Post Closure Plan

CFR 257.104(d)

Fly Ash Reservoir II

Cardinal Plant

Brilliant, Ohio

September, 2016

Prepared for: Cardinal Operating Company - Cardinal Plant

Brilliant, Ohio

Prepared by: Geotechnical Engineering Services

American Electric Power Service Corporation

1 Riverside Plaza

Columbus, OH 43215

GERS-16-048

Post Closure Plan
CFR 257.104(d)
Fly Ash Reservoir FAR II
Cardinal Plant

GERS-16-048

PREPARED BY Mohammad A. Ajlouni, Ph.D.,P.E. **DATE** 9/1/2016

REVIEWED BY Daniel W. Pizzino, P.E. **DATE** 9/14/2016

APPROVED BY Gary F. Zych, P.E. **DATE** 9/14/2016

Manager – AEP Geotechnical Engineering

STATE OF OHIO
MOHAMMAD
A
AJLOUNI
67074
REGISTERED
PROFESSIONAL ENGINEER

PROFESSIONAL ENGINEER

SEAL & SIGNATURE

I certify to the best of my knowledge, information, and belief that the information contained in this post closure plan meets the requirements of 40 CFR § 257.104.

CONTENTS

1.0 OBJECTIVE

This report was prepared by AEP- Geotechnical Engineering Services (GES) section to fulfill requirements of CFR 257.104(d) for Post Closure Plans of CCR units.

2.0 DESCRIPTION OF THE CCR IMPOUNDMENT

The Cardinal Power Plant in Wells Township, Jefferson County, near the town of Brilliant in eastern Ohio.

It is owned by Buckeye Power and AEP Generation Resources (GENCO) and is operated by Cardinal Operating Company. The facility operates two surface impoundments for storing CCR; the Bottom Ash Complex and Cardinal Fly Ash Reservoir II (FAR II) Dam. This report deals with the post closure plan for the Fly Ash Pond FAR II.

The FAR II Dam is a valley filled dam with a unique structure whose current configuration is the result of the original earth fill dam and two separate raisings. The original earth fill dam (Stage 1) consisted of a 180 feet high arched earth embankment incorporating a zoned cross section. At 925 feet NGVD, the dam featured a 70-foot wide by 1,055-feet long crest. The maximum operating pool that could be achieved with the original configuration was El. 913. In 1997, the original dam was raised, referred to as Stage 2. Following this raising, the dam was 237 feet high with a 30-foot wide crest. In 2013, the dam was raised 13 feet using back-to-back MSE walls, bringing the dam into its current, Stage 3 configuration. The principal features of the typical section are the MSE wall themselves and a vinyl sheet pile wall extending from the existing clay core to the top of the PMF flood level for seepage cutoff purposes. The FAR II Dam received sluiced fly ash and waste water from the plant via the bottom ash pond.

3.0 DESCRIPTION OF POST CLOSURE PLAN 257.104(d)(1)(i)

[A description of the monitoring and maintenance activities required in paragraph (b) of this section for the CCR unit, and the frequency at which these activities will be performed.]

3.1 SECTION 257.104(B)(1)

[Maintaining the integrity and effectiveness of the final cover system including making repairs to the final cover as necessary to correct the effects of settlement, subsidence, erosion, or other events, and preventing run-on and run-off from eroding or otherwise damaging the final cover.]

Inspections are performed for the items noted below. The inspection frequencies are scheduled to properly detect any issues so that repairs can be performed before significant harm occurs.

- Soil Dike: The soil dike will be inspected for slides, displacement, seepage, and erosion.
- Cover: The final cover will be inspected for erosion and for the condition of the vegetated cover, i.e., gaps in vegetation or presence of undesirable trees or brush. The integrity of the cover drainage system will also be inspected.

- Final Cover Surface: The Final Cover surface will be inspected for any ponding of water or flat areas. Due to the design contours required to achieve the final cap grade, special attention will be focused to ensure that no settlement, subsidence, erosion, depressions or flat areas exist and that no water is allowed to pond above the cap system.

- Surface Drainage System: The surface drainage system, including channels, culverts, slope drains, etc., will be inspected for erosion, integrity of channel lining, ponding, and accumulated sediment.

Maintenance during the post-closure care period will be performed as discussed below, based upon the facility inspections described above.

- Erosion Damage Repair: Any areas exhibiting erosion will be repaired by replacing and compacting the material in-kind to design grade/specifications, and reseeding the area to the specifications. Applications of additional fertilizer, selective herbicides, rodent control measures, etc. will be implemented as necessary. In the selection of fertilizers and herbicides, ensure their use will not impact the groundwater negatively. Follow-up monitoring of the repaired area will be conducted to ascertain the integrity of the repair.

- Settlement, Subsidence, Displacement: Any areas at the closed site exhibiting evidence of settlement, subsidence, or displacement will be examined to determine the cause of the movement. If backfilling or placing additional fill material is needed to maintain the integrity of the closed structure, it will be performed in accordance with the site/closure specifications, including seeding. If the condition reoccurs or persists, or if the severity of the condition initially is judged to warrant it, a detailed investigation of the cause will be performed and remedial action will be performed. Similarly, any areas of the soil dike exhibiting sliding, displacement, or seepage will be investigated. Repairs will be made as necessary. Follow-up monitoring of the area will be performed to ascertain that the problem has been corrected.

- Closure Cap Surface: Any areas that show signs of ponding water or flat contours will be examined and rectified. Due to the design contours required to achieve the final cap grade, special attention will be focused on the cap surface to ensure that any areas that hold water are re-graded to promote drainage, re-seeded to promote vegetative growth, and maintained to ensure that the ponding of water does not persist.

- Surface Water Drainage System: The channel linings are designed to withstand the design velocities. Maintenance of the surface water drainage system will consist of removing sediment and/or undesirable vegetation from the surface water runoff control system (channels and culverts) as required. Eroded areas will be repaired by back-filling and reseeding according to the specifications. Damage to culverts will be repaired; structure replacement will be performed if needed.

3.2 SECTION 257.104(b)(3)

[Maintaining the groundwater monitoring system and monitoring the groundwater in accordance with the requirements of §257.90 through 257.98.]

The groundwater monitoring system will be inspected for the general integrity of the wells, well casings and well protective casings. Any damaged portions of the monitoring wells and/or their protective casings will be replaced in-kind.

Monitoring the groundwater will be in accordance with the groundwater monitoring plan for this facility and in accordance with the requirements of §§257.90 through 257.98.

4.0 POST-CLOSURE CONTACT 257.104 (d)(1)(ii)

[The name, address, telephone number and email address of the person or office to contact about the facility during the post-closure care period.]

The name, address, and telephone number of the person to contact about the Facility during the post-closure period shall be provided upon notice of closure.

5.0 POST-CLOSURE PLANNED USE 257.104 (d)(1)(iii)

[A description of the planned uses of the property during the post-closure period. Post-closure use of the property shall not disturb the integrity of the final cover, liner(s), or any other component of the containment system, or the function of the monitoring systems unless necessary to comply with the requirements in this subpart…]

The post-closure use of the property will be undisturbed vacant land space. The only activities occurring on the closed CCR unit will be related to the Post-Closure care activities. All other activities will be prohibited.

ATTACHMENT A

Excerpts from 2012 Cardinal FAR II Closure Plan

PERMIT-TO-INSTALL APPLICATION
CARDINAL PLANT
FLY ASH RESERVOIR II (FAR II) DAM RAISING PROJECT

VOLUME 3
FINAL CLOSURE/POST-CLOSURE PLAN

Submitted to:

Ohio Environmental Protection Agency

Submitted and Owned by:

Cardinal Operating Company
Cardinal Plant
Brilliant, Ohio

Prepared by:

American Electric Power Service Corporation
1 Riverside Plaza, Columbus, Ohio 43215

and

S&ME Engineering, Inc.
6190 Enterprise Court, Dublin, Ohio 43016

May 2012

FINAL CLOSURE/POST-CLOSURE PLAN

CARDINAL FLY ASH RESERVIOR II CLOSURE

Christopher K. Hall, P.G.
S&ME, Inc.

STATE OF OHIO
STEPHEN J. LOSKOTA E-57966
REGISTERED
PROFESSIONAL ENGINEER

Stephen J. Loskota, P.E.
S&ME, Inc.

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APPENDICES

I. INTRODUCTION

This document presents information for the Final Closure and Post-Closure Care of Fly Ash Reservoir (FAR) II at the Cardinal Generating Station located near Brilliant, Ohio. This Plan for the closure of the surface water facility has been prepared generally in accordance with the requirements for the closure and post-closure care of residual solid waste disposal facilities as described in Ohio Administrative Code (OAC) 3745-30-09 and OAC 3745-30-10.

The closure of the facility will generally include:

1) Termination of the pumping of ash slurry into the reservoir;
2) Regrading of the surface of the ash to create positive drainage from all areas.
3) Installing a cap system over the exposed ash.
4) Establishing vegetation growth.
5) Lowering the invert elevation of the emergency spillway so that the reservoir will no longer impound water except as needed for temporary construction sedimentation control.
6) Improving the drainage between the emergency spillway and the receiving stream to include installation of a plunge pool/stilling basin.
7) Installation of a new leachate treatment system for FAR No. 1 Landfill.

With the exception of Item 7, details of the above listed activities are depicted in the Drawing Set entitled "Fly Ash Reservoir II Closure" which is included as Appendix D of this document. Details regarding Item No. 7 (leachate treatment for the FAR 1 Landfill) will be depicted in a Permit Alteration Application to be submitted to OEPA Division of Materials and Waste Management for approval prior to the installation of the new system.

II. FINAL CLOSURE

A. General

1) Facility Location

Cardinal FAR II is located approximately 1.5 miles north of the Cardinal Plant electrical generating facility near the town of Brilliant in Wells Township, Jefferson County, Ohio. More specifically, the reservoir is located approximately 6,500 feet northeast of the intersection of Riddles Run Road (Township Road 163) and Township Road 164.

2) Contacts

Any questions regarding FAR II during the final closure and post-closure care period should be directed to:

American Electric Power
Land Environmental and Remediation Services Manager
1 Riverside Plaza
Columbus, Ohio 43215
Ph. (614) 716-1266

or

Cardinal FAR II
306 County Road 7E
Brilliant, Ohio 43913
Ph. (740) 598-6540

3) Information

a) Grading Plans

The drawing set entitled "Fly Ash Reservoir II Closure" included as Appendix D of this document depicts the anticipated horizontal and vertical limits of the following:

- ash at the initiation of closure activities;
- ash at the completion of closure activities; and,
- the final cap system.

b) Grid System – Horizontal and Vertical Control

The grid system used to construct and operate the facility and which will be used for closure and post-closure care is depicted on the grading plans contained in the drawing set included as Appendix D of this document. Benchmarks with known coordinates and elevations are also depicted on the drawings.

c) Details

Details for the construction of the cap system and other components to be constructed as part of Final Closure are depicted in the drawing set included as Appendix D of this document.

d) Erosion Control

Details for permanent surface water control structures are depicted in the drawing set included as Appendix D of this document; a permanent sediment pond will not be required for the facility. Temporary erosion control measures to be used during Final Closure construction activities will be developed as part of a Storm Water Pollution Prevention Plan prior to the initiation of Final Closure construction.

e) Static and Seismic Stability Analysis

The static and seismic stability analyses for the reservoir dam were completed as part of the analyses for the raising of the FAR II Dam and are presented in the document entitled "Cardinal Plant, Fly Ash Retention Pond II, Final Design Report for Proposed Mechanically-Stabilized Earth Rasing of Dam" S&ME, April 2012 which has been submitted to the ODNR Division of Dam Safety. All factors of safety values calculated exceed the required minimum values established by Ohio Department of Natural Resources, Division of Dam Safety.

f) Groundwater Monitoring Plan

Groundwater monitoring wells are present around FAR II. The wells are monitored as part of an OEPA, DMWM approved *Groundwater Monitoring Plan* for the FAR No. 1 Residual Solid Waste Landfill. Compliance with the existing Groundwater Monitoring Plan for the FAR No. 1 Landfill will continue throughout Final Closure of FAR II.

g) Closure and Post Closure Care Costs

Estimated costs for the Final Closure of FAR II and Post-Closure Care of FAR II are included in Appendix A of this document.

4) Availability of Cap Material

The soil which will be used to cover the regarded ash during Final Closure will be obtained from borrow areas near the site. It is anticipated that adequate resources will be available to satisfy the needs of the facility. It is estimated that 536,400 cubic yards of cover soil will be required to construct the cap system.

5) Quality Assurance/Quality Control

A *Quality Assurance and Quality Control Plan* for the Final Closure construction activities is included as Appendix C of this document. The QA/QC Plan addresses material qualification and material placement specifications to be used during Final Closure construction.

B. Future Maintenance

The reservoir will be closed in the manner depicted in the drawings included as Appendix D of this document and in accordance with the applicable procedures described in the QA/QC Plan included as Appendix C of this document. The intent of the final grading plan and surface water control structures is to minimize the need for post-closure maintenance.

C. Initiation of Closure

Final closure activities will begin once the reservoir has exhausted its useful life for ash storage and wastewater treatment.

D. Notification of Anticipated Closure

Cardinal Operating Company will provide written notice by certified mail to Ohio EPA and the ODNR Division of Dam Safety at least ninety (90) days in advance of commencing Final Closure construction activities.

Any changes to the information that identifies the facility's contact person will be provided to the Ohio EPA in writing by certified mail at least thirty (30) days prior to commencing Final Closure.

E. Notification of Actual Closure

Within seven (7) days of the date that the reservoir has exhausted its useful life for ash storage and wastewater treatment, written notice by certified mail will be provided to the Ohio EPA and the ODNR Division of Dam Safety informing the agencies of the actual date.

F. Final Closure Activities

1) Fences and Gates

Security consisting of fencing and gates will be maintained during the closure and post-closure period unless the facility is to be used for other purposes as deemed acceptable by the Ohio EPA. Access will be maintained to all active monitoring sites throughout the closure and post-closure care period.

2) Signs

Because the reservoir exclusively accepts only ash generated by AEP owned facilities, installation of closure signage is not required and will not be completed.

3) Cap System

The cap system above the regraded ash will consist of a geosynthetic drainage net overlain by a protective layer of soil overlain by a soil vegetative layer. The material used to construct the cap system will be qualified, placed, and tested in accordance with the *Quality Assurance/Quality Control Plan* included as Appendix C of this document.

The final grades of the completed cap system will slope at a nominal 2% grade to drainage swales. Calculations demonstrating soil erosion rate at less than 5 tons per acre per year are included in Appendix B of this document.

Installation of the final cap system may be initiated while the reservoir remains operational. In this event, capping would begin in the upstream areas and would be placed so as to maintain positive drainage to the reservoir pool.

4) Surface Water Controls

All permanent surface water control structures depicted on the drawings included as Appendix D of this document will be installed as part of Final Closure construction activities. Closure construction will be completed so as to minimize ponding and erosion. Temporary sediment and erosion control measures will be installed, as necessary, until a vegetative cover is established. Surface water control structures will be inspected routinely to monitor erosion or blockage of flow.

5) Groundwater Monitoring System

Groundwater monitoring in accordance with the OEPA, DMWM approved Groundwater Monitoring Plan for the FAR No. 1 Residual Solid Waste Landfill will continue uninterrupted throughout Final Closure activities.

6) Plat and Deed Notations

As part of Final Closure, the Plat and deed for each parcel comprising the reservoir site will be modified with a notation indicating that coal combustion ash has been placed in the parcel. The notation will be filed with the County Recorder and will including, at a minimum, the following information: location, depth, volume, and nature of the ash.

7) Operating Requirements

During Final Closure activities the facility will continue to operate in accordance with the governing permit documents approved by the OEPA, DSW including monitoring and reporting.

G. Annual Report of Closure Activities

Closure of the reservoir may be initiated while the facility remains in operation and will continue for a number of years after the placement of ash in the reservoir has ceased. Annual Reports of Closure Activities will be submitted any year that closure construction is completed throughout the Final Closure construction period. The reports will be submitted by April 1st of the year following construction and will contain, at a minimum, the following:

- Description of closure activities completed during the reporting year;
- Description of proposed closure activities for the following year;
- Topographic mapping depicting the ash grades and final cover grades in the areas where closure activities were completed during the reporting year; and,
- Documentation of test results as required by the QA/QC Plan for activities completed during the reporting year.

H. Final Closure Certification

Within ninety (90) days of completing final closure activities, a final closure certification report will be submitted to the Ohio EPA and will include:

- A summary of the documentation of construction of the entire final cover system;
- A topographic map of the closed facility showing the information specified in OAC 3745-30-09(H)(1);
- Documentation on the groundwater monitoring system;
- A copy of the plat and deed notation filed with the County Recorder; and
- Documentation that the facility is protected from unauthorized access

I. Regulatory Access

Access to the facility during Final Closure will be provided to the OEPA and the ODNR Division of Dam Safety during normal operating hours.

III. POST-CLOSURE CARE ACTIVITIES

A. Duration

Post-closure care activities will begin upon submittal of the final closure certification report and will continue for a period of fifteen (15) years unless shortened or extended in accordance with OAC 3745-30-10(B).

B. Activities

Post-closure care activities will include:

- Continued operation and maintenance of the stormwater/surface water management system and the groundwater monitoring program;
- Maintenance of the final cover system;
- Fulfilling all inspection, monitoring, and reporting requirements; and
- Submitting a post-closure care certification.

C. Inspections

Inspections of the closed facility will be conducted quarterly throughout the post-closure care period. A written summary of the inspection will be submitted to the Ohio EPA within fifteen (15) days of conducting the inspection. The inspection report will document the nature and extent of any problem areas identified, as well as provide an estimated starting and completion date for corrective measures to be taken. Access to the site by regulatory personnel will be made throughout the Post-Closure Care period.

1) Surface Water Controls

The stormwater/surface water management systems, including ditches and berms will be inspected for erosion, ponding, blockage of flow, sediment accumulation, and other evidence of improper performance. Discharge structures will also be inspected to ensure operational performance.

2) Monitoring Wells

Groundwater monitoring well locks, casing protectors and surface seals will be visually inspected during each sampling event and any unusual operational problems will be described in the groundwater reports submitted to the Ohio EPA.

3) Cap System

The cap system will be inspected for evidence of ponding, settlement, and erosion, as well as damage caused by burrowing animals. Any damaged areas will be repaired by replacing the materials and restoring the site to final grade. If a condition reoccurs or persists, an investigation will be conducted to determine if a more permanent solution is warranted. Any permanent corrective measures that involve revisions to the facility's authorizing documents will be submitted to the Ohio EPA for review.

The condition of the vegetative cover will be evaluated (i.e. thickness, bare spots, invasive woody species) during each inspection. Corrective actions such as reseeding, fertilizing, and selective herbicide applications will be implemented as necessary. Maintenance mowing will be conducted as necessary to discourage woody plant growth and to maintain the appearance and health of the vegetation.

D. NPDES Compliance

The facility will continue to monitor and report stormwater/surface water discharges in accordance with the facility's NPDES permit throughout the post-closure care period.

E. Groundwater Monitoring

Groundwater wells around FAR II are monitored as part of an OEPA, DMWM approved *Groundwater Monitoring Plan* for the FAR No. 1 Residual Solid Waste Landfill. Compliance with the existing Groundwater Monitoring Plan for the FAR No. 1 Landfill will continue throughout the Post-Closure Care period of FAR II.

F. Final Certification

Upon completion of the post-closure care period, a written certification will be prepared and submitted to the Ohio EPA with supporting documentation that all post-closure care activities have been completed in accordance with this Post-Closure Care Plan. The certification will be signed and sealed by a professional engineer registered in Ohio.

APPENDIX A
CLOSURE AND POST CLOSURE CARE COST ESTIMATES

Appendix A checked and reviewed by:

Michael G. Rowland, P.E.
S&ME, Inc.

Appendix A prepared by:

Christopher K. Hall, P.G.
S&ME, Inc.

Final Closure Cost Estimate
Fly Ash Reservoir No. 2

CKH: 4/6/12

		Quantity	Unit	Rate	Item Total
1	Mobilization	10%	of	Items 2-12	$1,987,000
2	Ash - Dewater, Excavate, Transport, and Place	1,384,000	c.y.	$10.00	$13,840,000
3	Geosynthetic Drainage net	140	acres	$22,000	$3,080,000
4	Filter Fabric	21.8	acres	$10,000	$218,000
5	Cap, General Fill	401,700	c.y.	$4.00	$1,606,800
5	Cap, Topsoil	137,100	c.y.	$2.50	$342,750
6	No. 1 Stone, Channel C Erosion Protection	580	tons	$25.00	$14,500
7	No. 57 Stone, Geo-Net Outlet	4,230	tons	$30.00	$126,900
8	Re-Vegetation	170	acres	$2,500	$425,000
9	Spillway Excavation	15,200	c.y.	$4.00	$60,800
10	Fabriform Channel	350	c.y.	$150.00	$52,500
11	Plunge Pool	1	lump	$50,000	$50,000
12	Erosion and Sedimentation Control	1	lump	$50,000	$50,000
13	QA/QC and Certification	5%	of	Items 1-12	$1,093,000
				Estimated Total	**$22,947,250**

Post Closure Care Cost Estimate
Fly Ash Reservoir No. 2

CKH: 3/15/12

Annual Costs

		Quantity	Unit	Rate	Item Total
1	Quarterly Inspection and Reporting	4	ea	$2,500	$10,000
2	Monthly NPDES Monitoring	12	ea	$4,000	$48,000
3	Cap Maintenance and Mowing	170	acres	$300	$51,000
4	Surface Water Control Structures Maintenance	1	lump	$20,000	$20,000
5	Access Road Maintenance	1	lump	$10,000	$10,000
6	Miscellaneous Maintenance	1	lump	$5,000	$5,000
7	General Administration	15%	of	$144,000	$21,600
				Estimated Annual Total	**$165,600**
				Years of Post Closure Care	15
				Sub-Total	$2,484,000
				Final Certification Report	$25,000
				Estimated Overall Total	**$2,509,000**

G:\Columbus_CMH\11000-11999\11497\11497-042 Cardinal FAD2 Raising\Submittals_Originals\Closure\2012-03-16 Check Set\FAR 2 Close Pln App A-Cost Est-2012 Mar.xlsx

APPENDIX B
CALCULATIONS

STATE OF OHIO
ALLEN J.
SMITH JR
E-71835
REGISTERED
PROFESSIONAL ENGINEER

4-20-12

Appendix B calculations checked and reviewed by:

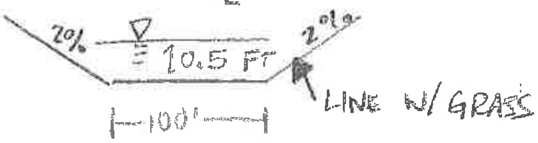
A.J. Smith, P.E.
S&ME, Inc.

Appendix B calculations prepared by:

Adam R. Weinandy, E.I.
S&ME, Inc.

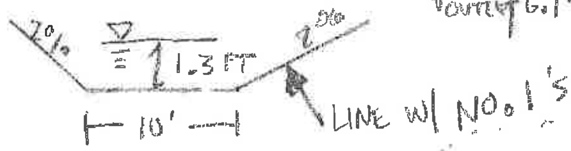
CHANNEL A 0+00 to 47+00

Long Slope = 1%
Qp = 210 CFS
V = 3.2 FT/S



CHANNEL C

Long Slope = 2.5%
Qp = 420 CFS
V = 4.5 FT/S

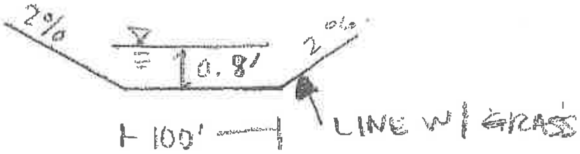


PLUNGE POOL

	GDOT B	TYPE C
LENGTH	85'	125'
WIDTH	60'	86'
DEPTH	6'	8.5'
Vouter	6.1 FT/S	5.4 FT/S

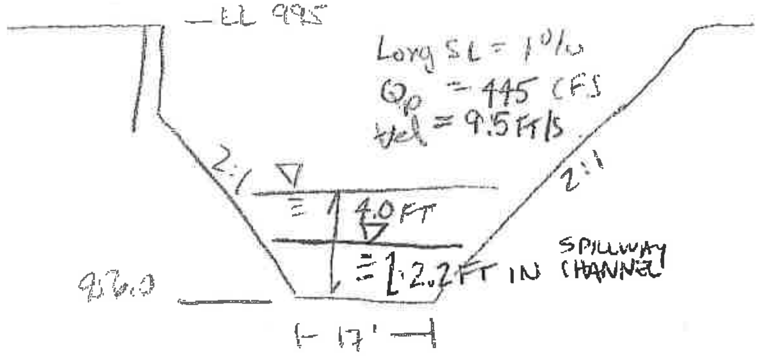
CHANNEL A 47+00 to 51+00

Long Slope = 1%
Qp = 431 CFS
Vel = 4.0 FT/S



Revised SPILLWAY

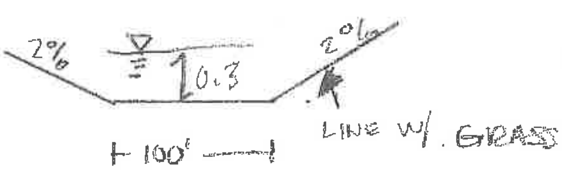
Long SL = 1%
Qp = 445 CFS
Vel = 9.5 FT/S



CHANNEL A 51+00 to 70+00

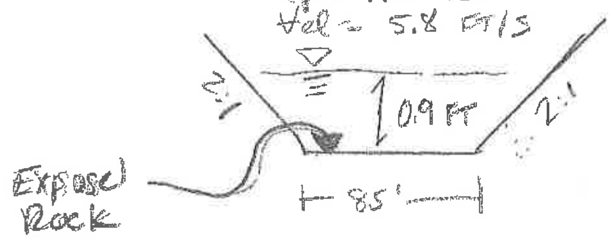
Long. slope = 1%
Qp = 445 CFS
Vel = 5.1 FT/S

– Soil Survey channels within 100' width may need to be stabilized with stone.



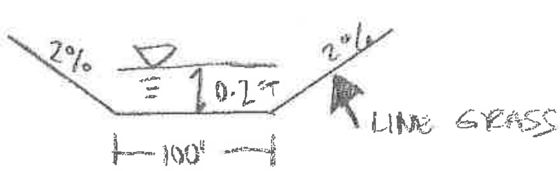
EX SPILLWAY CHANNEL

Long SLOPE = 3%
Qp = 445 CFS
Vel = 5.8 FT/S



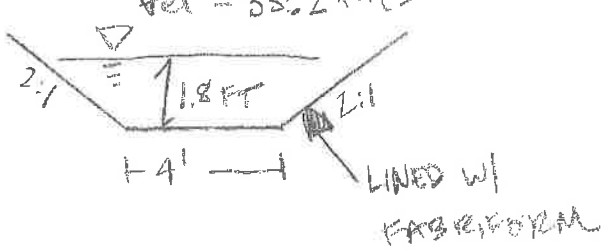
CHANNEL B

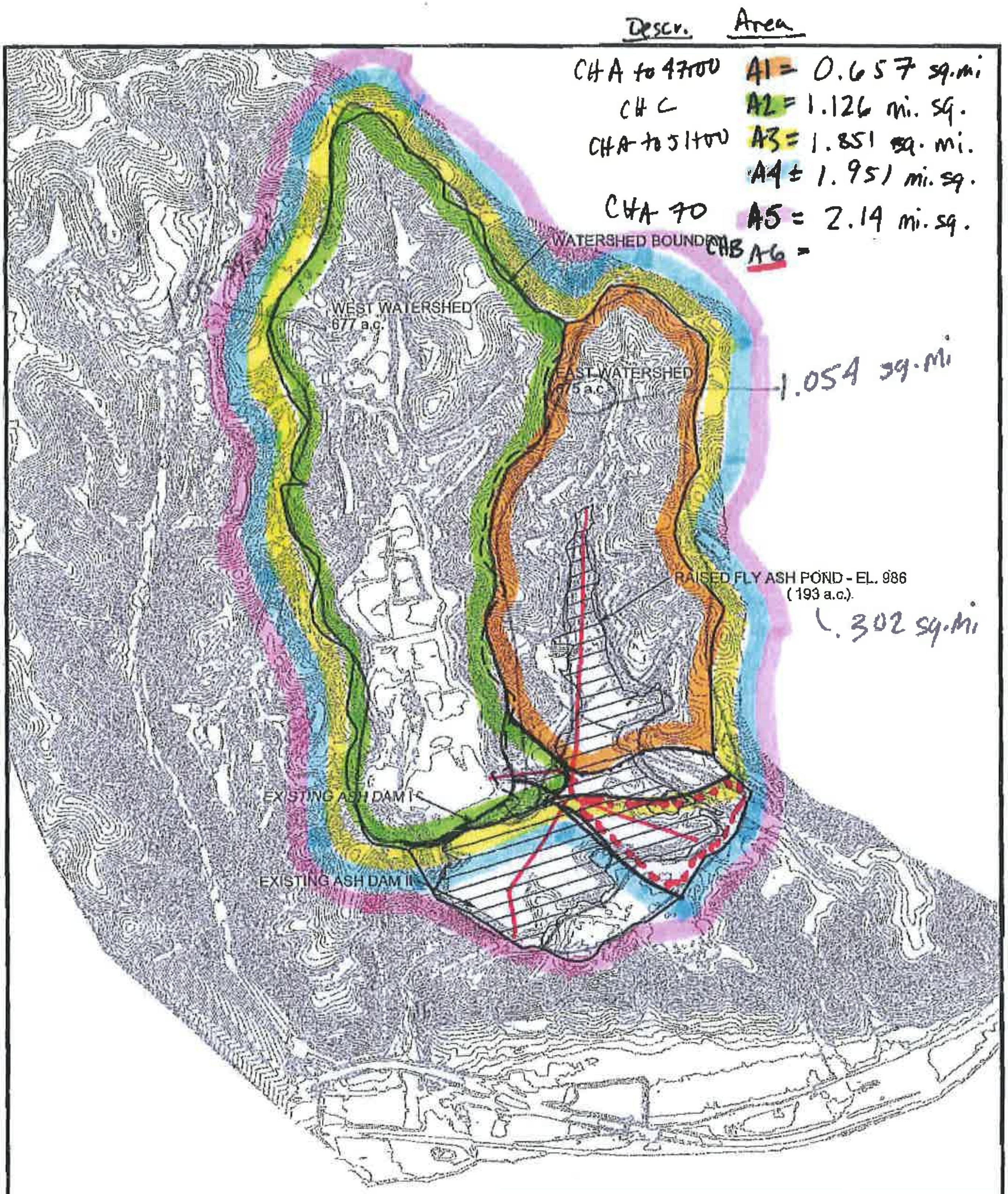
LONG. SLOPE = 1%
Qp = 38 CFS
Vel = 1.8 FT/S



FABRIFORM CHANNEL (D)

Avg slope = 31%
Qp = 445 cfs
Vel = 35.2 Ft/S





WATERSHED MAP

CARDINAL PLANT FLY ASH RETENTION POND II BRILLIANT, OHIO		BBCM Solutions To Build On Columbus (614) 793-2226 Cleveland (216) 901-1000 Cincinnati (513) 771-8471 Dayton (937) 424-1011
Project: 011-11497-042	Drawn By: BAM	
Drawing Date: 09/08/2011	Approved By: AJS	
Revision Date:	Scale: 1" = 800'	

PLATE 2

CARDINAL CLOSURE
H+H: EROSION CALCULATION
3/7/12
Sheet 1 OF 7

Soil Erosion Rate

Revised Universal Soil Loss Equation (RUSLE)
A=R*K*Ls*C*P

A= Average annual soil loss (tons/acre)
R= Rainfall runoff erosivity factor
K= Soil erodibility factor
Ls= Slope Length/Steepness Factor
C= Cover Management Factor
P= Land Support Practice Factor

Find R

From Isoerodent map of the Eastern US

R= 125

Find K

Assume Silty Clay Loam

K= 0.37

Find Ls

From Table 2-2

Descr	Slope	Avg. Length	**Ls**
AVG	2.5%	800	**1.1**

Find C

From Table 3-3
Type of Ground Cover
Permanent Seedings therefore **C= 0.01**

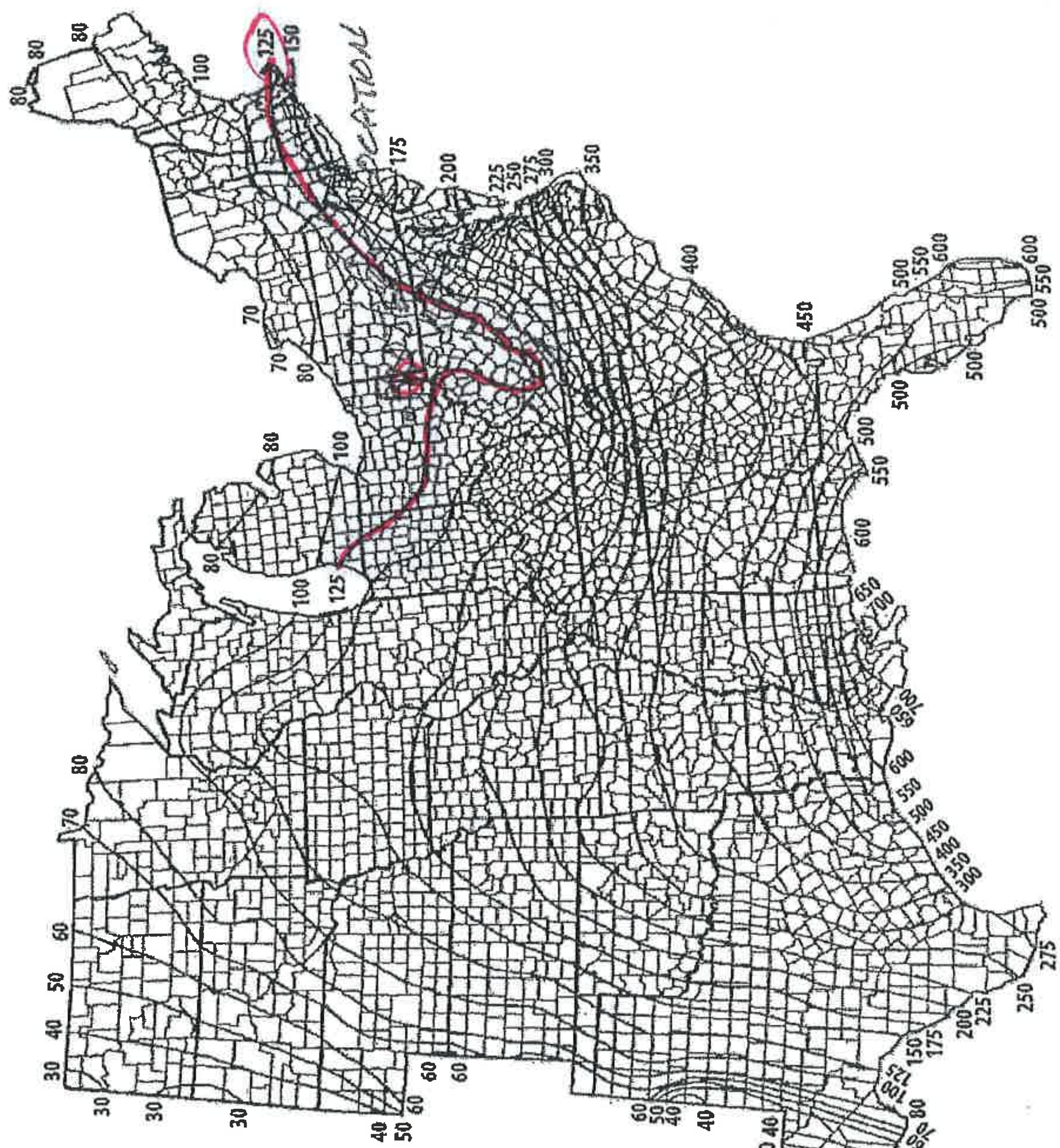
Find P

No Specific Land Support Practice Factor
Therefore **P= 1**

A= 0.51 tons/acre/year

Sheet ~~1~~ 2 of ~~1~~ 7 sheets

Figure 2. Isoerodent Map of the Eastern U.S.



Note: Units for all maps on this page are are hundreds ft•tonf•in(ac•h•yr)^-1

Sheet ~~8~~ 3 of ~~8~~ 7 sheets

5.3.2 Soil Erodibility Factor

The soil erodibility factor (K-factor) is a quantitative description of the inherent erodibility of a particular soil; it is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. For a particular soil, the soil erodibility factor is the rate of erosion per unit erosion index from a standard plot. The factor reflects the fact that different soils erode at different rates when the other factors that affect erosion (e.g., infiltration rate, permeability, total water capacity, dispersion, rain splash, and abrasion) are the same. Texture is the principal factor affecting K_{fact}, but structure, organic matter, and permeability also contribute. The soil erodibility factor ranges in value from 0.02 to 0.69 (Goldman et al. 1986; Mitchell and Bubenzer 1980).

Goldman et al. (1986) note that several methods can be used to estimate the K-factor. The most frequently used are 1) SCS County Soil Survey reports compiled for many counties in the United States and 2) nomographs relating K-factors to topsoil conditions. The SCS county soil surveys contain soil maps superimposed on aerial photographs. The maps permit easy location of sites and tentative determination of soil series. Recent surveys list K-factors for the soil series in the table outlining the soil's physical and chemical properties. Goldman et al. (1986) note that this method of determining K-factors should only be used if minimal soil disturbance at the site is anticipated and a site analysis is unavailable.

The preferred method, according to Goldman et al. (1986), for determining K-factors is the nomograph method based on the work by Wischmeier et al. (1971) and is mathematically represented as follows:

$$K_{fact} = (1.292)\,[2.1\times10^{-6}\, f_p^{1.14}\,(12 - P_{om}) + 0.0325\,(S_{struc} - 2) + 0.025\,(f_{perm} - 3)] \qquad (5.51)$$

in which

$$f_p = P_{silt}(100 - P_{clay}) \qquad (5.52)$$

where

f_p is the particle size parameter (unitless)
P_{om} is the percent organic matter (unitless)
S_{struc} is the soil structure index (unitless)
f_{perm} is the profile-permeability class factor (unitless)
P_{clay} is the percent clay (unitless).

In Equation 5.51 the factor (1.292) is needed to convert K_{fact} from the English units used in Golman et al. (1986) to the metric units used in this report. The soil structure index, S_{struc}, is equal to: 1 for very fine granular soil; 2 for fine granular soil; 3 for medium or coarse granular soil; 4 for blocky, platy, or massive soil. The profile-permeability class factor, f_{perm}, is equal to: 1 for very slow infiltration; 2 for slow infiltration; 3 for slow to moderate infiltration; 4 for moderate infiltration; 5 for moderate to rapid infiltration; 6 for rapid infiltration. Erickson (1977), as reported by Goldman et al. (1986), used the information from the nomograph and

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superimposed K-factors for 2% organic matter on a U.S. Department of Agriculture (USDA) soil textural classification triangle. Goldman et al. (1986) also presents tables to modify the results to account for

- soils with greater than 15% very fine sand
- soils with organic matter content different from that of 2%
- soils with rock (i.e., soil particle size greater than 2 mm) content greater than 14% by volume
- permeability
- structure.

Stewart et al. (1975), as reported by Mills et al. (1985), Mitchell and Bubenzer (1980), and Novotny and Chesters (1981), also developed a table indicating the general magnitude of the K-factor as a function of organic matter content and soil textural class. Their results are presented in Table 5.10.

Goldman et al. (1986) note that if site inspection or data analyses indicate significant variations in the soil erodibility, different K-factors can be assigned to different areas of the site. They also note that a simpler and more conservative approach is to use the highest value obtained for all parts of the site, because it may not be possible to know exactly what soils will be exposed or how varied the soils are.

Table 5.10. Soil Erodibility Factor K_{fact} (after Stewart et al. 1975)[(a)]

	P_{om}(%)		
Textural Class	<0.5	2	4
Sand	0.05	0.03	0.02
Fine sand	0.16	0.14	0.10
Very finesand	0.42	0.36	0.28
Loamy sand	0.12	0.10	0.08
Loamy finesand	0.24	0.20	0.16
Loamy veryfine sand	0.44	0.38	0.30
Sandy loam	0.27	0.24	0.19
Fine sandyloam	0.35	0.30	0.24
Very fine sandy loam	0.47	0.41	0.33
Loam	0.38	0.34	0.29
Silt loam	0.48	0.42	0.33
Silt	0.60	0.52	0.42
Sandy clayloam	0.27	0.25	0.21
Clay loam	0.28	0.25	0.21

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Silty clayloam	0.37	0.32	0.26
Sandy clay	0.14	0.13	0.12
Silty clay	0.25	0.23	0.19
Clay		0.13-0.2	

(a) The values shown are estimated averages of broad ranges of specific soil values. When a texture is near the border line of two texture classes, use the average of the two K_{fact} values. In addition, the values shown are commensurate with the English units used in the cited reference (and as used in the source-term module input files). To obtain analagous values in the metric units used in this report, the above values should be multiplied by 1.292.

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TABLE 3-2
LS FACTORS FOR CONSTRUCTION SITES

Values for topographic factor, LS, for high ratio of rill to interrill erosion.[1]

	Horizontal Slope Length (ft.)																
Slope (%)	<3	6	9	12	15	25	50	75	100	150	200	250	300	400	600	800	1000
0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06
0.5	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.09	0.09	0.10	0.10	0.10	0.11	0.12	0.12	0.13
1.0	0.09	0.09	0.09	0.09	0.09	0.10	0.13	0.14	0.15	0.17	0.18	0.19	0.20	0.22	0.24	0.26	0.27
2.0	0.13	0.13	0.13	0.13	0.13	0.16	0.21	0.25	0.28	0.33	0.37	0.40	0.43	0.48	0.56	0.63	0.69
3.0	0.17	0.17	0.17	0.17	0.17	0.21	0.30	0.36	0.41	0.50	0.57	0.64	0.69	0.80	0.96	1.10	1.23
4.0	0.20	0.20	0.20	0.20	0.20	0.26	0.38	0.47	0.55	0.68	0.79	0.89	0.98	1.14	1.42	1.65	1.86
5.0	0.23	0.23	0.23	0.23	0.23	0.31	0.46	0.58	0.68	0.86	1.02	1.16	1.28	1.51	1.91	2.25	2.55
6.0	0.26	0.26	0.26	0.26	0.26	0.36	0.54	0.69	0.82	1.05	1.25	1.43	1.60	1.90	2.43	2.89	3.30
8.0	0.32	0.32	0.32	0.32	0.32	0.45	0.70	0.91	1.10	1.43	1.72	1.99	2.24	2.70	3.52	4.24	4.91
10.0	0.35	0.37	0.38	0.39	0.40	0.57	0.91	1.20	1.46	1.92	2.34	2.72	3.09	3.75	4.95	6.03	7.02
12.0	0.36	0.41	0.45	0.47	0.49	0.71	1.15	1.54	1.88	2.51	3.07	3.60	4.09	5.01	6.67	8.17	9.57
14.0	0.38	0.45	0.51	0.55	0.58	0.85	1.40	1.87	2.31	3.09	3.81	4.48	5.11	6.30	8.45	10.40	12.23
16.0	0.39	0.49	0.56	0.62	0.67	0.98	1.64	2.21	2.73	3.68	4.56	5.37	6.15	7.60	10.26	12.69	14.96
20.0	0.41	0.56	0.67	0.76	0.84	1.24	2.10	2.86	3.57	4.85	6.04	7.16	8.23	10.24	13.94	17.35	20.57
25.0	0.45	0.64	0.80	0.93	1.04	1.56	2.67	3.67	4.59	6.30	7.88	9.38	10.81	13.53	18.57	23.24	27.66
30.0	0.48	0.72	0.91	1.08	1.24	1.86	3.22	4.44	5.58	7.70	9.67	11.55	13.35	16.77	23.14	29.07	34.71
40.0	0.53	0.85	1.13	1.37	1.59	2.41	4.24	5.89	7.44	10.35	13.07	15.67	18.17	22.95	31.89	40.29	48.29
50.0	0.58	0.97	1.31	1.62	1.91	2.91	5.16	7.20	9.13	12.75	16.16	19.42	22.57	28.60	39.95	50.63	60.84
60.0	0.63	1.07	1.47	1.84	2.19	3.36	5.97	8.37	10.63	14.89	18.92	22.78	26.51	33.67	47.18	59.93	72.15

1 Such as for freshly prepared construction and other highly disturbed soil conditions with little or no cover (not applicable to thawing soil).

TABLE 3-3
COVER MANAGEMENT FACTORS (C) – CONSTRUCTION SITES

Type of Cover		Factor C	Percent[1]
None (fallow ground)		1.0	0.0
Temporary Seedings (90 percent stand):			
Ryegrass (perennial type)		0.05	95
Ryegrass (annuals)		0.1	90
Small grain		0.05	95
Millet or sudan grass		0.05	95
Field bromegrass		0.03	97
Permanent Seedings (90 percent stand):		0.01	99
Sod (laid immediately):		0.01	99
	Application Rate Tons Per Acre		
Mulch:			
Hay	.50	0.25	75
Hay	1.00	0.13	87
Hay	1.50	0.07	93
Hay	2.00	0.02	98
Small grain straw	2.00	0.02	98
Wood chips	6.00	0.06	94
Wood cellulose	1.75	0.10	90

[1] Percent soil loss reduction as compacted/with fallow ground.

Source: USDA-NRCS, Connecticut Technical Guide.

Project: 011.11497.042	By: ARW	Date: 1-Mar-12
Location: Cardinal FAR II Closure Plan	Checked: AJS	Date:

Channel A: 0+00 to 47+00 - GRAPHICAL PEAK DISCHARGE METHOD

(Based off of and Modified from Worksheet 4 In Appendix D of 210-VI-TR-55, Second Ed., June 1986)

Basin Data		
Drainage Area, A_m	0.657	sq mi
Runoff Curve Number, CN	64	
Time of Concentration, T_c	0.676	hr
Rainfall Distribution, SCS Type ___	II	(I, IA, II, III)
Pond and swamp areas spread throughout watershed	0	% of A_m

Computational Step	Storm 1	Storm 2	
Frequency	100	0	yr
Rainfall, P (24-hour)	3.8	0	in
Initial Abstraction, I_a (Use CN with Table 4-1 in TR-55 Manual)	1.125	0	in
Compute I_a/P	0.296	#DIV/0!	
Unit Peak Discharge, q_u (Use Tc and I_a/P with Equation for Exhibit 4-II in Appendix F as well as Table F-1, lineraly interpolated)	370	370	csm/in
Runoff, Q (Equations 2-3 and 2-4 in TR-55 Manual)	0.862	0.281	in
Pond and swamp adjustment factor, F_p	1	0	
Peak Discharge, q_p ($q_p = q_u A_m Q F_p$)	209.6	0.0	cfs

The graphical peak discharge method is used as a check for the results returned by the HEC-1 program

Project:	011.11497.042		By: ARW	Date: 1-Mar-12
Location:	Cardinal FAR II Closure Plan		Checked: AJS	Date:

Channel A 0+00 to 47+00 - CALCULATE T_c AND T_L

Based off of Worksheet 3 in Appendix D of 210-VI-TR-55, Second Ed., June 1986

Overland (Sheet) Flow

Segment	1	2		
Surface Description	Dense Grass			
Manning's roughness coefficient, n	0.24	0.01		
Flow Length, L	300	0.01	ft	
2-year, 24-hour rainfall, P_2	2.5	0.0	in	
Top/Bottom elevation of segment	1015 | 1012	|	ft	
Land Slope, s	0.25	0.1	ft/ft	
Travel Time, T_t	0.236	0	0.236	hr

$$T_t = \frac{0.007(nL)^{0.8}}{P_2^{0.5} s^{0.4}}$$

Shallow Concentrated Flow

Segment	3	4		
Surface Description (Paved or Unpaved)	Unpaved			
Flow Length, L	3600	0.01	ft	
Top/Bottom elevation of segment	1012 | 1009	|	ft	
Watercourse slope, s	0.25	0.01	ft/ft	
Average velocity, V (equation in Appendix F)	8.07	0.01	ft/s	
Travel Time, T_t	0.124	0	0.124	hr

$$T_t = \frac{L}{3600\ V}$$

Channel Flow

Segment	2	6		
Base Width, b	100	1	ft	
Side Slopes, w	0.02	0.01	ft/ft	
Depth, d	0.53	0.01	ft	
Cross sectional flow area, a	53	0.01	ft^2	
Wetted Perimeter, p_w	101.1	0.01	ft	
Hydraulic Radius, r	0.524	1	ft	
Top/Bottom elevation of segment	1009 | 952	|	ft	
Channel Slope, s	0.01	0.01	ft/ft	
Manning's roughness coefficient, n	0.027	0.01		
Velocity, V	3.6	0.01	ft/s	
Flow Length, L	4100	0.01	ft	
Travel Time, T_t	0.316	0.000	0.316	hr

$$T_L = 0.6T_c$$

Area Time of Concentration, T_c	0.676	hr
Area Lag Time, T_L	0.4056	hr
Area Lag Time, T_L	24.336	min

Use Manning's Equation:

Channel A: Sta. 0+00 to 47+00

Bottom Width: 100 Feet
Left Side Slope = 50 H:V
Right Side Slope = 50 H:V
Manning's n= **0.027** Short Grass, Few Weeds
Slope = *0.01 ft/ft*
Channel Depth = 10.0 feet

Q = 210 cfs

At yc, Fr=1 and E=min

Depth (ft.)	Area (sq. ft.)	Wetted Perimeter	Hydraulic Radius	Conveyance 1.49/n	R^2/3	Slope ^1/2	Flow (cfs)	Velocity (fps)	T (ft.)	Fr	E
0.10	10.5	110.00	0.10	55.19	0.21	0.10	12.0	1.14	110	0.65	0.12
0.20	22.0	120.00	0.18	55.19	0.32	0.10	39.0	1.77	120	0.73	0.25
0.30	34.5	130.01	0.27	55.19	0.41	0.10	78.3	2.27	130	0.78	0.38
0.40	48.0	140.01	0.34	55.19	0.49	0.10	129.3	2.69	140	0.81	0.51
0.50	62.5	150.01	0.42	55.19	0.56	0.10	191.8	3.07	150	0.84	0.65
0.60	78.0	160.01	0.49	55.19	0.62	0.10	266.0	3.41	160	0.86	0.78
0.70	94.5	170.01	0.56	55.19	0.67	0.10	351.9	3.72	170	0.88	0.92
0.80	112.0	180.02	0.62	55.19	0.73	0.10	449.7	4.02	180	0.90	1.05
0.90	130.5	190.02	0.69	55.19	0.78	0.10	559.9	4.29	190	0.91	1.19
1.00	150.0	200.02	0.75	55.19	0.82	0.10	682.6	4.55	200	0.93	1.32
0.53	66.3	152.55	0.43	55.19	0.57	0.10	209.6	3.16	152.5444821	0.84	0.68

Channel C - GRAPHICAL PEAK DISCHARGE METHOD

(Based off of and Modified from Worksheet 4 in Appendix D of 210-VI-TR-55, Second Ed., June 1986)

Basin Data		
Drainage Area, A_m	1.13	sq mi
Runoff Curve Number, CN	70	
Time of Concentration, T_c	1.004	hr
Rainfall Distribution, SCS Type ___	II	(I, IA, II, III)
Pond and swamp areas spread throughout watershed	0	% of A_m

Computational Step	Storm 1	Storm 2	
Frequency	100	0	yr
Rainfall, P (24-hour)	3.8	0	in
Initial Abstraction, I_a (Use CN with Table 4-1 in TR-55 Manual)	0.8571	0	in
Compute I_a/P	0.226	#DIV/0!	
Unit Peak Discharge, q_u (Use Tc and I_a/P with Equation for Exhibit 4-II in Appendix F as well as Table F-1, lineraly interpolated)	310	310	csm/in
Runoff, Q (Equations 2-3 and 2-4 in TR-55 Manual)	1.198	0.214	in
Pond and swamp adjustment factor, F_p	1	0	
Peak Discharge, q_p ($q_p = q_u A_m Q F_p$)	419.7	0.0	cfs

The graphical peak discharge method is used as a check for the results returned by the HEC-1 program

Project:	**011.11497.042**		**By: ARW**	**Date: 25-Oct-11**
Location:	**Cardinal FAR II Closure Plan**		**Checked: AJS**	**Date:**

Channel C - CALCULATE T_c AND T_L

Based off of Worksheet 3 in Appendix D of 210-VI-TR-55, Second Ed., June 1986

Overland (Sheet) Flow

Segment	1	2		
Surface Description	Dense Grass			
Manning's roughness coefficient, n	0.24	0.01		
Flow Length, L	300	0.01	ft	
2-year, 24-hour rainfall, P_2	2.5	0.0	in	
Top/Bottom elevation of segment	|	|	ft	
Land Slope, s	0.25	0.1	ft/ft	
Travel Time, T_t	0.236	0	0.236	hr

$$T_t = \frac{0.007(nL)^{0.8}}{P_2^{0.5} s^{0.4}}$$

Shallow Concentrated Flow

Segment	3	4		
Surface Description (Paved or Unpaved)	Unpaved			
Flow Length, L	13800	0.01	ft	
Top/Bottom elevation of segment	|	|	ft	
Watercourse slope, s	0.12	0.01	ft/ft	
Average velocity, V (equation in Appendix F)	5.59	0.01	ft/s	
Travel Time, T_t	0.686	0	0.686	hr

$$T_t = \frac{L}{3600\ V}$$

Channel Flow

Segment	2	6		
Base Width, b	10	1	ft	
Side Slopes, w	0.02	0.01	ft/ft	
Depth, d	1.26	0.01	ft	
Cross sectional flow area, a	12.6	0.01	ft^2	
Wetted Perimeter, p_w	12.5	0.01	ft	
Hydraulic Radius, r	1.008	1	ft	
Top/Bottom elevation of segment	| 954	|	ft	
Channel Slope, s	0.025	0.01	ft/ft	
Manning's roughness coefficient, n	0.04	0.01		
Velocity, V	5.9	0.01	ft/s	
Flow Length, L	1750	0.01	ft	
Travel Time, T_t	0.082	0.000	0.082	hr

$$T_L = 0.6 T_c$$

Area Time of Concentration, T_c	1.004	hr
Area Lag Time, T_L	0.6024	hr
Area Lag Time, T_L	36.144	min

Use Manning's Equation:

Channel C

Bottom Width: 10 Feet
Left Side Slope = 50 H:V
Right Side Slope = 50 H:V
Manning's n= **0.040** Cobble Bottom and clean sides
Slope = 0.025 ft/ft
Channel Depth = 10.0 feet

Q = 420 cfs

At yc, **Fr**=1 and E=min

Depth (ft.)	Area (sq. ft.)	Wetted Perimeter	Hydraulic Radius	Conveyance 1.49/n	R^2/3	Slope ^1/2	Flow (cfs)	Velocity (fps)	T (ft.)	Fr	E
0.10	1.5	20.00	0.07	37.25	0.18	0.16	1.6	1.04	20.00	0.67	0.12
0.20	4.0	30.00	0.13	37.25	0.26	0.16	6.1	1.53	30.00	0.74	0.24
0.30	7.5	40.01	0.19	37.25	0.33	0.16	14.4	1.92	40.00	0.78	0.36
0.40	12.0	50.01	0.24	37.25	0.38	0.16	27.2	2.26	50.00	0.81	0.48
0.50	17.5	60.01	0.29	37.25	0.44	0.16	45.1	2.58	60.00	0.84	0.60
0.60	24.0	70.01	0.34	37.25	0.49	0.16	69.0	2.87	70.00	0.87	0.73
0.70	31.5	80.01	0.39	37.25	0.54	0.16	99.3	3.15	80.00	0.89	0.85
0.80	40.0	90.02	0.44	37.25	0.58	0.16	136.8	3.42	90.00	0.90	0.98
0.90	49.5	100.02	0.49	37.25	0.62	0.16	182.0	3.68	100.00	0.92	1.11
1.00	60.0	110.02	0.55	37.25	0.67	0.16	235.4	3.92	110.00	0.94	1.24
1.26	92.5	136.41	0.68	37.25	0.77	0.16	420.0	4.54	136.39	0.97	1.58

Project: 011.11497.042	By: ARW	Date: 1-Mar-12
Location: Cardinal FAR II Closure Plan	Checked: AJS	Date:

Channel A: 51+00 - GRAPHICAL PEAK DISCHARGE METHOD

(Based off of and Modified from Worksheet 4 in Appendix D of 210-VI-TR-55, Second Ed., June 1986)

Basin Data		
Drainage Area, A_m	1.851	sq mi
Runoff Curve Number, CN	64	
Time of Concentration, T_c	1.158	hr
Rainfall Distribution, SCS Type ___	II	(I, IA, II, III)
Pond and swamp areas spread throughout watershed	0	% of A_m

Computational Step	Storm 1	Storm 2	
Frequency	100	0	yr
Rainfall, P (24-hour)	3.8	0	in
Initial Abstraction, I_a (Use CN with Table 4-1 in TR-55 Manual)	1.125	0	in
Compute I_a/P	0.296	#DIV/0!	
Unit Peak Discharge, q_u (Use Tc and I_a/P with Equation for Exhibit 4-II in Appendix F as well as Table F-1, lineraly interpolated)	270	270	csm/in
Runoff, Q (Equations 2-3 and 2-4 in TR-55 Manual)	0.862	0.281	in
Pond and swamp adjustment factor, F_p	1	0	
Peak Discharge, q_p ($q_p = q_u A_m Q F_p$)	430.9	0.0	cfs

The graphical peak discharge method is used as a check for the results returned by the HEC-1 program

Project:	011.11497.042		By: ARW	Date: 1-Mar-12
Location:	Cardinal FAR II Closure Plan		Checked: AJS	Date:

Channel A: 51+00 - CALCULATE T_c AND T_L

Based off of Worksheet 3 in Appendix D of 210-VI-TR-55, Second Ed., June 1986

Overland (Sheet) Flow

Segment	1	2		
Surface Description	Dense Grass			
Manning's roughness coefficient, n	0.24	0.01		
Flow Length, L	300	0.01	ft	
2-year, 24-hour rainfall, P_2	2.5	0.0	in	
Top/Bottom elevation of segment			ft	
Land Slope, s	0.25	0.1	ft/ft	
Travel Time, T_t	0.236	0	0.236	hr

$$T_t = \frac{0.007(nL)^{0.8}}{P_2^{0.5} s^{0.4}}$$

Shallow Concentrated Flow

Segment	3	4		
Surface Description (Paved or Unpaved)	Unpaved			
Flow Length, L	13800	0.01	ft	
Top/Bottom elevation of segment			ft	
Watercourse slope, s	0.12	0.01	ft/ft	
Average velocity, V (equation in Appendix F)	5.59	0.01	ft/s	
Travel Time, T_t	0.686	0	0.686	hr

$$T_t = \frac{L}{3600\ V}$$

Channel Flow

Segment	2	6		
Base Width, b	10	100	ft	
Side Slopes, w	0.02	0.02	ft/ft	
Depth, d	1.26	0.78	ft	
Cross sectional flow area, a	12.6	78	ft^2	
Wetted Perimeter, p_w	12.5	101.6	ft	
Hydraulic Radius, r	1.008	0.768	ft	
Top/Bottom elevation of segment	1009 / 952		ft	
Channel Slope, s	0.025	0.01	ft/ft	
Manning's roughness coefficient, n	0.04	0.027		
Velocity, V	5.9	4.6	ft/s	
Flow Length, L	4500	400	ft	
Travel Time, T_t	0.212	0.024	0.236	hr

$$T_L = 0.6T_c$$

Area Time of Concentration, T_c	1.158	hr
Area Lag Time, T_L	0.6948	hr
Area Lag Time, T_L	41.688	min

Use Manning's Equation:

Channel A: Sta. 51+00

Bottom Width:	100	Feet
Left Side Slope =	50	H:V
Right Side Slope =	50	H:V
Manning's n=	**0.027**	Short Grass, Few Weeds
Slope =	0.01	ft/ft
Channel Depth =	10.0	feet

Q = 431 cfs

At yc, Fr=1 and E=min

Depth (ft.)	Area (sq. ft.)	Wetted Perimeter	Hydraulic Radius	Conveyance 1.49/n	R^2/3	Slope ^1/2	Flow (cfs)	Velocity (fps)	T (ft.)	Fr	E
0.10	10.5	110.00	0.10	55.19	0.21	0.10	12.0	1.14	110	0.65	0.12
0.20	22.0	120.00	0.18	55.19	0.32	0.10	39.0	1.77	120	0.73	0.25
0.30	34.5	130.01	0.27	55.19	0.41	0.10	78.3	2.27	130	0.78	0.38
0.40	48.0	140.01	0.34	55.19	0.49	0.10	129.3	2.69	140	0.81	0.51
0.50	62.5	150.01	0.42	55.19	0.56	0.10	191.8	3.07	150	0.84	0.65
0.60	78.0	160.01	0.49	55.19	0.62	0.10	266.0	3.41	160	0.86	0.78
0.70	94.5	170.01	0.56	55.19	0.67	0.10	351.9	3.72	170	0.88	0.92
0.80	112.0	180.02	0.62	55.19	0.73	0.10	449.7	4.02	180	0.90	1.05
0.90	130.5	190.02	0.69	55.19	0.78	0.10	559.9	4.29	190	0.91	1.19
1.00	150.0	200.02	0.75	55.19	0.82	0.10	682.6	4.55	200	0.93	1.32
0.78	108.7	178.18	0.61	55.19	0.72	0.10	430.9	3.96	178.2	0.89	1.03

Project: 011.11497.042	By: ARW	Date: 25-Oct-11
Location: Cardinal FAR II Closure Plan	Checked: AJS	Date:

Channel B - GRAPHICAL PEAK DISCHARGE METHOD

(Based off of and Modified from Worksheet 4 in Appendix D of 210-VI-TR-55, Second Ed., June 1986)

Basin Data		
Drainage Area, A_m	0.10	sq mi
Runoff Curve Number, CN	64	
Time of Concentration, T_c	0.507	hr
Rainfall Distribution, SCS Type ___	II	(I, IA, II, III)
Pond and swamp areas spread throughout watershed	0	% of A_m

Computational Step	Storm 1	Storm 2	
Frequency	100	0	yr
Rainfall, P (24-hour)	3.8	0	in
Initial Abstraction, I_a (Use CN with Table 4-1 in TR-55 Manual)	1.125	0	in
Compute I_a/P	0.296	#DIV/0!	
Unit Peak Discharge, q_u (Use Tc and I_a/P with Equation for Exhibit 4-II in Appendix F as well as Table F-1, lineraly interpolated)	440	440	csm/in
Runoff, Q (Equations 2-3 and 2-4 in TR-55 Manual)	0.862	0.281	in
Pond and swamp adjustment factor, F_p	1	0	
Peak Discharge, q_p ($q_p = q_u A_m Q F_p$)	37.9	0.0	cfs

The graphical peak discharge method is used as a check for the results returned by the HEC-1 program

Project:	011.11497.042		By: ARW	Date: 25-Oct-11
Location:	Cardinal FAR II Closure Plan		Checked: AJS	Date:

Channel B - CALCULATE T_c AND T_L

Based off of Worksheet 3 In Appendix D of 210-VI-TR-55, Second Ed., June 1986

Overland (Sheet) Flow

Segment	1	2			
Surface Description	Dense Grass				
Manning's roughness coefficient, n	0.24	0.01			
Flow Length, L	300	0.01	ft		
2-year, 24-hour rainfall, P_2	2.5	0.0	in		
Top/Bottom elevation of segment	|	|	ft		
Land Slope, s	0.25	0.1	ft/ft		
Travel Time, T_t	0.236	0		0.236	hr

$$T_t = \frac{0.007(nL)^{0.8}}{P_2^{0.5} s^{0.4}}$$

Shallow Concentrated Flow

Segment	3	4			
Surface Description (Paved or Unpaved)	Unpaved				
Flow Length, L	300	0.01	ft		
Top/Bottom elevation of segment	|	|	ft		
Watercourse slope, s	0.02	0.01	ft/ft		
Average velocity, V (equation in Appendix F)	2.28	0.01	ft/s		
Travel Time, T_t	0.037	0		0.037	hr

$$T_t = \frac{L}{3600\ V}$$

Channel Flow

Segment	2	6			
Base Width, b	100	1	ft		
Side Slopes, w	0.02	0.01	ft/ft		
Depth, d	0.2	0.01	ft		
Cross sectional flow area, a	20	0.01	ft^2		
Wetted Perimeter, p_w	100.4	0.01	ft		
Hydraulic Radius, r	0.199	1	ft		
Top/Bottom elevation of segment	| 954	|	ft		
Channel Slope, s	0.01	0.01	ft/ft		
Manning's roughness coefficient, n	0.027	0.01			
Velocity, V	1.9	0.01	ft/s		
Flow Length, L	1600	0.01	ft		
Travel Time, T_t	0.234	0.000		0.234	hr

$$T_L = 0.6 T_c$$

Area Time of Concentration, T_c	0.507	hr
Area Lag Time, T_L	0.3042	hr
Area Lag Time, T_L	18.252	min

Use Manning's Equation:

Channel B

Bottom Width: 100 Feet
Left Side Slope = 50 H:V
Right Side Slope = 50 H:V
Manning's n= **0.027** Short Grass, Few Weeds
Slope = 0.01 ft/ft
Channel Depth = 10.0 feet

Q = 38 cfs

At yc, Fr=1 and E=min

Depth (ft.)	Area (sq. ft.)	Wetted Perimeter	Hydraulic Radius	Conveyance 1.49/n	R^2/3	Slope ^1/2	Flow (cfs)	Velocity (fps)	T (ft.)	Fr	E
0.10	10.5	110.00	0.10	55.19	0.21	0.10	12.0	1.14	110.00	0.65	0.12
0.20	22.0	120.00	0.18	55.19	0.32	0.10	39.0	1.77	120.00	0.73	0.25
0.30	34.5	130.01	0.27	55.19	0.41	0.10	78.3	2.27	130.00	0.78	0.38
0.40	48.0	140.01	0.34	55.19	0.49	0.10	129.3	2.69	140.00	0.81	0.51
0.50	62.5	150.01	0.42	55.19	0.56	0.10	191.8	3.07	150.00	0.84	0.65
0.60	78.0	160.01	0.49	55.19	0.62	0.10	266.0	3.41	160.00	0.86	0.78
0.70	94.5	170.01	0.56	55.19	0.67	0.10	351.9	3.72	170.00	0.88	0.92
0.80	112.0	180.02	0.62	55.19	0.73	0.10	449.7	4.02	180.00	0.90	1.05
0.90	130.5	190.02	0.69	55.19	0.78	0.10	559.9	4.29	190.00	0.91	1.19
1.00	150.0	200.02	0.75	55.19	0.82	0.10	682.6	4.55	200.00	0.93	1.32
0.20	21.6	119.68	0.18	55.19	0.32	0.10	37.9	1.75	119.68	0.73	0.24

Project: 011.11497.042	By: ARW	Date: 1-Mar-12
Location: Cardinal FAR II Closure Plan	Checked: AJS	Date:

Channel A: 70+00 - GRAPHICAL PEAK DISCHARGE METHOD

(Based off of and Modified from Worksheet 4 in Appendix D of 210-VI-TR-55, Second Ed., June 1986)

Basin Data		
Drainage Area, A_m	2.150	sq mi
Runoff Curve Number, CN	64	
Time of Concentration, T_c	1.389	hr
Rainfall Distribution, SCS Type ___	II	(I, IA, II, III)
Pond and swamp areas spread throughout watershed	0	% of A_m

Computational Step	Storm 1	Storm 2	
Frequency	100	0	yr
Rainfall, P (24-hour)	3.8	0	in
Initial Abstraction, I_a (Use CN with Table 4-1 in TR-55 Manual)	1.125	0	in
Compute I_a/P	0.296	#DIV/0!	
Unit Peak Discharge, q_u (Use Tc and I_a/P with Equation for Exhibit 4-II in Appendix F as well as Table F-1, lineraly interpolated)	240	240	csm/in
Runoff, Q (Equations 2-3 and 2-4 in TR-55 Manual)	0.862	0.281	in
Pond and swamp adjustment factor, F_p	1	0	
Peak Discharge, q_p ($q_p = q_u A_m Q F_p$)	444.9	0.0	cfs

The graphical peak discharge method is used as a check for the results returned by the HEC-1 program

Project:	011.11497.042		By: ARW	Date:	1-Mar-12
Location:	Cardinal FAR II Closure Plan		Checked: AJS	Date:	

Channel A: 70+00 - CALCULATE T_c AND T_L

Based off of Worksheet 3 in Appendix D of 210-VI-TR-55, Second Ed., June 1986

Overland (Sheet) Flow

Segment	1	2		
Surface Description	Dense Grass			
Manning's roughness coefficient, n	0.24	0.01		
Flow Length, L	300	0.01	ft	
2-year, 24-hour rainfall, P_2	2.5	0.0	in	
Top/Bottom elevation of segment	|	|	ft	
Land Slope, s	0.25	0.1	ft/ft	
Travel Time, T_t	0.236	0	0.236	hr

$$T_t = \frac{0.007(nL)^{0.8}}{P_2^{0.5} s^{0.4}}$$

Shallow Concentrated Flow

Segment	3	4		
Surface Description (Paved or Unpaved)	Unpaved			
Flow Length, L	13800	0.01	ft	
Top/Bottom elevation of segment	|	|	ft	
Watercourse slope, s	0.12	0.01	ft/ft	
Average velocity, V (equation in Appendix F)	5.59	0.01	ft/s	
Travel Time, T_t	0.686	0	0.686	hr

$$T_t = \frac{L}{3600\ V}$$

Channel Flow

Segment	2	6		
Base Width, b	10	100	ft	
Side Slopes, w	0.02	0.02	ft/ft	
Depth, d	1.26	0.66	ft	
Cross sectional flow area, a	12.6	66	ft^2	
Wetted Perimeter, p_w	12.5	101.3	ft	
Hydraulic Radius, r	1.008	0.652	ft	
Top/Bottom elevation of segment	|	|	ft	
Channel Slope, s	0.01	0.01	ft/ft	
Manning's roughness coefficient, n	0.04	0.027		
Velocity, V	3.7	4.1	ft/s	
Flow Length, L	4500	1900	ft	
Travel Time, T_t	0.338	0.129	0.467	hr

$$T_L = 0.6 T_c$$

Area Time of Concentration, T_c	1.389	hr
Area Lag Time, T_L	0.8334	hr
Area Lag Time, T_L	50.004	min

Use Manning's Equation:

Channel A Sta 70+00

Bottom Width:	100	Feet
Left Side Slope =	50	H:V
Right Side Slope =	50	H:V
Manning's n=	**0.027**	Short Grass, Few Weeds
Slope =	0.02	ft/ft
Channel Depth =	10.0	feet

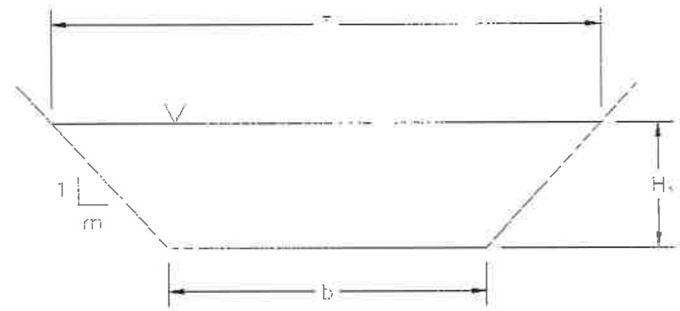
Q = 445 cfs

At yc, Fr=1 and E=min

Depth (ft.)	Area (sq. ft.)	Wetted Perimeter	Hydraulic Radius	Conveyance 1.49/n	R^2/3	Slope ^1/2	Flow (cfs)	Velocity (fps)	T (ft.)	Fr	E
0.1	10.5	110.00	0.10	55.19	0.21	0.14	17.0	1.62	110	0.92	0.14
0.2	22.0	120.00	0.18	55.19	0.32	0.14	55.1	2.50	120	1.03	0.30
0.3	34.5	130.01	0.27	55.19	0.41	0.14	110.7	3.21	130	1.10	0.46
0.4	48.0	140.01	0.34	55.19	0.49	0.14	182.8	3.81	140	1.15	0.63
0.5	62.5	150.01	0.42	55.19	0.56	0.14	271.3	4.34	150	1.19	0.79
0.6	78.0	160.01	0.49	55.19	0.62	0.14	376.1	4.82	160	1.22	0.96
0.7	94.5	170.01	0.56	55.19	0.67	0.14	497.6	5.27	170	1.24	1.13
0.8	112.0	180.02	0.62	55.19	0.73	0.14	636.0	5.68	180	1.27	1.30
0.9	130.5	190.02	0.69	55.19	0.78	0.14	791.8	6.07	190	1.29	1.47
1	150.0	200.02	0.75	55.19	0.82	0.14	965.4	6.44	200	1.31	1.64
0.66	87.50	165.84	0.53	55.19	0.65	0.14	444.90	5.08	165.83	1.23	1.06

Emergency Spillway Rating
Trapezoidal Broad Crested Weir Equation (French, 1985):

$$Q_2 = C_D\left(Ty_c + my_c^2\right)\left[2g\left(H_1 - y_c\right)\right]^{\frac{1}{2}}$$



Definition of Critical Depth:

$$y_c = \left(\frac{Q_1^2}{b^2 g}\right)^{\frac{1}{3}}$$

Solve for Q:

$$Q_1 = b\sqrt{g}\,y_c^{\frac{3}{2}}$$

Q from Combined Runoff Channels = 445 cfs

Determine weir flow by equating Q_1 to Q_2 by varying y_c.

Input: **b= 17** **m= 2** **C_D= 0.85**
Weir Crest Elevation= 956.0

Headwater Elevation	**H_1** (ft)	**y_c** (ft)	**Q_1** (cfs)	**T** (ft)	**C_D**	**Q_2** (cfs)	**Q_1-Q_2** (cfs)	**Q** (cfs)
956.00	0.00	0.00	0.0	17	0.85	0.0	0.0	**0**
957.00	0.70	0.48	31.9	19.8	0.85	31.9	0.0	**32**
957.50	1.50	1.14	117.8	23	0.85	117.8	0.0	**118**
958.00	2.00	1.60	194.9	25	0.85	194.9	0.0	**195**
958.50	2.50	2.07	287.9	27	0.85	287.9	0.0	**288**
959.00	3.00	2.56	395.2	29	0.85	395.2	0.0	**395**
960.00	4.00	3.56	647.4	33	0.85	647.4	0.0	**647**
961.00	5.00	4.57	942.6	37	0.85	942.6	0.0	**943**
962.00	6.00	5.56	1264.8	41	0.85	1311.0	46.2	**1288**
963.00	7.00	6.56	1620.9	45	0.85	1724.8	103.9	**1673**

Use Manning's Equation:

REVISED SPILLWAY CHANNEL

Bottom Width:	17	Feet
Left Side Slope =	2	H:V
Right Side Slope =	2	H:V
Manning's n=	0.023	RCC
Slope =	**0.010**	ft/ft
Channel Depth =	10	feet

Q = 445.00 cfs

At yc, Fr=1 and E=min

Depth (ft.)	Area (sq. ft.)	Wetted Perimeter	Hydraulic Radius	Conveyance 1.49/n	R^2/3	Slope ^1/2	Flow (cfs)	Velocity (fps)	T (ft.)	Fr	E
1	19	21.47213595	0.884867721	64.7826087	0.92	0.10	113.4	5.968523782	21	1.11	1.55
0	0.0	17.00	0.00	64.78	0.00	0.10	0.0	#DIV/0!	17	#DIV/0!	#DIV/0!
0.5	9.0	19.24	0.47	64.78	0.60	0.10	35.0	3.89	19	1.00	0.74
1	19.0	21.47	0.88	64.78	0.92	0.10	113.4	5.97	21	1.11	1.55
1.1	21.1	21.92	0.96	64.78	0.98	0.10	133.5	6.32	21.4	1.12	1.72
1.2	23.3	22.37	1.04	64.78	1.03	0.10	154.9	6.65	21.8	1.13	1.89
1.3	25.5	22.81	1.12	64.78	1.08	0.10	177.8	6.98	22.2	1.15	2.06
1.4	27.7	23.26	1.19	64.78	1.12	0.10	202.0	7.29	22.6	1.16	2.22
1.5	30.0	23.71	1.27	64.78	1.17	0.10	227.5	7.58	23	1.17	2.39
2.20	47.1	26.85	1.76	64.78	1.46	0.10	445.0	9.44	25.8	1.23	3.59

Use Manning's Equation:

NATURAL SPILLWAY CHANNEL

Bottom Width:	85	Feet
Left Side Slope =	2	H:V
Right Side Slope =	2	H:V
Manning's n=	0.04	Jagged and irregular rock
Slope =	**0.030**	ft/ft
Channel Depth =	10	feet

Q = 445.00 cfs

At yc, Fr=1 and E=min

Depth (ft.)		Area (sq. ft.)	Wetted **Perimeter**	Hydraulic **Radius**	Conveyance **1.49/n**	**R^2/3**	**Slope ^1/2**	Flow (cfs)	Velocity **(fps)**	T (ft.)	**Fr**	E
1		**87**	**89.47213595**	**0.972369767**	**37.25**	**0.98**	**0.17**	**550.9**	**6.331898932**	89	1.13	1.62
	0	0.0	85.00	0.00	37.25	0.00	0.17	0.0	#DIV/0!	85	#DIV/0!	#DIV/0!
	0.5	43.0	87.24	0.49	37.25	0.62	0.17	172.7	4.02	87	1.01	0.75
	1	87.0	89.47	0.97	37.25	0.98	0.17	550.9	6.33	89	1.13	1.62
	1.1	95.9	89.92	1.07	37.25	1.04	0.17	646.2	6.74	89.4	1.15	1.80
	1.2	104.9	90.37	1.16	37.25	1.10	0.17	747.7	7.13	89.8	1.16	1.99
	1.3	113.9	90.81	1.25	37.25	1.16	0.17	855.1	7.51	90.2	1.18	2.18
	1.4	122.9	91.26	1.35	37.25	1.22	0.17	968.2	7.88	90.6	1.19	2.36
	1.5	132.0	91.71	1.44	37.25	1.28	0.17	1,087.0	8.23	91	1.20	2.55
	0.88	78.4	88.94	0.88	37.25	0.90	0.17	445.0	5.83	88.5	1.11	1.41

Use Manning's Equation:

Fabriform Channel D

Bottom Width:	4	Feet
Left Side Slope =	2	H:V
Right Side Slope =	2	H:V
Manning's n=	0.025	Fabri Form
Slope =	**0.310**	ft/tt
Channel Depth =	10	feet

Q = 445.00 cfs

At yc, Fr=1 and E=min

Depth (ft.)	Area (sq. ft.)	Wetted **Perimeter**	Hydraulic **Radius**	Conveyance **1.49/n**	**R^2/3**	**Slope ^1/2**	Flow **(cfs)**	Velocity **(fps)**	T **(ft.)**	**Fr**	**E**
1	6	8.472135955	0.708203932	59.6	0.79	0.56	158.0	26.33499198	8	5.36	11.77
0	0.0	4.00	0.00	59.60	0.00	0.56	0.0	#DIV/0!	4	#DIV/0!	#DIV/0!
1	6.0	8.47	0.71	59.60	0.79	0.56	158.0	26.33	8	5.36	11.77
1.1	6.8	8.92	0.76	59.60	0.84	0.56	189.1	27.72	8.4	5.42	13.03
1.2	7.7	9.37	0.82	59.60	0.88	0.56	223.1	29.05	8.8	5.48	14.30
1.3	8.6	9.81	0.87	59.60	0.91	0.56	260.2	30.33	9.2	5.53	15.58
1.4	9.5	10.26	0.93	59.60	0.95	0.56	300.4	31.56	9.6	5.58	16.86
1.5	10.5	10.71	0.98	59.60	0.99	0.56	343.9	32.75	10	5.63	18.15
1.708	12.670	11.640	1.088	59.600	1.058	0.557	445.000	35.123	10.833	5.724	20.864

ODOT TYPE C

3/9/12

Using HEC 14: Chapter 10 For Riprap Stilling Basin

INLET DIMENSIONS

Channel CS area = 10.5 ft^2 (From Manning's)

Equivalent Diameter = 44 in. = 3.7 ft

Step 1

Compute the culvert outlet velocity, Vo, and depth, yo. Compute Froude number

yo= 1 ft

Vo= 35.2 ft/s

Non-rectangular Section (yo=ye for box section)

C.S Area= 10.5 ft^2

ye= 2.29 ft

Step 2

Select a trial D50 for locally available riprap. Determine Co from Eqn. 10.2 or 10.3 and obtain hs/ye from Eqn. 10.1. Check hs/D50 $\geq$ 2

Try D50= 1 ft for ODOT Type C

Check D50/ye= 0.44 $\geq$ 0.1 PASS

Determine Co

Tailwater El. (TW) = 0 ft above inlet invert SEE figure 10.1

Check TW/ye= 0.00 , therefore Co = 2

if	TW/ye<0.75	then	Co=2.0	
if	0.75< TW/ye<1.0	then	Co=4.0(TW/ye)-1.0	
if	1.0<TW/ye	then	Co=3.0	(EQN 10.3)

Determine hs/ye

hs/ye= 3.6 (EQN. 10.1)

hs= 8.2 ft

Check hs/D50= 8.16 $\geq$ 2 PASS

ODOT TYPE C

3/9/12

Step 3

Determine the dimensions as shown in figures 10.1 and 10.2.

Wo=	3.7	ft	(inlet width)	Fig 10.1 and 10.2
LS=	81.6	ft		
Lsmin=	11.0	ft	Use LS= 81.6 ft	
LB=	122.4	ft		
LBmin=	14.6	ft	Use LB= 122.4 ft	
WB=	85.2	ft		

Step 4

Determine the basin exit depth, yb=yc, and exit velocity, VB=VC and compare with the allowable exit veloctity.

Qo= 445 cfs Z= 2

(Q^2)/g= 6149.8 (EQN. 7.14)

Find yc

(Q^2)/g	yc	
6149.8	0.94	ft
^	^	
^	^	

Use Goalseek function to find yc

Find Ac for yc

Ac=yc(Wb+z*yc)

Ac= 81.80 ft^2

Find Tc for yc

Tc=(Wb+z*yc)

Tc= 87.1 ft

Find Vc (Outlet Velocity)

Vc=Q/Ac

Vc= 5.4 ft/s

V allow = 6.5 ft/s from max velocity allowed for Type of Rip Rap Selected

Compare Vc and V allow Pass

Step 5

Assess need for additional riprap downstream

if TW/yo≤0.75 then No Additional Riprap Needed

if TW/yo>0.75 then estimate centerline velocity at a series of downstream cross sections using Fig. 10.3 to determine size and extent of additional protection.

- The riprap floor is constructed at the approximate depth of scour, h_s, that would occur i thick pad of riprap. The h_s/D_{50} of the material should be greater than 2.
- The length of the energy dissipating pool, L_S, is $10h_s$, but no less than $3W_o$; the length apron, L_A, is $5h_s$, but no less than W_o. The overall length of the basin (pool plus apron is $15h_s$, but no less than $4W_o$.
- A riprap cutoff wall or sloping apron can be constructed if downstream channel degrad is anticipated as shown in Figure 10.1.

ODOT TYPE C 3/9/12

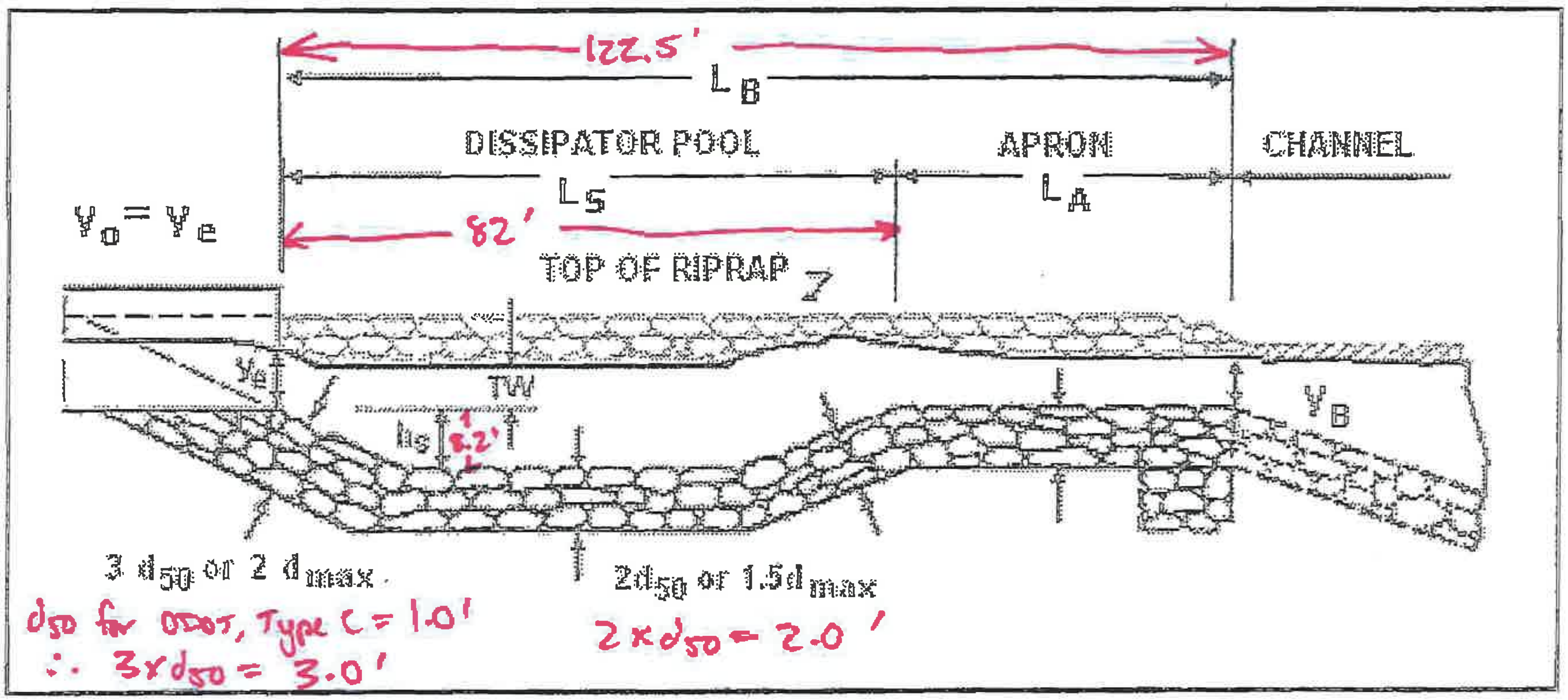


Figure 10.1. Profile of Riprap Basin

ODOT TYPE C 3/9/12

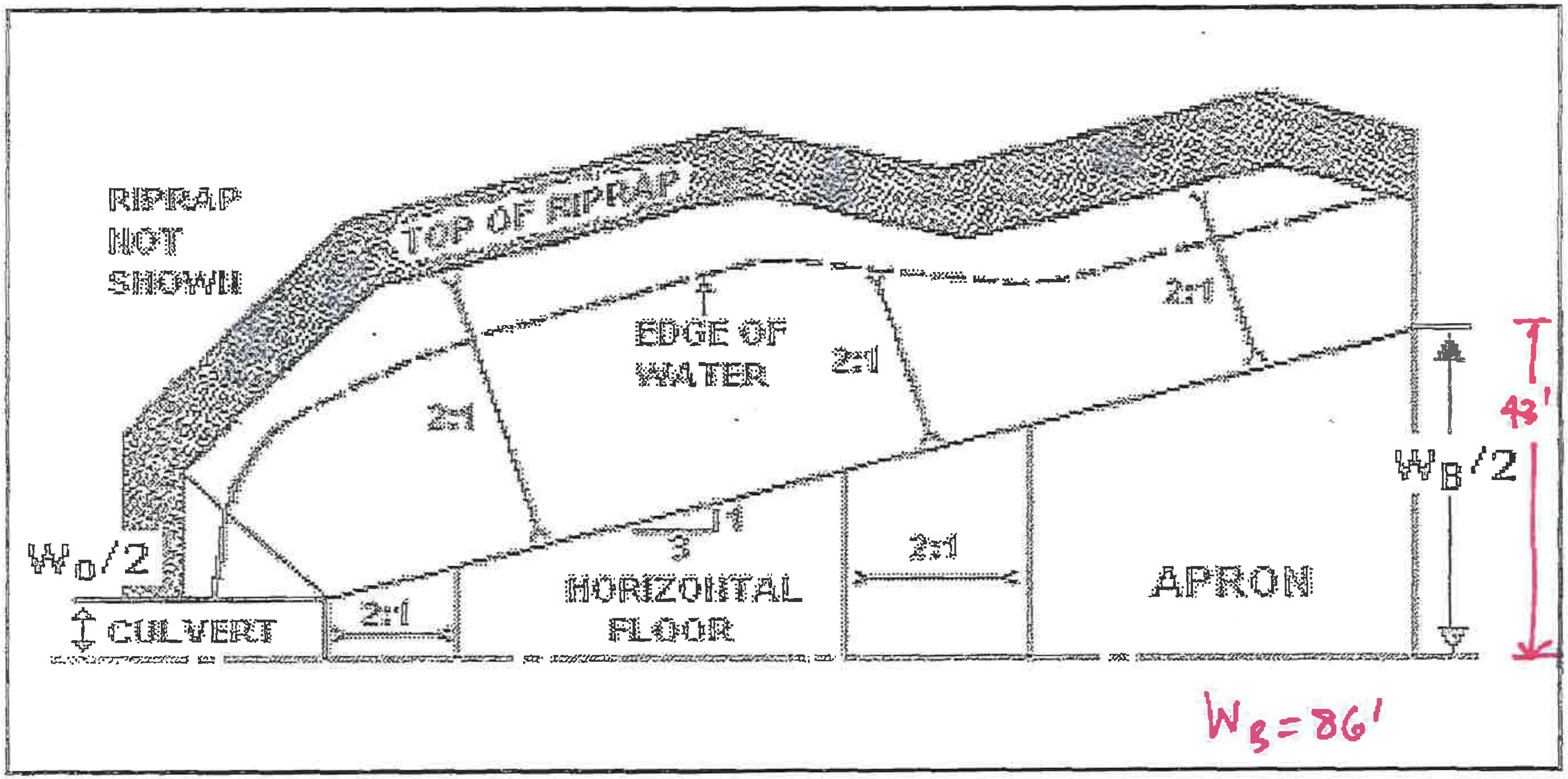


Figure 10.2. Half Plan of Riprap Basin

esign Development

re conducted with pipes from 152 mm (6 in) to 914 mm (24 in) and 152 mm (6 in) hi
x culverts from 305 mm (12 in) to 610 mm (24 in) in width. Discharges ranged fro
2.8 m^3/s (0.1 to 100 ft^3/s). Both angular and rounded rock with an average size D

ODOT TYPE B 3/9/12

Using HEC 14: Chapter 10 For Riprap Stilling Basin

INLET DIMENSIONS

Channel CS area = 10.5 ft^2 (From Manning's)

Equivalent Diameter = 44 in. = 3.7 ft

Step 1

Compute the culvert outlet velocity, Vo, and depth, yo. Compute Froude number

yo= 1 ft

Vo= 35.2 ft/s

Non-rectangular Section (yo=ye for box section)

C.S Area= 10.5 ft^2

ye= 2.29 ft

Step 2

Select a trial D50 for locally available riprap. Determine Co from Eqn. 10.2 or 10.3 and obtain hs/ye from Eqn. 10.1. Check hs/D50 ≥ 2

Try D50= 1.5 ft for **ODOT Type B**

Check D50/ye= 0.65 ≥ 0.1 PASS

Determine Co

Tailwater El. (TW) = 0 ft above inlet invert SEE figure 10.1

Check TW/ye= 0.00 , therefore Co = 2

if	TW/ye<0.75	then	Co=2.0	
if	0.75< TW/ye<1.0	then	Co=4.0(TW/ye)-1.0	
if	1.0<TW/ye	then	Co=3.0	(EQN 10.3)

Determine hs/ye

hs/ye= 2.4 (EQN. 10.1)

hs= 5.6 ft

Check hs/D50= 3.74 ≥ 2 PASS

ODOT TYPE B 3/9/12

Step 3

Determine the dimensions as shown in figures 10.1 and 10.2.

Wo=	3.7	ft	(inlet width)		Fig 10.1 and 10.2
LS=	56.1	ft			
Lsmin=	11.0	ft	Use LS=	56.1 ft	
LB=	84.2	ft			
LBmin=	14.6	ft	Use LB=	84.2 ft	
WB=	59.8	ft			

Step 4

Determine the basin exit depth, yb=yc, and exit velocity, VB=VC and compare with the allowable exit veloctity.

Qo= 445 cfs   Z:1 sideslope: 2

(Q^2)/g= 6149.8   (EQN. 7.14)

Find yc

(Q^2)/g	yc	
6149.8	1.18	ft
^	^	
^	^	

Use Goalseek function to find yc

Find Ac for yc

Ac=yc(Wb+z*yc)

Ac= 73.48 ft^2

Find Tc for yc

Tc=(Wb+z*yc)

Tc= 62.1 ft

Find Vc (Outlet Velocity)

Vc=Q/Ac

Vc= 6.1 ft/s

V allow = 8 ft/s   from max velocity for Type of Rip Rap Selected

Compare Vc and V allow   Pass

Step 5

Assess need for additional riprap downstream

if TW/yo≤0.75 then No Additional Riprap Needed

if TW/yo>0.75 then estimate centerline velocity at a series of downstream cross sections using Fig. 10.3 to determine size and extent of additional protection.

The riprap floor is constructed at the approximate depth of scour, h_s, that would occur i thick pad of riprap. The h_s/D_{50} of the material should be greater than 2.

The length of the energy dissipating pool, L_s, is $10h_s$, but no less than $3W_o$; the length apron, L_A, is $5h_s$, but no less than W_o. The overall length of the basin (pool plus apron is $15h_s$, but no less than $4W_o$.

A riprap cutoff wall or sloping apron can be constructed if downstream channel degrad is anticipated as shown in Figure 10.1.

ODOT TYPE B 3/9/12

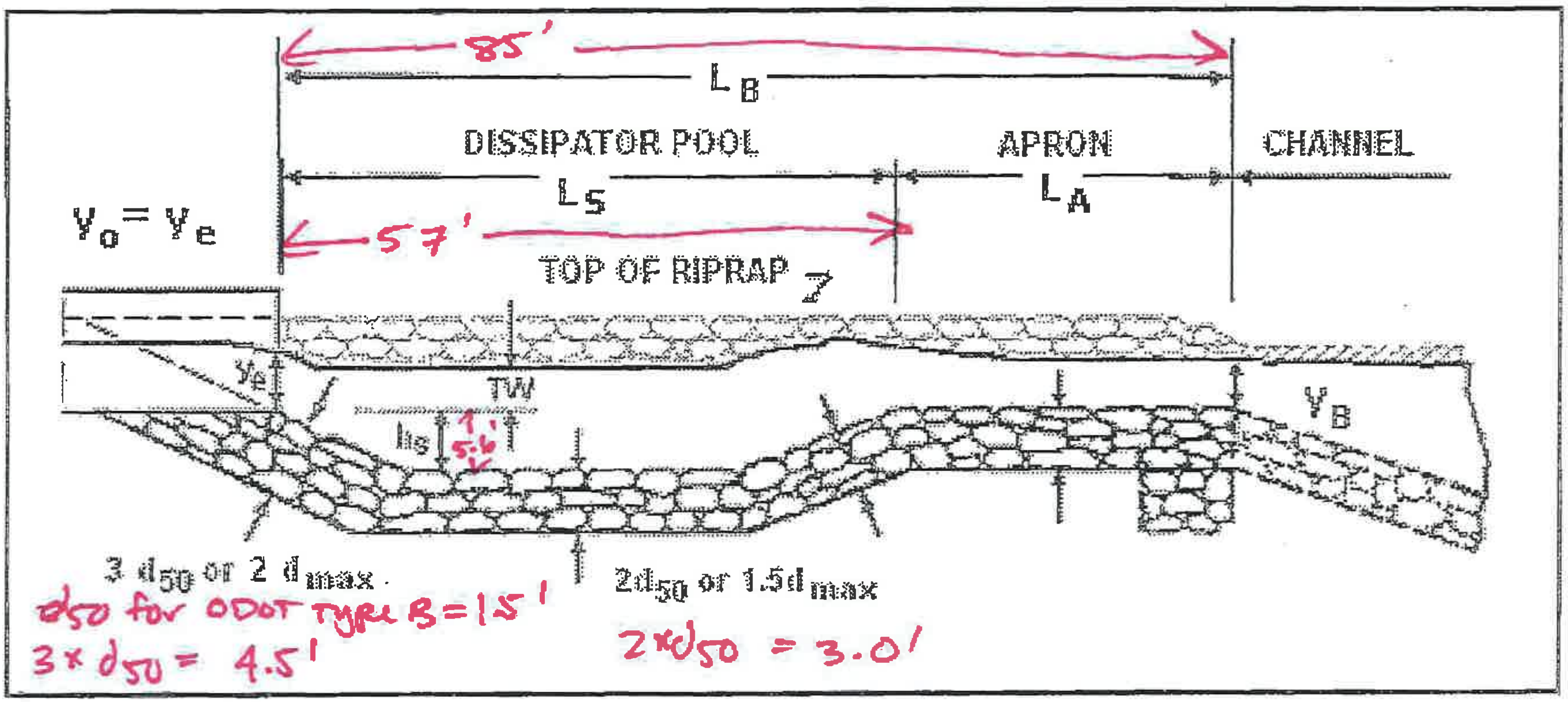


Figure 10.1. Profile of Riprap Basin

ODOT TYPE B

3/9/12

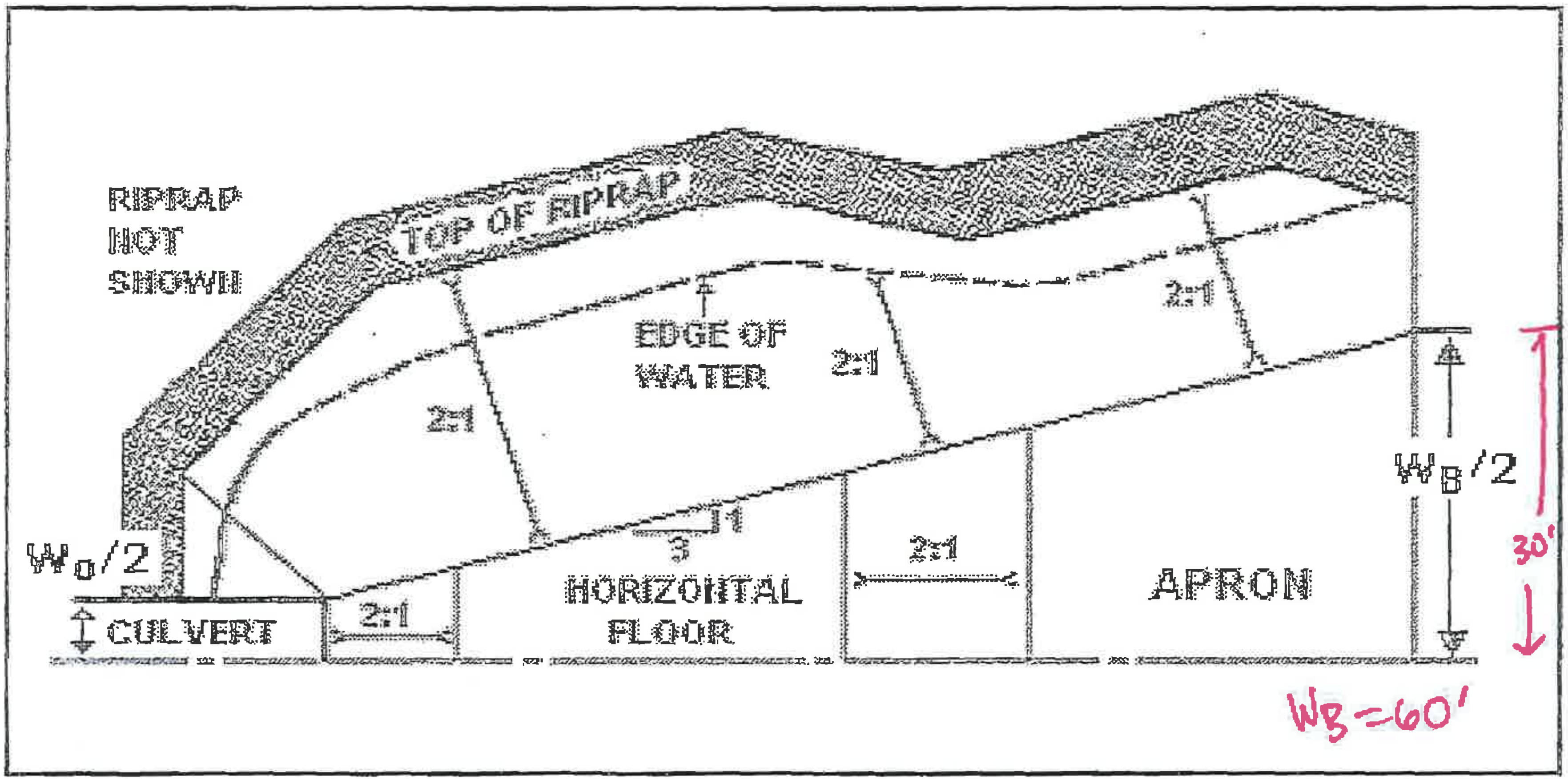


Figure 10.2. Half Plan of Riprap Basin

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re conducted with pipes from 152 mm (6 in) to 914 mm (24 in) and 152 mm (6 in) hi
ıx culverts from 305 mm (12 in) to 610 mm (24 in) in width. Discharges ranged frc
2.8 m^3/s (0.1 to 100 ft^3/s). Both angular and rounded rock with an average size D

Sheet flow

Sheet flow is flow over plane surfaces. It usually occurs in the headwater of streams. With sheet flow, the friction value (Manning's n) is an effective roughness coefficient that includes the effect of raindrop impact; drag over the plane surface; obstacles such as litter, crop ridges, and rocks; and erosion and transportation of sediment. These n values are for very shallow flow depths of about 0.1 foot or so. Table 3-1 gives Manning's n values for sheet flow for various surface conditions.

Table 3-1 Roughness coefficients (Manning's n) for sheet flow

Surface description	n [1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses [2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods: [3]	
Light underbrush	0.40
Dense underbrush	0.80

1 The n values are a composite of information compiled by Engman (1986).

2 Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.

3 When selecting n , consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

For sheet flow of less than 300 feet, use Manning's kinematic solution (Overtop and Meadows 1976) to compute T_t:

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5} s^{0.4}} \qquad \text{[eq. 3-3]}$$

where:

T_t = travel time (hr),
n = Manning's roughness coefficient (table 3-1)
L = flow length (ft)
P_2 = 2-year, 24-hour rainfall (in)
s = slope of hydraulic grade line (land slope, ft/ft)

This simplified form of the Manning's kinematic solution is based on the following: (1) shallow steady uniform flow, (2) constant intensity of rainfall excess (that part of a rain available for runoff), (3) rainfall duration of 24 hours, and (4) minor effect of infiltration on travel time. Rainfall depth can be obtained from appendix B.

Shallow concentrated flow

After a maximum of 300 feet, sheet flow usually becomes shallow concentrated flow. The average velocity for this flow can be determined from figure 3-1, in which average velocity is a function of watercourse slope and type of channel. For slopes less than 0.005 ft/ft, use equations given in appendix F for figure 3-1. Tillage can affect the direction of shallow concentrated flow. Flow may not always be directly down the watershed slope if tillage runs across the slope.

After determining average velocity in figure 3-1, use equation 3-1 to estimate travel time for the shallow concentrated flow segment.

Open channels

Open channels are assumed to begin where surveyed cross section information has been obtained, where channels are visible on aerial photographs, or where blue lines (indicating streams) appear on United States Geological Survey (USGS) quadrangle sheets. Manning's equation or water surface profile information can be used to estimate average flow velocity. Average flow velocity is usually determined for bank-full elevation.

Table 3-1 (Continued) Manning's 'n' Values

Type of Channel and Description	Minimum	Normal	Maximum
C. *Excavated or Dredged Channels*			
1. **Earth, straight and uniform**			
a. Clean, recently completed	0.016	0.018	0.020
b. Clean, after weathering	0.018	0.022	0.025
c. Gravel, uniform section, clean	0.022	0.025	0.030
d. With short grass, few weeds	0.022	0.027	0.033
2. **Earth, winding and sluggish**			
a. No vegetation	0.023	0.025	0.030
b. Grass, some weeds	0.025	0.030	0.033
c. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
d. Earth bottom and rubble side	0.028	0.030	0.035
e. Stony bottom and weedy banks	0.025	0.035	0.040
f. Cobble bottom and clean sides	0.030	0.040	0.050
3. **Dragline-excavated or dredged**			
a. No vegetation	0.025	0.028	0.033
b. Light brush on banks	0.035	0.050	0.060
4. **Rock cuts**			
a. Smooth and uniform	0.025	0.035	0.040
b. Jagged and irregular	0.035	0.040	0.050
5. **Channels not maintained, weeds and brush**			
a. Clean bottom, brush on sides	0.040	0.050	0.080
b. Same as above, highest stage of flow	0.045	0.070	0.110
c. Dense weeds, high as flow depth	0.050	0.080	0.120
d. Dense brush, high stage	0.080	0.100	0.140

Other sources that include pictures of selected streams as a guide to n value determination are available (Fasken, 1963; Barnes, 1967; and Hicks and Mason, 1991). In general, these references provide color photos with tables of calibrated n values for a range of flows.

Although there are many factors that affect the selection of the n value for the channel, some of the most important factors are the type and size of materials that compose the bed and banks of a channel, and the shape of the channel. Cowan (1956) developed a procedure for estimating the effects of these factors to determine the value of Manning's n of a channel. In Cowan's procedure, the value of n is computed by the following equation:

Table 3-1 (Continued) Manning's 'n' Values

Type of Channel and Description	Minimum	Normal	Maximum
B. *Lined or Built-Up Channels*			
1. **Concrete**			
a. Trowel finish	0.011	0.013	0.015
b. Float Finish	0.013	0.015	0.016
c. Finished, with gravel bottom	0.015	0.017	0.020
d. Unfinished	0.014	0.017	0.020
e. Gunite, good section	0.016	0.019	0.023
f. Gunite, wavy section	0.018	0.022	0.025
g. On good excavated rock	0.017	0.020	
h. On irregular excavated rock	0.022	0.027	
2. **Concrete bottom float finished with sides of:**			
a. Dressed stone in mortar	0.015	0.017	0.020
b. Random stone in mortar	0.017	0.020	0.024
c. Cement rubble masonry, plastered	0.016	0.020	0.024
d. Cement rubble masonry	0.020	0.025	0.030
e. Dry rubble on riprap	0.020	0.030	0.035
3. **Gravel bottom with sides of:**			
a. Formed concrete	0.017	0.020	0.025
b. Random stone in mortar	0.020	0.023	0.026
c. Dry rubble or riprap	0.023	0.033	0.036
4. **Brick**			
a. Glazed	0.011	0.013	0.015
b. In cement mortar	0.012	0.015	0.018
5. **Metal**			
a. Smooth steel surfaces	0.011	0.012	0.014
b. Corrugated metal	0.021	0.025	0.030
6. **Asphalt**			
a. Smooth	0.013	0.013	
b. Rough	0.016	0.016	
7. **Vegetal lining**	0.030		0.500

Table 3-1 Manning's 'n' Values

Type of Channel and Description	Minimum	Normal	Maximum
A. *Natural Streams*			
1. Main Channels			
a. Clean, straight, full, no rifts or deep pools	0.025	0.030	0.033
b. Same as above, but more stones and weeds	0.030	0.035	0.040
c. Clean, winding, some pools and shoals	0.033	0.040	0.045
d. Same as above, but some weeds and stones	0.035	0.045	0.050
e. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. Same as "d" but more stones	0.045	0.050	0.060
g. Sluggish reaches, weedy. deep pools	0.050	0.070	0.080
h. Very weedy reaches, deep pools, or floodways with heavy stands of timber and brush	0.070	0.100	0.150
2. Flood Plains			
a. Pasture no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
b. Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
2. Same as above, but heavy sprouts	0.050	0.060	0.080
3. Heavy stand of timber, few down trees, little undergrowth, flow below branches	0.080	0.100	0.120
4. Same as above, but with flow into branches	0.100	0.120	0.160
5. Dense willows, summer, straight	0.110	0.150	0.200

3. Mountain Streams, no vegetation in channel, banks usually steep, with trees and brush on banks submerged			
a. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
b. Bottom: cobbles with large boulders	0.040	0.050	0.070

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Hydraulic Design of Energy Dissipators for Culverts and Channels

National Highway Institute

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CHAPTER 10: RIPRAP BASINS AND APRONS

Riprap is a material that has long been used to protect against the forces of water. The material can be pit-run (as provided by the supplier) or specified (standard or special). State DOTs have standard specifications for a number of classes (sizes or gradations) of riprap. Suppliers maintain an inventory of frequently used classes. Special gradations of riprap are produced on-demand and are therefore more expensive than both pit-run and standard classes.

This chapter includes discussion of both riprap aprons and riprap basin energy dissipators. Both can be used at the outlet of a culvert or chute (channel) by themselves or at the exit of a stilling basin or other energy dissipator to protect against erosion downstream. Section 10.1 provides a design procedure for the riprap basin energy dissipator that is based on armoring a pre-formed scour hole. The riprap for this basin is a special gradation. Section 10.2 includes discussion of riprap aprons that provide a flat armored surface as the only dissipator or as additional protection at the exit of other dissipators. The riprap for these aprons is generally from State DOT standard classes. Section 10.3 provides additional discussion of riprap placement downstream of energy dissipators.

10.1 RIPRAP BASIN

The design procedure for the riprap basin is based on research conducted at Colorado State University (Simons, et al., 1970; Stevens and Simons, 1971) that was sponsored by the Wyoming Highway Department. The recommended riprap basin that is shown on Figure 10.1 and Figure 10.2 has the following features:

- The basin is pre-shaped and lined with riprap that is at least $2D_{50}$ thick.
- The riprap floor is constructed at the approximate depth of scour, h_s, that would occur in a thick pad of riprap. The h_s/D_{50} of the material should be greater than 2.
- The length of the energy dissipating pool, L_s, is $10h_s$, but no less than $3W_o$; the length of the apron, L_A, is $5h_s$, but no less than W_o. The overall length of the basin (pool plus apron), L_B, is $15h_s$, but no less than $4W_o$.
- *A riprap cutoff wall or sloping apron can be constructed if downstream channel degradation is anticipated as shown in Figure 10.1.*

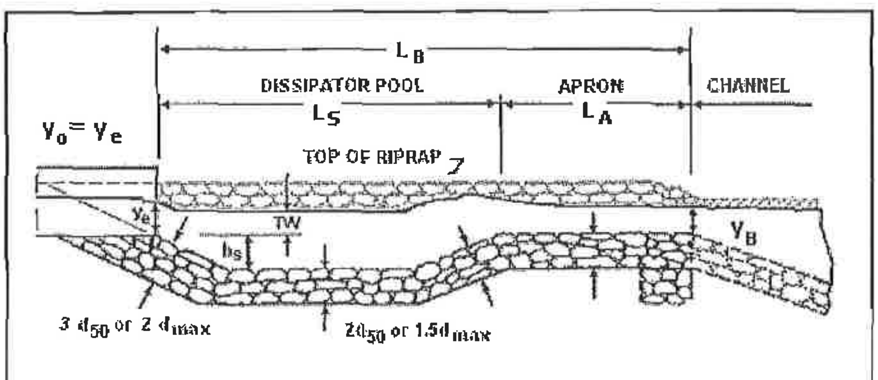


Figure 10.1. Profile of Riprap Basin

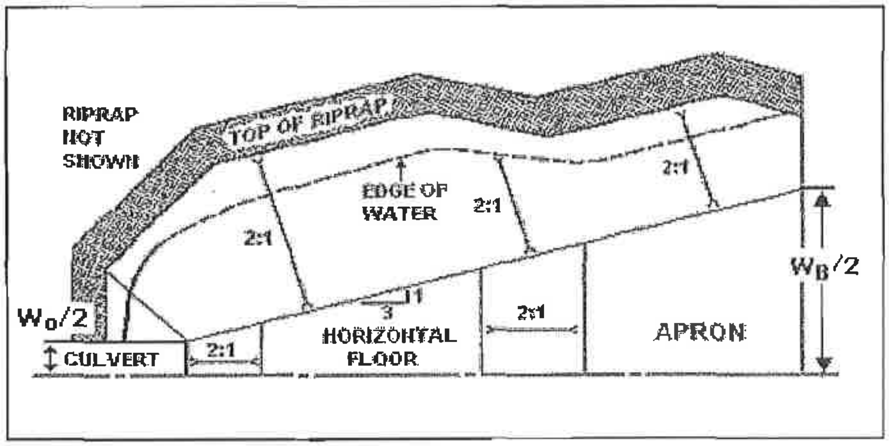


Figure 10.2. Half Plan of Riprap Basin

10.1.1 Design Development

Tests were conducted with pipes from 152 mm (6 in) to 914 mm (24 in) and 152 mm (6 in) high model box culverts from 305 mm (12 in) to 610 mm (24 in) in width. Discharges ranged from 0.003 to 2.8 m^3/s (0.1 to 100 ft^3/s). Both angular and rounded rock with an average size, D_{50}, ranging from 6 mm (1.4 in) to 177 mm (7 in) and gradation coefficients ranging from 1.05 to 2.66 were tested. Two pipe slopes were considered, 0 and 3.75%. In all, 459 model basins were studied. The following conclusions were drawn from an analysis of the experimental data and observed operating characteristics:

- The scour hole depth, h_s; length, L_s; and width, W_s, are related to the size of riprap, D_{50}; discharge, Q; brink depth, y_o; and tailwater depth, TW.
- Rounded material performs approximately the same as angular rock.
- For low tailwater ($TW/y_o < 0.75$), the scour hole functions well as an energy dissipator if $h_s/D_{50} > 2$. The flow at the culvert brink plunges into the hole, a jump forms and flow is generally well dispersed.
- For high tailwater ($TW/y_o > 0.75$), the high velocity core of water passes through the basin and diffuses downstream. As a result, the scour hole is shallower and longer.
- The mound of material that forms downstream contributes to the dissipation of energy and reduces the size of the scour hole. If the mound is removed, the scour hole enlarges somewhat.

Plots were constructed of h_s/y_e versus $V_o/ (gy_e)^{1/2}$ with D_{50}/y_e as the third variable. Equivalent brink depth, y_e, is defined to permit use of the same design relationships for rectangular and circular culverts. For rectangular culverts, $y_e = y_o$ (culvert brink depth). For circular culverts, $y_e = (A/2)^{1/2}$, where A is the brink area.

Anticipating that standard or modified end sections would not likely be used when a riprap basin is located at a culvert outlet, the data with these configurations were not used to develop the design relationships. This assumption reduced the number of applicable runs to 346. A total of 128 runs had a D_{50}/y_e of less than 0.1. These data did not exhibit relationships that appeared useful for design and were eliminated. An additional 69 runs where $h_s/D_{50}<2$ were also eliminated by the authors of this edition of HEC 14. These runs were not considered reliable for design, especially those with $h_s = 0$. Therefore, the final design development used 149 runs from the study. Of these, 106 were for pipe culverts and 43 were for box culverts. Based on these data, two design relationships are presented here: an envelope design and a best fit design.

To balance the need for avoiding an underdesigned basin against the costs of oversizing a basin, an envelope design relationship in the form of Equation 10.1 and Equation 10.2 was developed. These equations provide a design envelope for the experimental data equivalent to the design figure (Figure XI-2) provided in the previous edition of HEC 14 (Corry, et al., 1983). *Equations 10.1 and 10.2, however, improve the fit to the experimental data reducing the root-*mean-square (RMS) error from 1.24 to 0.83.

$$\frac{h_s}{y_e} = 0.86\left(\frac{D_{50}}{y_e}\right)^{-0.55}\left(\frac{V_o}{\sqrt{gy_e}}\right) - C_o \qquad (10.1)$$

where,

h_s = dissipator pool depth, m (ft)

y_e = equivalent brink (outlet) depth, m (ft)

D_{50} = median rock size by weight, m (ft)

C_o = tailwater parameter

The tailwater parameter, C_o, is defined as:

$$\begin{array}{ll} C_o = 1.4 & TW/y_e < 0.75 \\ C_o = 4.0(TW/y_e) - 1.6 & 0.75 < TW/y_e < 1.0 \\ C_o = 2.4 & 1.0 < TW/y_e \end{array} \qquad (10.2)$$

A best fit design relationship that minimizes the RMS error when applied to the experimental data was also developed. Equation 10.1 still applies, but the description of the tailwater parameter, C_o, is defined in Equation 10.3. The best fit relationship for Equations 10.1 and 10.3 exhibits a RMS error on the experimental data of 0.56.

$$\begin{array}{ll} C_o = 2.0 & TW/y_e < 0.75 \\ C_o = 4.0(TW/y_e) - 1.0 & 0.75 < TW/y_e < 1.0 \\ C_o = 3.0 & 1.0 < TW/y_e \end{array} \qquad (10.3)$$

Use of the envelope design relationship (Equations 10.1 and 10.2) is recommended when the consequences of failure at or near the design flow are severe. Use of the best fit design relationship (Equations 10.1 and 10.3) is recommended when basin failure may easily be addressed as part of routine maintenance. Intermediate risk levels can be adopted by the use of intermediate values of C_o.

10.1.2 Basin Length

Frequency tables for both box culvert data and pipe culvert data of relative length of scour hole ($L_s/h_s < 6$, $6 < L_s/h_s < 7$, $7 < L_s/h_s < 8$ . . . $25 < L_s/h_s < 30$), with relative tailwater depth TW/y_e in increments of 0.03 m (0.1 ft) as a third variable, were constructed using data from 346 experimental runs. For box culvert runs L_s/h_s was less than 10 for 78% of the data and L_s/h_s was less than 15 for 98% of the data. For pipe culverts, L_s/h_s was less than 10 for 91% of the data and, L_s/h_s was less than 15 for all data. A 3:1 flare angle is recommended for the basins walls. This angle will provide a sufficiently wide energy dissipating pool for good basin operation.

10.1.3 High Tailwater

Tailwater influenced formation of the scour hole and performance of the dissipator. For tailwater depths less than 0.75 times the brink depth, scour hole dimensions were unaffected by tailwater. Above this the scour hole became longer and narrower. The tailwater parameter defined in Equations 10.2 and 10.3 captures this observation. In addition, under high tailwater conditions, it is appropriate to estimate the attenuation of the flow velocity downstream of the culvert outlet using Figure 10.3. This attenuation can be used to determine the extent of riprap protection required. HEC 11 (Brown and Clyde, 1989) or the method provided in Section 10.3 can be used for sizing riprap.

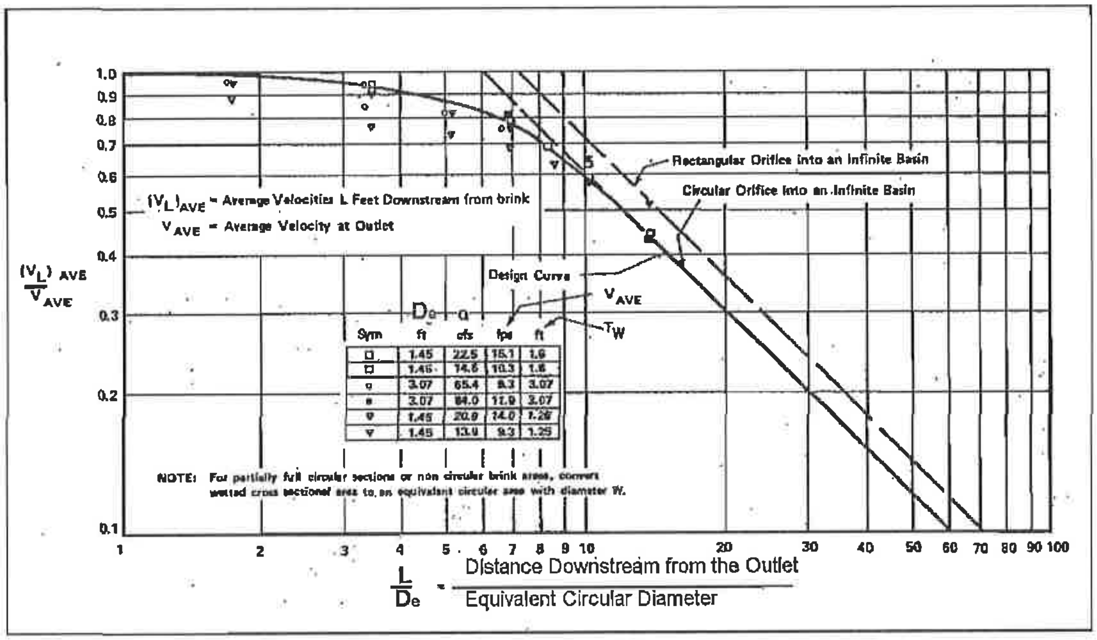


Figure 10.3. Distribution of Centerline Velocity for Flow from Submerged Outlets

10.1.4 Riprap Details

Based on experience with conventional riprap design, the recommended thickness of riprap for the floor and sides of the basin is $2D_{50}$ or $1.50D_{max}$, where D_{max} is the maximum size of rock in the riprap mixture. Thickening of the riprap layer to $3D_{50}$ or $2D_{max}$ on the foreslope of the roadway culvert outlet is warranted because of the severity of attack in the area and the necessity for preventing undermining and consequent collapse of the culvert. Figure 10.1 illustrates these riprap details. The mixture of stone used for riprap and need for a filter should meet the specifications described in HEC 11 (Brown and Clyde, 1989).

10.1.5 Design Procedure

The design procedure for a riprap basin is as follows:

Step 1. Compute the culvert outlet velocity, V_o, and depth, y_o.

For subcritical flow (culvert on mild or horizontal slope), use Figure 3.3 or Figure 3.4 to obtain y_o/D, then obtain V_o by dividing Q by the wetted area associated with y_o. D is the height of a box culvert or diameter of a circular culvert.

For supercritical flow (culvert on a steep slope), V_o will be the normal velocity obtained by using the Manning's Equation for appropriate slope, section, and discharge.

Compute the Froude number, Fr, for brink conditions using brink depth for box culverts (y_e=y_o) and equivalent depth ($y_e = (A/2)^{1/2}$) for non-rectangular sections.

Step 2. Select D_{50} appropriate for locally available riprap. Determine C_o from Equation 10.2 or 10.3 and obtain h_s/y_e from Equation 10.1. Check to see that $h_s/D_{50} \geq 2$ and $D_{50}/y_e \geq 0.1$. If h_s/D_{50} or D_{50}/y_e is out of this range, try a different riprap size. (Basins sized where h_s/D_{50} is greater than, but close to, 2 are often the most economical choice.)

Step 3. Determine the length of the dissipation pool (scour hole), L_s, total basin length, L_B, and basin width at the basin exit, W_B, as shown in Figures 10.1 and 10.2. The walls and apron of the basin should be warped (or transitioned) so that the cross section of the basin at the exit conforms to the cross section of the natural channel. Abrupt transition of surfaces should be avoided to minimize separation zones and resultant eddies.

Step 4. Determine the basin exit depth, $y_B = y_c$, and exit velocity, $V_B = V_c$ and compare with the allowable exit velocity, V_{allow}. The allowable exit velocity may be taken as the estimated normal velocity in the tailwater channel or a velocity specified based on stability criteria, whichever is larger. Critical depth at the basin exit may be determined iteratively using Equation 7.14:

$Q^2/g = (A_c)^3/T_c = [y_c(W_B + zy_c)]^3/ (W_B + 2zy_c)$ by trial and success to determine y_B.

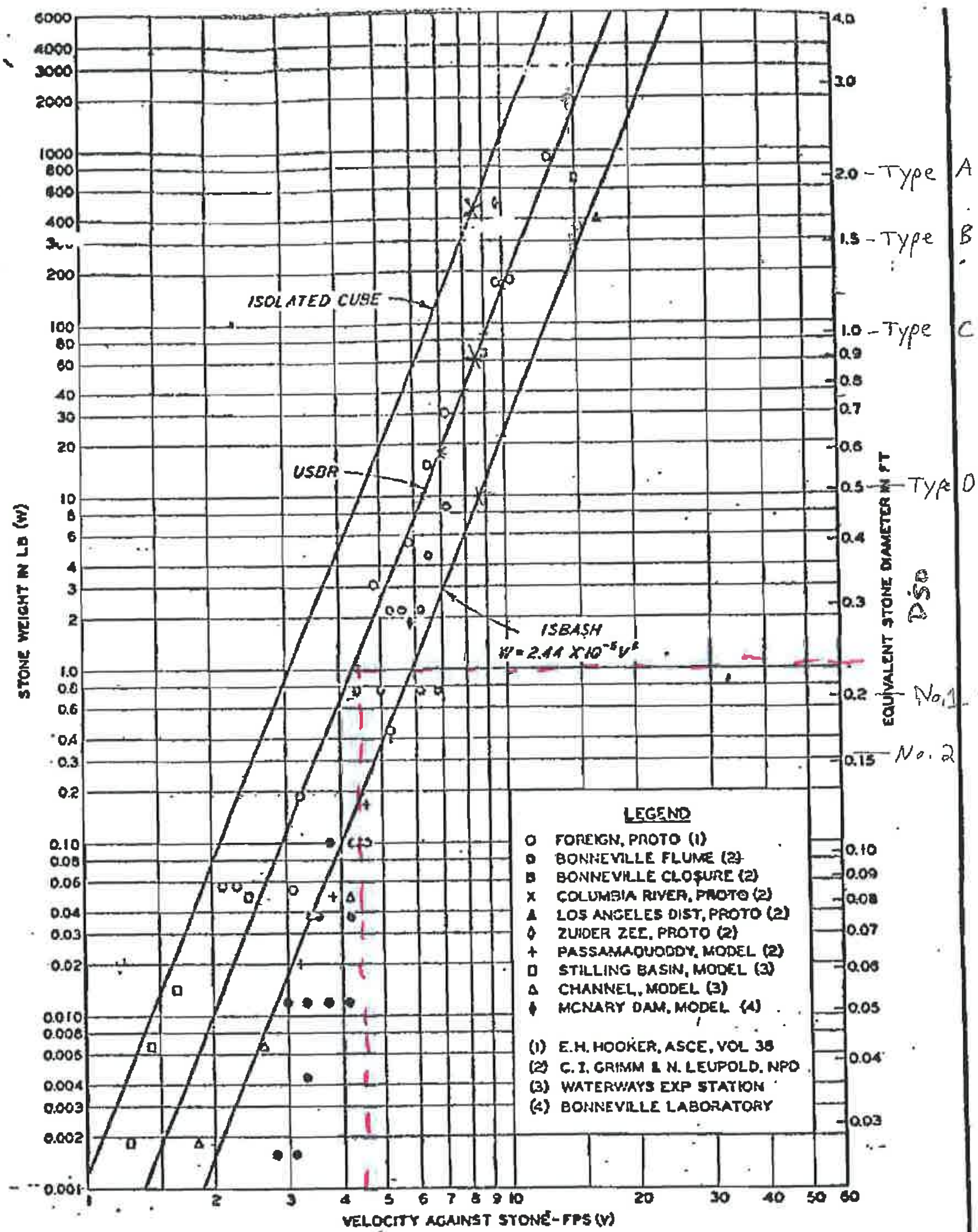
$V_c = Q/A_c$

z = basin side slope, z:1 (H:V)

If $V_c \leq V_{allow}$, the basin dimensions developed in step 3 are acceptable. However, it may be possible to reduce the size of the dissipator pool and/or the apron with a larger riprap size. It may also be possible to maintain the dissipator pool, but reduce the flare on the apron to reduce the exit width to better fit the downstream channel. Steps 2 through 4 are repeated to evaluate alternative dissipator designs.

Step 5. Assess need for additional riprap downstream of the dissipator exit. If $TW/y_o \leq 0.75$, no additional riprap is needed. With high tailwater ($TW/y_o \geq 0.75$), estimate centerline velocity at a series of downstream cross sections using Figure 10.3 to determine the size and extent of additional protection. The riprap design details should be in accordance with specifications in HEC 11 (Brown and Clyde, 1989) or similar highway department specifications.

AJS



NOTE: SPECIFIC WEIGHT OF ROCK=155 LB/CU FT.

RIVER CLOSURES

VELOCITY VS STONE WEIGHT

HYDRAULIC DESIGN CHART 712-1

From WES MP No 2-265, April 1958

WES 4-57

APPENDIX C

Quality Assurance and Quality Control Plan

Cardinal Fly Ash Reservoir II Closure

Submitted to

Ohio Environmental Protection Agency
Division of Surface Water

Submitted and Owned by

Cardinal Operating Company
Brilliant, Ohio

Prepared by

American Electric Power Service Corporation
1 Riverside Plaza, Columbus Ohio 43215

and

S&ME, Inc.
6190 Enterprise Ct.
Dublin, Ohio 43016

April 2012

TABLE OF CONTENTS

1. INTRODUCTION

This document presents QA/QC procedures for the closure of Fly Ash Reservoir (FAR) II at the Cardinal Generating Station located near Brilliant, Ohio. This plan addresses inspection and verification activities and procedures to ensure and document the quality of key components of the closure construction. The main component of construction is installation of the cap system. Details of the closure are depicted in the Drawing Set entitled "Fly Ash Reservoir II Closure" which is included as Appendix D of this document. This *QA/QC Plan* will be incorporated into all applicable construction and/or operation contracts.

2. PERSONNEL AND QUALIFICATIONS

The quality assurance personnel involved in the closure of Cardinal FAR II includes the following:

- Construction Quality Assurance (CQA) Certifying Engineer;
- Quality Assurance Officer (QAO);
- Quality Assurance (QA) Inspectors; and,
- Quality Assurance (QA Surveyors.

The qualifications, responsibilities of these personnel are defined in the following sections.

A. Construction Quality Assurance Certifying Engineer

The CQA Certifying Engineer will have overall CQA responsibility to ensure the closure of FAR II is constructed as specified and in accordance with this *QA/QC Plan*. The CQA Certifying Engineer will be a registered State of Ohio Professional Engineer (P.E.) and will be an employee or representative (consulting engineer) of AEP. All construction certification documents will be prepared under the direction of the CQA Certifying Engineer.

B. Quality Assurance Officer

The QAO will direct the day to day CQA activities during construction and will supervise the QA Inspectors. The QAO will be an employee or representative of AEP or Cardinal Operating Company. The QAO will understand the site design, proper construction practices, and the applicability and theory of the quality assurance activities. Specific responsibilities of the QAO will include:

- Review and fully understand all aspects of the closure design and proposed construction techniques.
- Provide QA Reports to the CQA Certifying Engineer documenting results of inspections, testing, and remedial actions during construction.
- Advise the CQA Certifying Engineer of work that should be corrected, rejected, or uncovered for inspection; and, identify work that may require special testing, inspection, or approval.
- Review inspection and test results and reject defective work.
- Direct the QA Inspectors in performing site inspections and testing.

C. Quality Assurance Inspectors

The QA Inspectors will be employees of an independent consultant or inspection services contractor contracted by AEP or will be AEP employees. The inspectors will be trained in the proper use of the test methods and equipment for which they are responsible. They will be able to calibrate their equipment, conduct the required tests, record and interpret data, and record their observations. Specific responsibilities of the QA Inspectors will include:

- Conduct observations and tests to assess compliance with the plans, specifications, and quality assurance documents.
- Monitor tests and construction procedures conducted by the construction contractor.
- Report to the QAO the results of all inspections and observations including work that does not meet the specifications, fails to meet contract requirements, or deviates from permissible construction procedures.

D. Quality Assurance Surveyor

The CQ Surveyor will be a registered State of Ohio Professional Surveyor (P.S.) and will be an employee or representative (consulting surveyor) of AEP. CQA surveying of lines and grades will be performed on an ongoing basis during construction to independently verify that the work of the Contractor meets the design plans. The CQA surveyor will use the project benchmarks depicted on the Closure Drawings and other control points established by the CQA surveyor during construction.

The scope of CQA surveying will include, but not necessarily be limited to, the following:

- verifying the horizontal and vertical coordinates of certification points;
- verifying soil component layer thickness; and,
- providing sufficient survey information of interim conditions such that material quantities can be calculated.

It will be the responsibility of the CQA personnel to coordinate the CQA surveying work such that areas are promptly surveyed, interim results are reviewed, and approval is granted for the Contractor to proceed with subsequent work in the areas.

3. RECORD RETENTION PROCEDURES

The QAO will be responsible for the keeping and maintaining construction QA/QC records. QA/QC records will be stored throughout the post-closure care period in the FAR No. 1 Landfill Office. Select records or summaries of records will be included in the construction documentation report described in Section 5 of this Plan.

Quality assurance records that will be kept and maintained will include, but not necessarily be limited to, the following:

- QA Inspector's daily logs;
- Equipment calibration records;
- Field testing records;
- Laboratory testing records;
- Any deviations from the design plans and specifications;
- CQA Survey documents; and,
- Contractor Record drawings showing the plan view of test locations, cross sections, and necessary details.

4. CONSTRUCTION AND MATERIALS TESTING

A. Ash Re-Grading

CQA activities associated with the re-grading of the ash will include CQA surveying of the surface of the ash immediately prior to installation of non-ash materials above the ash to ensure that the final ash grade does not exceed the grades depicted in the approved Closure Drawings. This activity will be completed by the QA Surveyor and will include, at a minimum, the following:

- Establish a certification grid with certification points on 100 foot centers;
- Collect northings, eastings, and elevations of the final ash grade at each certification point; and
- Report the data to the CAO and CQA Engineer in both tabular and map form.

The tabulated data will include, at a minimum, the following:

- Certification point identification number;
- Northing and easting of each certification point;
- Design maximum ash elevation;
- Actual final ash elevation;
- Deviation of actual final ash elevation from the design maximum elevation at each point; and,
- The date each point was surveyed.

The map submittal shall depict the certification points, certification point number, and the spot elevation of the final ash surface at each certification point. The map shall bear the seal of the QA Surveyor.

B. Geotextile Fabric

1) Material

Geotextile fabric shall be non-woven and conform to the requirements of the 2010 edition of the Ohio Department of Transportation Construction and Materials Specifications for Item 712.09, Type D.

2) Conformance Verification

The QA Inspector will document that the material meets the project specification and is properly handled prior to installation. Specific monitoring activities include, but are not limited to the following:

- review the manufacturers documentation to verify that the geotextile meets specifications;

- collecting and reviewing the Geosynthetic Manufacturers' quality control documentation to verify that the certifications comply with specifications;
- tracking inventory of the geotextile rolls delivered to the Facility;
- observing geotextile rolls that have been delivered to the Facility for damage during transportation and, if damaged, marking damaged locations for repair or replacement; and,
- observing and documenting material unloading, transporting, and storage.

3) Construction Monitoring

The QA Inspector will visually monitor geotextile installation. Specific monitoring activities include, but are not limited to the following:

- observing that immediately prior to geotextile placement, the subgrade is free of sharp protrusions or other obstructions that could potentially damage the geotextile;
- observe that in the presence of wind, the geotextile is weighted with sandbags (or equivalent ballast weight approved by the QA Inspectors), and that sandbags remain until the overlying layer is placed;
- observe that efforts are made to minimize the presence of wrinkles in the geotextile, and if necessary, the geotextile is positioned by hand after being unrolled to minimize wrinkles;
- examination of the entire surface, after installation, to verify that no potentially harmful foreign objects, such as needles or tools, are present; and
- verify that the geotextile is not left exposed for longer that the manufacturer's recommended maximum allowable period after placement unless a longer exposure period is approved by the QAO.

The QA Inspectors will verify that the Contractor places all soil materials on top of the geotextile such that:

- the geotextile and underlying materials are not damaged;
- wrinkles are minimized; and,
- excess tensile stresses are not produced in the geotextile.

4) Surveying

QA surveying of the geotextile shall include determination of the installed lateral limits of the material. The determination shall be completed by collection of spot northings and eastings on 50 foot intervals along the lateral edge of the installed material. The findings of the survey will be reported to the CAO and CQA Engineer in both tabular and map form.

The tabulated data will include, at a minimum, the following:

- Northing and easting of each survey point; and,
- Date the actual ash grade was surveyed.

The map submittal shall depict the surveyed point locations. The map shall bear the seal of the QA Surveyor.

C. Geosynthetic Drainage Net

1) Material

The geosynthetic drainage net will consist of a HDPE geonet with non-woven geotextile fabric heat bonded on both sides of geonet. The geosynthetic drainage net shall be GSE FabriNet as manufactured by GSE Lining Technology, Inc., or approved equal. If an alternate material is proposed, equivalency shall be evaluated based on:

- presence of geotextile fabric on both sides of the geonet; and,
- minimum transmissivity (as determined by ASTM D4716) which shall be equal to or greater than the following:

Gradient	0.1	1
Normal Pressure	209 lbs/ft (10kPa)	10,000 lbs/ft (479 kPa)
Transmissivity	5 x 10^{-4} m^2/sec	1 x 10^{-4} m^2/sec

2) Conformance Verification

The QA Inspector will document that the geosynthetic drainage net meets the project specification and is properly handled prior to installation. Specific monitoring activities include, but are not limited to the following:

- review the manufacturers documentation to verify that the material meets project specifications;
- collecting and reviewing the Manufacturers' quality control documentation to verify that the certifications comply with specifications;
- tracking inventory of the delivered material;
- observing the delivered material for damage during transportation and, if damaged, marking damaged locations for repair or replacement; and,
- observing and documenting material unloading, transporting, and storage.

3) Construction Monitoring

The QA Inspector will visually monitor geosynthetic drainage net installation. Installation shall be in accordance with the manufacturer's recommendations. Specific monitoring activities include, but are not limited to the following:

- observing that immediately prior to placement, the subgrade is free of sharp protrusions or other obstructions that could potentially damage the material;
- observe that in the presence of wind, the material is weighted with sandbags (or equivalent ballast weight approved by the QA Inspectors), and that sandbags remain until the overlying layer is placed;
- observe that efforts are made to minimize the presence of wrinkles in the material, and if necessary, that the material is positioned by hand after being unrolled to minimize wrinkles;

- examination of the entire surface, after installation, to verify that no potentially harmful foreign objects, such as needles or tools, are present; and
- verifying that the material is not left exposed for longer that the manufacturer's recommended maximum allowable period after placement unless a longer exposure period is approved by the QAO.

The QA Inspectors will verify that the Contractor places all soil materials on top of the gesynthetic drainage net such that:

- the geosynthetic drainage layer and underlying materials are not damaged;
- wrinkles are minimized; and,
- excess tensile stresses are not produced.

4) Surveying

QA surveying of the geosynthetic drainage net shall include determination of the installed lateral limits of the material. The determination shall be completed by collection of spot northings and eastings on 50 foot intervals along the lateral edge of the installed material. The findings of the survey will be reported to the CAO and CQA Engineer in both tabular and map form.

The tabulated data will include, at a minimum, the following:

- Northing and easting of each survey point; and,
- Data the actual ash grade was surveyed.

The map submittal shall depict the surveyed point locations. The map shall bear the seal of the QA Surveyor.

D. Vegetative Layer

1) Material

The vegetative layer is comprised of general fill and topsoil that combine to promote stormwater runoff and facilitate vegetation growth.

a) General Fill

Not less than the lower 20-inches of the vegetative layer shall consist of general fill. The general fill portion of the vegetative layer shall consist of in-organic soil meeting the following gradation requirements:

- the maximum particle size shall not exceed 4-inches;
- not less than 30% of the material shall pass the No. 200 sieve; and,
- the maximum permeability shall not exceed $1x10^{-5}$ cm/sec.

b) Topsoil

Not less than the upper 4-inches of the vegetative layer shall consist of topsoil. Topsoil shall have at least 4 percent by weight organic matter and be free of roots, stones larger than 3 inches or other foreign material. Topsoil will be placed and spread without compactive effort.

2) <u>Conformance Verification</u>

Material to be used as general fill shall be pre-qualified prior to use. Pre-qualification testing shall include, at a minimum, the following testing at the prescribed frequency:

- ASTM D422 - Sieve and Hydrometer Analyses — 1 test for each 3,000 cubic yards
- ASTM D4318 - Atterberg Limits — 1 test for each 3,000 cubic yards
- ASTM D698 - Standard Proctor — 1 test per each 10,000 cubic yards
- ASTM 5084 - Re-molded permeability — 1 test per each 10,000 cubic yards

Only material which conformance testing has demonstrated compliance with the requirements of paragraph 4.D.1.a. of this QA/QC Plan may be used as general fill.

3) <u>Construction Monitoring</u>

a) General Fill

The compacted density and moisture of the general fill shall be tested by the QA Inspectors at a frequency of not less than 5 tests per lift per acre. Density testing shall be in accordance with ASTM D2922, D2167, D2937, or D1556; moisture testing shall be in accordance with ASTM D3017, D4643, or D2216.

The compacted density of the general fill shall be equal to or greater than the density used for pre-qualification testing of the same material where compliance with the permeability requirement was demonstrated. However, in no case shall the density be less than 95.0% of maximum dry density as determined by ASTM D698. The moisture content of the compacted general fill shall be equal to or greater than the moisture used for pre-qualification testing of the same material where compliance with the permeability requirement was demonstrated.

b) Topsoil

Topsoil shall be sampled by the QA Inspectors at a rate of one sample per acre. The samples shall be collected after the material has been placed and spread. The samples shall be submitted to an agricultural laboratory for analysis. The analysis shall include, at a minimum, the following:

- pH
- organic content
- grain size, and
- soil nutrient levels

Results of the analysis shall be reported to the QAO. The laboratory reports shall also include recommendations for fertilizer and other soil amendments. The recommendations shall include, at a minimum, application rates, types, and ratios for lime, P, K, S, Fe and other micronutrients.

4) Surveying

CQA surveying of the top of the general fill and the final grade shall be completed to ensure that the minimum material thicknesses have been achieved. This activity will be completed by the QA Surveyor and will include, at a minimum, the following:

- Collect northings, eastings, and elevations of the top of the general fill at each certification point established for the re-grading of the ash;
- Collect northings, eastings, and elevations of the final grade at each certification point established for the re-grading of the ash; and
- Report the data to the CAO and CQA Engineer in both tabular and map form.

The tabulated data will include, at a minimum, the following:

- Certification point identification number;
- Northing and easting of each certification point;
- Final elevation of cap system;
- Final elevation of the top of the general fill;
- Final elevation of the underlying ash at the same location;
- Cap thickness; and,
- The date each point was surveyed.

The map submittal shall depict the certification points surveyed and the spot elevation of the top of the general fill and the final cap elevation at each certification point. The map shall bear the seal of the QA Surveyor.

E. Vegetation

The requirements of 2010 edition of the Ohio Department of Transportation Construction and Materials Specifications for Item 659 shall govern the materials, construction, and QA/QC for the establishment of vegetation on the cap system, except as modified herein.

1) Topsoil

Topsoil shall be in accordance with the requirements of Section 4.D.1.b. of this QA/QC Plan

2) Soil Amendments

Soil amendment applications shall be based on the results of the agronomic analysis completed as per Section 4.D.3 of this QA/QC Plan.

3) Seed

Seed mix shall be Type 4B from ODOT Table 659.09-1.

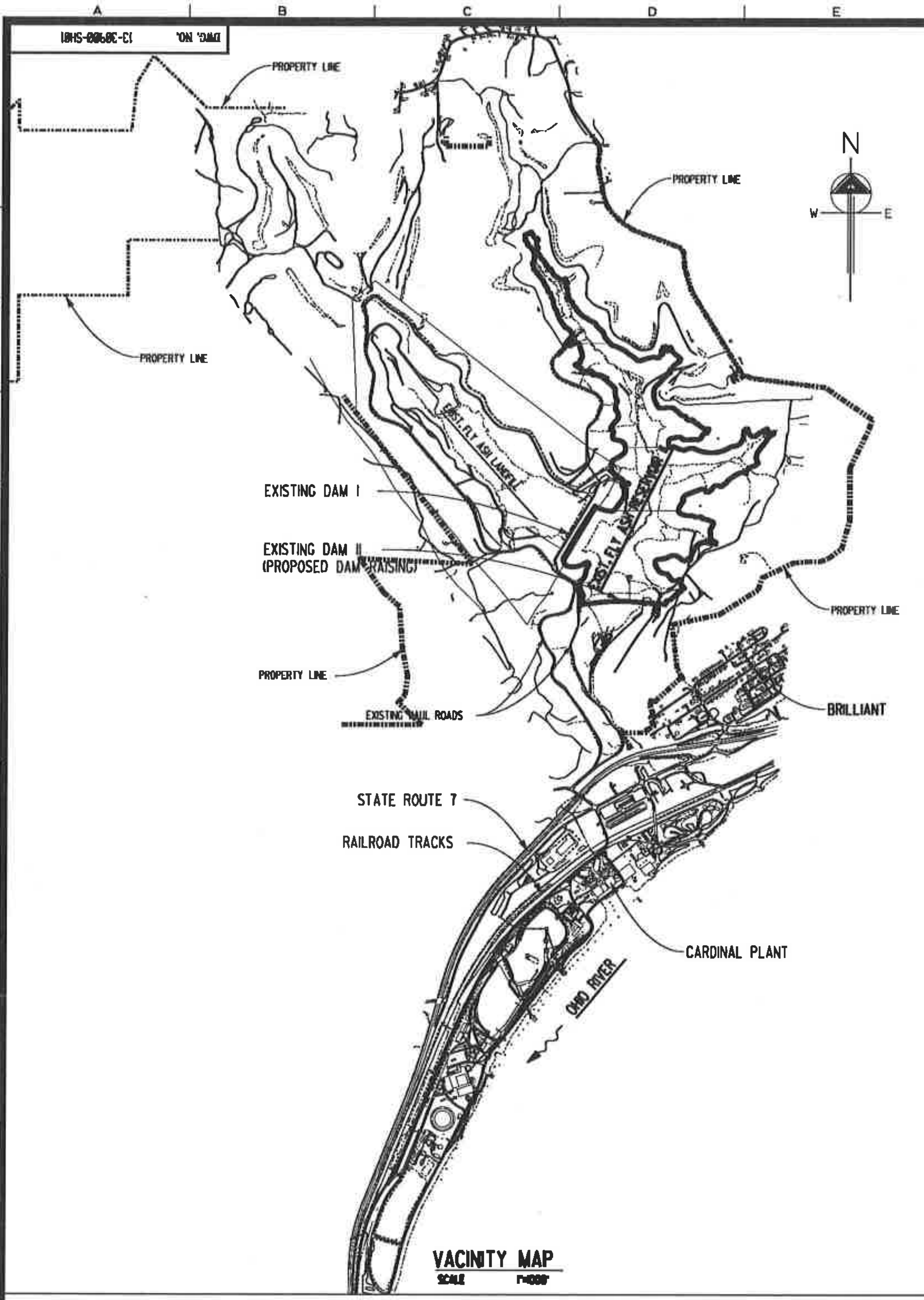
5. CONSTRUCTION DOCUMENTATION REPORTS

The QAO is responsible for the review of all activities associated with the closure construction including but not limited to documents such as daily reports, field test results, and laboratory test results. A construction documentation report addressing all applicable items required by the QA/QC Plan will be prepared at the completion of construction activities. In the event that closure construction is completed incrementally over multiple years, a Construction Documentation Report will be prepared for each calendar year that construction is completed. The construction documentation report(s) will include, at a minimum, the following:

1. Results of testing required by this QA/QC Plan.
2. Any deviations from the approved permit.
3. Record Drawings showing:
    a) Plan views with test locations.
    b) Cross sections.
    c) Necessary details.

The report(s) will document the results of the various field and laboratory tests performed and assess whether or not the constructed systems are in compliance with the Drawings and this QA/QC Plan. A copy of the construction documentation report(s) will be provided to the OEPA.

APPENDIX D



PERMIT APPLICATION
FOR THE
CLOSURE
OF
FLY ASH RESERVOIR II
AT THE
CARDINAL PLANT
BRILLIANT, OHIO

SECTION 5, WELLS TOWNSHIP

JEFFERSON COUNTY

PREPARED FOR:

CARDINAL OPERATING COMPANY

SUBMITTED TO:

OHIO ENVIRONMENTAL PROTECTION AGENCY

PREPARED BY:

S&ME, INC.
6190 ENTERPRISE COURT, DUBLIN, OHIO 43016

AND

AMERICAN ELECTRIC POWER SERVICE CORP.
1 RIVERSIDE PLAZA, COLUMBUS, OHIO 43215

APRIL 2012

DRAWING INDEX

WWW.SMEINC.COM
S&ME, INC.
6190 ENTERPRISE COURT
DUBLIN, OH 43016
PHONE: 614-793-2226
FAX: 614-793-2410

STATE OF OHIO — MICHAEL GILBERT ROWLAND — E-65559 — REGISTERED — PROFESSIONAL ENGINEER

MICHAEL GILBERT ROWLAND — E-65559 NUMBER — 4/9/12 DATE

PROJECT NUMBER:	011-11497-042	DRAWN BY:	EDV
DRAWING DATE:	4/9/12	ENGINEER:	MTR
LAST UPDATED:	4/9/12	APPROVED BY:	MGR
		SCALE:	AS NOTED

S&ME

DATE	NO.	DESCRIPTION	APPD.
	A	ISSUED FOR PERMIT SSB	MAA

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CARDINAL OPERATING COMPANY
CARDINAL PLANT
BRILLIANT OHIO

CLOSURE
FLY ASH RESERVOIR II
COVER SHEET

DWG. NO. 13-30900-SH01

ARCH — ELEC — MECH — STR

SCALE: AS SHOWN — CIVIL ENGINEERING DIVISION

AMERICAN ELECTRIC POWER
1 RIVERSIDE PLAZA
COLUMBUS, OH 43215

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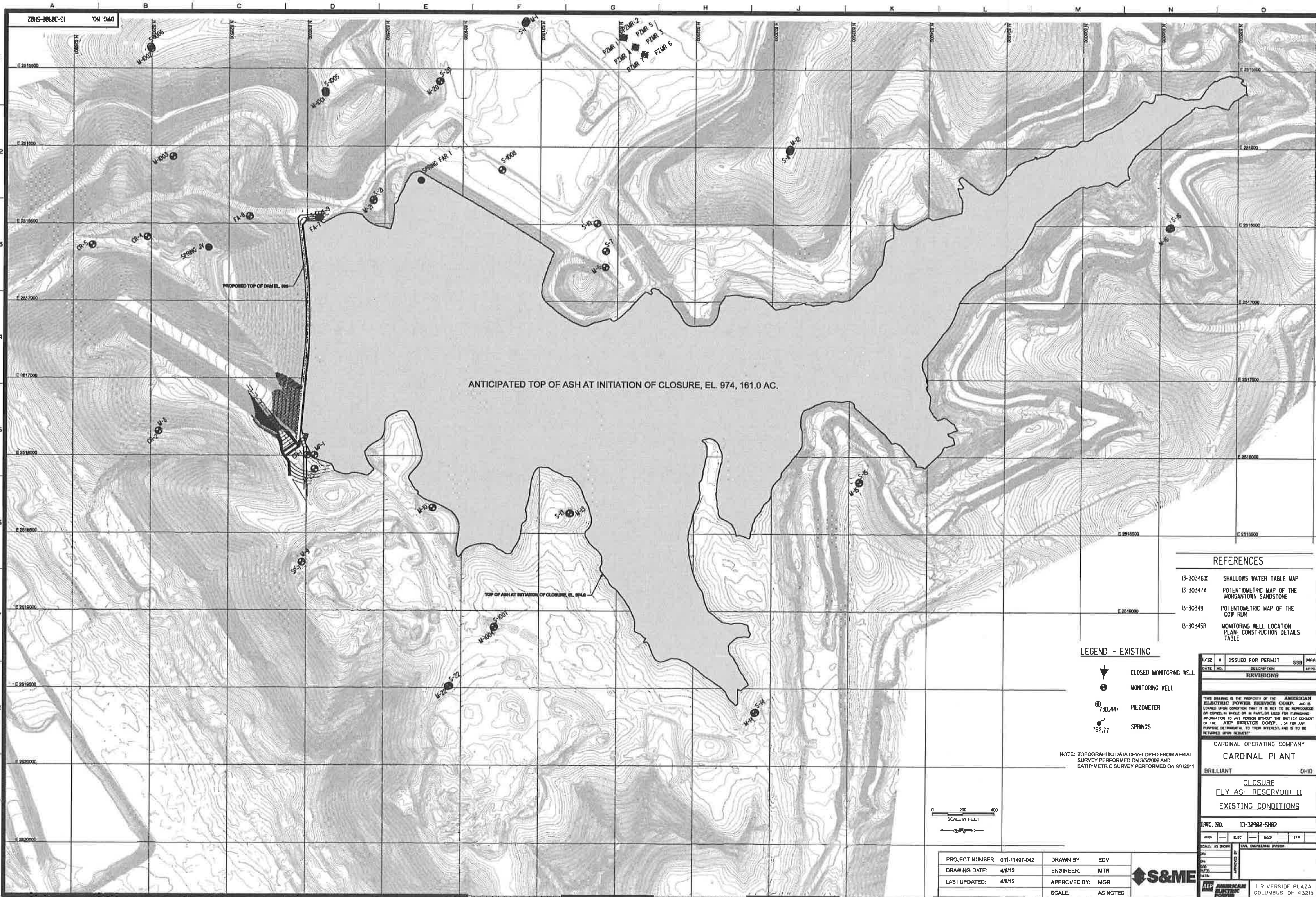
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PROPOSED TOP OF DAM EL. 986
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SPRING FAR I
SPRING JV
REFERENCES
13-30346X SHALLOWS WATER TABLE MAP
13-30347A POTENTIOMETRIC MAP OF THE MORGANTOWN SANDSTONE
13-30349 POTENTOMETRIC MAP OF THE COW RUN
13-30345B MONITORING WELL LOCATION PLAN- CONSTRUCTION DETAILS TABLE
LEGEND - EXISTING
CLOSED MONITORING WELL
MONITORING WELL
730.44 PIEZOMETER
762.77 SPRINGS
NOTE: TOPOGRAPHIC DATA DEVELOPED FROM AERIAL SURVEY PERFORMED ON 3/5/2009 AND BATHYMETRIC SURVEY PERFORMED ON 9/7/2011
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A ISSUED FOR PERMIT SSB MAA
DATE NO. DESCRIPTION APPD.
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CARDINAL PLANT
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CLOSURE
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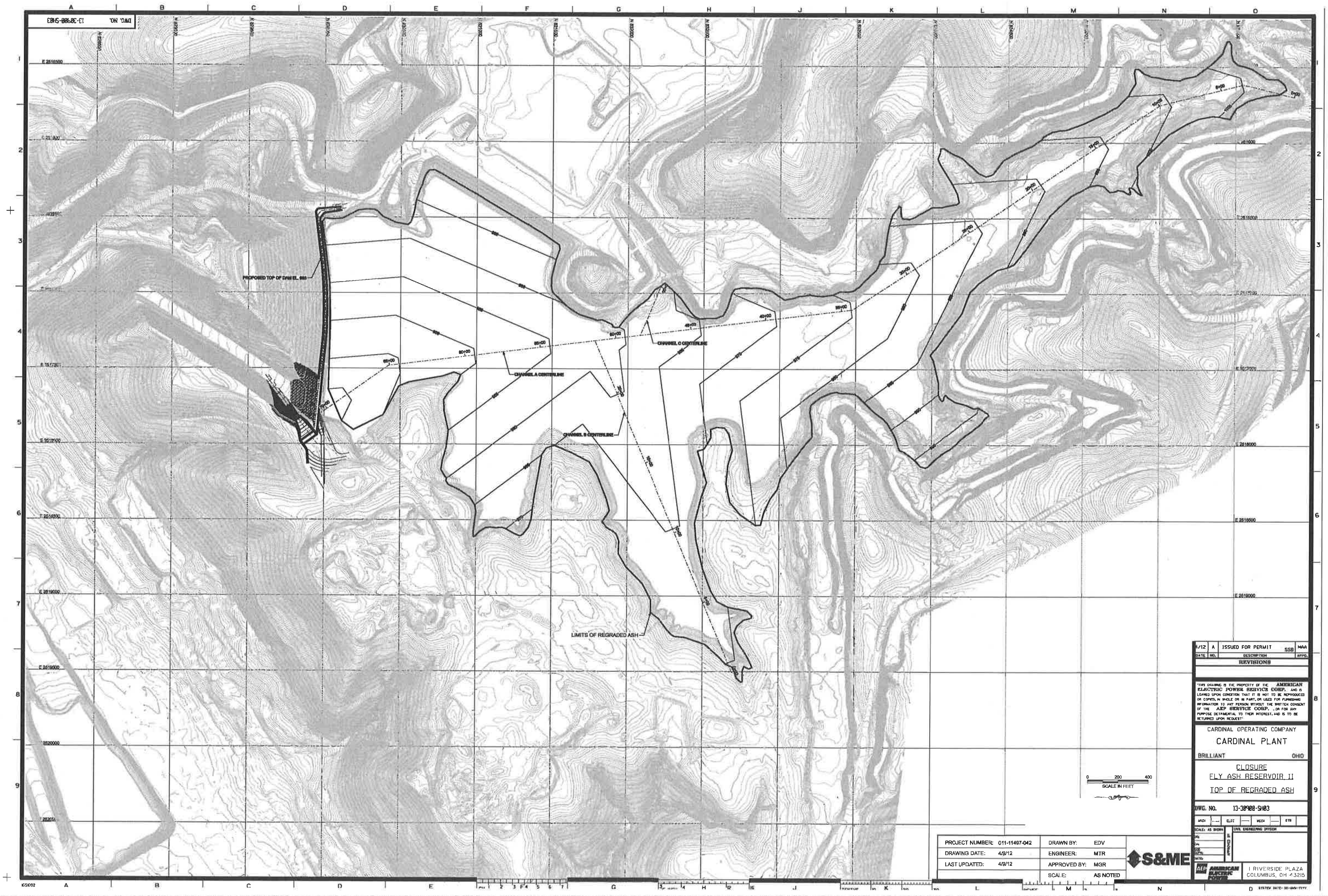
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FLY ASH RESERVOIR II
TOP OF REGRADED ASH
DWG. NO. 13-30900-SH03
SCALE: AS SHOWN
CIVIL ENGINEERING DIVISION
PROJECT NUMBER: 011-11497-042
DRAWING DATE: 4/9/12
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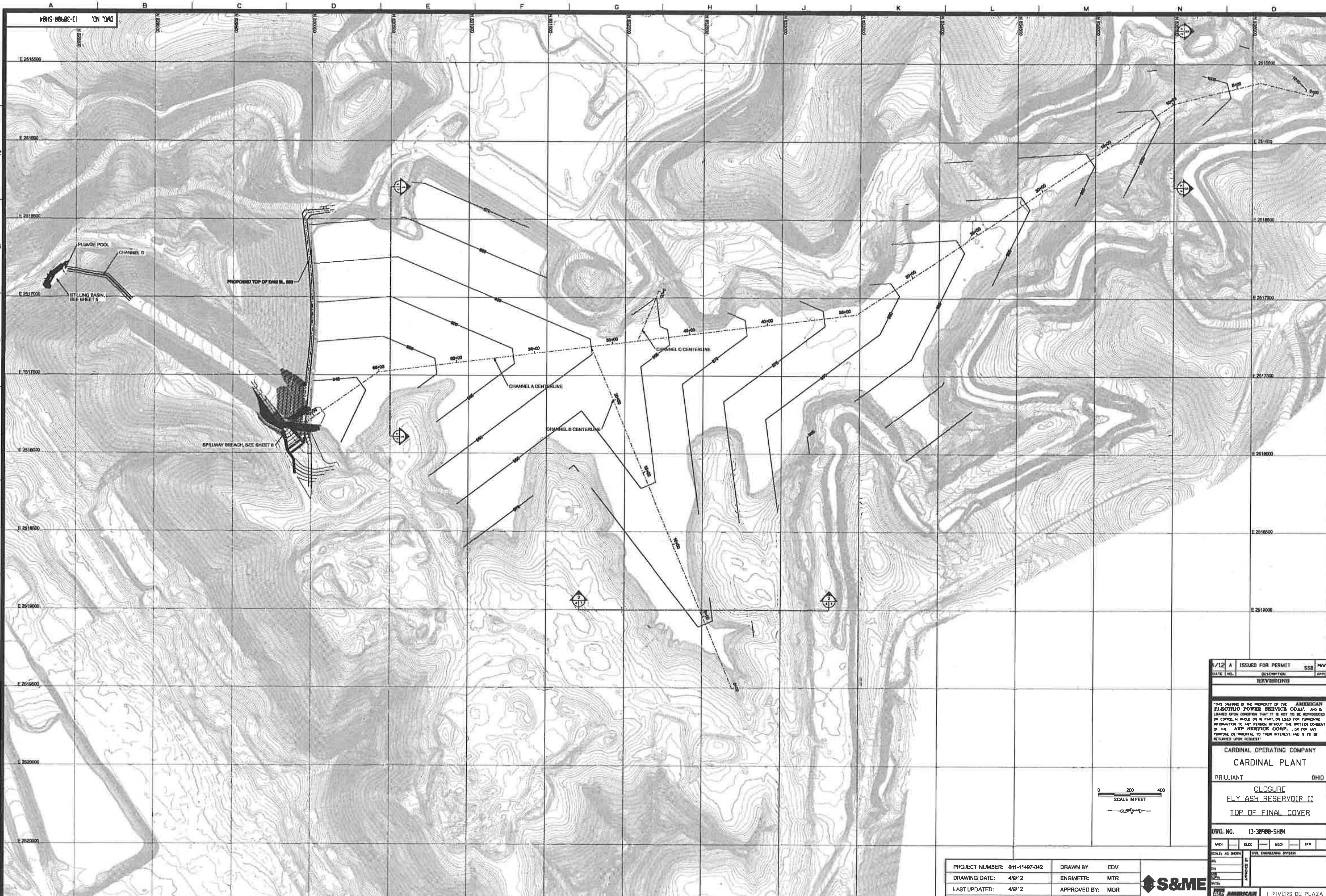

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BRILLIANT OHIO

CLOSURE
FLY ASH RESERVOIR II
TOP OF FINAL COVER

DWG. NO. 13-30900-SH04

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CIVIL ENGINEERING DIVISION

PROJECT NUMBER:	011-11497-042	DRAWN BY:	EDV
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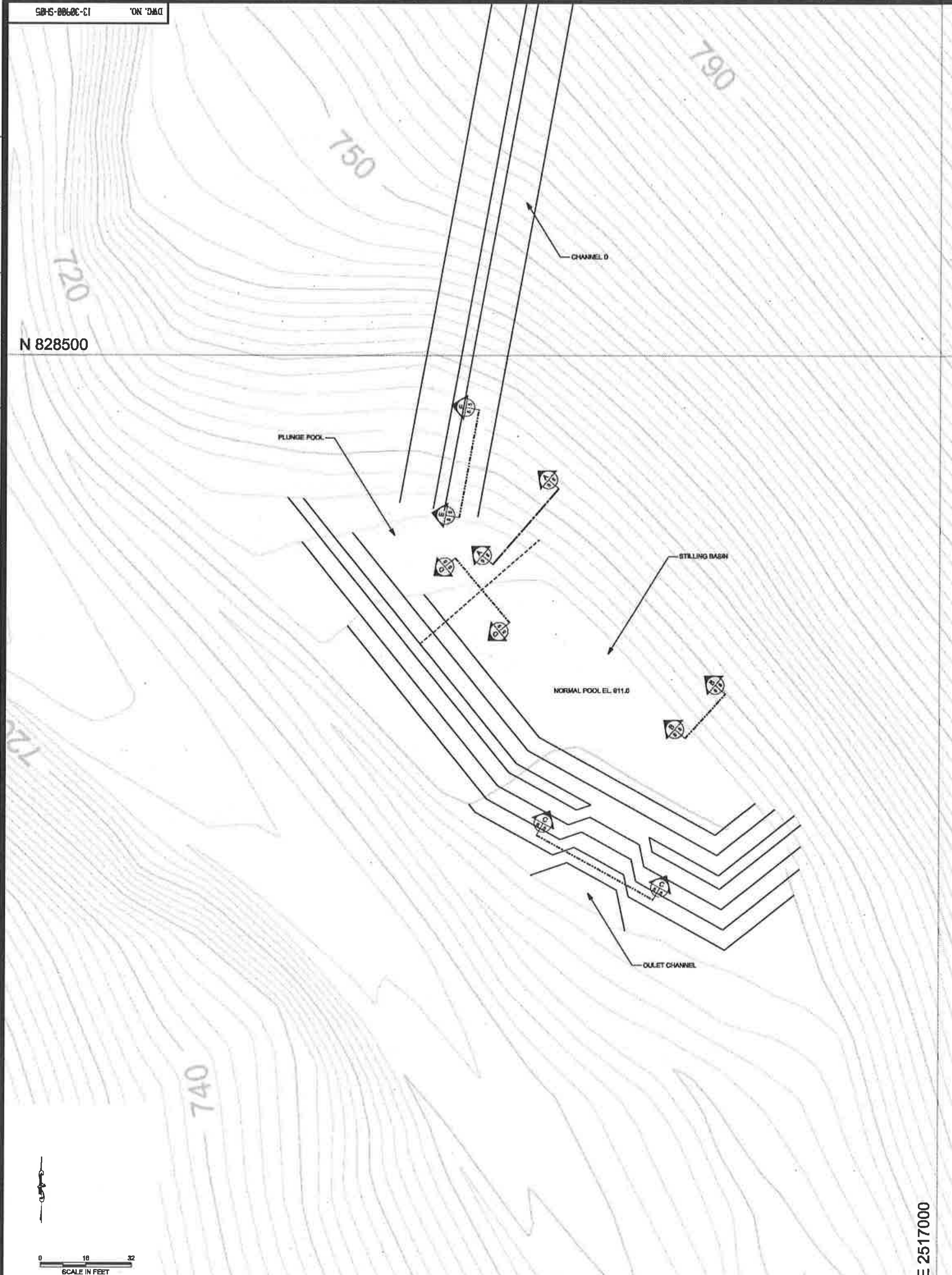

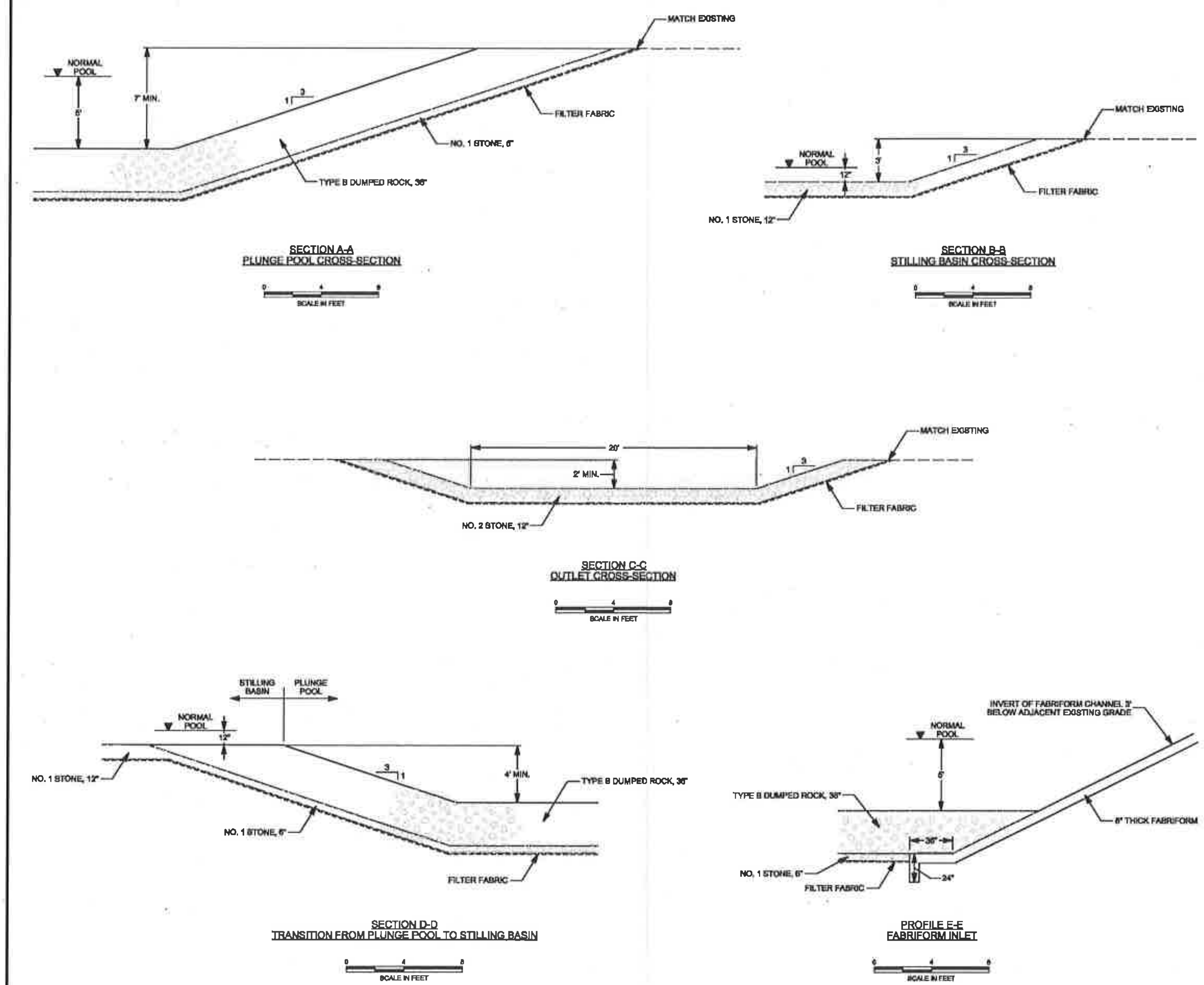

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REVISIONS

CARDINAL OPERATING COMPANY

CARDINAL PLANT

BRILLIANT OHIO

CLOSURE
FLY ASH RESERVOIR II
DETAILS - PLUNGE POOL & STILLING BASIN

DWG. NO. 13-30900-SH05

ARCH — ELEC — MECH — STR

SCALE: AS SHOWN | CIVIL ENGINEERING DIVISION

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		SCALE:	AS NOTED

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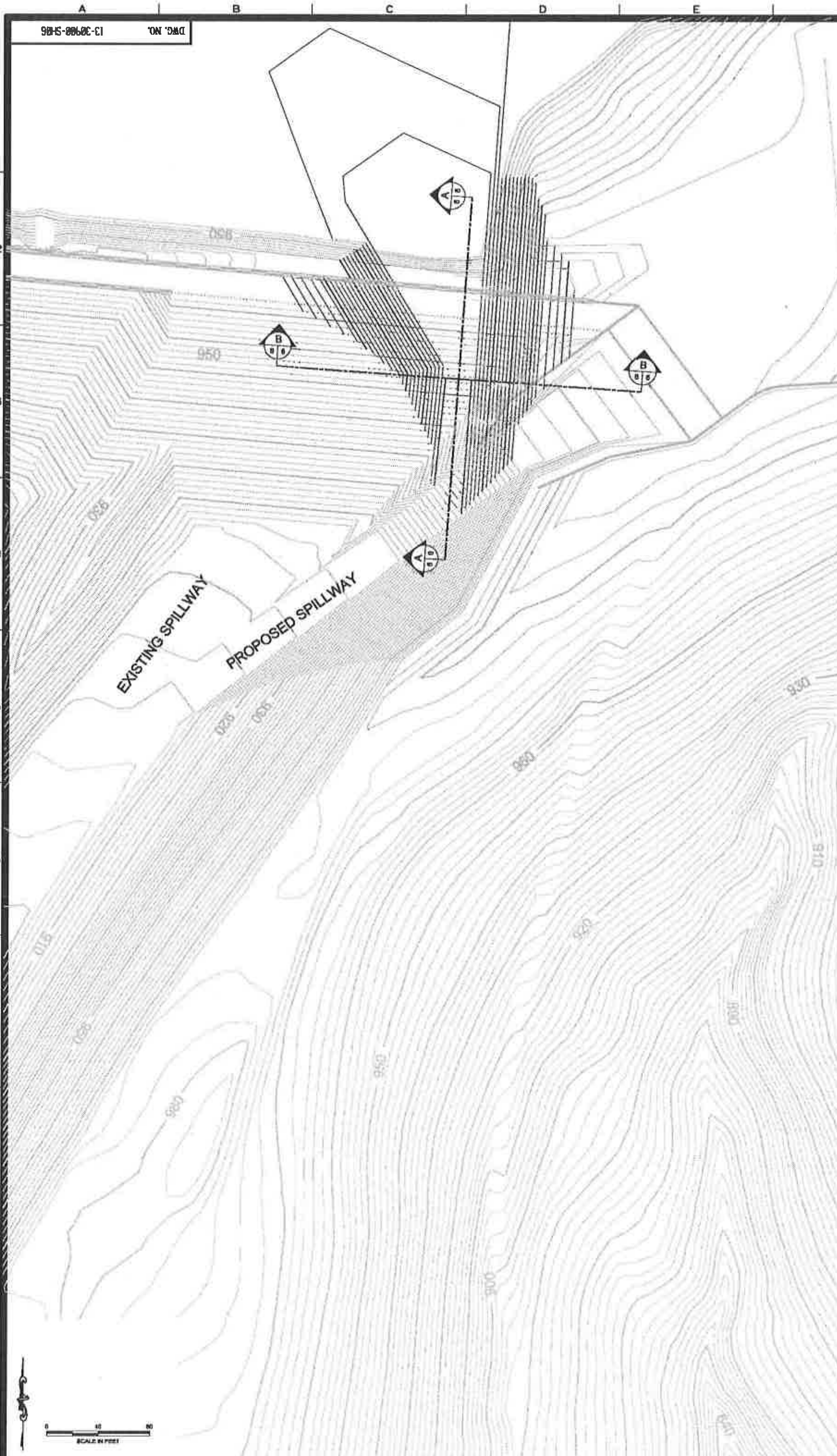

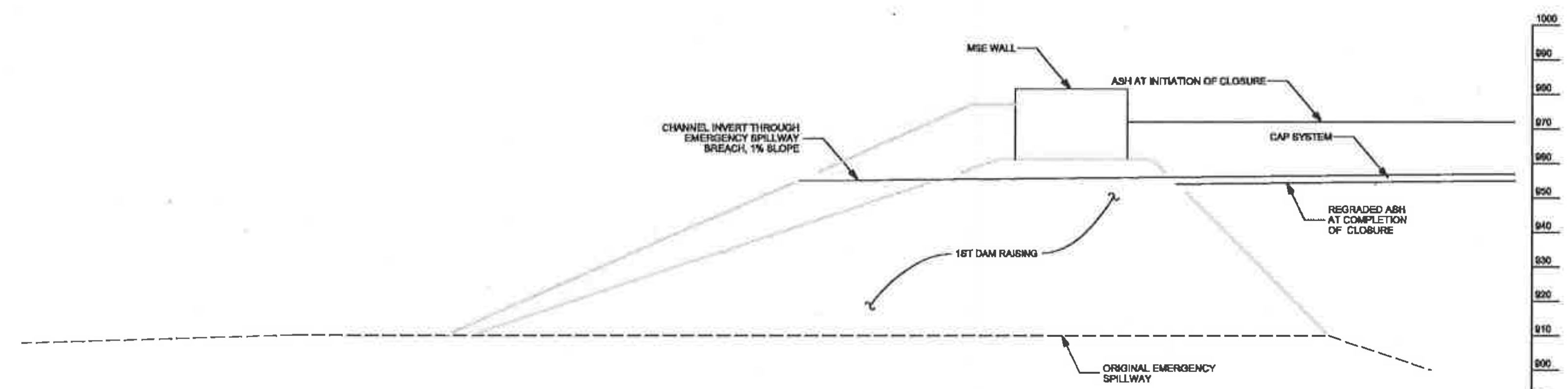

SECTION A-A
PROFILE THROUGH SPILLWAY BREACH
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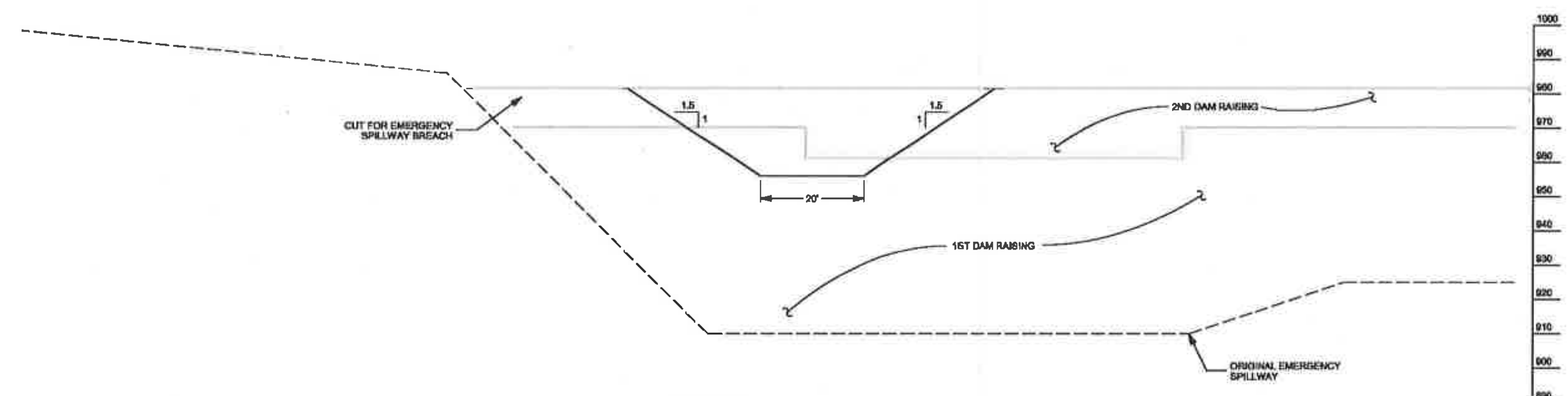

SECTION B-B
EMERGENCY SPILLWAY BREACH, CROSS-SECTION
0 20 40 SCALE IN FEET

DATE	NO.	DESCRIPTION		APPD.
4/12	A	ISSUED FOR PERMIT	SSB	MAA

REVISIONS

CARDINAL OPERATING COMPANY

CARDINAL PLANT

BRILLIANT OHIO

CLOSURE
FLY ASH RESERVOIR II
DETAILS - SPILLWAY BREACH

DWG. NO. 13-30900-SH06

SCALE: AS SHOWN — CIVIL ENGINEERING DIVISION

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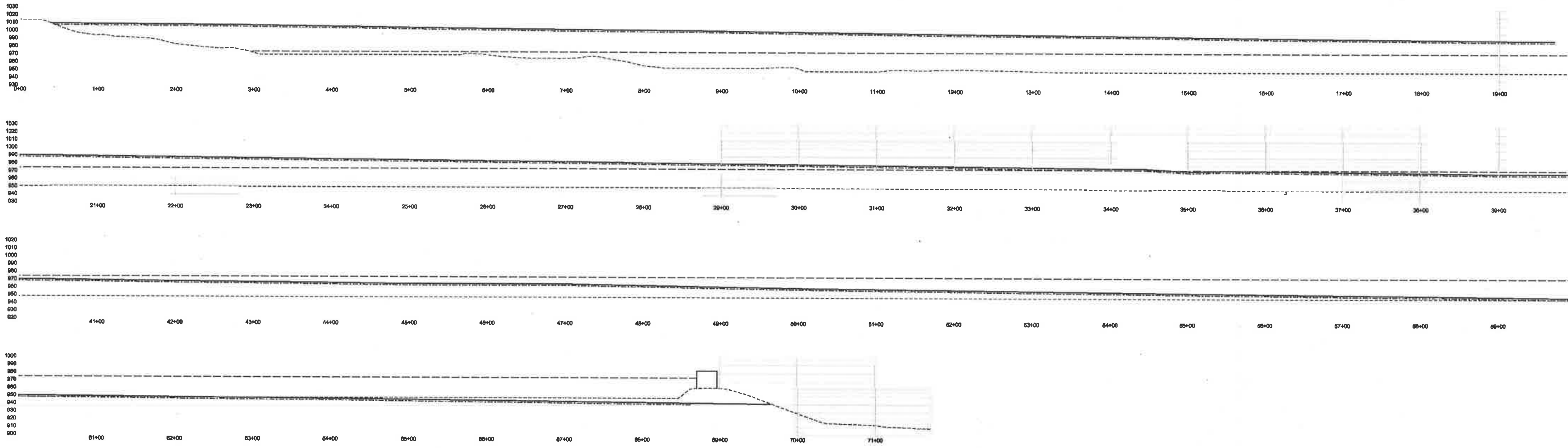
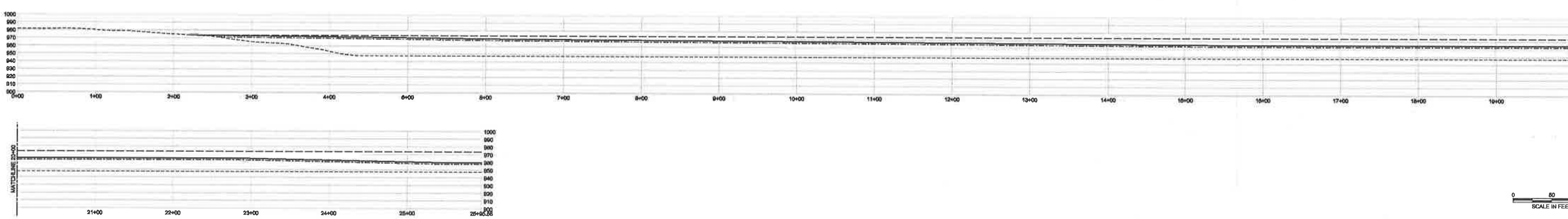
COLUMBUS, OH 43215

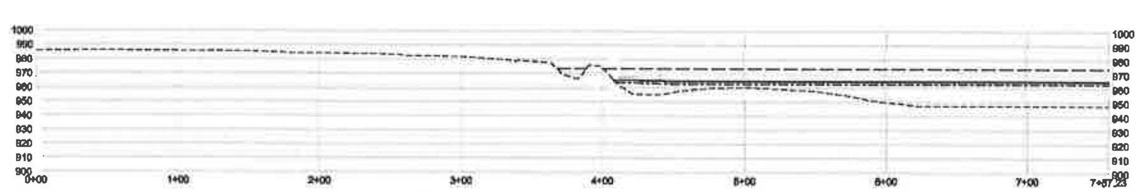
DWG. NO. 13-30900-SH07



CHANNEL A PROFILE



CHANNEL B PROFILE



CHANNEL C PROFILE

0 50 100
SCALE IN FEET

LEGEND

- 2010 EXISTING GROUND SURFACE
- TOP OF ASH AT INITIATION OF CLOSURE (EL. 974)
- TOP OF ASH AT COMPLETION OF CLOSURE
- TOP OF FINAL CAP

DATE	NO.	DESCRIPTION		APPD.
4/12	A	ISSUED FOR PERMIT	SSB	MAA

REVISIONS

CARDINAL OPERATING COMPANY

CARDINAL PLANT

BRILLIANT OHIO

CLOSURE
FLY ASH RESERVOIR II

PROFILES

DWG. NO. 13-30900-SH07

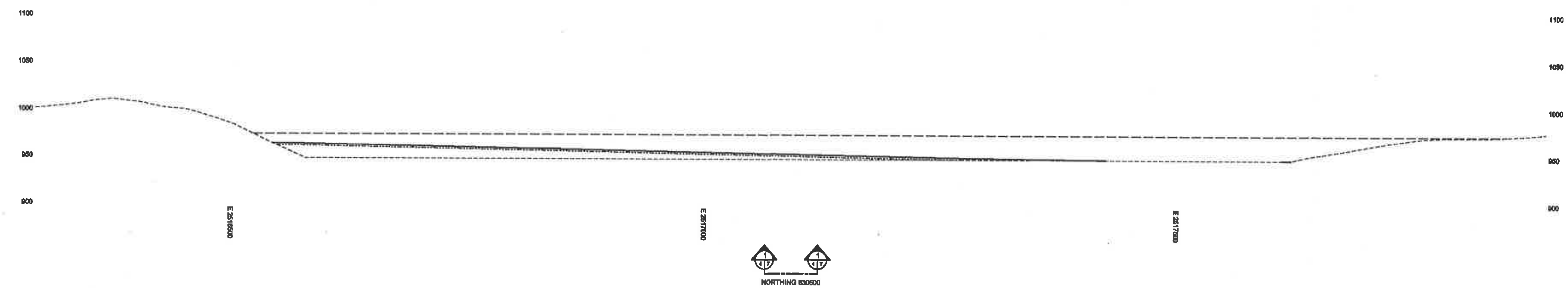
ARCH — ELEC — MECH — STR

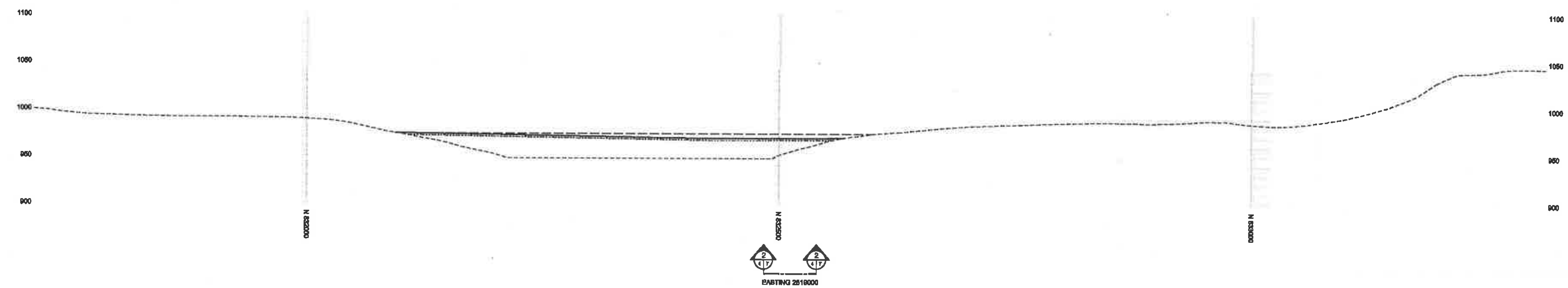
SCALE: AS SHOWN — CIVIL ENGINEERING DIVISION

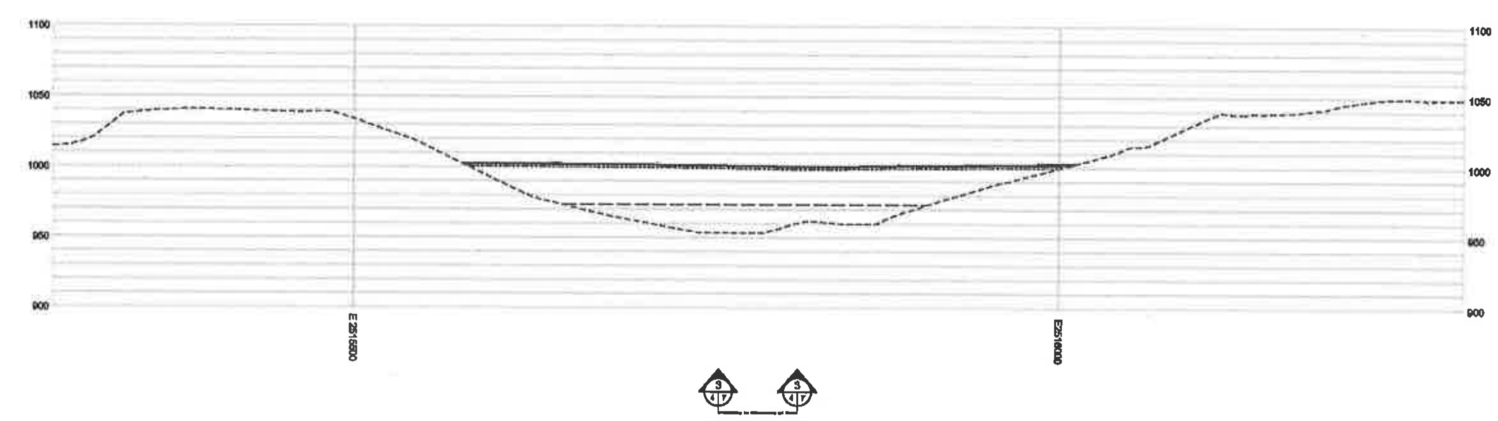
PROJECT NUMBER:	011-11497-042	DRAWN BY:	EDV
DRAWING DATE:	4/9/12	ENGINEER:	MTR
LAST UPDATED:	4/9/12	APPROVED BY:	MGR
		SCALE:	AS NOTED

S&ME

AMERICAN ELECTRIC POWER
1 RIVERSIDE PLAZA
COLUMBUS, OH 43215







0 50 100
SCALE IN FEET

LEGEND

- 2010 EXISTING GROUND SURFACE
- TOP OF ASH AT INITIATION OF CLOSURE (EL. 974)
- TOP OF ASH AT COMPLETION OF CLOSURE
- TOP OF FINAL CAP

DATE	NO.	DESCRIPTION		APPD.
4/12	A	ISSUED FOR PERMIT	SSB	MAA

REVISIONS

CARDINAL OPERATING COMPANY

CARDINAL PLANT

BRILLIANT OHIO

CLOSURE
FLY ASH RESERVOIR NO. II

SECTIONS

DWG. NO. 13-30900-SH00

PROJECT NUMBER:	011-11497-042	DRAWN BY:	EDV
DRAWING DATE:	4/9/12	ENGINEER:	MTR
LAST UPDATED:	4/9/12	APPROVED BY:	MGR
		SCALE:	AS NOTED

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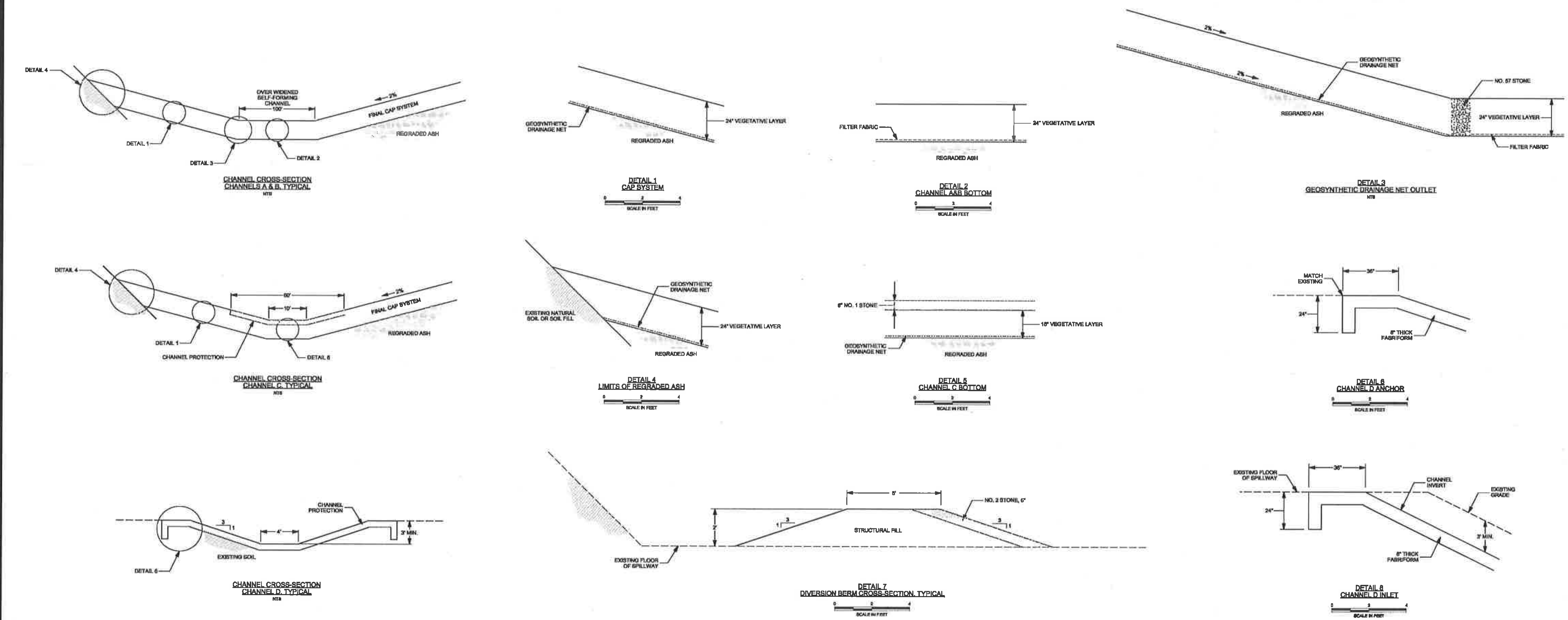
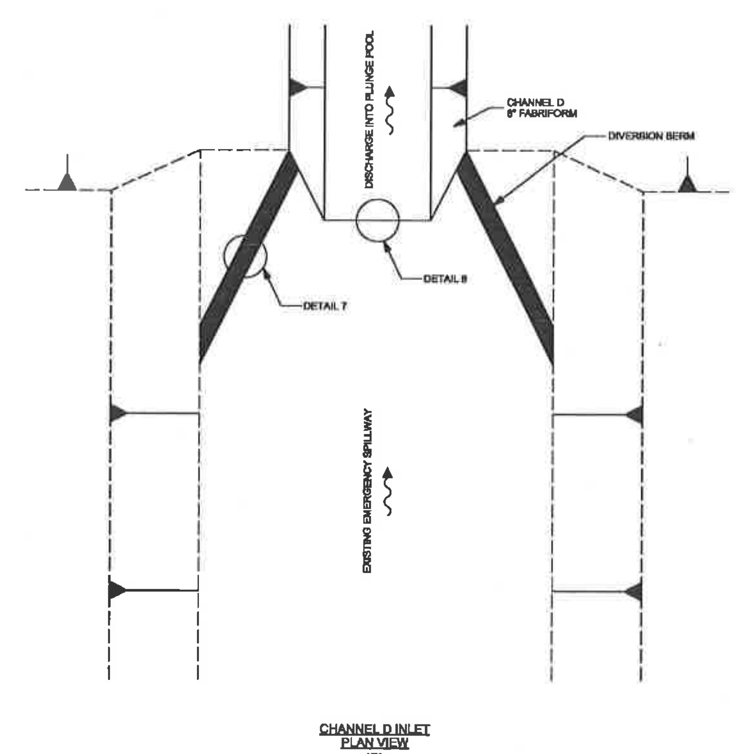
COLUMBUS, OH 43215

DWG. NO. 13-30900-SH09





DATE	NO.	DESCRIPTION		APPD.
4/12	A	ISSUED FOR PERMIT	SSB	MAA

REVISIONS

CARDINAL OPERATING COMPANY

CARDINAL PLANT

BRILLIANT OHIO

CLOSURE
FLY ASH RESERVOIR II

PLUNGE PLAN SHEET

DWG. NO. 13-30900-SH09

ARCH — ELEC — MECH — STR

SCALE: AS SHOWN — CIVIL ENGINEERING DIVISION

DR. CK. ENG. SUPV. DATE: APPROVED BY

PROJECT NUMBER:	011-11497-042	DRAWN BY:	EDV
DRAWING DATE:	4/9/12	ENGINEER:	MTR
LAST UPDATED:	4/9/12	APPROVED BY:	MGR
		SCALE:	AS NOTED

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AEP AMERICAN ELECTRIC POWER

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