Prepared for

Lower Colorado River Authority (LCRA)
P.O. Box 220
Austin, Texas 78767

RUN-ON AND RUN-OFF CONTROL SYSTEM PLAN FOR COMBUSTION BYPRODUCT LANDFILL REGISTRATION NO. 31575

LCRA FAYETTE POWER PROJECT
FAYETTE COUNTY, TEXAS

Prepared by

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October 2016

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1. INTRODUCTION

1.1 Purpose

This document presents the Run-on and Run-off Control System Plan (Plan) for the Combustion Byproduct Landfill (CBL) at LCRA's Fayette Power Project (FPP). This Plan was prepared to comply with the United States Environmental Protection Agency's (USEPA's) requirements for run-on and run-off control systems plans (40 CFR §257.81(c)) for coal combustion residuals (CCR) landfills. The Plan was prepared by Geosyntec Consultants (Geosyntec) under the direction of Dr. Beth A. Gross, P.E., a qualified professional engineer.

1.2 Background

The FPP is a coal-fired power plant located east of La Grange in Fayette County, Texas. CCR generated at the facility are disposed in the CBL, a CCR landfill located south of the power plant and north of the railroad that borders the FPP site (Drawing 1). At final buildout, the CBL will consist of up to three cells, Cells 1 to 3 (Drawing 2). Depending on the rates of CCR production and beneficial use, all cells may not be needed for CCR disposal and the final CBL footprint would be smaller (e.g., Cells 1 and 2, Drawing 3).

Cell 1 was constructed in 1988 with a recompacted clay liner installed over natural clay subgrade. This liner is equivalent to the liner recommended at that time in Texas Water Commission (TWC) Guideline No. 3 for Class II industrial waste landfills: a 2-foot thick (minimum) recompacted clay-rich liner or 3 feet of in-place soil exhibiting a permeability less than 1×10^{-7} cm/s (TWC, 1988). The northern slope of Cell 1 was closed with a final cover system in 1992 (Drawing 2). From October 2014 to May 2015, Subcell 2D was constructed with a 3-foot thick compacted clay liner with a hydraulic conductivity less than 1×10^{-7} cm/s, which meets the recommendations of Texas Commission on Environmental Quality (TCEQ) Technical Guideline No. 3 (2015) for Class 2 monofills of consistent, well characterized waste. This subcell currently includes a contact water retention pond lined with a geomembrane/compacted clay composite liner (Drawing 2). Subcell 2D is being used as a waste storage/product preparation area during CCR operations in Cell 1 and future Subcells 2A, 2B and 2C. Cell 1 and Subcell 2D are existing CCR landfill areas under 40 CFR §257.53. The remainder of Cells 2 and 3 will be constructed with a liner system that meets the requirements of 40 CFR §257.70(b) and (d), which includes a leachate collection system and underlying geomembrane/compacted clay composite liner.

Runoff from active areas in Cell 1 of the CBL currently drains to the Runoff Retention Pond via the runoff channel (Drawing 2). Contact water from the Subcell 2D Contact Water Retention Pond can also drain to the Runoff Retention Pond by pumping it to the runoff channel. The Runoff Retention Pond is permitted under LCRA's Texas Pollutant Discharge Elimination System (TPDES) Permit No. WQ0002105000 and is designated as the CBL Pond in the permit. The permit allows water in the pond to be managed by conveying it to the FPP Reclaim Pond or, if effluent limitations are met, by discharging via Outfall 004. The Runoff Retention Pond will be used for management of contact water and leachate from the active area until the Leachate Evaporation Pond (Drawing 4) is constructed, which will occur prior to disposal of CCR in Subcell 2A (Drawing 4).

Stormwater run-off from the final cover system of the CBL flows in drainage channels along the perimeter of the CBL that primarily discharge south of the CBL but also discharge to a drainage ditch north of the CBL. When CCR disposal operations are initiated in Cell 2, the majority of stormwater run-off from the final cover system will flow into a stormwater pond prior to being discharged from the site (Drawing 4).

1.3 Organization of Plan

The remainder of this Plan is organized as follows:

- Section 2 summaries the regulatory requirements for the run-on and run-off controls systems and the Plan (40 CFR §257.81);
- Section 3 describes how the run-on control system for the CBL has been designed and constructed to prevent flow onto the active portion of the CBL;
- Section 4 describes how the run-off controls system for the CBL has been designed and constructed to collect and control flow from the active portion of the CBL;
- Section 5 presents a certification by a qualified professional engineer that this initial Run-on and Run-off Control System Plan meets the requirements of 40 CFR §257.81(a) and (b); and
- Section 6 provides a list of references cited in the Plan.

2. REGULATORY REQUIREMENTS

2.1 Run-on and Run-off Controls

In accordance with 40 CFR §257.81(a), the run-on and run-off control systems for the CBL must be designed, constructed, operated, and maintained to prevent flow onto the active portion of the CBL and collect and control flow from the active portion of the CBL during the peak discharge from a 24-hour, 25-year storm. TCEQ Technical Guideline No. 3 recommends that run-off control systems be designed for a 24-hour, 100-year storm, a storm that would result in greater peak discharge and require larger drainage features than a 24-hour, 25-year storm. As discussed in Section 4.3 and demonstrated in the calculations presented in Appendix A, the run-on and run-off features for the CBL were designed to convey a 24-hour, 100-year storm. Therefore, the design of these features meets and exceeds the design requirements of 40 CFR §257.81(a) and is consistent with the recommendations of TCEQ Technical Guideline No. 3.

As described in the rule preamble, the purpose of the run-on controls is to prevent erosion, prevent the surface discharge of CCR in solution or suspension, and minimize the percolation of run-on through wastes. The purpose of the run-off controls is to collect and control the water volume falling on the active portion. Run-off from the active portion must be handled in manner that complies with the National Pollutant Discharge Elimination System (40 CFR §257.81(b)). Although the term “active portion” has often been used to refer to a portion of a landfill that is actively receiving waste, under USEPA’s CCR regulations “active portion” is that part of a CCR unit that has received or is receiving waste and has not completed closure (40 CFR §257.53). Thus, the active portion includes areas where waste is being disposed and inactive areas, including areas overlain with intermediate cover.

2.2 Preparation of Plan

In accordance with 40 CFR §257.81(c), a Run-on and Run-off Control System Plan that documents how the run-on and run-off control systems have been designed and constructed to meet the requirements of 40 CFR §257.81(a) and (b) must be prepared and placed in the facility’s Operating Record. The Plan must be supported by engineering calculations, and a certification from a qualified professional engineer must be obtained to document that the Plan meets the requirements of 40 CFR §257.81(a) and (b).

As described in the rule preamble, submittal of the Plan documents that run-on and run-off control systems have been design and operated to meet 40 CFR §257.81(a) and (b), and the requirement of 40 CFR §257.81(c)(4) that the Plan be revised every five years is consist with the requirement that run-on and run-off control systems also be operated and maintained to meet 40 CFR §257.81(a) and (b).

2.3 Amendment of Plan

In accordance with 40 CFR §257.81(c)(2), this Plan may be amended at any time provided the revised Plan is placed in the facility's Operating Record. This Plan must be revised whenever there is a change in conditions that would substantially affect the Plan in effect. Any amendment of the Plan requires a certification by a qualified professional engineer that the revised Plan meets the requirements of 40 CFR §257.81(a) and (b).

3. RUN-ON CONTROL SYSTEM

3.1 Overview

This section describes the run-on control system for the CBL as it currently exists and at final grades. In general, run-on to active areas of the CBL is controlled by topography and by the landfill perimeter berm. The north side of the CBL is on a topographic high, and the ground surface around the CBL primarily slopes to the south, and south of the CBL also towards two central stormwater channels (Drawing 2). In addition, the perimeter berm for the CBL deflects stormwater run-on, and this potential run-on is collected in a stormwater channel at the toe of the outboard side slope of the berm (Drawings 2 and 6).

3.2 Initial Run-On Control System Plan

Cell 1 is the current active cell for the CBL, and the northern portion of this cell has been covered with final cover. The final cover slopes towards the perimeter; thus, based on topography, stormwater from the final cover of the CBL will not run-on to active areas of Cell 1 (Drawing 2). Futhermore, potential run-on from outside of Cell 1 will not overtop the existing perimeter berm and enter into Cell 1 along the east and west sides of the cell or overtop the interim berm on the south side of Cell 1. Subcell 2D is also protected from run-on by topography and a perimeter berm (Drawing 2).

As new subcells are developed, run-on will continue to be controlled by perimeter and interim berms and adjacent stormwater channels located at the outboard toe of the berms. Stormwater collected in these channels will be conveyed to the two central stormwater channels located south of the CBL or to a stormwater pond (Drawing 4). In addition, run-on from inactive waste slopes that have received soil intermediate cover will be directed from subcells actively receiving CCR by temporary tack-on berms (Drawing 5).

3.3 Final Run-On Control System Plan

At final conditions, the CBL will be closed with final cover and will no longer be active. Run-on to the closed CBL will continue to be controlled by topography and the landfill perimeter berm and adjacent stormwater channel.

3.4 Compliance Assessment

Based on review of the topography of the ground surface around the CBL perimeter and the engineering controls designed for the CBL (e.g., perimeter berm and stormwater channel, temporary tack-on berms), the CBL will continue to be designed, constructed, operated, and maintained to prevent flow onto the active portion of the CBL. Therefore the CBL is in compliance with the run-on control requirement of 40 CFR §257.81(a).

4. RUN-OFF CONTROL SYSTEM

4.1 Overview

This section describes the run-off control system for the CBL as it currently exists and at final grades. In general, run-off from the CBL is controlled by topography, the landfill perimeter berm and stormwater channel, and the stormwater management system components that will be constructed on the CBL as it is developed (Drawings 2, 5, and 6).

4.2 Initial Run-Off Control System Plan

Run-off from areas of Cell 1 that have not been covered with intermediate cover or final cover will have potentially come in contact with CCR and will therefore be managed as contact water. Contact water collected in the cell is conveyed in the runoff channel to the Runoff Retention Pond (Drawing 2), as authorized under an individual TPDES permit (WQ0002105000). The perimeter and interim berms of Cell 1, as well as the underlying recompacted clay liner, keep runoff that has contacted CCR within the cell. In addition, CCR is placed in Cell 1 in a manner that directs this runoff to the runoff channel. As Cell 1 is filled, the side slopes of the cell will be covered with intermediate or final cover (Drawing 5). Until a soil cover is placed, run-off from the CCR slopes will be collected and directed to the runoff channel. Run-off from areas of the CBL with intermediate or final cover has not contacted CCR and can be directed into a stormwater channel and conveyed away from the CBL rather than being conveyed to the Runoff Retention Pond.

As new subcells are developed, run-off of contact water will continue to be controlled by perimeter and interim berms and the internal topography of the CBL, and the existing Runoff Retention Pond will be converted into a Leachate Evaporation Pond (Drawing 4). Areas will be covered with final cover and the permanent stormwater management system as they reach final grade (Drawing 5).

4.3 Final Run-Off Control System Plan

After the final cover has been constructed on the CBL, storm water runoff from the surface of the landfill will be conveyed off the landfill through a series of components, including drainage benches orientated approximately parallel to the final cover system side slopes and drainage downchutes that intersect the drainage benches and are designed to convey runoff to a perimeter drainage channel and then to one or two Stormwater Ponds (Drawings 4 and 6). As previously discussed in Section 2.1, the stormwater management system components are designed to route stormwater run-off resulting from the 100-year, 24-hour design storm event as recommended by TCEQ Technical Guideline No. 3 (2015). The design of the stormwater management system components and associated calculations are presented in Appendix A, and details of these components are shown on Drawings 7 and 8.

The stormwater management features are also designed to control runoff velocities and limit soil loss to permissible values. The soil loss on the final cover system top deck and side slope is calculated in Appendix B using the Revised Universal Soil Loss Equation (RUSLE) and compared to a permissible maximum soil loss of 3 tons/acre/year (0.015 inches/year). Based on this calculation, the maximum spacing between drainage benches was limited to 170 feet. To control erosion in the drainage downchutes, the downchutes will be lined with articulated concrete block (ACB) or an alternative lining material that provides sufficient erosion resistance.

4.4 Compliance Assessment

Based on review of the topography of the ground surface around the CBL perimeter, the engineering controls designed for the CBL (e.g., perimeter berm and stormwater channel, temporary tack-on berms), the operational procedures for the CBL, and the fact that the CBL is operated under a TPDES permit, the CBL will continue to be designed, constructed, operated, and maintained to collect and control flow from the active portion of the CBL and handle run-off in a manner that complies with the National Pollutant Discharge Elimination System. Therefore the CBL is in compliance with the run-off control requirement of 40 CFR §257.81(a) and the run-off management requirement of 40 CFR §257.81(b).

5. PROFESSIONAL ENGINEER CERTIFICATION

Based on the demonstrations and evaluations presented in this Run-on and Run-off Control System Plan for the Combustion Byproduct Landfill at LCRA's Fayette Power Project, it is my professional opinion that the Plan meets the requirements of 40 CFR §257.81(a) and (b).

GEOSYNTEC CONSULTANTS
F- 1182

Beth Ann Gross

Beth Ann Gross, Ph.D., P.E., D.GE

10/13/2016

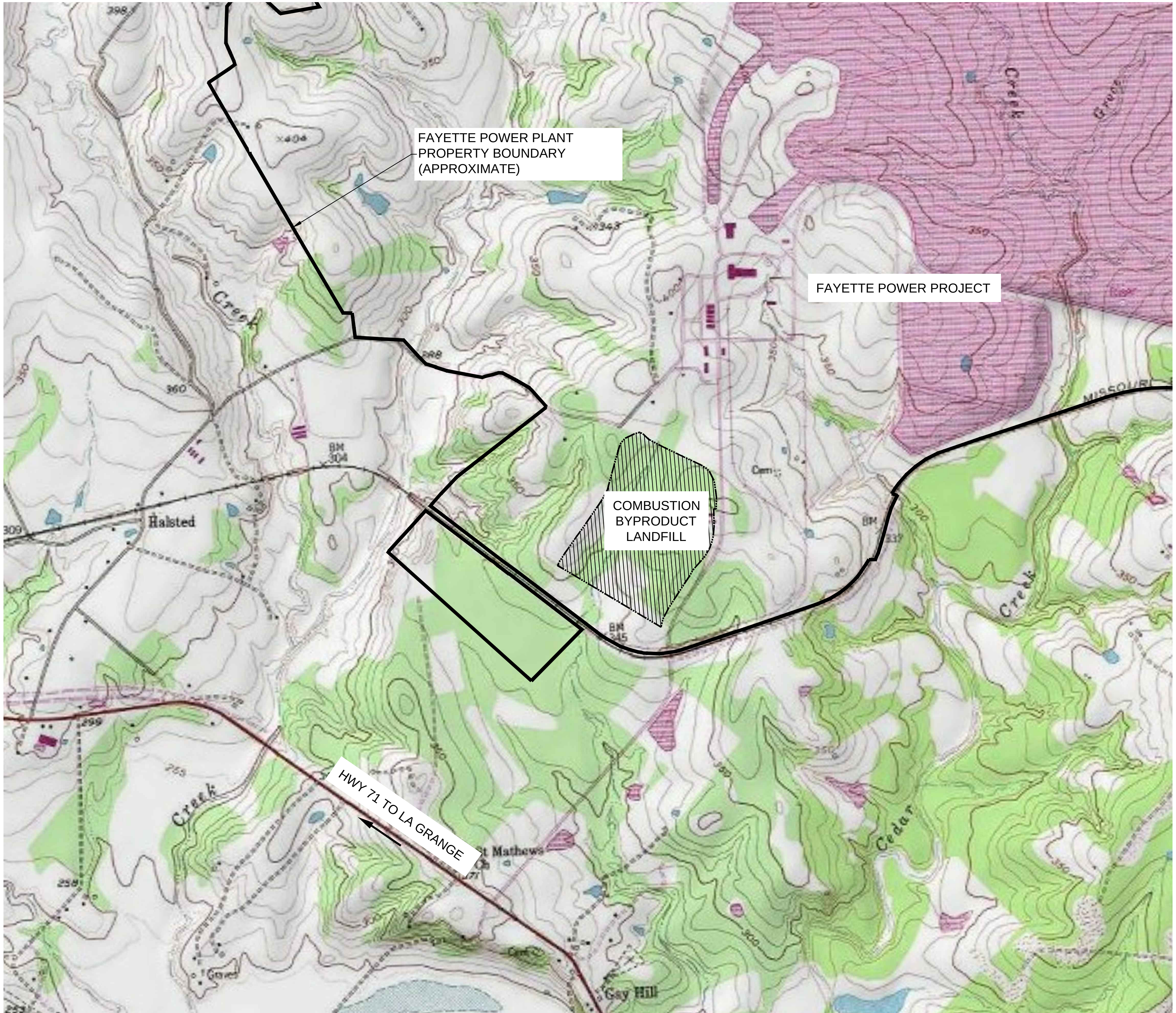
Date

6. REFERENCES

Texas Commission on Environmental Quality (2015). "Nonhazardous Industrial Solid Waste Landfills," Industrial Solid Waste Management, Draft Technical Guideline No. 3.

Texas Water Commission (1988). Letter from Minor Brooks Hibbs, Permits Section Chief, Hazardous and Solid Waste Division of TWC to Tom Remaley, Director of Environmental Quality, LCRA, indicating that the design of Cell 1 substantially conforms to the TWC Industrial Solid Waste Technical Guidelines, Jan 18.

DRAWINGS



NOTE:

BASE MAP SOURCE: UNITED STATES GEOLOGIC SURVEY (USGS), 7.5 MINUTE SERIES QUADRANGLE (TOPOGRAPHIC) MAP OF LA GRANGE EAST, TEXAS 1957, REVISED 1981 AND FAYETTEVILLE, TEXAS 1958, REVISED 1981

0 800 1600
SCALE IN FEET

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TITLE:
OVERALL SITE PLAN

PROJECT:
RUN-ON AND RUN-OFF CONTROL SYSTEM PLAN

SITE:
FAYETTE POWER PROJECT
COMBUSTION BYPRODUCT LANDFILL

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Beth Gross
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10/13/2016
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STATE OF TEXAS
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REVIEWED BY:	BG	DRAWING NO.:	1 OF 8
APPROVED BY:	BG		

LEGEND

350	EXISTING GROUND ELEVATION (FT,MSL) (NOTES 1,2)
350	EXISTING TOP OF CLAY LINER ELEVATION (FT,MSL) (NOTE 2)
	EXISTING ROAD
	EXISTING BUILDING
	EXISTING RAILROAD
	EXISTING VEGETATION / TREE
N 9949000 E 3428000	COORDINATE GRID (NOTE 2)
	EXISTING FENCE
	EXISTING LIMIT OF LANDFILL
	EXISTING LIMIT OF FINAL COVER
P P	EXISTING POWER POLE AND OVERHEAD POWER LINE
	EXISTING COMBUSTION WASTE FORCE MAIN
	PROPOSED PHASE BOUNDARY
	PROPOSED LIMIT OF WASTE

NOTES:

1. THE EXISTING CONTOUR BASE MAP SHOWN ON THIS DRAWING WAS COMPILED USING AN AERIAL SURVEY BASED ON PHOTOGRAPHY PERFORMED ON 23 OCTOBER 2013 BY SURDEX CORPORATION AND LIDAR DATA PUBLISHED DECEMBER 2008 AND PROVIDED BY LCRA SURVEYING, MAPPING, AND GIS.
2. ELEVATIONS ARE IN FEET (FT) AS DEFINED BY THE NORTH AMERICAN VERTICAL DATUM (NAVD) OF 1988. STATE PLANE COORDINATE GRID CORRESPONDS TO TEXAS STATE PLANE COORDINATE SYSTEM, TEXAS CENTRAL ZONE (4203), NORTH AMERICAN DATUM 83 (NAD-83) 1983.
3. EXISTING COMBUSTION WASTE FORCE MAIN CONVEYS WATER FROM EXISTING RUNOFF RETENTION POND TO RECLAIM POND.

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TITLE: EXISTING SITE CONDITIONS

PROJECT: RUN-ON AND RUN-OFF CONTROL SYSTEM PLAN

SITE: FAYETTE POWER PROJECT
COMBUSTION BYPRODUCT LANDFILL

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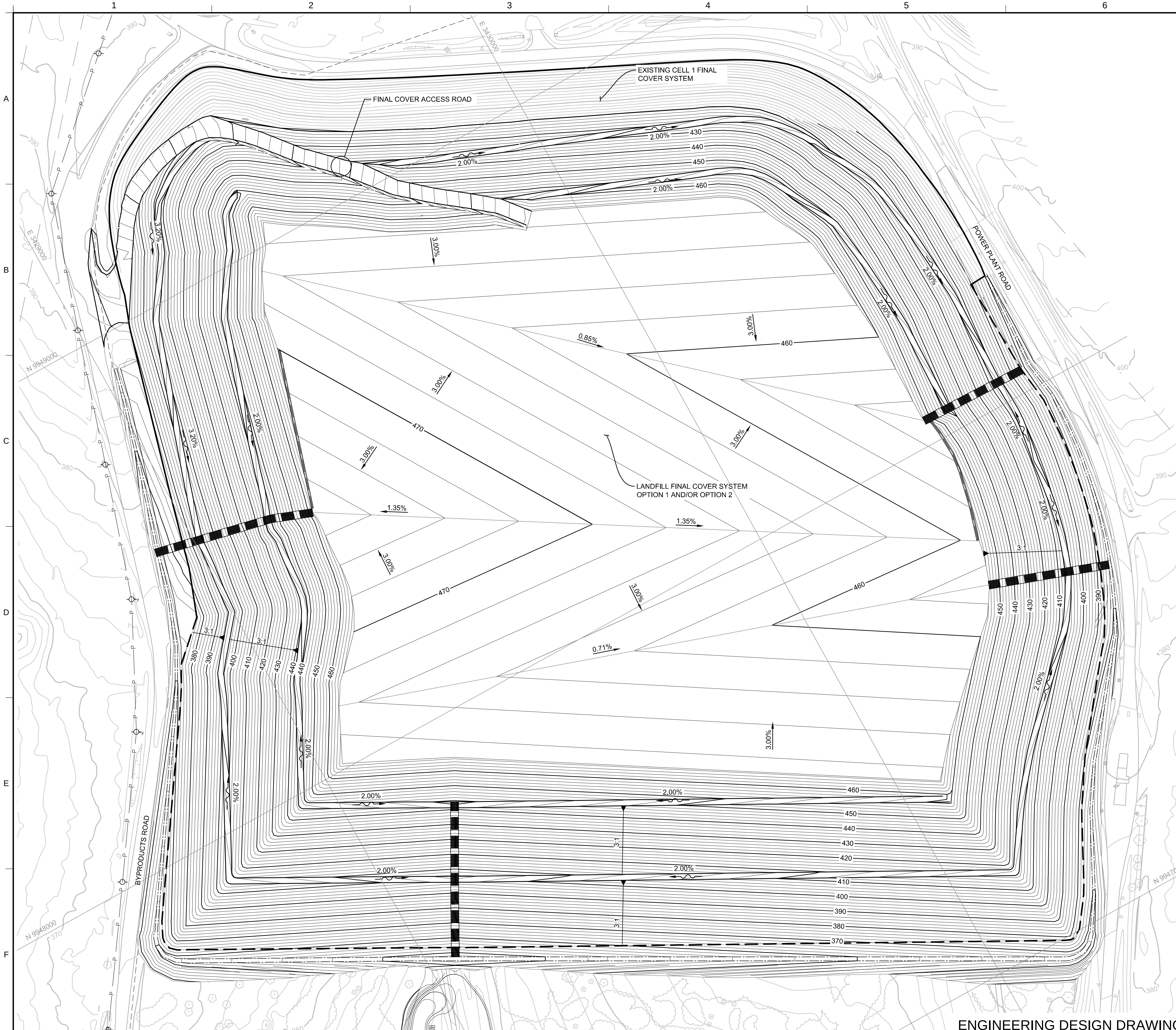

LEGEND

350	EXISTING GROUND ELEVATION (FT,MSL) (NOTES 1,2)
	EXISTING ROAD
	EXISTING VEGETATION / TREE
N 9949000 E 3428000	COORDINATE GRID (NOTE 2)
	EXISTING FENCE
	EXISTING UNDERGROUND RUNOFF DISCHARGE PIPE
	EXISTING LIMIT OF LANDFILL
	PROPOSED LIMIT OF LANDFILL
420	PROPOSED TOP OF FINAL COVER ELEVATION (FT,MSL)
	PROPOSED DRAINAGE DOWNCHUTE
	PROPOSED DRAINAGE TERRACE
	PROPOSED DRAINAGE BENCH
	PROPOSED PERIMETER DRAINAGE CHANNEL

NOTES:

1. THE EXISTING CONTOUR BASE MAP SHOWN ON THIS DRAWING WAS COMPILED USING AN AERIAL SURVEY BASED ON PHOTOGRAPHY PERFORMED ON 23 OCTOBER 2013 BY SURDEX CORPORATION AND LIDAR DATA PUBLISHED DECEMBER 2008 AND PROVIDED BY LCRA SURVEYING, MAPPING, AND GIS.
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TITLE: FINAL COVER GRADING PLAN

PROJECT: RUN-ON AND RUN-OFF CONTROL SYSTEM PLAN

SITE: FAYETTE POWER PROJECT
COMBUSTION BYPRODUCT LANDFILL

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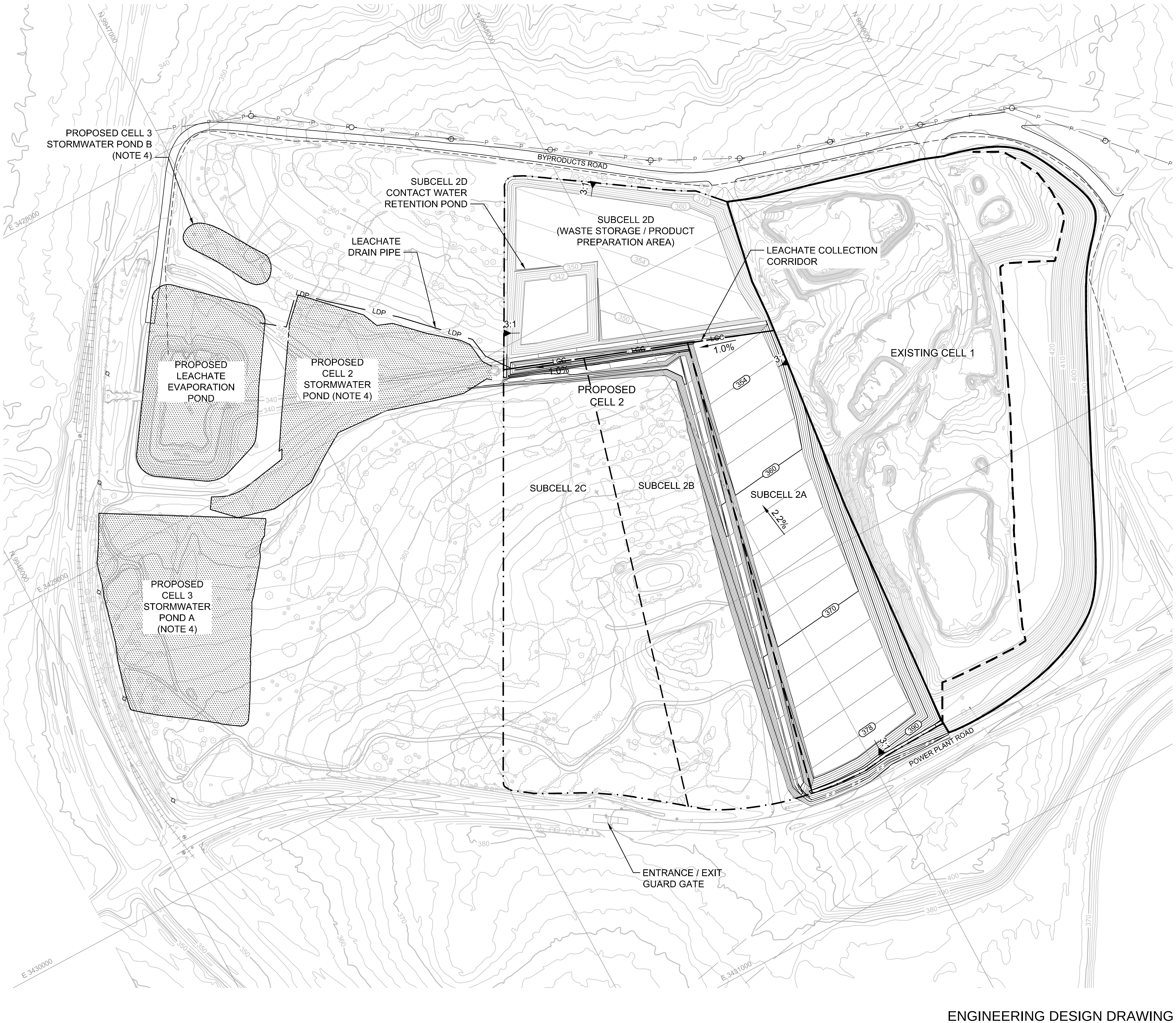

LEGEND

350	EXISTING GROUND ELEVATION (FT,MSL) (NOTES 1,2)
350	EXISTING TOP OF LINER ELEVATION (FT,MSL))
	EXISTING ROAD
	EXISTING RAILROAD
	EXISTING COMBUSTION WASTE FORCE MAIN
P P	EXISTING POWER POLE AND OVERHEAD POWER LINE
	EXISTING VEGETATION / TREE
N 9949000 E 3428000	COORDINATE GRID (NOTE 2)
	EXISTING LIMIT OF LANDFILL
	EXISTING LIMIT OF FINAL COVER
	PROPOSED LIMIT OF WASTE
	PROPOSED PHASE BOUNDARY
330	PROPOSED TOP OF LINER ELEVATION (FEET) (NOTE 3)
LCC	PROPOSED LEACHATE COLLECTION CORRIDOR
LDP	PROPOSED LEACHATE DRAIN PIPE

NOTES:

1. THE EXISTING CONTOUR BASE MAP SHOWN ON THIS DRAWING WAS COMPILED USING AN AERIAL SURVEY BASED ON PHOTOGRAPHY PERFORMED ON 23 OCTOBER 2013 BY SURDEX CORPORATION AND LIDAR DATA PUBLISHED DECEMBER 2008 AND PROVIDED BY LCRA SURVEYING, MAPPING, AND GIS.
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3. LANDFILL BASE GRADES MAY BE ADJUSTED BASED ON SUBSURFACE CONDITIONS.
4. STORMWATER PONDS TO BE CONSTRUCTED IN SEQUENCE WITH LANDFILL OPERATIONS. CELL 2 STORMWATER POND TO BE DECOMMISSIONED PRIOR TO CELL 3 LANDFILL CONSTRUCTION. CELL 3 STORMWATER POND MAY BE CONSTRUCTED IN LIEU OF CELL 2 STORMWATER POND.

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SCALE IN FEET

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TITLE: SUBCELLS 2A & 2D BASE GRADING PLAN

PROJECT: RUN-ON AND RUN-OFF CONTROL SYSTEM PLAN

SITE: FAYETTE POWER PROJECT
COMBUSTION BYPRODUCT LANDFILL

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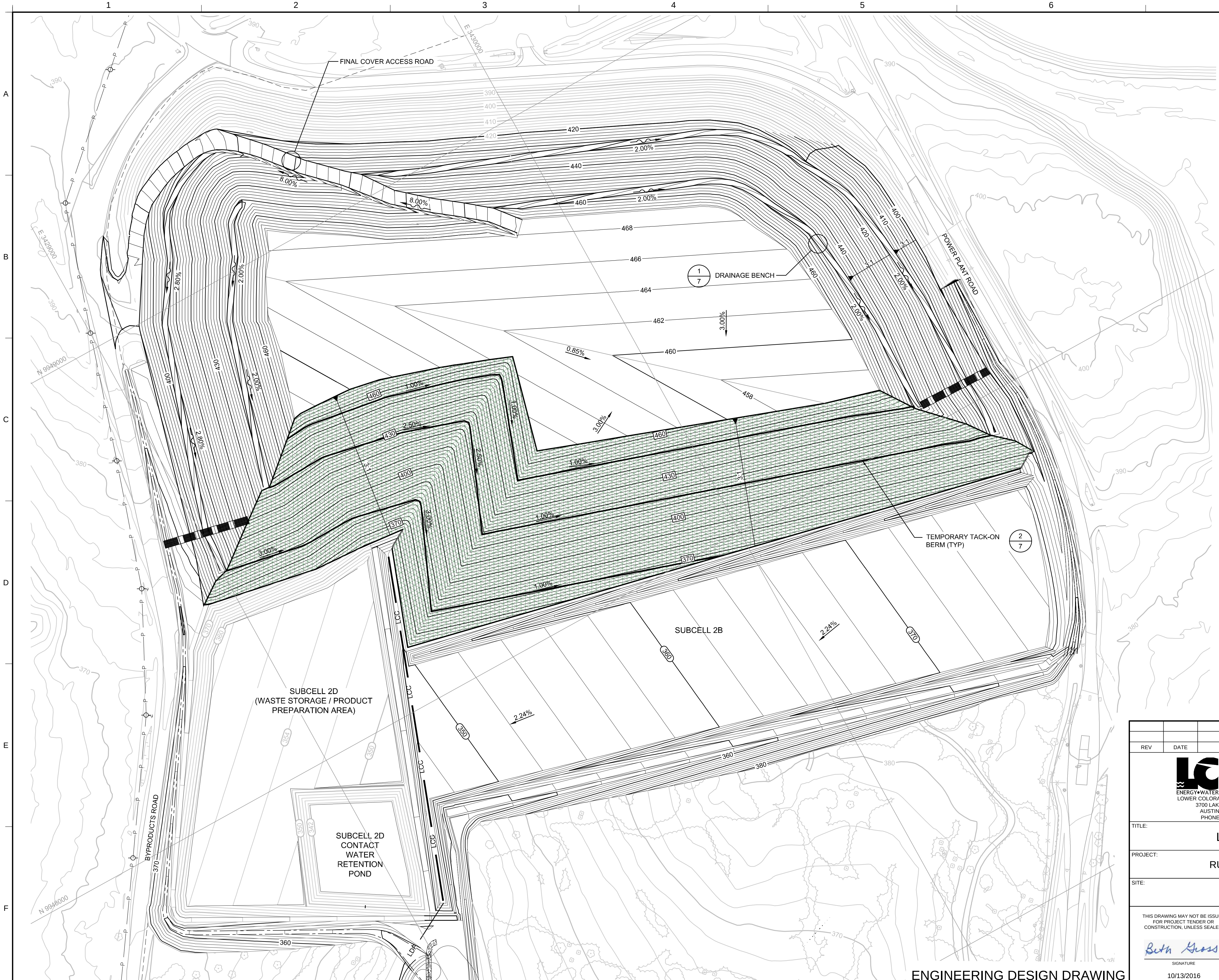

LEGEND

- 350 — EXISTING GROUND ELEVATION (FT,MSL) (NOTES 1,2)
- 350 — EXISTING TOP OF LINER ELEVATION (FT,MSL))
- EXISTING ROAD
- EXISTING VEGETATION / TREE
- N 9949000 / E 3428000 — COORDINATE GRID
- 330 — PROPOSED FINISHED GROUND ELEVATION (FT, MSL)
- 350 — PROPOSED TOP OF CLAY ELEVATION (FT, MSL)
- 460 — PROPOSED INTERIM WASTE ELEVATION (FT, MSL)
- LCC — LEACHATE COLLECTION CORRIDOR
- LDP — LEACHATE COLLECTION DRAIN PIPE
- PROPOSED DOWNCHUTE
- PROPOSED DRAINAGE BENCH
- PROPOSED TEMPORARY TACK-ON BERM
- PROPOSED DRAINAGE TERRACE
- AREA WITH INTERMEDIATE COVER

NOTES:

1. THE EXISTING CONTOUR BASE MAP SHOWN ON THIS DRAWING WAS COMPILED USING AN AERIAL SURVEY BASED ON PHOTOGRAPHY PERFORMED ON 23 OCTOBER 2013 BY SURDEX CORPORATION AND LIDAR DATA PUBLISHED DECEMBER 2008 AND PROVIDED BY LCRA SURVEYING, MAPPING, AND GIS.
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TITLE:
LANDFILL FILLING PLAN - SUBCELL 2A

PROJECT:
RUN-ON AND RUN-OFF CONTROL SYSTEM PLAN

SITE:
FAYETTE POWER PROJECT
COMBUSTION BYPRODUCT LANDFILL

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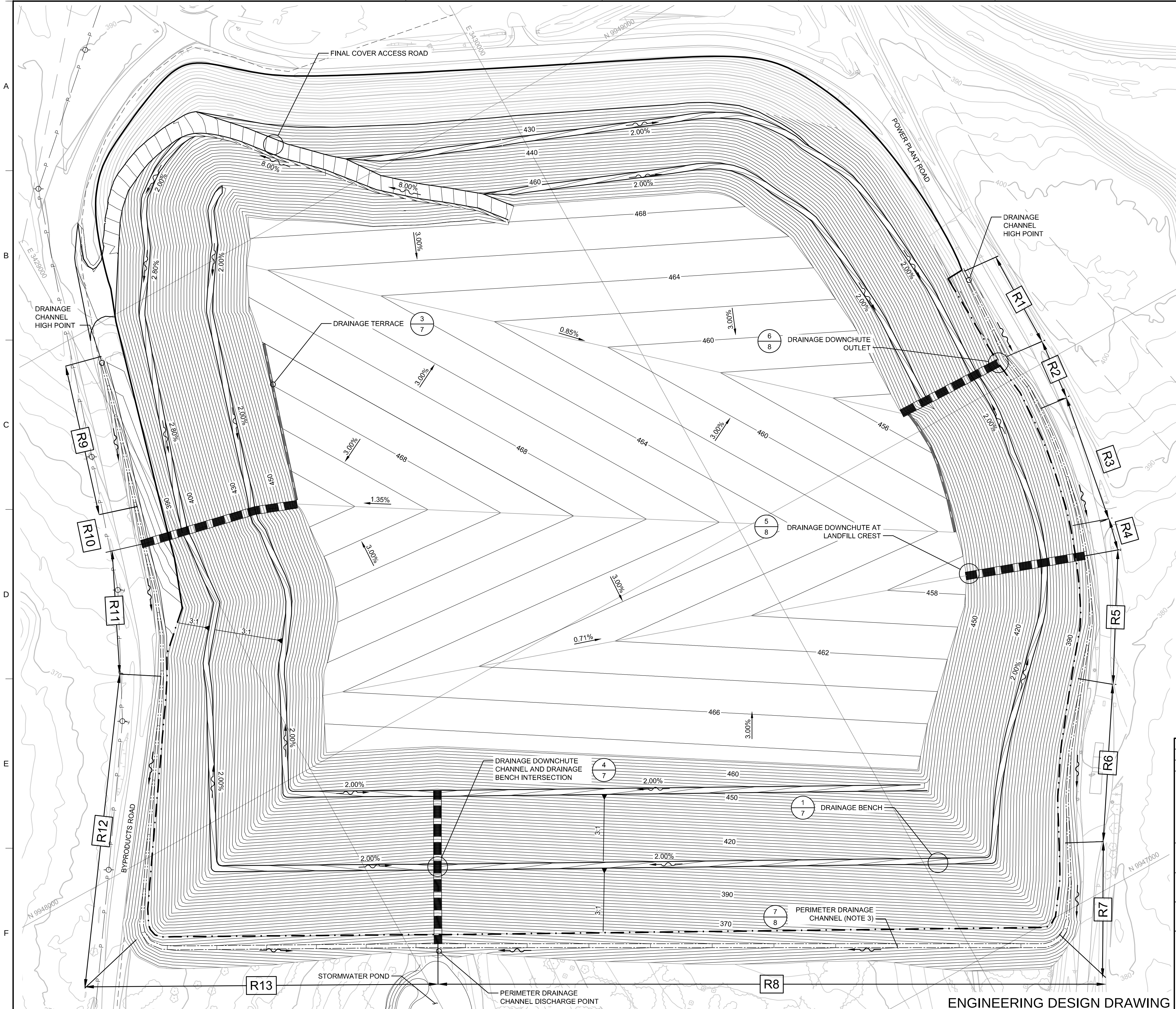
Beth Gross
SIGNATURE
10/13/2016
DATE

STATE OF TEXAS
BETH ANN GROSS
79864
LICENSED
PROFESSIONAL ENGINEER

DESIGN BY:	BG	DATE:	OCTOBER 2016
DRAWN BY:	JJV	PROJECT NO.:	TXL0225.04
CHECKED BY:	BG	FILE:	TXL0225CCRR5
REVIEWED BY:	BG	DRAWING NO.:	
APPROVED BY:	BG	5 OF 8	

ENGINEERING DESIGN DRAWING



LEGEND

350	EXISTING GROUND ELEVATION (FT,MSL) (NOTES 1,2)
	EXISTING ROAD
	EXISTING VEGETATION / TREE
N 9949000 E 3428000	COORDINATE GRID
	EXISTING FENCE
	EXISTING LIMIT OF LANDFILL
	PROPOSED LIMIT OF LANDFILL
400	PROPOSED TOP OF FINAL COVER ELEVATION (FT,MSL)
	PROPOSED DOWNCHUTE
	PROPOSED DRAINAGE TERRACE
	PROPOSED DRAINAGE BENCH
	PROPOSED PERIMETER DRAINAGE CHANNEL
R2	PERIMETER DRAINAGE CHANNEL REACH (NOTE 3)
	DRAINAGE FLOW ARROW

NOTES:

1. THE EXISTING CONTOUR BASE MAP SHOWN ON THIS DRAWING WAS COMPILED USING AN AERIAL SURVEY BASED ON PHOTOGRAPHY PERFORMED ON 23 OCTOBER 2013 BY SURDEX CORPORATION AND LIDAR DATA PUBLISHED DECEMBER 2008 AND PROVIDED BY LCRA SURVEYING, MAPPING, AND GIS.
2. ELEVATIONS ARE IN FEET (FT) AS DEFINED BY THE NORTH AMERICAN VERTICAL DATUM (NAVD) OF 1988. STATE PLANE COORDINATE GRID CORRESPONDS TO TEXAS STATE PLANE COORDINATE SYSTEM, TEXAS CENTRAL ZONE (4203), NORTH AMERICAN DATUM 83 (NAD-83) 1983.
3. SEE DRAWING 8 FOR TABLE OF PERIMETER DRAINAGE CHANNEL DESIGNATIONS (REACHES) AND DIMENSIONS (WIDTH, DEPTH).

ENGINEERING DESIGN DRAWING

REV	DATE	DESCRIPTION	DRN	APP

LCRA
ENERGY • WATER • COMMUNITY SERVICES
LOWER COLORADO RIVER AUTHORITY
3700 LAKE AUSTIN BLVD.
AUSTIN, TEXAS 78703
PHONE: 512.473.3200

Geosyntec consultants
GEOSYNTEC CONSULTANTS, INC.
TEXAS ENG. FIRM REGISTRATION NUMBER 1182
8217 SHOAL CREEK BLVD, SUITE 200
AUSTIN, TEXAS 78757
PHONE: 512.451.4003

TITLE: STORMWATER MANAGEMENT PLAN

PROJECT: RUN-ON AND RUN-OFF CONTROL SYSTEM PLAN

SITE: FAYETTE POWER PROJECT
COMBUSTION BYPRODUCT LANDFILL

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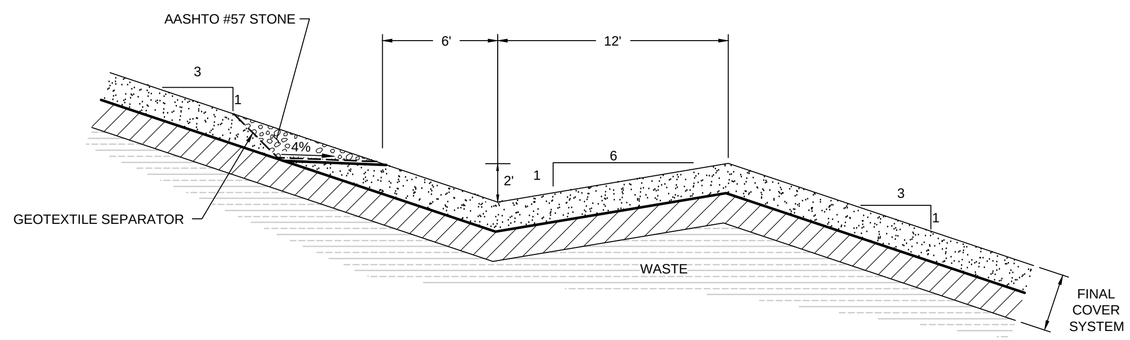
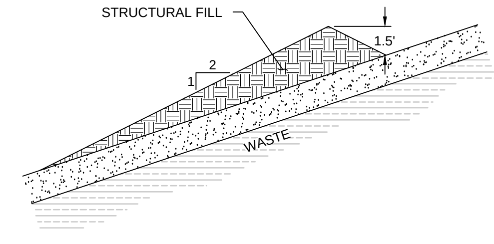
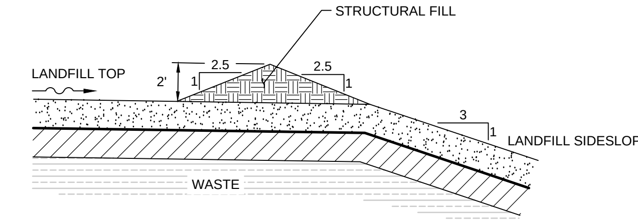
DESIGN BY:	BG	DATE:	OCTOBER 2016
DRAWN BY:		PROJECT NO.:	TXL0225.04
CHECKED BY:	BG	FILE:	TXL0225CCRR6
REVIEWED BY:	BG	DRAWING NO.:	6 OF 8
APPROVED BY:	BG		



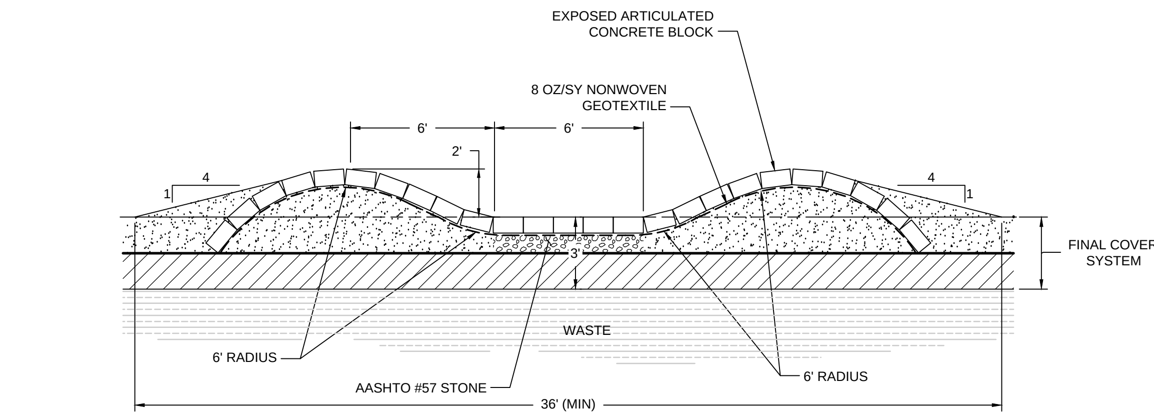
1/5 DETAIL
DRAINAGE BENCH
SCALE: 1" = 5'
0 5' 10'
SCALE IN FEET



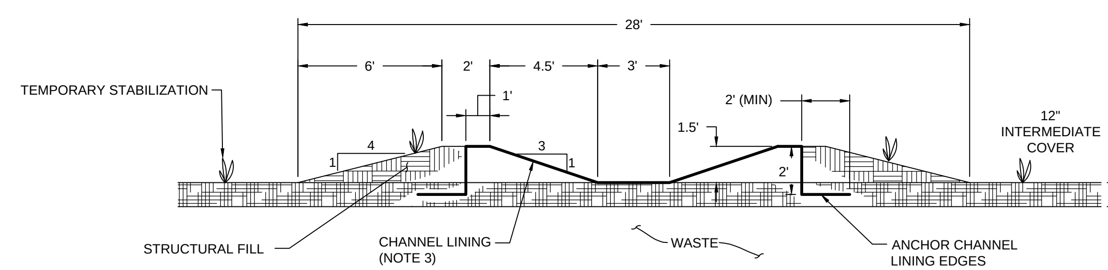
2/5 DETAIL
TEMPORARY TACK-ON BERM
SCALE: 1" = 5'
0 5' 10'
SCALE IN FEET



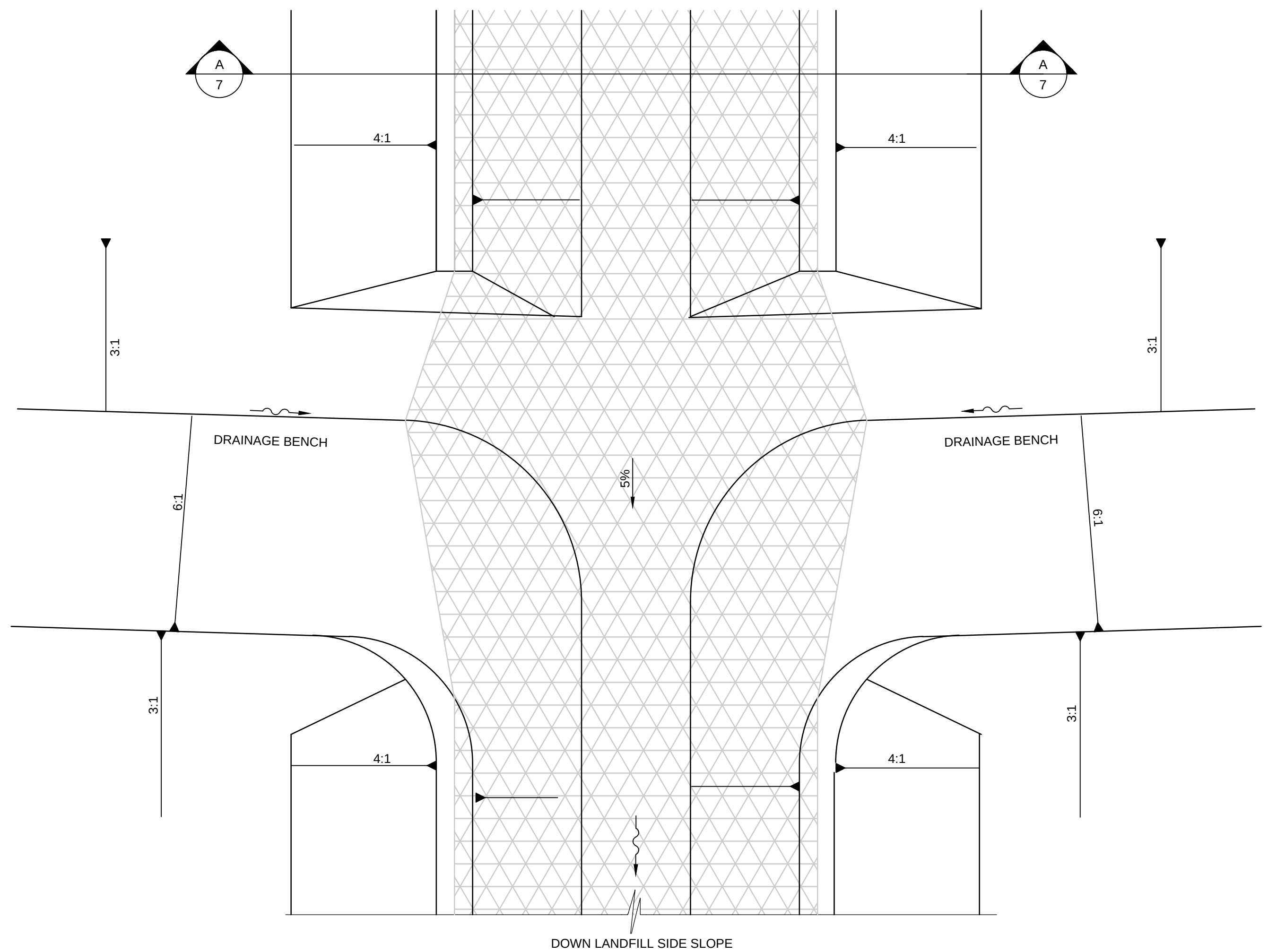
3/6 DETAIL
DRAINAGE TERRACE
SCALE: 1" = 5'
0 5' 10'
SCALE IN FEET



A/7 SECTION
DRAINAGE DOWNCHUTE CHANNEL
SCALE: 1" = 4'
0 4' 8'
SCALE IN FEET



A/7 DETAIL
TEMPORARY DRAINAGE DOWNCHUTE CHANNEL
SCALE: 1" = 4'
0 4' 8'
SCALE IN FEET



4/6 DETAIL
DRAINAGE DOWNCHUTE CHANNEL AND DRAINAGE BENCH INTERSECTION
SCALE: 1" = 5'
0 5' 10'
SCALE IN FEET

NOTES:

1. DETAILS ARE DRAWN TO SCALE AS NOTED EXCEPT FOR GEOSYNTHETICS WHICH MAY BE SHOWN AT AN EXAGGERATED SCALE FOR CLARITY.
2. DETAILS SHOW FINAL COVER SYSTEM OPTION WITH COMPOSITE CAP.
3. TEMPORARY DRAINAGE DOWNCHUTE CHANNEL TO BE LINED WITH PLASTIC SHEETING, TURF REINFORCEMENT MAT, OR OTHER ALTERNATIVE LINING MATERIAL WITH PERMISSIBLE VELOCITY OF 25.1 FPS AND PERMISSIBLE TRACTIVE STRESS OF 6.1 PSF.

ENGINEERING DESIGN DRAWING

REV	DATE	DESCRIPTION	DRN	APP

LCRA ENERGY•WATER•COMMUNITY SERVICES
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8217 SHOAL CREEK BLVD, SUITE 200
AUSTIN, TEXAS 78757
PHONE: 512.451.4003

TITLE: STORMWATER MANAGEMENT DETAILS I

PROJECT: RUN-ON AND RUN-OFF CONTROL SYSTEM PLAN

SITE: FAYETTE POWER PROJECT
COMBUSTION BYPRODUCT LANDFILL

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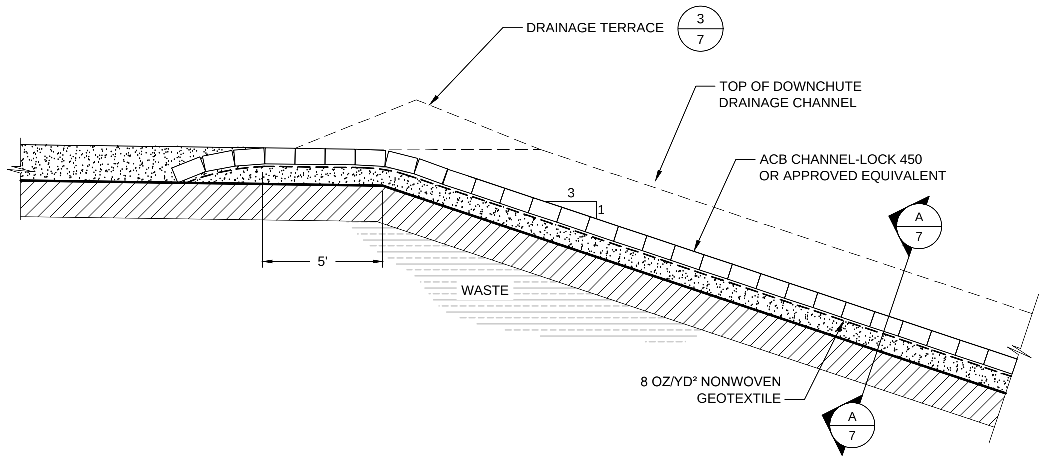
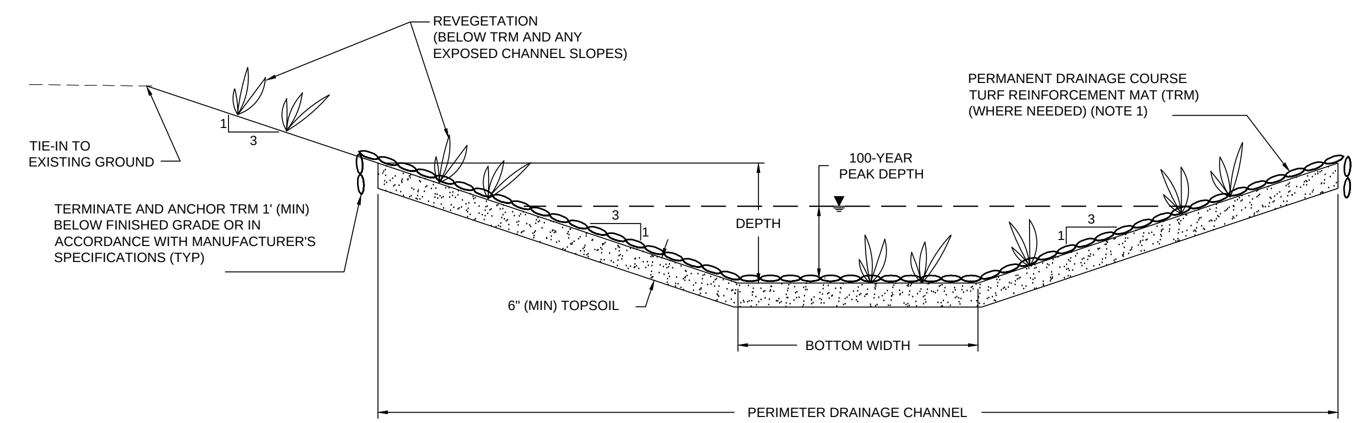
STATE OF TEXAS
BETH ANN GROSS
79864
LICENSED
PROFESSIONAL ENGINEER

DESIGN BY:	BG	DATE:	OCTOBER 2016
DRAWN BY:	JJV	PROJECT NO.:	TXL0225.04
CHECKED BY:	BG	FILE:	TXL0225CCRR7
REVIEWED BY:	BG	DRAWING NO.:	
APPROVED BY:	BG		7 OF 8

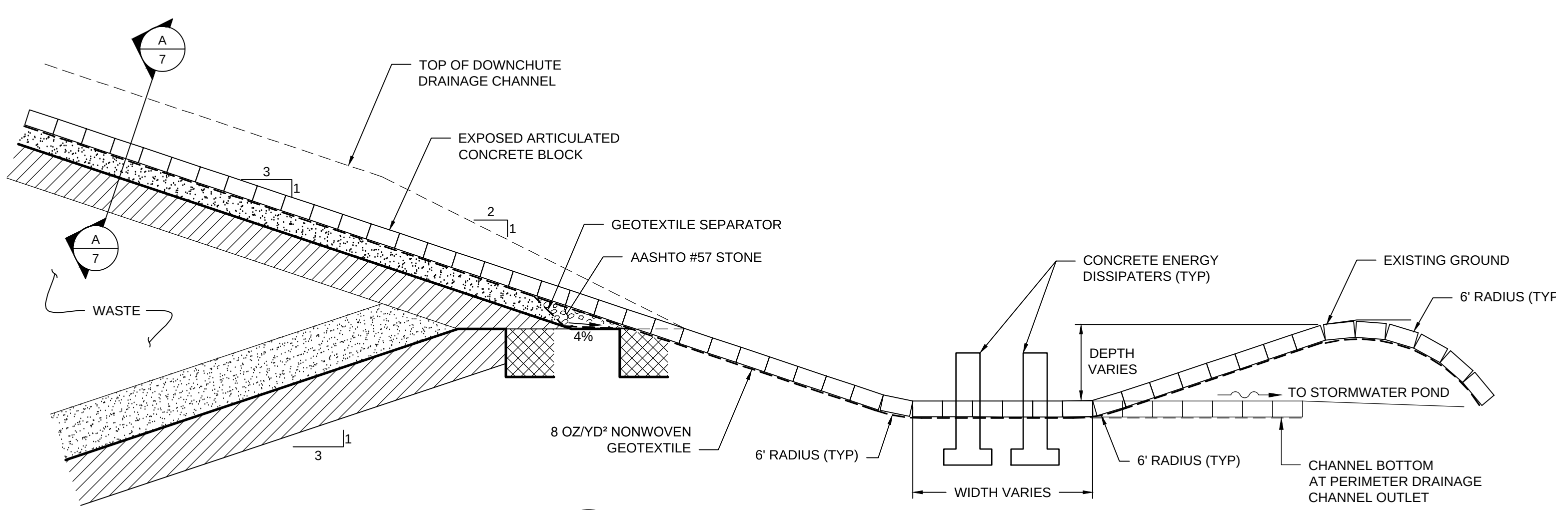
PERIMETER CHANNEL SEGMENT	Channel Slope (ft/ft)	CHANNEL DIMENSIONS (MINIMUM)					25-YEAR				100-YEAR				Channel Lining
		Length (ft)	Bottom Width (ft)	Depth (ft)	Side Slopes (H:V)	Top Width (ft)	Peak Flow (cfs)	Peak Depth (ft)	Peak Velocity (ft/s)	Tractive Stress (psf)	Peak Flow (cfs)	Peak Depth (ft)	Peak Velocity (ft/s)	Tractive Stress (psf)	
Reach 1	0.015	196	5.0	3.0	3:1	23	1.87	0.20	1.72	0.16	2.80	0.25	1.98	0.20	Grass
Reach 2	0.015	127	5.0	3.0	3:1	23	79.13	1.52	5.47	0.92	115.98	1.83	6.05	1.07	Grass
Reach 3	0.009	249	5.0	3.0	3:1	23	81.97	1.76	4.54	0.61	120.22	2.11	5.03	0.71	Grass
Reach 4	0.020	66	5.0	3.0	3:1	23	82.67	1.37	6.63	1.15	121.26	1.66	7.35	1.34	TRM
Reach 5	0.021	252	5.0	3.0	3:1	23	140.62	1.76	7.78	1.48	206.21	2.11	8.61	1.72	TRM
Reach 6	0.016	335	5.0	3.0	3:1	23	146.77	1.92	7.11	1.20	215.41	2.30	7.87	1.40	TRM
Reach 7	0.017	218	5.0	3.0	3:1	23	149.61	1.92	7.23	1.24	219.65	2.31	8.00	1.44	TRM
Reach 8	0.016	1250	8.0	3.0	3:1	26	178.98	1.82	7.29	1.25	263.57	2.22	8.12	1.46	TRM
Reach 9	0.033	301	5.0	2.5	3:1	20	9.31	0.39	3.85	0.66	13.92	0.49	4.38	0.80	Grass
Reach 10	0.017	77	5.0	2.5	3:1	20	10.17	0.50	3.16	0.42	15.21	0.62	3.57	0.50	Grass
Reach 11	0.017	273	5.0	2.5	3:1	20	74.30	1.42	5.63	0.99	110.98	1.73	6.27	1.16	Grass
Reach 12	0.018	496	5.0	2.5	3:1	20	82.81	1.41	6.37	1.05	123.70	1.72	7.10	1.23	TRM
Reach 13	0.020	641	8.0	3.0	3:1	26	95.22	1.24	6.57	1.13	142.26	1.53	7.38	1.34	TRM
Outfall Ditch	0.010	550	10.0	4.0	3:1	34	306.60	2.49	7.05	1.05	554.80	3.35	8.28	1.34	TRM



5/6 DETAIL
DRAINAGE DOWNCHUTE AT LANDFILL CREST
SCALE: 1" = 4'
0 4' 8'
SCALE IN FEET



7/6 DETAIL
PERIMETER DRAINAGE CHANNEL
SCALE: 1" = 2'
0 2' 4'
SCALE IN FEET



6/6 DETAIL
DRAINAGE DOWNCHUTE OUTLET
SCALE: 1" = 4'
0 4' 8'
SCALE IN FEET

NOTES:

1. PERMANENT TURF REINFORCEMENT MAT TO BE INSTALLED ON PERIMETER CHANNEL REACHES 4 THROUGH 8 AND 12 AND 13.
2. TURF REINFORCEMENT MAT (TRM) SHALL BE PERMANENT (I.E., LONG-TERM) SYNTHETIC MATERIALS THAT ALLOW GRASS VEGETATION TO BECOME ESTABLISHED AND ENHANCE THE ABILITY OF GRASS VEGETATION TO STABILIZE SOILS. THE TRM SHOULD HAVE A MINIMUM RESISTANCE TO TRACTIVE STRESS OF 6 psf.
3. DETAILS SHOW FINAL COVER SYSTEM OPTION WITH COMPOSITE CAP.

ENGINEERING DESIGN DRAWING

REV	DATE	DESCRIPTION	DRN	APP

LCRA ENERGY•WATER•COMMUNITY SERVICES
LOWER COLORADO RIVER AUTHORITY
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TEXAS ENG. FIRM REGISTRATION NUMBER 1182
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PHONE: 512.451.4003

TITLE: STORMWATER MANAGEMENT DETAILS II

PROJECT: RUN-ON AND RUN-OFF CONTROL SYSTEM PLAN

SITE: FAYETTE POWER PROJECT
COMBUSTION BYPRODUCT LANDFILL

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STATE OF TEXAS
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79864
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PROFESSIONAL ENGINEER

DESIGN BY:	BG	DATE: OCTOBER 2016
DRAWN BY:	JJV	PROJECT NO.: TXL0225.04
CHECKED BY:	BG	FILE: TXL0225CCRR8
REVIEWED BY:	BG	DRAWING NO.:
APPROVED BY:	BG	8 OF 8

P:\CADD\PROJECTS\FAYETTE POWER PLANT\ENG DESIGN\CCR RULE COMPLIANCE (TXL0225.08)\RUN-OFF CONTROL PLANS\DRAWINGS\TXL0225CCRR8

APPENDICES

APPENDIX A

Stormwater Management System Design – Final Conditions

Written by:	**H. Douglas & J. McNash**	Date:	**7/14/2015**	Reviewed & Revised by:	**B. Klenzendorf & Z. Islam**	Date:	**10/6/2016**
Client:	**LCRA**	Project:	**FPP CBL Expansion**	Project No.:	**TXL0225**	Phase No.:	**08**

SURFACE WATER MANAGEMENT SYSTEM DESIGN – FINAL CONDITIONS

Beth Ann Gross

10/13/2016

GEOSYNTEC CONSULTANTS, INC.
TX ENG FIRM REGISTRATION NO. F-1182

PURPOSE

The purpose of this calculation package is to present the analysis and design of the surface water management system for the final cover system of the Combustion Byproduct Landfill (CBL) at LCRA's Fayette Power Project (FPP) in La Grange, Texas. This package assumes Cells 1 and 2 of the CBL will be constructed and provides calculations of peak design discharges (i.e., hydrology) and design of surface water management system components (i.e., hydraulic design), which include:

- drainage downchutes;
- mid-slope drainage benches;
- top deck drainage terraces;
- a perimeter drainage channel;
- an access road channel; and
- a chambered sediment/stormwater detention pond.

CALCULATION METHODOLOGY

Surface Water Management System Components

The final cover system of the CBL consists of a shallowly sloped (3% minimum) top deck and exterior 3 horizontal to 1 vertical (3H:1V) side slopes. Storm water runoff from the final cover will be conveyed off the landfill through a series of components, including drainage benches and terraces orientated approximately parallel to the final cover system side slopes, and drainage downchutes that intersect the drainage benches and are designed to convey runoff to a perimeter drainage channel and then to a chambered sediment/stormwater detention pond. The downchutes will be lined with articulated concrete block (ACB), drainage benches and terraces will be grass-lined, the access road channel will be lined with long-term turf reinforcement mat (TRM), and the perimeter drainage will be lined with grass or long-term TRM.

The pond is designed with an upstream sediment chamber to capture the “first flush” of runoff and allow sediment to settle out. The sediment chamber discharges to a downstream detention chamber through a controlled skimmer outlet structure. Flows greater than the volume of the sediment chamber are designed to bypass the chamber and enter the detention pond. The stormwater detention pond is comprised of a lower retention storage volume and an upper detention storage volume. The permanent pond within the retention volume can be used on-site for dust suppression and other beneficial uses. Flows from the chambered sediment/stormwater detention pond will be discharged through two culverts with an outlet riser structure and/or an overflow spillway and to a permanent drainage channel located adjacent to the east perimeter of the leachate evaporation pond. Discharge will leave the site at the southern site perimeter and through the existing culvert beneath the existing off-site railroad.

Design Storm Return Period

The United States Environmental Protection Agency (USEPA) coal combustion residuals (CCR) rule (40 CFR 257.81(a)) requires that runoff control systems be designed to collect and control flow from a 24-hour, 25-year storm. Texas Commission on Environmental Quality (TCEQ) Technical Guideline No. 3 (2015) recommends that runoff control systems for industrial landfills be designed for a 100-year, 24-hour rainfall event, a storm that would result in greater peak discharge and require larger drainage features than a 24-hour, 25-year storm. TCEQ Technical Guideline No. 3 does not address the design of detention ponds. However, TCEQ’s 2006 guideline for municipal solid waste landfills recommends the 25-year, 24-hour design storm event for peak flow and volume sizing of stormwater ponds. In designing the stormwater management system for the CBL, Geosyntec followed the TCEQ (2006, 2015) guidelines.

Rainfall Information

The design rainfall distribution of the site is selected from the rainfall distribution map of the United States in Figure 1 (USDA, 1986). The site is located in an area categorized by Soil Conservation Service (SCS) Type III Rainfall Distribution. This rainfall distribution is used as input to the hydrologic model and is converted into a runoff hydrograph.

The 2-year, 25-year, and 100-year rainfall depths for a 24-hour storm event utilized for analyses were obtained from the USGS *Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas* (USGS, 2004) as specified in the Texas Department of Transportation (TxDOT) Hydraulic Design Manual (TxDOT, 2011). A 2-year, 24-hour rainfall depth of 3.7 inches is used in the hydrologic model to estimate travel times for sheet flow conditions for the times of concentration for each subarea (Figure 2). Similarly, rainfall depths of 7.8 inches and 10.5 inches were selected for 25-year, 24-hour and 100-year, 24-hour rainfall events, respectively (Figure 3 and Figure 4).

Hydrology

Intensity of rainfall for design is based on calculations for times of concentration and intensity-duration-frequency relationships using the procedures outlined by the TxDOT *Hydraulic Design Manual* (TxDOT, 2011). Peak design discharges are calculated based on the Rational Method recommended for small basins for either undeveloped or developed lands. The Rational Method is appropriate for estimating peak discharges for drainage areas less than 200 acres (TxDOT, 2011).

The Rational Method is useful for estimating peak flow rates but does not estimate runoff volumes. Therefore, the SCS Curve Number method outlined in TR-55 (USDA, 1986) is used to estimate runoff volumes as recommended by TCEQ (2006) and to check the design of the stormwater detention pond.

Hydraulic Design

Hydraulic design of the mid-slope drainage benches, drainage downchutes, and perimeter drainage channels are performed using Manning's equation (Chow, 1959). HydroCAD version 8.5 (HydroCAD, 2006) was used to develop an outflow curve for the detention pond riser structure, culverts, and overflow spillway. HydroCAD allows for complex outlet structures and models the structure using orifice and weir equations. The outlet structure outflow curve was used as input to the pond structure in the hydrologic model, HEC-HMS version 3.5 (USACE, 2000). Average tractive shear stresses are calculated for each hydraulic feature. The channel lining was selected such that the calculated tractive stress for a 25-year design storm event is less than the permissible tractive stress for the lining material. In addition, the depth of the hydraulic feature is selected to convey the calculated 100-year design storm depth.

COMPUTATIONS

Rational Method for Hydrologic Design

The Rational Method was applied to design the stormwater drainage features (downchutes, mid-slope berms, and perimeter channels). The Rational Method is expressed as follows:

$$Q = C \times I \times A$$

where:
Q = flow rate (cfs);
C = runoff coefficient;
I = rainfall intensity (in./hr); and
A = contributing drainage area (acres).

Estimation of Contributing Drainage Areas

Figure 5 delineates the contributing drainage areas for each of the surface water management system components. Table 1 provides the calculated area, in acres, for each of the drainage areas (subcatchments) labeled on Figure 5. The area of each subcatchment was calculated from the design drawings using computer-aided design (CAD) software. The proposed final cover system drainage areas are divided based on the surface water management component. Additional areas draining to the detention pond and the down gradient discharge channel were estimated based on existing contours provided by LCRA.

Estimation of Runoff Coefficient for Rational Method

The runoff coefficient is estimated from the TxDOT *Hydraulic Design Manual* (TxDOT, 2011) for rural watersheds as presented in Table 2. The total runoff coefficient is estimated based on the following equation:

$$C = C_r + C_i + C_v + C_s$$

where: C = total runoff coefficient;
C_r = relief runoff coefficient;
C_i = soil infiltration runoff coefficient;
C_v = vegetal cover runoff coefficient; and
C_s = surface runoff coefficient.

The total runoff coefficient equation above applies to design storm events of less than or equal to a 10-year frequency. For higher frequency events, the runoff coefficient is modified due to infiltration and other abstractions having a proportionally smaller effect on runoff. Adjustment factors for the Rational Method, C_f, are given by TxDOT (2011) as 1.10, 1.20, and 1.25 for 25-year, 50-year, and 100-year recurrence intervals, respectively.

Estimation of Time of Concentration for Rational Method

The time of concentration is defined as the time for runoff to flow from the most hydraulically remote point of the drainage area to the point under investigation. The time of concentration (T_c) is a summation of sheet flow travel time, shallow concentrated flow travel time, and open channel flow travel time.

The method to estimate the sheet flow travel time was obtained from the U.S. Department of Agriculture (USDA) document *Urban Hydrology for Small Watersheds, Technical Release 55 (TR-55)* (USDA, 1986). Manning's kinematic solution is used for estimating travel time for sheet flow for flow distances less than 300 ft (USDA, 1986):

$$T_t = \frac{0.007(nL)^{0.8}}{P_{2-24}{}^{0.5} S^{0.4}}$$

where: T_t = travel time for overland sheet flow (hr);
n = Manning's roughness coefficient;
L = flow length (ft);
$P_{2\text{-}24}$ = 2-year, 24-hour rainfall (in.); and
S = slope of hydraulic grade line (land slope, ft/ft).

To estimate sheet flow travel time (T_t), a Manning's roughness coefficient (n) of 0.15 was selected for short grass prairie surfaces as shown in Table 3 (USDA, 1986). Maximum flow lengths (L) were measured for each subcatchment area of the final cover system. The rainfall depth for the 2-year, 24-hour frequency ($P_{2\text{-}24}$) is provided as 3.7 inches (USGS, 2004). The slope of the hydraulic grade line, or land slope (S), for all subcatchment areas of the final cover system is shown in Table 1.

Based on the designed conveyance system, runoff will be converted from sheet flow to open channel flow quickly, and shallow concentrated flow is negligible. Surface water runoff within each subcatchment area will sheet flow along the top deck or side slopes of the final cover system until the water reaches either a drainage bench or the perimeter drainage channel, at which point the flow will be classified as open channel flow. For the undeveloped areas to the south of the landfill which drain directly to the detention pond or drainage channel, shallow concentrated flow will not be negligible. The Upland Method (USDA, 1986) is used to estimate the shallow concentrated flow velocities using Table 4 and the equation below.

$$V = K_v \sqrt{S}$$

where: V = average velocity (ft/sec),
K_v = shallow concentrated flow velocity factor (ft/sec) based on surface type (see Table 4), and
S = land slope (ft/ft).

A velocity factor of K_v = 7.0 ft/sec was selected for the undeveloped areas based on a short grass pasture surface description. The land slopes were estimated from the existing conditions topographic maps.

The method selected to estimate the shallow concentrated flow and open channel flow travel time is based on guidance provided in TR-55 (USDA, 1986). Travel time for shallow concentrated flow and open channel flow is estimated by dividing the longest drainage path by the velocity of runoff:

$$T_t = \frac{L}{V}\left(\frac{1}{60}\right)$$

where: T_t = travel time (min);
L = flow length (ft); and

V = average velocity (ft/sec).

The shallow concentrated flow velocities are defined above. The open channel flow velocities were estimated using Manning's equation based on guidance provided in TR-55 (USDA, 1986). The average flow velocities were determined for bank-full elevation as:

$$V = \frac{1.49}{n} R_h^{2/3} S^{1/2}$$

where:

V = average velocity (ft/sec);
n = Manning's roughness coefficient;
R_h = hydraulic radius (ft) = A/P;
A = cross sectional area (ft^2);
P = wetted perimeter (ft); and
S = slope of hydraulic grade line (channel slope, ft/ft).

To estimate open channel flow travel time (T_t), a Manning's roughness coefficient (n) was selected for clean and straight earthen open channels as shown in Table 5 (Chow, 1959). A Manning's roughness coefficient value of 0.027 was selected for the mid-slope drainage benches and some perimeter channel reaches which are proposed to be grass-lined, and a value of 0.030 was selected (see Table 6 from FHWA, 2005) for the remaining perimeter channel reaches and the access road channel which are proposed to be lined with TRM. The mid-slope drainage benches are designed with a minimum of 2% slope, the access road channel is designed with a slope of 8%, and the perimeter drainage channels are designed with slopes ranging from 0.9% to 3.3%.

The velocities and times of concentration used in the design are presented in Table 1. A minimum time of concentration of 10 minutes was used to calculate the rainfall intensity as recommended by the TxDOT Hydraulic Design Manual (TxDOT, 2011) and TCEQ RG-417 (TCEQ, 2006) because small areas with exceedingly short times of concentration could result in design rainfall intensities that are unrealistically high.

Estimation of Peak Rainfall Intensity for Rational Method

Rainfall intensity was estimated based on guidance provided in the TxDOT Hydraulic Design Manual (TxDOT, 2011). The design rainfall intensity was calculated from the following equation:

$$I = \frac{P_d}{T_c}$$

where: I = design rainfall intensity (in/hr);
T_c = computed time of concentration (hr); and
P_d = depth of rainfall (inches) for design storm of duration T_c.

The values of P_d for each design storm event were obtained from the USGS (2004) for both the 25-year and the 100-year rainfall events for various storm durations. The storm durations represented are 15 and 30 minutes for both the 25-year and 100-year storm events as shown in Figure 6 through Figure 9, respectively. The depth for the desired duration is calculated by performing an interpolation between depth-duration pairs provided in the figures. For times of concentration less than 15 minutes, the depth of rainfall is taken as a fraction of the 15 minute rainfall depth.

Estimation of Peak Design Discharges for Rational Method

The Rational Method was used to estimate peak discharge rates for each drainage area as described above. The runoff coefficients for each drainage area on the final cover system and the calculated peak discharges for the 25-year, 24-hour and 100-year, 24-hour rainfall events for each drainage area are shown in Table 1.

To obtain the design discharge for a specific point in the surface water management system, the peak discharges for each drainage area upstream of the point were added at the point of interest. This technique slightly overestimates peak discharge because peak flows from upstream drainage areas will likely combine downstream at different times. However, this technique is conservative and appropriate for design given the small drainage areas and short times of concentration. The drainage areas upstream of each surface water management system component area are shown in Table 7. The calculated design discharges for the downstream end of each surface water management system component are provided in Table 8.

SCS Curve Number Method for Hydrologic Design

The TCEQ RG-417 (TCEQ, 2006) indicates that the Rational Method is insufficient in modeling the volume of stormwater runoff and hydrograph development. Therefore, it is recommended (TCEQ, 2006) to use TR-55 SCS Curve Number Method to compute runoff volumes for detention pond sizing. Stormwater discharges for the landfill expansion are estimated using the computer program HEC-HMS (USACE, 2000). HEC-HMS applies hydrology design methods, such as the SCS Curve Number Method, as presented in TR-55 (USDA, 1986). Hydrographs generated within the computer program are routed through a user-specified network of reaches and ponds using documented hydraulic routing techniques.

HEC-HMS simulations were conducted to calculate surface water runoff volumes, peak flow rates, and flow characteristics for the surface water management features. Modeling performed using HEC-HMS included the following procedures built-in within the program.

- Runoff volumes were calculated within HEC-HMS using the SCS Curve Number Method as required by TR-55.
- Time-response of runoff (i.e., the process of converting a volume of runoff into a runoff hydrograph) was calculated within HEC-HMS using time of concentration, lag time, and unit hydrograph methods as required by TR-55 using a Type III rainfall distribution (see Figure 1).
- Runoff hydrographs generated within HEC-HMS were routed through a user specified network of reaches using industry standard hydraulic routing techniques such as: Kinematic Wave method for reach routing and an Outflow Curve method for routing through ponds. The Outflow Curve method was used for the detention pond since the outlet structure has a complex design with a combination of orifices, weirs, and culverts. The Outflow Curve was calculated using HydroCAD software that allows for a combination of multiple outflow structures as previously mentioned (HydroCAD, 2006).

The design storm event for peak flow and volume sizing of stormwater ponds is the 25-year, 24-hour storm (TCEQ, 2006). In addition, the pond outflow structure is designed to convey the peak flow rate of a 100-year, 24-hour event without overtopping the pond berm. Analyses of the post-development conditions for both a 25-year and 100-year design storm event are presented below.

For post-development conditions, the contributing drainage area to the detention pond outfall is approximately 84.8 acres as shown in Figure 5 based on the design contours developed by Geosyntec. The landfill area draining to the detention pond is approximately 71.6 acres and is classified as pasture, grassland, or range under fair condition with 50% to 75% ground cover which corresponds to a curve number 84 for hydrologic soil group (HSG) D used for analysis as shown in Table 9 (USDA, 1986). The remaining undeveloped area south of the landfill which drains directly to the detention pond consists of 13.2 acres. This undeveloped area was based on the USGS topography map for brush under good condition with greater than 75% ground cover which corresponds to a curve number of 73 for HSG D used for analysis as shown in Table 9. This additional area is accounted for in the detention pond design. Additional undeveloped areas to the south of the detention pond drain directly to the down gradient drainage channel and site outfall and consist of an additional 30.9 acres. The same undeveloped curve number of 73 is applied to this area which is accounted for in the drainage channel design.

Estimation of Time of Concentration for SCS Curve Number Method

The equations used to estimate the time of concentration described above for the Rational Method apply to the SCS Curve Number Method. The lag times calculated for each drainage area are presented in Table 10 for use in the SCS Curve Number Method and HEC-HMS software. The lag time is estimated as 0.6 times the time of concentration (USDA, 2010).

For the undeveloped contributing areas, shallow concentrated flow will occur after the allowable 300 ft of sheet flow but prior to open channel flow. The travel time for shallow concentrated flow is estimated using the Upland Method (USDA, 1986) as described above.

Surface Water Management System Components Hydraulic Design

Manning's equation was used to estimate the average velocity for the mid-slope drainage benches, downchutes, and perimeter channels. Manning's equation for velocity (Chow, 1959) is presented earlier. Manning's roughness coefficient was selected from Table 5 for a grass-lined channel. Average discharge is equal to the average velocity times the area of cross-section of flow (i.e., $Q = VA$). The mid-slope drainage benches, downchutes, and perimeter channels were designed to accommodate the peak discharge from the 100-year, 24-hour design storm without overtopping consistent with TCEQ TG-3 (TCEQ, 2009).

The tractive stresses in the mid-slope drainage benches, downchutes, and drainage channel outlets for various depths of flow are estimated using the following equation (Chow, 1959):

$$\tau_0 = \gamma_w R_h S$$

where: τ_o = average tractive stress (lb/ft^2);
γ_w = unit weight of water (lb/ft^3);
R_h = hydraulic radius of flow (ft); and
S = channel slope (ft/ft).

The tractive stress at the 25-year design discharge for the mid-slope drainage benches, downchutes, and perimeter drainage channel outlets was calculated using the tractive stress equation. Permissible tractive stresses for grass-lined channels range from 0.35 psf to 3.70 psf depending on the retardation class of vegetation. Retardation Class C (which includes Bermuda and Crab grasses among others) is selected for the design of grass-lined channels (Table 11) and has a maximum permissible tractive stress of 1.0 psf (Table 12) according to TxDOT (2011). Where the calculated tractive stress was greater than 1.0 psf, TRM was used. In the TxDOT (2011) reference (see Table 12), the maximum permissible tractive stress of synthetic mat is 2.00 psf. However, there are TRMs available that provide resistance against higher tractive stresses. TxDOT Class 2, Type G TRMs have maximum permissible stresses up to 6 psf, and Type H TRMs have maximum permissible stresses up to 8 psf (TxDOT, 2015).

The allowable tractive stress for the ACB-lined downchutes is documented in published research data (e.g., Ayres, 2001) and selected for design. The ACB-lined downchute is designed to accommodate the design storm event without shifting of the blocks or any loss of embankment soil beneath the ACB system. The maximum allowable tractive stress, or shear stress, for the ACB-lined downchutes ranges from approximately 9.1 to 10.7 psf (Ayres, 2001), as shown in Table 13 with an average value of 9.9 psf which is recommended as the maximum allowable tractive stress.

RESULTS

Hydraulic design calculations for mid-slope benches, downchutes, and perimeter channels were performed using the spreadsheets presented in Appendix A-1 of this calculation package for the hydraulic elements with the largest design flow rates. HEC-HMS output results are provided in Appendix A-2. The design parameters and results of the hydraulic design of each component of the surface water management system are summarized below. Additionally, the mid-slope drainage benches and the perimeter channel dimensions are summarized in Table 14 and Table 15 at the end of this document. The Reach ID corresponds with the drainage area contributing to the adjacent surface water management component.

Summary of Mid-Slope Drainage Benches (Table 14)

- 100-year Rainfall Design Discharge = 4.72 to 32.56 cfs
- Top Width = 18 ft
- Channel Slope = 2.0 to 2.8%
- Manning's *n* = 0.027 (Table 5)
- Side Slopes = 6H:1V and 3H:1V[a]
- Bottom Width = 0 ft
- Available Depth of Flow = 2.0 ft
- **100-year Calculated Depth of Flow** = 0.56 to 1.12 ft
- ***Calculated Depth of Flow < Available Depth of Flow***
- Allowable Tractive Stress = 1.0 psf (Table 12)
- **25-year Calculated Average Tractive Stress** = 0.29 to 0.80 psf
- ***Calculated Average Tractive Stress < Allowable Tractive Stress***

[a]Note: The mid-slope drainage benches are graded channels. A 2.0 ft deep (minimum) channel with 6H:1V slopes provides the outer slope of the channel. The 3H:1V slope of the landfill provides the inner slope of the channel.

Summary of Access Road Channel (Table 14)

- 100-year Rainfall Design Discharge = 13.04 cfs
- Top Width = 12 ft
- Channel Slope = 8.0%
- Manning's *n* = 0.030 (Table 5)
- Side Slopes = 3H:1V
- Bottom Width = 0 ft
- Available Depth of Flow = 2.0 ft
- **100-year Calculated Depth of Flow** = 0.78 ft
- ***Calculated Depth of Flow < Available Depth of Flow***
- Allowable Tractive Stress = 2.0 psf (Table 12) or 6 to 8 psf for TxDOT Class 2, Type G or H TRM (TxDOT, 2015)

- **25-year Calculated Average Tractive Stress** = 1.58 psf
- ***Calculated Average Tractive Stress < Allowable Tractive Stress***

Summary of Drainage Downchutes[a] (Table 14)

- 100-year Rainfall Design Discharge = 57.84 to 111.34 cfs
- Top Width = 18 ft[b]
- Channel Slope = 33.3%
- Manning's *n* = 0.036 (Table 13)
- Side Slopes = 6 ft radius
- Bottom Width = 6.0 ft[b]
- Available Depth of Flow = 2.0 ft
- **100-year Calculated Depth of Flow** = 0.55 to 0.73 ft
- ***Calculated Depth of Flow < Available Depth of Flow***
- Allowable Tractive Stress = 9.9 psf (Table 13)
- **25-year Calculated Average Tractive Stress** = 7.55 to 9.62 psf
- ***Calculated Average Tractive Stress < Allowable Tractive Stress***

[a]Note: Downchutes will be lined with ACB and constructed with a 6 ft radius of curvature. The downchutes were conservatively designed as trapezoidal channels with a 6 ft bottom width (except Downchute 1 as noted below) and 3H:1V side slopes.

[b]Note: Downchute 1 will be constructed with a bottom width of 8.0 ft and a resulting top width of 20 ft.

Eastern Perimeter Drainage Channel (Reach 1 to Reach 7)

- 100-year Rainfall Design Discharge = 2.80 to 219.65 cfs
- Top Width = 23 ft
- Channel Slope = 0.9 to 2.1% (Table 15)
- Manning's *n* = 0.030 to 0.033 (Table 5 and Table 6)
- Side Slopes = 3H:1V
- Bottom Width = 5 ft
- Available Depth of Flow = 3.0 ft
- **100-year Calculated Depth of Flow** = 0.25 to 2.31 ft
- ***Calculated Depth of Flow < Available Depth of Flow***

- Allowable Tractive Stress = 1.0 psf (grass-lined) or 2.0 psf (turf reinforcement mat) (Table 12)
- **25-year Calculated Average Tractive Stress** = 0.16 to 1.48 psf
- ***Calculated Average Tractive Stress < Allowable Tractive Stress***

<u>Western Perimeter Drainage Channel (Reach 9 to Reach 12)</u>

- 100-year Rainfall Design Discharge = 13.92 to 123.70 cfs
- Top Width = 20 ft
- Channel Slope = 1.7 to 3.3% (Table 15)
- Manning's *n* = 0.030 to 0.033 (Table 5 and Table 6)
- Side Slopes = 3H:1V
- Bottom Width = 5 ft
- Available Depth of Flow = 2.5 ft
- **100-year Calculated Depth of Flow** = 0.49 to 1.73 ft
- ***Calculated Depth of Flow < Available Depth of Flow***
- Allowable Tractive Stress = 1.0 psf (grass-lined) or 2.0 psf (turf reinforcement mat) (Table 12)
- **25-year Calculated Average Tractive Stress** = 0.42 to 1.05 psf
- ***Calculated Average Tractive Stress < Allowable Tractive Stress***

<u>Southern Perimeter Drainage Channel (Reach 8 and Reach 13)</u>

- 100-year Rainfall Design Discharge = 142.26 to 263.57 cfs
- Top Width = 26 ft
- Channel Slope = 1.6 to 2.0% (Table 15)
- Manning's *n* = 0.030 (Table 6)
- Side Slopes = 3H:1V
- Bottom Width = 8 ft
- Available Depth of Flow = 3.0 ft
- **100-year Calculated Depth of Flow** = 1.53 to 2.22 ft
- ***Calculated Depth of Flow < Available Depth of Flow***
- Allowable Tractive Stress = 2.0 psf (turf reinforcement mat) (Table 12)
- **25-year Calculated Average Tractive Stress** = 1.13 to 1.25 psf
- ***Calculated Average Tractive Stress < Allowable Tractive Stress***

Chambered Sediment/Stormwater Detention Pond Hydraulic Design

The SCS Curve Number method is used for hydrologic design of the chambered sediment/stormwater detention pond. This method is evaluated with HEC-HMS software and is used as input for the hydraulic design of the stormwater detention pond. Stormwater runoff is routed through the detention pond which is sized to detain water from a 25-year, 24-hour rainfall event. The pond outlet structure was sized to convey the peak flow rate for the 100-year, 24-hour storm event without overtopping the pond berm. The primary pond outlet structure consists of two 36 inch diameter pipes with an invert elevation of 340-ft. A tiered concrete headwall is designed up gradient from the outlet culverts to manage outflows from the pond. The headwall consists of a tiered weir design with a lower weir crest at elevation 342.25-ft and length of 15 ft. The upper weir crest is at elevation 343.0-ft and has a length of 20 ft. A series of low flow orifices are spaced within the headwall structure. The orifices are six inches in diameter and spaced eight inches apart vertically in two rows and four columns (for a total of eight orifices). An emergency overflow spillway is modeled as a broad-crested weir at elevation 345-ft with a crest length of 100 ft and crest breadth of 13 ft.

The proposed chambered sediment/stormwater detention pond is designed to convey the peak flow rate for the 100-year, 24-hour storm event as required by TCEQ TG-3 (TCEQ, 2009). The 100-year, 24-hour peak flow rate is conveyed through the overflow spillway keeping 1.0 feet of freeboard. Modeling results for the peak flow rates and maximum water surface elevations are presented in Table 16 of this calculation package.

CONCLUSIONS

Results from calculations presented in this calculation package indicate that the surface water management system for the proposed Cell 1 vertical expansion and Cell 2 lateral expansion of the Coal Combustion Byproduct Landfill at the LCRA Fayette Power Project site in La Grange, Texas will collect and control the runoff resulting from a 100-year, 24-hour design storm event. The proposed surface water management system includes drainage downchutes, mid-slope drainage benches, perimeter drainage channels, an access road channel, and a chambered sediment/stormwater detention pond which will collect runoff from the landfill final cover system and adjacent up gradient undeveloped areas. Stormwater runoff will be routed to the facility's site outfall point.

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Table 1 – Subcatchment Areas, Time of Concentration, and Peak Discharge Calculations

SUBCATCHMENT DESIGNATION	Area Acres (Ac.)	Sheet Flow				Shallow Concentrated Flow or Channel Flow									T_c	Runoff Coefficient for Rural Watersheds				25-year Return Interval			100-year Return Interval		
		Length L (ft)	Slope S (ft/ft)	Manning's n	Time T_t (min)	Length L (ft)	Depth d (ft)	Area A (ft^2)	Wetted P (ft)	Hydraulic Radius R (ft)	Manning's n	Slope S (ft/ft)	Velocity V (ft/s)	Time T_t (min)	Design T_c (min)	Relief C_r	Soil Infiltration C_i	Vegetal Cover C_v	Surface C_s	Intensity I_{25} (in/hr)	Runoff Coefficient C_{25}	Peak Flow Rate Q_{25} (cfs)	Intensity I_{100} (in/hr)	Runoff Coefficient C_{100}	Peak Flow Rate Q_{100} (cfs)
1	0.35	40	0.333	0.150	1.42	180	3.0	42.0	24.0	1.75	0.033	0.015	7.98	0.38	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**1.87**	10.00	0.800	**2.80**
2A	15.54	300	0.030	0.150	18.66	700	1.0	33.3	66.7	0.50	0.027	0.009	3.20	3.64	22.30	0.12	0.16	0.06	0.12	5.98	0.51	**47.03**	7.61	0.575	**67.98**
2B	1.39	25	0.333	0.150	0.98	1050	2.0	18.0	18.5	0.97	0.027	0.020	7.67	2.28	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**7.44**	10.00	0.800	**11.12**
2C	3.42	115	0.333	0.150	3.31	1250	2.0	18.0	18.5	0.97	0.027	0.02	7.67	2.72	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**18.30**	10.00	0.800	**27.36**
2D	0.61	150	0.333	0.150	4.09	170	2.0	18.0	18.5	0.97	0.027	0.02	7.67	0.37	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**3.26**	10.00	0.800	**4.88**
2E	0.23	50	0.333	0.150	1.70	120	3.0	42.0	24.0	1.75	0.033	0.015	7.98	0.25	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**1.23**	10.00	0.800	**1.84**
3	0.53	60	0.333	0.150	1.97	250	3.0	42.0	18.5	2.27	0.033	0.01	7.28	0.57	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**2.84**	10.00	0.800	**4.24**
4	0.13	65	0.333	0.150	2.10	70	3.0	42.0	24.0	1.75	0.033	0.020	9.30	0.13	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**0.70**	10.00	0.800	**1.04**
5A	12.63	300	0.030	0.150	18.66	425	1.0	33.3	66.7	0.50	0.027	0.007	2.93	2.42	21.08	0.12	0.16	0.06	0.12	6.19	0.51	**39.55**	7.91	0.575	**57.44**
5B	2.03	160	0.333	0.150	4.31	460	2.0	18.0	18.5	0.97	0.027	0.020	7.67	1.00	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**10.86**	10.00	0.800	**16.24**
5C	0.82	150	0.333	0.150	4.09	230	2.0	18.0	18.5	0.97	0.027	0.020	7.67	0.50	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**4.39**	10.00	0.800	**6.56**
5D	0.59	70	0.333	0.150	2.22	250	2.0	18.0	18.5	0.97	0.033	0.021	6.44	0.65	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**3.16**	10.00	0.800	**4.72**
6	1.15	130	0.333	0.150	3.65	0	3.0	42.0	24.0	1.75	0.033	0.016	8.30	0.00	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**6.15**	10.00	0.800	**9.20**
7	0.53	130	0.333	0.150	3.65	170	3.0	42.0	24.0	1.75	0.033	0.017	8.43	0.34	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**2.84**	10.00	0.800	**4.24**
8	5.49	150	0.333	0.150	4.09	1130	3.0	51.0	27.0	1.89	0.033	0.016	8.70	2.16	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**29.37**	10.00	0.800	**43.92**
9	1.74	70	0.285	0.150	2.37	320	2.5	31.3	20.8	1.50	0.033	0.033	10.72	0.50	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**9.31**	10.00	0.800	**13.92**
10	0.16	50	0.426	0.150	1.54	70	2.5	31.3	20.8	1.50	0.033	0.017	7.67	0.15	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**0.86**	10.00	0.800	**1.29**
11A	3.57	250	0.030	0.150	16.13	0	1.0	33.3	66.7	0.50	0.027	0.014	4.04	0.00	16.13	0.12	0.16	0.06	0.12	7.27	0.51	**13.14**	9.51	0.575	**19.53**
11B	1.32	75	0.333	0.150	2.35	700	2.0	18.0	18.5	0.97	0.027	0.020	7.67	1.52	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**7.06**	10.00	0.800	**10.56**
11C	1.63	200	0.333	0.150	5.15	0	2.0	12.0	12.6	0.95	0.027	0.080	15.07	0.00	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**8.72**	10.00	0.800	**13.04**
11D	2.44	100	0.333	0.150	2.96	880	2.0	18.0	18.5	0.97	0.027	0.032	9.70	1.51	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**13.05**	10.00	0.800	**19.52**
11E	2.21	140	0.333	0.150	3.87	560	2.0	18.0	18.5	0.97	0.027	0.020	7.67	1.22	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**11.82**	10.00	0.800	**17.68**
11F	1.24	80	0.333	0.150	2.47	500	2.0	18.0	18.5	0.97	0.027	0.02	7.67	1.09	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**6.63**	10.00	0.800	**9.92**
11G	0.69	80	0.333	0.150	2.47	0	2.5	31.3	20.8	1.50	0.033	0.02	7.67	0.00	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**3.69**	10.00	0.800	**5.52**
12	1.59	80	0.333	0.150	2.47	550	2.5	31.3	20.8	1.50	0.033	0.018	7.94	1.15	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**8.51**	10.00	0.800	**12.72**
13	2.32	150	0.333	0.150	4.09	460	2.5	35.0	23.8	1.47	0.033	0.020	8.19	0.94	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**12.41**	10.00	0.800	**18.56**
14A	0.59	80	0.333	0.150	2.47	220	2.0	18.0	18.5	0.97	0.027	0.020	7.67	0.48	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**3.16**	10.00	0.800	**4.72**
14B	1.64	90	0.333	0.150	2.72	0	2.0	18.0	18.5	0.97	0.027	0.020	7.67	0.00	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**8.77**	10.00	0.800	**13.12**
14C	1.33	140	0.333	0.150	3.87	320	2.0	18.0	18.5	0.97	0.027	0.020	7.67	0.70	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**7.12**	10.00	0.800	**10.64**
14D	3.67	140	0.333	0.150	3.87	1000	2.0	18.0	18.5	0.97	0.027	0.020	7.67	2.17	10.00	0.30	0.16	0.06	0.12	7.60	0.70	**19.64**	10.00	0.800	**29.36**
OS1	13.20	300	0.033	0.150	17.89	400						0.030	1.21	5.50	23.39	0.30	0.16	0.06	0.12	5.81	0.70	**54.01**	7.36	0.800	**77.74**
OS2	22.82	300	0.040	0.150	16.63	800						0.038	1.36	9.84	26.47	0.30	0.16	0.06	0.12	5.39	0.70	**86.64**	6.76	0.800	**123.41**
OS3	8.11	300	0.020	0.150	21.94	550						0.044	1.46	6.27	28.21	0.30	0.16	0.06	0.12	5.19	0.70	**29.63**	6.47	0.800	**41.97**

2-year, 24-hr Design Rainfall Depth, P_{2-24} =	3.7	inches
25-year, 15-min Design Rainfall Depth =	1.9	inches
25-year, 30-min Design Rainfall Depth =	2.5	inches
100-year, 15-min Design Rainfall Depth =	2.5	inches
100-year, 30-min Design Rainfall Depth =	3.1	inches

Notes:

1. Manning's Roughness coefficients: n = 0.150 represents grass (short grass prairie) for sheet flow (USDA, 1986); n = 0.027 to 0.033 represents the range for excavated open channel of earth that is straight and uniform with short grass and few weeds (Chow, 1959).

2. Travel Time (T_t) is calculated using Manning's kinematic solutions for sheet flow (USDA, 1986).

$$T_t = 0.007(nL)^{0.8} / (P_{2\text{-}24})^{0.5} S^{0.4}$$

4. Open Channel Velocity (V) is calculated using Manning's equation (USDA, 1986).

$$V = (1.49r^{2/3} S^{1/2}) / n$$ *where: r = hydraulic radius (ft) and is equal to A/P [area (ft^2)/wetted perimeter (ft)]*

5. Travel Time (T_t) is calculated as the ration of flow length to flow velocity (USDA, 1986).

$$T_t = L / V * (1/60)$$ *where: (1/60) is a conversion from seconds to minutes*

6. Intensity was calculated using the 25-year or 100-year design rainfall depth for a storm of duration equal to time of concentration for Fayette County provided by USGS (2004).

7. The runoff coefficient is based on rural watersheds using guidance provided by TxDOT (2011).

8. The Rational Method was used to estimate peak discharge rates (Q) for each subcatchment area.

9. The Design Rainfall Depths are taken from USGS (2004) rainfall depth for Fayette County.

Table 2 – Runoff Coefficients (C) for Rural Watersheds

(from TxDOT, 2011)

Watershed characteristic	Extreme	High	Normal	Low
Relief - C_r	0.28-0.35 Steep, rugged terrain with average slopes above 30%	0.20-0.28 Hilly, with average slopes of 10-30%	0.14-0.20 Rolling, with average slopes of 5-10%	0.08-0.14 Relatively flat land, with average slopes of 0-5%
Soil infiltration - C_i	0.12-0.16 No effective soil cover; either rock or thin soil mantle of negligible infiltration capacity	0.08-0.12 Slow to take up water, clay or shallow loam soils of low infiltration capacity or poorly drained	0.06-0.08 Normal; well drained light or medium textured soils, sandy loams	0.04-0.06 Deep sand or other soil that takes up water readily; very light, well-drained soils
Vegetal cover - C_v	0.12-0.16 No effective plant cover, bare or very sparse cover	0.08-0.12 Poor to fair; clean cultivation, crops or poor natural cover, less than 20% of drainage area has good cover	0.06-0.08 Fair to good; about 50% of area in good grassland or woodland, not more than 50% of area in cultivated crops	0.04-0.06 Good to excellent; about 90% of drainage area in good grassland, woodland, or equivalent cover
Surface Storage - C_s	0.10-0.12 Negligible; surface depressions few and shallow, drainageways steep and small, no marshes	0.08-0.10 Well-defined system of small drainageways, no ponds or marshes	0.06-0.08 Normal; considerable surface depression, e.g., storage lakes and ponds and marshes	0.04-0.06 Much surface storage, drainage system not sharply defined; large floodplain storage, large number of ponds or marshes
Table 4-11 note: The total runoff coefficient based on the 4 runoff components is $C = C_r + C_i + C_v + C_s$				

Table 3 – Manning's Roughness Coefficient for Sheet Flow (from USDA, 1986)

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.

Table 4 – Upland Method Velocity Factors for Shallow Concentrated Flow

Surface Description	K_V [ft/sec]	K_V [m/sec]
Paved	20.33	6.2
Unpaved	16.13	4.92
Grassed Waterway	15.0	4.57
Nearly Bare & Untilled	10.0	3.05
Cultivated Straight Rows	9.0	2.74
Short Grass Pasture	7.0	2.13
Woodland	5.0	1.52
Forest w/Heavy Litter	2.5	0.76

Table 5 – Manning's Roughness Coefficient for Open Channel Flow

(from Chow, 1959)

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

Table 6 – Typical Roughness Coefficients for Selected Linings

(from FHWA, 2005)

Lining Category	Lining Type	Manning's n[1] Maximum	Typical	Minimum
Rigid	Concrete	0.015	0.013	0.011
	Grouted Riprap	0.040	0.030	0.028
	Stone Masonry	0.042	0.032	0.030
	Soil Cement	0.025	0.022	0.020
	Asphalt	0.018	0.016	0.016
Unlined	Bare Soil[2]	0.025	0.020	0.016
	Rock Cut (smooth, uniform)	0.045	0.035	0.025
RECP	Open-weave textile	0.028	0.025	0.022
	Erosion control blankets	0.045	0.035	0.028
	Turf reinforcement mat	0.036	0.030	0.024

[1]Based on data from Kouwen, et al. (1980), Cox, et al. (1970), McWhorter, et al. (1968) and Thibodeaux (1968).
[2]Minimum value accounts for grain roughness. Typical and maximum values incorporate varying degrees of form roughness.

Table 7 – Contributing Areas to each Storm Water Management System Component

System Component	Drainage Areas Upstream of Stormwater Management System Component													
Reach 1	1													
Reach 2	1	2A	2B	2C	2D	2E								
Reach 3	1	2A	2B	2C	2D	2E	3							
Reach 4	1	2A	2B	2C	2D	2E	3	4						
Reach 5	1	2A	2B	2C	2D	2E	3	4	5A	5B	5C	5D		
Reach 6	1	2A	2B	2C	2D	2E	3	4	5A	5B	5C	5D	6	
Reach 7	1	2A	2B	2C	2D	2E	3	4	5A	5B	5C	5D	6	7	
Reach 8	1	2A	2B	2C	2D	2E	3	4	5A	5B	5C	5D	6	7	8
Reach 9	9														
Reach 10	9	10													
Reach 11	9	10	11A	11B	11C	11D	11E	11F	11G						
Reach 12	9	10	11A	11B	11C	11D	11E	11F	11G	12					
Reach 13	9	10	11A	11B	11C	11D	11E	11F	11G	12	13				
Outfall Ditch	Pond Ouflow		Undeveloped Areas												
Downchute 1	2A	2B	2C	2D											
Downchute 2	5A	5B	5C												
Downchute 3	11A	11B	11C	11D	11E	11F									
Downchute 4	14A	14B	14C	14D											

Table 8 – Calculated Design Discharges for Each Stormwater Management System Component

System Component	Flow Rates from Contributing Areas Upstream of Stormwater Management Component (100-year event)															100-year Total Flow (cfs)	25-year Total Flow (cfs)
Reach 1	2.80															2.80	1.87
Reach 2	2.80	67.98	11.12	27.36	4.88	1.84										115.98	79.13
Reach 3	2.80	67.98	11.12	27.36	4.88	1.84	4.24									120.22	81.97
Reach 4	2.80	67.98	11.12	27.36	4.88	1.84	4.24	1.04								121.26	82.67
Reach 5	2.80	67.98	11.12	27.36	4.88	1.84	4.24	1.04	57.44	16.24	6.56	4.72				206.21	140.62
Reach 6	2.80	67.98	11.12	27.36	4.88	1.84	4.24	1.04	57.44	16.24	6.56	4.72	9.20			215.41	146.77
Reach 7	2.80	67.98	11.12	27.36	4.88	1.84	4.24	1.04	57.44	16.24	6.56	4.72	9.20	4.24		219.65	149.61
Reach 8	2.80	67.98	11.12	27.36	4.88	1.84	4.24	1.04	57.44	16.24	6.56	4.72	9.20	4.24	43.92	263.57	178.98
Reach 9	13.92															13.92	9.31
Reach 10	13.92	1.29														15.21	10.17
Reach 11	13.92	1.29	19.53	10.56	13.04	19.52	17.68	9.92	5.52							110.98	74.30
Reach 12	13.92	1.29	19.53	10.56	13.04	19.52	17.68	9.92	5.52	12.72						123.70	82.81
Reach 13	13.92	1.29	19.53	10.56	13.04	19.52	17.68	9.92	5.52	12.72	18.56					142.26	95.22
Outfall Ditch	424.30	130.50														554.80	306.60
Downchute 1	67.98	11.12	27.36	4.88												111.34	76.03
Downchute 2	57.44	16.24	6.56													80.24	57.95
Downchute 3	19.53	10.56	13.04	19.52	17.68	9.92										90.25	60.44
Downchute 4	4.72	13.12	10.64	29.36												57.84	38.68
Mid Slope Bench 2B	11.12															11.12	7.44
Mid Slope Bench 2C	27.36															27.36	18.30
Mid Slope Bench 2D	4.88															4.88	3.26
Mid Slope Bench 5B	16.24															16.24	10.86
Mid Slope Bench 5C	6.56															6.56	4.39
Mid Slope Bench 11B	10.56															10.56	7.06
Mid Slope Bench 11C	13.04															13.04	8.72
Mid Slope Bench 11D	13.04	19.52														32.56	21.78
Mid Slope Bench 11E	17.68															17.68	11.82
Mid Slope Bench 11F	9.92															9.92	6.63
Mid Slope Bench 14A	4.72															4.72	3.16
Mid Slope Bench 14B	13.12															13.12	8.77
Mid Slope Bench 14C	10.64															10.64	7.12
Mid Slope Bench 14D	29.36															29.36	19.64

Table 9 – Runoff Curve Numbers for Other Agricultural Lands

(from USDA, 1986)

Cover description: Cover type	Hydrologic condition	Curve numbers for hydrologic soil group: A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. [2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. [3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 [4]	48	65	73
Woods—grass combination (orchard or tree farm). [5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. [6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 [4]	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

1 Average runoff condition, and $I_a = 0.2S$.

2 *Poor:* <50%) ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.

3 *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

4 Actual curve number is less than 30; use CN = 30 for runoff computations.

5 CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

6 *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Table 10 – SCS Method Lag Time Calculations

SUBCATCHMENT DESIGNATION	Area (mi^2)	Length (ft)	Slope (%)	CN	T_{lag} (min)	Sheet Flow, T_t	Shallow Conc or Channel, T_t
1	0.000547	220	7.265	84	6.00	1.42	0.38
2A	0.024281	1000	1.495	84	13.38	18.66	3.64
2B	0.002172	1075	2.728	84	6.00	0.98	2.28
2C	0.005344	1365	4.637	84	6.00	3.31	2.72
2D	0.000953	320	16.672	84	6.00	4.09	0.37
2E	0.000359	170	10.839	84	6.00	1.70	0.25
3	0.000828	310	7.147	84	6.00	1.97	0.57
4	0.000203	135	17.076	84	6.00	2.10	0.13
5A	0.019734	725	1.658	84	12.65	18.66	2.42
5B	0.003172	620	10.077	84	6.00	4.31	1.00
5C	0.001281	380	14.355	84	6.00	4.09	0.50
5D	0.000922	320	8.933	84	6.00	2.22	0.65
6	0.001797	130	33.300	84	6.00	3.65	0.00
7	0.000828	300	15.365	84	6.00	3.65	0.34
8	0.008578	1280	5.306	84	6.00	4.09	2.16
9	0.002719	390	7.814	84	6.00	2.37	0.50
10	0.000252	120	18.747	84	6.00	1.54	0.15
11A	0.005578	250	3.000	84	9.68	16.13	0.00
11B	0.002063	775	5.029	84	6.00	2.35	1.52
11C	0.002547	200	33.300	84	6.00	5.15	0.00
11D	0.003813	980	6.271	84	6.00	2.96	1.51
11E	0.003453	700	8.260	84	6.00	3.87	1.22
11F	0.001938	580	6.317	84	6.00	2.47	1.09
11G	0.001078	80	33.300	84	6.00	2.47	0.00
12	0.002484	630	5.800	84	6.00	2.47	1.15
13	0.003625	610	9.674	84	6.00	4.09	0.94
14A	0.000922	300	10.347	84	6.00	2.47	0.48
14B	0.002563	90	33.300	84	6.00	2.72	0.00
14C	0.002078	460	11.526	84	6.00	3.87	0.70
14D	0.005734	1140	5.844	84	6.00	3.87	2.17
OS1	0.020625	600	3.5	73	14.03	17.54	3.82
OS2	0.035656	1050	3.1429	73	15.88	18.31	10.07
OS3	0.012672	1406	2.7027	73	16.93	19.45	16.02

Table 11 – Retardation Class for Lining Materials (from TxDOT, 2011)

Retardance Class	Cover	Condition
A	Weeping Lovegrass	Excellent stand, tall (average 30 in. or 760 mm)
	Yellow Bluestem Ischaemum	Excellent stand, tall (average 36 in. or 915 mm)
B	Kudzu	Very dense growth, uncut
	Bermuda grass	Good stand, tall (average 12 in. or 305 mm)
	Native grass mixture little bluestem, bluestem, blue gamma, other short and long stem medwest grasses	Good stand, unmowed
	Weeping lovegrass	Good Stand, tall (average 24 in. or 610 mm)
	Lespedeza sericea	Good stand, not woody, tall (average 19 in. or 480 mm)
	Alfalfa	Good stand, uncut (average 11 in or 280 mm)
	Weeping lovegrass	Good stand, unmowed (average 13 in. or 330 mm)
	Kudzu	Dense growth, uncut
	Blue gamma	Good stand, uncut (average 13 in. or 330 mm)
C	Crabgrass	Fair stand, uncut (10-to-48 in. or 55-to-1220 mm)
	Bermuda grass	Good stand, mowed (average 6 in. or 150 mm)
	Common lespedeza	Good stand, uncut (average 11 in. or 280 mm)
	Grass-legume mixture: summer (orchard grass redtop, Italian ryegrass, and common lespedeza)	Good stand, uncut (6-8 in. or 150-200 mm)
	Centipedegrass	Very dense cover (average 6 in. or 150 mm)
	Kentucky bluegrass	Good stand, headed (6-12 in. or 150-305 mm)
D	Bermuda grass	Good stand, cut to 2.5 in. or 65 mm
	Common lespedeza	Excellent stand, uncut (average 4.5 in. or 115 mm)
	Buffalo grass	Good stand, uncut (3-6 in. or 75-150 mm)
	Grass-legume mixture: fall, spring (orchard grass Italian ryegrass, and common lespedeza	Good Stand, uncut (4-5 in. or 100-125 mm)
	Lespedeza sericea	After cutting to 2 in. or 50 mm (very good before cutting)
E	Bermuda grass	Good stand, cut to 1.5 in. or 40 mm
	Bermuda grass	Burned stubble

Table 12 – Permissible Shear Stresses for Various Linings (from TxDOT, 2011)

Protective Cover	(lb./sq.ft.)	t_p (N/m^2)
Retardance Class A Vegetation (See the "Retardation Class for Lining Materials" table above)	3.70	177
Retardance Class B Vegetation (See the "Retardation Class for Lining Materials" table above)	2.10	101
Retardance Class C Vegetation (See the "Retardation Class for Lining Materials" table above)	1.00	48
Retardance Class D Vegetation (See the "Retardation Class for Lining Materials" table above)	0.60	29
Retardance Class E Vegetation (See the "Retardation Class for Lining Materials" table above)	0.35	17
Woven Paper	0.15	7
Jute Net	0.45	22
Single Fiberglass	0.60	29
Double Fiberglass	0.85	41
Straw W/Net	1.45	69
Curled Wood Mat	1.55	74
Synthetic Mat	2.00	96
Gravel, D_{50} = 1 in. or 25 mm	0.40	19
Gravel, D_{50} = 2 in. or 50 mm	0.80	38
Rock, D_{50} = 6 in. or 150 mm	2.50	120
Rock, D_{50} = 12 in. or 300 mm	5.00	239
6-in. or 50-mm Gabions	35.00	1675
4-in. or 100-mm Geoweb	10.00	479
Soil Cement (8% cement)	>45	>2154
Dycel w/out Grass	>7	>335
Petraflex w/out Grass	>32	>1532
Armorflex w/out Grass	12-20	574-957
Erikamat w/3-in or 75-mm Asphalt	13-16	622-766
Erikamat w/1-in. or 25 mm Asphalt	<5	<239
Armorflex Class 30 with longitudinal and lateral cables, no grass	>34	>1628
Dycel 100, longitudinal cables, cells filled with mortar	<12	<574
Concrete construction blocks, granular filter underlayer	>20	>957
Wedge-shaped blocks with drainage slot	>25	>1197

Table 13 – Manning's Roughness Coefficient and Design Summary for ACB (from Ayres, 2001)

Table 3.1. Summary of Hydraulic Conditions, Channel Lock 450 System.					
Test Number	**1**	**2**	**3**	**4**	**5**
Nominal Overtopping depth, ft	0.75	1.25	2	3	4
Discharge, ft^3/s (based on pint velocities)	6.0	14.10	28.8	50.8	80.0
Bed slope, ft/ft (vert./horiz.)	0.33	0.33	0.33	0.33	0.33
Stations used for analysis (ft)	19.7 - 31.1	19.7 - 31.1	18.0 - 25.4	19.7 - 29.2	21.6 - 27.5
Energy slope, ft/ft (along slope)	0.33	0.30	0.23	0.22	0.15
Representative depth, ft	0.15	0.25	0.49	0.77	1.05
Representative velocity, ft/s	10.0	14.2	14.7	16.6	19.0
Range of shear stress, lb/ft^2	2.7 - 3.1	3.6 - 4.6	6.7 - 7.0	9.1 - 10.7	7.5 - 9.1
Manning's n value	0.024	0.023	0.030	0.036	0.030
Darcy friction factor	0.128	0.095	0.134	0.161	0.104
Comments	Stable	Stable	Stable	Minor, isolated voids in soil downstream of sta. 37.0 ft. Intimate contact maintained.	Failed downstream of Sta. 27.5

Table 14 – Mid-Slope Drainage Bench and Drainage Downchute Geometry and Results

Contributing Drainage Area	Channel Slope (ft/ft)	Channel Dimensions (minimum)						25-year				100-year				Channel Lining
		Length (ft)	Bottom Width (ft)	Depth (ft)	Left Side Slope (H:V)	Right Side Slope (H:V)	Top Width (ft)	Peak Flow (cfs)	Peak Depth (ft)	Peak Velocity (ft/s)	Tractive Stress (psf)	Peak Flow (cfs)	Peak Depth (ft)	Peak Velocity (ft/s)	Tractive Stress (psf)	
2B	0.020	1072	0.0	2.0	3:1	6:1	18	7.44	0.67	3.69	0.41	11.12	0.78	4.08	0.47	Grass
2C	0.020	1205	0.0	2.0	3:1	6:1	18	18.30	0.94	4.63	0.57	27.36	1.09	5.11	0.66	Grass
2D	0.020	175	0.0	2.0	3:1	6:1	18	3.26	0.49	3.01	0.30	4.88	0.57	3.32	0.35	Grass
5B	0.020	613	0.0	2.0	3:1	6:1	18	10.86	0.77	4.06	0.47	16.24	0.90	4.49	0.54	Grass
5C	0.020	231	0.0	2.0	3:1	6:1	18	4.39	0.55	3.24	0.33	6.56	0.64	3.58	0.39	Grass
11B	0.020	1307	0.0	2.0	3:1	6:1	18	7.06	0.66	3.65	0.40	10.56	0.76	4.03	0.46	Grass
11C	0.080	631	0.0	2.0	3:1	3:1	12	8.72	0.67	6.52	1.58	13.04	0.78	7.21	1.84	TRM
11D	0.028	882	0.0	2.0	3:1	6:1	18	21.78	0.94	5.48	0.80	32.56	1.09	6.06	0.93	Grass
11E	0.020	1142	0.0	2.0	3:1	6:1	18	11.82	0.80	4.15	0.48	17.68	0.93	4.59	0.56	Grass
11F	0.020	892	0.0	2.0	3:1	6:1	18	6.63	0.64	3.59	0.39	9.92	0.75	3.97	0.45	Grass
14A	0.020	305	0.0	2.0	3:1	6:1	18	3.16	0.49	2.98	0.29	4.72	0.56	3.30	0.34	Grass
14B	0.020	997	0.0	2.0	3:1	6:1	18	8.77	0.71	3.85	0.43	13.12	0.83	4.26	0.50	Grass
14C	0.020	445	0.0	2.0	3:1	6:1	18	7.12	0.66	3.65	0.40	10.64	0.77	4.04	0.46	Grass
14D	0.020	1124	0.0	2.0	3:1	6:1	18	19.64	0.96	4.71	0.58	29.36	1.12	5.21	0.68	Grass
Downchute 1	0.333	245	8.0	2.0	3:1	3:1	20	76.03	0.55	14.29	9.62	111.34	0.68	16.19	11.59	ACB
Downchute 2	0.333	255	6.0	2.0	3:1	3:1	18	57.95	0.55	13.86	9.19	80.24	0.66	15.35	10.70	ACB
Downchute 3	0.333	333	6.0	2.0	3:1	3:1	18	60.44	0.56	14.04	9.37	90.25	0.70	15.91	11.30	ACB
Downchute 4	0.333	323	6.0	2.0	3:1	3:1	18	38.68	0.44	12.16	7.55	57.84	0.55	13.85	9.18	ACB

Table 15 – Perimeter Drainage Channel Geometry and Results

Perimeter Channel Segment	Channel Slope (ft/ft)	Channel Dimensions (minimum)					25-year				100-year				Channel Lining
		Length (ft)	Bottom Width (ft)	Depth (ft)	Side Slopes (H:V)	Top Width (ft)	Peak Flow (cfs)	Peak Depth (ft)	Peak Velocity (ft/s)	Tractive Stress (psf)	Peak Flow (cfs)	Peak Depth (ft)	Peak Velocity (ft/s)	Tractive Stress (psf)	
Reach 1	0.015	196	5.0	3.0	3:1	23	1.87	0.20	1.72	0.16	2.80	0.25	1.98	0.20	Grass
Reach 2	0.015	127	5.0	3.0	3:1	23	79.13	1.52	5.47	0.92	115.98	1.83	6.05	1.07	Grass
Reach 3	0.009	249	5.0	3.0	3:1	23	81.97	1.76	4.54	0.61	120.22	2.11	5.03	0.71	Grass
Reach 4	0.020	66	5.0	3.0	3:1	23	82.67	1.37	6.63	1.15	121.26	1.66	7.35	1.34	TRM
Reach 5	0.021	252	5.0	3.0	3:1	23	140.62	1.76	7.78	1.48	206.21	2.11	8.61	1.72	TRM
Reach 6	0.016	335	5.0	3.0	3:1	23	146.77	1.92	7.11	1.20	215.41	2.30	7.87	1.40	TRM
Reach 7	0.017	218	5.0	3.0	3:1	23	149.61	1.92	7.23	1.24	219.65	2.31	8.00	1.44	TRM
Reach 8	0.016	1250	8.0	3.0	3:1	26	178.98	1.82	7.29	1.25	263.57	2.22	8.12	1.46	TRM
Reach 9	0.033	301	5.0	2.5	3:1	20	9.31	0.39	3.85	0.66	13.92	0.49	4.38	0.80	Grass
Reach 10	0.017	77	5.0	2.5	3:1	20	10.17	0.50	3.16	0.42	15.21	0.62	3.57	0.50	Grass
Reach 11	0.017	273	5.0	2.5	3:1	20	74.30	1.42	5.63	0.99	110.98	1.73	6.27	1.16	Grass
Reach 12	0.018	496	5.0	2.5	3:1	20	82.81	1.41	6.37	1.05	123.70	1.72	7.10	1.23	TRM
Reach 13	0.020	641	8.0	3.0	3:1	26	95.22	1.24	6.57	1.13	142.26	1.53	7.38	1.34	TRM
Outfall Ditch	0.010	550	10.0	4.0	3:1	34	306.60	2.49	7.05	1.05	554.80	3.35	8.28	1.34	TRM

Table 16 – HEC-HMS Model Results

	25-year, 24-hour Design Storm Event	**100-year, 24-hour Design Storm Event**
Peak Discharge to Detention Pond (cfs)	383.0	550.6
Peak Outflow from Detention Pond (cfs)	214.5	424.3
Peak Pond Water Surface Elevation (ft)	345.4	346.0
Peak Storage in Detention Pond (ac-ft)	13.7	15.6
Peak Discharge to Site Outfall (cfs)	297.3	574.2

FIGURES

- Figure 1 – Rainfall Distribution Map of the United States (from USDA, 1986)
- Figure 2 – Depth of Precipitation for 2-year Storm for 24-hour Duration in Texas (from USGS, 2004)
- Figure 3 – Depth of Precipitation for 25-year Storm for 24-hour Duration in Texas (from USGS, 2004)
- Figure 4 – Depth of Precipitation for 100-year Storm for 24-hour Duration in Texas (from USGS, 2004)
- Figure 5 – Contributing Drainage Areas for Surface Water Management Components
- Figure 6 – Depth of Precipitation for 25-year Storm for 15-minute Duration in Texas (from USGS, 2004)
- Figure 7 – Depth of Precipitation for 25-year Storm for 30-minute Duration in Texas (from USGS, 2004)
- Figure 8 – Depth of Precipitation for 100-year Storm for 15-minute Duration in Texas (from USGS, 2004)
- Figure 9 – Depth of Precipitation for 100-year Storm for 30-minute Duration in Texas (from USGS, 2004)

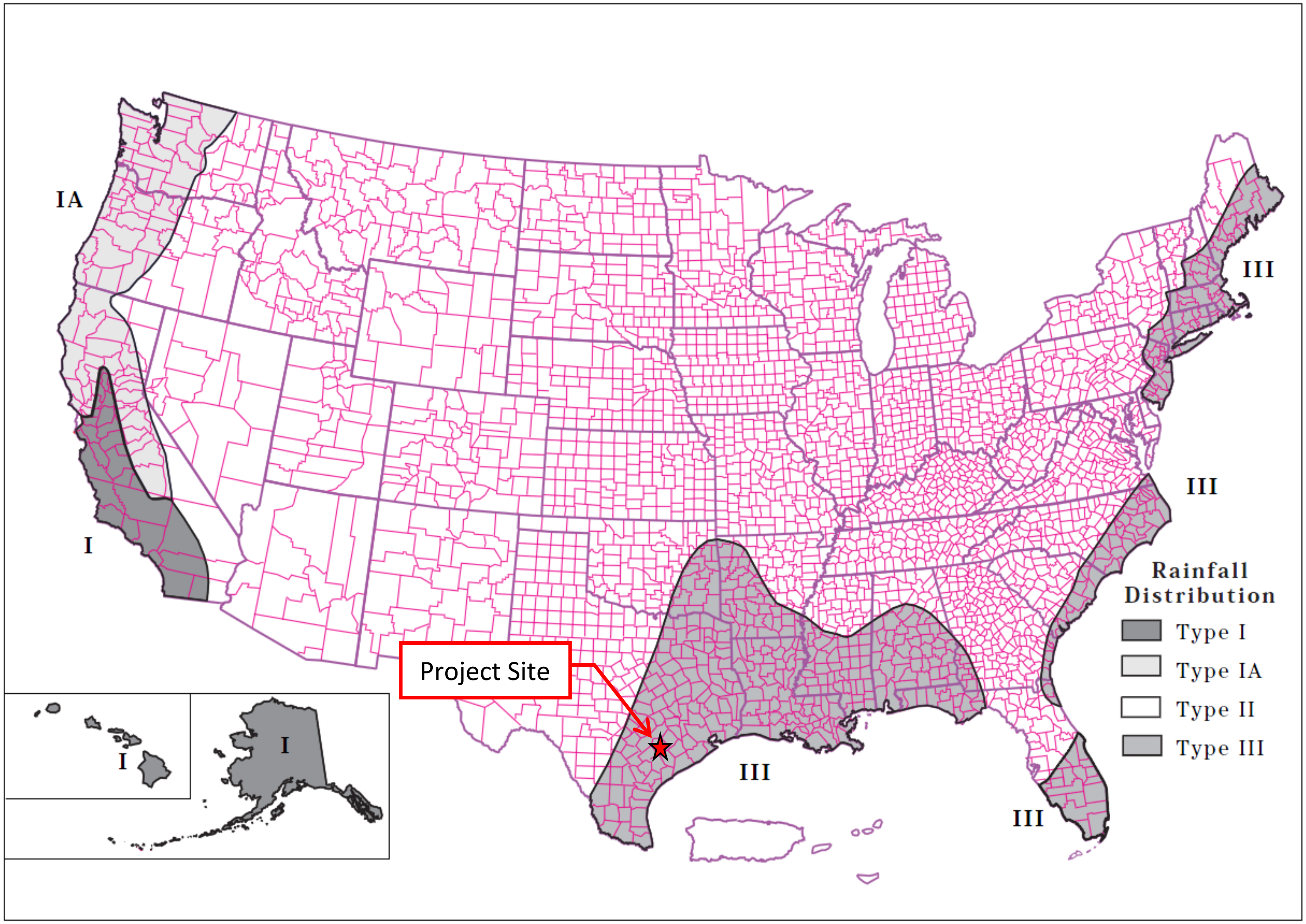


Figure 1 – Rainfall Distribution Map of the United States (from USDA, 1986)

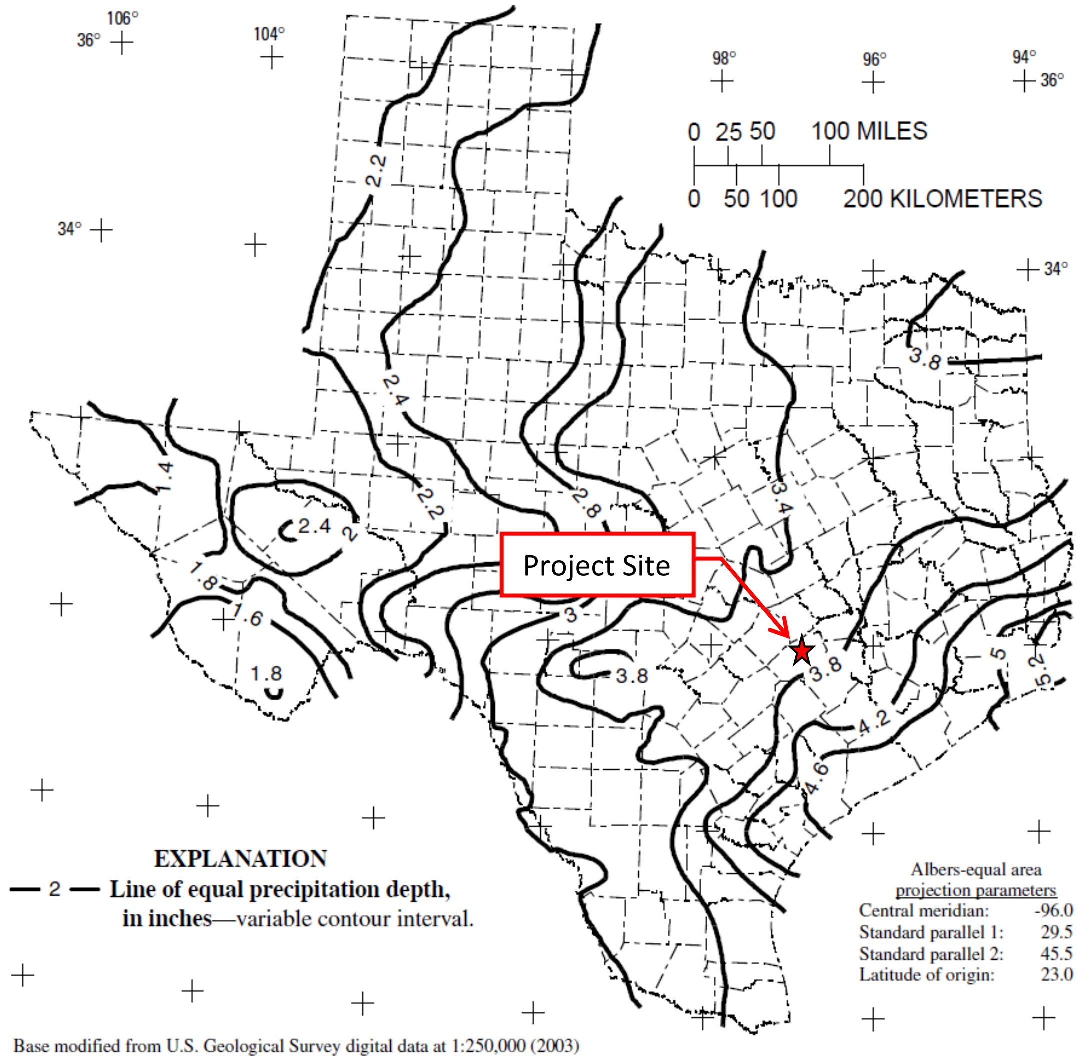


Figure 2 – Depth of Precipitation for 2-year Storm for 24-hour Duration in Texas (from USGS, 2004)

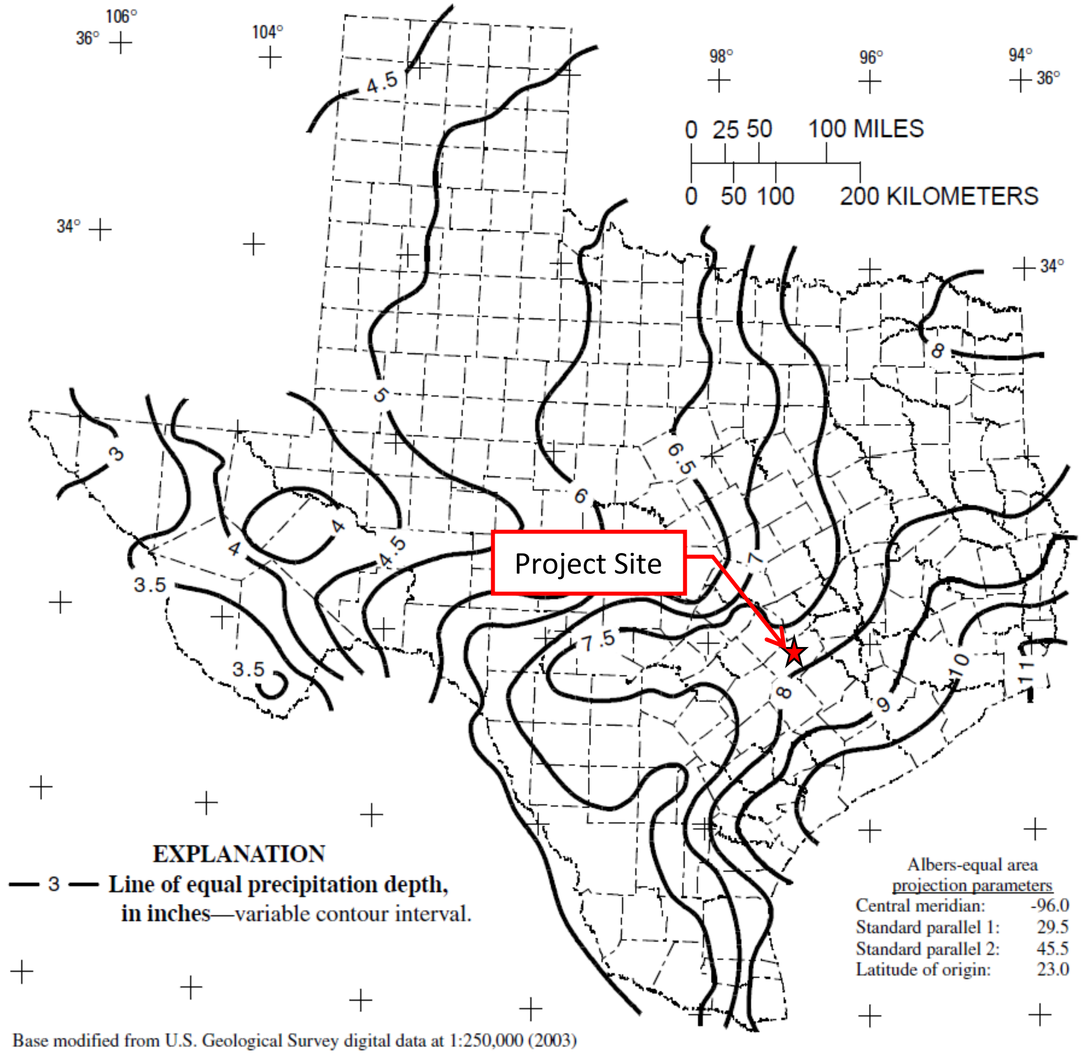


Figure 3 – Depth of Precipitation for 25-year Storm for 24-hour Duration in Texas (from USGS, 2004)

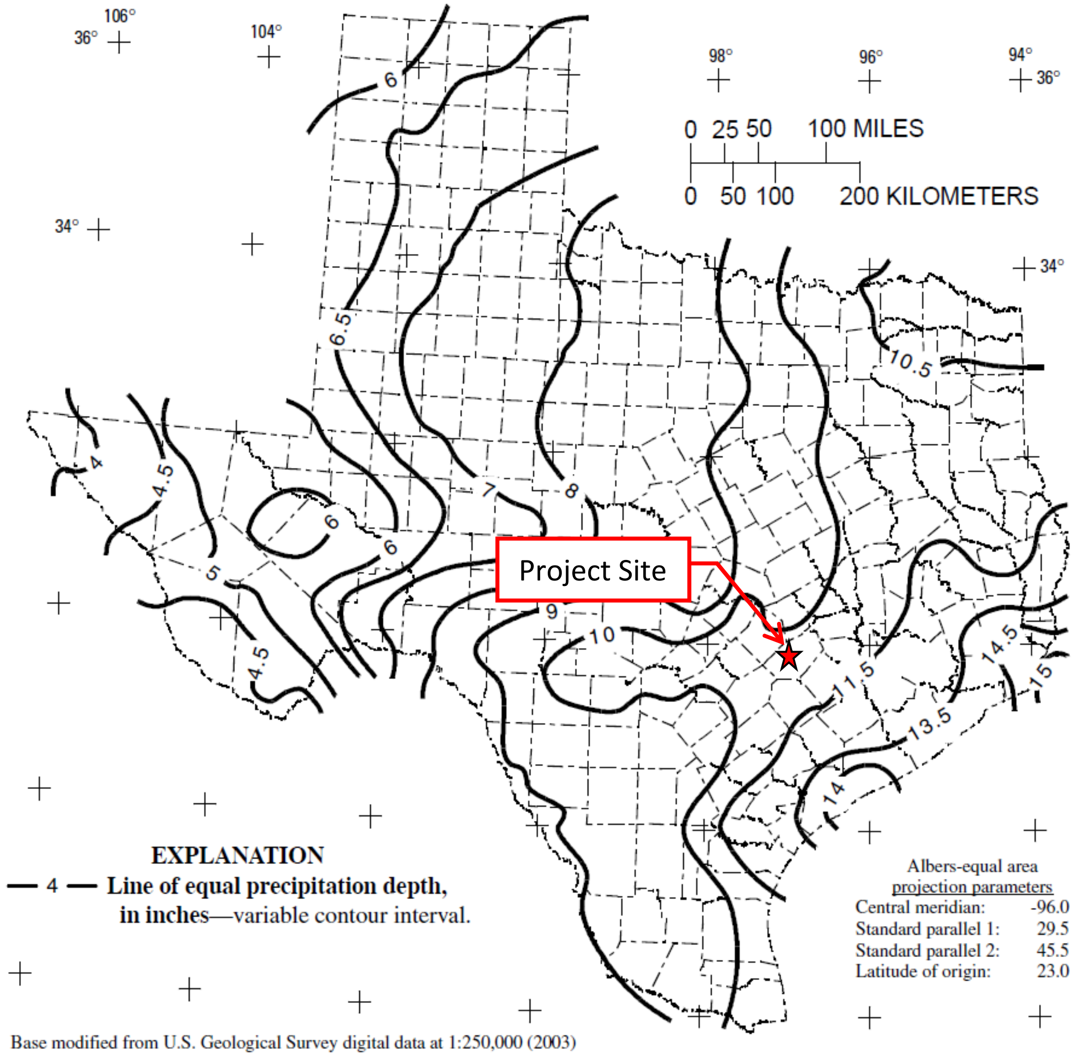
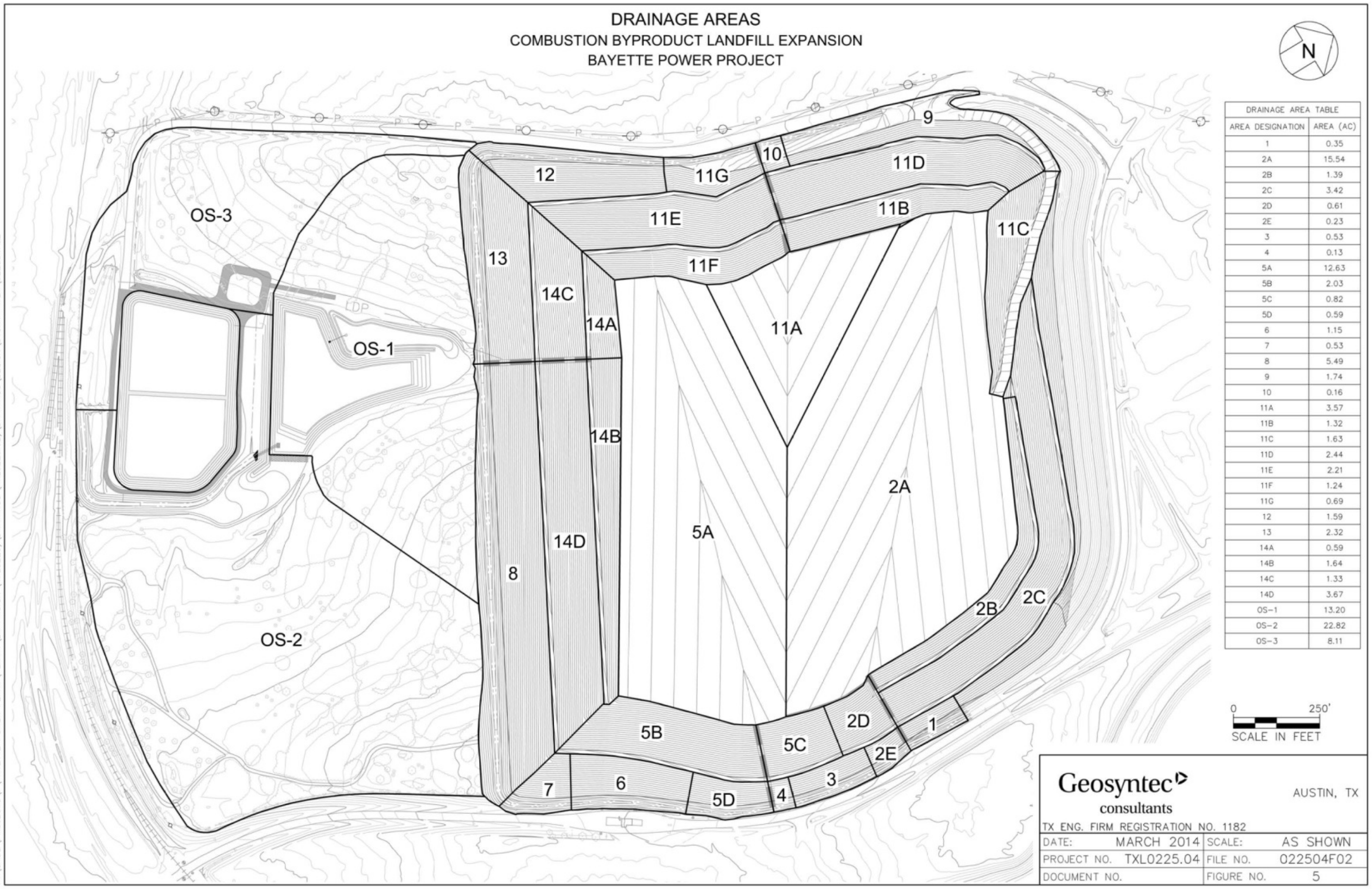


Figure 4 – Depth of Precipitation for 100-year Storm for 24-hour Duration in Texas (from USGS, 2004)



DRAINAGE AREA TABLE	
AREA DESIGNATION	AREA (AC)
1	0.35
2A	15.54
2B	1.39
2C	3.42
2D	0.61
2E	0.23
3	0.53
4	0.13
5A	12.63
5B	2.03
5C	0.82
5D	0.59
6	1.15
7	0.53
8	5.49
9	1.74
10	0.16
11A	3.57
11B	1.32
11C	1.63
11D	2.44
11E	2.21
11F	1.24
11G	0.69
12	1.59
13	2.32
14A	0.59
14B	1.64
14C	1.33
14D	3.67
OS-1	13.20
OS-2	22.82
OS-3	8.11

Figure 5 – Contributing Drainage Areas for Surface Water Management Components

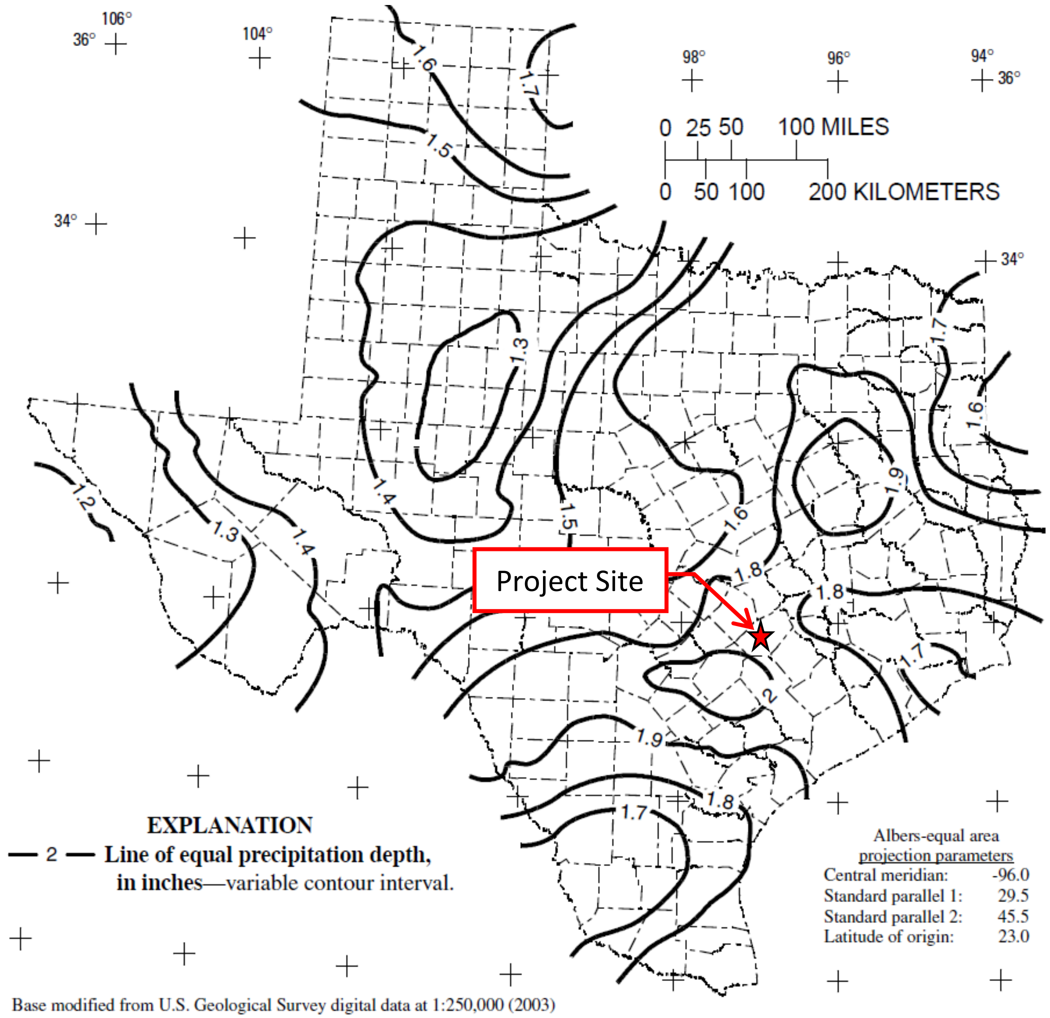


Figure 6 – Depth of Precipitation for 25-year Storm for 15-minute Duration in Texas (from USGS, 2004)

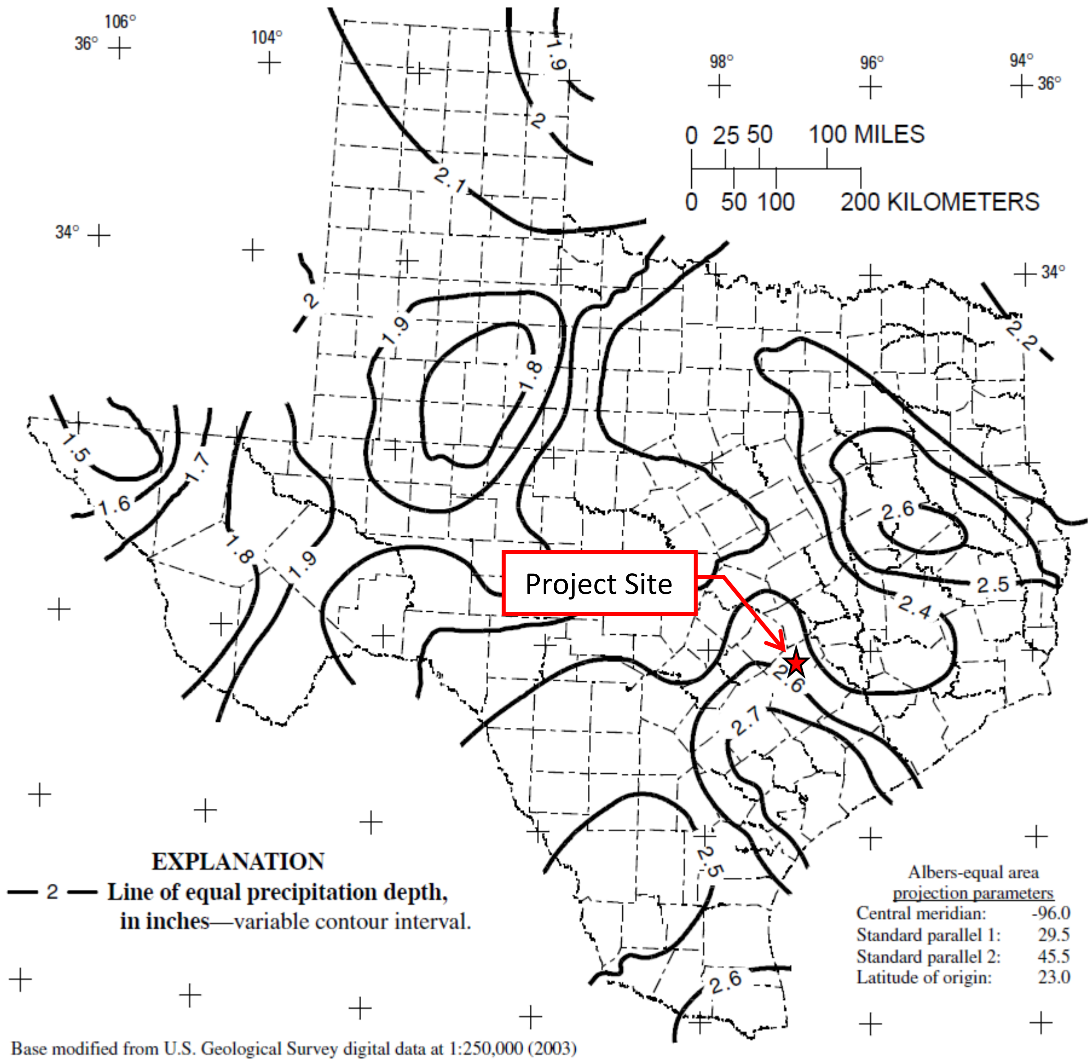


Figure 7 – Depth of Precipitation for 25-year Storm for 30-minute Duration in Texas (from USGS, 2004)

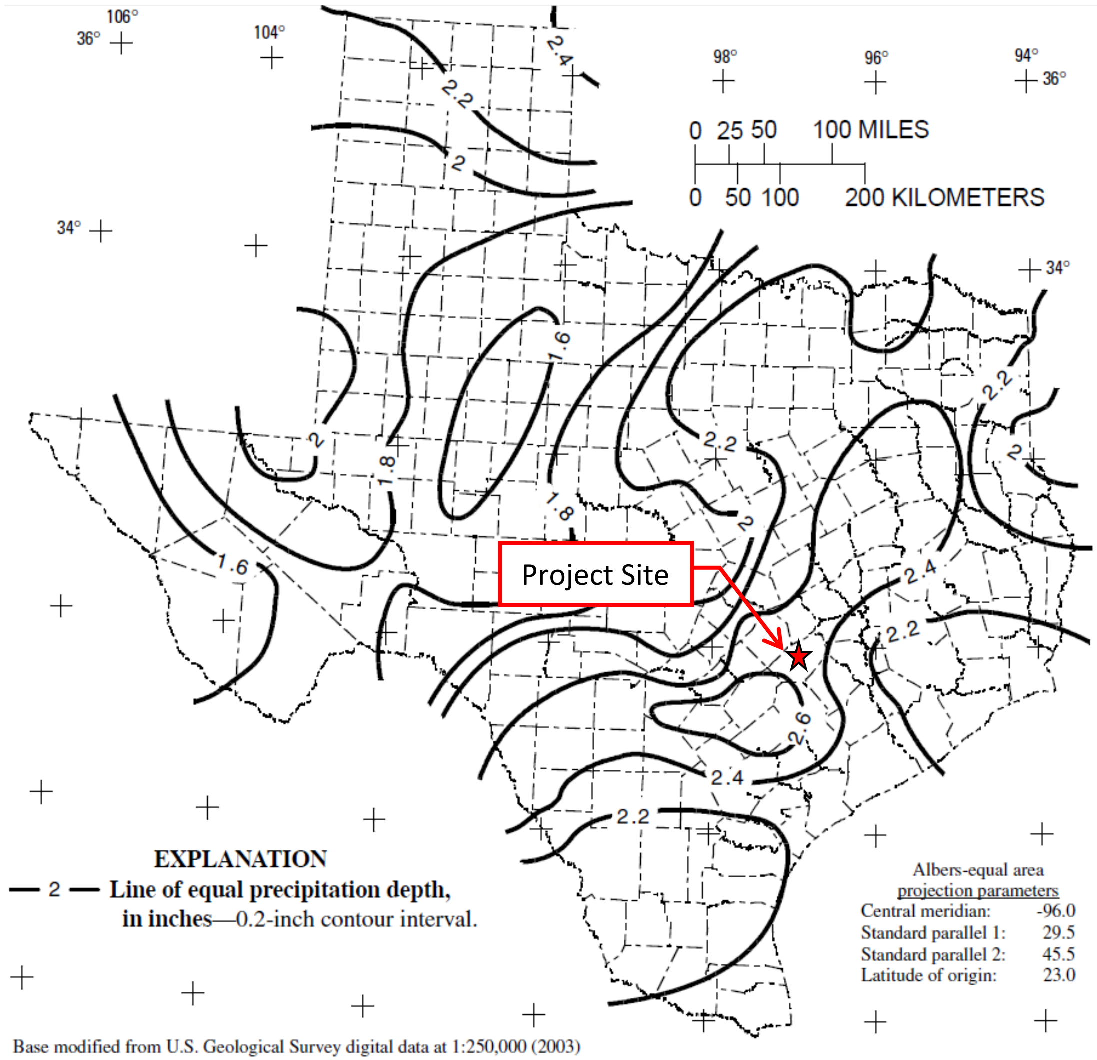


Figure 8 – Depth of Precipitation for 100-year Storm for 15-minute Duration in Texas (from USGS, 2004)

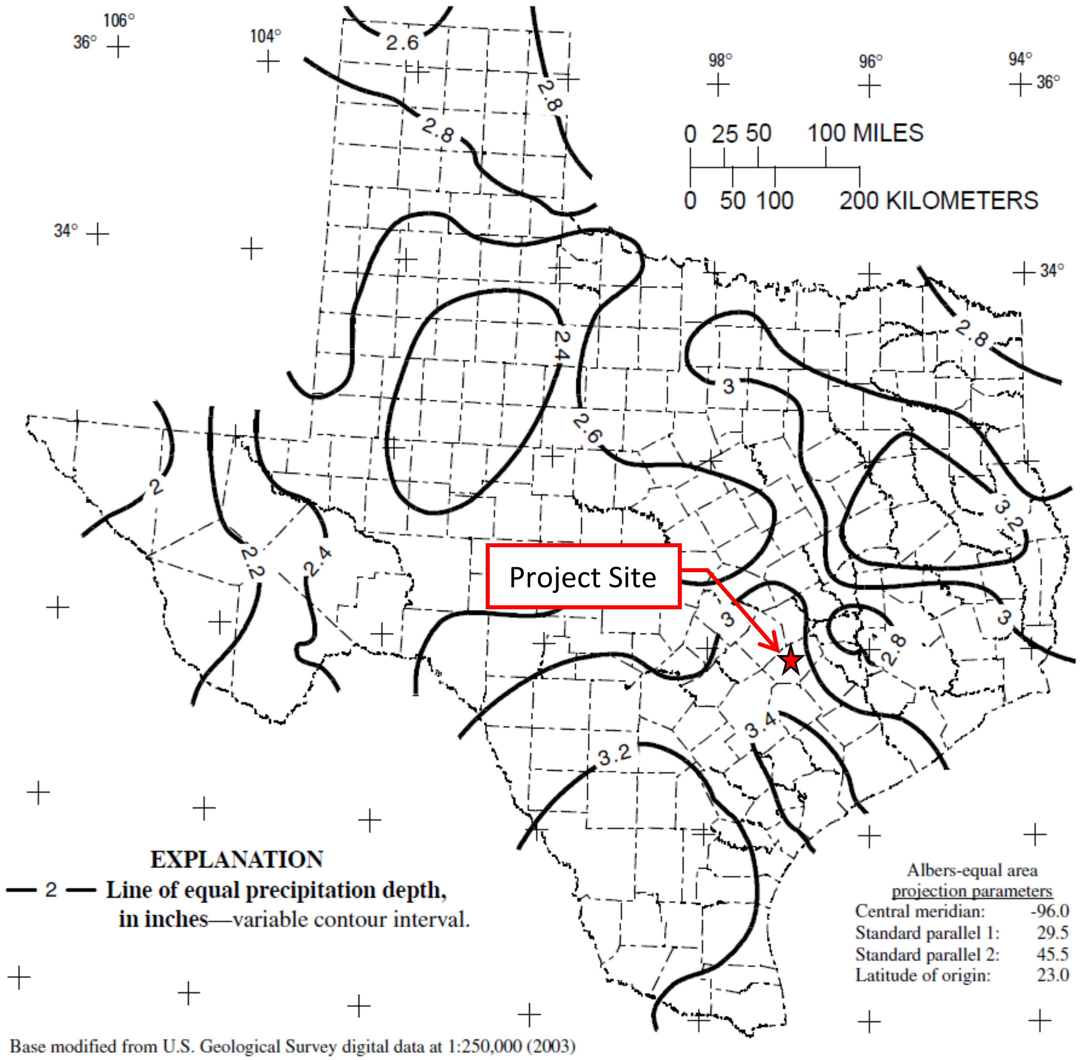


Figure 9 – Depth of Precipitation for 100-year Storm for 30-minute Duration in Texas (from USGS, 2004)

APPENDIX A-1
HYDRAULIC DESIGN CALCULATIONS
FOR LARGEST FLOW RATE

Design/Check: Trapezoidal/Triangular Channel

Methodology: Manning's Equation

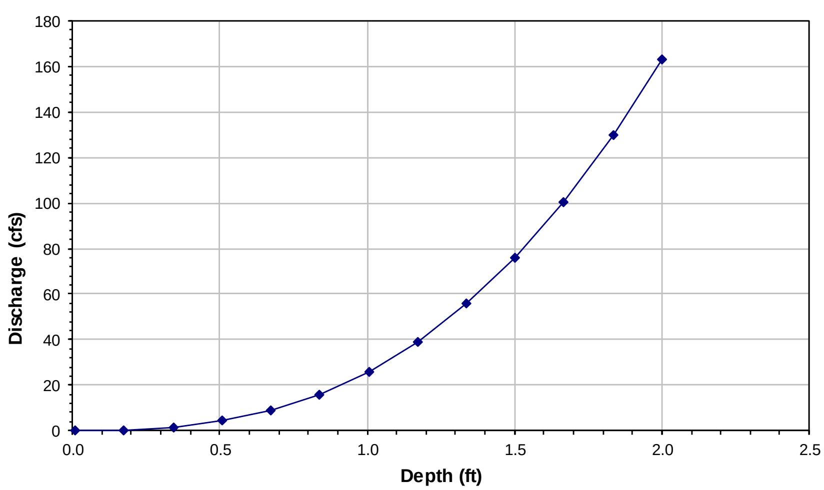
Project: LCRA Fayette Power Project, La Grange, TX

Ditch ID: **Mid-Slope Drainage Bench 11D - 100-yr Flow**

Peak Discharge, Q_{100} =	32.56	cfs
Bottom Width, B =	0.00	ft
Left Side Slope, Z_1 =	3.00	horizontal :1 vertical
Right Side Slope, Z_2 =	6.00	horizontal :1 vertical
Channel Depth, Y =	2.00	ft
Top Width, T =	18.00	ft
Manning's Roughness Coeff., n =	0.027	
Longitudinal Channel Slope, S_o =	0.0280	ft/ft

Depth of Flow Y ft	Area of Flow A ft^2	Wetted Perimeter P ft	Hydraulic Radius R=A/P ft	Average Velocity V ft/s	Discharge (Flow Rate) Q=AV ft^3/s	Avg. Tractive Stress τ_0 lb/ft^2	Comments
0.01	0.00	0.09	0.00	0.26	0.0	0.01	
0.18	0.14	1.63	0.09	1.79	0.2	0.15	
0.34	0.53	3.16	0.17	2.79	1.5	0.29	
0.51	1.16	4.69	0.25	3.63	4.2	0.43	
0.67	2.04	6.22	0.33	4.39	9.0	0.57	
0.84	3.17	7.76	0.41	5.08	16.1	0.71	
1.01	4.55	9.29	0.49	5.73	26.1	0.85	
1.17	6.17	10.82	0.57	6.35	39.1	1.00	
1.34	8.04	12.36	0.65	6.93	55.7	1.14	
1.50	10.16	13.89	0.73	7.49	76.1	1.28	
1.67	12.53	15.42	0.81	8.04	100.7	1.42	
1.83	15.14	16.96	0.89	8.56	129.6	1.56	
2.00	18.00	18.49	0.97	9.07	163.3	1.70	
1.09	5.37	10.10	0.53	6.06	32.56	0.93	DESIGN Q

Discharge versus Depth Relationship



Design/Check: Trapezoidal/Triangular Channel

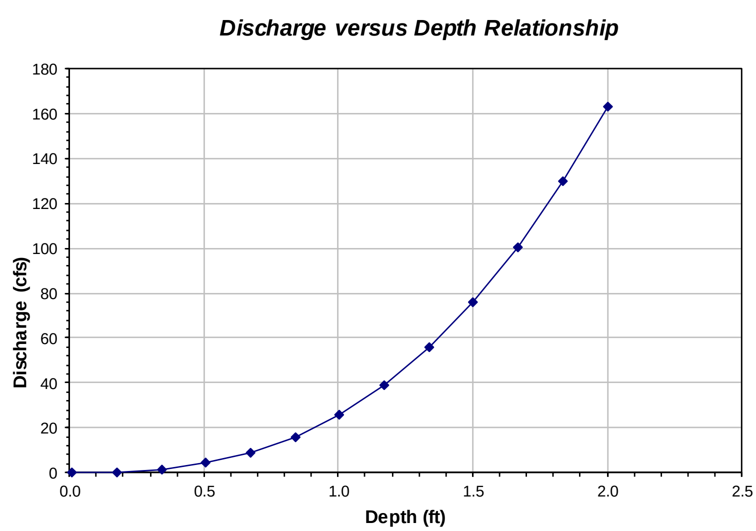
Methodology: Manning's Equation

Project: LCRA Fayette Power Project, La Grange, TX

Ditch ID: **Mid-Slope Drainage Bench 11D - 25-yr Flow**

Peak Discharge, Q_{25} =	21.78	cfs
Bottom Width, B =	0.00	ft
Left Side Slope, Z_1 =	3.00	horizontal :1 vertical
Right Side Slope, Z_2 =	6.00	horizontal :1 vertical
Channel Depth, Y =	2.00	ft
Top Width, T =	18.00	ft
Manning's Roughness Coeff., n =	0.027	
Longitudinal Channel Slope, S_o =	0.0280	ft/ft

Depth of Flow Y ft	Area of Flow A ft^2	Wetted Perimeter P ft	Hydraulic Radius R=A/P ft	Average Velocity V ft/s	Discharge (Flow Rate) Q=AV ft^3/s	Avg. Tractive Stress τ_0 lb/ft^2	Comments
0.01	0.00	0.09	0.00	0.26	0.0	0.01	
0.18	0.14	1.63	0.09	1.79	0.2	0.15	
0.34	0.53	3.16	0.17	2.79	1.5	0.29	
0.51	1.16	4.69	0.25	3.63	4.2	0.43	
0.67	2.04	6.22	0.33	4.39	9.0	0.57	
0.84	3.17	7.76	0.41	5.08	16.1	0.71	
1.01	4.55	9.29	0.49	5.73	26.1	0.85	
1.17	6.17	10.82	0.57	6.35	39.1	1.00	
1.34	8.04	12.36	0.65	6.93	55.7	1.14	
1.50	10.16	13.89	0.73	7.49	76.1	1.28	
1.67	12.53	15.42	0.81	8.04	100.7	1.42	
1.83	15.14	16.96	0.89	8.56	129.6	1.56	
2.00	18.00	18.49	0.97	9.07	163.3	1.70	
0.94	3.97	8.69	0.46	5.48	21.78	0.80	DESIGN Q



Design/Check: Trapezoidal/Triangular Channel

Methodology: Manning's Equation

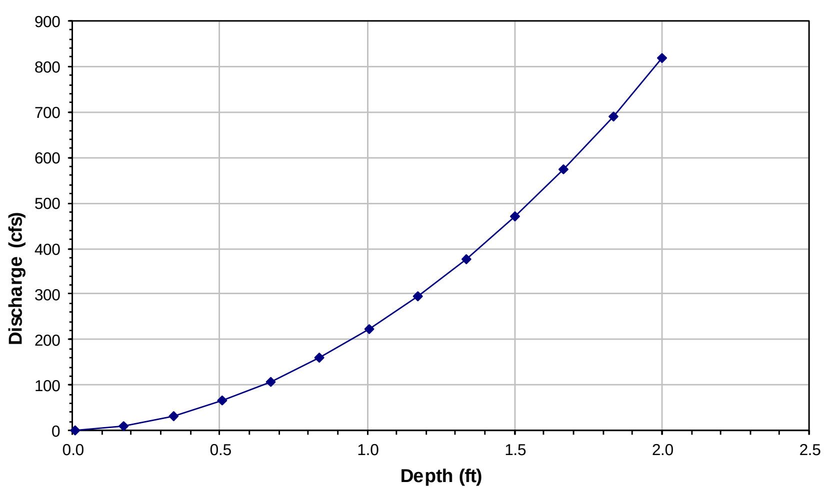
Project: LCRA Fayette Power Project, La Grange, TX

Ditch ID: **Downchute 1 - Area 2 - 100-yr Flow**

Peak Discharge, Q_{100} =	111.34	cfs
Bottom Width, B =	8.00	ft
Left Side Slope, Z_1 =	3.00	horizontal :1 vertical
Right Side Slope, Z_2 =	3.00	horizontal :1 vertical
Channel Depth, Y =	2.00	ft
Top Width, T =	20.00	ft
Manning's Roughness Coeff., n =	0.036	
Longitudinal Channel Slope, S_o =	0.3330	ft/ft

Depth of Flow Y ft	Area of Flow A ft^2	Wetted Perimeter P ft	Hydraulic Radius R=A/P ft	Average Velocity V ft/s	Discharge (Flow Rate) Q=AV ft^3/s	Avg. Tractive Stress τ_0 lb/ft^2	Comments
0.01	0.08	8.06	0.01	1.10	0.1	0.21	
0.18	1.50	9.11	0.16	7.17	10.7	3.42	
0.34	3.08	10.16	0.30	10.78	33.2	6.31	
0.51	4.83	11.21	0.43	13.63	65.9	8.96	
0.67	6.75	12.26	0.55	16.04	108.2	11.44	
0.84	8.83	13.31	0.66	18.16	160.3	13.78	
1.01	11.07	14.36	0.77	20.08	222.3	16.02	
1.17	13.48	15.41	0.87	21.85	294.5	18.18	
1.34	16.05	16.45	0.98	23.49	377.2	20.27	
1.50	18.79	17.50	1.07	25.04	470.6	22.31	
1.67	21.70	18.55	1.17	26.51	575.3	24.30	
1.83	24.77	19.60	1.26	27.92	691.4	26.26	
2.00	28.00	20.65	1.36	29.26	819.4	28.18	
0.68	6.88	12.33	0.56	16.19	111.34	11.59	DESIGN Q

Discharge versus Depth Relationship



Design/Check: Trapezoidal/Triangular Channel

Methodology: Manning's Equation

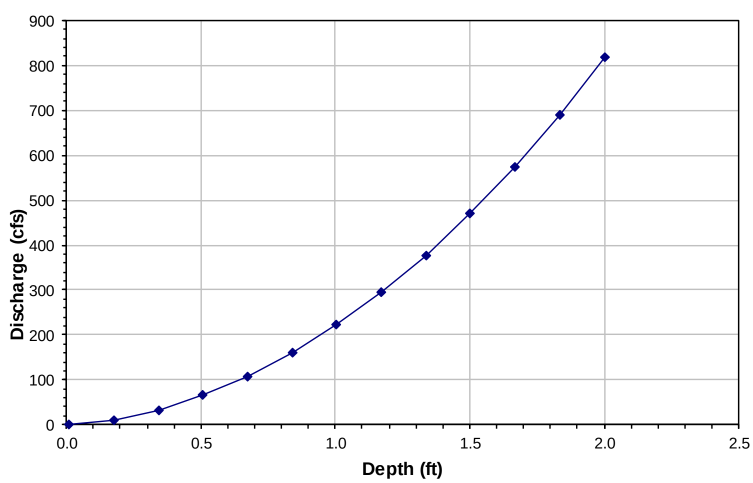
Project: LCRA Fayette Power Project, La Grange, TX

Ditch ID: **Downchute 1 - Area 2 - 25-yr Flow**

Peak Discharge, Q_{25} =	76.03	cfs
Bottom Width, B =	8.00	ft
Left Side Slope, Z_1 =	3.00	horizontal :1 vertical
Right Side Slope, Z_2 =	3.00	horizontal :1 vertical
Channel Depth, Y =	2.00	ft
Top Width, T =	20.00	ft
Manning's Roughness Coeff., n =	0.036	
Longitudinal Channel Slope, S_o =	0.3330	ft/ft

Depth of Flow Y ft	Area of Flow A ft^2	Wetted Perimeter P ft	Hydraulic Radius R=A/P ft	Average Velocity V ft/s	Discharge (Flow Rate) Q=AV ft^3/s	Avg. Tractive Stress τ_0 lb/ft^2	Comments
0.01	0.08	8.06	0.01	1.10	0.1	0.21	
0.18	1.50	9.11	0.16	7.17	10.7	3.42	
0.34	3.08	10.16	0.30	10.78	33.2	6.31	
0.51	4.83	11.21	0.43	13.63	65.9	8.96	
0.67	6.75	12.26	0.55	16.04	108.2	11.44	
0.84	8.83	13.31	0.66	18.16	160.3	13.78	
1.01	11.07	14.36	0.77	20.08	222.3	16.02	
1.17	13.48	15.41	0.87	21.85	294.5	18.18	
1.34	16.05	16.45	0.98	23.49	377.2	20.27	
1.50	18.79	17.50	1.07	25.04	470.6	22.31	
1.67	21.70	18.55	1.17	26.51	575.3	24.30	
1.83	24.77	19.60	1.26	27.92	691.4	26.26	
2.00	28.00	20.65	1.36	29.26	819.4	28.18	
0.55	5.32	11.49	0.46	14.29	76.03	9.62	DESIGN Q

Discharge versus Depth Relationship



Design/Check: Trapezoidal/Triangular Channel

Methodology: Manning's Equation

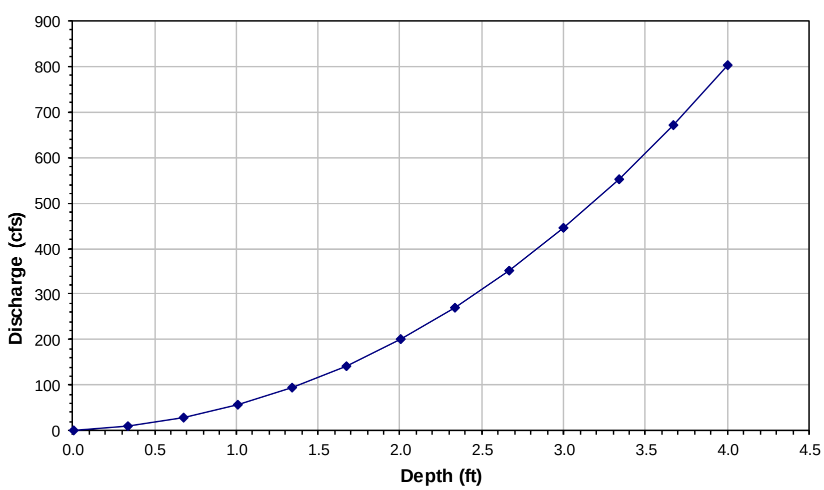
Project: LCRA Fayette Power Project, La Grange, TX

Ditch ID: **Outfall Ditch - 100-yr Flow**

Peak Discharge, Q_{100} =	554.80	cfs
Bottom Width, B =	10.00	ft
Left Side Slope, Z_1 =	3.00	horizontal :1 vertical
Right Side Slope, Z_2 =	3.00	horizontal :1 vertical
Channel Depth, Y =	4.00	ft
Top Width, T =	34.00	ft
Manning's Roughness Coeff., n =	0.030	
Longitudinal Channel Slope, S_o =	0.0100	ft/ft

Depth of Flow Y ft	Area of Flow A ft^2	Wetted Perimeter P ft	Hydraulic Radius R=A/P ft	Average Velocity V ft/s	Discharge (Flow Rate) Q=AV ft^3/s	Avg. Tractive Stress τ_0 lb/ft^2	Comments
0.01	0.10	10.06	0.01	0.23	0.0	0.01	
0.34	3.78	12.17	0.31	2.28	8.6	0.19	
0.68	8.12	14.27	0.57	3.41	27.7	0.35	
1.01	13.12	16.37	0.80	4.28	56.2	0.50	
1.34	18.79	18.47	1.02	5.02	94.4	0.63	
1.67	25.12	20.58	1.22	5.67	142.5	0.76	
2.01	32.11	22.68	1.42	6.26	201.1	0.88	
2.34	39.77	24.78	1.60	6.81	270.7	1.00	
2.67	48.09	26.89	1.79	7.32	352.0	1.12	
3.00	57.07	28.99	1.97	7.80	445.3	1.23	
3.34	66.72	31.09	2.15	8.26	551.4	1.34	
3.67	77.03	33.20	2.32	8.71	670.7	1.45	
4.00	88.00	35.30	2.49	9.13	803.8	1.56	
3.35	67.02	31.16	2.15	8.28	554.80	1.34	DESIGN Q

Discharge versus Depth Relationship



Design/Check: Trapezoidal/Triangular Channel

Methodology: Manning's Equation

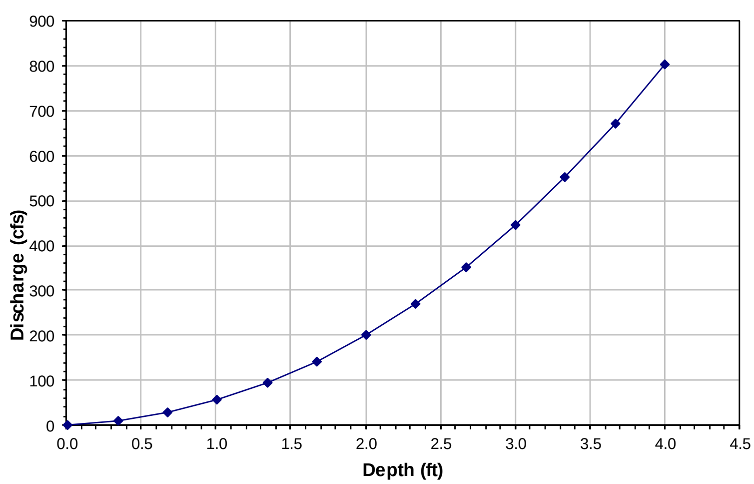
Project: LCRA Fayette Power Project, La Grange, TX

Ditch ID: **Outfall Ditch - 25-yr Flow**

Peak Discharge, Q_{25} =	306.60	cfs
Bottom Width, B =	10.00	ft
Left Side Slope, Z_1 =	3.00	horizontal :1 vertical
Right Side Slope, Z_2 =	3.00	horizontal :1 vertical
Channel Depth, Y =	4.00	ft
Top Width, T =	34.00	ft
Manning's Roughness Coeff., n =	0.030	
Longitudinal Channel Slope, S_o =	0.0100	ft/ft

Depth of Flow Y ft	Area of Flow A ft^2	Wetted Perimeter P ft	Hydraulic Radius R=A/P ft	Average Velocity V ft/s	Discharge (Flow Rate) Q=AV ft^3/s	Avg. Tractive Stress τ_0 lb/ft^2	Comments
0.01	0.10	10.06	0.01	0.23	0.0	0.01	
0.34	3.78	12.17	0.31	2.28	8.6	0.19	
0.68	8.12	14.27	0.57	3.41	27.7	0.35	
1.01	13.12	16.37	0.80	4.28	56.2	0.50	
1.34	18.79	18.47	1.02	5.02	94.4	0.63	
1.67	25.12	20.58	1.22	5.67	142.5	0.76	
2.01	32.11	22.68	1.42	6.26	201.1	0.88	
2.34	39.77	24.78	1.60	6.81	270.7	1.00	
2.67	48.09	26.89	1.79	7.32	352.0	1.12	
3.00	57.07	28.99	1.97	7.80	445.3	1.23	
3.34	66.72	31.09	2.15	8.26	551.4	1.34	
3.67	77.03	33.20	2.32	8.71	670.7	1.45	
4.00	88.00	35.30	2.49	9.13	803.8	1.56	
2.49	43.51	25.75	1.69	7.05	306.60	1.05	DESIGN Q

Discharge versus Depth Relationship



APPENDIX A-2
HEC-HMS OUTPUT RESULTS

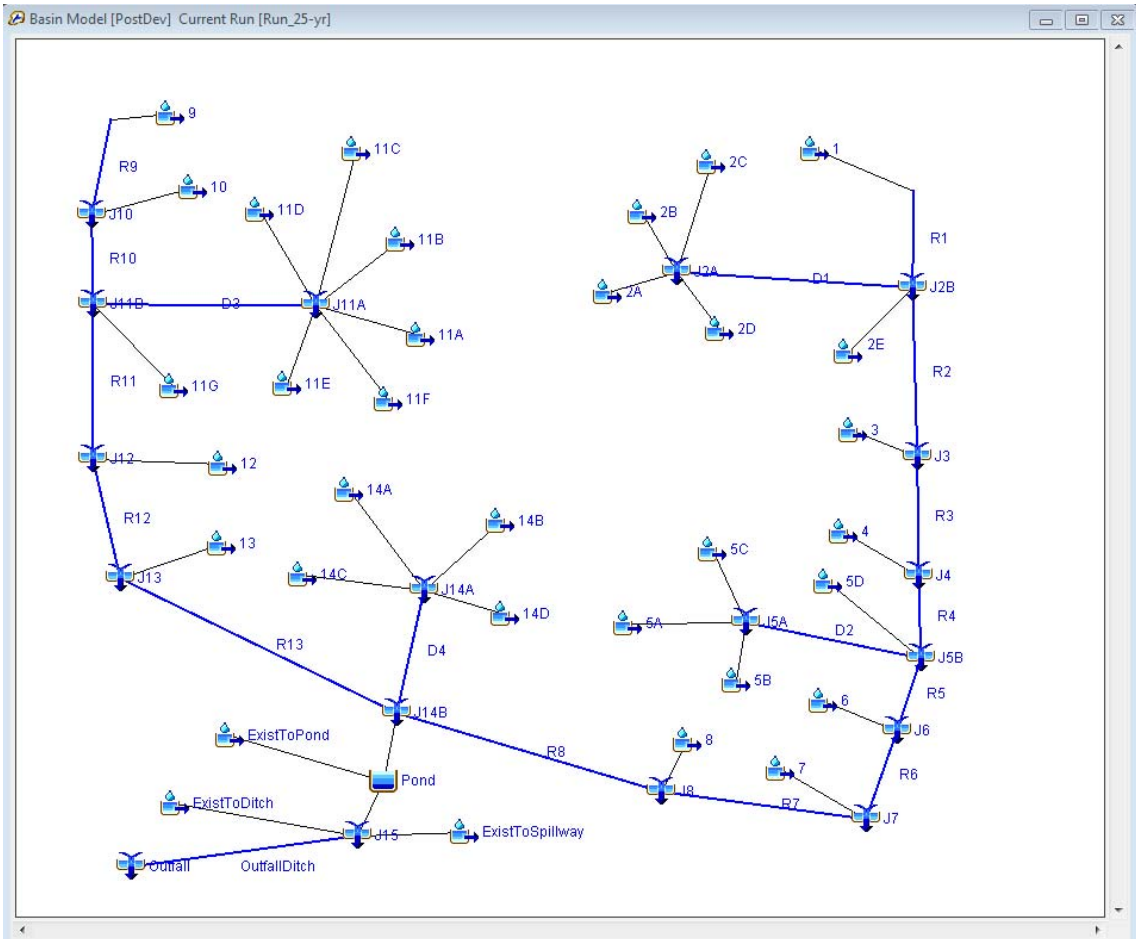


Figure B.1 – HEC-HMS Nodal Network

Table B.1 – 25-Year HEC-HMS Results

Hydrologic Element	Drainage Area (mi^2)	Peak Discharge (cfs)	Time of Peak	Volume (ac-ft)
1	0.000547	2	01Jan2013, 12:07	0.2
10	0.000252	0.9	01Jan2013, 12:07	0.1
11A	0.005578	17.9	01Jan2013, 12:11	1.8
11B	0.002063	7.5	01Jan2013, 12:07	0.6
11C	0.002547	9.2	01Jan2013, 12:07	0.8
11D	0.003813	13.8	01Jan2013, 12:07	1.2
11E	0.003453	12.5	01Jan2013, 12:07	1.1
11F	0.001938	7	01Jan2013, 12:07	0.6
11G	0.001078	3.9	01Jan2013, 12:07	0.3
12	0.002484	9	01Jan2013, 12:07	0.8
13	0.003625	13.1	01Jan2013, 12:07	1.1
14A	0.000922	3.3	01Jan2013, 12:07	0.3
14B	0.002563	9.3	01Jan2013, 12:07	0.8
14C	0.002078	7.5	01Jan2013, 12:07	0.7
14D	0.005734	20.8	01Jan2013, 12:07	1.8
2A	0.024281	69.7	01Jan2013, 12:15	7.6
2B	0.002172	7.9	01Jan2013, 12:07	0.7
2C	0.00534	19.4	01Jan2013, 12:07	1.7
2D	0.000953	3.5	01Jan2013, 12:07	0.3
2E	0.000359	1.3	01Jan2013, 12:07	0.1
3	0.000828	3	01Jan2013, 12:07	0.3
4	0.000203	0.7	01Jan2013, 12:07	0.1
5A	0.019734	57.9	01Jan2013, 12:14	6.2
5B	0.003172	11.5	01Jan2013, 12:07	1
5C	0.001281	4.6	01Jan2013, 12:07	0.4
5D	0.000922	3.3	01Jan2013, 12:07	0.3
6	0.001797	6.5	01Jan2013, 12:07	0.6
7	0.000828	3	01Jan2013, 12:07	0.3
8	0.008578	31.1	01Jan2013, 12:07	2.7
9	0.002719	9.9	01Jan2013, 12:07	0.9
D1	0.032746	93.2	01Jan2013, 12:12	10.3
D2	0.024187	70.3	01Jan2013, 12:12	7.6
D3	0.019392	66.7	01Jan2013, 12:08	6.1
D4	0.011297	40.9	01Jan2013, 12:08	3.6
J10	0.002971	10.7	01Jan2013, 12:08	0.9
J11A	0.019392	66.9	01Jan2013, 12:08	6.1

J11B	0.023441	81.4	01Jan2013, 12:08	7.4
J12	0.025925	90.1	01Jan2013, 12:09	8.2
J13	0.02955	102.3	01Jan2013, 12:10	9.3
J14A	0.011297	41	01Jan2013, 12:07	3.6
J14B	0.111842	333.9	01Jan2013, 12:12	35.2
J15	0.168132	274.8	01Jan2013, 12:29	49.1
J2A	0.032746	93.3	01Jan2013, 12:12	10.3
J2B	0.033652	96.1	01Jan2013, 12:12	10.6
J3	0.03448	98.6	01Jan2013, 12:12	10.9
J4	0.034683	99	01Jan2013, 12:12	10.9
J5A	0.024187	70.4	01Jan2013, 12:12	7.6
J5B	0.059792	172	01Jan2013, 12:12	18.8
J6	0.061589	177	01Jan2013, 12:13	19.4
J7	0.062417	179.3	01Jan2013, 12:13	19.7
J8	0.070995	203.7	01Jan2013, 12:12	22.4
OS1	0.02063	49.8	01Jan2013, 12:14	5.1
OS2	0.03566	76.4	01Jan2013, 12:18	8.8
OS3	0.01267	24.5	01Jan2013, 12:23	3.1
Outfall	0.180802	297.3	01Jan2013, 12:30	52.2
OutfallDitch	0.168132	274.5	01Jan2013, 12:30	49.1
Pond	0.132472	214.5	01Jan2013, 12:30	40.2
R1	0.000547	2	01Jan2013, 12:09	0.2
R10	0.002971	10.7	01Jan2013, 12:09	0.9
R11	0.023441	81.3	01Jan2013, 12:09	7.4
R12	0.025925	89.9	01Jan2013, 12:10	8.2
R13	0.02955	102.2	01Jan2013, 12:11	9.3
R2	0.033652	96	01Jan2013, 12:12	10.6
R3	0.03448	98.4	01Jan2013, 12:13	10.9
R4	0.034683	99	01Jan2013, 12:13	10.9
R5	0.059792	171.9	01Jan2013, 12:13	18.8
R6	0.061589	176.9	01Jan2013, 12:13	19.4
R7	0.062417	178.9	01Jan2013, 12:13	19.7
R8	0.070995	203.1	01Jan2013, 12:14	22.4
R9	0.002719	9.8	01Jan2013, 12:08	0.9

Table B.2 – 100-Year HEC-HMS Results

Hydrologic Element	Drainage Area (mi^2)	Peak Discharge (cfs)	Time of Peak	Volume (ac-ft)
1	0.000547	2.8	01Jan2013, 12:07	0.2
10	0.000252	1.3	01Jan2013, 12:07	0.1
11A	0.005578	25.4	01Jan2013, 12:11	2.5
11B	0.002063	10.6	01Jan2013, 12:07	0.9
11C	0.002547	13.1	01Jan2013, 12:07	1.2
11D	0.003813	19.6	01Jan2013, 12:07	1.7
11E	0.003453	17.7	01Jan2013, 12:07	1.6
11F	0.001938	9.9	01Jan2013, 12:07	0.9
11G	0.001078	5.5	01Jan2013, 12:07	0.5
12	0.002484	12.7	01Jan2013, 12:07	1.1
13	0.003625	18.6	01Jan2013, 12:07	1.6
14A	0.000922	4.7	01Jan2013, 12:07	0.4
14B	0.002563	13.2	01Jan2013, 12:07	1.2
14C	0.002078	10.7	01Jan2013, 12:07	0.9
14D	0.005734	29.4	01Jan2013, 12:07	2.6
2A	0.024281	98.8	01Jan2013, 12:15	11
2B	0.002172	11.1	01Jan2013, 12:07	1
2C	0.00534	27.4	01Jan2013, 12:07	2.4
2D	0.000953	4.9	01Jan2013, 12:07	0.4
2E	0.000359	1.8	01Jan2013, 12:07	0.2
3	0.000828	4.2	01Jan2013, 12:07	0.4
4	0.000203	1	01Jan2013, 12:07	0.1
5A	0.019734	82	01Jan2013, 12:14	9
5B	0.003172	16.3	01Jan2013, 12:07	1.4
5C	0.001281	6.6	01Jan2013, 12:07	0.6
5D	0.000922	4.7	01Jan2013, 12:07	0.4
6	0.001797	9.2	01Jan2013, 12:07	0.8
7	0.000828	4.2	01Jan2013, 12:07	0.4
8	0.008578	44	01Jan2013, 12:07	3.9
9	0.002719	14	01Jan2013, 12:07	1.2
D1	0.032746	132.2	01Jan2013, 12:12	14.9
D2	0.024187	99.7	01Jan2013, 12:12	11
D3	0.019392	94.6	01Jan2013, 12:08	8.8
D4	0.011297	57.8	01Jan2013, 12:08	5.1
J10	0.002971	15.2	01Jan2013, 12:08	1.3
J11A	0.019392	94.8	01Jan2013, 12:08	8.8

J11B	0.023441	115.3	01Jan2013, 12:08	10.6
J12	0.025925	127.5	01Jan2013, 12:09	11.8
J13	0.02955	145.3	01Jan2013, 12:09	13.4
J14A	0.011297	58	01Jan2013, 12:07	5.1
J14B	0.111842	475.8	01Jan2013, 12:12	50.8
J15	0.168132	537.7	01Jan2013, 12:21	72
J2A	0.032746	132.2	01Jan2013, 12:12	14.9
J2B	0.033652	136.2	01Jan2013, 12:12	15.3
J3	0.03448	139.7	01Jan2013, 12:12	15.7
J4	0.034683	140.5	01Jan2013, 12:12	15.8
J5A	0.024187	99.8	01Jan2013, 12:12	11
J5B	0.059792	244	01Jan2013, 12:12	27.2
J6	0.061589	251.2	01Jan2013, 12:12	28
J7	0.062417	254.3	01Jan2013, 12:13	28.4
J8	0.070995	289.7	01Jan2013, 12:12	32.2
OS1	0.02063	75.5	01Jan2013, 12:13	7.8
OS2	0.03566	116	01Jan2013, 12:18	13.5
OS3	0.01267	37.2	01Jan2013, 12:23	4.8
Outfall	0.180802	574.2	01Jan2013, 12:22	76.8
OutfallDitch	0.168132	537	01Jan2013, 12:22	72
Pond	0.132472	424.3	01Jan2013, 12:21	58.5
R1	0.000547	2.8	01Jan2013, 12:08	0.2
R10	0.002971	15.2	01Jan2013, 12:08	1.3
R11	0.023441	115.1	01Jan2013, 12:09	10.6
R12	0.025925	127.3	01Jan2013, 12:10	11.8
R13	0.02955	144.9	01Jan2013, 12:10	13.4
R2	0.033652	136.2	01Jan2013, 12:12	15.3
R3	0.03448	139.6	01Jan2013, 12:12	15.7
R4	0.034683	140.4	01Jan2013, 12:12	15.8
R5	0.059792	243.6	01Jan2013, 12:13	27.2
R6	0.061589	251	01Jan2013, 12:13	28
R7	0.062417	254.1	01Jan2013, 12:13	28.4
R8	0.070995	288.9	01Jan2013, 12:14	32.2
R9	0.002719	13.9	01Jan2013, 12:08	1.2

APPENDIX B

Final Cover Soil Erosion Loss Calculation

Written by:	**V. Krishnan**	Date:	**10/12/2015**	Reviewed & Revised by:	**Z. Islam**	Date:	**10/29/2015**
Client:	**LCRA**	Project:	**FPP CBL Expansion**	Project No.:	**TXL0225**	Phase No.:	**08**

FINAL COVER SOIL EROSION LOSS CALCULATIONS
LCRA FPP COMBUSTION BYPRODUCT LANDFILL

STATE OF TEXAS
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Beth Ann Gross
10/13/2016

GEOSYNTEC CONSULTANTS, INC.
TX ENG FIRM REGISTRATION NO. F-1182

1 PURPOSE

The purpose of this calculation package is to present the evaluation of the long term effects of erosion and soil loss for the completed final cover system of the LCRA FPP Combustion Byproduct Landfill (site) in La Grange, Texas. This package provides calculations for the annual soil loss from the vegetative support layer of the final cover system on the top deck and side slopes of Cells 1 and 2 of the landfill. The estimated amount of erosion was calculated using the Revised Universal Soil Loss Equation (RUSLE).

2 PROJECT BACKGROUND

The final cover placement and closure of the landfill is expected to be completed when the design capacity of Cells 1 and 2 is reached. The top deck of the landfill will have a surface slope of approximately 3% and the external side slopes will be graded to 3 horizontal to 1 vertical (3H:1V). The final cover is designed with a surface water management system with permanent drainage features, including drainage downchutes, mid-slope drainage benches, perimeter drainage channels, and a chambered sediment/storm water detention pond. The drainage downchutes will convey flow from the top deck to the perimeter drainage channel and will be lined with articulated concrete block (ACB). The mid-slope drainage benches will collect and convey storm water runoff from the side slopes to the downchutes. The perimeter drainage channel will also collect and convey flow from the downchutes and side slopes to the storm water detention pond.

3 FINAL COVER SOIL EROSION LOSS CALCULATION METHODOLOGY

The method to calculate the soil erosion loss over the project area was obtained from the guidance document *Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE)* (USDA, 1997) as well as previously published information provided by USDA. This document presents the RUSLE methodology and rationale for selecting each of the equation's parameters. The RUSLE is written as follows:

$$A = R \times K \times LS \times C \times P$$

where: A = computed spatial average annual soil loss (tons/acre/year);

R = average annual rainfall runoff erosivity factor;

K = soil erodibility factor;

LS = topographic factor;

C = cover management factor; and

P = erosion control practice factor.

4 RUSLE INPUT PARAMETERS

4.1 Rainfall Runoff Erosivity Factor (R)

The rainfall runoff erosivity factor is defined as the average annual rainfall erosion index specific for the project area. Based on USDA (1997), the value was determined to be approximately 330 for Fayette County, Texas, as shown in Figure 1 at the end of this document.

4.2 Soil Erodibility Factor (K)

The soil erodibility factor is a function of the physical and chemical properties of the soil and is specific to the source of the cover material. The soil erodibility factor can be thought of as the ease with which soil is detached by splash during rainfall or by surface flow. The soils to be used for the final cover system of the landfill may be from native soils available at the project site or from local off-site sources. For soil loss calculation purposes, assessments were made of on-site soils and those nearby, using the Fayette

County soil survey (USDA, 2004). This information shows that the site and nearby area has soils that are a combination of Straber gravelly loamy fine sand with 2-5% slopes (SxC), Latium gravelly clay with 5-12% slopes (LgD), Rek extremely gravelly coarse sandy loam with 2-5% slopes (RkC), and Frelsburg clay with 3-5% slopes (FrC). The Straber gravelly loamy fine sand formation constitute the majority of the site and will be used for cover material as shown in Figure 2 at the end of this document.

The Web Soil Survey tool operated by the USDA Natural Resources Conservation Service (NRCS) (USDA, 2014) was consulted for Fayette County for information on the corresponding soil erodibility factors. Near-surface soils (i.e., topsoil) will be used to construct the topsoil layer of the final cover system. The value of K for the project location soils near the surface varies from 0.24 to 0.32, where the estimate considers the erodibility of fine-earth fraction for material less than two mm in size (using the Kf erosion factor provided in Table 1). The surface layer soils which are proposed to be used for cover materials are Straber gravelly loamy fine sand, and value of K for this soil is 0.32. The use of 0.32 in the calculation is using a conservative value of the formations that are predominant at the site and surrounding areas (i.e., a likely candidate source of future final cover topsoil).

4.3 Topographic Factor (LS)

The slope length factor and slope steepness factor are typically combined into one topographic factor, LS, to facilitate field application of these equation components. USDA (1997) presents values of the LS factor for slope lengths in feet up to 1,000 feet and percent slopes up to 60%, as shown in Table 2, for soils with vegetated cover with consolidated soil conditions.

The longest slope lengths for the side slope and top deck surfaces of the final cover system were used to select the LS factor for each area, and these lengths were applied to compute the soil loss for both portions of the landfill. The top deck surface will consist of a 3% slope with maximum length of 370 ft. The final cover system will consist of 3H:1V (33.3%) side slopes with mid-slope drainage benches. The maximum length of 3H:1V final cover side slope between benches is 170 ft. Also, a computation was performed for a hypothetical scenario of a 200 ft long side slope at 33.3% (in order to back-calculate the maximum bench spacing that would yield an acceptably low soil loss design). Based on these slope lengths, the following LS factors were selected (and interpolated if necessary) from Table 2:

- Side Slopes – 3H:1V (33.3%) over the maximum design slope length (between benches) of 170 ft, LS = 8.46
- Side Slopes – 3H:1V (33.3%) over a hypothetical design slope length (between benches) of 200 ft, LS = 9.44
- Top Deck – 3% slope over the maximum design slope length of 370 ft, LS = 0.59

4.4 Cover Management Factor (C)

The cover management factor is a function of the type of land cover, based on three factors: (i) the vegetative cover in direct contact with the soil surface, (ii) the canopy cover, and (iii) the effects at and beneath the surface. The final cover is categorized as having no appreciable canopy with a vegetated cover of grass, grass-like plants, decaying compacted duff or litter ("litter" is an agronomic term which refers to mulch, leaves, and similar organic matter) at least 2 inches deep. The long-term post-closure ground cover condition is estimated to be 95-100% ground cover, which results in a C value of 0.003, as shown in Table 3 (USDA, 1977).

4.5 Erosion Control Practice Factor (P)

The erosion control practice factor considers topographical practices that will reduce erosion by altering runoff drainage patterns. This factor generally applies to agricultural cropping practices and is not anticipated for the landfill. Therefore, the P factor is assumed to be equal to one (1).

4.6 Tolerable Soil Loss (T)

The calculated soil loss should be compared to the tolerable (i.e., permissible) soil loss (T). A draft guidance document from Texas Commission on Environmental Quality (TCEQ, 2007) suggests that landfill final cover designs should have a permissible soil loss rate of 2 to 3 tons/acre/year. Also, the USDA soil-specific survey of Fayette County soils (USDA, 2014) lists the "T" factors recommended for each soil type. This value represents the maximum average annual rate of soil erosion "*that can occur without affecting crop productivity over a sustained period*". For the landfill case, the term "crop productivity" refers to vegetation sustainability (lack of excessive erosion). As shown in Table 1, the USDA's recommended permissible soil loss rate for the Frelsburg clay, Latium gravelly clay, Rek extremely gravelly coarse sandy loam and Straber gravelly loamy fine sand in the site is 5 tons/acre/year. Based on the TCEQ and USDA publications, a maximum permissible soil loss value of 3 tons/acre/year will be used as the comparison criteria for this evaluation. However, it is important to recognize that the area/site-specific USDA soil survey indicates the properties of these soils can tolerate greater soil loss without affecting long-term conditions.

5 SOIL EROSION LOSS RESULTS

Applying the RUSLE with the parameters defined above, the computed soil loss in tons/acre/year is calculated as follows:

$$A = R \times K \times LS \times C \times P$$

- Side Slopes, Design Case (maximum spacing of 170 ft between benches): $A = 330 \times 0.32 \times 8.46 \times 0.003 \times 1 = 2.68$ tons/acre/year
- Side Slopes, Back-Calculated Hypothetical Case (200 ft between benches): $A = 330 \times 0.32 \times 9.44 \times 0.003 \times 1 = 2.99$ tons/acre/year
- Top Deck, Design Case: $A = 330 \times 0.32 \times 0.59 \times 0.003 \times 1 = 0.19$ tons/acre/year

6 CONCLUSIONS

Based on the analyses presented herein, the following conclusions are drawn:

- Overall, the calculated soil loss from the final cover system design is below or within the permissible soil loss of 2 to 3 tons/acre/year suggested by TCEQ (2007), and is also below the permissible soil loss recommended by USDA (2014) for the area/site-specific soils. Specifically, results are:
  - The average annual soil loss from the final cover on the external side slopes as-designed for all of the variables selected as the design case is 2.68 tons/acre/year, which is within the permissible rate of soil loss suggested by TCEQ (2007) for the final cover, and also below the permissible soil loss recommended by USDA (2014) for the area/site-specific soils.
  - The annual soil loss from the final cover on the top deck surface as-designed for all of the variables selected as the design case is 0.19

tons/acre/year. This is much lower than the 2 to 3 tons/acre/year permissible rate of soil loss suggested by TCEQ (2007) for the final cover, and even further below permissible soil loss recommended by USDA (2014) for the area/site-specific soils.

- To provide effective erosional stability against soil loss, the maximum spacing of the final cover side slope drainage benches on the 3H:1V external side slopes should be 200 ft or less. The design meets this spacing requirement.

7 REFERENCES

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TABLES

- Table 1. Soil Erodibility Factor K for Site Soils (from USDA, 2014)
- Table 2. Values for Topographic Factor, LS, for Low Ratio of Rill to Interrill Erosion (from USDA, 1997)
- Table 3. C Factor Cover Values for Permanent Pasture, Rangeland, Idle Land, and Grazed Woodland (from USDA, 1977)

Table 1. Soil Erodibility Factor K for Site Soils (from USDA, 2014)

RUSLE2 Related Attributes–Fayette County, Texas								
Map symbol and soil name	Pct. of map unit	Slope length (ft)	Hydrologic group	Kf	T factor	Representative value		
						% Sand	% Silt	% Clay
FrC—Frelsburg clay, 3 to 5 percent slopes								
Frelsburg	85	180	D	.24	5	22.0	28.0	50.0
LgD—Latium gravelly clay, 5 to 12 percent slopes								
Latium	100	125	D	.24	5	22.1	27.9	50.0
RkC—Rek extremely gravelly coarse sandy loam, 2 to 5 percent slopes								
Rek	100	180	D	.24	5	65.2	23.3	11.5
SxC—Straber gravelly loamy fine sand, 2 to 5 percent slopes								
Straber	100	180	D	.32	5	86.4	6.6	7.0

Table 2. Values for Topographic Factor, LS, for Low Ratio of Rill to Interrill Erosion[1]

(from USDA, 1997)

Table 4-2.
Values for topographic factor, LS, for moderate ratio of rill to interrill erosion.[1]

Slope (%)	Horizontal slope length (ft)																
	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	0.05	0.05	0.05	0.05	0.06	0.06	0.06
0.5	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10
1.0	0.11	0.11	0.11	0.11	0.11	0.12	0.13	0.14	0.14	0.15	0.16	0.17	0.17	0.18	0.19	0.20	0.20
2.0	0.17	0.17	0.17	0.17	0.17	0.19	0.22	0.25	0.27	0.29	0.31	0.33	0.35	0.37	0.41	0.44	0.47
3.0	0.22	0.22	0.22	0.22	0.22	0.25	0.32	0.36	0.39	0.44	0.48	0.52	0.55	0.60	0.68	0.75	0.80
4.0	0.26	0.26	0.26	0.26	0.26	0.31	0.40	0.47	0.52	0.60	0.67	0.72	0.77	0.86	0.99	1.10	1.19
5.0	0.30	0.30	0.30	0.30	0.30	0.37	0.49	0.58	0.65	0.76	0.85	0.93	1.01	1.13	1.33	1.49	1.63
6.0	0.34	0.34	0.34	0.34	0.34	0.43	0.58	0.69	0.78	0.93	1.05	1.16	1.25	1.42	1.69	1.91	2.11
8.0	0.42	0.42	0.42	0.42	0.42	0.53	0.74	0.91	1.04	1.26	1.45	1.62	1.77	2.03	2.47	2.83	3.15
10.0	0.46	0.48	0.50	0.51	0.52	0.67	0.97	1.19	1.38	1.71	1.98	2.22	2.44	2.84	3.50	4.06	4.56
12.0	0.47	0.53	0.58	0.61	0.64	0.84	1.23	1.53	1.79	2.23	2.61	2.95	3.26	3.81	4.75	5.56	6.28
14.0	0.48	0.58	0.65	0.70	0.75	1.00	1.48	1.86	2.19	2.76	3.25	3.69	4.09	4.82	6.07	7.15	8.11
16.0	0.49	0.63	0.72	0.79	0.85	1.15	1.73	2.20	2.60	3.30	3.90	4.45	4.95	5.86	7.43	8.79	10.02
20.0	0.52	0.71	0.85	0.96	1.06	1.45	2.22	2.85	3.40	4.36	5.21	5.97	6.68	7.97	10.23	12.20	13.99
25.0	0.56	0.80	1.00	1.16	1.30	1.81	2.82	3.65	4.39	5.69	6.83	7.88	8.86	10.65	13.80	16.58	19.13
30.0	0.59	0.89	1.13	1.34	1.53	2.15	3.39	4.42	5.34	6.98	8.43	9.76	11.01	13.30	17.37	20.99	24.31
40.0	0.65	1.05	1.38	1.68	1.95	2.77	4.45	5.87	7.14	9.43	11.47	13.37	15.14	18.43	24.32	29.60	34.48
50.0	0.71	1.18	1.59	1.97	2.32	3.32	5.40	7.17	8.78	11.66	14.26	16.67	18.94	23.17	30.78	37.65	44.02
60.0	0.76	1.30	1.78	2.23	2.65	3.81	6.24	8.33	10.23	13.65	16.76	19.64	22.36	27.45	36.63	44.96	52.70

[1]Such as for row-cropped agricultural and other moderately consolidated soil conditions with little-to-moderate cover (not applicable to thawing soil)

Table 3. C Factor Cover Values for Permanent Pasture, Rangeland, Idle Land, and Grazed Woodland[1]
(from USDA, 1977)

Vegetal Canopy: Type and Height of Raised Canopy 2/	Canopy Cover 3/ %	Type 4/	Cover That Contacts the Surface: Percent Ground Cover 0	20	40	60	80	95-100
No appreciable canopy		G	.45	.20	.10	.042	.013	.003
		W	.45	.24	.15	.090	.043	.011
Canopy of tall weeds or short brush (0.5 m fall ht.)	25	G	.36	.17	.09	.038	.012	.003
		W	.36	.20	.13	.082	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.075	.039	.011
	75	G	.17	.10	.06	.031	.011	.003
		W	.17	.12	.09	.067	.038	.011
Appreciable brush or bushes (2 m fall ht.)	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.085	.042	.011
	50	G	.34	.16	.085	.038	.012	.003
		W	.34	.19	.13	.081	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.077	.040	.011
Trees but no appreciable low brush (4 m fall ht.)	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.087	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.085	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.083	.041	.011

1/ All values shown assume: (1) random distribution of mulch or vegetation, and (2) mulch of appreciable depth where it exists. Idle land refers to land with undisturbed profiles for at least a period of three consecutive years. Also to be used for burned forest land and forest land that has been harvested less than three years ago.

2/ Average fall height of waterdrops from canopy to soil surface: m = meters.

3/ Portion of total-area surface that would be hidden from view by canopy in a vertical projection, (a bird's-eye view).

4/ G: Cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 inches deep.

W: Cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface), and/or undecayed residue.

FIGURES

- Figure 1. Average Annual Erosivity Factor, R, Isoerodent Map (from USDA, 1996)
- Figure 2. Soil Survey Map

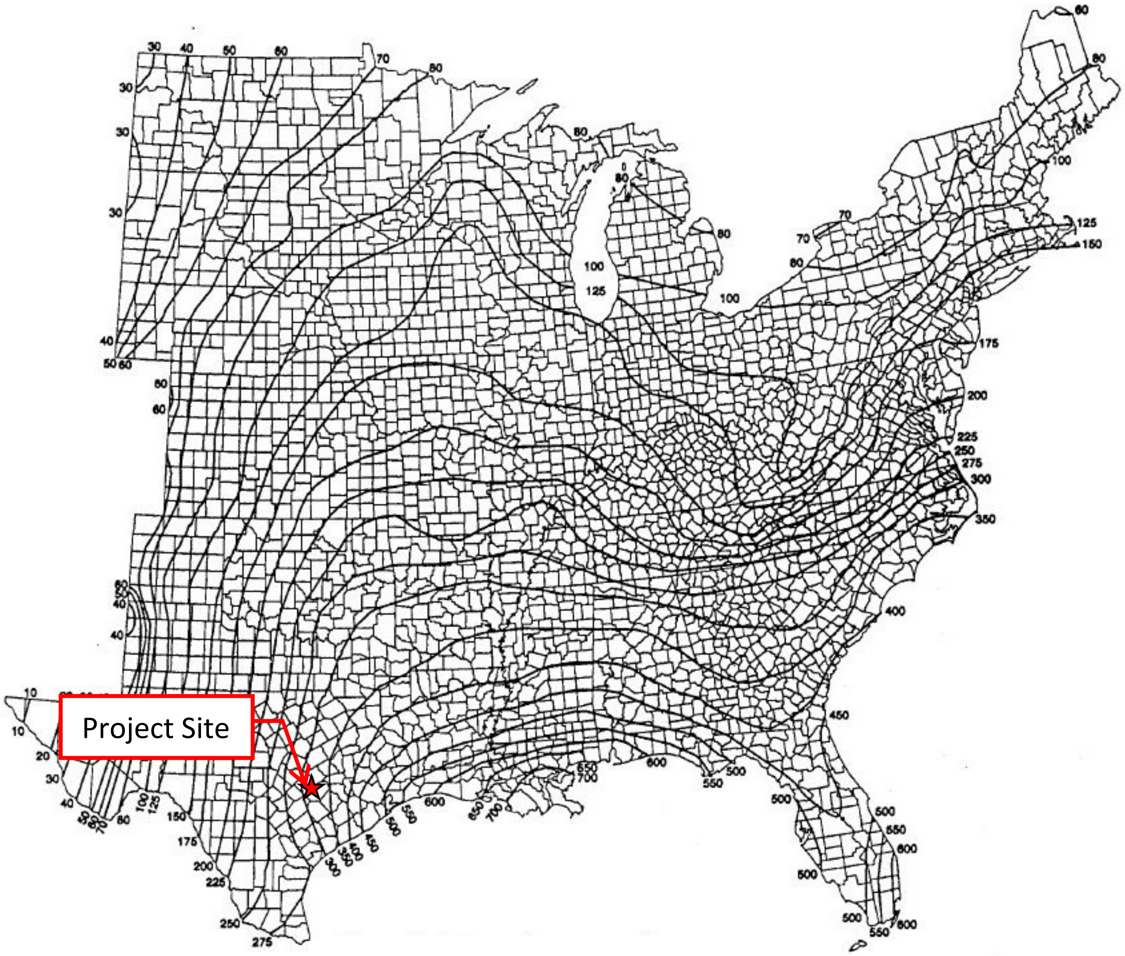

Figure 1. Average Annual Rainfall Runoff Erosivity Factor, R, Isoerodent Map (from USDA, 1997)

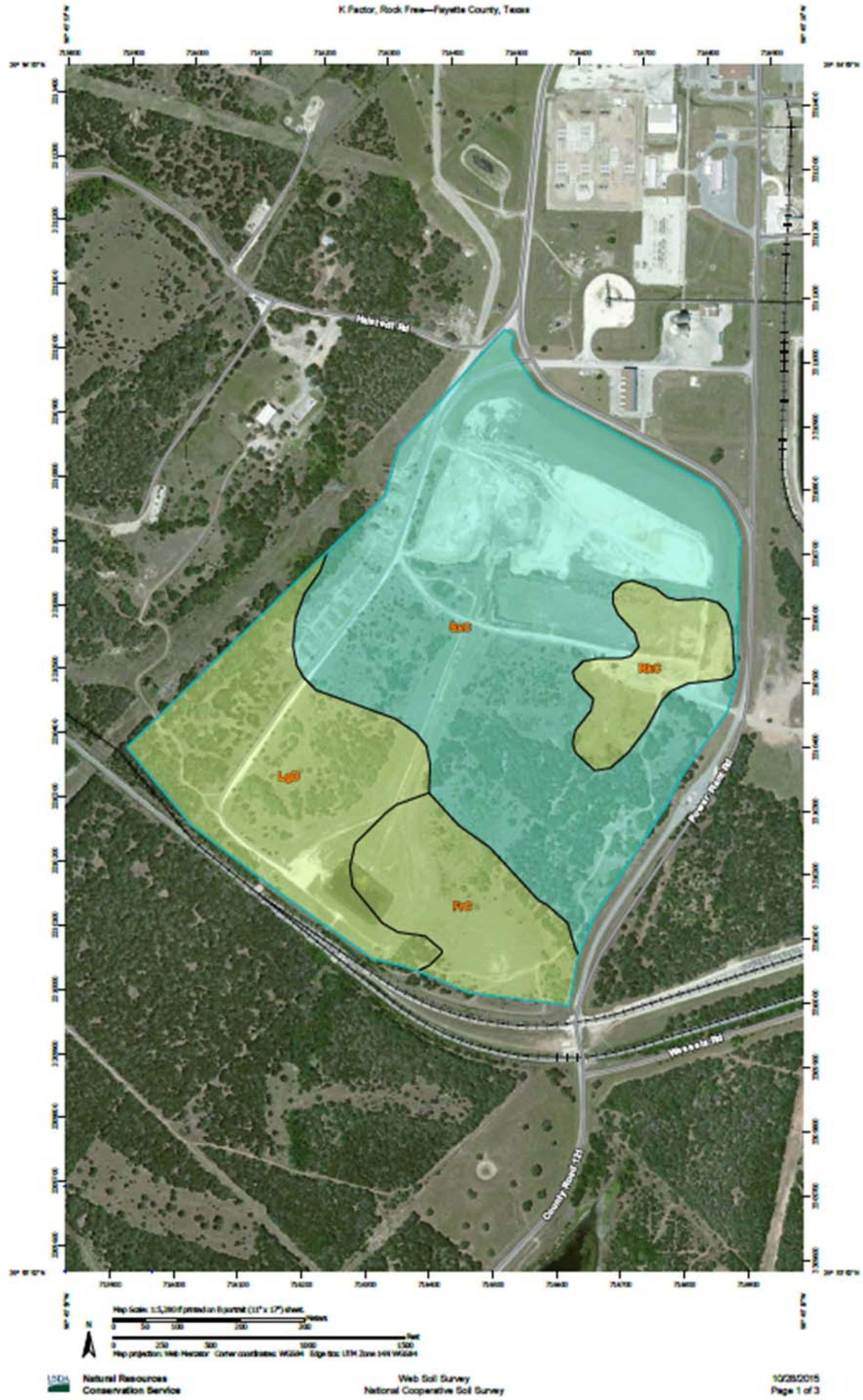

Figure 2. Soil Survey Map (from USDA, 2014)