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STORMWATER RUN-ON AND RUN-OFF CONTROL PLAN

ENTERGY ARKANSAS, INC. WHITE BLUFF PLANT CLASS 3N CCR LANDFILL

PERMIT NO. 0199-S3N-R3
AFIN: 35-00110

OCTOBER 13, 2016

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AFIN: 35-00110

Prepared for

Entergy Arkansas, Inc. - White Bluff Plant
1100 White Bluff Road
Redfield, AR 72132

Prepared by

FTN Associates, Ltd.
3 Innwood Circle, Suite 220
Little Rock, AR 72211

FTN Project No. R06040-0996-001

October 13, 2016

PROFESSIONAL ENGINEER'S CERTIFICATION

In accordance with §257.81 I certify under penalty of law that I have personally examined and am familiar with the information submitted in this demonstration and all attached documents, and that, based on my inquiry of those individuals immediately responsible for obtaining the information, I believe that the submitted information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment.

This Stormwater Run-on and Run-off Control Plan for the Entergy Arkansas, Inc. White Bluff Plant Class 3N CCR Landfill was prepared under the direction and supervision of a qualified, State of Arkansas-registered Professional Engineer. Mr. Jason Ghidotti, PE, of FTN Associates, Ltd., was responsible for the overall preparation of the plan.

CERTIFICATE OF AUTHORIZATION FTN Associates, Ltd. No. 63 ARKANSAS - ENGINEER

STATE OF ARKANSAS REGISTERED PROFESSIONAL ENGINEER No. 10031 JASON J. GHIDOTTI

10-13-16

Jason Ghidotti, PE #10031 Date

PLAN AMENDMENTS

Amendment No.	Description of Amendment	Page Number in Plan

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1.0 INTRODUCTION

1.1 Purpose of Plan

In accordance with 40 CFR *§257, Subpart D - Disposal of Coal Combustion Residuals From Electric Utilities* (the CCR Rule), the purpose of this plan is to provide information that demonstrates that the stormwater run-on and run-off control system for the Entergy Arkansas, Inc. White Bluff Plant (the Plant) Class 3N CCR Landfill (the Landfill) will collect and convey a 24-hour, 25-year storm event. From §257.81(a):

> *The owner or operator of an existing or new CCR landfill or any lateral expansion of a CCR landfill must design, construct, operate, and maintain:*
>
> > *(1) A run-on control system to prevent flow onto the active portion of the CCR unit during the peak discharge from a 24-hour, 25-year storm; and*
> >
> > *(2) A run-off control system from the active portion of the CCR unit to collect and control at least the water volume resulting from a 24-hour, 25-year storm.*

This Stormwater Run-on and Run-off Control Plan (the Plan) includes:

1. A discussion of how the stormwater run-on and run-off control system has been designed and constructed (Section 2.0 Existing Conditions); and
2. Demonstration of how these controls prevent stormwater run-on and run-off at the Landfill (3.0 Methodology).

Appendix A includes definitions for terms included in this Plan.

1.2 White Bluff Power Plant Information

The Plant is located on the west bank of the Arkansas River, near Redfield in Jefferson County, Arkansas, as shown on Figure 1 (all figures are located in Appendix B, unless otherwise noted). The 3,400-acre site is situated on a bluff overlooking the relatively flat alluvial plain east of the Arkansas River.

The Plant generates electricity through the combustion of coal and has been in operation since 1981. Coal combustion by-products (residues) (CCRs) that are generated during the electrical generation process are disposed in the onsite landfill. The CCR is generally segregated into two categories, “fly” and “bottom.”

Approximately 80% of the CCR produced is classified as fly ash, which is derived from the boiler exhaust gas and is collected in electrostatic precipitators. The fly ash is composed of very fine particles similar to glass and has the consistency of a powder. Collected fly ash is pneumatically transferred to silos for short-term storage. A subcategory of the fly ash is known as economizer ash. This material is the coarsest fraction of the fly ash, which drops out before the electrostatic precipitators, and represents approximately 2% of the total CCR production. The Plant collects this material in a separate silo system.

The remaining 18% of CCR produced from the combustion of coal is comprised of bottom ash, which is composed of angular, glassy particles with a porous surface texture and has the consistency of coarse sand. The bottom ash is sluiced to dewatering hoppers for removal of water and for storage.

Historically, approximately 60 to 70 % of the two types of CCR have been marketed regionally to construction-related industries. The remaining amount of CCR is placed in the onsite landfill for disposal. The amount placed in the Landfill varies from year to year, but the average for the past 5 years is approximately 100,000 cubic yards (cy).

1.3 Permit History

The CCR Landfill was initially issued a solid waste permit in 1982 by the Arkansas Department of Pollution Control and Ecology (now the Arkansas Department of Environmental Quality (ADEQ)) and has received three permit modifications to date. The facility permit history is as follows:

1. In October 1982, Chem-Ash, Inc. (Chem-Ash), the onsite landfill contractor which managed coal ash sales and landfill disposal operations for Arkansas Power & Light (AP&L), was granted a permit (No. 199-S) from the Arkansas Department of Environmental Quality ((ADEQ) to construct and operate a solid waste disposal facility at the White Bluff Plant (Entergy Arkansas, Inc. became AP&L’s successor in interest as of April 1996).

2. In March 1983, ADEQ granted, among other provisions, a permit modification request to transfer the landfill permit from Chem-Ash to AP&L and revised the permit number to 199-SR-1.
3. In June 1984, AP&L submitted an application for permit modification requesting operational changes and other provisions to include an increase of the permitted landfill area from 110 acres to 177 acres, with 153 acres for waste disposal. ADEQ granted the permit modification request in September 1985. The permit number was revised to 199-SR-2.
4. Entergy Arkansas submitted a permit modification application to the ADEQ-SWMD to upgrade the Landfill to Arkansas Regulation No. 22 (Regulation No. 22) standards in December 1997. The ADEQ issued the revised permit (0199-S3N-R3) November 2000.
5. Entergy Arkansas submitted a minor permit modification in April 2011 and the ADEQ approved the request in May 2011 to reconfigure the waste disposal areas into five disposal cells, which is the current landfill configuration.

1.4 Existing Conditions of Landfill

The ADEQ-permitted landfill area consists of approximately 177 acres (153 acres for solid waste disposal) and is located in the southwestern portion of the plant site as shown on Figure 2 in Appendix B.

The current ADEQ-permitted layout of the CCR Landfill includes a total of five disposal cells (Cells 1 through 5) and has a permitted waste capacity of approximately 2,600,000 cubic yards (cy). Waste Cells 1 through 4 have been constructed and comprise the active disposal area of the CCR Landfill that received CCR materials after October 19, 2015 (Figure 2).

Construction of the CCR units has followed the numerical sequence of the cell numbers. Cells 1 through 4 are active landfill CCR units and will be operated in accordance with requirements of the CCR Rule.

No final cover system has been installed on the active CCR units, Cells 1 through 4. As shown on Figure 2 (Appendix B), older portions of the landfill facility that received CCR material prior to the issuance of the 2000 permit have been closed and covered in accordance with the original facility ADEQ-issued permit (1982). These areas did not receive CCR after October 2015.

2.0 EXISTING STORMWATER CONTROL SYSTEM

The existing stormwater control system for the facility has been developed to collect and convey stormwater around and away from the site to prevent run-on. The Landfill's perimeter ditches generally drain to the south, and then east to discharge into the facility Surge Pond, located east of the landfill. The water from the Surge Pond is either used for cooling water at the Plant, or is eventually released from the site through the facility's National Pollutant Discharge Elimination System (NPDES) permitted outfall. An overview of the existing stormwater system is shown on Figure 3 in Appendix B.

The stormwater system is composed of grass-, fabric-, and riprap-lined channels, riprap check dams, and culverts at roadway crossings. Typical details are included as Figures 4 and 5 in Appendix B. These system components were designed and constructed to convey stormwater and to minimize erosion. Clay-lined perimeter berms and compacted clay expansion berms (Figure 6, Appendix B) at the external edges of each landfill cell also prevent stormwater from entering the cells and becoming run-on.

As defined by the CCR Rule, stormwater run-off includes any stormwater that falls upon and is discharged from active areas of the landfill. In the case of covered slopes, the stormwater does not come in contact with CCR and can be directly discharged to adjacent stormwater channels. In the case of open landfill areas, the stormwater is either stored within the waste mass or is collected as leachate and discharged as allowed by the facility landfill permit.

For Cells 1 and 2, the leachate discharges from the southeast corner of each cell to the adjacent stormwater ditch and flows to the facility Surge Pond. For Cells 3 and 4, the leachate flows to a lined collection sump in the southwest corner of Cell 4 and is pumped to the Surge Pond. Cell 3 is allowed to be discharged directly to the stormwater system, but Entergy Arkansas chose to reroute it to the Cell 4 leachate collection and transmission system. The clay-lined perimeter berms and compacted clay expansion berms shown in Figure 6 also prevent run-off from Cells 3 and 4.

3.0 METHODOLOGY

Hydrologic and Hydraulic analyses were completed for the run-on and run-off stormwater system based on the 24-hour, 25-year storm event. For the Hydrologic analysis, flows were calculated using the Rational Method, which is given by the following formula:

$$Q = CIA$$

where,

Q = Flow in cubic feet per second (cfs)
C = Run-off coefficient (dimensionless)
I = Rainfall intensity in inches per hour (in/hr)
A = Drainage area in acres (ac)

The values for the run-off coefficient, C, were based on the slope and the surface conditions. The drainage area, A, was delineated for each basin. Data from the NOAA Atlas 14, Volume 9, Version 2 was used to develop a formula for calculating the rainfall intensity, I. This formula was created by plotting the site's precipitation frequency estimates for the 25-year storm event against the prescribed 24-hour duration. Microsoft Excel was utilized to add a power trend line to the plotted data. The resulting equation of the trend line was used to calculate the intensity and is given by the following equation:

$$I = 20.667 \times {T_c}^{-0.505}$$

Where,

I = Rainfall intensity in inches per hour (in/hr)
T_c = Time of Concentration (minutes)

The Time of Concentration, T_c, is time for the most hydraulically distant particle of water to travel to the discharge point of each respective drainage area and is calculated using the methodology described in the USDA Technical Release 55 (TR-55), *Urban Hydrology for Small Watersheds*. The TR-55 method computes T_c assuming that water moves through a drainage area as either sheet flow, shallow concentrated flow, open channel flow, or some combination thereof. The input variables used in the T_c calculations include flow length, slope, 2-year 24-hour rainfall depth, and surface roughness of the flow path. The flow length and slope were measured in AutoCAD. The 2-year 24-hour rainfall was taken from the NOAA Atlas 14, Volume 9, Version 2. The open channel dimensions used in the T_c calculations were based on the landfill construction drawings and recent survey data. The Manning's "n" values used to represent roughness in the T_c calculations were based on observations from site reconnaissance and best engineering judgment.

For the hydraulic analysis, Manning's formula, the most widely used open channel uniform flow equation, was used to compute the water surface elevation and to evaluate the capacity of the stormwater ditches:

$$V = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

where

V = Mean velocity (ft/sec)
n = Manning's coefficient
R = Hydraulic radius (ft)
S = Friction slope (ft/ft)

The capacity of each individual channel reach was computed using Bentley FlowMaster v8i software.

Culvert capacities were evaluated based upon the methodologies set forth in *Hydraulic Design Series No. 5, Hydraulic Design of Highway Culverts (1985)* as prepared by the U.S. Federal Highway Administration. The culverts were analyzed using both inlet and outlet control assumptions to determine which would generate the greater headwater depth. The capacity of each culvert was computed using Bentley CulvertMaster v8i software.

3.1 Prevention of Stormwater Run-on

Stormwater is generated from three different watersheds adjacent to the landfill on the north and west sides. Basin 1, a small grassed area north of the landfill, consists of approximately 6.9 acres. Basins 2 and 3 are areas of dense grass west of the landfill that cover approximately 14.7 acres and 16.7 acres, respectively. The basin delineations and their corresponding longest flow paths are shown on Figure 3 in Appendix B.

As shown on Figure 3, the areas to the east and south of the site drain away from the landfill, and therefore were not considered for run-on Hydrologic and Hydraulic analyses.

The perimeter stormwater channels used to route stormwater run-on around the active landfill were divided into 5 reaches based upon drainage area and relative slope for the hydraulic analysis. Associated culverts were numbered for reference.

3.2 Stormwater Run-off

The landfill was divided into two drainage basins for the stormwater run-off hydrologic and hydraulic analysis. Basin 4 comprises the eastern portion of the landfill, Cells 1 and 2, and is 15.9 acres in size. Basin 5 comprises the western portion which includes Cells 3 and 4, covering 14.6 acres. Stormwater that does not infiltrate the waste material runs to the perimeters of the cells where space left between the fill slope and the perimeter clay berms creates wide channels to convey the stormwater to the outlet or leachate sump. Both basins and their corresponding longest flow paths are shown on Figure 3 (Appendix B).

4.0 RESULTS

Hydrologic and hydraulic calculation for the run-on and run-off analysis are presented in Appendices C and D, respectively.

4.1 Prevention of Stormwater Run-on

As described above, three separate basins contribute to the stormwater at the landfill. Hydrologic analysis of these three basins for the 24-hour 25-year storm event are presented in Appendix C. Results are summarized in Table 4.1, below.

Table 4.1, Stormwater hydrologic analysis results.

Basin	**Area, A (acres)**	**Time of Concentration, Tc (minutes)**	**Composite Run-off Coefficient, C**	**Rainfall Intensity, I_{25} (in/hr)**	**Peak Discharge, Q_{25} (ft^3/sec)**
1	6.9	42.2	0.28	3.47	4.8
2	14.7	57.2	0.28	3.00	12.4
3	16.7	80.6	0.20	2.55	11.9

To prevent run-on, stormwater is conveyed around the landfill via perimeter stormwater channels and culverts as shown on Figure 3. For this analysis, the stormwater channels have been divided into five separate reaches. Hydraulic analysis of these channel reaches using the calculated peak flow rates from Table 4.1 are presented in Appendix C. Results are summarized in Table 4.2, below.

Table 4.2, Stormwater channel hydraulic analysis results.

Channel Reach	Length, L (ft)	Slope, S (ft/ft)	Chanel Depth, D (ft)	Channel Roughness Coefficient, n	Peak Flow, Q_{25} (ft^3/sec)	Peak Velocity, V_{25} (ft/sec)	Flow Depth, D_{25} (ft)
1	1200	0.005	2.0	0.045	4.8	1.4	0.8
2	430	0.035	2.5	0.069	4.8	2.1	0.5
3	570	0.040	2.5	0.069	35.4	3.8	1.4
4	1545	0.026	2.0	0.035	12.4	4.1	0.8
5	635	0.008	2.5	0.035	24.3	3.1	1.1

Hydraulic analysis of the culverts is presented in Appendix C. Results are summarized in Table 4.3, below.

Table 4.3, Stormwater culvert hydraulic analysis results.

Culvert	Length, L (ft)	Slope, S (ft/ft)	Number/ Diameter (in)	Type	Peak Flow, Q_{25} (ft^3/sec)	Peak Velocity, V_{25} (ft/sec)	Headwater Depth, H (ft)
1	96	0.015	24”	RCP	4.8	6.58	1.1
2	72	0.042	30”	RCP	4.8	9.26	1.0
3	38	0.013	2@30”	RCP	35.4	8.22	2.1
4	40	0.007	30”	CMP	24.3	7.60	2.6

The calculations confirm that the existing stormwater system will convey the peak flow rates from the 24-hour, 25-year storm event and will prevent stormwater from becoming run-on, running into or inundating the active landfill area.

4.2 Stormwater Run-off

Within the active portion of the landfill, all four cells are open and are used for landfilling operations. As described in Section 3.2, the landfill can be divided into two hydrologic basins. Basin 4, which includes Cells 3 and 4, is collected in the Cell 4 leachate sump and is pumped to the Surge Pond. Basin 5, which includes Cells 1 and 2, is collected in Cell 2 where it is discharged to the adjacent stormwater channel, designated as Channel Reach 3. Results from the hydrologic analysis of these two basins for the 24-hour 25-year storm event are presented in Appendix D. Results are summarized in Table 4.4, below.

Table 4.4, Run-off hydrologic analysis results.

Basin	Area, A (acres)	Time of Concentration, Tc (minutes)	Composite Run-off Coefficient, C	Rainfall Intensity, I_{25} (in/hr)	Peak Discharge, Q_{25} (ft^3/sec)
4	15.9	21.7	0.44	4.76	33.3
5	14.6	16.0	0.44	5.50	35.4

The leachate collection and transmission systems in landfill Cells 3 and 4 have been designed to store and convey the leachate resulting from the 24-hour 25-year storm in Basin 4. Run-off from Basin 5, landfill Cells 1 and 2, discharges through two 24-inch diameter RCP culverts to Channel Reach 3, shown in Table 4.2. The run-off flows to the facility Surge Pond which is designed and operated to have sufficient volume to handle the stormwater from the entire facility.

APPENDIX A

Definitions

DEFINITIONS

The following definitions are from §257.53 of the CCR Rule and used in this Plan:

Active Life or In Operation: the period of operation beginning with the initial placement of CCR in the CCR unit and ending at completion of closure activities in accordance with §257.102.

Active portion: that part of the CCR unit that has received or is receiving CCR or non-CCR waste and that has not completed closure in accordance with §257.102.

Coal Combustion Residuals (CCR): fly ash, bottom ash, boiler slag, and flue gas desulfurization materials generated from burning coal for the purpose of generating electricity by electric utilities and independent power producers.

CCR Landfill: an area of land or land excavation that receives CCR and which is not a surface impoundment, an underground injection well, a salt dome formation, a salt bed formation, an underground or surface coal mine, or a cave. It also includes sand and gravel pits and quarries that receive CCR, CCR piles, and any practice that does not meet the definition of a beneficial use of CCR.

CCR Unit: any CCR landfill, CCR surface impoundment, or lateral expansion of a CCR unit, or a combination of more than one of these units based on the context of the paragraph(s) in which it is used. This term includes both new and existing units, unless otherwise specified.

Closed Unit or Landfill: placement of CCR in a CCR unit has ceased, and the owner or operator has completed closure of the CCR unit in accordance with § 257.102 and has initiated post-closure care in accordance with § 257.104.

Existing CCR Landfill: a CCR Landfill that receives CCR both before and after October 15, 2015, or for which construction commenced prior to October 14, 2015 and receives CCR on or after October 14, 2015. A CCR landfill has commenced construction if the owner or operator has obtained the federal, state, and local approvals or permits necessary to begin physical construction and a continuous onsite physical construction program had begun prior to October 14, 2015.

Hydraulic Conductivity: the rate at which water can move through a permeable medium (i.e., the coefficient of permeability).

Lateral Expansion: a horizontal expansion of the waste boundaries of an existing CCR landfill or existing CCR surface impoundment made after October 14, 2015.

New CCR Landfill: a CCR landfill or lateral expansion of a CCR landfill that first receives CCR or commences construction after October 14, 2015. A CCR landfill has commenced construction if the owner or operator has obtained the federal, state, and local approvals or permits necessary to begin physical construction and a continuous onsite physical construction program had begun after to October 14, 2015.

Operator: the person(s) responsible for the overall operation of a CCR unit.

Qualified Professional Engineer: an individual who is licensed by a state as a Professional Engineer to practice one or more disciplines of engineering and who is qualified by education, technical knowledge and experience to make the specific technical certifications required under this subpart. Professional engineers making these certifications must be currently licensed in the state where the CCR unit(s) is located.

Recognized and Generally Accepted Good Engineering Practices: engineering maintenance or operation activities based on established codes, widely accepted standards, published technical reports, or a practice widely recommended throughout the industry. Such practices generally detail approved ways to perform specific engineering, inspection, or mechanical integrity activities.

Run-Off: any rainwater, leachate, or other liquid that drains over land from any part of a CCR landfill or lateral expansion of a CCR landfill.

Run-On: any rainwater, leachate, or other liquid that drains over land onto any part of a CCR landfill or lateral expansion of a CCR landfill.

Structural Components: liners, leachate collection and removal systems, final covers, run-on and run-off systems, inflow design flood control systems, and any other component used in the construction and operation of the CCR unit that is necessary to ensure the integrity of the unit and that the contents of the unit are not released into the environment.

APPENDIX B

Figures

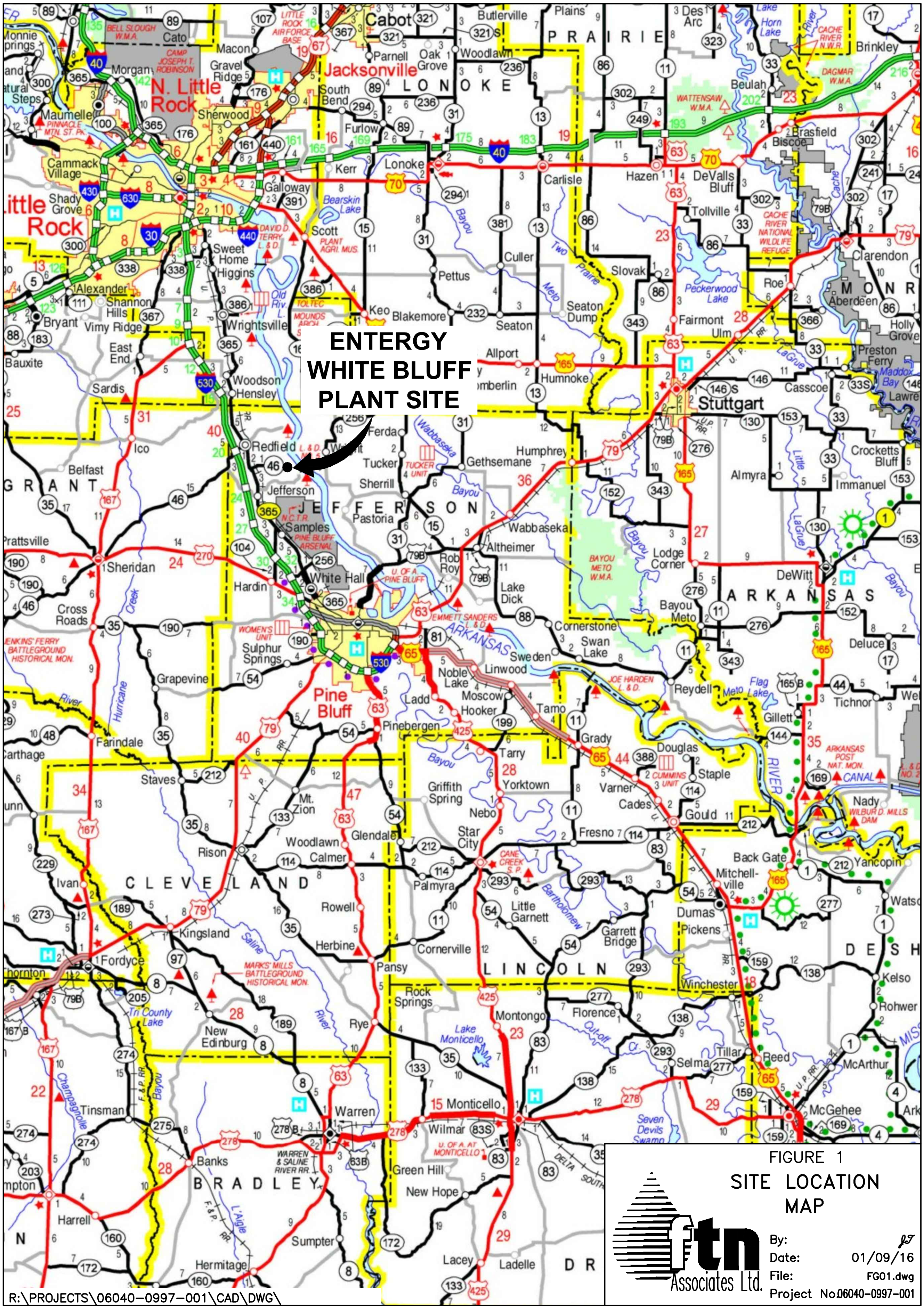


FIGURE 1

SITE LOCATION MAP

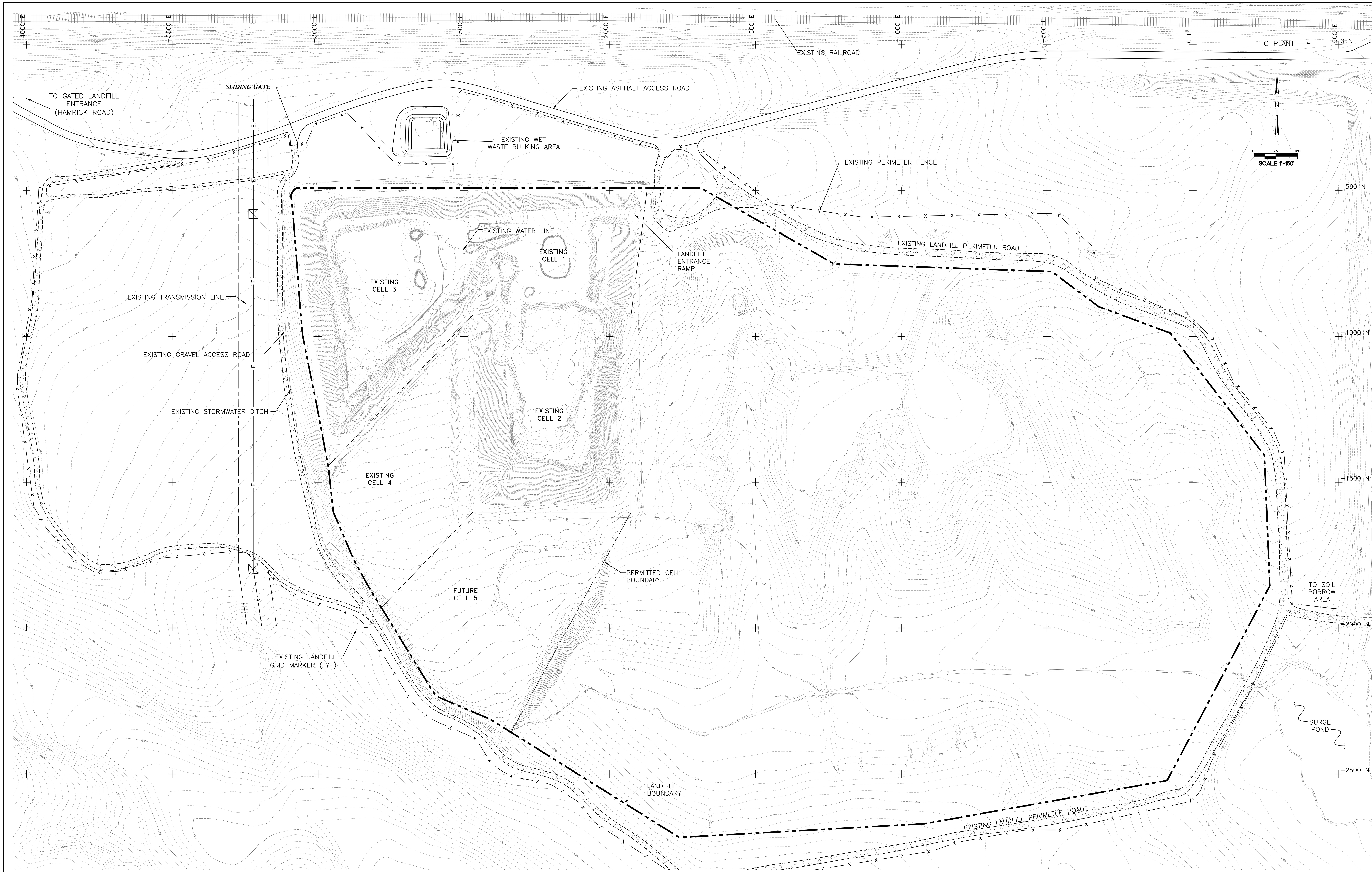
ftn Associates Ltd.

By: JT

Date: 01/09/16

File: FG01.dwg

Project No. 06040-0997-001



LEGEND

- 340 — EXISTING INDEX CONTOUR
- EXISTING MINOR CONTOUR
- EXISTING DRAINAGE CHANNEL
- E — E — EXISTING ELECTRIC TRANSMISSION LINE
- EXISTING PAVED ROAD
- EXISTING UNPAVED ROAD
- x — x — EXISTING PERIMETER FENCE
- CELL BOUNDARY

NOTES:

1. TOPOGRAPHIC INFORMATION IS FROM A FIELD SURVEY BY HARMON SURVEYING (MARCH 2015) AND AN AERIAL SURVEY BY AMI ENGINEERING, INC (2011).

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STORMWATER RUN-ON/RUN-OFF CONTROL PLAN
REDFIELD, ARKANSAS

FIGURE 2
SITE MAP

DRAWN BY: JJB	FILE NAME: FG02.DWG
APPROVED: JJB	PROJECT NO. 06040-0996-001
SCALE: 1"=150'	DATE: 10/13/16
SHEET NO. 1 OF 1	

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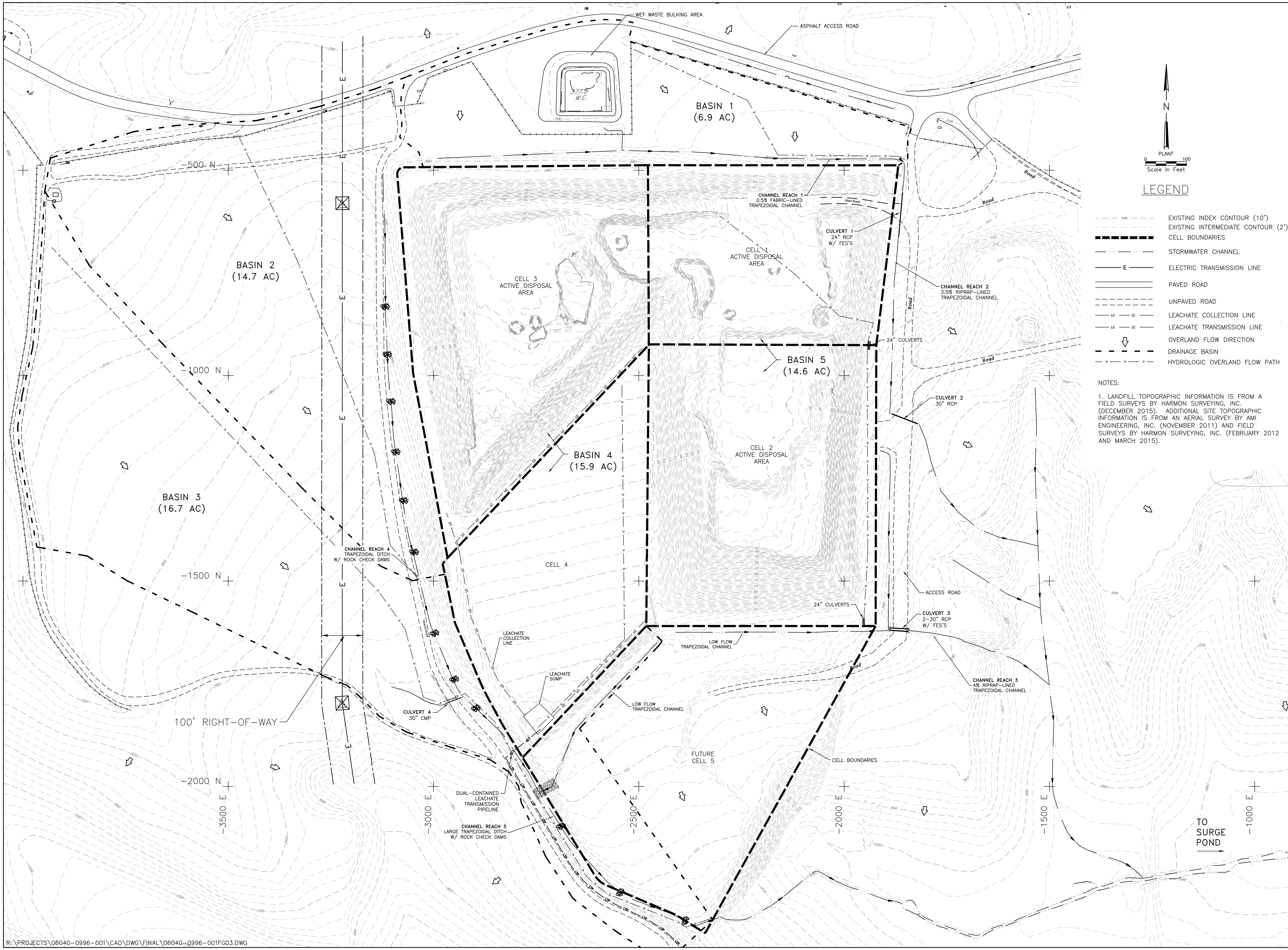

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ENTERGY WHITE BLUFF PLANT
CLASS 3N LANDFILL
STORMWATER RUN-ON/RUN-OFF CONTROL PLAN
REDFIELD, ARKANSAS

FIGURE 3
STORMWATER SYSTEM

DRAWN BY: JJB	FILE NAME: FG03.DWG
APPROVED: PWC	PROJECT NO. 06040-0997-001
SCALE: 1" = 100'	DATE: 10/13/16
SHEET NO. 1 OF 1	

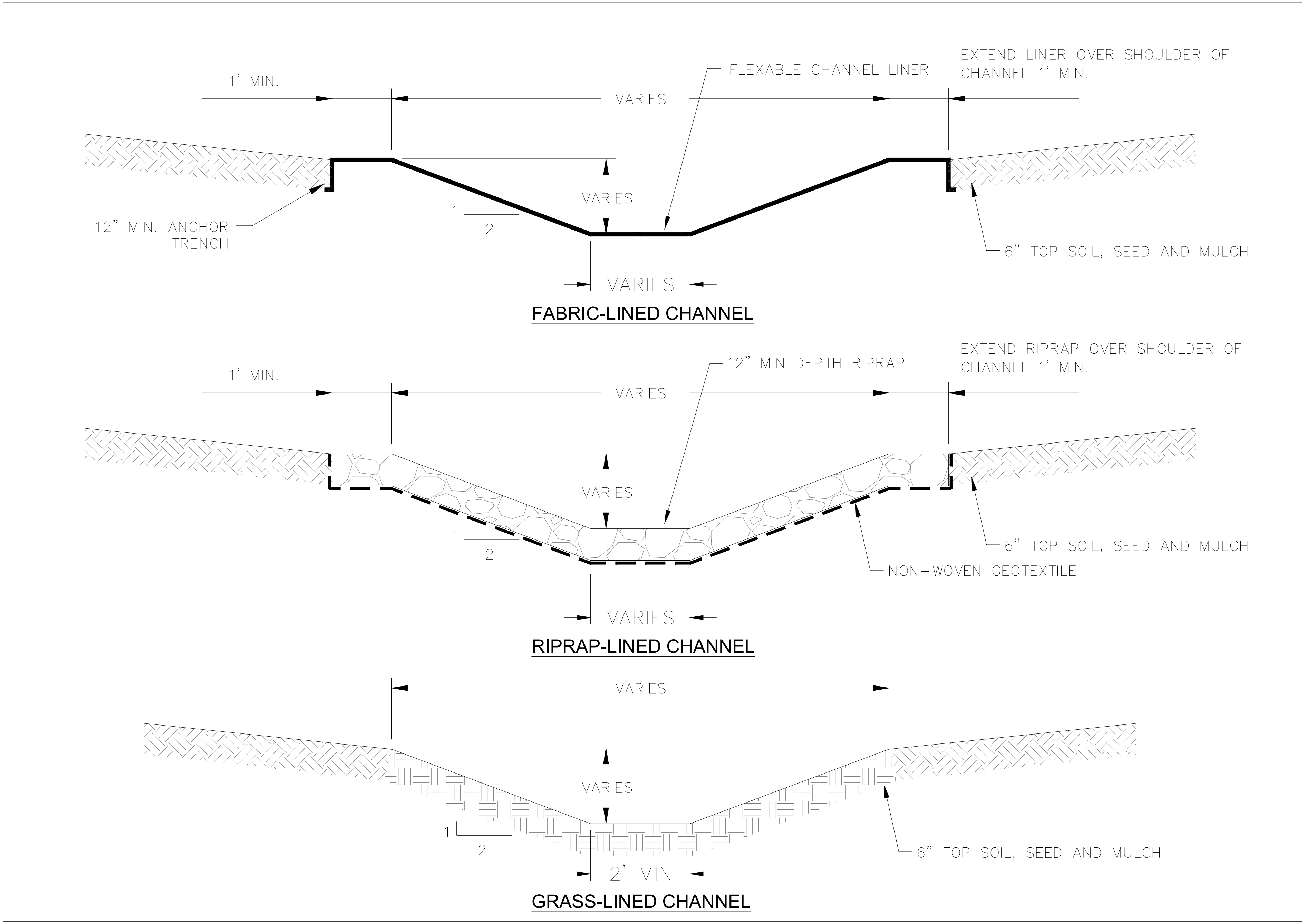


Figure 4. Typical Stormwater Channel Details.

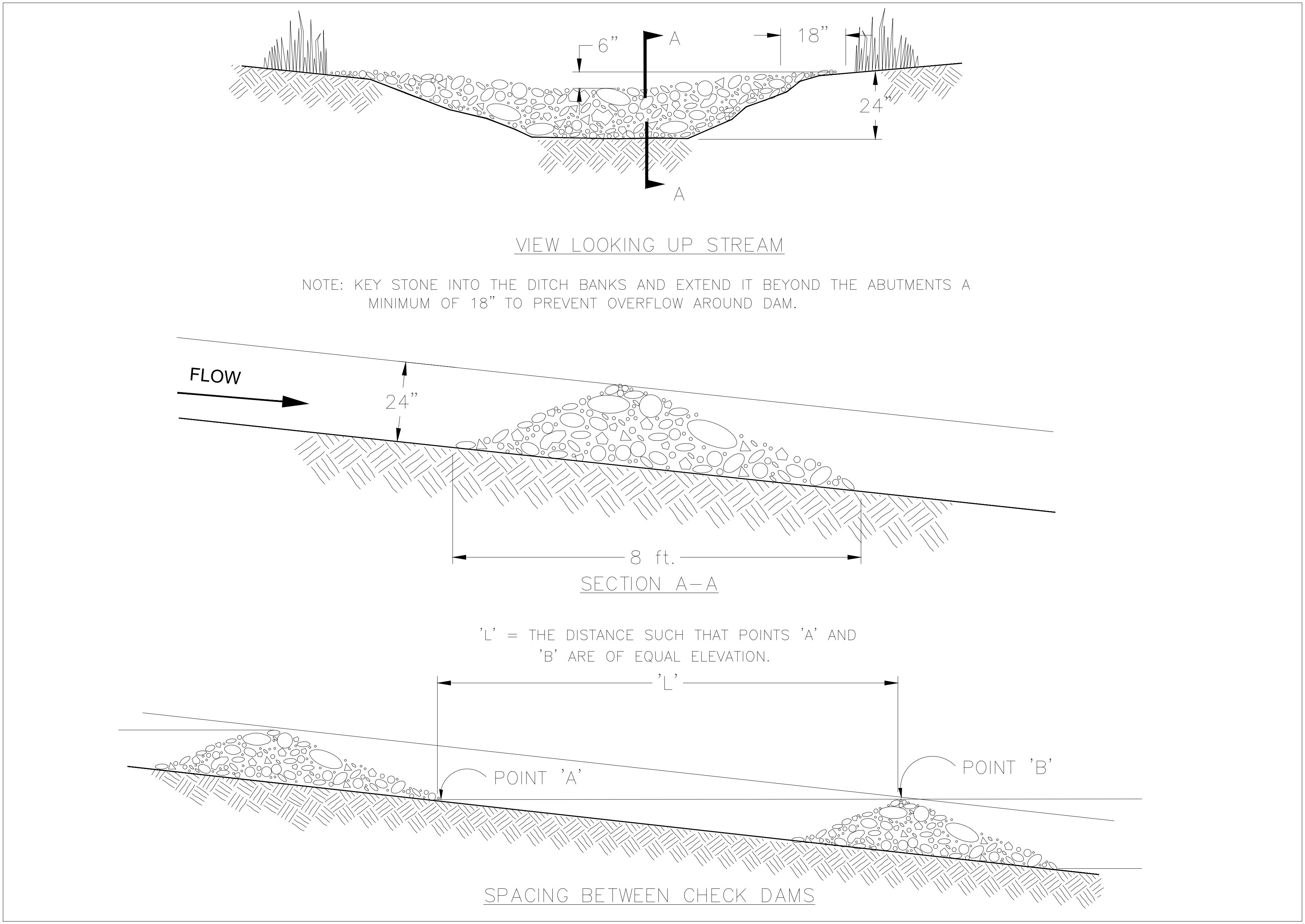


Figure 5. Typical Check Dam Details.

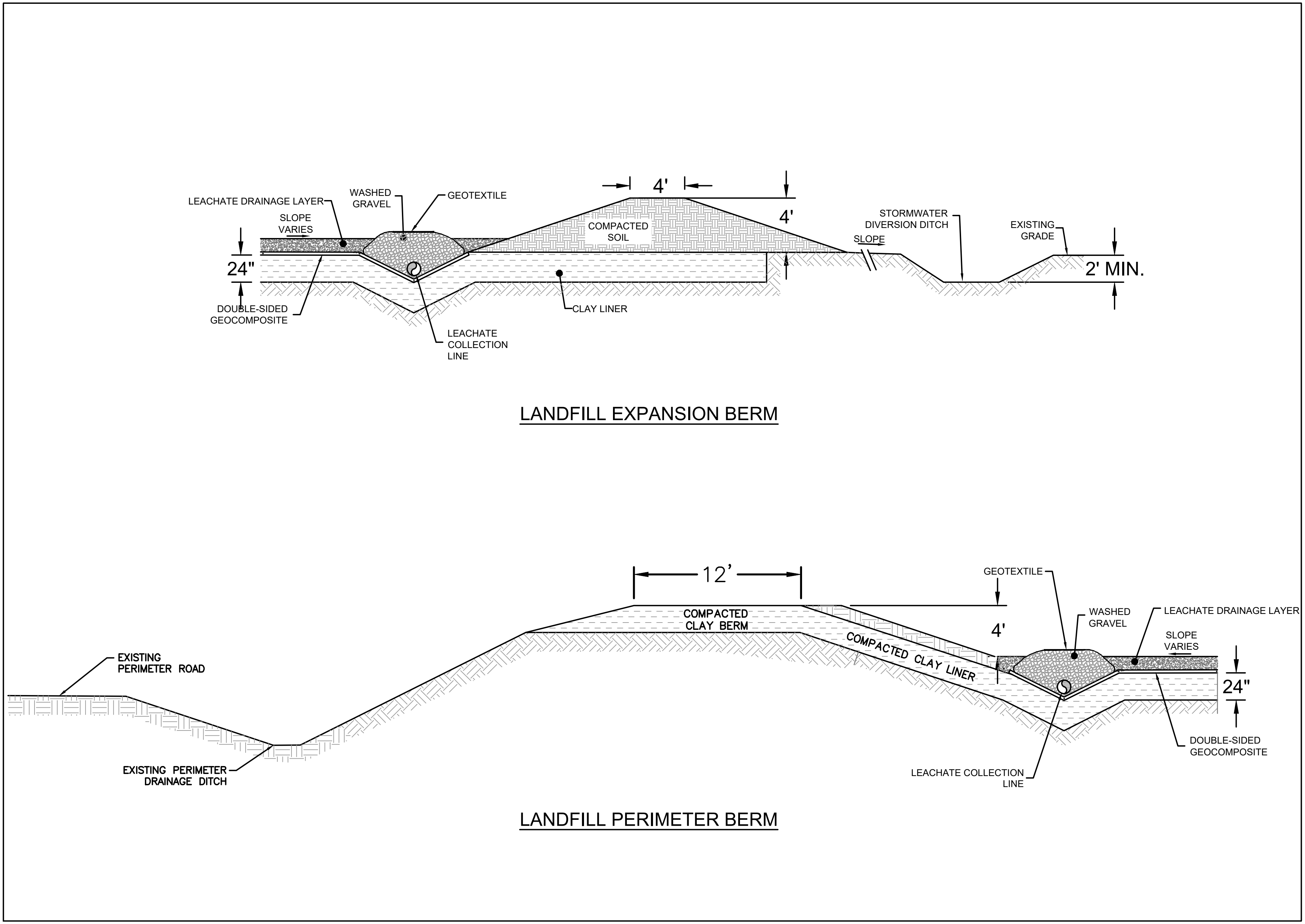


Figure 6. Berm Details.

APPENDIX C

Run-on Hydrologic and Hydraulic Calculations

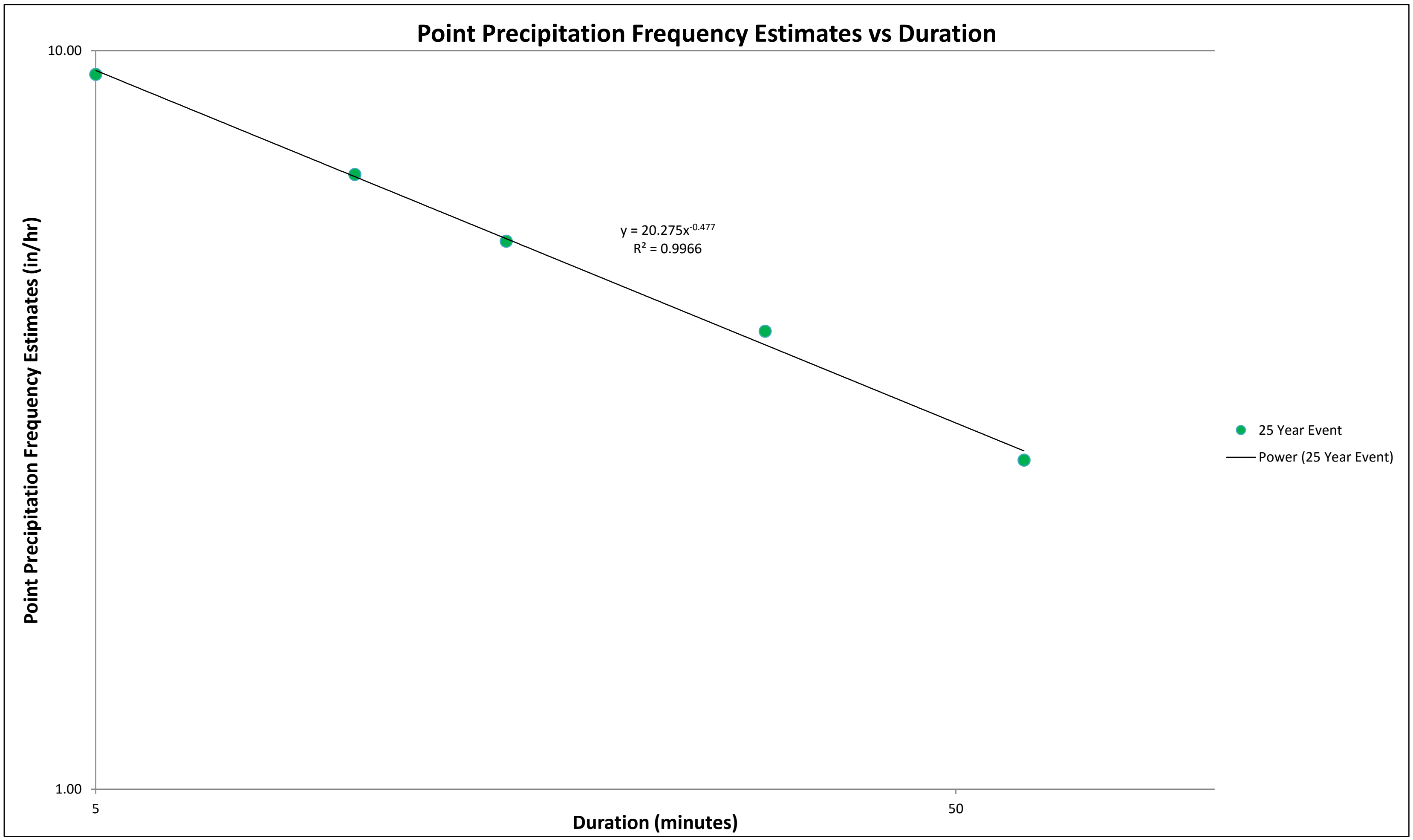
Precipitation intensities for Redfield AR obtained from the NOAA Precipitation Frequency Data Server (PFDS)
http://hdsc.nws.noaa.gov/hdsc/pfds/

Point precipitation frequency estimates (inches)
NOAA Atlas 14 Volume 9 Version 2
Data type: Precipitation depth
Time series type: Partial duration
Project area: Southeastern States
Latitude (decimal degrees): 34.4158°
Longitude (decimal degrees): -92.1499°

PRECIPITATION FREQUENCY ESTIMATES

Duration	25 Year Event
5-min:	9.29 (in/hr)
10-min:	6.8 (in/hr)
15-min:	5.52 (in/hr)
30-min:	4.17 (in/hr)
60-min:	2.79 (in/hr)

Date/time (GMT): Fri Aug 12 00:04:46 2016
pyRunTime: 0.124566078186



T_c and Flow Calculations for Basin 1

INPUT

Flow Type	Length	Slope
Overland	455	0.020
Channel	312	0.005
Total Length	767	

OVERLAND FLOW

(Sheet Flow)

$$T_c = \frac{.007*(n*L)^{.8}}{(P2yr,24hr)^{.5}*s^{.4}}$$ (TR-55)

Minimum Assumed Slope = 0.0005 ft/ft
Rainfall = 2yr, 24-hour 4.32 in

Segment	Length, ft	Manning's	Slope (ft/ft)	Tc (hr)
1	455	0.240	0.0200	0.688

CHANNEL FLOW

t=L/3600V
V=(1.49*r^2/3*s^.5)/n (TR-55)

Segment	Length, ft	Slope (ft/ft)	ManningsN	Side Slope	Bottom Width	Depth	Area	WP*	HydrRadius	Velocity	Tc (hr)
2	312.00	0.01	0.020	4	3	2	22.000	19.492	1.13	5.71	0.015

hydraulic radius = area/wetted perimter

*Note: Assume channel is full

TOTAL TIME

$T_C = T_{SHEET} + T_{SHALLOW} + T_{CHANNEL}$

Segment	T_C	T_C
	(hr)	(min)
1	0.688	41.27
3	0.015	0.91
CUMULATIVE T_c	**0.703**	**42.2**

FLOW CALCULATION

Q = CIA

C =	0.20
I (in/hr) =	3.47
A (ac) =	6.90
Therefore Q =	**4.79** cfs

T_c and Flow Calculations for Basin 2

INPUT

Flow Type	Length	Slope
Overland	840	0.033
Shallow	330	0.030
Channel	20	0.025
Total Length	1190	

OVERLAND FLOW
(Sheet Flow)

$$T_c = \frac{.007*(n*L)^{.8}}{(P2yr,24hr)^{.5}*s^{.4}}$$ (TR-55)

Minimum Assumed Slope = 0.0005 ft/ft
Rainfall = 2yr, 24-hour 4.32 in

Segment	Length, ft	Manning's	Slope (ft/ft)	Tc (hr)
1	840	0.240	0.0330	0.919

SHALLOW FLOW
Unpaved V = 16.1345*S^0.5
t=L/3600V (TR-55)
Paved V = 20.3282*S^0.5

Segment	Length, ft	Paved	Slope (ft/ft)	Velocity	Tc	
2	330	No	0.030	2.79	0.033	Tc in hr

CHANNEL FLOW
t=L/3600V
V=(1.49*r^2/3*s^.5)/n (TR-55)

Segment	Length, ft	Slope (ft/ft)	ManningsN	Side Slope	Bottom Width	Depth	Area	WP*	HydrRadius	Velocity	Tc (hr)
3	20.00	0.03	0.020	3	2	3	33.000	20.974	1.57	15.94	0.000

hydraulic radius = area/wetted perimter
*Note: Assume channel is full

TOTAL TIME

$T_C = T_{SHEET} + T_{SHALLOW} + T_{CHANNEL}$

Segment	T_C	T_C
	(hr)	(min)
1	0.919	55.17
2	0.033	1.97
3	0.000	0.02
CUMULATIVE T_c	**0.953**	**57.2**

FLOW CALCULATION

Q = CIA

C =	0.28	
I (in/hr) =	3.00	
A (ac) =	14.70	
Therefore Q =	**12.35**	cfs

T_c and Flow Calculations for Basin 3

INPUT

Flow Type	Length	Slope
Overland	1265	0.031
Shallow	185	0.030
Channel	980	0.015
Total Length	2430	

OVERLAND FLOW
(Sheet Flow)

$$T_c = \frac{.007*(n*L)^{.8}}{(P2yr,24hr)^{.5}*s^{.4}}$$ (TR-55)

Minimum Assumed Slope = 0.0005 ft/ft
Rainfall = 2yr, 24-hour 4.32 in

Segment	Length, ft	Manning's	Slope (ft/ft)	Tc (hr)
1	1265	0.240	0.0310	1.308

SHALLOW FLOW
Unpaved V = 16.1345*S^0.5
t=L/3600V (TR-55)
Paved V = 20.3282*S^0.5

Segment	Length, ft	Paved	Slope (ft/ft)	Velocity	Tc	
2	185	No	0.030	2.79	0.018	Tc in hr

CHANNEL FLOW
t=L/3600V
V=(1.49*r^2/3*s^.5)/n (TR-55)

Segment	Length, ft	Slope (ft/ft)	ManningsN	Side Slope	Bottom Width	Depth	Area	WP*	HydrRadius	Velocity	Tc (hr)
3	980.00	0.02	0.020	3	5	4	68.000	30.298	2.24	15.64	0.017

hydraulic radius = area/wetted perimter
*Note: Assume channel is full

TOTAL TIME

$T_C = T_{SHEET} + T_{SHALLOW} + T_{CHANNEL}$

Segment	T_C (hr)	T_C (min)
1	1.308	78.49
2	0.018	1.10
3	0.017	1.04
CUMULATIVE T_c	**1.344**	**80.6**

FLOW CALCULATION

Q = CIA

C =	0.28	
I (in/hr) =	2.55	
A (ac) =	16.70	
Therefore Q =	**11.91**	cfs

Worksheet for Reach 1

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.045	
Channel Slope	0.00500	ft/ft
Left Side Slope	3.00	ft/ft (H:V)
Right Side Slope	3.00	ft/ft (H:V)
Bottom Width	2.00	ft
Discharge	4.80	ft³/s

Results

Normal Depth	0.77	ft
Flow Area	3.33	ft²
Wetted Perimeter	6.88	ft
Hydraulic Radius	0.48	ft
Top Width	6.63	ft
Critical Depth	0.45	ft
Critical Slope	0.04496	ft/ft
Velocity	1.44	ft/s
Velocity Head	0.03	ft
Specific Energy	0.80	ft
Froude Number	0.36	
Flow Type	Subcritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s
Normal Depth	0.77	ft
Critical Depth	0.45	ft
Channel Slope	0.00500	ft/ft

Worksheet for Reach 2

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.069	
Channel Slope	0.03500	ft/ft
Left Side Slope	3.00	ft/ft (H:V)
Right Side Slope	3.00	ft/ft (H:V)
Bottom Width	3.00	ft
Discharge	4.80	ft³/s

Results

Normal Depth	0.51	ft
Flow Area	2.31	ft²
Wetted Perimeter	6.22	ft
Hydraulic Radius	0.37	ft
Top Width	6.06	ft
Critical Depth	0.38	ft
Critical Slope	0.10736	ft/ft
Velocity	2.08	ft/s
Velocity Head	0.07	ft
Specific Energy	0.58	ft
Froude Number	0.59	
Flow Type	Subcritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s
Normal Depth	0.51	ft
Critical Depth	0.38	ft
Channel Slope	0.03500	ft/ft

Worksheet for Reach 3

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.069	
Channel Slope	0.04000	ft/ft
Left Side Slope	3.00	ft/ft (H:V)
Right Side Slope	3.00	ft/ft (H:V)
Bottom Width	3.00	ft
Discharge	35.40	ft^3/s

Results

Normal Depth	1.34	ft
Flow Area	9.39	ft^2
Wetted Perimeter	11.47	ft
Hydraulic Radius	0.82	ft
Top Width	11.03	ft
Critical Depth	1.13	ft
Critical Slope	0.08056	ft/ft
Velocity	3.77	ft/s
Velocity Head	0.22	ft
Specific Energy	1.56	ft
Froude Number	0.72	
Flow Type	Subcritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s
Normal Depth	1.34	ft
Critical Depth	1.13	ft
Channel Slope	0.04000	ft/ft

Worksheet for Reach 4

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.035	
Channel Slope	0.02600	ft/ft
Left Side Slope	3.00	ft/ft (H:V)
Right Side Slope	3.00	ft/ft (H:V)
Bottom Width	2.00	ft
Discharge	12.40	ft³/s

Results

Normal Depth	0.73	ft
Flow Area	3.04	ft²
Wetted Perimeter	6.60	ft
Hydraulic Radius	0.46	ft
Top Width	6.36	ft
Critical Depth	0.74	ft
Critical Slope	0.02384	ft/ft
Velocity	4.08	ft/s
Velocity Head	0.26	ft
Specific Energy	0.99	ft
Froude Number	1.04	
Flow Type	Supercritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s
Normal Depth	0.73	ft
Critical Depth	0.74	ft
Channel Slope	0.02600	ft/ft

Worksheet for Reach 5

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.035	
Channel Slope	0.00800	ft/ft
Left Side Slope	3.00	ft/ft (H:V)
Right Side Slope	3.00	ft/ft (H:V)
Bottom Width	4.00	ft
Discharge	24.30	ft³/s

Results

Normal Depth	1.09	ft
Flow Area	7.92	ft²
Wetted Perimeter	10.89	ft
Hydraulic Radius	0.73	ft
Top Width	10.54	ft
Critical Depth	0.84	ft
Critical Slope	0.02193	ft/ft
Velocity	3.07	ft/s
Velocity Head	0.15	ft
Specific Energy	1.24	ft
Froude Number	0.62	
Flow Type	Subcritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s
Normal Depth	1.09	ft
Critical Depth	0.84	ft
Channel Slope	0.00800	ft/ft

Culvert Calculator Report
Culvert 1

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	3.00	ft	Headwater Depth/Height	0.54	
Computed Headwater Eleva	366.58	ft	Discharge	4.50	cfs
Inlet Control HW Elev.	366.52	ft	Tailwater Elevation	1.00	ft
Outlet Control HW Elev.	366.58	ft	Control Type	Entrance Control	

Grades					
Upstream Invert	365.50	ft	Downstream Invert	364.00	ft
Length	96.00	ft	Constructed Slope	0.015625	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	0.54	ft
Slope Type	Steep		Normal Depth	0.54	ft
Flow Regime	Supercritical		Critical Depth	0.75	ft
Velocity Downstream	6.58	ft/s	Critical Slope	0.004516	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	366.58	ft	Upstream Velocity Head	0.28	ft
Ke	0.20		Entrance Loss	0.06	ft

Inlet Control Properties					
Inlet Control HW Elev.	366.52	ft	Flow Control	N/A	
Inlet Type	Groove end projecting		Area Full	3.1	ft²
K	0.00450		HDS 5 Chart	1	
M	2.00000		HDS 5 Scale	3	
C	0.03170		Equation Form	1	
Y	0.69000				

Culvert Calculator Report
Culvert 2

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	3.00	ft	Headwater Depth/Height	0.41	
Computed Headwater Eleva	350.03	ft	Discharge	4.80	cfs
Inlet Control HW Elev.	349.93	ft	Tailwater Elevation	0.50	ft
Outlet Control HW Elev.	350.03	ft	Control Type	Entrance Control	

Grades

Upstream Invert	349.00	ft	Downstream Invert	346.00	ft
Length	72.00	ft	Constructed Slope	0.041667	ft/ft

Hydraulic Profile

Profile	S2		Depth, Downstream	0.41	ft
Slope Type	Steep		Normal Depth	0.41	ft
Flow Regime	Supercritical		Critical Depth	0.72	ft
Velocity Downstream	9.26	ft/s	Critical Slope	0.004138	ft/ft

Section

Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	2.50	ft
Section Size	30 inch		Rise	2.50	ft
Number Sections	1				

Outlet Control Properties

Outlet Control HW Elev.	350.03	ft	Upstream Velocity Head	0.26	ft
Ke	0.20		Entrance Loss	0.05	ft

Inlet Control Properties

Inlet Control HW Elev.	349.93	ft	Flow Control	Unsubmerged	
Inlet Type	Groove end projecting		Area Full	4.9	ft²
K	0.00450		HDS 5 Chart	1	
M	2.00000		HDS 5 Scale	3	
C	0.03170		Equation Form	1	
Y	0.69000				

Culvert Calculator Report
Culvert 3

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	3.00	ft	Headwater Depth/Height	0.85	
Computed Headwater Eleva	335.12	ft	Discharge	35.40	cfs
Inlet Control HW Elev.	335.05	ft	Tailwater Elevation	1.40	ft
Outlet Control HW Elev.	335.12	ft	Control Type	Entrance Control	

Grades					
Upstream Invert	333.00	ft	Downstream Invert	332.50	ft
Length	38.00	ft	Constructed Slope	0.013158	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	1.13	ft
Slope Type	Steep		Normal Depth	1.06	ft
Flow Regime	Supercritical		Critical Depth	1.42	ft
Velocity Downstream	8.22	ft/s	Critical Slope	0.004849	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	2.50	ft
Section Size	30 inch		Rise	2.50	ft
Number Sections	2				

Outlet Control Properties					
Outlet Control HW Elev.	335.12	ft	Upstream Velocity Head	0.58	ft
Ke	0.20		Entrance Loss	0.12	ft

Inlet Control Properties					
Inlet Control HW Elev.	335.05	ft	Flow Control	Unsubmerged	
Inlet Type	Groove end projecting		Area Full	9.8	ft²
K	0.00450		HDS 5 Chart	1	
M	2.00000		HDS 5 Scale	3	
C	0.03170		Equation Form	1	
Y	0.69000				

Culvert Calculator Report
Culvert 4

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	4.00	ft	Headwater Depth/Height	1.03	
Computed Headwater Eleva	339.10	ft	Discharge	24.30	cfs
Inlet Control HW Elev.	339.05	ft	Tailwater Elevation	1.00	ft
Outlet Control HW Elev.	339.10	ft	Control Type	Entrance Control	

Grades

Upstream Invert	336.52	ft	Downstream Invert	336.23	ft
Length	40.00	ft	Constructed Slope	0.007250	ft/ft

Hydraulic Profile

Profile	S2		Depth, Downstream	1.55	ft
Slope Type	Steep		Normal Depth	1.54	ft
Flow Regime	Supercritical		Critical Depth	1.68	ft
Velocity Downstream	7.60	ft/s	Critical Slope	0.005593	ft/ft

Section

Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	2.50	ft
Section Size	30 inch		Rise	2.50	ft
Number Sections	1				

Outlet Control Properties

Outlet Control HW Elev.	339.10	ft	Upstream Velocity Head	0.75	ft
Ke	0.20		Entrance Loss	0.15	ft

Inlet Control Properties

Inlet Control HW Elev.	339.05	ft	Flow Control	Unsubmerged	
Inlet Type	Groove end projecting		Area Full	4.9	ft²
K	0.00450		HDS 5 Chart	1	
M	2.00000		HDS 5 Scale	3	
C	0.03170		Equation Form	1	
Y	0.69000				

APPENDIX D

Run-off Hydrologic and Hydraulic Calculations

T_c and Flow Calculations for
Basin 4

INPUT

Flow Type	Length	Slope
Overland	619	0.025
Channel	300	0.009
Total Length	919	

OVERLAND FLOW
(Sheet Flow)

$$T_c = \frac{.007*(n*L)^{.8}}{(P2yr,24hr)^{.5}*s^{.4}}$$ (TR-55)

Minimum Assumed Slope = 0.0005 ft/ft
Rainfall = 2yr, 24-hour 4.32 in

Segment	Length, ft	Manning's	Slope (ft/ft)	Tc (hr)
1	619	0.060	0.0120	0.356

CHANNEL FLOW
t=L/3600V
V=(1.49*r^2/3*s^.5)/n (TR-55)

Segment	Length, ft	Slope (ft/ft)	ManningsN	Side Slope	Bottom Width	Depth	Area	WP*	HydrRadius	Velocity	Tc (hr)
2	300.00	0.01	0.012	3	6	2	24.000	18.649	1.29	13.94	0.006

hydraulic radius = area/wetted perimter
*Note: Assume channel is full

TOTAL TIME

$T_C = T_{SHEET} + T_{SHALLOW} + T_{CHANNEL}$

Segment	T_C	T_C
	(hr)	(min)
1	0.356	21.37
2	0.006	0.36
CUMULATIVE T_c	**0.362**	**21.7**

FLOW CALCULATION

Q = CIA

C =	0.44
I (in/hr) =	4.76
A (ac) =	15.90
Therefore Q =	**33.31** cfs

T_c and Flow Calculations for Basin 5

INPUT

Flow Type	Length	Slope
Overland	380	0.010
Overland	85	0.333
Channel	980	0.020
Total Length	1445	

OVERLAND FLOW
(Sheet Flow)

$$T_c = \frac{.007*(n*L)^{.8}}{(P2yr,24hr)^{.5}*s^{.4}}$$ (TR-55)

Minimum Assumed Slope = 0.0005 ft/ft
Rainfall = 2yr, 24-hour 4.32 in

Segment	Length, ft	Manning's	Slope (ft/ft)	Tc (hr)
1	380	0.050	0.0100	0.224
2	85	0.060	0.3330	0.019

CHANNEL FLOW
t=L/3600V
V=(1.49*r^2/3*s^.5)/n (TR-55)

Segment	Length, ft	Slope (ft/ft)	ManningsN	Side Slope	Bottom Width	Depth	Area	WP*	HydrRadius	Velocity	Tc (hr)
3	980.00	0.02	0.015	3	6	1	9.000	12.325	0.73	11.39	0.024

hydraulic radius = area/wetted perimter
*Note: Assume channel is full

TOTAL TIME

$T_C = T_{SHEET} + T_{SHALLOW} + T_{CHANNEL}$

Segment	T_C (hr)	T_C (min)
1	0.224	13.44
2	0.019	1.16
3	0.024	1.43
CUMULATIVE T_c	**0.267**	**16.0**

FLOW CALCULATION

Q = CIA

C =	0.44
I (in/hr) =	5.50
A (ac) =	14.60
Therefore Q =	**35.35** cfs