meet)
1	1	3	208	MicroSpike	0.15	0.8	meets suggested criteria
	2	32	111	Super Gripnet/ MicroDrain	0.48	0.8	meets suggested criteria
2	1	27	383	Super Gripnet	0.53	0.8	meets suggested criteria

ATTACHMENT 1-6

Drainage Path 1 – MicroSpike® on Top Deck & Super Gripnet®/MicroDrain® on the Side Slope – 100-year, 60-minute Design Storm

Drainage Path 1 consists of a top deck with a 3.0% slope and a drainage length of approximately 208 ft which drains to a side slope with a drainage length of approximately 111 ft at a 32% slope (3.1H:1V). The calculation assumes MicroSpike geomembrane for the top deck and Super Gripnet or MicroDrain geomembrane for the side slope.

Design Parameters:

Top Deck:

- Drainage length: L_1 = 208 ft (See Figure 1)
- Slope: S_1 = 3%
- Slope angle: $\alpha_1 = \tan^{-1}(3/100) = 1.72°$
- Hydraulic gradient: i_1 = 3.0% or 0.03
- Manning's roughness coefficient: n_1 = 0.22 (for slope ≤ 10%; See Watershed Geo ClosureTurf Design Guidance Manual)
- Geomembrane type: MicroSpike (without internal drainage layer)

Side Slope:

- Drainage length: L_2 = 111 ft (see Figure 1)
- Slope: S_2 = 3.1H:1V (32.3%)
- Slope angle: $\alpha_2 = \tan^{-1}(1/3.1) = 17.9°$
- Hydraulic gradient: i_2 = 32.3% or 0.323
- Manning's roughness coefficient: n_2 = 0.12 (for slope > 10%; See Watershed Geo ClosureTurf Design Guidance Manual)
- Geomembrane type: Super Gripnet or MicroDrain (with internal drainage layer)
- Transmissivity of ClosureTurf with Super Gripnet or MicroDrain (use the data in Figure 4, the ClosureTurf transmissivity test report by SGI to calculate the transmissivity at the slope of 32.3% or $i = 0.323$):
    - Flow Rate: $q = 12.28 \times i^{0.624} = 12.28 \times 0.323^{0.624} = 6.07\ gpm/ft$
    - Transmissivity: $\theta_{i=0.323} = 0.00020697 \times \frac{q}{i} = 0.00020697 \times \frac{6.07}{0.323} = 3.89 \times 10^{-3}\ m^2/sec$

Other Design Parameters:

- Design rainfall intensity (see Figures 2 and 3, the 100-yr, 1-hr rainfall intensity map):

$$R = 3.78\frac{in}{hr} = 0.315\frac{ft}{hr}$$

- Critical hydraulic shear stress of ClosureTurf with manufactured sand infill:

$$\tau_C = 0.8\ psf$$

ATTACHMENT 1-7

Step 1: Calculate the maximum hydraulic shear stress of flow on the top deck:

Flow rate on the top deck under the design rainfall intensity (assuming unit width of 1 ft of final cover):

$$\boxed{q_1 = L_1 \cdot R \cdot \cos \alpha_1} = 208\, ft \times 0.315 \frac{ft}{hr} \times \cos 1.72^\circ = 65.49 \frac{ft^2}{hr} = 0.0182 \frac{ft^2}{s}$$

The flow rate:

$$\boxed{q_1 = v_1 \cdot A_1 = v_1 \cdot (H_1 \times 1\, ft) = v_1 \cdot H_1}$$

Where, *H₁* is flow depth on the top deck (ft). Using the Manning's Equation and assuming the hydraulic radius equals to the flow depth (in ft):

$$\boxed{v_1 = \frac{1.49}{n_1} H_1^{\frac{2}{3}} \sqrt{S_1}}$$

Therefore,

$$q_1 = v_1 \cdot H_1 = \frac{1.49}{n_1} H_1^{\frac{2}{3}} \sqrt{S_1} \cdot H_1 = \frac{1.49}{n_1} H_1^{\frac{5}{3}} \sqrt{S_1}$$

Solve the above equation for *H₁*,

$$\boxed{H_1 = \left(\frac{q_1 \cdot n_1}{1.49 \cdot \sqrt{S_1}}\right)^{\frac{3}{5}}} = \left(\frac{0.0182 \times 0.22}{1.49 \cdot \sqrt{0.03}}\right)^{\frac{3}{5}} = 0.0821 ft$$

The maximum hydraulic shear stress by the water flow on slope:

$$\boxed{\tau_1 = \gamma_w \cdot H_1 \cdot S_1} = 62.4 \frac{lb}{ft^3} \times 0.0821 ft \times 0.03 = 0.15\, psf < \tau_c (= 0.8\, psf) \quad \checkmark$$

The calculated maximum hydraulic shear stress on the sand infill is less than the suggested critical hydraulic shear stress, indicating minimal sand infill mobilization is expected to occur.

ATTACHMENT 1-8

Step 2: Calculate the maximum hydraulic shear stress of flow on the side slope

Water from the top deck will flow onto the side slope. The total flow at the end of the side slope is:

$$\boxed{q_{total} = q_1 + q_2 = q_1 + L_2 \cdot R \cdot \cos\alpha_2} = 65.49\frac{ft^2}{hr} + \left(111ft \times 0.315\frac{ft}{hr} \times \cos 17.9°\right)$$

$$= 98.76\frac{ft^2}{hr} = 0.0274\frac{ft^2}{s}$$

Part of the flow is expected to be through the internal drainage channel of the Super Gripnet or MicroDrain (i.e., the space within the drainage studs of Super Gripnet or MicroDrain). The internal flow capacity of ClosureTurf with Super Gripnet or MicroDrain is:

$$\boxed{q_{int} = \theta_{i=0.323} \cdot i_2} = 3.89 \times 10^{-3}\frac{m^2}{sec} \times 0.323$$

$$= 3.89 \times 10^{-3} \times \frac{(3.28ft)^2}{\left(\frac{1}{3600}\right)hr} \times 0.323 = 48.66\frac{ft^2}{hr}$$

The remaining flow will be through the turf and sand infill:

$$\boxed{q'_{total} = q_{total} - q_{int}} = 98.76\frac{ft^2}{hr} - 48.66\frac{ft^2}{hr} = 50.10\frac{ft^2}{hr} = 0.0139\frac{ft^2}{s}$$

The flow rate:

$$\boxed{q'_{total} = v_2 \cdot A_2 = v_2 \cdot (H_2 \times 1\,ft) = v_2 \cdot H_2}$$

Where, H_2 is flow depth on the slope (ft). Using the Manning's Equation and assuming the hydraulic radius equals to the flow depth (in ft):

$$\boxed{v_2 = \frac{1.49}{n_2}H_2^{\frac{2}{3}}\sqrt{S_2}}$$

Therefore,

$$\boxed{q'_{total} = v_2 \cdot H_2 = \frac{1.49}{n_2}H_2^{\frac{2}{3}}\sqrt{S_2} \cdot H_2 = \frac{1.49}{n_2}H_2^{\frac{5}{3}}\sqrt{S_2}}$$

Solve the above equation for H_2,

$$\boxed{H_2 = \left(\frac{q'_{total} \cdot n_2}{1.49 \cdot \sqrt{S_2}}\right)^{\frac{3}{5}}} = \left(\frac{0.0139 \times 0.12}{1.49 \cdot \sqrt{0.323}}\right)^{\frac{3}{5}} = 0.0238ft$$

The maximum hydraulic shear stress by the water flow on the slope:

$$\boxed{\tau_2 = \gamma_w \cdot H_2 \cdot S_2} = 62.4\frac{lb}{ft^3} \times 0.0238ft \times 0.323 = 0.48\,psf < \tau_c(= 0.8\,psf) \quad \checkmark$$

The calculated maximum hydraulic shear stress on the sand infill is less than the suggested critical hydraulic shear stress, indicating minimal sand infill mobilization is expected to occur.

ATTACHMENT 2-1

NOAA Atlas 14, Volume 8, Version 2
Location name: Detroit, Michigan, USA*
Latitude: 42.3317°, Longitude: -83.048°
Elevation: 602.23 ft**
* source: ESRI Maps
** source: USGS

POINT PRECIPITATION FREQUENCY ESTIMATES

Sanja Perica, Deborah Martin, Sandra Pavlovic, Ishani Roy, Michael St. Laurent, Carl Trypaluk, Dale Unruh, Michael Yekta, Geoffery Bonnin

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]

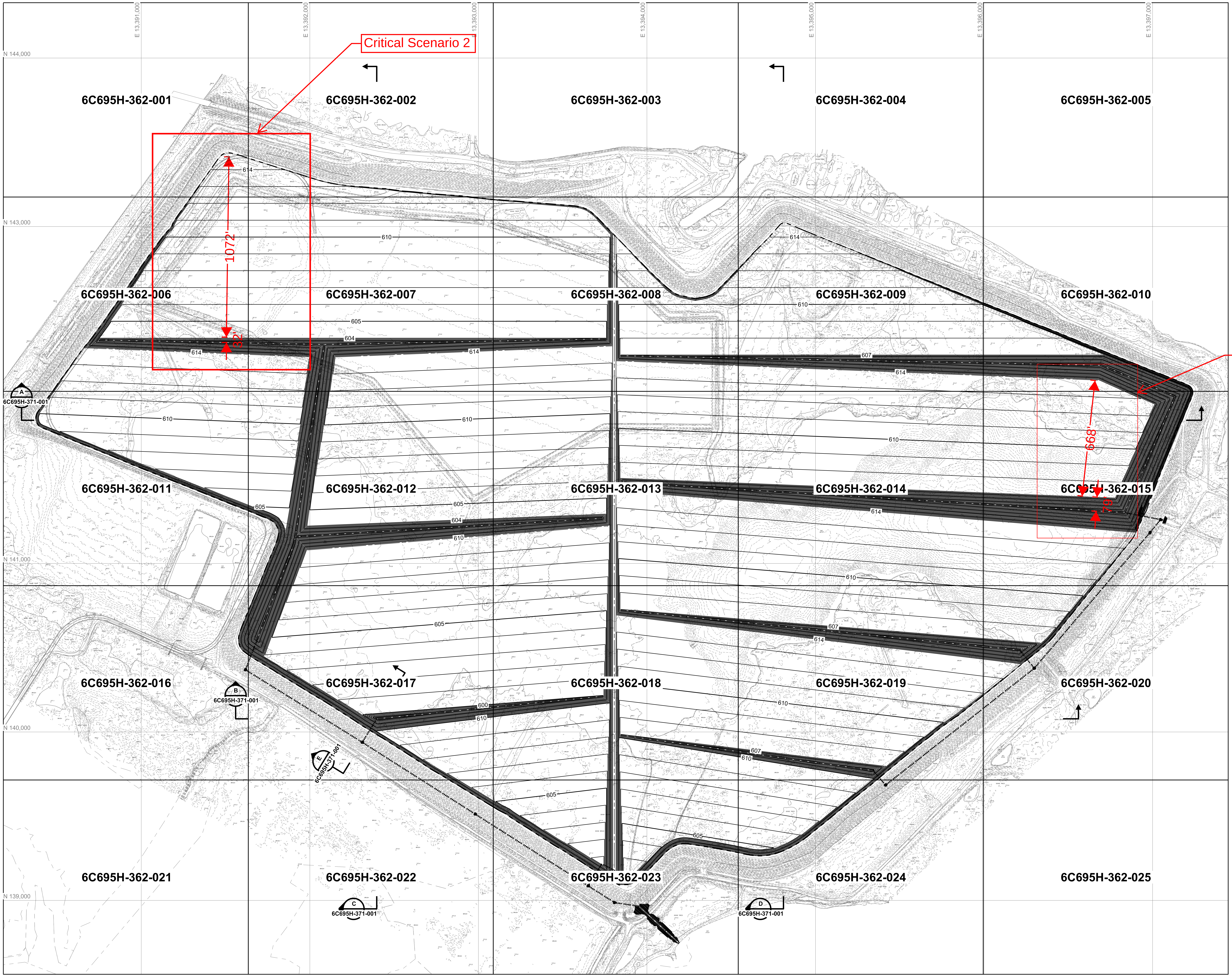
Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.301 (0.253-0.362)	0.356 (0.299-0.429)	0.448 (0.375-0.541)	0.526 (0.437-0.638)	0.637 (0.510-0.795)	0.725 (0.566-0.913)	0.815 (0.612-1.05)	0.907 (0.651-1.19)	1.03 (0.710-1.39)	1.13 (0.755-1.53)
10-min	0.440 (0.370-0.530)	0.521 (0.437-0.628)	0.656 (0.549-0.792)	0.771 (0.641-0.934)	0.933 (0.747-1.16)	1.06 (0.828-1.34)	1.19 (0.896-1.53)	1.33 (0.953-1.74)	1.51 (1.04-2.03)	1.66 (1.11-2.25)
15-min	0.537 (0.451-0.647)	0.635 (0.533-0.766)	0.800 (0.669-0.966)	0.940 (0.781-1.14)	1.14 (0.912-1.42)	1.29 (1.01-1.63)	1.46 (1.09-1.87)	1.62 (1.16-2.13)	1.85 (1.27-2.48)	2.02 (1.35-2.74)
30-min	0.755 (0.635-0.910)	0.892 (0.748-1.08)	1.12 (0.937-1.35)	1.32 (1.09-1.59)	1.59 (1.27-1.98)	1.81 (1.41-2.28)	2.03 (1.53-2.61)	2.27 (1.62-2.97)	2.58 (1.77-3.46)	2.83 (1.89-3.83)
60-min	0.967 (0.813-1.17)	1.14 (0.958-1.38)	1.44 (1.20-1.73)	1.69 (1.40-2.05)	2.05 (1.64-2.56)	2.34 (1.82-2.94)	2.63 (1.98-3.38)	2.94 (2.11-3.86)	3.36 (2.31-4.51)	3.69 (2.46-5.00)
2-hr	1.18 (0.998-1.41)	1.39 (1.18-1.66)	1.75 (1.48-2.10)	2.06 (1.73-2.48)	2.51 (2.02-3.11)	2.86 (2.25-3.58)	3.23 (2.44-4.12)	3.61 (2.61-4.71)	4.14 (2.87-5.52)	4.55 (3.06-6.13)
3-hr	1.30 (1.11-1.55)	1.54 (1.30-1.83)	1.93 (1.63-2.30)	2.27 (1.91-2.72)	2.77 (2.25-3.42)	3.17 (2.50-3.95)	3.58 (2.72-4.55)	4.01 (2.92-5.22)	4.62 (3.21-6.13)	5.09 (3.44-6.82)
6-hr	1.53 (1.31-1.80)	1.78 (1.52-2.11)	2.23 (1.89-2.63)	2.61 (2.21-3.10)	3.18 (2.61-3.91)	3.65 (2.91-4.52)	4.13 (3.17-5.22)	4.65 (3.41-6.00)	5.37 (3.77-7.09)	5.94 (4.05-7.91)
12-hr	1.78 (1.53-2.08)	2.05 (1.76-2.39)	2.52 (2.16-2.95)	2.94 (2.50-3.45)	3.56 (2.94-4.34)	4.07 (3.28-5.01)	4.62 (3.58-5.80)	5.21 (3.85-6.68)	6.03 (4.27-7.91)	6.69 (4.59-8.84)
24-hr	2.04 (1.77-2.37)	2.33 (2.02-2.71)	2.84 (2.45-3.30)	3.30 (2.83-3.85)	3.98 (3.31-4.81)	4.54 (3.68-5.54)	5.13 (4.00-6.39)	5.77 (4.30-7.34)	6.66 (4.76-8.67)	7.38 (5.11-9.68)
2-day	2.34 (2.04-2.69)	2.67 (2.33-3.07)	3.25 (2.82-3.74)	3.75 (3.24-4.34)	4.49 (3.76-5.37)	5.09 (4.15-6.15)	5.72 (4.49-7.05)	6.38 (4.79-8.05)	7.31 (5.26-9.42)	8.04 (5.62-10.5)
3-day	2.57 (2.25-2.94)	2.92 (2.56-3.34)	3.52 (3.07-4.04)	4.04 (3.51-4.65)	4.80 (4.03-5.70)	5.41 (4.43-6.50)	6.05 (4.77-7.41)	6.72 (5.06-8.42)	7.64 (5.53-9.80)	8.38 (5.88-10.8)
4-day	2.77 (2.44-3.16)	3.13 (2.75-3.57)	3.75 (3.29-4.29)	4.28 (3.73-4.91)	5.05 (4.26-5.98)	5.67 (4.66-6.78)	6.31 (4.99-7.70)	6.99 (5.28-8.72)	7.92 (5.74-10.1)	8.64 (6.08-11.2)
7-day	3.28 (2.91-3.71)	3.68 (3.25-4.17)	4.35 (3.83-4.93)	4.92 (4.30-5.60)	5.73 (4.85-6.71)	6.37 (5.26-7.56)	7.04 (5.60-8.52)	7.73 (5.88-9.58)	8.68 (6.33-11.0)	9.42 (6.67-12.1)
10-day	3.74 (3.33-4.21)	4.17 (3.70-4.69)	4.87 (4.31-5.50)	5.47 (4.81-6.21)	6.33 (5.38-7.37)	7.00 (5.80-8.25)	7.69 (6.14-9.26)	8.40 (6.42-10.4)	9.37 (6.87-11.8)	10.1 (7.21-12.9)
20-day	5.09 (4.56-5.68)	5.60 (5.01-6.25)	6.43 (5.73-7.20)	7.13 (6.31-8.01)	8.09 (6.92-9.32)	8.84 (7.38-10.3)	9.60 (7.72-11.4)	10.4 (7.98-12.7)	11.4 (8.42-14.2)	12.2 (8.74-15.5)
30-day	6.26 (5.63-6.96)	6.87 (6.17-7.64)	7.86 (7.03-8.75)	8.66 (7.70-9.68)	9.75 (8.36-11.1)	10.6 (8.85-12.2)	11.4 (9.19-13.5)	12.2 (9.41-14.8)	13.2 (9.81-16.4)	14.0 (10.1-17.7)
45-day	7.81 (7.05-8.62)	8.59 (7.75-9.49)	9.82 (8.82-10.9)	10.8 (9.64-12.0)	12.1 (10.4-13.7)	13.0 (10.9-14.9)	13.9 (11.2-16.3)	14.7 (11.4-17.7)	15.7 (11.7-19.4)	16.5 (11.9-20.7)
60-day	9.16 (8.30-10.1)	10.1 (9.15-11.1)	11.6 (10.5-12.8)	12.7 (11.4-14.1)	14.2 (12.2-16.0)	15.2 (12.8-17.4)	16.1 (13.1-18.8)	17.0 (13.2-20.3)	18.0 (13.4-22.1)	18.7 (13.6-23.4)

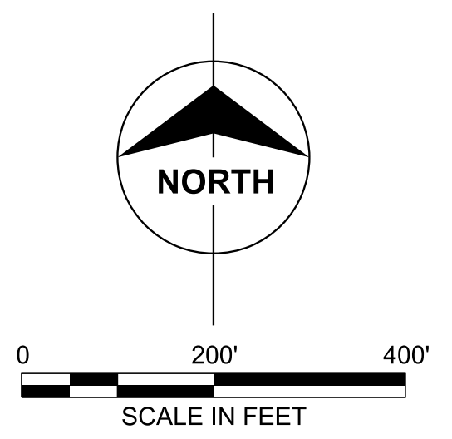
[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

ATTACHMENT 3-1





6C695H-362

LATEST REVISION "0"

6				
5				
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1	30JUN23	ISSUED FOR 30% REVIEW	ENR AMM	–
NO.	DATE	ISSUED FOR	DISPLN/RSP ENG	PRJ ENG
PROJECT ENGINEER: –			APPROVALS	

PRECONSTRUCTION REVISION BLOCK – REV. 0

Vendor:

BURNS McDONNELL

2111 Woodward Avenue, Suite 202
Detroit, MI 48201
313-309-5711
Burns & McDonnell Michigan, Inc.

DTE ELECTRIC COMPANY

TITLE

FLY ASH BASIN CLOSURE PROJECT
FINISH GRADING PLAN
KEY PLAN

LOCATION NAME MONROE POWER PLANT	UNIT NUMBER 1
ORIGINATING SOURCE BURNS & MCDONNELL MICHIGAN, INC.	SCALE AS SHOWN
	USE DIMENSIONS ONLY DO NOT SCALE
DTE ELECTRIC COMPANY DRAWING NUMBER 6C695H-362	

DESIGN FILE NAME: 0695-C-H-0362.dgn

PRELIMINARY - NOT FOR CONSTRUCTION

THIS IS A CAD PRODUCED DRAWING. ANY CHANGES OR REVISIONS TO THIS DRAWING MUST BE COMPLETED USING THE CAD SYSTEM

DTE ELECTRIC APPROVALS		DATE
ENS TECH ORG	–	–
	–	–
ENS PLANT ENG	–	–
	–	–
DIST OPR	–	–
	–	–
PROJECT ENG	–	–
ENG COMP	–	–

OTHER APPROVALS		DATE
VERIFYER	–	–
ARCH	–	–
CIVIL	–	–
MECH	–	–
	–	–
ELEC	–	–
	–	–
I&C	–	–

DESIGNED BY	DATE
A. MYERS	18MAY23
DRAWN BY	DATE
J. RIDDER	18MAY23
CHECKED BY	DATE
APPROVED BY	DATE
PROJECT ENGINEER	DATE
PROJECT MANAGER	DATE

J PROJ. ENG. PROJ. MGR. MADE BY DATE I&C ELECT. CHK BY DATE MECH. APPROVED BY

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A PROJ. ENG. – PROJ. MGR. – REVISION DESCRIPTION MADE BY – DATE – I&C – ELECT. – CHK BY – DATE – MECH. – APPROVED BY –

ATTACHMENT D - ASSESSMENT OF UV LONGEVITY

Geosyntec
consultants

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Kennesaw, Georgia 30144
PH 678.202.9500
FAX 678.202.9501
www.geosyntec.com

22 November 2022

José Urrutia, P.E.
Vice President of Engineering
Watershed Geosynthetics
11400 Atlantis Place, Suite 200
Alpharetta, GA 30022

Subject: Assessment of ClosureTurf® UV Longevity

Dear Mr. Urrutia:

Watershed Geosynthetics, Inc. (Watershed) has patented an alternative landfill closure system termed ClosureTurf®. ClosureTurf® consists of high-density polyethylene (HDPE) grass blades tufted through a double-layer polypropylene (PP) geotextile backing which overlies an HDPE or linear low-density polyethylene (LLDPE) structured geomembrane (i.e., Super Gripnet®, MicroDrain®, or MicroSpike®) manufactured by AGRU America Inc. The addition of a layer of sand ballast during installation completes the system. The sand ballast provides cover for the lower portion of the HDPE grass blades, the PP geotextile backing, and the structured geomembrane (Figure 1).

A report titled "Literature Review and Assessment of ClosureTurf® UV Longevity" was prepared by Geosyntec Consultants, Inc. (Geosyntec) and dated 15 May 2015 (Geosyntec, 2015). Watershed has requested that Geosyntec provide an updated assessment of the longevity of the ClosureTurf® system with regard to ultraviolet (UV) exposure and degradation. This report (Report) supersedes the Geosyntec (2015) report. Since ClosureTurf® has elements (i.e., the HDPE grass blades) that are permanently exposed to UV radiation, this Report will be focused on the exposed portion of the system.

Geosyntec's approach to this Report incorporates updated laboratory and field data from samples at multiple sites throughout the Southeastern United States (U.S.) and Arizona into the assessment of HDPE grass blade longevity. This Report concludes with a summary of the analysis along with brief discussion for recommendations.

EXECUTIVE SUMMARY

This Report incorporates updated laboratory and field data regarding the retained tensile strength of HDPE geomembrane and synthetic grass blade materials as a function of exposure to ultraviolet (UV) radiation to estimate the longevity of the exposed grass blades of the ClosureTurf® product.

The laboratory update includes a release of additional data from a Geosynthetics Research Institute (GRI) testing program measuring the effects of UV radiation on HDPE geomembrane strips. The test program incubates HDPE geomembrane strip samples under a UV lamp at elevated temperatures (60°C, 70°C, and 80°C) to accelerate the degradation. The tensile strength and elongation of each strip are then measured after a given period of exposure. Data from this test program for HDPE geomembrane can be converted to field exposure for a given site following the method presented in Richgels (2016). Such a conversion was performed for this Report for five sites, where field test data for the ClosureTurf® HDPE grass blades were also obtained. The five sites are: (i) Atlas Testing Facility, New River, Arizona; (ii) Saufley Field Landfill, Pensacola, Florida; (iii) LaSalle-Grant Landfill in Jena, Louisiana; (iv) Baldwin County Landfill, Georgia; and (v) Berkely County Landfill, South Carolina.

Once the conversion from the GRI laboratory UV exposure to the field UV exposure at each site was completed, extrapolations of retained tensile strength of HDPE geomembrane as a function of UV exposure were made to obtain estimates of half-life (i.e., 50% retained tensile strength) and 12.5% retained tensile strength. The 12.5% value was selected to illustrate extended longevity when performance requirements support the selection of service-life tensile strength values lower than the half-life tensile strength values. The extrapolations included an upper bound (Arrhenius) and a lower bound (linear) of retained tensile strength as a function of UV exposure. Based on the GRI laboratory data for HDPE geomembrane, the resulting upper bound estimate of the half-life of an HDPE grass blade is 93 years in New River, Arizona with a lower bound estimate of 75 years, assuming that the laboratory results of HDPE geomembrane are applicable to HDPE grass blades. For the sites in the Southeastern U.S., the upper bound half-life estimate is 157 years, while the lower bound estimate is 83 years. If the 12.5% retained strength is considered for the HDPE grass blades, rather than the half-life, the upper and lower bound estimates for the New River, Arizona site are 216 years and 181 years, respectively. For the Southeastern U.S., if the 12.5% retained strength is considered, the upper bound and lower bound estimates are 376 and 204 years, respectively.

The field test data from the five sites consisted of measurements of the tensile strength of the ClosureTurf® HDPE grass blades at given durations of field exposure. The New River, Arizona site is a field weathering testing facility where samples of ClosureTurf® HDPE grass blades were exposed to sunlight concentrated by an array of mirrors to accelerate the degradation process by a factor of seven. The remaining four sites in the Southeastern U.S. are waste facilities where ClosureTurf® was installed. The field test data of ClosureTurf® HDPE grass blades from the New River, Arizona site (i.e., the accelerated weathering testing site) as well as the four Southeastern U.S. sites (i.e., the real-world weathering sites) consistently plotted above the upper bound curve developed from the GRI laboratory data for HDPE geomembrane. This suggests that the length of time required to reach half-life (or any other value of the percent retained tensile strength) of the HDPE grass blades in the field is longer than indicated by the estimates from the conversion of GRI laboratory data. The disparity is likely due to ignoring the antioxidant depletion phase in the laboratory data as well as site environmental factors (e.g., moisture, shading, slopes, etc.) that are not included in the method of conversion from laboratory exposure to field exposure.

Given these factors and results it is reasonable to expect that the half-life of the HDPE grass blades of the ClosureTurf® product is on the order of 100 years under the New River, Arizona climatic conditions. Since the New River, Arizona site has the highest levels of UV irradiance and temperature in the United States, sites located elsewhere will have greater half-life estimates in general proportion to the ratio of UV irradiance. Furthermore, performance requirements of the ClosureTurf® HDPE grass blades may permit evaluation of longevity beyond the half-life, thereby extending the expected duration of field performance.

DATA SUMMARY

Data sets currently available when this Report is prepared represent an expansion over what was available during the Geosyntec (2015) study. The current data includes measurements of tensile strength of HDPE grass blades after UV exposure from multiple sites where ClosureTurf® has been installed and tensile strength of HDPE geomembrane and grass blades from additional accelerated weathering tests. The data sets of direct measurement of tensile strength as a function of UV exposure utilized in this Report include:

1. Geosynthetics Research Institute (GRI) laboratory data release on the effects of accelerated weathering of HDPE geomembrane strips presented by Dr. Robert Koerner at GeoAmericas (2016). The effects are measured in terms of changes to tensile strength as a function of UV exposure under a fluorescent lamp at various temperatures. The data contains updates from GRI in addition to what was included in the Geosyntec (2015) Report.

2. Data from the New River, Arizona field testing facility. The data includes measurements of retained tensile strength of HDPE grass blades exposed to full spectrum radiation using sunlight concentrated by mirrors to accelerate the weathering process. The testing setup accelerates the effects of exposure duration by a factor of seven.

3. Tensile strength test results of HDPE grass blade samples retrieved from the following ClosureTurf® sites: (i) Saufley Field Landfill, Pensacola, Florida; (ii) LaSalle-Grant Landfill, Jena, Louisiana; (iii) Baldwin County Landfill, Georgia; and (iv) Berkely County Landfill,

South Carolina. The data include measurements of retained tensile strength as a function of real-world sunlight exposure in years.

DATA DISCUSSION

The GRI data set involves controlled exposure of geosynthetic samples to temperature and UV radiation simulating solar maximum exposure with a UV source at three constant temperatures (60°C, 70°C, and 80°C). The testing program is performed in accordance with ASTM D7238 procedures for *Standard Test Method for Effect of Exposure of Unreinforced Polyolefin Geomembrane Using Fluorescent UV Condensation Apparatus.* Charts were produced with this updated data in Richgels (2016), which presents the retained tensile strength of the HDPE geomembrane test samples incubated at each temperature set as a function of the cumulative UV exposure (Figure 2). Stages A to B (antioxidant depletion and transition periods) and Stage C (polymer oxidation) are distinguished in the charts, and the Stage C data points were selected for the regression.

The application of the GRI laboratory data to individual field sites requires conversion of the exposure conditions of the laboratory to local site conditions. While site specific exposure information for the Atlas Testing Facility in New River, Arizona was included in Richgels (2015a, 2015b), exposure conversion to other sites had to be developed. Richgels (2016) performed such a conversion from the GRI laboratory data to several sites in Florida using solar radiation and temperature data from the National Renewable Energy Laboratory (NREL). The temperature and radiation data for each site is expressed by NREL in a Total Meteorological Year (TMY3), a multiyear dataset from which 12 months are chosen that best represent the median conditions. Geosyntec adopted this same procedure for the sites included in this Report.

The Geosyntec (2015) report presented tensile property testing of the field samples of the HDPE grass blades exposed to the New River, Arizona environment at the Atlas Testing Facility for approximate exposure periods of 1, 5, 7, and 10 years. The average values for tensile strength retained at each corresponding period was determined to be 97.2%, 89.7%, 83.8%, and 82.5%, respectively. Watershed is conducting additional accelerated weathering testing at the same facility using the Equatorial Mount with Mirrors for Acceleration (EMMA) solar concentration device, which provides approximately seven years of UV radiation exposure in one calendar year. Additional tensile property testing was performed on samples of the HDPE grass blades collected from the accelerated weathering testing. The approximate exposure periods for these samples were one, two, and three calendar years, which correspond to accelerated exposure periods of approximately 7, 14, and 21 years, respectively. The average values for tensile strength retained for these exposure periods are 92.2%, 83.3%, and 80.7%, respectively (Figure 3).

Similar data was collected for field samples of the HDPE grass blades weathered under climatic conditions at the landfills in Berkley County, South Carolina, Baldwin County, Georgia, Pensacola, Florida, and Jena, Louisiana. The exposure periods of the samples for these sites were:

- Berkley County, 2 years
- Baldwin County, 3 years
- Pensacola, Florida, 5 years
- Jean, Louisiana, 7 and 8 years

The average values for tensile strength retained for these exposure periods were 100%, 99.1%, 97.3%, 85.4%, and 96.8%, respectively (Figure 4). Because the yearly irradiation is fairly uniform in the Southeastern region of the U.S. (Figure 5), the field data obtained from sites in this region were grouped together on a single plot, as shown in Figure 4. The new EMMA and field test data were added onto the figure of half-life projections presented in the Geosyntec (2015) Report, as shown in Figure 6. The new data, which are plotted at or above the trend lines, support the longevity of ClosureTurf projected in the Geosyntec (2015) Report.

PERFORMANCE REQUIREMENTS

The acceptable level of degradation for a given property of polyolefins due to exposure to UV radiation should be based on the performance requirements of that particular aspect of the product. In the case of HDPE grass blades of the ClosureTurf® system, performance requirements for tensile strength may be as low as 2.5 to 3.5 pounds (lbs.) based on the applied loads of pullout forces from equipment operation and water runoff (Diguilo, 2013). Since the original manufactured strength of an HDPE grass blade is a minimum of approximately 20 lbs., the performance requirement is approximately 12.5%, if no factor of safety is included. Both the original manufactured strength of the product and the performance requirement should be evaluated for each individual application. However, for the purposes of this Report, Geosyntec utilized 12.5% of original strength as the performance requirement to illustrate the difference in duration with the half-life criterion.

HDPE GRASS BLADE LONGEVITY EVALUATION

In order to develop a prediction for the longevity of the HDPE grass blades with respect to UV degradation for each of the sites from which field data was collected, Geosyntec implemented the method found in Richgels (2016) for two levels of retained tensile strength (i.e., 50% and 12.5% of the original property value). The method uses the same calculation procedure used in Richgels (2015a and 2015b) but incorporates the updated data from GRI and UV irradiance and temperature data collected from NREL for each site. In the Geosyntec (2015) Report, Geosyntec performed the calculations in accordance with the Richgels (2015a and 2015b) procedure for Arizona climatic conditions and compared the results with the results presented therein, which were generally in agreement. Once the half-life estimates were calculated, Geosyntec repeated the calculations for 12.5% of retained strength. The same two levels of retained tensile strength (i.e., 50% and 12.5%) were utilized in this Report.

Half-Life Estimation (50% of Retained Strength)

The assessment of half-life is based on the updated data from GRI using retained tensile strength of HDPE geomembrane samples incubated under a UV lamp at elevated temperatures. The elevated temperatures accelerate the UV weathering process in accordance with ASTM D7238.

The GRI data includes samples tested at three elevated temperatures: (i) 80 degrees Celsius (°C); (ii) 70°C; and (iii) 60°C. The 80°C data set reached 50% retained strength, the 70°C data set reached approximately 60% retained strength, and the 60°C data set reached approximately 80% retained strength. Logarithmic extrapolations to 50% retained strength were performed for each temperature data set. The amount of exposure time (on a log scale) corresponding to the 50% retained strength plotted vs. the inverse of the corresponding temperature (80°C, 70°C and 60°C) is shown in Figure 7. Figure 7 allows for extrapolation to find the laboratory exposure time required to achieve 50% retained strength at temperatures lower than the test temperatures (i.e., actual field temperatures).

Once the relationship between temperature and laboratory exposure is defined, a relationship between laboratory exposure and field exposure for a particular site can be constructed. Sites included in this Report are: (i) Atlas Testing Facility, New River, Arizona; (ii) Saufley Field Landfill, Pensacola, Florida; (iii) Lasalle-Grant Landfill, Jena, Louisiana; (iv) Berkley County Landfill, South Carolina; and (v) Baldwin County Landfill, Georgia. These locations correspond to the sites where Watershed has obtained tensile strength measurements on HDPE grass blade samples.

Richgels (2015a and 2015b) presents monthly averages at the Arizona site for: (i) peak turf temperature; and (ii) irradiance as a fraction of the laboratory lamp irradiance. The monthly averages of these parameters for the sites outside of Arizona were obtained from NREL, and the irradiance as a fraction of the laboratory lamp irradiance was determined for each site. The average turf temperature was conservatively estimated by increasing the measured ambient temperature by a factor of two (Richgels, 2016). Using these two parameters for a given month combined with the Arrhenius function, an estimate of half-life loss per month is obtained. Summation of the half-life lost per month over a year yields the annual half-life loss. The inverse of the annual half-life loss is the predicted half-life in years. Using this method to estimate the half-life for the Pensacola region, Richgels obtained a half-life of approximately 200 years, while Geosyntec obtained a half-life of 132 years (Table 1). The difference is attributable to rounding errors in the logarithmic projections and updates to the solar radiation and temperature information used in NREL datasets. The half-life estimates for the sites in New River, Arizona, Jena, Louisiana, Berkley County, South Carolina, and Baldwin County, Georgia were calculated by Geosyntec as 93, 151, 157, and 157 years, respectively.

Following the suggestion of Koerner et al. (2015), Richgels (2016) treated the results of the half-life mentioned above as an upper bound estimate. For the lower bound estimate, Koerner et al. (2015) suggested performing a linear extrapolation of the laboratory data to lower field temperatures, rather than using the Arrhenius function. With the linear extrapolation, the ratio of monthly irradiance to laboratory lamp irradiance is scaled linearly to calculate the number of months required to reach half-life at 80°C, 70°C and 60°C. Linear extrapolations per month are made from the elevated lab temperatures to the corresponding average turf temperature in that month (Table 2 and Figures 8 through 12). The resulting half-life loss per month is summed to obtain half-life loss per year. The inverse of that result is the half-life in years. For the Pensacola region, Richgels (2016) calculates a half-life of 118 years using this linear model. Geosyntec's calculation resulted in a half-life of 83 years. The half-life estimates for the sites located in New River, Arizona, Jena, Louisiana, Berkley County, South Carolina, and Baldwin County, Georgia were calculated as 75, 91, 90, and 90 years, respectively.

Figure 13 shows the upper (Arrhenius - logarithmic) and lower (linear) bound curves calculated by Geosyntec along with the field data on the HDPE grass blades provided by Watershed (2014 and 2022) for the New River, AZ site. Because of the uniformity of the annual irradiance among the southeastern sites (Figure 5), little variation was observed in the calculated upper and lower bound curves for these sites. Therefore, Figure 14 shows the limits of the calculated upper and lower bound curves for the southeastern sites along with the field data from these sites. As shown in these figures, the field data falls above the upper and lower bound curves. Note that the first point from the field data collected from the Atlas Testing Facility in Arizona at approximately 1 year is omitted from the trend line (Figure 13). This is because the first data point is assumed to be within the antioxidant phase of degradation rather than the polymer oxidation stage as suggested by Rowe et al. (2010). Additional discussion regarding the stages of degradation for polyolefin materials can be found in CUR 243 (2012).

Service Life Estimation Based on Performance Requirements (12.5% of Retained Strength)

Geosyntec repeated the calculations discussed above but extrapolated the GSI laboratory data down to 12.5% retained strength rather than 50% at 80°C, 70°C and 60°C for the sites located in New River, Arizona, Pensacola, Florida, Jena, Louisiana, Berkley County, South Carolina, and Baldwin County, Georgia. The upper bound (Arrhenius - logarithmic) estimates were 216, 314, 359, 376, and 376 years, respectively. The lower bound (linear) estimates were 181, 204, 223, 236, and 221 years, respectively.

The estimates of service life at 12.5% retained strength provided in the Geosyntec (2015) Report were too large to be reasonable. A likely explanation is that the samples tested at 80°C, 70°C and 60°C had not degraded enough to produce accurate predictions at 12.5% retained strength. Given that the updated data from GRI included additional exposure at each of the three test temperatures, a better estimate for time of exposure to reach 12.5% strength was obtained for this Report. However, if the retained strength for laboratory samples approaches 12.5% retained strength in future data releases, the estimates for the corresponding time of exposure may be further refined.

SUMMARY AND CONCLUSIONS

Watershed has provided Geosyntec with supplemental ClosureTurf® accelerated weathering test data from the Atlas Testing Facility, New River, AZ and new field test data from four ClosureTurf® sites located in the Southeastern U.S. Following the laboratory to field conversion method presented in Richgels (2016), Geosyntec calculated the expected exposure duration at the 50% and 12.5% retained tensile strengths of HDPE grass blades under the exposure conditions at the five locations, based on the GRI laboratory UV test results for HDPE geomembrane and then compared them with the test results of field samples of HDPE grass blades.

The method included upper bound and lower bound calculations for each site. The results of the upper bound calculations using the GRI laboratory data yielded exposure durations for 50% retained tensile strength of: (i) 132 years for Saufley Field Landfill in Pensacola, Florida; (ii) 151 years for LaSalle-Grant Landfill in Jena, Louisiana; (iii) 157 years for the Berkely County Landfill; (iv) 157 years for the Baldwin County Landfill; and (v) 93 years for the Atlas Testing Facility in New River, Arizona.

The results of the lower bound calculations using the GRI laboratory data yielded exposure durations for 50% retained tensile strength of: (i) 83 years for Saufley Field Landfill in Pensacola, Florida; (ii) 91 years for LaSalle-Grant Landfill in Jena, Louisiana; (iii) 90 years for the Berkely County Landfill; (iv) 90 years for the Baldwin County Landfill; and (v) 75 years for the Atlas Testing Facility in New River, Arizona.

These calculations were repeated using 12.5% retained tensile strength to illustrate the difference in exposure duration if a performance-based criteria is used rather than half-life. The results of the upper bound calculations yielded exposure durations of: (i) 314 years for Saufley Field Landfill in Pensacola, Florida; (ii) 359 years for LaSalle-Grant Landfill in Jena, Louisiana; (iii) 376 years for the Berkely County Landfill; (iv) 376 years for the Baldwin County Landfill; and (v) 216 years for the Atlas Testing Facility in New River, Arizona.

The lower bound calculations yielded exposure durations for 12.5% retained tensile strength of: (i) 204, years for Saufley Field Landfill in Pensacola, Florida; (ii) 223 years for LaSalle-Grant Landfill in Jena, Louisiana; (iii) 236 years for the Berkely County Landfill; (iv) 221 years for the Baldwin County Landfill; and (v) 181 years for the Atlas Testing Facility in New River, Arizona.

The results above for the Saufley Field Landfill site in Pensacola, Florida were compared with the results given in Richgels (2016) where a similar conversion was performed. Richgels (2016) obtained an upper bound duration for 50% retained strength of 200 years and a lower bound result of 118 years, compared with Geosyntec's results of 132 years and 83 years, respectively. The differences between Geosyntec and Richgels calculations were attributed to rounding and updates to solar radiation and temperature information used in NREL datasets. However, the comparison generally demonstrates agreement between Geosyntec and Richgels (2016).

Plots of the field data and the upper and lower bound half-life estimates based on the GRI data for the New River, AZ site and the sites in the Southeastern U.S. are shown in Figures 13 and 14, respectively. As displayed in the figures, the field data consistently plots above the upper bound estimates. This difference may be attributable to environmental factors not accounted for in the laboratory or laboratory to field conversion method. These environmental factors may include orientation of the samples in the field, shading from slopes or adjacent grass blades, moisture conditions, etc. (GRI, 2019). Furthermore, as demonstrated in GRI (2019), it is seen that the laboratory lifetimes are somewhat lower than the field lifetimes, indicating that the laboratory incubation devices are more severe in their exposure and radiation when compared to field conditions. Additionally, field samples in the early stages of weathering may be within the antioxidant phase of degradation rather than the polymer oxidation stage as suggested by Rowe *et. al.* (2010). As indicated in Koerner (2011), the duration of the antioxidant depletion phase is dependent upon the type and amount of the various antioxidants present in the formulation. Furthermore, the physical loss of antioxidants involves the distribution of antioxidants in the material and their volatility and extractability to the site-specific environment (Koerner, 2011). Therefore, variations between the field data and the half-life estimates using the GRI laboratory data may be attributable to differences in the rate at which the proprietary antioxidant formulation present in the HDPE grass blades degrades due to site-specific environmental conditions. Finally, because the extrapolation performed to estimate laboratory exposure time required to reach 50% degradation was based upon the regression of the polymer oxidation data points (Stage C) from the GRI data, the half-life projections herein represent a conservative estimate which do not account for the antioxidant depletion phase.

Therefore, a 100-year half-life estimate for the HDPE grass blades of ClosureTurf® is supported for sites in the Southeastern U.S., given that the upper and lower bound estimates bracket a 100-year half-life and the field data regressions plot above the upper bound (Figure 14). While the estimated upper-bound half-life for New River, AZ falls slightly below 100 years due to the higher solar irradiance, the trends observed in the field data also support a half-life estimate that is also on the order of 100 years (Figure 13). The slight disparity between the upper bound estimate and field data is consistent with the discussion provided above. Furthermore, performance requirements of the ClosureTurf® HDPE grass blades may permit evaluation of longevity beyond the half-life, thereby extending the expected duration of field performance with a longer service life.

CLOSING

Geosyntec appreciates the opportunity to assist Watershed in the development of its ClosureTurf® products. Questions and comments may be directed to either of the undersigned at 678-202-9500.

Sincerely,

Will Tanner

Will Tanner, P.E.
Principal Engineer (GA, NC, SC, AL, FL)

Chris Abdeen

Chris Abdeen, E.I.T.
Senior Staff Engineer

Attachments: References
Tables
Figures

Copies to: Bryan Scholl (Watershed)
Mike Ayers (Watershed)

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TABLES

Table 1. HDPE Grass Blade Upper Bound Half-Life Calculations- Saufley Landfill, Pensacola, FL

Month	UV Lamp On(1) (hrs/day)	Average Peak Turf Temp (2) (C)	Average Peak Turf Temp (K)	Average Peak Turf Temp (1/K)	Reaction Rate(3)	Lab Half-Life(4) (lamp hrs)	Field Equivalent(5) (days)	Field Equivalent(6) (months)	Half Life Loss per Month(7)
January	5.19	24.99	298.14	0.0034	-13.72	909876	175241	5653	0.000176899
February	5.42	25.13	298.28	0.0034	-13.71	902464	166396	5943	0.000168273
March	6.80	29.60	302.75	0.0033	-13.45	692347	101754	3282	0.000304656
April	7.09	38.19	311.34	0.0032	-12.96	425411	60016	2001	0.000499866
May	8.83	46.69	319.84	0.0031	-12.50	269585	30519	984	0.001015757
June	7.43	51.58	324.73	0.0031	-12.25	209627	28210	940	0.001063454
July	6.41	54.56	327.71	0.0031	-12.10	180417	28147	908	0.001101362
August	6.15	53.40	326.55	0.0031	-12.16	191246	31118	1037	0.000964064
September	7.15	52.63	325.78	0.0031	-12.20	198737	27785	896	0.001115708
October	7.14	42.52	315.67	0.0032	-12.73	336152	47112	1520	0.000658012
November	6.75	31.70	304.85	0.0033	-13.33	613209	90913	3030	0.000329987
December	5.06	26.43	299.58	0.0033	-13.63	834692	164850	5318	0.000188049
Lab	20							**Yearly Half-life Loss(8)**	0.007586087
								Half-life(9) (years)	131.82

Notes:

(1) UV lamp on (hours per day) is determined as the ratio of UV irradiance determined in accordance with Richgels (2016) to the lamp irradiance used in the laboratory study conducted by GRI (3.05 MJ/m^2/day).
(2) Monthly average ambient temps for Pensacola, FL from NREL database multiplied by a factor of 2 to estimate monthly average peak turf temp (Richgels, 2016).
(3) Reaction rate is calculated from the regression curve shown in Figure 7 for the upper bound (logarithmic) case.
(4) Lab half-life in hours is equal to 1/e^(Reaction Rate).
(5) Field equivalent (days) is calculated by dividing the lab half-life in hours by the UV lamp on hours per day.
(6) Field equivalent in days is converted to months using the given days in that particular month.
(7) Half-life loss per month is the inverse of the corresponding field equivalent in months.
(8) The yearly half-life loss is the sum of each individual months half-life loss.
(9) The half-life in years is the inverse of the yearly half-life loss.

Table 2. HDPE Grass Blade Lower Bound Half-Life Calculations- Saufley Landfill, Pensacola, FL

Month	UV Lamp On(1) (hours/day)	Months @ 80 C(2)	Months @ 70 C(2)	Months @ 60 C(2)	Average Peak Turf Temp(3) (C.)	Half-life Months (from Regression)	Half-life Loss per month
January	5.19	316	644	787	24.99	1700	0.000588355
February	5.42	334	682	834	25.13	1794	0.000557343
March	6.80	241	491	601	29.60	1208	0.000828074
April	7.09	239	487	596	38.19	1037	0.000963898
May	8.83	185	378	463	46.69	682	0.001465817
June	7.43	228	465	568	51.58	750	0.001333715
July	6.41	256	521	638	54.56	782	0.001279345
August	6.15	267	544	665	53.40	839	0.001192233
September	7.15	237	483	590	52.63	759	0.001316773
October	7.14	230	468	573	42.52	920	0.001086971
November	6.75	251	512	626	31.70	1219	0.000820551
December	5.06	324	660	807	26.43	1706	0.000586084
Lab	20					**Yearly Half-life Loss**	0.01106492
						Half-life (years)	83.20

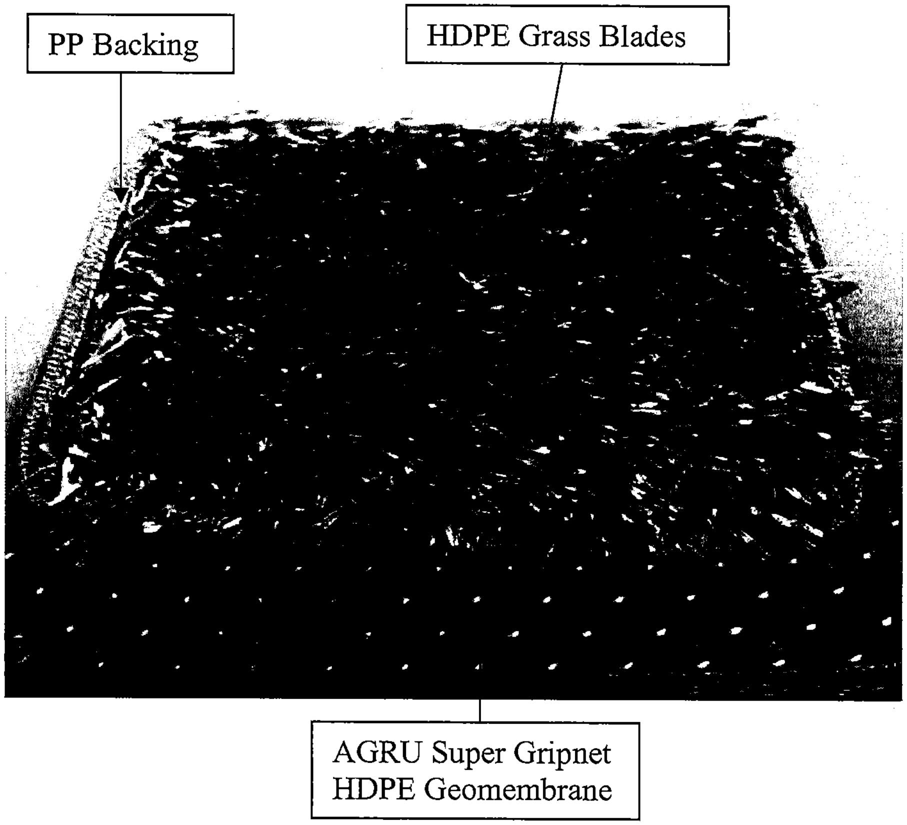
Notes:

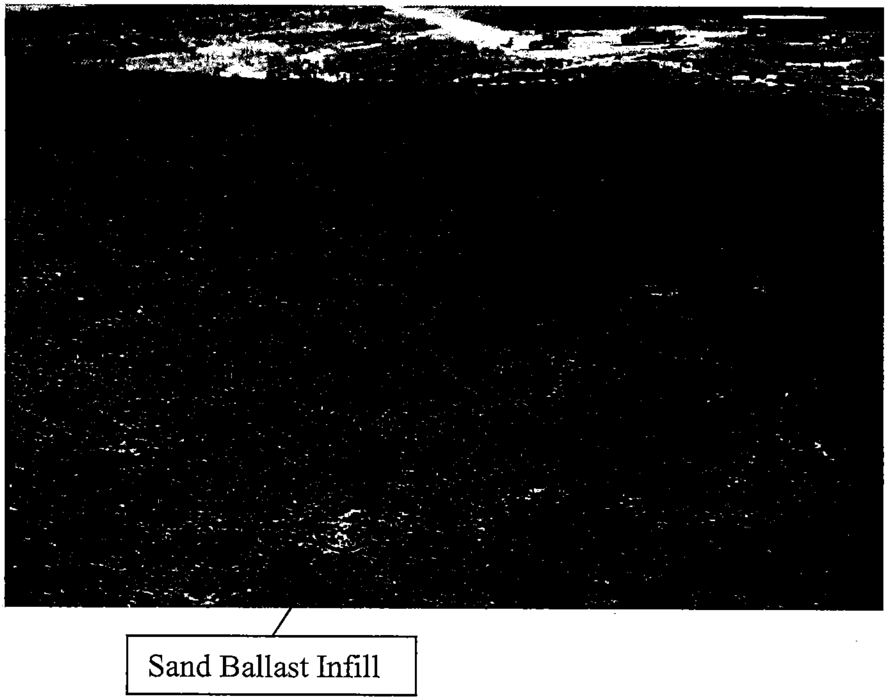
(1) UV lamp on (hours per day) is determined as the ratio of UV irradiance determined in accordance with Richgels (2016) to the lamp irradiance used in the laboratory study conducted by GRI (3.05 MJ/m^2/day).

(2) The months required at each temperature is calculated using the regressions from Figure 8 for each temperature, projected down to half-life, then dividing the lamp-hours at half-life by the UV lamp on hours per day for a given month. Once this calculation is done for 80, 70 and 60 C, a linear regression (as shown in Figure 8) is used to obtain the half-life months at the corresponding average peak turf temp.

(3) Monthly average ambient temps for Pensacola, FL from NREL database multiplied by a factor of 2 to estimate monthly average peak turf temp (Richgels, 2016).

FIGURES





Note: The sand ballast infill is not shown in the sample photo on the left, but is shown in a field application photo on the right.

ClosureTurf®Components

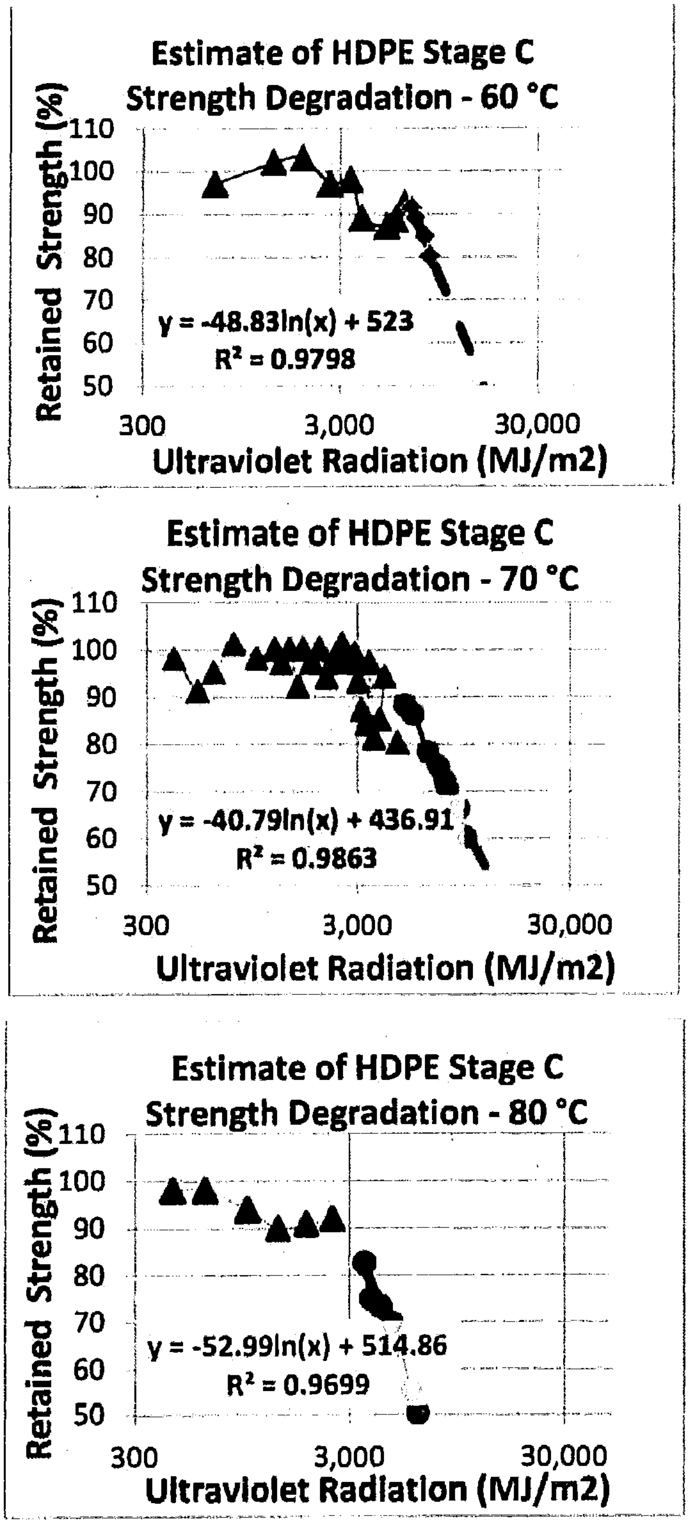
Watershed Geosynthetics – ClosureTurf® UV Assessment

Geosyntec
consultants

Kennesaw, GA

August 2022

Figure
1

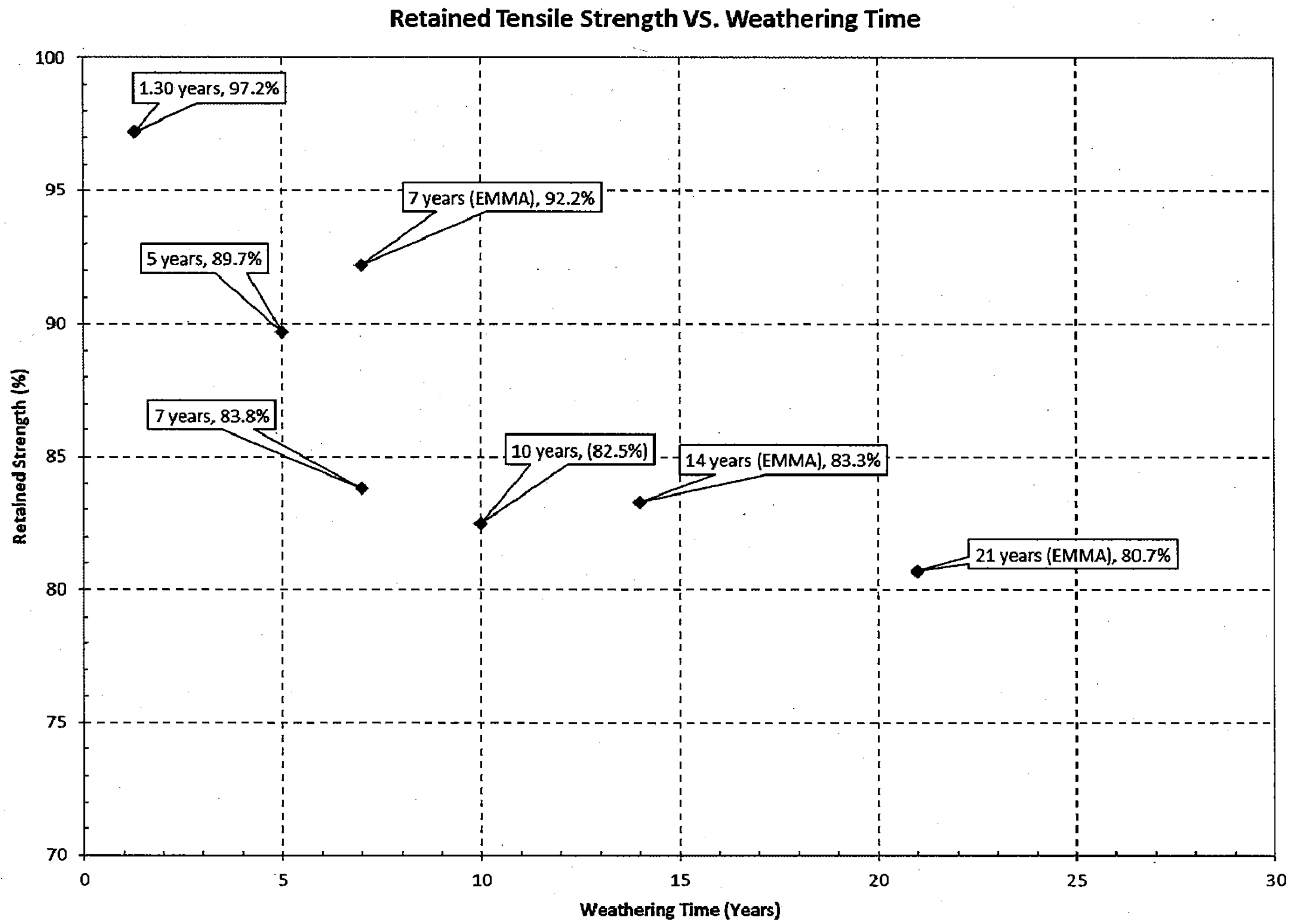


GRI Data Release - Three Stage Oxidation of HDPE for Different Temperatures
Watershed Geosynthetics – ClosureTurf® UV Assessment

Geosyntec
consultants

Figure
2

Kennesaw, GA | August 2022



Notes:

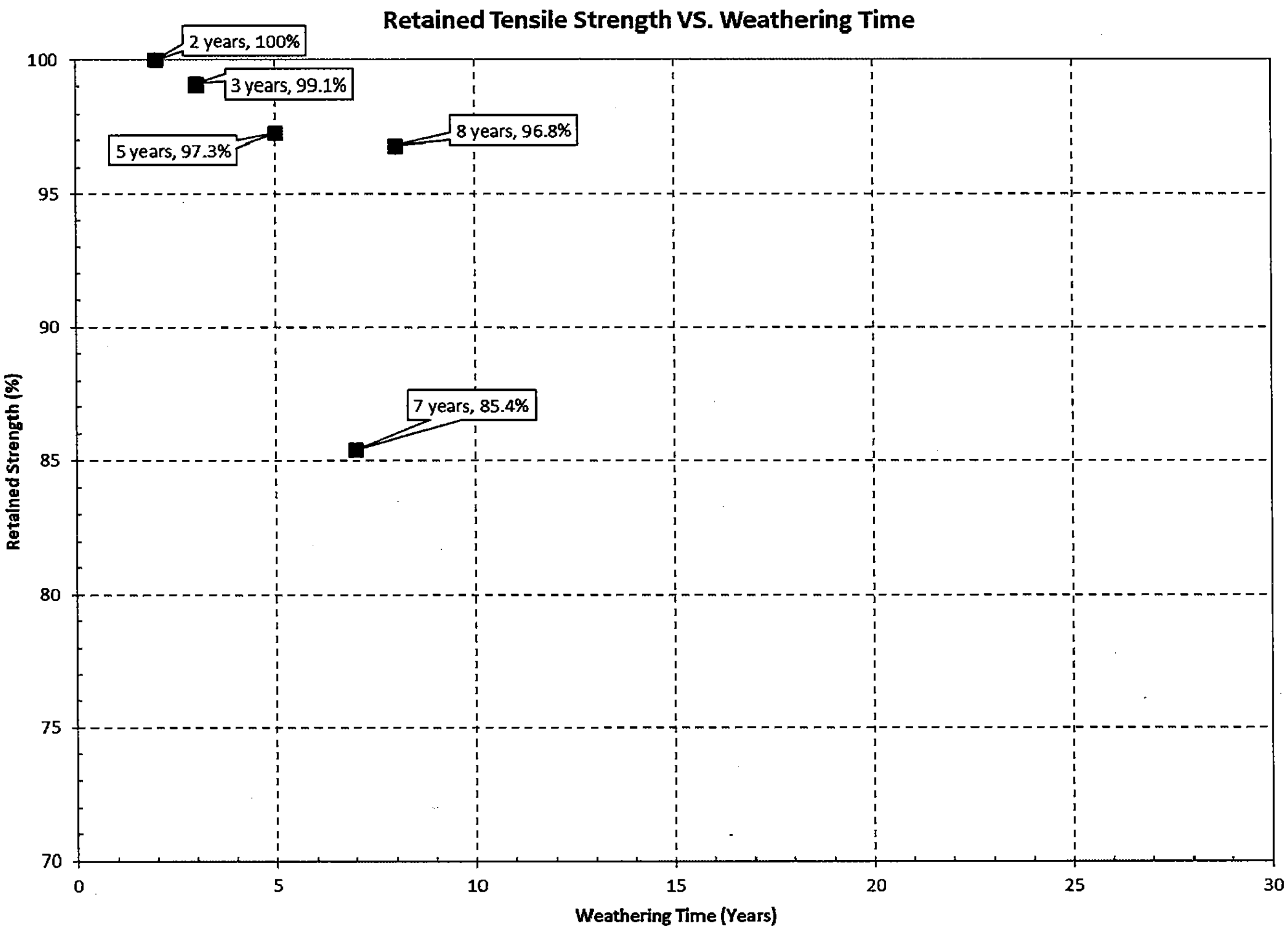
1. The first data point at Weathering Time of 1.3 years is considered to be within the initial stage of UV degradation (i.e., anti-oxidant depletion), rather than polymer oxidation which is represented by the final six data points.
2. Each data point represents the average result of 10 tensile strength tests.
3. The accelerated weathering testing is conducted using the Equatorial Mount with Mirrors for Acceleration (EMMA) solar concentration device, which provides approximately seven years of UV radiation exposure in one calendar year.

Field Test Data (Watershed 2014, 2022)
New River, AZ Atlas Testing Facility
Watershed Geosynthetics – ClosureTurf® UV Assessment

Geosyntec
consultants

Figure
3

Kennesaw, GA
November 2022



Notes:

1. Each data point represents the average result of 10 tensile strength tests.

Field Test Data (Watershed, 2022)
Southeastern United States Locations
Watershed Geosynthetics – ClosureTurf® UV Assessment

Geosyntec
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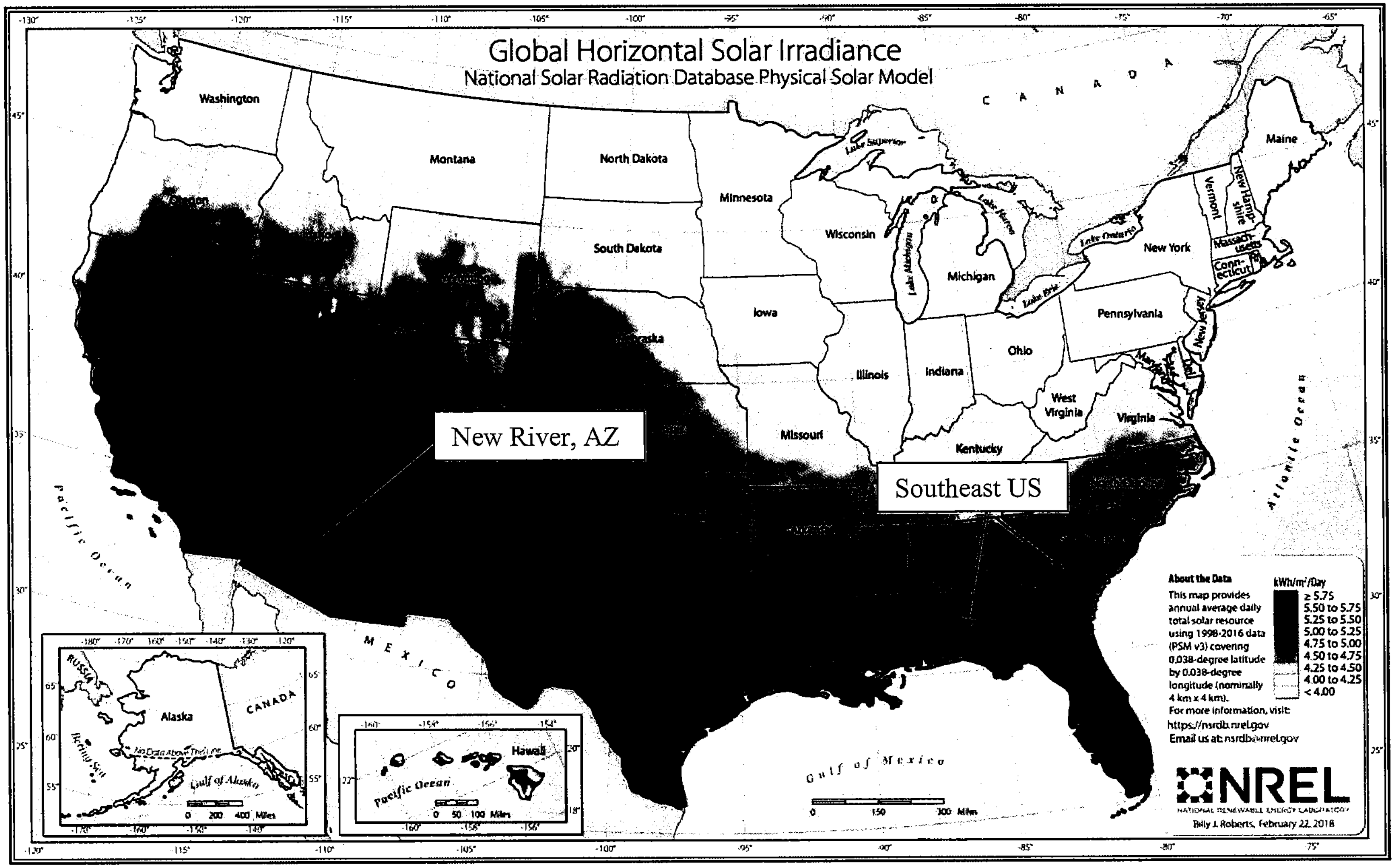
Kennesaw, GA
November 2022

Figure
4



About the Data

This map provides annual average daily total solar resource using 1998-2016 data (PSM v3) covering 0.038-degree latitude by 0.038-degree longitude (nominally 4 km x 4 km).

For more information, visit: https://nsrdb.nrel.gov

Email us at: nsrdb@nrel.gov

Image available at: https://www.nrel.gov/gis/solar-resource-maps.html

Horizontal Solar Irradiance

Watershed Geosynthetics – ClosureTurf® UV Assessment

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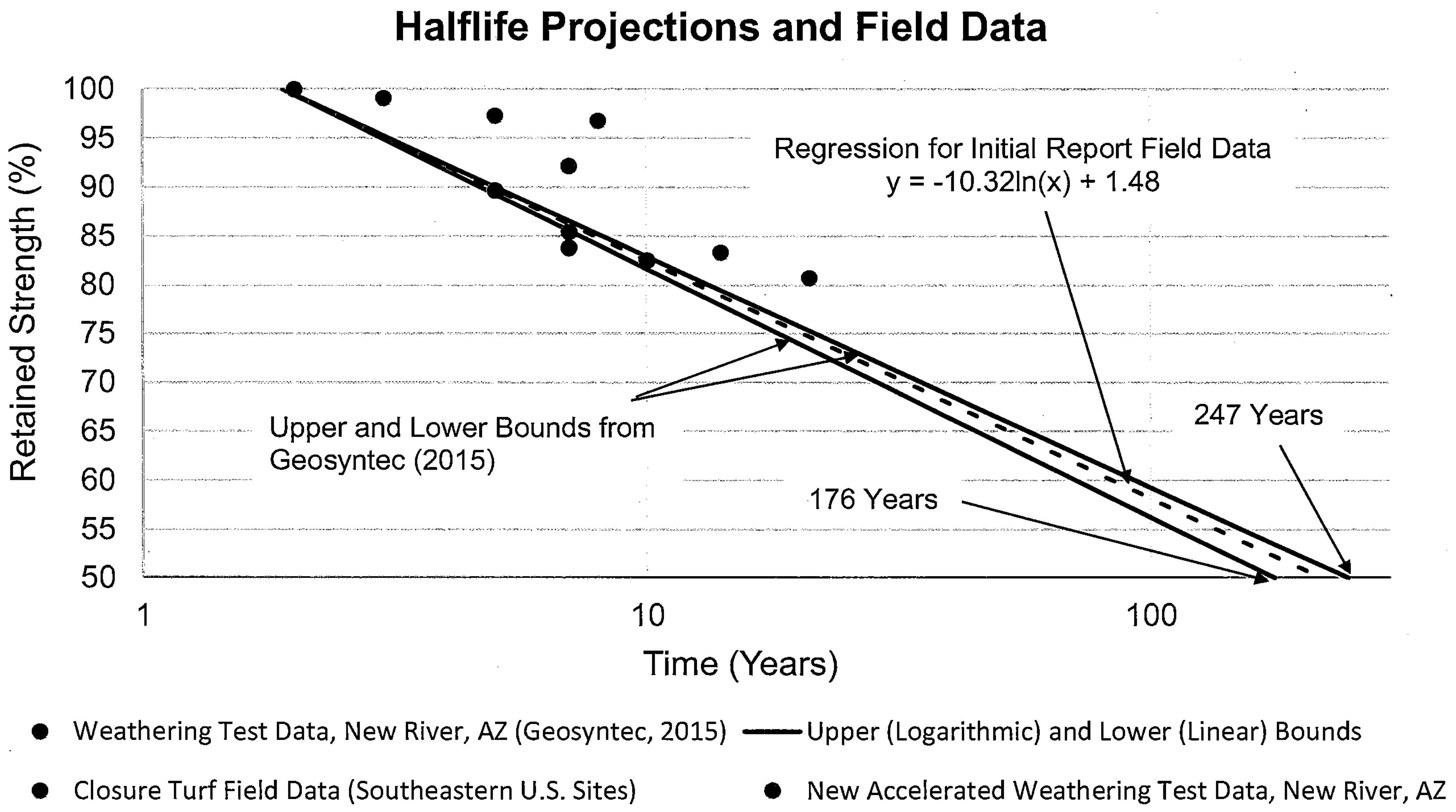
Kennesaw, GA

November 2022

Figure
5



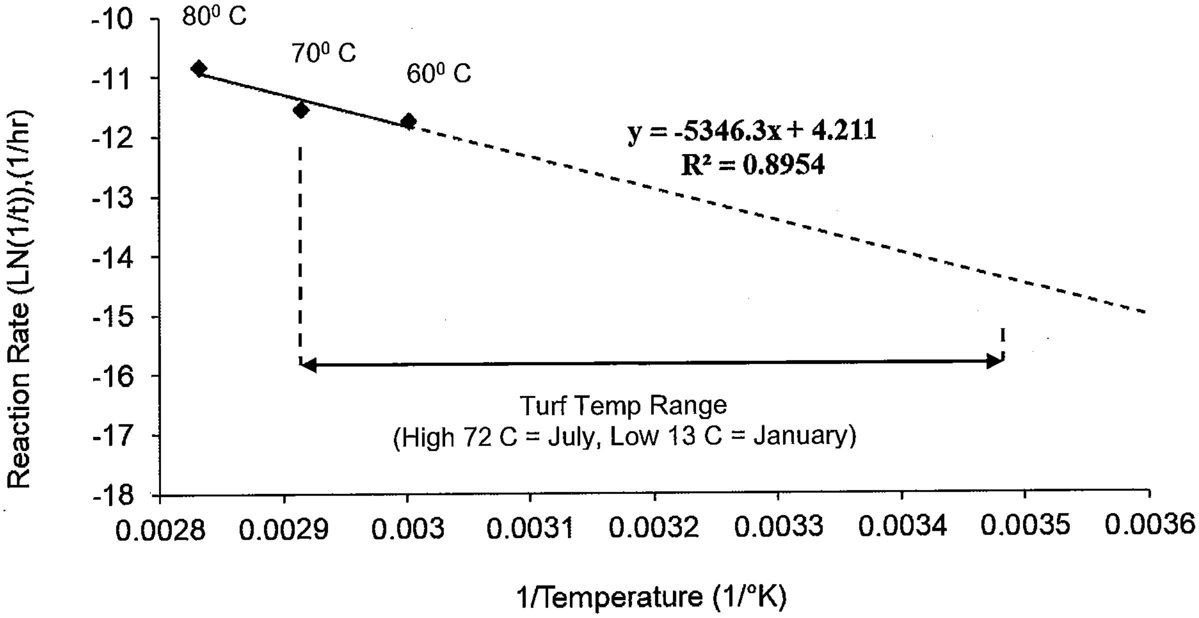
Geosyntec (2015) Halflife Projections
Vs. New Field and Accelerated Weathering Data
Watershed Geosvthetics – ClosureTurf® UV Assessment

Geosyntec
consultants

Figure
6

Kennesaw, GA
November 2022

Arrhenius Plot of Updated GRI Lab Data



Arrhenius Plot of Lab Data

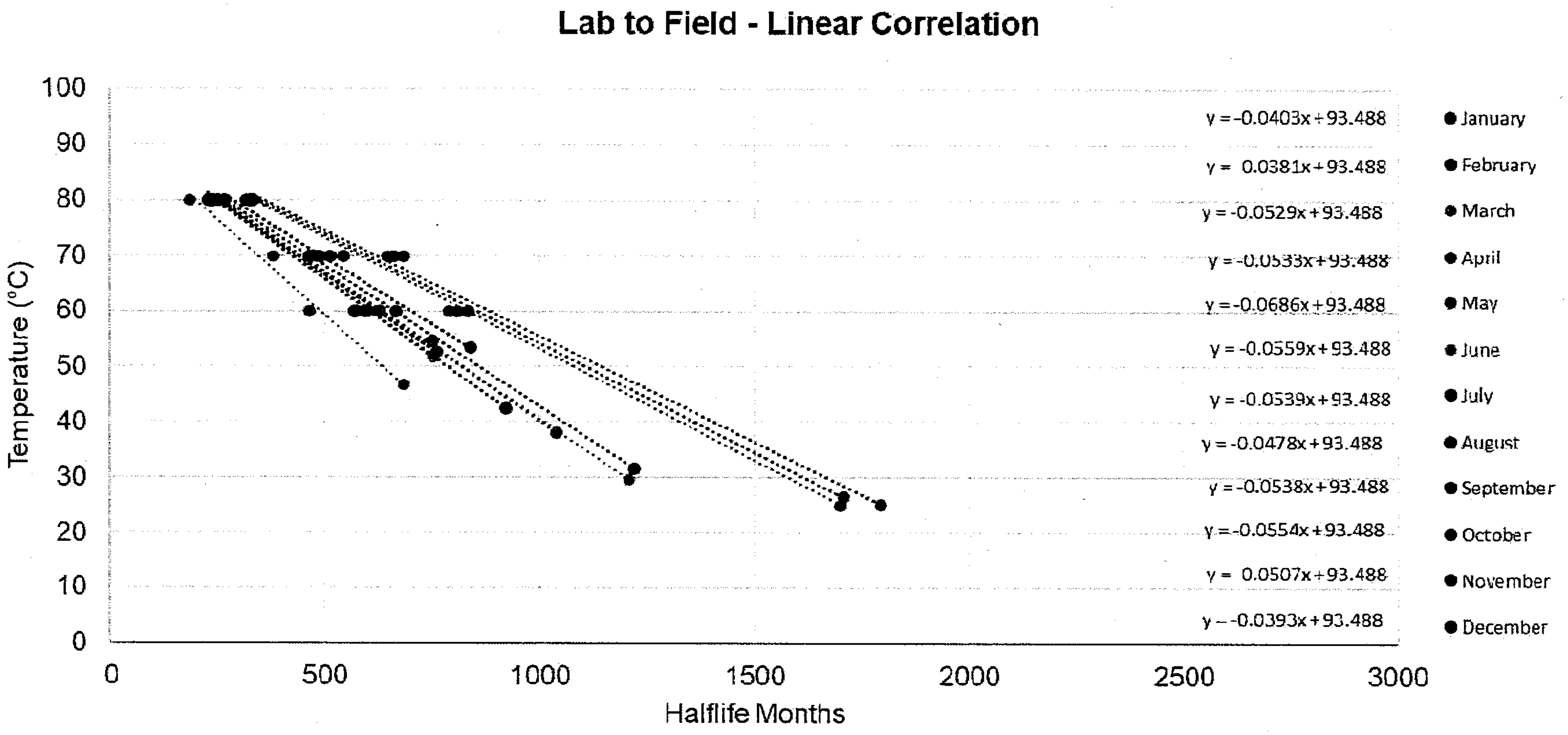
Watershed Geosynthetics – ClosureTurf® UV Assessment

Geosyntec consultants

Figure 7

Kennesaw, GA

November 2022



Notes:

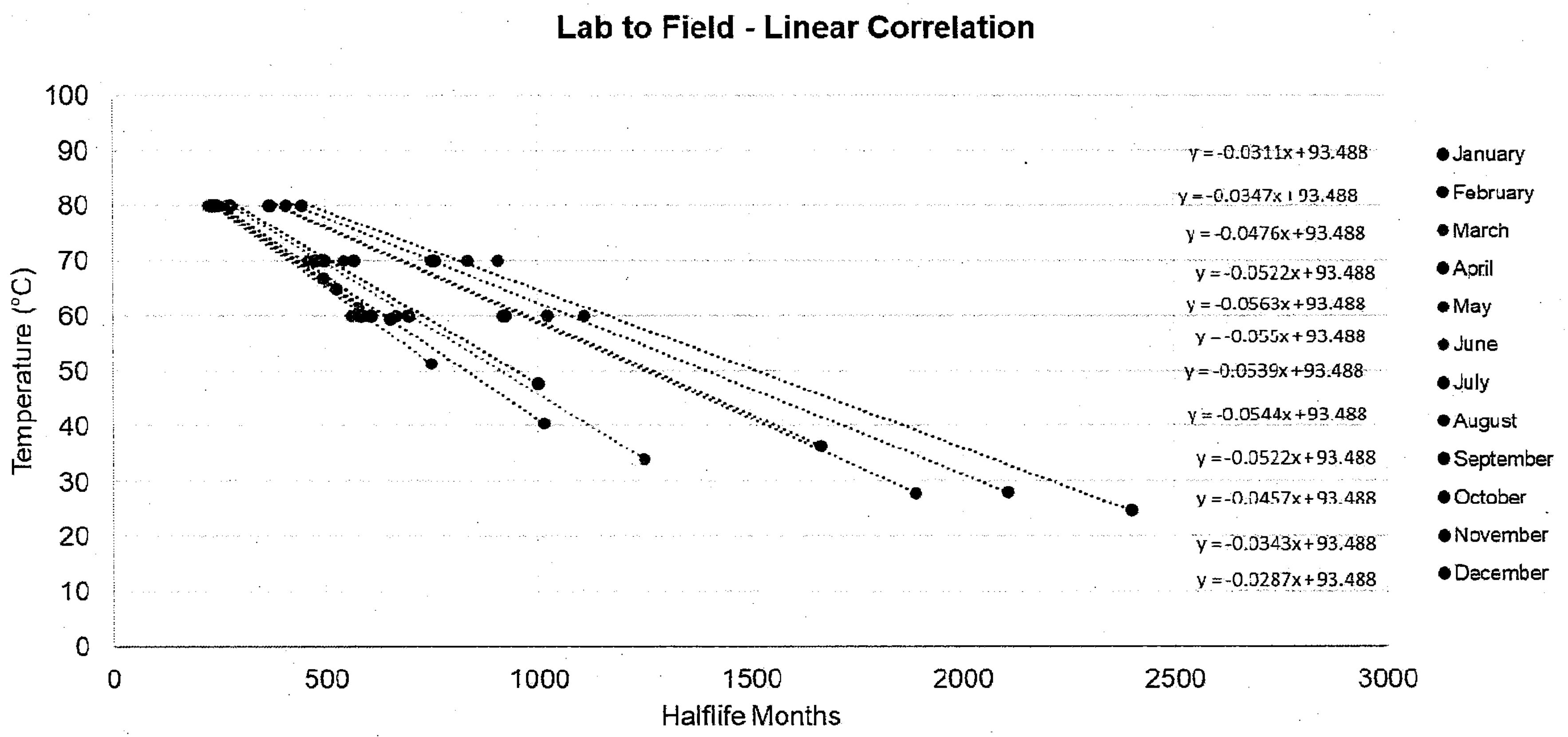
1. Each month was projected down to the turf temperature to get the half-life months. The inverse of half-life months is half-life loss per month. The sum of all the half-life losses for each month in a year is the yearly half-life loss, the inverse of which is the half-life. An example calculation for the Saufley Landfill site is provided in Table 2.
2. Trendline equations are listed in order chronologically from January to December.

Linear Extrapolations for Half-life Months –
Saufley Field Landfill, Pensacola, FL
Watershed Geosynthetics – ClosureTurf® UV Assessment

Geosyntec
consultants

Figure
8

Kennesaw, GA | November 2022



Notes:

1. Each month was projected down to the turf temperature to get the half-life months. The inverse of half-life months is half-life loss per month. The sum of all the half-life losses for each month in a year is the yearly half-life loss, the inverse of which is the half-life. An example calculation for the Saufley Landfill site is provided in Table 2.
2. Trendline equations are listed in order chronologically from January to December.

Linear Extrapolations for Half-life Months – New River, Arizona

Watershed Geosynthetics – ClosureTurf® UV Assessment

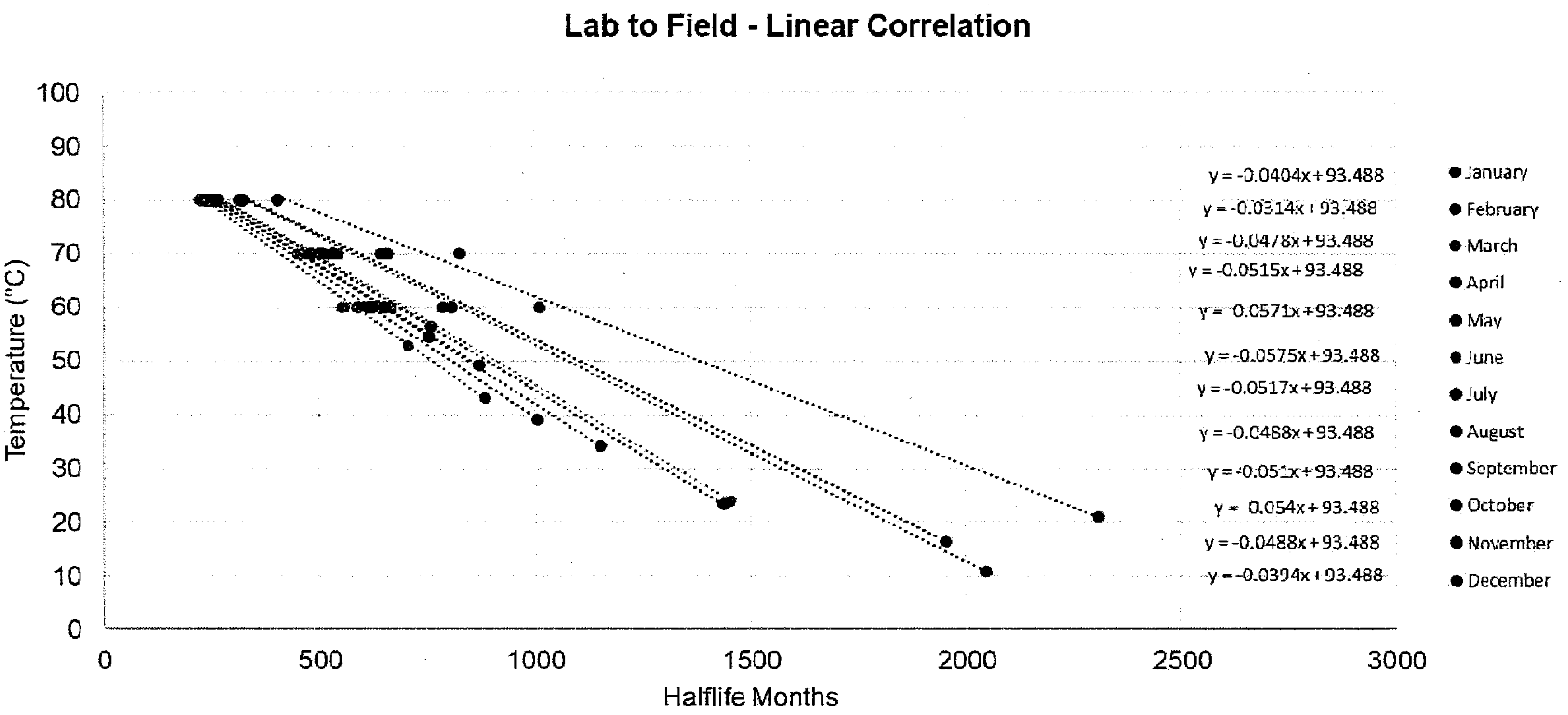
Geosyntec consultants

Kennesaw, GA

November 2022

Figure

9



Notes:

1. Each month was projected down to the turf temperature to get the half-life months. The inverse of half-life months is half-life loss per month. The sum of all the half-life losses for each month in a year is the yearly half-life loss, the inverse of which is the half-life. An example calculation for the Saufley Landfill site is provided in Table 2.
2. Trendline equations are listed in order chronologically from January to December.

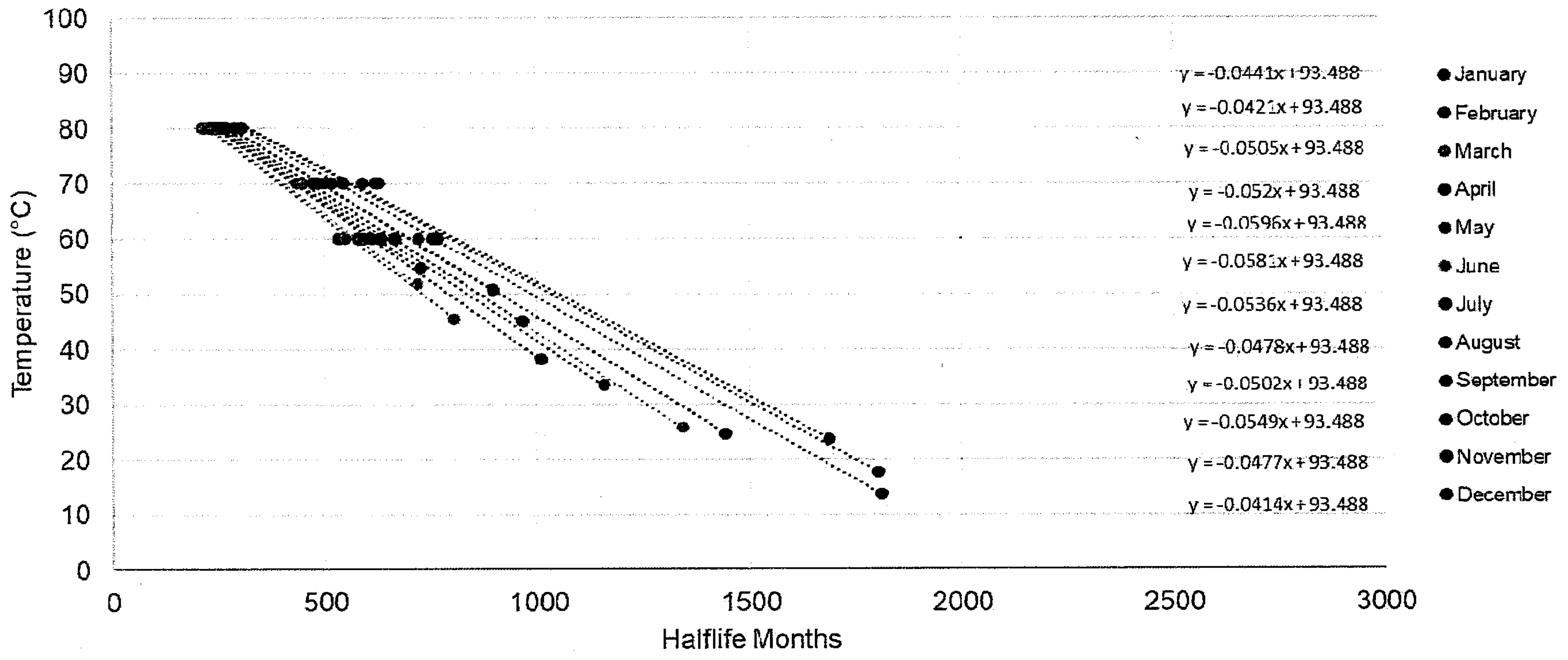
Linear Extrapolations for Half-life Months –
Lasalle-Grant Landfill, Jena, LA
Watershed Geosynthetics – ClosureTurf® UV Assessment

Geosyntec
consultants

Kennesaw, GA
November 2022

Figure
10

Lab to Field - Linear Correlation



Notes:

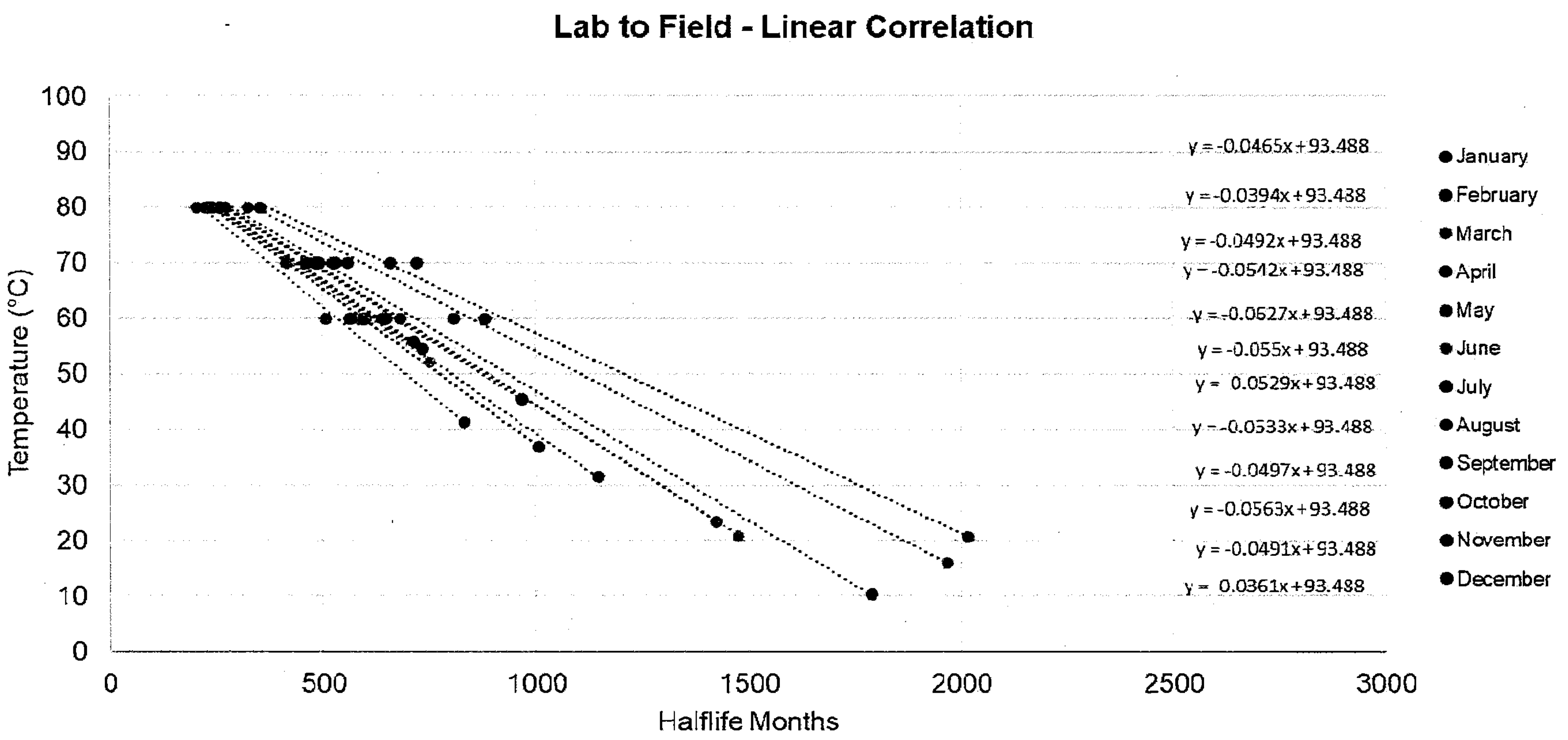
1. Each month was projected down to the turf temperature to get the half-life months. The inverse of half-life months is half-life loss per month. The sum of all the half-life losses for each month in a year is the yearly half-life loss, the inverse of which is the half-life. An example calculation for the Saufley Landfill site is provided in Table 2.
2. Trendline equations are listed in order chronologically from January to December.

Linear Extrapolations for Half-life Months –
Berkley Co., SC
Watershed Geosythetics – ClosureTurf® UV Assessment

Geosyntec
consultants

Kennesaw, GA
November 2022

Figure
11



Notes:

1. Each month was projected down to the turf temperature to get the half-life months. The inverse of half-life months is half-life loss per month. The sum of all the half-life losses for each month in a year is the yearly half-life loss, the inverse of which is the half-life. An example calculation for the Saufley Landfill site is provided in Table 2.
2. Trendline equations are listed in order chronologically from January to December.

Linear Extrapolations for Half-life Months –
Baldwin Co., GA
Watershed Geosynthetics – ClosureTurf® UV Assessment

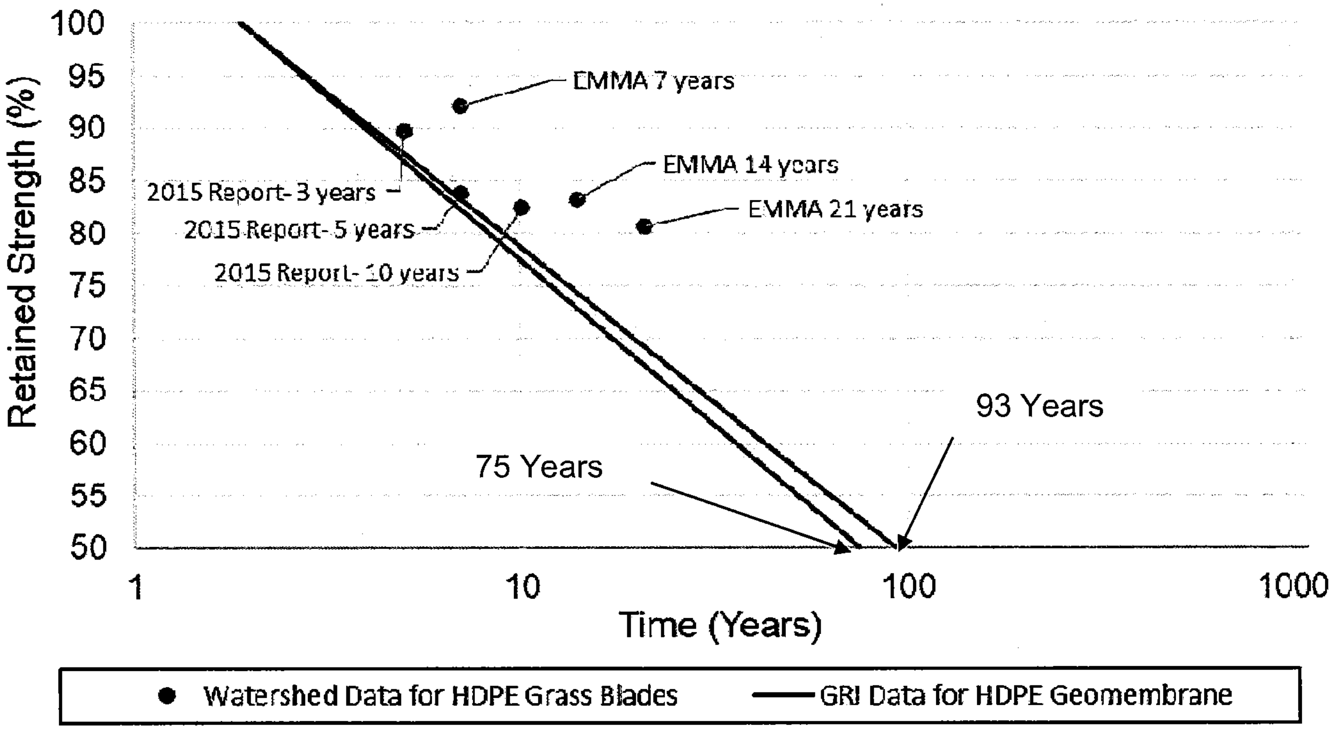
Geosyntec consultants

Kennesaw, GA

November 2022

Figure
12

Halflife Projections and Field Data- New River, AZ



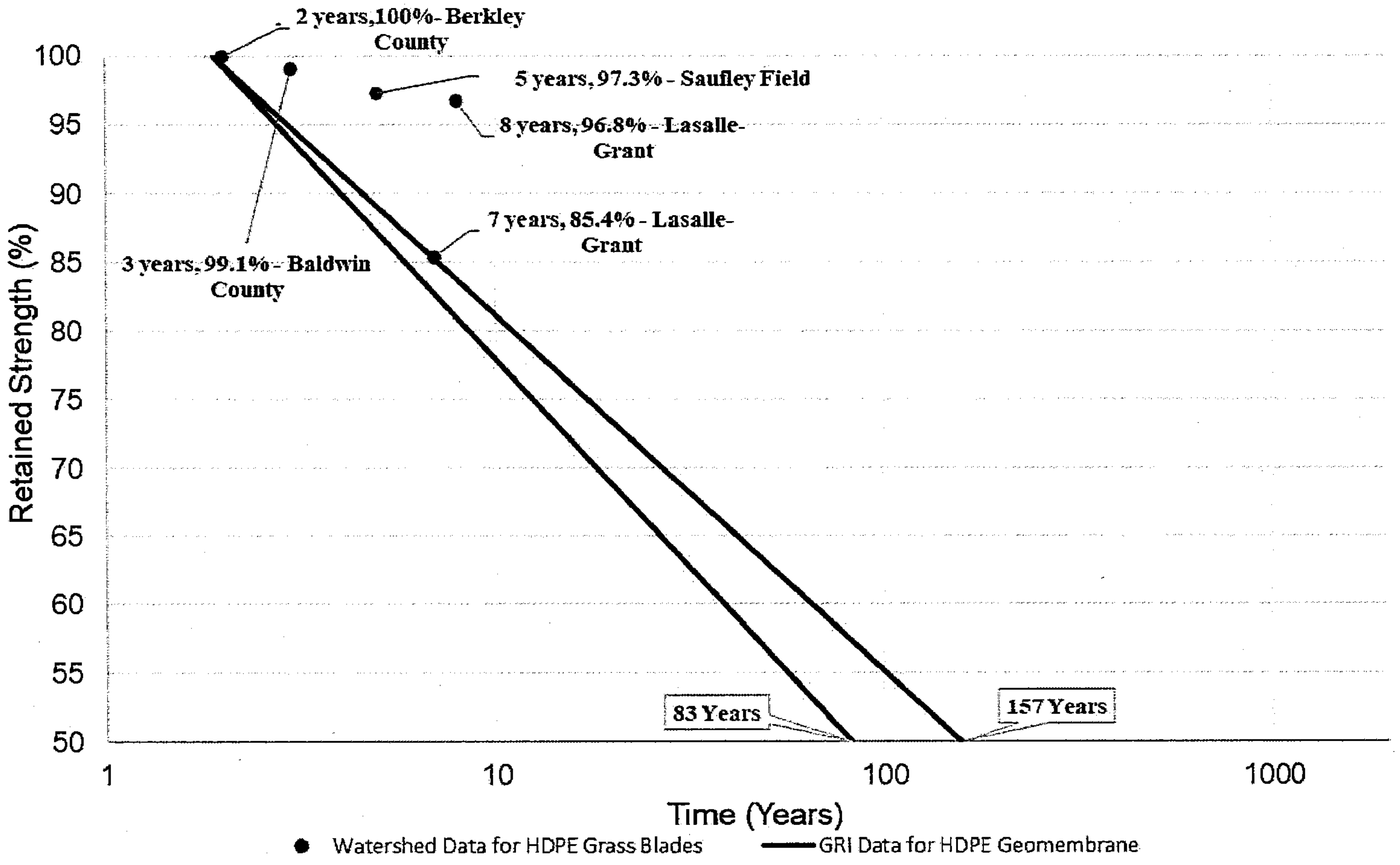
Halflife Projections
Upper and Lower Bound Estimates- New River, AZ
Watershed Geosythetics – ClosureTurf® UV Assessment

Geosyntec consultants

Figure **13**

Kennesaw, GA
November 2022

Half-Life Projections and Field Data- Southeastern United States



Note: The upper and lower bound half-life estimates represent the limits of the estimates for the sites in the Southeastern United States.

Halflife Projections
Upper and Lower Bound Estimates- SE United States
Watershed Geosynthetics – ClosureTurf® UV Assessment

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November 2022

Figure
14

ATTACHMENT E – GSI WHITE PAPER #28

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GSI White Paper #28

"Cold Temperature and Free-Thaw Cycling Behavior of Geomembranes and Their Seams"

by

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Denver, Colorado

June 17, 2013

“Cold Temperature and Free-Thaw Cycling Behavior of Geomembranes and Their Seams”

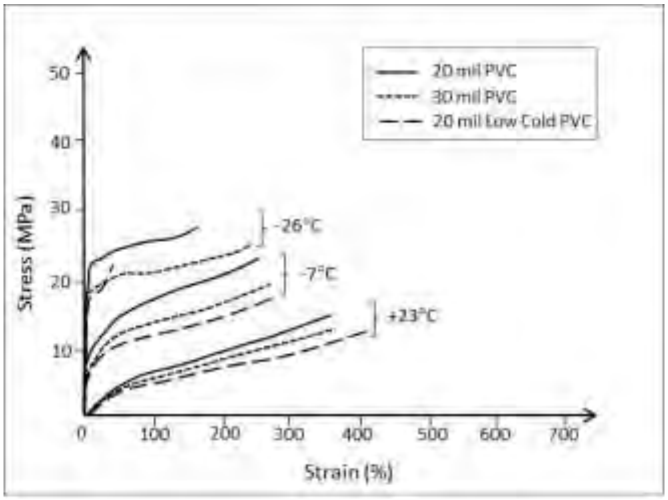
Introduction

It is common knowledge that materials in general, and polymeric materials in particular, will somewhat soften and increase in flexibility under high temperatures and will conversely somewhat harden and decrease in flexibility under cold temperatures. While there are indeed circumstances where high ambient temperatures are important, this white paper focuses entirely on cold ambient temperatures. Even further, it addresses cold temperature behavior of the various geomembranes by themselves and, most importantly, the freeze-thaw cycling behavior of a large number of geomembrane sheets and their seams.

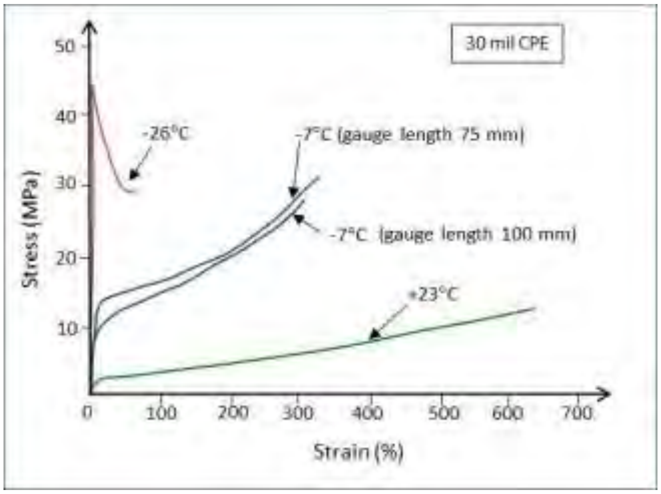
The stimulus for writing the white paper is the myriad questions that regularly come to GSI as to the potential negative effects on the tensile strength of geomembranes and their seams under cold temperature and cyclic freeze-thaw field conditions. As will be seen, the primary source for the information to be presented herein is a joint U.S. EPA/U.S. BuRec study conducted by Alice Comer and Grace Hsuan in 1996. Other companion technical information will also be presented.

Cold Temperature Behavior of Geomembranes

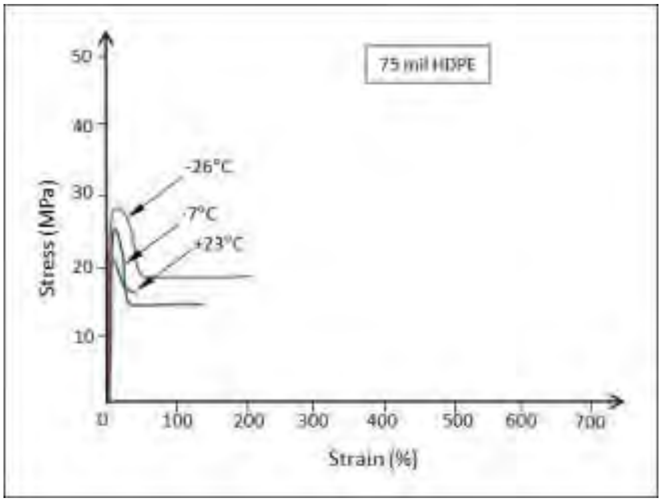
A report by Thornton and Blackall (1976) appears to be the first in describing Canadian experiences with geomembranes in cold regions. Subsequently, Rollin, et al. (1984) conducted a laboratory study on 21 types of geomembranes at temperatures down to - 35°C. They found increasing tensile strength with decreasing temperature. Richards, et al. (1985) did similar studies which also resulted in an increase in strength and a decrease in elongation with decreasing temperatures. They evaluated PVC, CPE and HDPE geomembranes and presented the stress-versus-strain curves at +23°C, -7°C and -26°C temperatures; see Figures 1a, 1b, and



(a) Tensile test results for PVC geomembranes



(b) Tensile test results for CPE geomembranes



(c) Tensile test results for HDPE geomembranes

Figure 1 – Stress-versus-strain behavior of three geomembrane types under progressively colder testing environments, Richards, et al. (1985)

1c. Here one can readily observe how the sets of curves transition from relatively ductile behavior at +23°C, to relatively brittle behavior at -26°C, with the intermediate behavior at -7°C. There are a few outliers, but the trends are undeniable. This general behavior was confirmed by Peggs, et al. (1990) and Giroud, et al. (1993), the latter working with both smooth and textured HDPE geomembranes.

While this type of thermal behavior is of interest, such information for a specific type of geomembrane must be obtained by performing or commissioning individual tests so as to obtain actual design information. Such individual testing is required due to the uniqueness of each polymer type and its specific formulation. Additives such as plasticizers, fillers, antioxidants, carbon black, colorants, etc., can influence the results to varying degrees. Even the resins themselves have behavioral differences at different temperatures. For example, the glass transition temperature of propylene is -7°C, below which the polymer is glassy and above which it is characterized as rubbery. In such a case the tensile properties are greatly influenced, as well as the material's creep and stress relaxation behavior.

There are other aspects of cold temperatures on geomembranes that go beyond the scope of this white paper. In particular are cases of impact shuttering failures in cold climates and installation concerns such as frozen subgrade, bridging, snow and ice removal and worker discomfort, Burns, et al. (1990).

Freeze-Thaw Cycling of Geomembrane Sheets and Seams

Budiman (1994) reported on both cold temperature behavior but also appears to be the first to include freeze-thaw cycling for up to 150 repetitions. He focused entirely on HDPE sheet (of different thicknesses) but not on seams. There was no degradation observed during his tests but he suggested that more cycles would be appropriate. At approximately the same time a much larger freeze-thaw study was ongoing. The final report by Comer and Hsuan was released by the U.S. Bureau of Reclamation in 1996. Related papers leading up to this final report are Hsuan, et al. (1993), Comer, et al. (1995), and Hsuan, et al. (1997). Their combined study involved 19 different geomembrane sheet materials and 31 different seam types. Furthermore, seven different resin types were evaluated. The resin types were the following:

- polyvinyl chloride (PVC)
- linear low density polyethylene (LLDPE)
- high density polyethylene (HDPE)
- flexible polypropylene (fPP)
- chlorosulfonated polyethylene (CSPE)
- fully crosslinked elastomeric alloy (FCEA)

All except FCEA are currently available, however, changes in additives and formulations have occurred and will likely to do so in the future. The entire study was conducted in four discrete parts although the fourth part was focused on induced tensile stress and stress relaxation and is not the specific purpose of this white paper. See Table 1 for the relevant three parts of their study.

Table 1 – Experimental Design of Different Parts of Comer and Hsuan (1996) Study

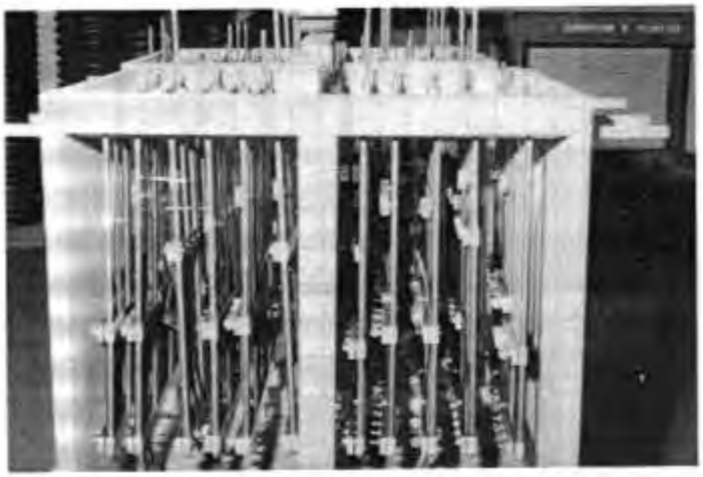
Part	Cyclic Temperature Range	Maximum Cycles	Incubation Condition	Tensile Test Temperature
I	+20°C to -20°C	200	relaxed	+20°C
II	+20°C to -20°C	200	relaxed	-20°C
III	+30°C to -20°C	500	constrained	+20°C

Part I consisted of 19 sheet materials and 27 seams. They underwent freeze-thaw cycles at +20°C for 8 hours and then -20°C for 16 hours. Tensile tests were then conducted at +20°C after 1, 5, 10, 20 50, 100 and 200 cycles.

Part II consisted of 6 sheet materials and 13 seams. They also underwent freeze-thaw cycling at +20°C for 8 hours and then -20°C for 16 hours. Different in this regard was that tensile tests were then conducted at -20°C after 1, 5, 10, 20, 50, 100 and 200 cycles. The -20°C tests were conducted in an environmental chamber (both specimens and their grips) cooled by liquid nitrogen and set at -20°C temperature.

Part III consisted of the same set of 19 sheet materials and 27 seams as in Part I but were now tensioned at a constant strain during the freeze-thaw cycling. The rack used for the tensioning is shown in Figure 2a and the assembly within the environmental chamber is shown in Figure 2b. After the targeted number of freeze-thaw cycles at +20°C for 8 hours and -20°C for 16 hours, specimens were removed and tested at +20°C after 1, 10, 50, 100, 200 and 500 cycles.

(a) Method of applying tensile load to test specimens in Part III tests



(b) Geomembrane racks in holding frame used in Part III series

Figure 2 – Method used for tensioning samples during incubation; Comer and Hsuan (1996)

Rather than showing the graphic results of the above freeze-thaw cycling study (it is available in full in the Comer and Hsuan report by the Bureau of Reclamation and the related papers by these authors) only the concluding comments will be reproduced here. They follow verbatim from the report.

Part I – Results on 200 Freeze-Thaw Cycles Tested at +20°C

- Tensile tests on geomembrane sheets: “The results show no change in either the peak strength or peak elongation of any of the tested materials”.
- Shear tests on the geomembrane seams: “The results show no change in shear strength of any of the tested seam materials”.
- Peel tests on the geomembrane seams: “The results show no change in peel strength of any of the tested seam materials.

Part II – Results on 200 Freeze-Thaw Cycles Tested at -20°C

- Tensile tests on geomembrane sheets: "The results show no change in either the peak strength or peak elongation of any of the tested materials".
- Shear tests on the geomembrane seams: "The results show no change in shear strength of any of the tested seam materials".
- Peel tests on the geomembrane seams: "The results show no change in peel strength of any of the tested seam materials.

Part III – Results on 500 Freeze-Thaw Cycles Tested at +20°C in a Constrained Condition

- Tensile tests on geomembrane sheets: "The results show no change in either the peak strength or peak elongation of any of the tested materials".
- Shear tests on the geomembrane seams: "The results show no change in shear strength of any of the tested seam materials".
- Peel tests on the geomembrane seams: "The results show no change in peel strength of any of the tested seam materials.

Conclusion and Recommendations

This two-part white paper focused initially on the cold temperature tensile behavior of the stress- versus-strain curves of several different types of geomembranes. As expected, the colder the temperature the more brittle, hence less ductile, were the response curves. Geomembranes made from PVC, CPE and HDPE were illustrated in this regard. The recommendation reached for this part of the white paper is that if a formulation-specific geomembrane under site-specific conditions is to be evaluated for its stress-versus-strain response, actual tests must be commissioned accordingly. The literature can only give general trends in this regard.

The second (and more important) part of this white paper focused entirely on freeze-thaw behavior of geomembranes and their different seam types. The U.S. Bureau of Reclamation report is extremely revealing in this regard. *The conclusion that the authors reached is that there is simply "no change" in tensile behavior of geomembrane sheets or their seams after freeze-thaw cycling.* It is felt that this conclusion in the context of their study is so impressive that it has essentially "closed the door" to further research on this specific topic. The essential question often raised in this regard, i.e., "will freeze-thaw conditions affect geomembrane sheets or their seam behavior," is answered with a resounding "NO".

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ATTACHMENT F – STORMWATER CALCULATIONS

BURNS McDONNELL

August 18, 2023

DTE Electric Company
Monroe Fly Ash Bain Closure
Operating License

To support closure of the DTE Monroe Power Plant Ash Basin, herein noted as the Fly Ash Basin (FAB), Burns & McDonnell prepared stormwater calculations for the proposed stormwater management system. The stormwater management system was modeled using HydroCAD software to determine peak flows for the design storm, which is a 25-year, 24-hour rainfall event. HydroCAD is a computer-aided design (CAD) program used for modeling the hydrology and hydraulics of stormwater runoff.

The HydroCAD model was prepared using the SCS TR-20 curve number method. The FAB area was divided into subcatchment areas with the downstream portion of the internal ditches modeled as detention basins such that the potential backup and temporary storage within the ditches could be evaluated for varying storm events. From the internal ditches, runoff drains offsite via storm drains. This document provides a summary of the model inputs and includes the following attachments:

- NOAA Point Precipitation Frequency Estimate
- Figure 1 – Option 3 Grading Plan Subcatchment Delineation
- HydroCAD Results for Option 3: 25-year, 24-hour storm event

Subcatchment Delineation

For each option, the FAB footprint was delineated into different watershed or "subcatchment" areas based on the contributing area draining to each individual discharge point around the perimeter of the basin. Figure 1, attached to this document, indicates the delineations for the subcatchments.

Rainfall

The rainfall depth for the design storm event was obtained using NOAA's Precipitation Frequency Data Server for the site location. The design storm depth is 3.99 inches. A copy of downloaded data is included as an attachment to this document. A Type II rainfall distribution was assumed.

Runoff

Runoff is defined as stormwater or snow melt that flows over the land and is not infiltrated into the ground. It is measured using local rainfall intensity and depths, runoff curve numbers, land use, and soil types. Because the FAB closure footprint will receive a synthetic turf system, the soil type is not relevant to the rainfall runoff calculations. Watershed Geo supplies recommended hydrology parameters for the ClosureTurf® system in their ClosureTurf® Design

Guidelines Manual (February 2023). As noted in the previous revision of the document, the curve number value range (92-95) was derived by TRI Environmental, Inc., and Colorado State University Hydraulics Laboratory in separate tests. For the calculations included in this document, a curve number of 95 was conservatively assumed in areas of sheet flow and a curve number of 96 was used in areas of ditch flow based on the assumption that ditch areas would be surfaced with crushed rock or similar material.

Time of Concentration

The time of concentration was determined following the guidelines in TR-55. In accordance with the ClosureTurf® Design Guidelines Manual, a Manning's n value of 0.22 was used for areas of sheet flow with slopes less than 10% and a value of 0.11 was used for areas greater than 10%. A value of 0.041 was used in areas of channel flow assuming the channels are lined with 2-inch rock riprap or similar material.

Results

Results from the HydroCAD model are attached to this document.

NOAA Atlas 14, Volume 8, Version 2
Location name: Monroe Twp, Michigan, USA*
Latitude: 41.884°, Longitude: -83.375°
Elevation: 612.33 ft**
* source: ESRI Maps
** source: USGS

POINT PRECIPITATION FREQUENCY ESTIMATES

Sanja Perica, Deborah Martin, Sandra Pavlovic, Ishani Roy, Michael St. Laurent, Carl Trypaluk, Dale Unruh, Michael Yekta, Geoffery Bonnin

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**0.312** (0.247-0.395)	**0.370** (0.293-0.468)	**0.465** (0.367-0.589)	**0.543** (0.427-0.689)	**0.651** (0.497-0.840)	**0.734** (0.551-0.954)	**0.817** (0.597-1.08)	**0.901** (0.637-1.21)	**1.01** (0.694-1.37)	**1.10** (0.737-1.50)
10-min	**0.457** (0.362-0.578)	**0.542** (0.429-0.685)	**0.680** (0.537-0.862)	**0.795** (0.625-1.01)	**0.953** (0.728-1.23)	**1.07** (0.806-1.40)	**1.20** (0.874-1.58)	**1.32** (0.933-1.76)	**1.48** (1.02-2.01)	**1.60** (1.08-2.20)
15-min	**0.557** (0.441-0.705)	**0.661** (0.523-0.836)	**0.829** (0.655-1.05)	**0.969** (0.762-1.23)	**1.16** (0.888-1.50)	**1.31** (0.983-1.70)	**1.46** (1.07-1.92)	**1.61** (1.14-2.15)	**1.81** (1.24-2.45)	**1.96** (1.32-2.68)
30-min	**0.765** (0.606-0.967)	**0.910** (0.720-1.15)	**1.15** (0.904-1.45)	**1.34** (1.05-1.70)	**1.61** (1.23-2.08)	**1.81** (1.36-2.36)	**2.02** (1.47-2.66)	**2.22** (1.57-2.97)	**2.50** (1.71-3.39)	**2.70** (1.82-3.71)
60-min	**0.978** (0.775-1.24)	**1.15** (0.912-1.46)	**1.45** (1.14-1.83)	**1.70** (1.33-2.15)	**2.05** (1.57-2.66)	**2.33** (1.76-3.05)	**2.62** (1.92-3.47)	**2.93** (2.08-3.93)	**3.34** (2.30-4.55)	**3.66** (2.46-5.02)
2-hr	**1.19** (0.956-1.49)	**1.40** (1.12-1.74)	**1.74** (1.39-2.18)	**2.05** (1.63-2.57)	**2.49** (1.94-3.21)	**2.85** (2.18-3.69)	**3.23** (2.40-4.23)	**3.63** (2.61-4.82)	**4.18** (2.91-5.64)	**4.62** (3.14-6.26)
3-hr	**1.32** (1.07-1.64)	**1.53** (1.24-1.90)	**1.91** (1.54-2.37)	**2.24** (1.80-2.79)	**2.74** (2.16-3.52)	**3.16** (2.43-4.07)	**3.61** (2.70-4.70)	**4.08** (2.96-5.41)	**4.76** (3.34-6.39)	**5.30** (3.62-7.14)
6-hr	**1.56** (1.27-1.90)	**1.78** (1.46-2.18)	**2.19** (1.79-2.68)	**2.57** (2.09-3.16)	**3.16** (2.53-4.01)	**3.66** (2.86-4.66)	**4.20** (3.18-5.42)	**4.79** (3.51-6.27)	**5.63** (3.99-7.49)	**6.32** (4.36-8.41)
12-hr	**1.80** (1.49-2.17)	**2.05** (1.70-2.47)	**2.50** (2.06-3.01)	**2.91** (2.40-3.53)	**3.56** (2.88-4.46)	**4.10** (3.24-5.16)	**4.69** (3.60-5.98)	**5.33** (3.95-6.90)	**6.26** (4.48-8.22)	**7.01** (4.88-9.21)
24-hr	**2.06** (1.74-2.45)	**2.35** (1.97-2.79)	**2.85** (2.39-3.40)	**3.31** (2.75-3.95)	**3.99** (3.26-4.91)	**4.56** (3.64-5.64)	**5.16** (4.00-6.48)	**5.82** (4.35-7.42)	**6.75** (4.87-8.73)	**7.49** (5.27-9.73)
2-day	**2.38** (2.03-2.79)	**2.70** (2.30-3.17)	**3.26** (2.77-3.83)	**3.75** (3.17-4.42)	**4.47** (3.69-5.40)	**5.05** (4.08-6.15)	**5.67** (4.43-7.00)	**6.32** (4.76-7.92)	**7.22** (5.26-9.20)	**7.93** (5.63-10.2)
3-day	**2.61** (2.24-3.03)	**2.94** (2.53-3.42)	**3.52** (3.01-4.10)	**4.02** (3.42-4.70)	**4.75** (3.94-5.68)	**5.34** (4.33-6.43)	**5.95** (4.68-7.28)	**6.60** (5.01-8.21)	**7.49** (5.49-9.48)	**8.20** (5.86-10.4)
4-day	**2.80** (2.42-3.24)	**3.15** (2.72-3.64)	**3.73** (3.21-4.32)	**4.24** (3.63-4.93)	**4.98** (4.16-5.93)	**5.58** (4.55-6.68)	**6.19** (4.90-7.53)	**6.84** (5.22-8.46)	**7.74** (5.70-9.74)	**8.45** (6.06-10.7)
7-day	**3.31** (2.89-3.78)	**3.68** (3.21-4.21)	**4.32** (3.76-4.94)	**4.87** (4.21-5.58)	**5.65** (4.75-6.63)	**6.27** (5.16-7.41)	**6.91** (5.52-8.30)	**7.58** (5.83-9.26)	**8.50** (6.30-10.6)	**9.21** (6.66-11.5)
10-day	**3.76** (3.31-4.26)	**4.17** (3.66-4.73)	**4.85** (4.25-5.51)	**5.43** (4.73-6.18)	**6.25** (5.29-7.27)	**6.90** (5.72-8.09)	**7.57** (6.08-9.02)	**8.26** (6.38-10.0)	**9.20** (6.85-11.4)	**9.93** (7.21-12.4)
20-day	**5.12** (4.57-5.71)	**5.60** (5.00-6.26)	**6.41** (5.70-7.17)	**7.08** (6.26-7.95)	**8.01** (6.87-9.17)	**8.74** (7.33-10.1)	**9.47** (7.70-11.1)	**10.2** (7.98-12.2)	**11.2** (8.44-13.6)	**12.0** (8.79-14.7)
30-day	**6.30** (5.67-6.98)	**6.89** (6.19-7.63)	**7.83** (7.02-8.69)	**8.60** (7.67-9.57)	**9.65** (8.32-10.9)	**10.4** (8.82-11.9)	**11.2** (9.17-13.0)	**12.0** (9.43-14.2)	**13.0** (9.85-15.7)	**13.8** (10.2-16.8)
45-day	**7.87** (7.14-8.64)	**8.61** (7.81-9.45)	**9.77** (8.83-10.8)	**10.7** (9.62-11.8)	**11.9** (10.3-13.3)	**12.8** (10.9-14.5)	**13.6** (11.2-15.7)	**14.5** (11.4-16.9)	**15.5** (11.7-18.4)	**16.2** (12.0-19.6)
60-day	**9.24** (8.44-10.1)	**10.1** (9.26-11.1)	**11.5** (10.5-12.6)	**12.6** (11.4-13.8)	**14.0** (12.2-15.5)	**15.0** (12.8-16.8)	**15.8** (13.1-18.0)	**16.7** (13.2-19.3)	**17.6** (13.4-20.9)	**18.3** (13.6-22.0)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

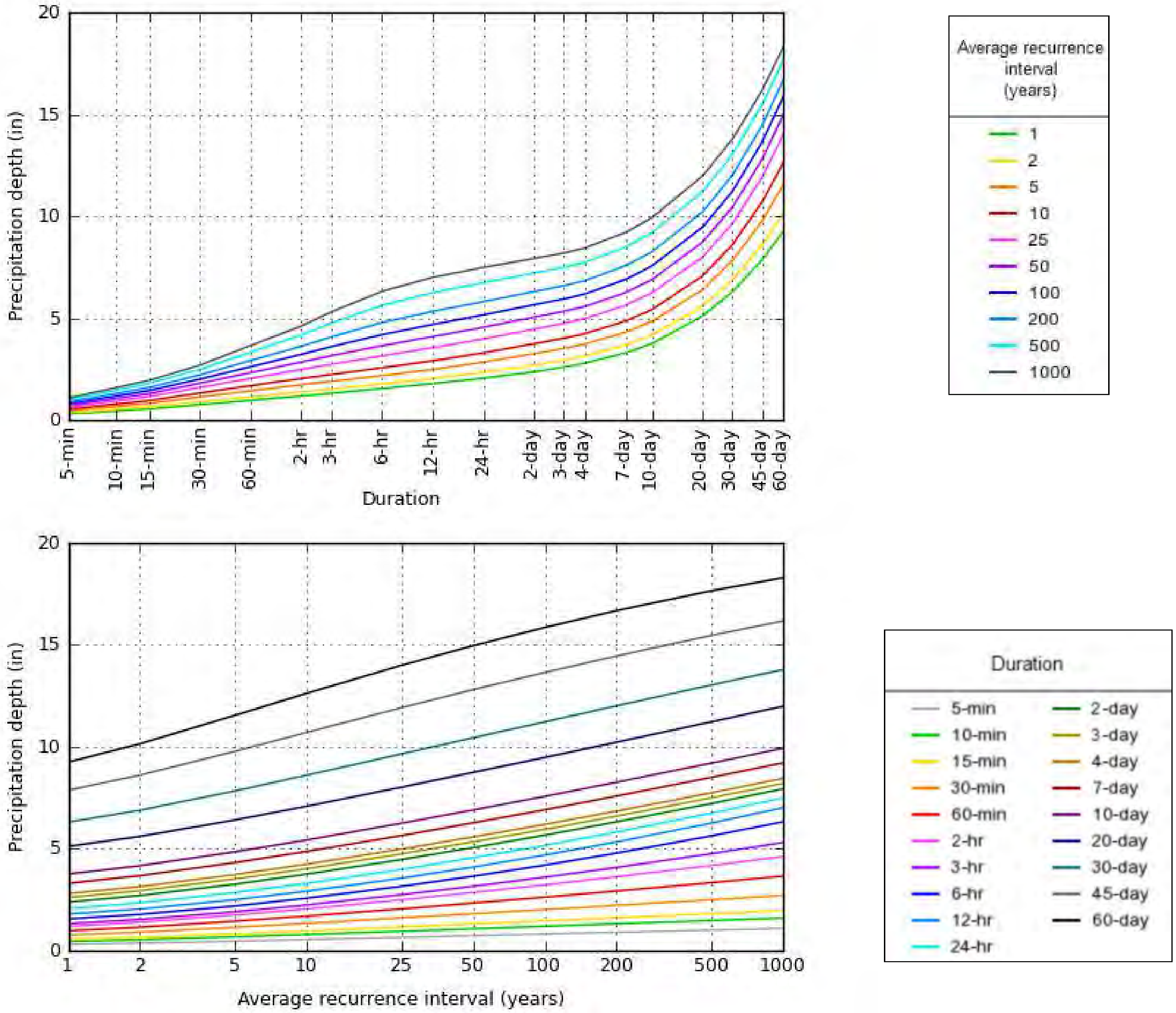
Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

Back to Top

PF graphical

PDS-based depth-duration-frequency (DDF) curves
Latitude: 41.8840°, Longitude: -83.3750°



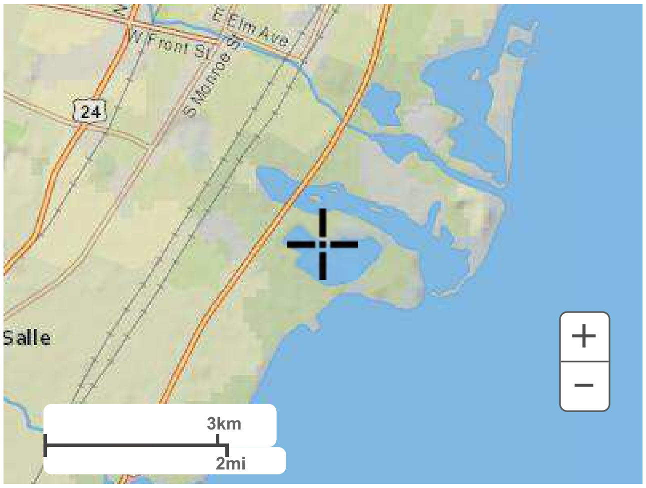
NOAA Atlas 14, Volume 8, Version 2

Created (GMT): Thu Jan 5 16:48:04 2023

Back to Top

Maps & aerials

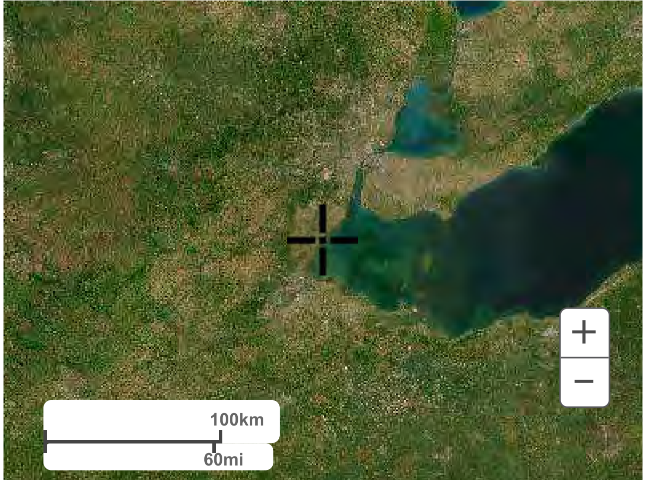
Small scale terrain



Large scale terrain

Large scale map

Large scale aerial



Back to Top

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National Weather Service
National Water Center
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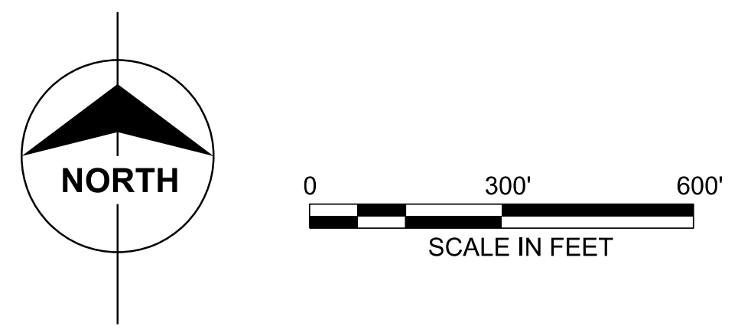

PRELIMINARY - NOT FOR CONSTRUCTION

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MONROE COUNTY, MICHIGAN

MONROE FLY ASH BASIN CLOSURE
OPTION 3 GRADING PLAN
SUBATCHMENT DELINEATION

project 151630 | contract 8120

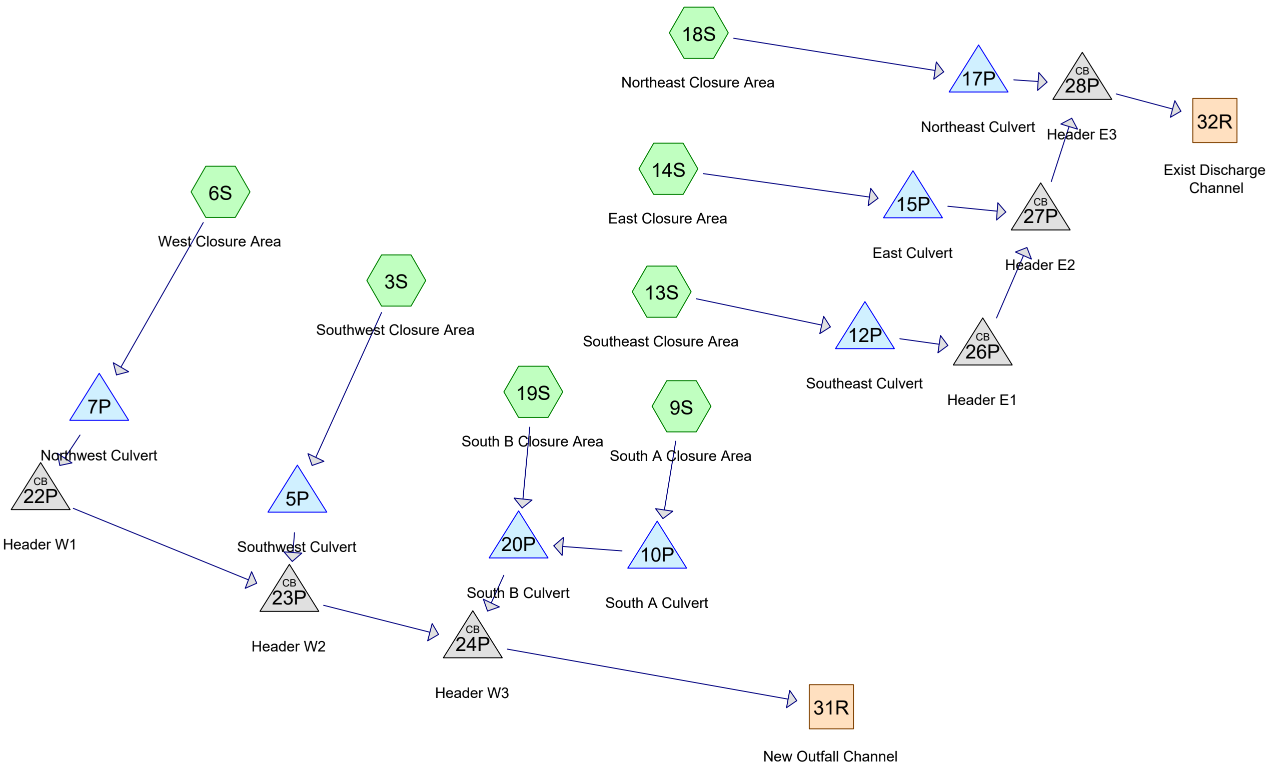
drawing **FIGURE 1** | rev. **A**

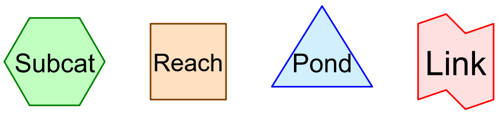
sheet of sheets

file 151630 FIGURE 1.DGN

\\bmcd\dfs\Clients\ENR\DTEEnr\151630_MonFABCloseDD\2_Design\Civil\Dwgs\Sketches\Slope Variance\151630 Figure 1.dgn

7/17/2023





Routing Diagram for Monroe Drainage-Opt3_revised pipe
Prepared by Burns & McDonnell, Printed 7/21/2023
HydroCAD® 10.20-3c s/n 08510 © 2023 HydroCAD Software Solutions LLC

Time span=0.00-96.00 hrs, dt=0.03 hrs, 3201 points
Runoff by SCS TR-20 method, UH=SCS, Weighted-CN
Reach routing by Dyn-Stor-Ind method - Pond routing by Dyn-Stor-Ind method

Subcatchment3S: Southwest Closure Area Runoff Area=46.873 ac 0.00% Impervious Runoff Depth=3.42"
Flow Length=2,354' Tc=176.6 min CN=95 Runoff=36.79 cfs 13.364 af

Subcatchment6S: West Closure Area Runoff Area=140.733 ac 0.01% Impervious Runoff Depth=3.42"
Flow Length=3,502' Tc=196.8 min CN=95 Runoff=101.54 cfs 40.123 af

Subcatchment9S: South A Closure Area Runoff Area=17.992 ac 0.00% Impervious Runoff Depth=3.42"
Flow Length=1,698' Tc=23.0 min CN=95 Runoff=59.39 cfs 5.130 af

Subcatchment13S: Southeast Closure Area Runoff Area=34.846 ac 0.00% Impervious Runoff Depth=3.42"
Flow Length=2,235' Tc=128.2 min CN=95 Runoff=34.91 cfs 9.935 af

Subcatchment14S: East Closure Area Runoff Area=50.623 ac 0.00% Impervious Runoff Depth=3.42"
Flow Length=3,083' Tc=132.8 min CN=95 Runoff=49.33 cfs 14.433 af

Subcatchment18S: Northeast Closure Area Runoff Area=99.954 ac 0.00% Impervious Runoff Depth=3.42"
Flow Length=4,769' Tc=137.4 min CN=95 Runoff=95.22 cfs 28.497 af

Subcatchment19S: South B Closure Area Runoff Area=17.843 ac 0.00% Impervious Runoff Depth=3.42"
Flow Length=1,552' Slope=0.0062 '/' Tc=20.4 min CN=95 Runoff=62.94 cfs 5.087 af

Reach 31R: New Outfall Channel Avg. Flow Depth=1.20' Max Vel=7.85 fps Inflow=140.15 cfs 63.703 af
n=0.017 L=321.3' S=0.0093 '/' Capacity=373.05 cfs Outflow=140.14 cfs 63.703 af

Reach 32R: Exist Discharge Channel Avg. Flow Depth=3.90' Max Vel=3.79 fps Inflow=175.82 cfs 52.864 af
n=0.017 L=1,841.0' S=0.0007 '/' Capacity=240.50 cfs Outflow=174.78 cfs 52.864 af

Pond 5P: Southwest Culvert Peak Elev=595.82' Storage=0.307 af Inflow=36.79 cfs 13.364 af
36.0" Round Culvert n=0.012 L=164.0' S=0.0452 '/' Outflow=36.41 cfs 13.364 af

Pond 7P: Northwest Culvert Peak Elev=591.93' Storage=1.658 af Inflow=101.54 cfs 40.123 af
60.0" Round Culvert n=0.012 L=218.9' S=0.0030 '/' Outflow=97.80 cfs 40.123 af

Pond 10P: South A Culvert Peak Elev=604.40' Storage=0.931 af Inflow=59.39 cfs 5.130 af
48.0" Round Culvert n=0.012 L=144.5' S=0.0069 '/' Outflow=33.61 cfs 5.130 af

Pond 12P: Southeast Culvert Peak Elev=601.92' Storage=0.319 af Inflow=34.91 cfs 9.935 af
36.0" Round Culvert n=0.012 L=112.8' S=0.0443 '/' Outflow=34.26 cfs 9.935 af

Pond 15P: East Culvert Peak Elev=597.93' Storage=0.403 af Inflow=49.33 cfs 14.433 af
42.0" Round Culvert n=0.012 L=138.4' S=0.0490 '/' Outflow=48.58 cfs 14.433 af

Pond 17P: Northeast Culvert Peak Elev=590.06' Storage=0.872 af Inflow=95.22 cfs 28.497 af
60.0" Round Culvert n=0.012 L=217.6' S=0.0256 '/' Outflow=93.20 cfs 28.497 af

Pond 20P: South B Culvert Peak Elev=603.22' Storage=1.913 af Inflow=91.17 cfs 10.217 af
48.0" Round Culvert n=0.012 L=155.5' S=0.1322 '/' Outflow=49.48 cfs 10.217 af

Pond 22P: Header W1 Peak Elev=590.86' Inflow=97.80 cfs 40.123 af
60.0" Round Culvert n=0.012 L=749.0' S=0.0026 '/' Outflow=97.80 cfs 40.123 af

Pond 23P: Header W2 Peak Elev=588.83' Inflow=132.53 cfs 53.487 af
72.0" Round Culvert n=0.012 L=1,588.6' S=0.0026 '/' Outflow=132.53 cfs 53.487 af

Pond 24P: Header W3 Peak Elev=584.71' Inflow=140.15 cfs 63.703 af
72.0" Round Culvert n=0.012 L=325.2' S=0.0026 '/' Outflow=140.15 cfs 63.703 af

Pond 26P: Header E1 Peak Elev=596.92' Inflow=34.26 cfs 9.935 af
36.0" Round Culvert n=0.012 L=1,122.0' S=0.0050 '/' Outflow=34.26 cfs 9.935 af

Pond 27P: Header E2 Peak Elev=590.22' Inflow=82.73 cfs 24.367 af
48.0" Round Culvert n=0.012 L=1,157.8' S=0.0050 '/' Outflow=82.73 cfs 24.367 af

Pond 28P: Header E3 Peak Elev=585.73' Inflow=175.82 cfs 52.864 af
72.0" Round Culvert n=0.012 L=33.9' S=0.0050 '/' Outflow=175.82 cfs 52.864 af

Total Runoff Area = 408.864 ac Runoff Volume = 116.568 af Average Runoff Depth = 3.42"
100.00% Pervious = 408.849 ac 0.00% Impervious = 0.015 ac

Summary for Subcatchment 3S: Southwest Closure Area

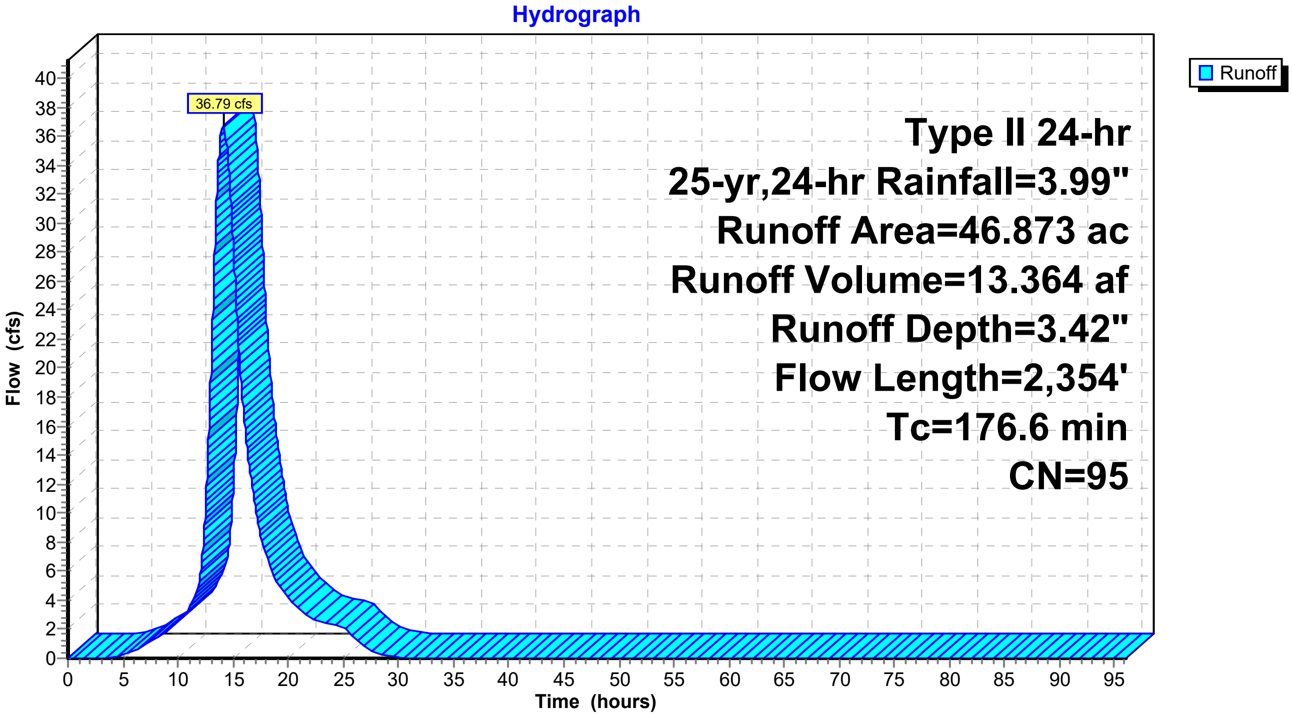
Runoff = 36.79 cfs @ 14.12 hrs, Volume= 13.364 af, Depth= 3.42"
Routed to Pond 5P : Southwest Culvert

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Type II 24-hr 25-yr,24-hr Rainfall=3.99"

	Area (ac)	CN	Description
*	45.646	95	ClosureTurf
	1.227	96	Gravel surface, HSG C
	46.873	95	Weighted Average
	46.873		100.00% Pervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
49.4	300	0.0100	0.10		**Sheet Flow, Closure Turf** n= 0.220 P2= 2.35"
49.4	300	0.0100	0.10		**Sheet Flow, Closure Turf** n= 0.220 P2= 2.35"
49.4	300	0.0100	0.10		**Sheet Flow, Closure Turf** n= 0.220 P2= 2.35"
21.1	104	0.0100	0.08		**Sheet Flow, Closure Turf** n= 0.220 P2= 2.35"
7.3	1,350	0.0050	3.06	98.01	**Trap/Vee/Rect Channel Flow,** Bot.W=8.00' D=2.00' Z= 4.0 '/' Top.W=24.00' n= 0.041 Riprap, 2-inch
176.6	2,354	Total			

Subcatchment 3S: Southwest Closure Area



Summary for Subcatchment 6S: West Closure Area

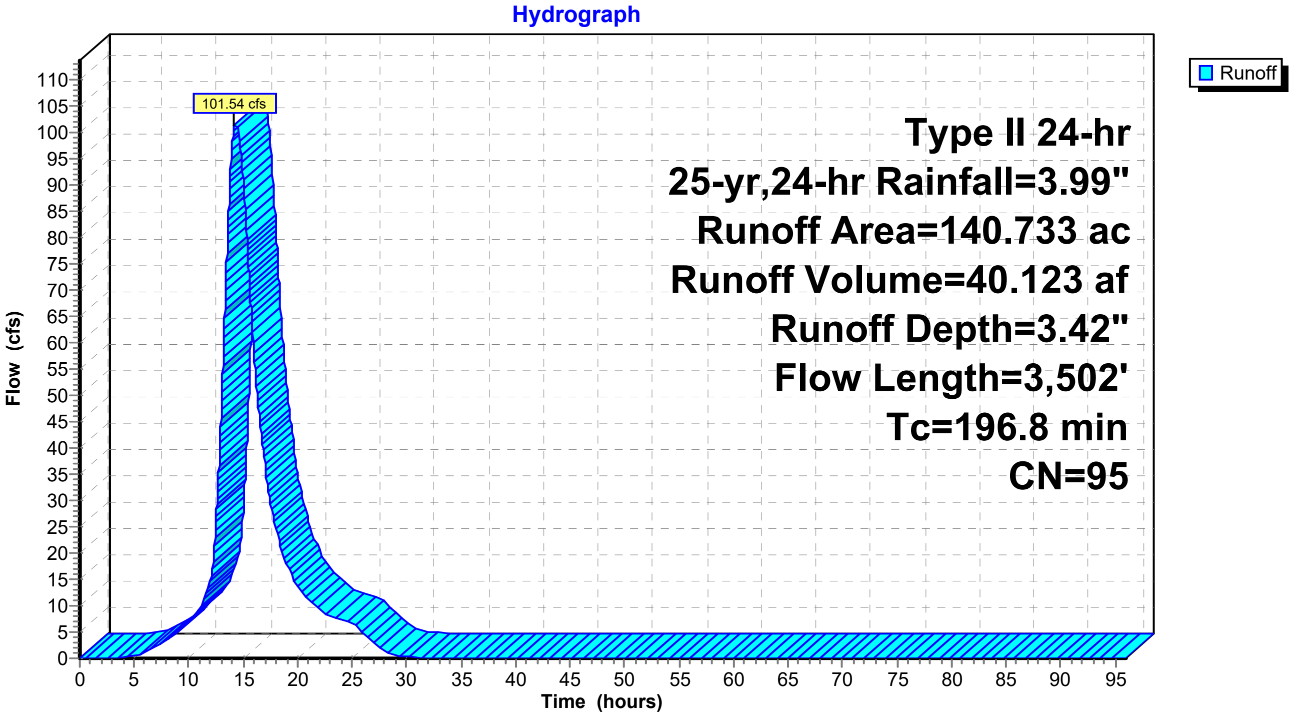
Runoff = 101.54 cfs @ 14.22 hrs, Volume= 40.123 af, Depth= 3.42"
Routed to Pond 7P : Northwest Culvert

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Type II 24-hr 25-yr,24-hr Rainfall=3.99"

	Area (ac)	CN	Description
*	133.610	95	ClosureTurf
	7.108	96	Gravel surface, HSG D
	0.015	98	Paved roads w/curbs & sewers, HSG D
	140.733	95	Weighted Average
	140.718		99.99% Pervious Area
	0.015		0.01% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
49.4	300	0.0100	0.10		**Sheet Flow, Closure Turf** n= 0.220 P2= 2.35"
49.4	300	0.0100	0.10		**Sheet Flow, Closure Turf** n= 0.220 P2= 2.35"
49.4	300	0.0100	0.10		**Sheet Flow, Closure Turf** n= 0.220 P2= 2.35"
35.5	199	0.0100	0.09		**Sheet Flow, Closure Turf** n= 0.220 P2= 2.35"
1.0	22	0.2500	0.35		**Sheet Flow, Closure Turf** n= 0.120 P2= 2.35"
12.1	2,381	0.0050	3.27	125.03	**Trap/Vee/Rect Channel Flow,** Bot.W=8.00' D=2.25' Z= 4.0 '/' Top.W=26.00' n= 0.041 Riprap, 2-inch
196.8	3,502	Total			

Subcatchment 6S: West Closure Area



Summary for Subcatchment 9S: South A Closure Area

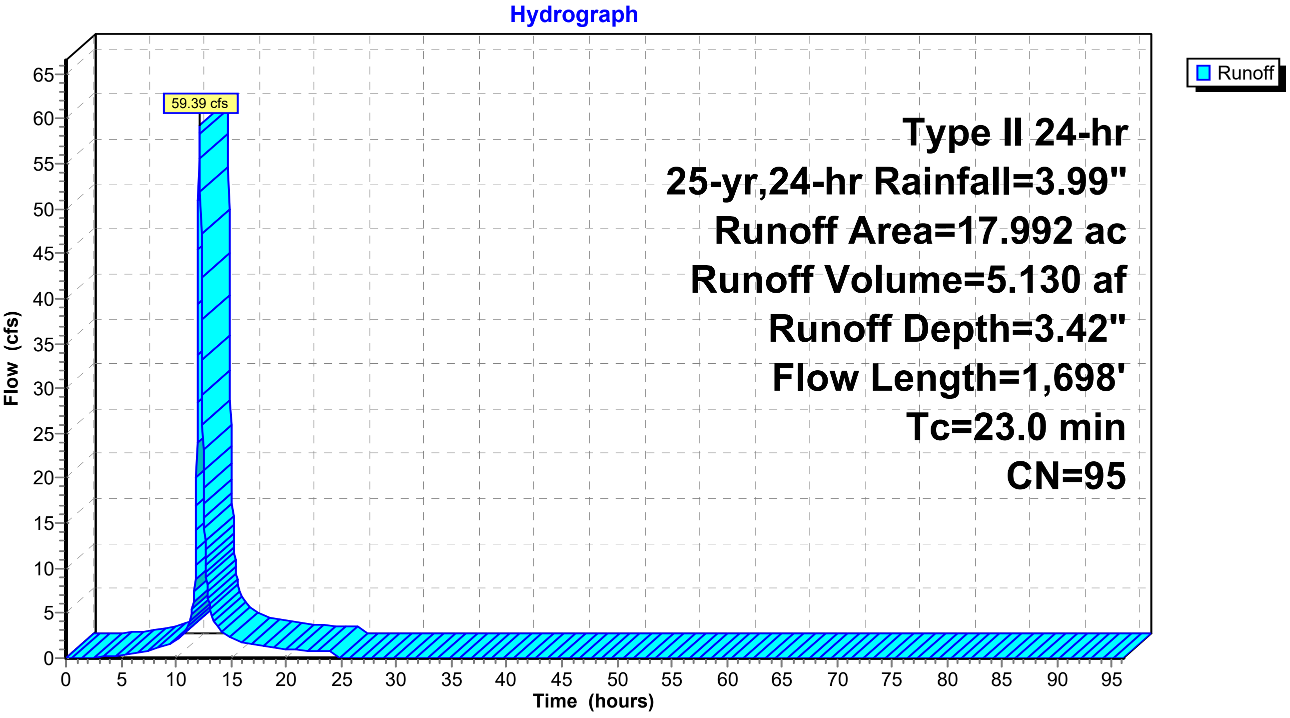
Runoff = 59.39 cfs @ 12.15 hrs, Volume= 5.130 af, Depth= 3.42"
Routed to Pond 10P : South A Culvert

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Type II 24-hr 25-yr,24-hr Rainfall=3.99"

	Area (ac)	CN	Description
*	17.740	95	Closure Turf
	0.252	96	Gravel surface, HSG D
	17.992	95	Weighted Average
	17.992		100.00% Pervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
8.8	725	0.0073	1.38		**Shallow Concentrated Flow,** Unpaved Kv= 16.1 fps
10.1	688	0.0050	1.14		**Shallow Concentrated Flow,** Unpaved Kv= 16.1 fps
3.8	257	0.0050	1.14		**Shallow Concentrated Flow,** Unpaved Kv= 16.1 fps
0.3	28	0.0070	1.35		**Shallow Concentrated Flow,** Unpaved Kv= 16.1 fps
23.0	1,698	Total			

Subcatchment 9S: South A Closure Area



Summary for Subcatchment 13S: Southeast Closure Area

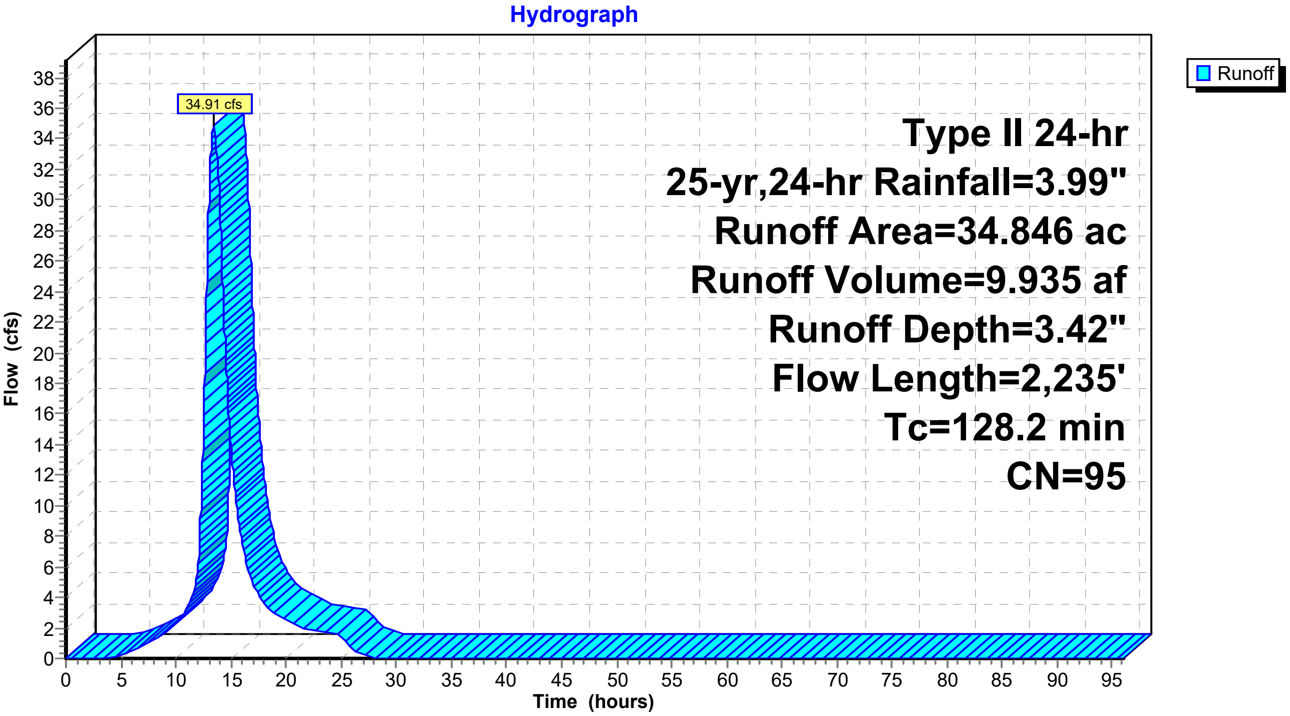
Runoff = 34.91 cfs @ 13.50 hrs, Volume= 9.935 af, Depth= 3.42"
Routed to Pond 12P : Southeast Culvert

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Type II 24-hr 25-yr,24-hr Rainfall=3.99"

	Area (ac)	CN	Description
*	33.693	95	ClosureTurf
	1.153	96	Gravel surface, HSG D
	34.846	95	Weighted Average
	34.846		100.00% Pervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
49.4	300	0.0100	0.10		**Sheet Flow, Closure Turf** n= 0.220 P2= 2.35"
49.4	300	0.0100	0.10		**Sheet Flow, Closure Turf** n= 0.220 P2= 2.35"
21.1	104	0.0100	0.08		**Sheet Flow, Closure Turf** n= 0.220 P2= 2.35"
8.3	1,531	0.0050	3.06	98.01	**Trap/Vee/Rect Channel Flow,** Bot.W=8.00' D=2.00' Z= 4.0 '/' Top.W=24.00' n= 0.041 Riprap, 2-inch
128.2	2,235	Total			

Subcatchment 13S: Southeast Closure Area



Summary for Subcatchment 14S: East Closure Area

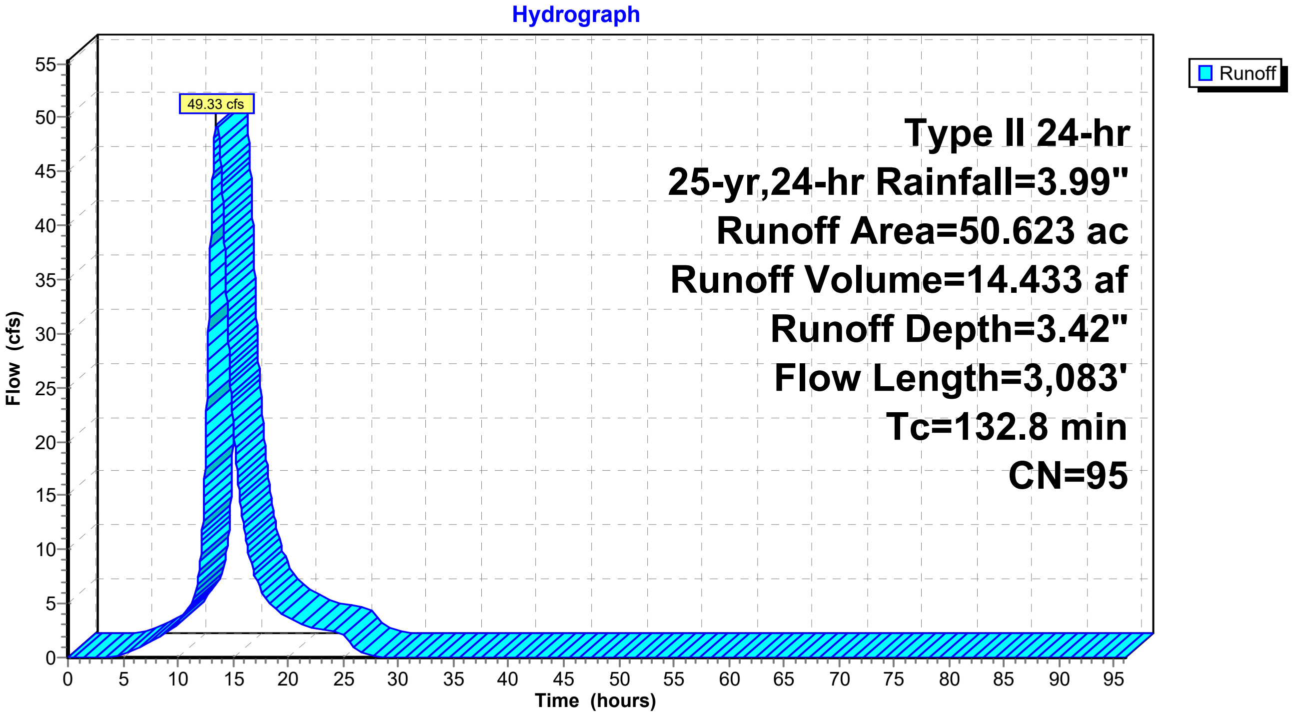
Runoff = 49.33 cfs @ 13.44 hrs, Volume= 14.433 af, Depth= 3.42"
Routed to Pond 15P : East Culvert

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Type II 24-hr 25-yr,24-hr Rainfall=3.99"

	Area (ac)	CN	Description
*	48.883	95	ClosureTurf
	1.740	96	Gravel surface, HSG D
	50.623	95	Weighted Average
	50.623		100.00% Pervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
49.4	300	0.0100	0.10		**Sheet Flow, Closure Turf** n= 0.220 P2= 2.35"
49.4	300	0.0100	0.10		**Sheet Flow, Closure Turf** n= 0.220 P2= 2.35"
21.1	104	0.0100	0.08		**Sheet Flow, Closure Turf** n= 0.220 P2= 2.35"
12.9	2,379	0.0050	3.06	98.01	**Trap/Vee/Rect Channel Flow,** Bot.W=8.00' D=2.00' Z= 4.0 '/' Top.W=24.00' n= 0.041 Riprap, 2-inch
132.8	3,083	Total			

Subcatchment 14S: East Closure Area



Summary for Subcatchment 18S: Northeast Closure Area

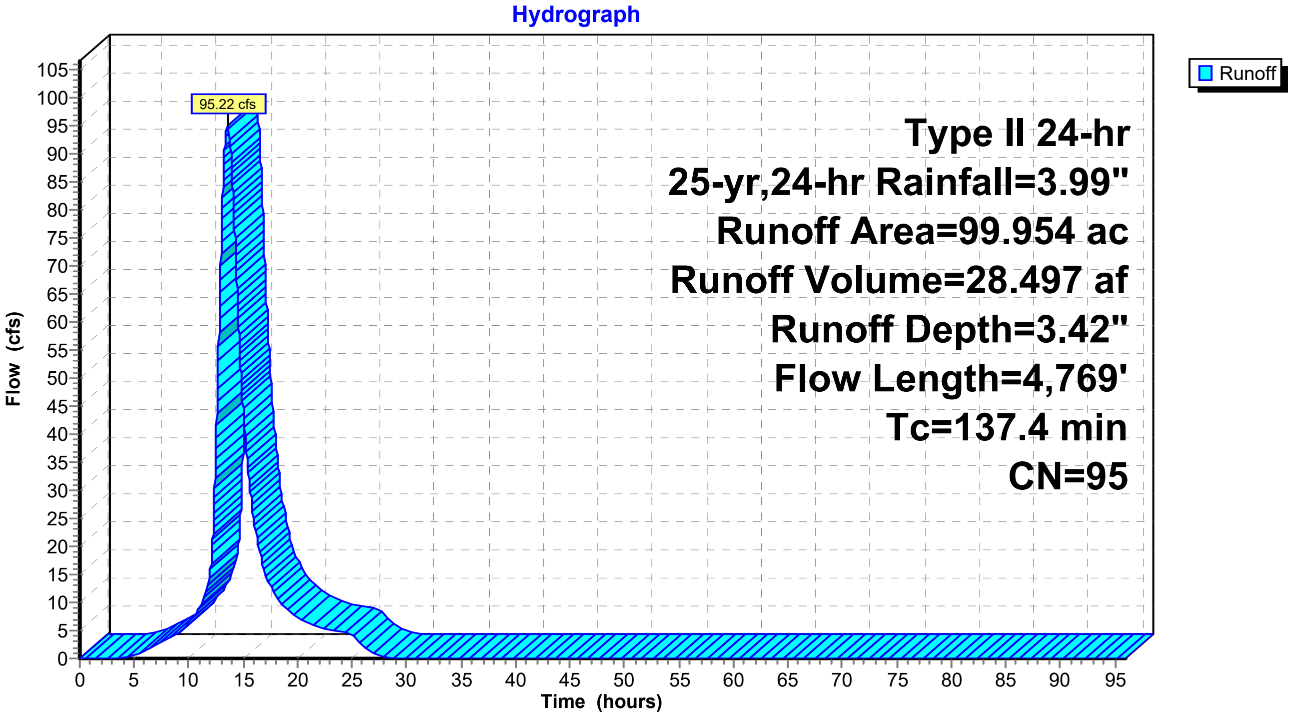
Runoff = 95.22 cfs @ 13.58 hrs, Volume= 28.497 af, Depth= 3.42"
Routed to Pond 17P : Northeast Culvert

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Type II 24-hr 25-yr,24-hr Rainfall=3.99"

	Area (ac)	CN	Description
*	92.875	95	ClosureTurf
	7.079	96	Gravel surface, HSG D
	99.954	95	Weighted Average
	99.954		100.00% Pervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
49.4	300	0.0100	0.10		**Sheet Flow, Closure Turf** n= 0.220 P2= 2.35"
49.4	300	0.0100	0.10		**Sheet Flow, Closure Turf** n= 0.220 P2= 2.35"
17.8	84	0.0100	0.08		**Sheet Flow, Closure Turf** n= 0.220 P2= 2.35"
20.8	4,085	0.0050	3.27	125.03	**Trap/Vee/Rect Channel Flow,** Bot.W=8.00' D=2.25' Z= 4.0 '/' Top.W=26.00' n= 0.041 Riprap, 2-inch
137.4	4,769	Total			

Subcatchment 18S: Northeast Closure Area



Summary for Subcatchment 19S: South B Closure Area

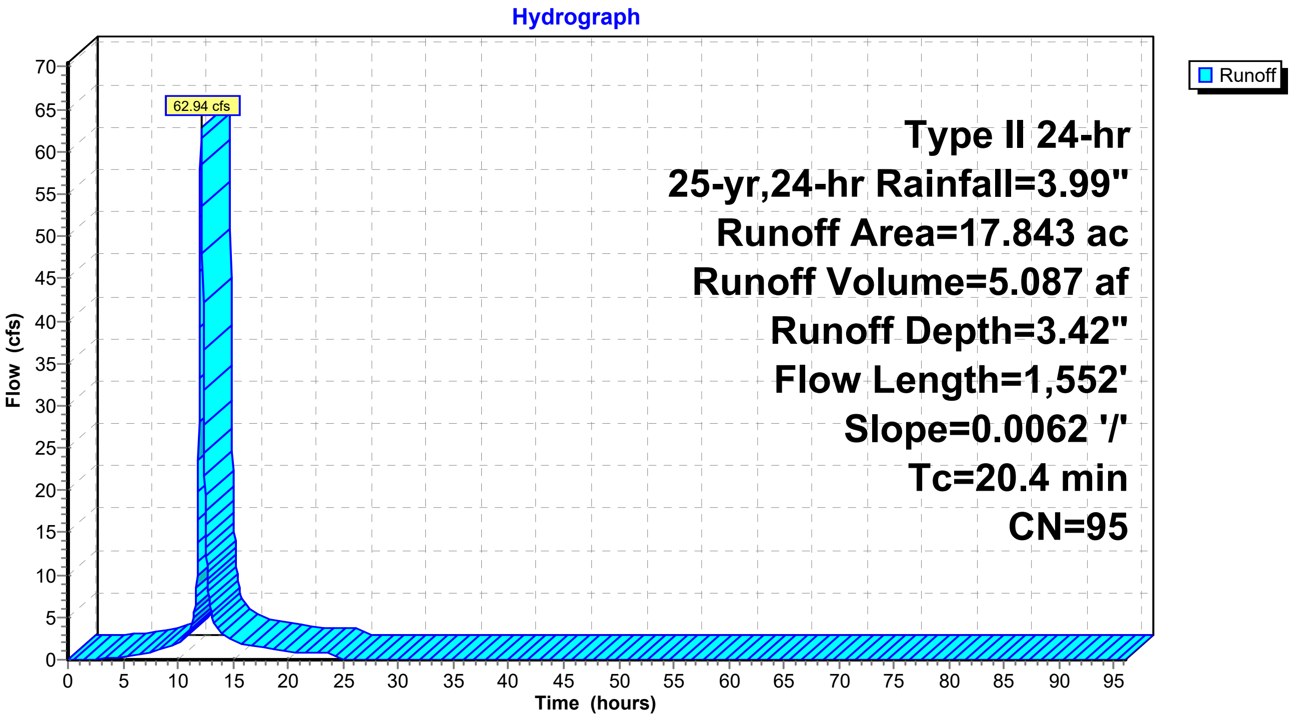
Runoff = 62.94 cfs @ 12.12 hrs, Volume= 5.087 af, Depth= 3.42"
Routed to Pond 20P : South B Culvert

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Type II 24-hr 25-yr,24-hr Rainfall=3.99"

	Area (ac)	CN	Description
*	17.424	95	Closure Turf
	0.419	96	Gravel surface, HSG D
	17.843	95	Weighted Average
	17.843		100.00% Pervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
20.4	1,552	0.0062	1.27		**Shallow Concentrated Flow, ClosureTurf** Unpaved Kv= 16.1 fps

Subcatchment 19S: South B Closure Area



Summary for Reach 31R: New Outfall Channel

Inflow Area =	223.441 ac,	0.01% Impervious,	Inflow Depth =	3.42"	for 25-yr,24-hr event
Inflow =	140.15 cfs @	14.46 hrs,	Volume=	63.703 af	
Outflow =	140.14 cfs @	14.47 hrs,	Volume=	63.703 af,	Atten= 0%, Lag= 0.5 min

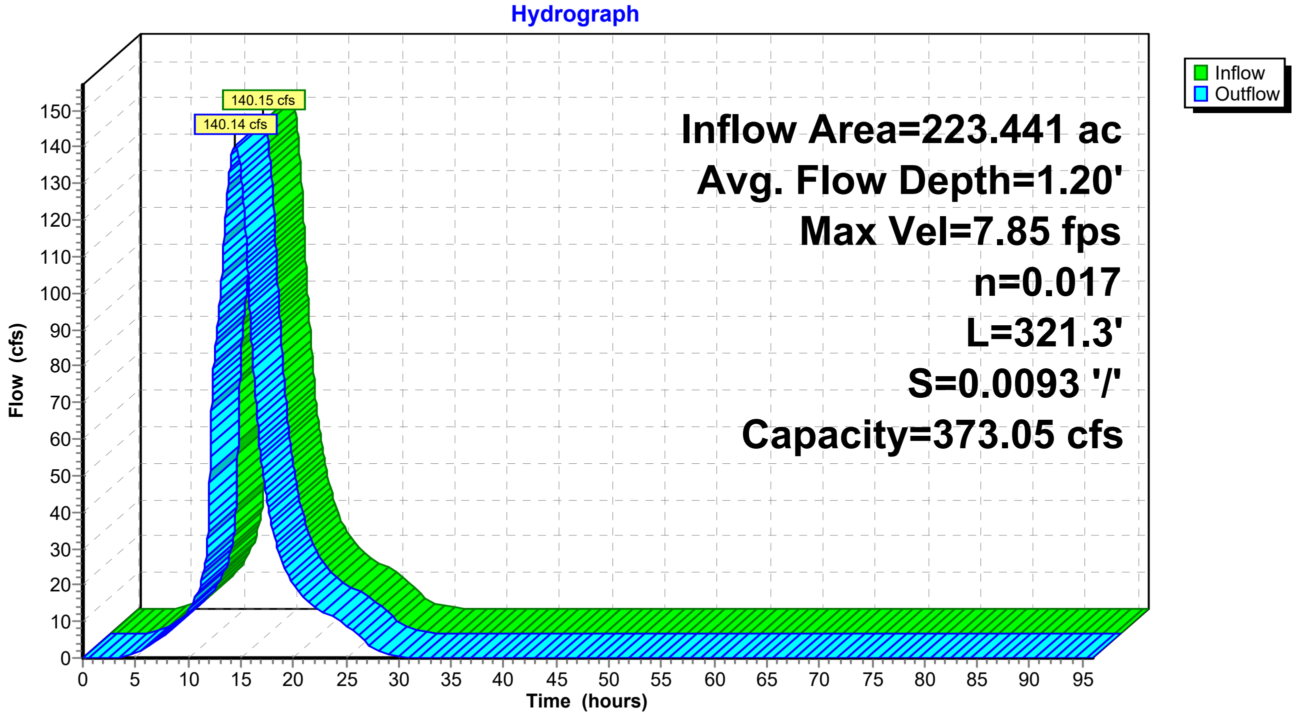
Routing by Dyn-Stor-Ind method, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Max. Velocity= 7.85 fps, Min. Travel Time= 0.7 min
Avg. Velocity = 3.10 fps, Avg. Travel Time= 1.7 min

Peak Storage= 5,737 cf @ 14.47 hrs
Average Depth at Peak Storage= 1.20' , Surface Width= 19.64'
Bank-Full Depth= 2.00' Flow Area= 36.0 sf, Capacity= 373.05 cfs

10.00' x 2.00' deep channel, n= 0.017 Concrete, unfinished
Side Slope Z-value= 4.0 '/' Top Width= 26.00'
Length= 321.3' Slope= 0.0093 '/'
Inlet Invert= 577.00', Outlet Invert= 574.00'

‡

Reach 31R: New Outfall Channel



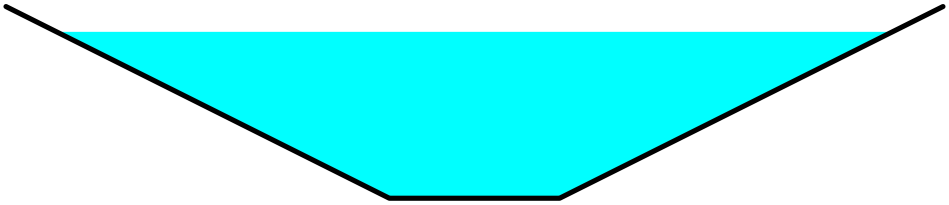
Summary for Reach 32R: Exist Discharge Channel

Inflow Area = 185.423 ac, 0.00% Impervious, Inflow Depth = 3.42" for 25-yr,24-hr event
Inflow = 175.82 cfs @ 13.70 hrs, Volume= 52.864 af
Outflow = 174.78 cfs @ 13.80 hrs, Volume= 52.864 af, Atten= 1%, Lag= 6.3 min

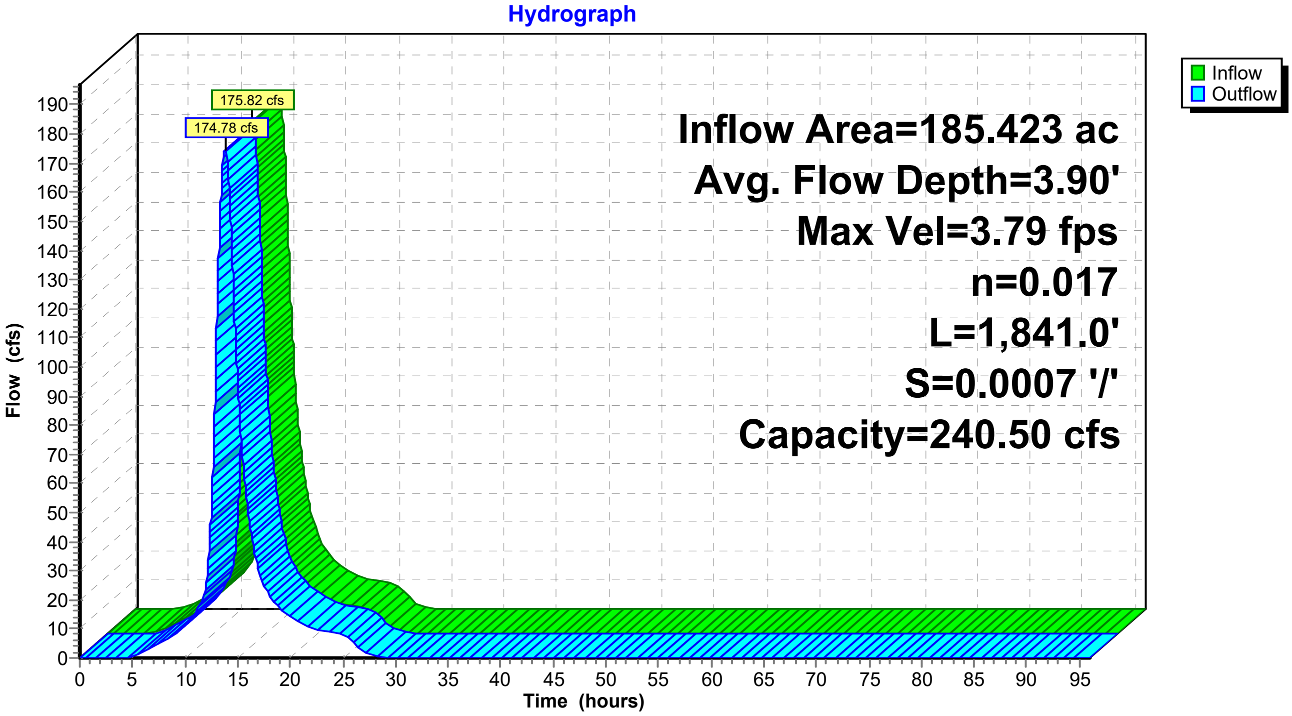
Routing by Dyn-Stor-Ind method, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Max. Velocity= 3.79 fps, Min. Travel Time= 8.1 min
Avg. Velocity = 1.24 fps, Avg. Travel Time= 24.8 min

Peak Storage= 84,856 cf @ 13.80 hrs
Average Depth at Peak Storage= 3.90' , Surface Width= 19.61'
Bank-Full Depth= 4.50' Flow Area= 58.5 sf, Capacity= 240.50 cfs

4.00' x 4.50' deep channel, n= 0.017
Side Slope Z-value= 2.0 '/' Top Width= 22.00'
Length= 1,841.0' Slope= 0.0007 '/'
Inlet Invert= 574.62', Outlet Invert= 573.37'



Reach 32R: Exist Discharge Channel



Summary for Pond 5P: Southwest Culvert

Inflow Area = 46.873 ac, 0.00% Impervious, Inflow Depth = 3.42" for 25-yr,24-hr event
Inflow = 36.79 cfs @ 14.12 hrs, Volume= 13.364 af
Outflow = 36.41 cfs @ 14.30 hrs, Volume= 13.364 af, Atten= 1%, Lag= 10.9 min
Primary = 36.41 cfs @ 14.30 hrs, Volume= 13.364 af
Routed to Pond 23P : Header W2

Routing by Dyn-Stor-Ind method, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Peak Elev= 595.82' @ 14.30 hrs Surf.Area= 0.276 ac Storage= 0.307 af

Plug-Flow detention time= 4.3 min calculated for 13.359 af (100% of inflow)
Center-of-Mass det. time= 4.3 min (934.2 - 929.9)

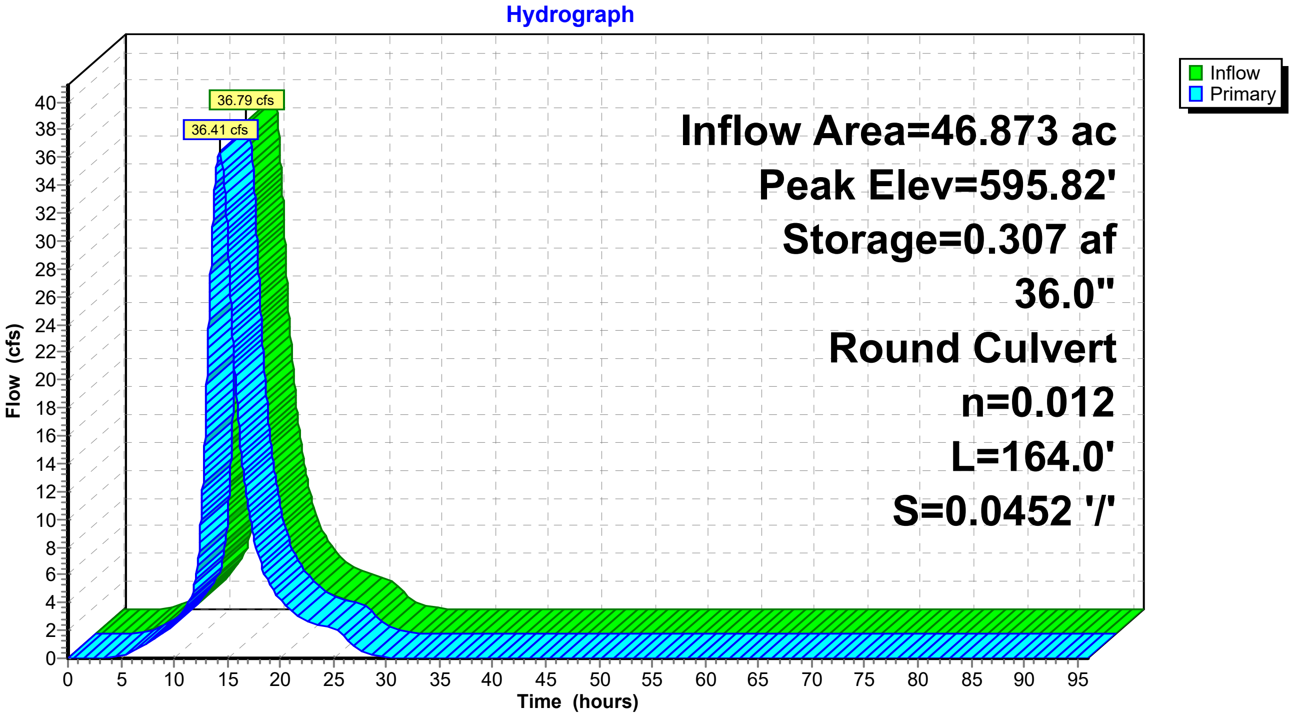
Volume	Invert	Avail.Storage	Storage Description
#1	593.18'	3.105 af	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (acres)	Inc.Store (acre-feet)	Cum.Store (acre-feet)
593.18	0.000	0.000	0.000
594.00	0.043	0.018	0.018
597.00	0.427	0.705	0.723
600.00	1.161	2.382	3.105

Device	Routing	Invert	Outlet Devices
#1	Primary	593.18'	**36.0" Round Culvert** L= 164.0' RCP, sq.cut end projecting, Ke= 0.500 Inlet / Outlet Invert= 593.18' / 585.76' S= 0.0452 '/' Cc= 0.900 n= 0.012, Flow Area= 7.07 sf

Primary OutFlow Max=36.41 cfs @ 14.30 hrs HW=595.82' TW=588.78' (Dynamic Tailwater)
↑—**1=Culvert** (Inlet Controls 36.41 cfs @ 5.53 fps)

Pond 5P: Southwest Culvert



Summary for Pond 7P: Northwest Culvert

Inflow Area = 140.733 ac, 0.01% Impervious, Inflow Depth = 3.42" for 25-yr,24-hr event
Inflow = 101.54 cfs @ 14.22 hrs, Volume= 40.123 af
Outflow = 97.80 cfs @ 14.78 hrs, Volume= 40.123 af, Atten= 4%, Lag= 33.4 min
Primary = 97.80 cfs @ 14.78 hrs, Volume= 40.123 af
Routed to Pond 22P : Header W1

Routing by Dyn-Stor-Ind method, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Peak Elev= 591.93' @ 14.74 hrs Surf.Area= 0.898 ac Storage= 1.658 af

Plug-Flow detention time= 8.2 min calculated for 40.123 af (100% of inflow)
Center-of-Mass det. time= 7.6 min (956.3 - 948.7)

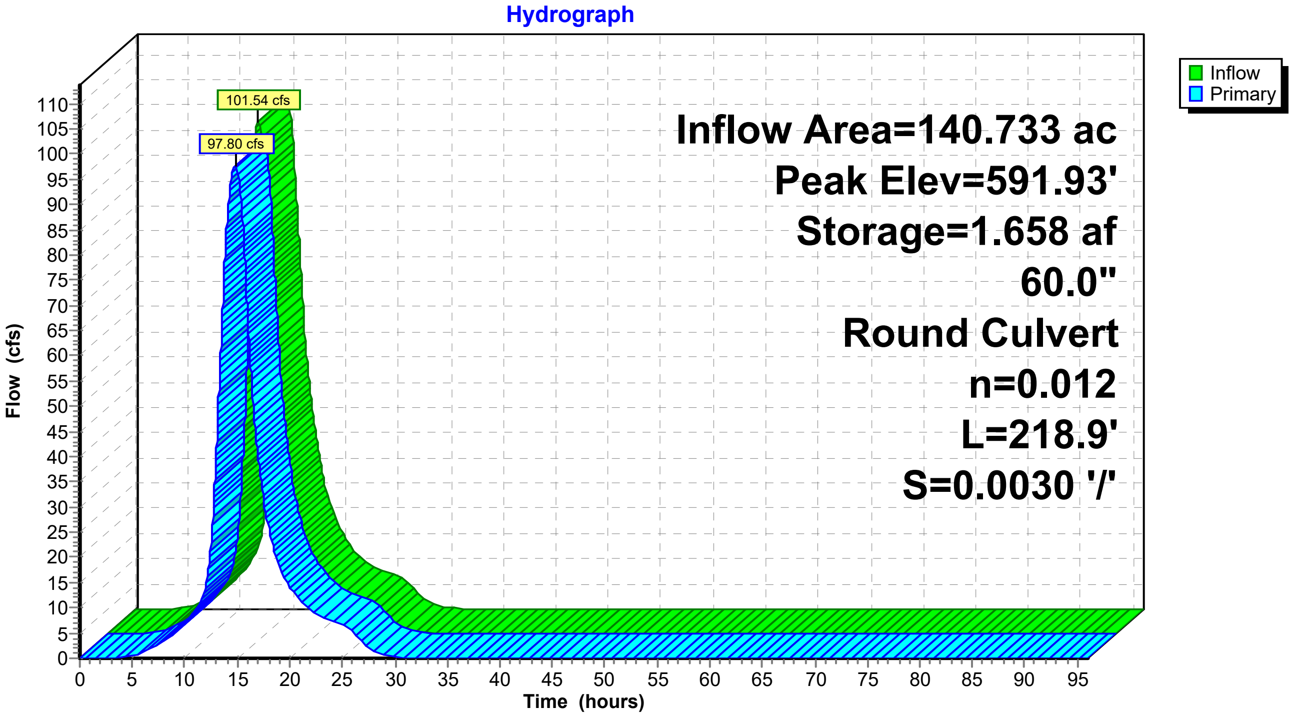
Volume	Invert	Avail.Storage	Storage Description
#1	586.50'	4.386 af	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (acres)	Inc.Store (acre-feet)	Cum.Store (acre-feet)
586.50	0.000	0.000	0.000
587.00	0.018	0.005	0.005
588.00	0.090	0.054	0.059
589.00	0.200	0.145	0.203
590.00	0.356	0.278	0.481
591.00	0.602	0.479	0.960
592.00	0.921	0.762	1.722
593.00	1.314	1.118	2.840
594.00	1.780	1.547	4.386

Device	Routing	Invert	Outlet Devices
#1	Primary	586.59'	**60.0" Round Culvert** L= 218.9' RCP, sq.cut end projecting, Ke= 0.500 Inlet / Outlet Invert= 586.59' / 585.93' S= 0.0030 '/' Cc= 0.900 n= 0.012 Concrete pipe, finished, Flow Area= 19.63 sf

Primary OutFlow Max=97.93 cfs @ 14.78 hrs HW=591.93' TW=590.85' (Dynamic Tailwater)
└─**1=Culvert** (Inlet Controls 97.93 cfs @ 4.99 fps)

Pond 7P: Northwest Culvert



Summary for Pond 10P: South A Culvert

Inflow Area = 17.992 ac, 0.00% Impervious, Inflow Depth = 3.42" for 25-yr,24-hr event
Inflow = 59.39 cfs @ 12.15 hrs, Volume= 5.130 af
Outflow = 33.61 cfs @ 12.31 hrs, Volume= 5.130 af, Atten= 43%, Lag= 9.5 min
Primary = 33.61 cfs @ 12.31 hrs, Volume= 5.130 af
Routed to Pond 20P : South B Culvert

Routing by Dyn-Stor-Ind method, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Peak Elev= 604.40' @ 12.36 hrs Surf.Area= 1.108 ac Storage= 0.931 af

Plug-Flow detention time= 14.5 min calculated for 5.128 af (100% of inflow)
Center-of-Mass det. time= 14.5 min (801.2 - 786.7)

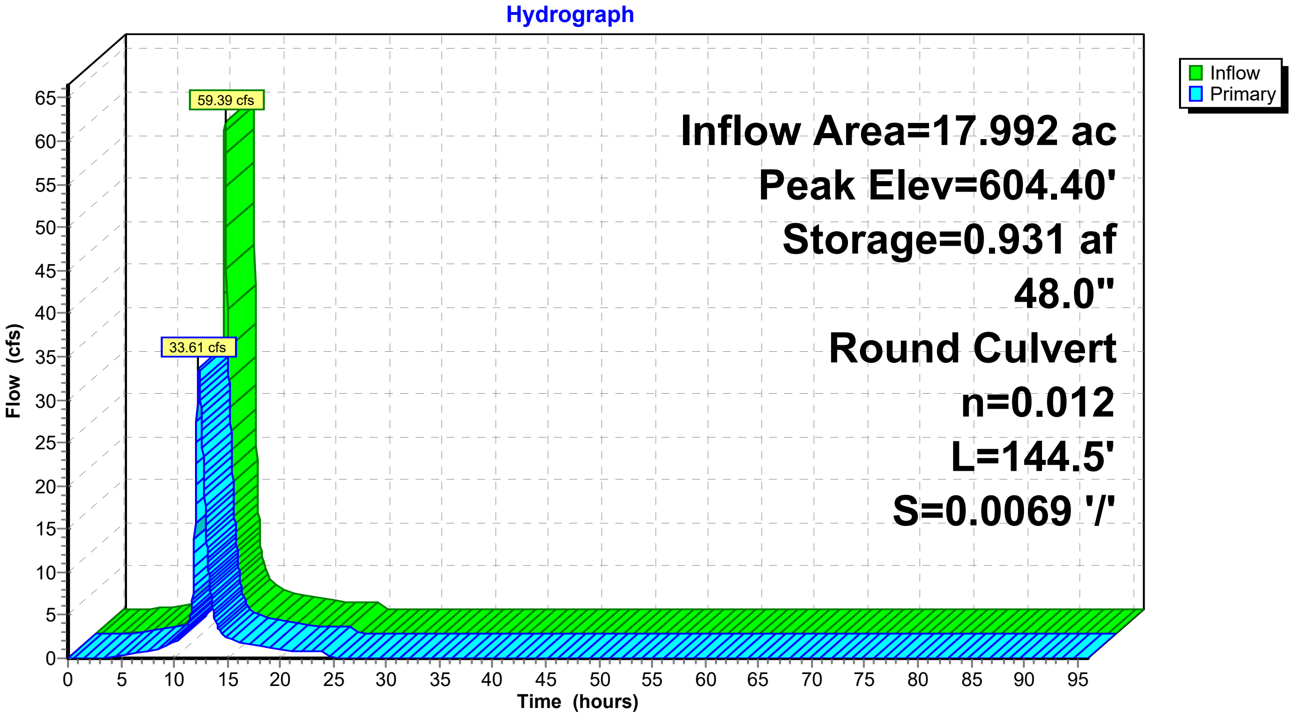
Volume	Invert	Avail.Storage	Storage Description
#1	602.00'	1.781 af	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (acres)	Inc.Store (acre-feet)	Cum.Store (acre-feet)
602.00	0.005	0.000	0.000
603.00	0.224	0.114	0.114
604.00	0.688	0.456	0.570
605.00	1.734	1.211	1.781

Device	Routing	Invert	Outlet Devices
#1	Primary	602.00'	**48.0" Round Culvert** L= 144.5' RCP, sq.cut end projecting, Ke= 0.500 Inlet / Outlet Invert= 602.00' / 601.00' S= 0.0069 '/' Cc= 0.900 n= 0.012 Concrete pipe, finished, Flow Area= 12.57 sf

Primary OutFlow Max=33.08 cfs @ 12.31 hrs HW=604.39' TW=603.14' (Dynamic Tailwater)
↑—**1=Culvert** (Outlet Controls 33.08 cfs @ 6.08 fps)

Pond 10P: South A Culvert



Summary for Pond 12P: Southeast Culvert

Inflow Area = 34.846 ac, 0.00% Impervious, Inflow Depth = 3.42" for 25-yr,24-hr event
Inflow = 34.91 cfs @ 13.50 hrs, Volume= 9.935 af
Outflow = 34.26 cfs @ 13.61 hrs, Volume= 9.935 af, Atten= 2%, Lag= 6.4 min
Primary = 34.26 cfs @ 13.61 hrs, Volume= 9.935 af
Routed to Pond 26P : Header E1

Routing by Dyn-Stor-Ind method, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Peak Elev= 601.92' @ 13.61 hrs Surf.Area= 0.294 ac Storage= 0.319 af

Plug-Flow detention time= 4.5 min calculated for 9.932 af (100% of inflow)
Center-of-Mass det. time= 4.5 min (888.3 - 883.7)

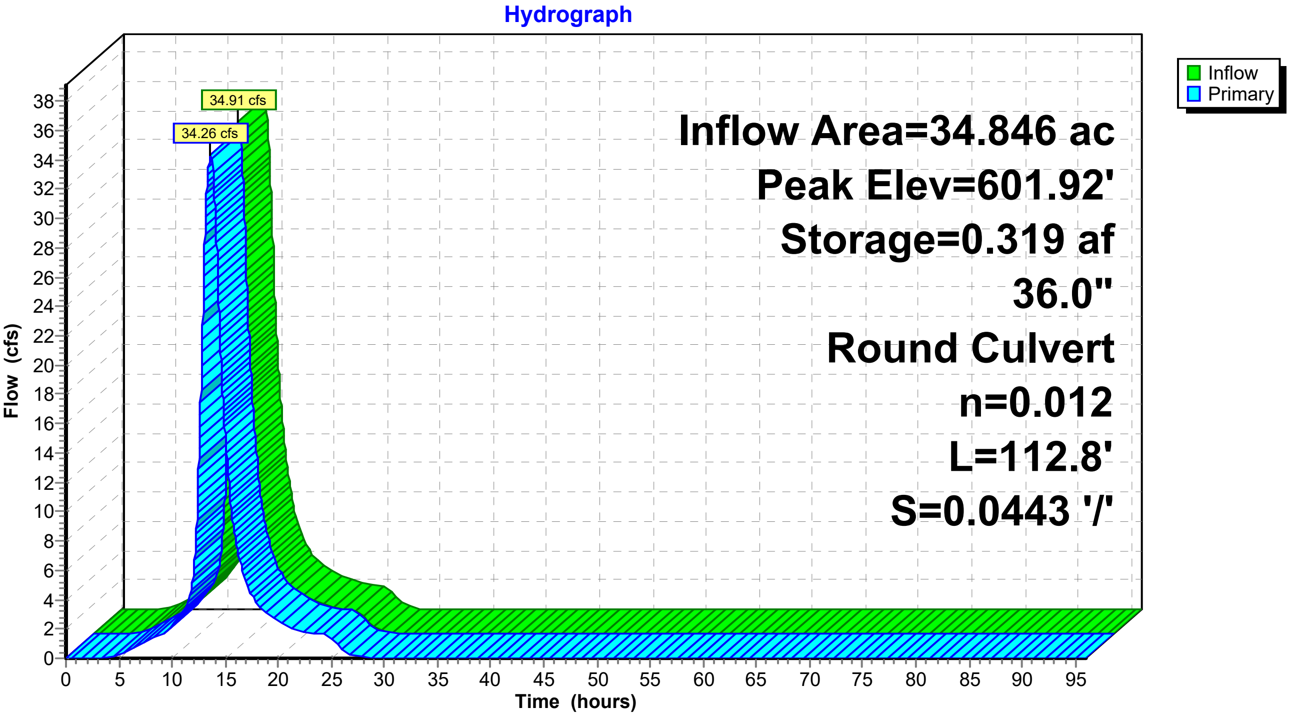
Volume	Invert	Avail.Storage	Storage Description
#1	599.40'	4.200 af	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (acres)	Inc.Store (acre-feet)	Cum.Store (acre-feet)
599.40	0.000	0.000	0.000
600.00	0.029	0.009	0.009
604.00	0.581	1.220	1.229
607.00	1.400	2.972	4.200

Device	Routing	Invert	Outlet Devices
#1	Primary	599.40'	**36.0" Round Culvert** L= 112.8' RCP, sq.cut end projecting, Ke= 0.500 Inlet / Outlet Invert= 599.40' / 594.40' S= 0.0443 '/' Cc= 0.900 n= 0.012 Concrete pipe, finished, Flow Area= 7.07 sf

Primary OutFlow Max=34.26 cfs @ 13.61 hrs HW=601.92' TW=596.92' (Dynamic Tailwater)
└─**1=Culvert** (Inlet Controls 34.26 cfs @ 5.40 fps)

Pond 12P: Southeast Culvert



Summary for Pond 15P: East Culvert

Inflow Area = 50.623 ac, 0.00% Impervious, Inflow Depth = 3.42" for 25-yr,24-hr event
Inflow = 49.33 cfs @ 13.44 hrs, Volume= 14.433 af
Outflow = 48.58 cfs @ 13.71 hrs, Volume= 14.433 af, Atten= 2%, Lag= 16.1 min
Primary = 48.58 cfs @ 13.71 hrs, Volume= 14.433 af
Routed to Pond 27P : Header E2

Routing by Dyn-Stor-Ind method, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Peak Elev= 597.93' @ 13.71 hrs Surf.Area= 0.342 ac Storage= 0.403 af

Plug-Flow detention time= 4.1 min calculated for 14.428 af (100% of inflow)
Center-of-Mass det. time= 4.1 min (893.0 - 889.0)

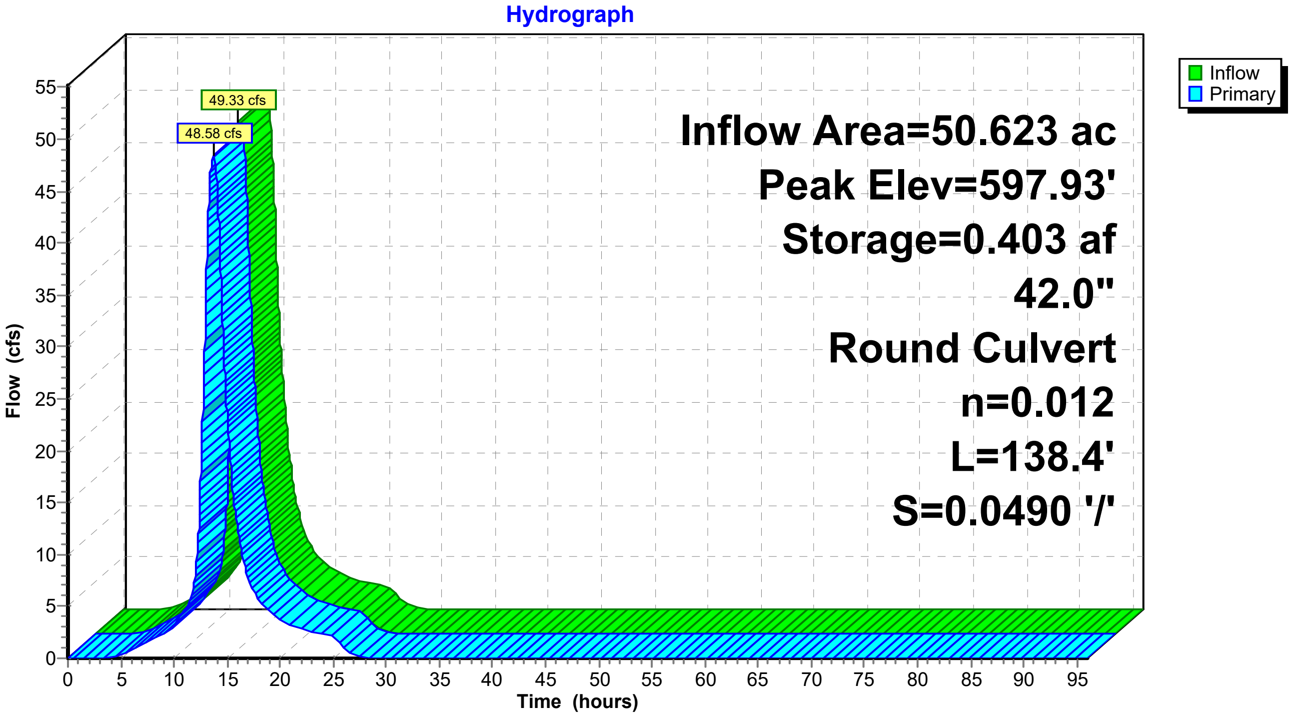
Volume	Invert	Avail.Storage	Storage Description
#1	595.07'	4.685 af	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (acres)	Inc.Store (acre-feet)	Cum.Store (acre-feet)
595.07	0.000	0.000	0.000
596.00	0.050	0.023	0.023
600.00	0.654	1.408	1.431
603.00	1.515	3.253	4.685

Device	Routing	Invert	Outlet Devices
#1	Primary	595.07'	**42.0" Round Culvert** L= 138.4' RCP, sq.cut end projecting, Ke= 0.500 Inlet / Outlet Invert= 595.07' / 588.29' S= 0.0490 '/' Cc= 0.900 n= 0.012 Concrete pipe, finished, Flow Area= 9.62 sf

Primary OutFlow Max=48.57 cfs @ 13.71 hrs HW=597.93' TW=590.21' (Dynamic Tailwater)
⮤**1=Culvert** (Inlet Controls 48.57 cfs @ 5.76 fps)

Pond 15P: East Culvert



Summary for Pond 17P: Northeast Culvert

Inflow Area = 99.954 ac, 0.00% Impervious, Inflow Depth = 3.42" for 25-yr,24-hr event
Inflow = 95.22 cfs @ 13.58 hrs, Volume= 28.497 af
Outflow = 93.20 cfs @ 13.73 hrs, Volume= 28.497 af, Atten= 2%, Lag= 8.6 min
Primary = 93.20 cfs @ 13.73 hrs, Volume= 28.497 af
Routed to Pond 28P : Header E3

Routing by Dyn-Stor-Ind method, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Peak Elev= 590.06' @ 13.73 hrs Surf.Area= 0.630 ac Storage= 0.872 af

Plug-Flow detention time= 4.6 min calculated for 28.488 af (100% of inflow)
Center-of-Mass det. time= 4.6 min (897.1 - 892.5)

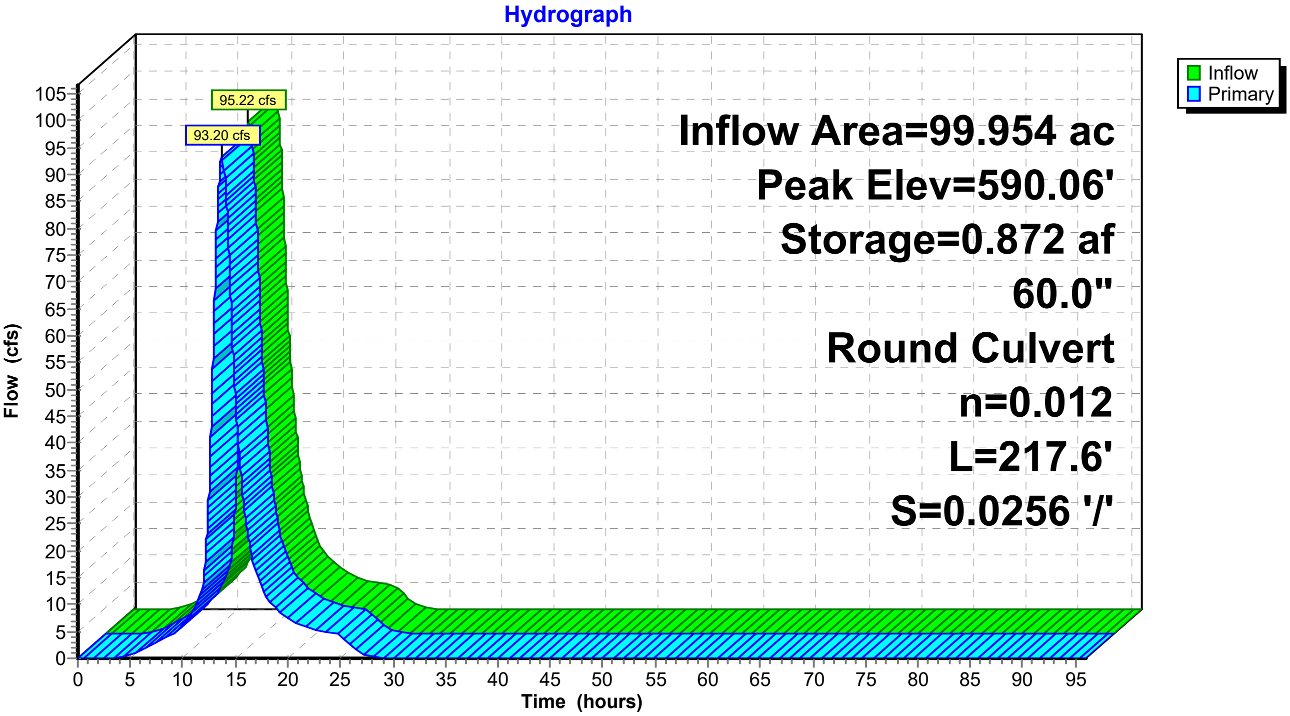
Volume	Invert	Avail.Storage	Storage Description
#1	586.57'	9.273 af	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (acres)	Inc.Store (acre-feet)	Cum.Store (acre-feet)
586.57	0.000	0.000	0.000
587.00	0.021	0.005	0.005
588.00	0.140	0.080	0.085
590.00	0.608	0.748	0.833
591.00	0.952	0.780	1.613
592.00	1.369	1.161	2.774
593.00	1.860	1.614	4.388
594.00	2.424	2.142	6.530
595.00	3.062	2.743	9.273

Device	Routing	Invert	Outlet Devices
#1	Primary	586.57'	**60.0" Round Culvert** L= 217.6' RCP, sq.cut end projecting, Ke= 0.500 Inlet / Outlet Invert= 586.57' / 581.00' S= 0.0256 '/' Cc= 0.900 n= 0.012 Concrete pipe, finished, Flow Area= 19.63 sf

Primary OutFlow Max=93.19 cfs @ 13.73 hrs HW=590.06' TW=585.73' (Dynamic Tailwater)
└─**1=Culvert** (Inlet Controls 93.19 cfs @ 6.36 fps)

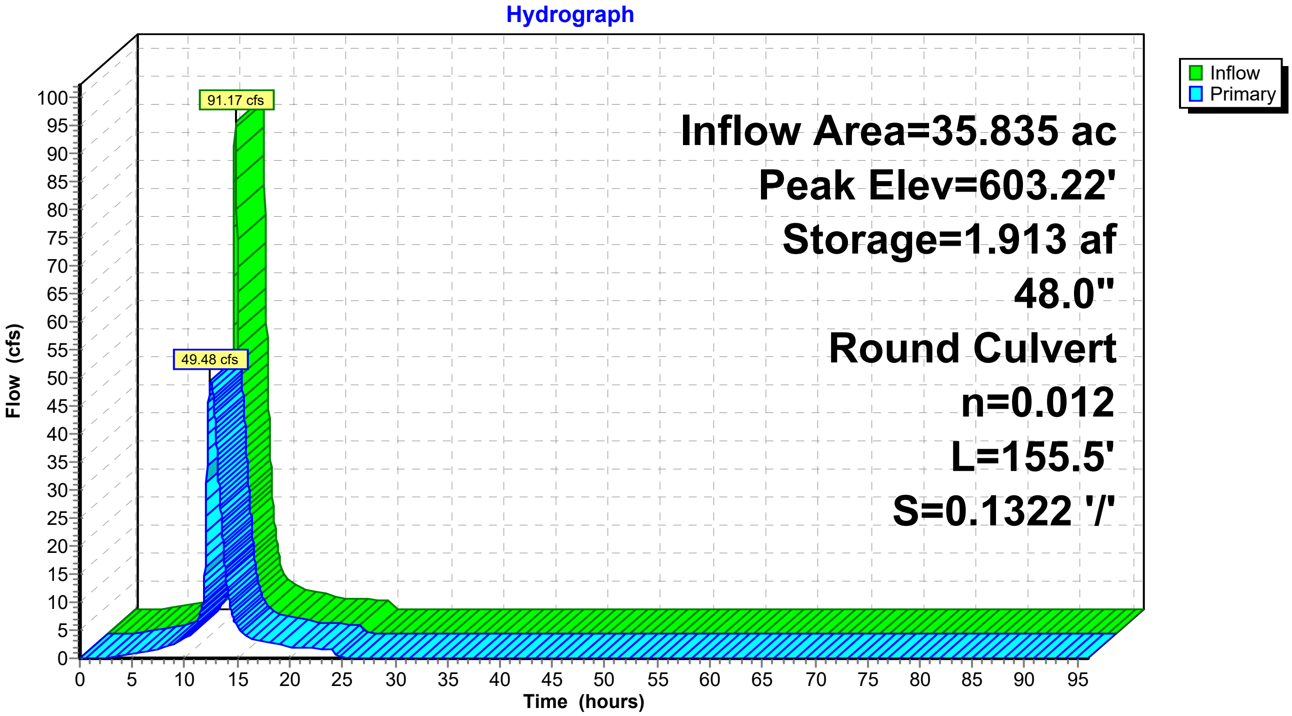
Pond 17P: Northeast Culvert



Summary for Pond 20P: South B Culvert

```
Inflow Area =     35.835 ac,   0.00% Impervious,  Inflow Depth =  3.42"    for  25-yr,24-hr event
Inflow      =     91.17 cfs @  12.14 hrs,  Volume=        10.217 af
Outflow     =     49.48 cfs @  12.47 hrs,  Volume=        10.217 af,  Atten= 46%,  Lag= 19.4 min
Primary     =     49.48 cfs @  12.47 hrs,  Volume=        10.217 af
   Routed to Pond 24P : Header W3

Routing by Dyn-Stor-Ind method, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Peak Elev= 603.22' @ 12.47 hrs   Surf.Area= 1.666 ac   Storage= 1.913 af

Plug-Flow detention time= 17.6 min calculated for 10.213 af (100% of inflow)
Center-of-Mass det. time= 17.6 min ( 810.4 - 792.8 )

Volume      Invert    Avail.Storage   Storage Description
  #1       600.55'         3.442 af   Custom Stage Data (Prismatic)Listed below (Recalc)

Elevation     Surf.Area      Inc.Store      Cum.Store
   (feet)       (acres)    (acre-feet)    (acre-feet)
   600.55         0.000          0.000          0.000
   601.00         0.050          0.011          0.011
   604.00         2.237          3.431          3.442

Device   Routing          Invert   Outlet Devices
  #1     Primary         600.55'   48.0"  Round Culvert
                                   L= 155.5'   RCP, sq.cut end projecting,  Ke= 0.500
                                   Inlet / Outlet Invert= 600.55' / 579.99'   S= 0.1322 '/'   Cc= 0.900
                                   n= 0.012  Concrete pipe, finished,  Flow Area= 12.57 sf

Primary OutFlow  Max=49.47 cfs @ 12.47 hrs  HW=603.22'  TW=583.34'   (Dynamic Tailwater)
└─1=Culvert  (Inlet Controls 49.47 cfs @ 5.56 fps)
```

Pond 20P: South B Culvert



Summary for Pond 22P: Header W1

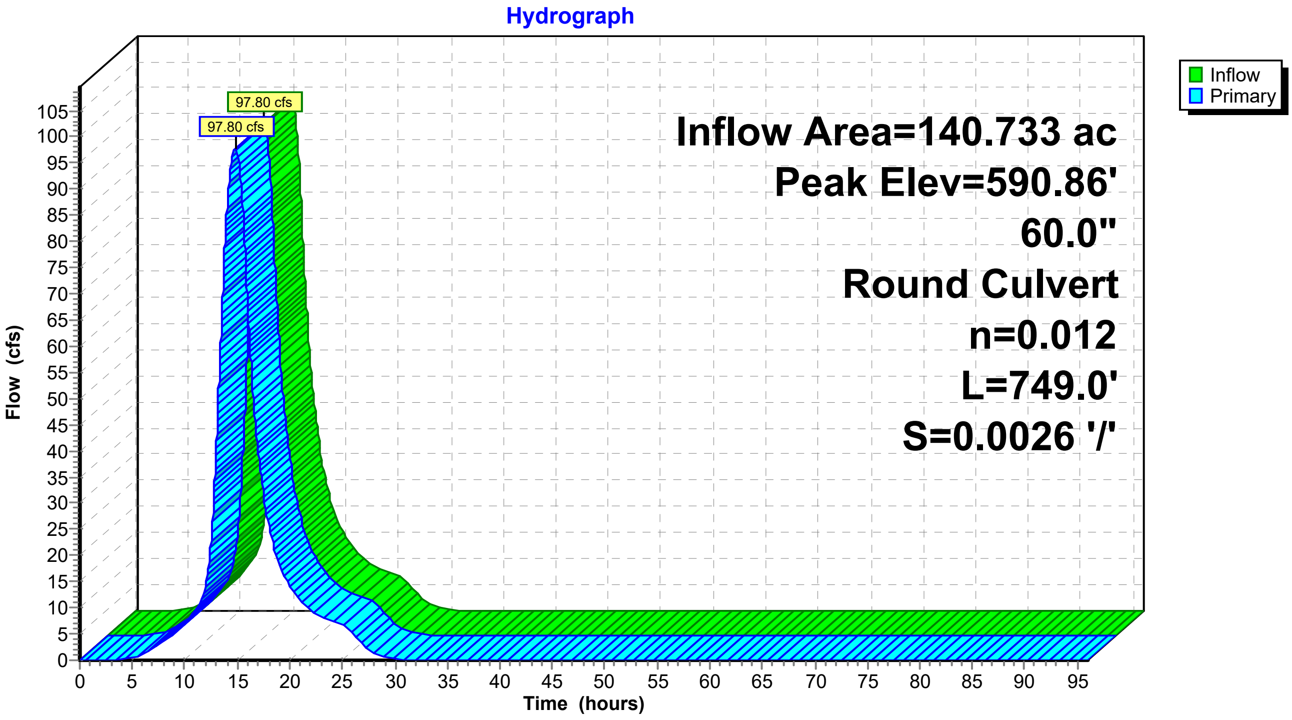
Inflow Area = 140.733 ac, 0.01% Impervious, Inflow Depth = 3.42" for 25-yr,24-hr event
Inflow = 97.80 cfs @ 14.78 hrs, Volume= 40.123 af
Outflow = 97.80 cfs @ 14.78 hrs, Volume= 40.123 af, Atten= 0%, Lag= 0.0 min
Primary = 97.80 cfs @ 14.78 hrs, Volume= 40.123 af
Routed to Pond 23P : Header W2

Routing by Dyn-Stor-Ind method, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Peak Elev= 590.86' @ 14.69 hrs

Device	Routing	Invert	Outlet Devices
#1	Primary	585.93'	**60.0" Round Culvert** L= 749.0' RCP, square edge headwall, Ke= 0.500 Inlet / Outlet Invert= 585.93' / 583.98' S= 0.0026 '/' Cc= 0.900 n= 0.012 Concrete pipe, finished, Flow Area= 19.63 sf

Primary OutFlow Max=97.98 cfs @ 14.78 hrs HW=590.85' TW=588.80' (Dynamic Tailwater)
└**1=Culvert** (Outlet Controls 97.98 cfs @ 6.30 fps)

Pond 22P: Header W1



Summary for Pond 23P: Header W2

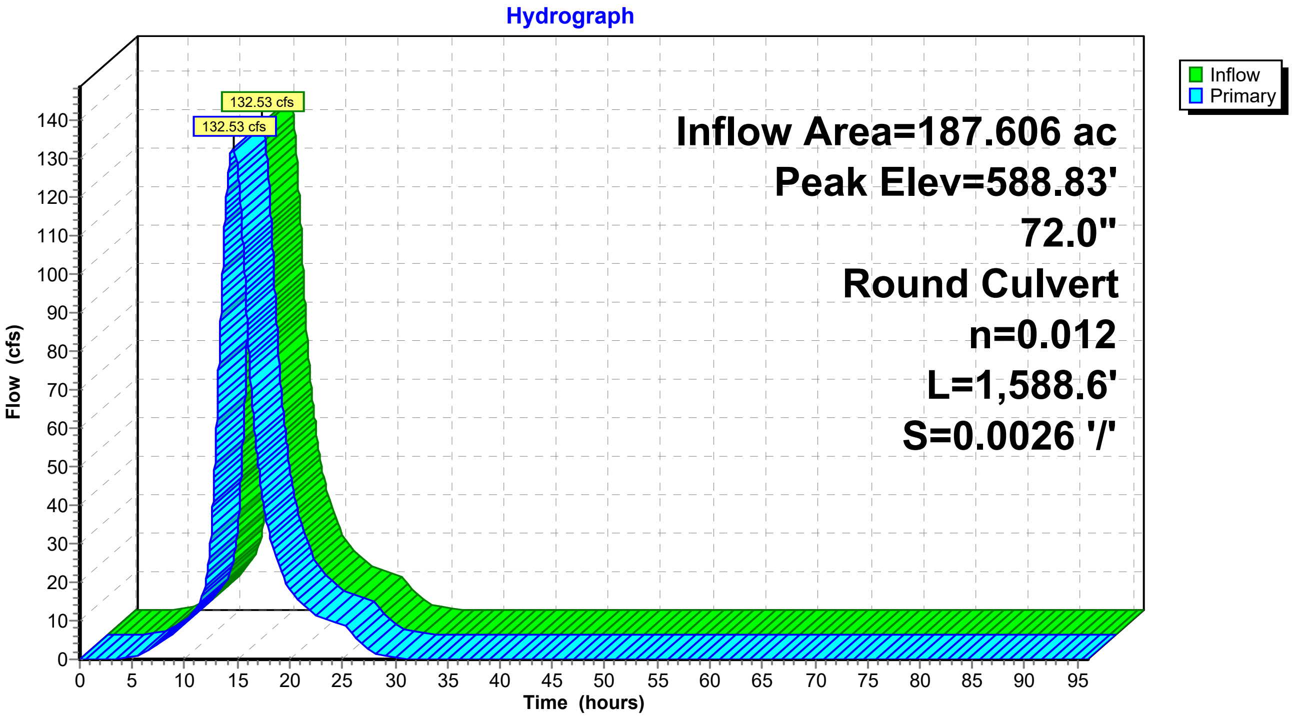
Inflow Area = 187.606 ac, 0.01% Impervious, Inflow Depth = 3.42" for 25-yr,24-hr event
Inflow = 132.53 cfs @ 14.57 hrs, Volume= 53.487 af
Outflow = 132.53 cfs @ 14.57 hrs, Volume= 53.487 af, Atten= 0%, Lag= 0.0 min
Primary = 132.53 cfs @ 14.57 hrs, Volume= 53.487 af
Routed to Pond 24P : Header W3

Routing by Dyn-Stor-Ind method, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Peak Elev= 588.83' @ 14.57 hrs

Device	Routing	Invert	Outlet Devices
#1	Primary	583.98'	**72.0" Round Culvert** L= 1,588.6' RCP, square edge headwall, Ke= 0.500 Inlet / Outlet Invert= 583.98' / 579.85' S= 0.0026 '/' Cc= 0.900 n= 0.012 Concrete pipe, finished, Flow Area= 28.27 sf

Primary OutFlow Max=132.56 cfs @ 14.57 hrs HW=588.83' TW=584.70' (Dynamic Tailwater)
1=Culvert (Outlet Controls 132.56 cfs @ 7.39 fps)

Pond 23P: Header W2



Summary for Pond 24P: Header W3

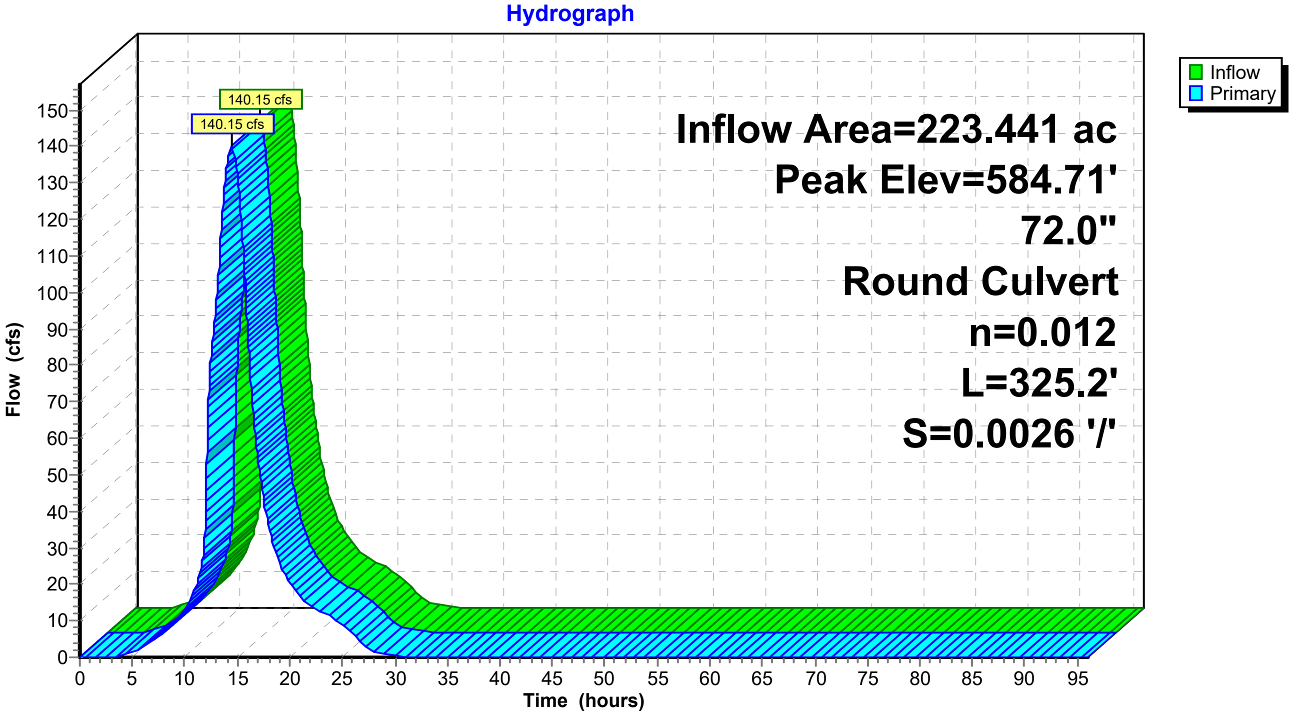
```
Inflow Area =      223.441 ac,   0.01% Impervious,  Inflow Depth =   3.42"    for  25-yr,24-hr event
Inflow      =     140.15 cfs @   14.46 hrs,  Volume=          63.703 af
Outflow     =     140.15 cfs @   14.46 hrs,  Volume=          63.703 af,  Atten= 0%,  Lag= 0.0 min
Primary     =     140.15 cfs @   14.46 hrs,  Volume=          63.703 af
    Routed to Reach 31R : New Outfall Channel
```

Routing by Dyn-Stor-Ind method, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Peak Elev= 584.71' @ 14.46 hrs

Device	Routing	Invert	Outlet Devices
#1	Primary	579.85'	**72.0" Round Culvert** L= 325.2' RCP, square edge headwall, Ke= 0.500 Inlet / Outlet Invert= 579.85' / 579.00' S= 0.0026 '/' Cc= 0.900 n= 0.012 Concrete pipe, finished, Flow Area= 28.27 sf

Primary OutFlow Max=140.15 cfs @ 14.46 hrs HW=584.71' TW=578.20' (Dynamic Tailwater)
└**1=Culvert** (Barrel Controls 140.15 cfs @ 7.80 fps)

Pond 24P: Header W3

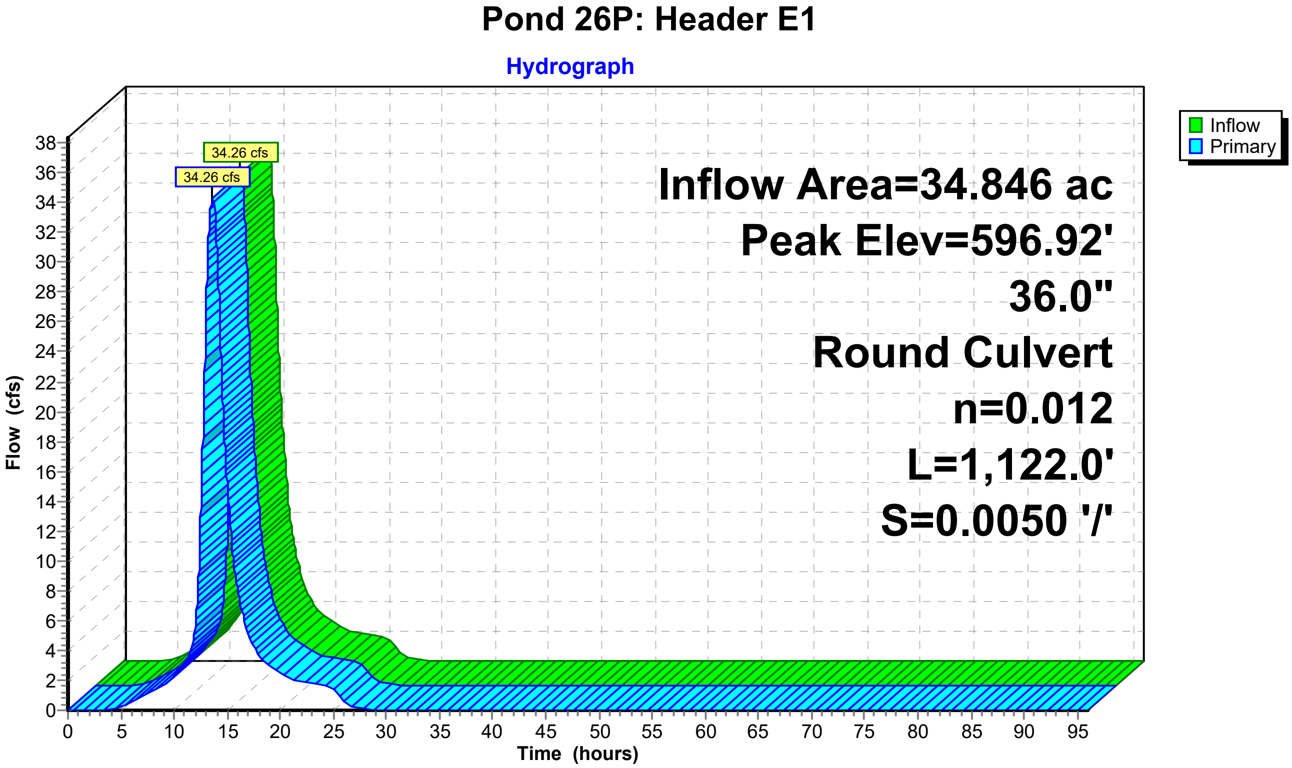


Summary for Pond 26P: Header E1

```
Inflow Area =       34.846 ac,   0.00% Impervious,  Inflow Depth =  3.42"    for  25-yr,24-hr event
Inflow      =      34.26 cfs @   13.61 hrs,  Volume=           9.935 af
Outflow     =      34.26 cfs @   13.61 hrs,  Volume=           9.935 af,  Atten= 0%,  Lag= 0.0 min
Primary     =      34.26 cfs @   13.61 hrs,  Volume=           9.935 af
    Routed to Pond 27P : Header E2

Routing by Dyn-Stor-Ind method, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Peak Elev= 596.92' @ 13.61 hrs
```

Device	Routing	Invert	Outlet Devices
#1	Primary	594.40'	**36.0" Round Culvert** L= 1,122.0' RCP, square edge headwall, Ke= 0.500 Inlet / Outlet Invert= 594.40' / 588.79' S= 0.0050 '/' Cc= 0.900 n= 0.012 Concrete pipe, finished, Flow Area= 7.07 sf

Primary OutFlow Max=34.26 cfs @ 13.61 hrs HW=596.92' TW=590.20' (Dynamic Tailwater)
↑—**1=Culvert** (Inlet Controls 34.26 cfs @ 5.40 fps)



Summary for Pond 27P: Header E2

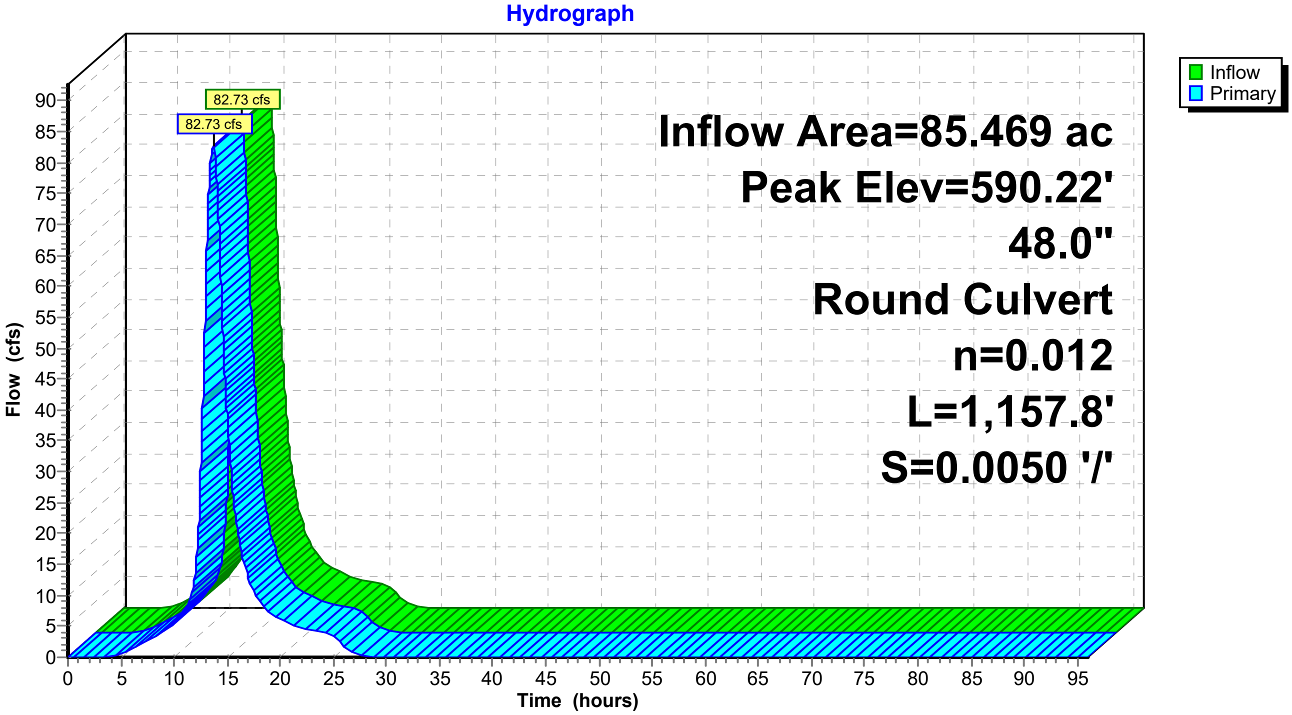
```
Inflow Area =      85.469 ac,   0.00% Impervious,  Inflow Depth =  3.42"    for  25-yr,24-hr event
Inflow      =      82.73 cfs @   13.66 hrs,  Volume=          24.367 af
Outflow     =      82.73 cfs @   13.66 hrs,  Volume=          24.367 af,  Atten= 0%,  Lag= 0.0 min
Primary     =      82.73 cfs @   13.66 hrs,  Volume=          24.367 af
    Routed to Pond 28P : Header E3
```

Routing by Dyn-Stor-Ind method, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Peak Elev= 590.22' @ 13.68 hrs

Device	Routing	Invert	Outlet Devices
#1	Primary	585.79'	**48.0" Round Culvert** L= 1,157.8' RCP, square edge headwall, Ke= 0.500 Inlet / Outlet Invert= 585.79' / 580.00' S= 0.0050 '/' Cc= 0.900 n= 0.012 Concrete pipe, finished, Flow Area= 12.57 sf

Primary OutFlow Max=82.66 cfs @ 13.66 hrs HW=590.22' TW=585.72' (Dynamic Tailwater)
└**1=Culvert** (Outlet Controls 82.66 cfs @ 7.42 fps)

Pond 27P: Header E2



Summary for Pond 28P: Header E3

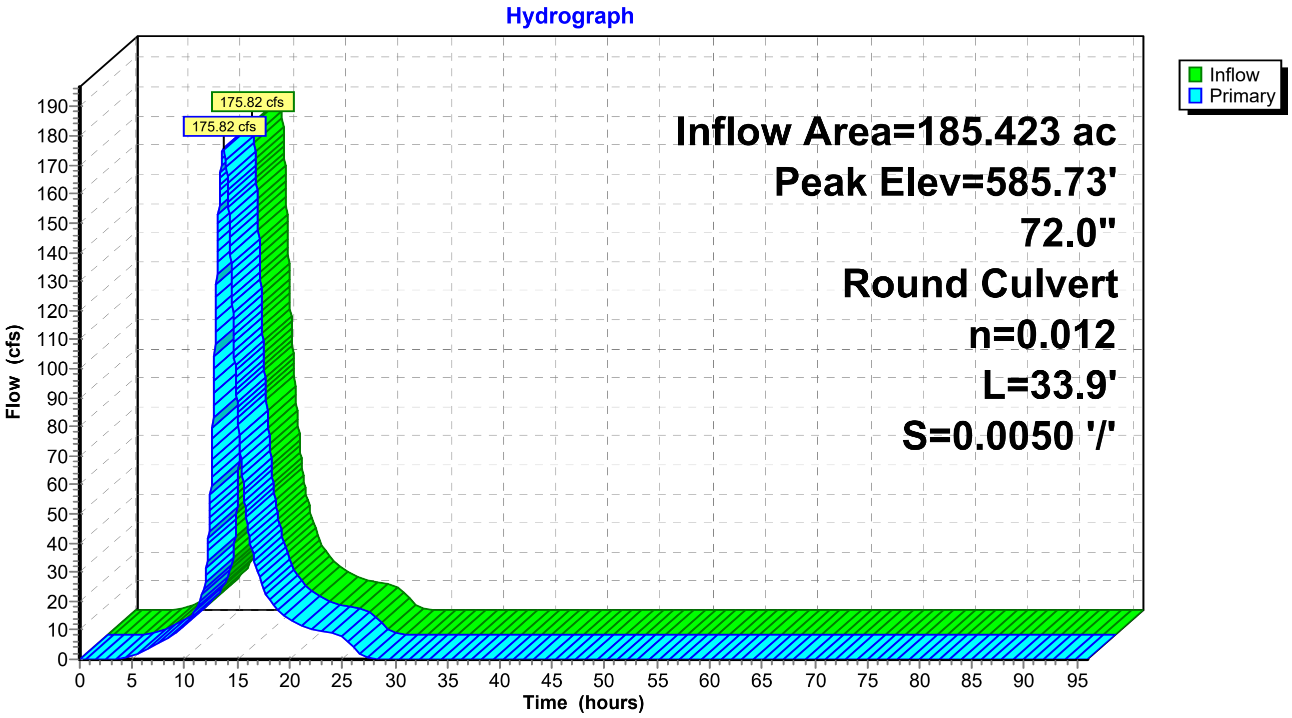
Inflow Area = 185.423 ac, 0.00% Impervious, Inflow Depth = 3.42" for 25-yr,24-hr event
Inflow = 175.82 cfs @ 13.70 hrs, Volume= 52.864 af
Outflow = 175.82 cfs @ 13.70 hrs, Volume= 52.864 af, Atten= 0%, Lag= 0.0 min
Primary = 175.82 cfs @ 13.70 hrs, Volume= 52.864 af
Routed to Reach 32R : Exist Discharge Channel

Routing by Dyn-Stor-Ind method, Time Span= 0.00-96.00 hrs, dt= 0.03 hrs
Peak Elev= 585.73' @ 13.70 hrs

Device	Routing	Invert	Outlet Devices
#1	Primary	580.00'	**72.0" Round Culvert** L= 33.9' RCP, square edge headwall, Ke= 0.500 Inlet / Outlet Invert= 580.00' / 579.83' S= 0.0050 '/' Cc= 0.900 n= 0.012 Concrete pipe, finished, Flow Area= 28.27 sf

Primary OutFlow Max=175.80 cfs @ 13.70 hrs HW=585.73' TW=578.51' (Dynamic Tailwater)
└─**1=Culvert** (Barrel Controls 175.80 cfs @ 8.12 fps)

Pond 28P: Header E3



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