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STORMWATER RUN-ON AND RUN-OFF CONTROL PLAN

ENTERGY ARKANSAS, INC. INDEPENDENCE PLANT CLASS 3N CCR LANDFILL

PERMIT NO. 0200-S3N-R2 AFIN: 32-00042

OCTOBER 12, 2016

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PERMIT NO. 0200-S3N-R2
AFIN: 32-00042

Prepared for

Entergy Arkansas, Inc. Independence Plant
555 Point Ferry Rd.
Newark, AR 72562

Prepared by

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FTN Project No. R06040-0992-001

October 12, 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. Independence Plant Class 3N CCR Landfill was prepared under the direction and supervision of a qualified, State of Arkansas-registered Professional Engineer. Mr. Nick Schoggin, PE, of FTN Associates, Ltd., was responsible for the overall preparation of the plan.

Nick Schoggin, PE #14268

10-12-16
Date

PLAN AMENDMENTS

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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. Independence 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 Independence Power Plant Information

The Plant is located on approximately 1,850 acres about 2-½ miles southeast of Newark in Independence County, Arkansas as shown on Figure 1 (all figures are located in Appendix B, unless otherwise noted). The site is characterized by minimal topographic relief and is situated within the White River floodplain.

The Plant has been in operation since 1983 and has historically generated electricity through the combustion of Powder River Basin (PRB) (Wyoming) sub-bituminous coal. 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 ash produced is classified as fly ash that is derived from the boiler exhaust gas and 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 blown 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 that drops out before the electrostatic precipitators, and represents approximately 2% of the total ash production. The remaining 18% of coal ash produced from the coal combustion is comprised of bottom ash. It is composed of angular, glassy particles with a porous surface texture and has the consistency of coarse sand. The bottom ash is sluiced principally to dewatering hoppers for removal of water and for storage.

Historically, approximately 60 to 70% of the two types of ash have been marketed regionally to construction-related industries. The remaining amount of ash has been placed in the onsite Landfill for disposal. The amount placed in the CCR Landfill varies from year to year, but the average for the past five years is approximately 125,000 cubic yards (cy).

1.3 Permit History

In October 1982, Arkansas Power & Light Company (AP&L) was granted a solid waste permit (#200-S) from the Arkansas Department of Environmental Quality (ADEQ) to construct and operate a solid waste disposal facility at the Plant. Entergy Arkansas, Inc. became AP&L’s successor in interest in April 1996. The permit was modified (0200-S3N-R1) in 2002 to update the landfill to comply with Arkansas Pollution Control and Ecology Commission (APCEC) Regulation No. 22 (Solid Waste Management Code) design and operational standards for Class 4 (inert waste) Landfills. The current facility permit (0200-S3N-R2) was issued in December 2014 and includes design and operational modifications to the landfill facility to comply with Regulation No. 22 requirements for Class 3N (Industrial) Landfills.

1.4 Existing Conditions of Landfill

The ADEQ-permitted landfill area consists of approximately 335 acres and is located in the northeastern portion of the plant site as shown on Figure 2. The CCR Landfill is designed to be developed through three phases, which only Phases 1 and 2 are currently permitted for development. The current ADEQ-permitted layout of the CCR Landfill includes a total of 22 disposal cells and has a permitted waste capacity of approximately 13,000,000 cubic yards (cy). Waste Cells 1 through 15 have been constructed, and Waste Cells 12, 13, 14, and 15 currently comprise the active disposal area of the CCR Landfill having received CCR materials after October 19, 2015 (Figure 3). The permitted waste disposal capacity for Cells 12 through 15 is approximately 4,703,000 cy, which includes CCR placed in the landfill prior to October 19, 2015.

Construction of the disposal cells has followed the numerical sequence of the cell numbers and have generally been designed, constructed, operated and maintained in compliance with the requirements of APCEC Regulation 22. Cells 1 through 11 were constructed, operated and closed prior to the effective date of the CCR Rule and are not covered by the requirements of the Rule. Cells 12 through 15 are the existing landfill CCR units and will be operated and closed in accordance with requirements of the CCR Rule.

No final cover system has been installed on the active CCR units, Cells 12 through 15. As shown on Figure 3, Cells 1 through 11 of the landfill facility that received CCR material prior to the issuance of the CCR Rule were closed and covered in accordance with the original facility ADEQ-issued permit (Cells 1 through 9) or the ADEQ-issued 2002 permit (Cells 10 and 11). 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 southwest to discharge into the facility Surge Pond, located south 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 (Permit Number AR0037451). An overview of the existing stormwater system is shown on Figure 3 in Appendix B.

The stormwater system is composed of berms, grass-lined channels, 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 5, 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 12, 13, and 14, the leachate is stored within the waste mass. For Cell 15, the leachate flows to a collection sump located in the east end of the Cell and is pumped to the Surge Pond.

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 = Runoff coefficient (dimensionless)
I = Rainfall intensity in inches per hour (in/hr)
A = Drainage area in acres (ac)

The coefficient, C, values were based on the slope and the surface conditions of the Landfill. 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 duration. Microsoft Excel was utilized to add a power trendline to the plotted data. The resulting equation of the trendline 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 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 site reconnaissance and 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.

Permanent 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

A perimeter berm and adjacent ditch encompasses the landfill and the Plant. The berm was built to the elevation of the 100-year storm event plus 1 foot of freeboard elevation. Therefore, stormwater from the 24-hour, 25-year event will not impact the landfill resulting in no stormwater run-on.

3.2 Stormwater Run-off

The area surrounding the Landfill was divided into three drainage basins for the stormwater run-off Hydrologic and Hydraulic analysis. Basin 1 comprises the eastern portion of the Landfill, Basin 2 comprises the western portion, and Basin 3 comprises the top portion of the closed Cells 1 through 11. Stormwater that does not infiltrate the waste material sheet flows into the stormwater ditch, which then discharges into the Surge Pond. The basins and their corresponding longest flow paths are shown on Figure 3 in Appendix B.

4.0 RESULTS

Hydrologic and Hydraulic calculation results for the run-off analysis are presented in Appendix C.

4.1 Stormwater Run-off Results

As shown in Appendix C, the existing stormwater system surrounding the Landfill will convey the 24-hour, 25-year storm event. As described in Section 3.2, the Landfill can be divided into three hydrologic basins. Results from the hydrologic analysis of these two 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, Run-off hydrologic analysis results.

Basin	Area, A (acres)	Time of Concentration, Tc (minutes)	Composite Runoff Coefficient, C	Rainfall Intensity, I_{25} (in/hr)	Peak Discharge, Q_{25} (ft^3/sec)
1	152.7	22.4	0.20	4.30	131.4
2	27.5	27.4	0.30	3.88	32.0
3	48.5	47.6	0.25	2.94	35.6

Results from the hydraulic analysis of the 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	6,312	0.005	6.0	0.027	131.4	4.9	1.9
2	5,332	0.005	6.0	0.027	32.0	3.2	0.9
3	723	0.005	6.0	0.027	35.6	3.3	0.9

Results from the 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	50	0.005	Triple 48”	CMP	131.4	7.06	3.6
2	70	0.005	Single 30”	CMP	32.0	7.9	4.9
3	40	0.005	Single 30”	CMP	35.6	8.4	4.8

The calculations confirm that the existing stormwater system will convey the peak flow rates from the 24-hour, 25-year storm.

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

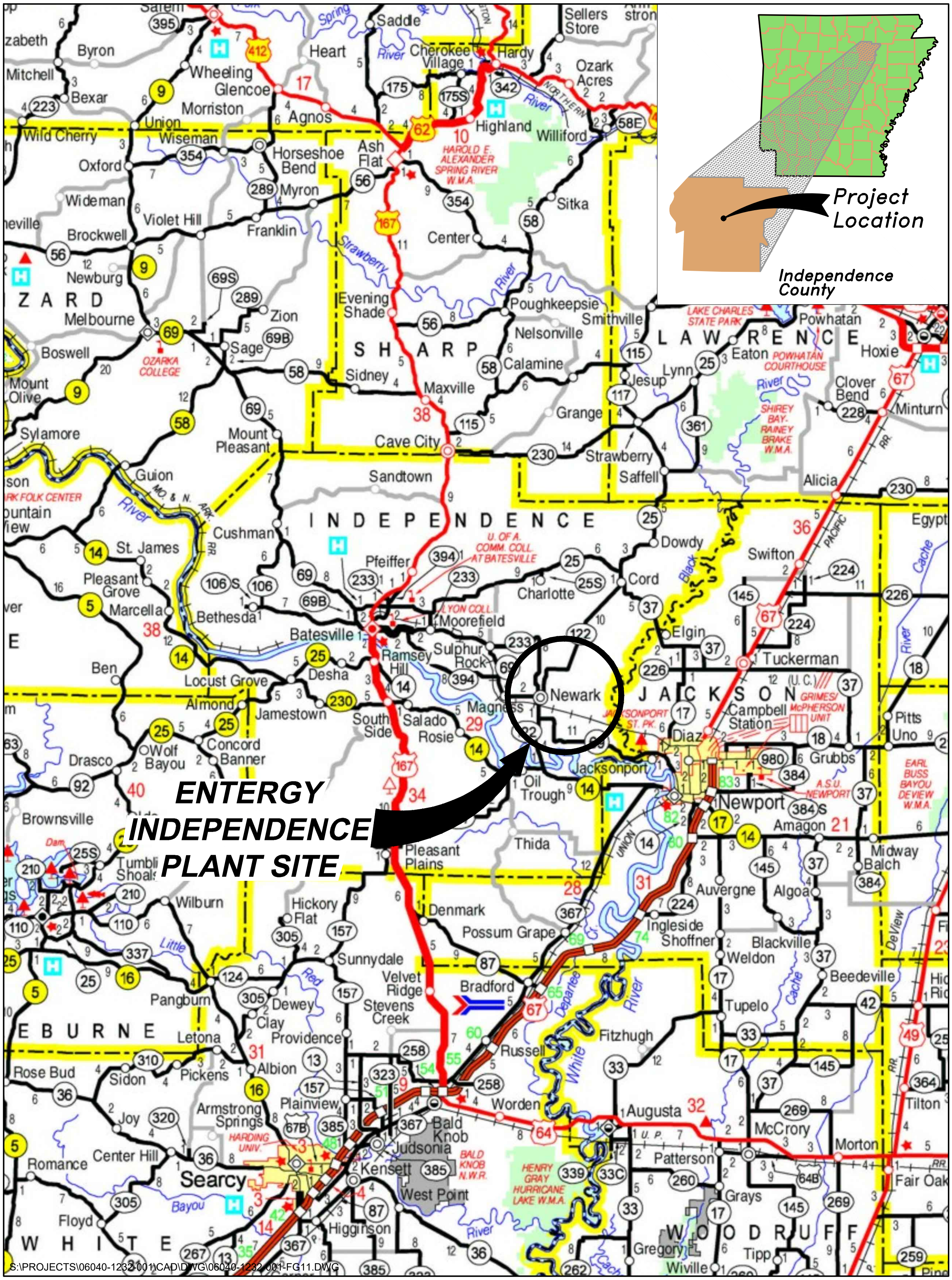

Figure 1. Site location map.

NORTH

SCALE 1"=500

NOTES:

1. LOCATIONS OF LANDFILL PERMIT BOUNDARY AND CELL BOUNDARIES ARE APPROXIMATE.

LEGEND

- EXISTING STREAM OR DITCH
- CELL BOUNDARY
- LANDFILL PERMIT BOUNDARY

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CLASS 3N CCR LANDFILL
STORMWATER RUN-ON/RUN-OFF CONTROL PLAN
NEWARK, ARKANSAS

FIGURE 2
SITE MAP
STORMWATER RUN-ON/RUN-OFF CONTROL PLAN

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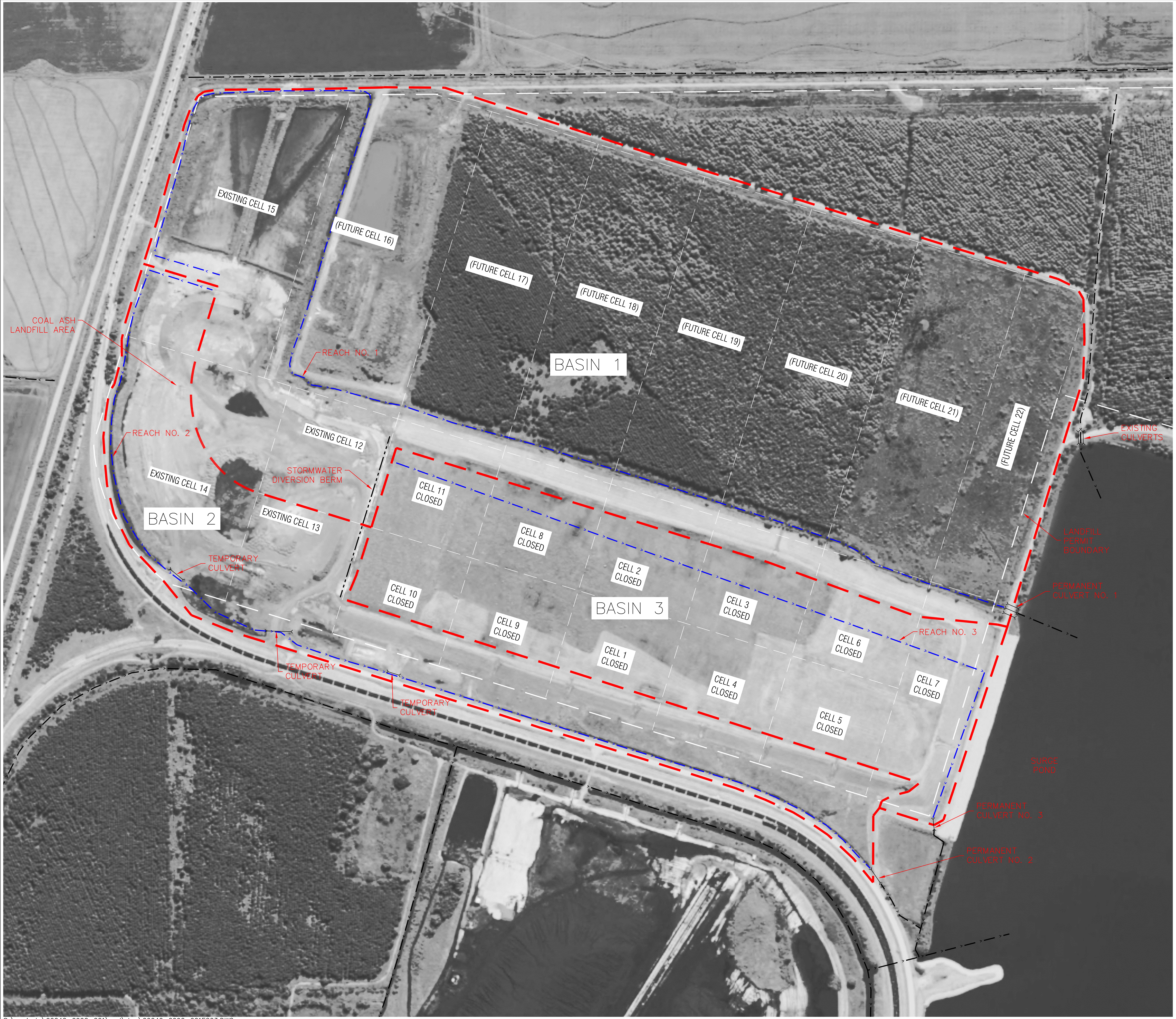

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N
NORTH
0 250 500
SCALE 1"=500'

NOTES:

1. LOCATIONS OF LANDFILL PERMIT BOUNDARY AND CELL BOUNDARIES ARE APPROXIMATE.

LEGEND

— > — > —	EXISTING STREAM OR DITCH
— — — —	CELL BOUNDARY
— — — —	LANDFILL PERMIT BOUNDARY
— > — > —	LONGEST FLOWPATH
— — —	DRAINAGE BASIN
>——<	CULVERT
—·—·—	STORMWATER DIVERSION BERM

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CLASS 3N CCR LANDFILL
STORMWATER RUN-ON/RUN-OFF CONTROL PLAN
NEWARK, ARKANSAS

FIGURE 3
RUN-OFF ANALYSIS
STORMWATER RUN-ON/RUN-OFF CONTROL PLAN

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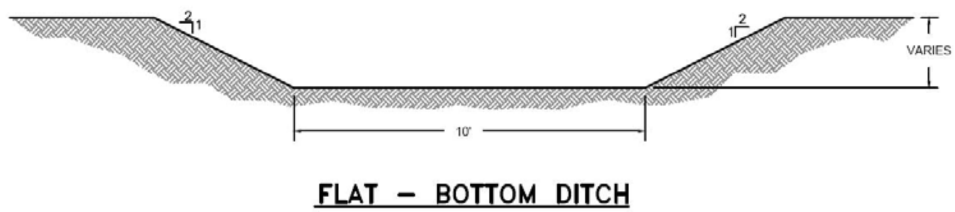
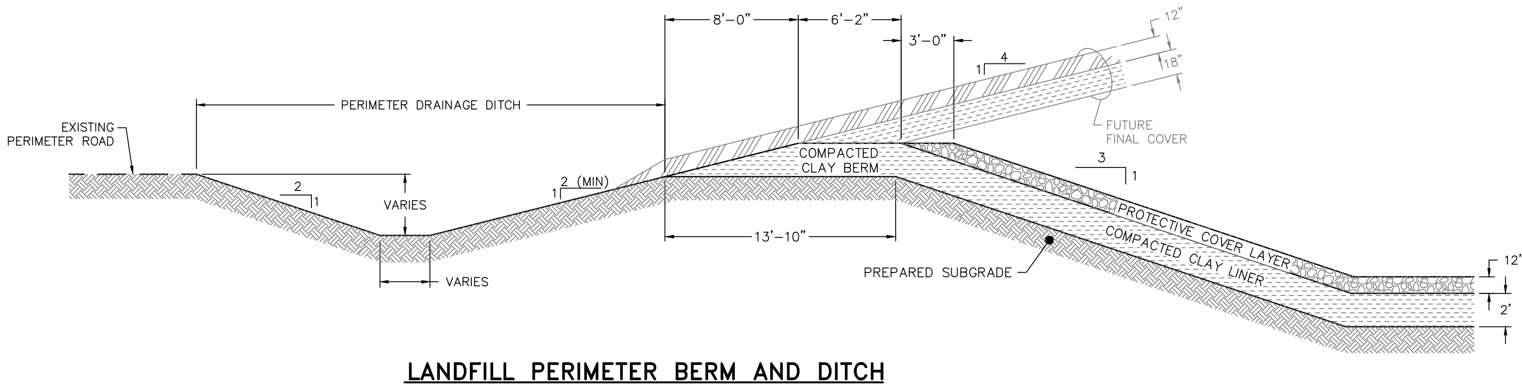


Figure 4. Typical Stormwater Channel Detail.



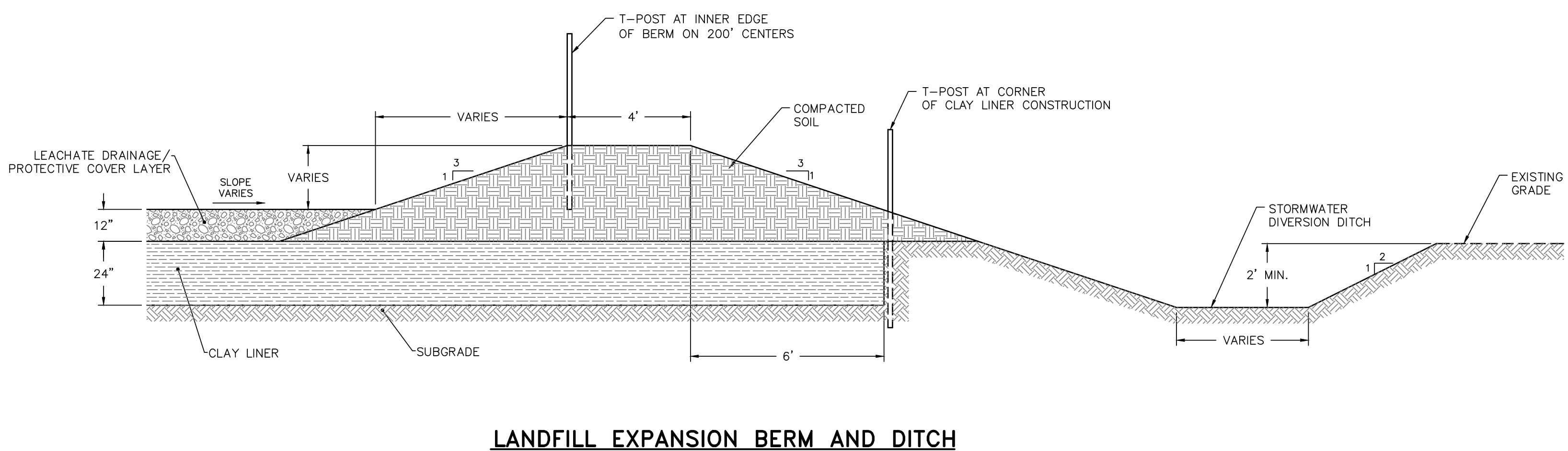


Figure 5. Berm Details.

APPENDIX C

Run-off Hydrologic and Hydraulic Calculation

Rainfall Intensity Formula

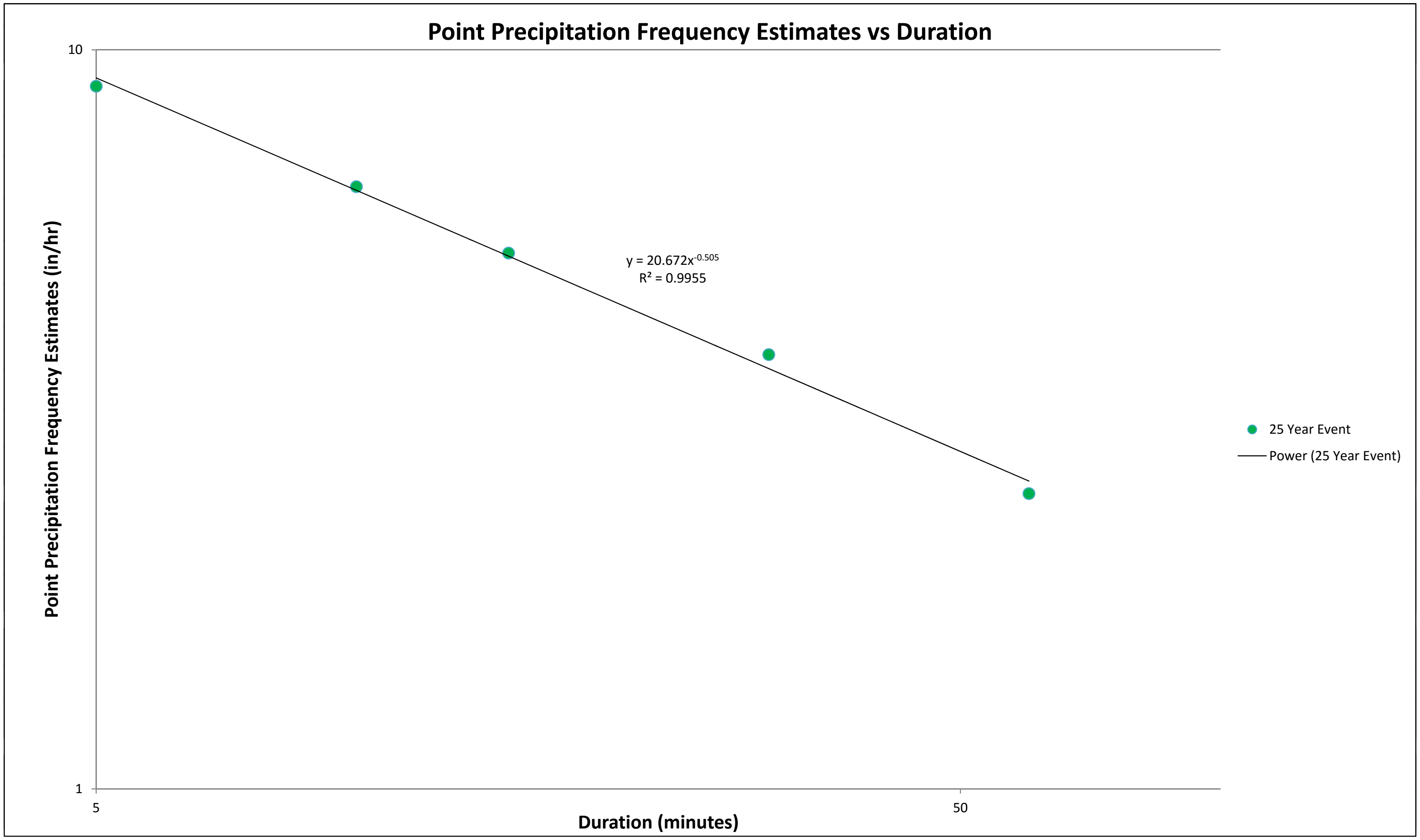
Precipitation intensities for Jonesboro AR obtained from the NOAA Precipitation Frequency Data Server (PFDS)
http://hdsc.nws.noaa.gov/hdsc/pfds/

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): 35.6790°
Longitude (decimal degrees): -91.3908°

PRECIPITATION FREQUENCY ESTIMATES

Duration	25 Year Event
5-min:	8.93 (in/hr)
10-min:	6.53 (in/hr)
15-min:	5.31 (in/hr)
30-min:	3.87 (in/hr)
60-min:	2.51 (in/hr)

Date/time (GMT): Thu Aug 11 23:54:40 2016
pyRunTime: 0.132289171219



T_c and Flow Calculations for Basin 1

INPUT

Flow Type	Length	Slope
Overland	100	0.330
Shallow	237	0.330
Channel	6312	0.005
Total Length	6649	

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 4.08 in

Segment	Length, ft	Manning's	Slope (ft/ft)	Tc (hr)
1	100	0.050	0.3300	0.020

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	237	No	0.330	9.27	0.007

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	6312.00	0.005	0.027	2	10	2	28.000	18.944	1.48	5.06	0.346

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	0.020	1.17
2	0.007	0.43
3	0.346	20.78
CUMULATIVE T_c	**0.373**	**22.4**

FLOW CALCULATION

Q = CIA

C =	0.20
I (in/hr) =	4.30
A (ac) =	152.70
Therefore Q =	**131.40** cfs

T_c and Flow Calculations for Basin 2

INPUT

Flow Type	Length	Slope
Overland	100	0.330
Shallow	247	0.330
Channel	5332	0.005
Total Length	5679	

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 4.08 in

Segment	Length, ft	Manning's	Slope (ft/ft)	Tc (hr)
1	100	0.050	0.3300	0.020

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	247	No	0.330	9.27	0.007	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	5332.00	0.005	0.027	2	10	1	12.000	14.472	0.83	3.44	0.430

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	0.020	1.17
2	0.007	0.44
3	0.430	25.80
CUMULATIVE T_c	**0.457**	**27.4**

FLOW CALCULATION

Q = CIA

C =	0.30	
I (in/hr) =	3.88	
A (ac) =	27.51	
Therefore Q =	**32.05**	cfs

T_c and Flow Calculations for Basin 3

INPUT

Flow Type	Length	Slope
Overland	100	0.005
Shallow	2573	0.005
Channel	126	0.330
Channel	723	0.005
Total Length	3522	

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 4.08 in

Segment	Length, ft	Manning's	Slope (ft/ft)	Tc (hr)
1	100	0.050	0.0050	0.105

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

Segment	Length, ft	Paved	Slope (ft/ft)	Velocity	Tc	
2	2573	No	0.005	1.14	0.626	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	126.00	0.330	0.075	2	10	1	12.000	14.472	0.83	10.07	0.003
4	723.00	0.005	0.027	2	10	1	12.000	14.472	0.83	3.44	0.058

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	0.105	6.27
2	0.626	37.59
3	0.003	0.21
4	0.058	3.50
CUMULATIVE T_c	**0.734**	**47.6**

FLOW CALCULATION

Q = CIA

C =	0.25	
I (in/hr) =	2.94	
A (ac) =	48.47	
Therefore Q =	**35.62**	cfs

Worksheet for Reach 1

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.027	
Channel Slope	0.00500	ft/ft
Left Side Slope	2.00	ft/ft (H:V)
Right Side Slope	2.00	ft/ft (H:V)
Bottom Width	10.00	ft
Discharge	131.40	ft³/s

Results

Normal Depth	1.92	ft
Flow Area	26.60	ft²
Wetted Perimeter	18.59	ft
Hydraulic Radius	1.43	ft
Top Width	17.69	ft
Critical Depth	1.57	ft
Critical Slope	0.01042	ft/ft
Velocity	4.94	ft/s
Velocity Head	0.38	ft
Specific Energy	2.30	ft
Froude Number	0.71	
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	1.92	ft
Critical Depth	1.57	ft
Channel Slope	0.00500	ft/ft
Critical Slope	0.01042	ft/ft

Worksheet for Reach 2

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.027	
Channel Slope	0.00500	ft/ft
Left Side Slope	2.00	ft/ft (H:V)
Right Side Slope	2.00	ft/ft (H:V)
Bottom Width	10.00	ft
Discharge	32.05	ft³/s

Results

Normal Depth	0.86	ft
Flow Area	10.14	ft²
Wetted Perimeter	13.87	ft
Hydraulic Radius	0.73	ft
Top Width	13.46	ft
Critical Depth	0.65	ft
Critical Slope	0.01311	ft/ft
Velocity	3.16	ft/s
Velocity Head	0.16	ft
Specific Energy	1.02	ft
Froude Number	0.64	
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	0.86	ft
Critical Depth	0.65	ft
Channel Slope	0.00500	ft/ft
Critical Slope	0.01311	ft/ft

Worksheet for Reach 3

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.027	
Channel Slope	0.00500	ft/ft
Left Side Slope	2.00	ft/ft (H:V)
Right Side Slope	2.00	ft/ft (H:V)
Bottom Width	10.00	ft
Discharge	35.62	ft³/s

Results

Normal Depth	0.92	ft
Flow Area	10.88	ft²
Wetted Perimeter	14.11	ft
Hydraulic Radius	0.77	ft
Top Width	13.68	ft
Critical Depth	0.70	ft
Critical Slope	0.01287	ft/ft
Velocity	3.27	ft/s
Velocity Head	0.17	ft
Specific Energy	1.09	ft
Froude Number	0.65	
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	0.92	ft
Critical Depth	0.70	ft
Channel Slope	0.00500	ft/ft
Critical Slope	0.01287	ft/ft

Culvert Calculator Report
Culvert for Basin 1

Solve For: Headwater Elevation

Culvert Summary			
Allowable HW Elevation	0.00 ft	Headwater Depth/Height	0.83
Computed Headwater Elevation	3.57 ft	Discharge	131.40 cfs
Inlet Control HW Elev.	3.31 ft	Tailwater Elevation	0.00 ft
Outlet Control HW Elev.	3.57 ft	Control Type	Outlet Control

Grades			
Upstream Invert	0.25 ft	Downstream Invert	0.00 ft
Length	50.00 ft	Constructed Slope	0.005000 ft/ft

Hydraulic Profile			
Profile	M2	Depth, Downstream	1.98 ft
Slope Type	Mild	Normal Depth	2.70 ft
Flow Regime	Subcritical	Critical Depth	1.98 ft
Velocity Downstream	7.06 ft/s	Critical Slope	0.013125 ft/ft

Section			
Section Shape	Circular	Mannings Coefficient	0.024
Section Material	CMP	Span	4.00 ft
Section Size	48 inch	Rise	4.00 ft
Number Sections	3		

Outlet Control Properties			
Outlet Control HW Elev.	3.57 ft	Upstream Velocity Head	0.46 ft
Ke	0.90	Entrance Loss	0.41 ft

Inlet Control Properties			
Inlet Control HW Elev.	3.31 ft	Flow Control	Unsubmerged
Inlet Type	Projecting	Area Full	37.7 ft²
K	0.03400	HDS 5 Chart	2
M	1.50000	HDS 5 Scale	3
C	0.05530	Equation Form	1
Y	0.54000		

Culvert Calculator Report
Culvert for Basin 2

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00	ft	Headwater Depth/Height	1.83	
Computed Headwater Elevation	4.92	ft	Discharge	32.05	cfs
Inlet Control HW Elev.	4.05	ft	Tailwater Elevation	0.00	ft
Outlet Control HW Elev.	4.92	ft	Control Type	Outlet Control	

Grades

Upstream Invert	0.35	ft	Downstream Invert	0.00	ft
Length	70.00	ft	Constructed Slope	0.005000	ft/ft

Hydraulic Profile

Profile	CompositeM2PressureProfile		Depth, Downstream	1.93	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	1.93	ft
Velocity Downstream	7.89	ft/s	Critical Slope	0.023498	ft/ft

Section

Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.50	ft
Section Size	30 inch		Rise	2.50	ft
Number Sections	1				

Outlet Control Properties

Outlet Control HW Elev.	4.92	ft	Upstream Velocity Head	0.66	ft
Ke	0.90		Entrance Loss	0.60	ft

Inlet Control Properties

Inlet Control HW Elev.	4.05	ft	Flow Control	Submerged	
Inlet Type	Projecting		Area Full	4.9	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert for Basin 3

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00	ft	Headwater Depth/Height	1.80	
Computed Headwater Elevation	4.84	ft	Discharge	35.62	cfs
Inlet Control HW Elev.	4.60	ft	Tailwater Elevation	0.00	ft
Outlet Control HW Elev.	4.84	ft	Control Type	Outlet Control	

Grades

Upstream Invert	0.35	ft	Downstream Invert	0.00	ft
Length	40.00	ft	Constructed Slope	0.008750	ft/ft

Hydraulic Profile

Profile	CompositeM2PressureProfile		Depth, Downstream	2.03	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	2.03	ft
Velocity Downstream	8.36	ft/s	Critical Slope	0.026258	ft/ft

Section

Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.50	ft
Section Size	30 inch		Rise	2.50	ft
Number Sections	1				

Outlet Control Properties

Outlet Control HW Elev.	4.84	ft	Upstream Velocity Head	0.82	ft
Ke	0.90		Entrance Loss	0.74	ft

Inlet Control Properties

Inlet Control HW Elev.	4.60	ft	Flow Control	Submerged	
Inlet Type	Projecting		Area Full	4.9	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				