Prepared for

NAES Corporation
Sandy Creek Energy Station
2161 Rattlesnake Road
Riesel, TX 76682

RUN-ON AND RUN-OFF CONTROL SYSTEM PLAN FOR SOLID WASTE DISPOSAL FACILITY REGISTRATION NO. 88448

SANDY CREEK ENERGY STATION
RIESEL, McLENNAN COUNTY, TEXAS

Prepared by

Geosyntec consultants
8217 Shoal Creek Blvd., Suite 200
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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 Solid Waste Disposal Facility (Landfill) at the Sandy Creek Energy Station (SCES). 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 SCES is a coal-fired power plant located in Riesel, McLennan County, Texas. CCR generated at the SCES are disposed in the Landfill, which is located on the southwest corner of the property east of a drainage easement maintained by the Texas Department of Transportation (TxDOT) (Drawing 1 of 16). At final buildout, the Landfill will occupy approximately 65 acres and will consist of four cells, Cells 1 to 4 (Drawing 1 of 16). Cells 1 and 2 were constructed with a 3-foot thick compacted clay liner with a hydraulic conductivity less than 1×10^{-7} cm/s and a leachate collection system and are currently being filled to interim grades with CCR.

Run-off from active areas of the Landfill and leachate collected in the leachate collection system are conveyed to the Leachate Evaporation Pond (Drawing 1 of 16); this pond will continue to be used for leachate management after the Landfill is closed. Stormwater run-off from areas of the Landfill with intermediate soil or final cover can be conveyed to the Stormwater Pond; this pond will continue to be used for management of stormwater from the final cover system after the Landfill is closed.

1.3 Organization of Plan

The remainder of this Plan is organized as follows:

- Section 2 summarizes 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 Landfill has been designed and constructed to prevent flow onto the active portion of the Landfill;
- Section 4 describes how the run-off control system for the Landfill has been designed and constructed to collect and control flow from the active portion of the Landfill;
- 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 Landfill must be designed, constructed, operated, and maintained to prevent flow onto the active portion of the Landfill and collect and control flow from the active portion of the Landfill during the peak discharge from a 24-hour, 25-year storm. 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-on 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 designed 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 consistent 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 Landfill as it currently exists and at final grades. In general, run-on to active areas of the Landfill is controlled by topography and by the Landfill perimeter berm. The north side of the Landfill is on a topographic high, and the ground surface around the Landfill primarily slopes to the west to southwest (Drawings 1 of 16 and 3 of 7). In addition, the perimeter berm for the Landfill 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 and conveyed to the Stormwater Pond located southwest of the Landfill.

3.2 Initial Run-On Control System Plan

Cells 1 and 2 of the Landfill are currently active. While waste has been placed across the floor of Cell 1, Cell 2 is being incrementally filled in five subcells (Subcells 2A to 2E) to facilitate management of stormwater and leachate. CCR is placed in Cells 1 and 2 in a manner that limits the active area of the Landfill. As exterior slopes reach interim grades, they are covered with soil cover, and run-off from the soil cover is directed to the perimeter channel which conveys stormwater to the Stormwater Pond (Drawings 5 of 16 and 6 of 16). Thus, based on topography, stormwater from the exterior slopes of the of the Landfill will not run-on to active areas of the cells. Futhermore, potential run-on from areas outside of the cells will not overtop the existing perimeter berm and enter into Landfill.

As new subcells are developed, run-on will continue to be controlled by perimeter berms and adjacent stormwater channels. In addition, run-on from inactive waste slopes that have received soil intermediate cover will be directed from cells actively receiving CCR by temporary diversion berms (Drawings 5 of 16, 6 of 16, and 7 of 16).

3.3 Final Run-On Control System Plan

At final conditions, the Landfill will be closed with final cover and will no longer be active (Drawing 3 of 7). Run-on to the closed Landfill 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 Landfill perimeter and the engineering controls designed for the Landfill (e.g., perimeter berm and stormwater channel, temporary stormwater diversion berms), the Landfill will continue to be designed, constructed, operated, and maintained to prevent flow onto the active portion of the Landfill. Therefore the Landfill 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 Landfill as it currently exists and at final grades. In general, run-off from the Landfill is controlled by topography, the landfill perimeter berm and stormwater channel, and the stormwater management system components that will be constructed on the Landfill as it is developed (Drawings 5 of 16, 6 of 16, 7 of 16, and 3 of 7).

4.2 Initial Run-Off Control System Plan

Run-off from areas of Cells 1 and 2 that have not been covered with intermediate cover or final cover could have potentially come in contact with CCR and is, therefore, managed as contact water. To facilitate the removal of contact water from the Landfill, CCR is placed in the Landfill in a manner that directs this run-off to a common collection point (low point) from which it is pumped to the Leachate Evaporation Pond. Contact water that infiltrates into the CCR in the Landfill and makes its way to the leachate collection system is also conveyed to the Leachate Evaporation Pond. The perimeter berm and temporary diversion berms in the Landfill, as well as the underlying liner system, keep run-off that has contacted CCR within the Landfill until the water is removed. As exterior slopes reach interim grades, they are covered with soil cover. Run-off from areas of the Landfill with intermediate or final cover has not contacted CCR and can be directed to the perimeter channel which conveys stormwater to the Stormwater Pond (Drawings 5 of 16 and 6 of 16).

As new subcells are developed, run-off of contact water will continue to be controlled by the perimeter and interior berms of the Landfill ((Drawings 5 of 16 and 6 of 16). Areas will be covered with final cover and the permanent stormwater management system as they reach final grade.

4.3 Final Run-Off Control System Plan

After the final cover has been constructed on the Landfill, stormwater run-off from the landfill surface will be conveyed off the landfill through a series of components, including top deck diversion berms, side slope diversion berms, downchutes, an access road channel, and a perimeter channel (Drawing 3 of 7). Except for one top deck diversion berm which routes water to the access road channel, the diversion berms direct water from the top deck and side slopes to the downchutes. Flow in the perimeter channel is conveyed to the Stormwater Pond.

While 40 CFR §257.81(a) requires that run-off control systems be designed to collect and control flow from a 24-hour, 25-year storm, the Texas Commission on Environmental Quality's (TCEQ's) Technical Guideline No. 3 (TCEQ, 2015) 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. Therefore, the stormwater management system components for the Landfill were conservatively designed to route stormwater run-off resulting from the 100-year, 24-hour design storm event. The design of these components is presented in Appendix A, and details of these components are shown on Drawings 5 of 7 and 6 of 7.

The stormwater management features are also designed to control run-off 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 vertical spacing between drainage benches was limited to 74 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 Landfill perimeter, the engineering controls designed for the Landfill (e.g., perimeter berm and stormwater channel, temporary stormwater diversion berms), the operational procedures for the Landfill, and the fact that contact water and leachate from the Landfill is managed in the Leachate Evaporation Pond, the Landfill will continue to be designed, constructed, operated, and maintained to collect and control flow from the active portion of the cells and handle run-off in a manner that complies with the National Pollutant Discharge Elimination System. Therefore the Landfill 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 Solid Waste Disposal Facility (Landfill) at the Sandy Creek Energy Station, it is my professional opinion that the Plan meet 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

10/14/2016

Date

6. REFERENCES

Geosyntec Consultants (2014a). "Cell 2 Operations Plan, Solid Waste Disposal Facility, TCEQ Registration No. 88448, Sandy Creek Energy Station, Riesel, McLennan County, Texas" prepared for NAES Corporation.

Geosyntec Consultants (2014b). "Engineering Design Drawings, Solid Waste Disposal Facility Final Cover, Sandy Creek Energy Station, Riesel, Texas," prepared for NAES Corporation.

Giroud, J.P., Bachus, R.C., and Bonaparte, R. (1995). "Influence of Water Flow on the Stability of Geosynthetic-Soil Layered Systems on Slopes", *Geosynthetics International*, Vol. 2, No. 6, pp. 1149-1180.

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

Texas Commission on Environmental Quality (2007). "Guidance for Addressing Erosional Stability During All Phases of Landfill Operation (Draft)", 14 February.

DRAWINGS

LEGEND

500	EXISTING GROUND ELEVATION (FT, MSL) (NOTES 1, 2)
	EXISTING SURFACE WATER LINE
x x x	EXISTING SITE FENCE
	EXISTING TREE LINE
	EXISTING ROAD
	EXISTING BUILDING
	PROPERTY BOUNDARY
	DEED RECORDED LIMITS OF WASTE
	CELL BOUNDARY
N 10514500 E 3349500	STATE PLANE COORDINATES
GB-3	EXISTING PIEZOMETER
	SWDF OPERATIONS ACCESS ROAD

0 250' 500'
SCALE IN FEET

NOTES:

1. THE EXISTING CONTOUR MAP SHOWN ON THIS DRAWING WAS COMPILED USING EXISTING TOPOGRAPHY DATED APRIL 2006 AND DESIGN GRADES DATED OCTOBER 2007 FROM BLACK & VEATCH CORPORATION; DESIGN GRADES DEVELOPED BY GEOSYNTEC CONSULTANTS, INC. FOR THE LEACHATE EVAPORATION POND AND CELL 2 DATED APRIL 2011 AND APRIL 2014, RESPECTIVELY; AND AREA 59 EXISTING TOPOGRAPHY SURVEY CONDUCTED BY WALKER PARTNERS DATED 9 MAY 2013.
2. ELEVATIONS ARE IN FEET ABOVE MEAN SEA LEVEL (FT, MSL) AS DEFINED BY THE USGS NATIONAL GEODETIC VERTICAL DATUM (NGVD) OF 1988. STATE PLANE COORDINATE GRID CORRESPONDS TO TEXAS STATE PLANE COORDINATE SYSTEM, TEXAS CENTRAL ZONE (4203), NORTH AMERICAN DATUM OF 1983 (NAD-83).

REV	DATE	DESCRIPTION	DRN	APP
1	9/24/2014	ADDED DRAINAGE EASEMENT AND SCRUBBER ASH SILO REFERENCE	JJV	MZI
0	6/10/2014	ISSUE FOR CONSTRUCTION	JJV	MZI

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TITLE: SITE LAYOUT

PROJECT: OPERATIONS PLAN – SOLID WASTE DISPOSAL FACILITY (CELL 2)

SITE: SANDY CREEK ENERGY STATION

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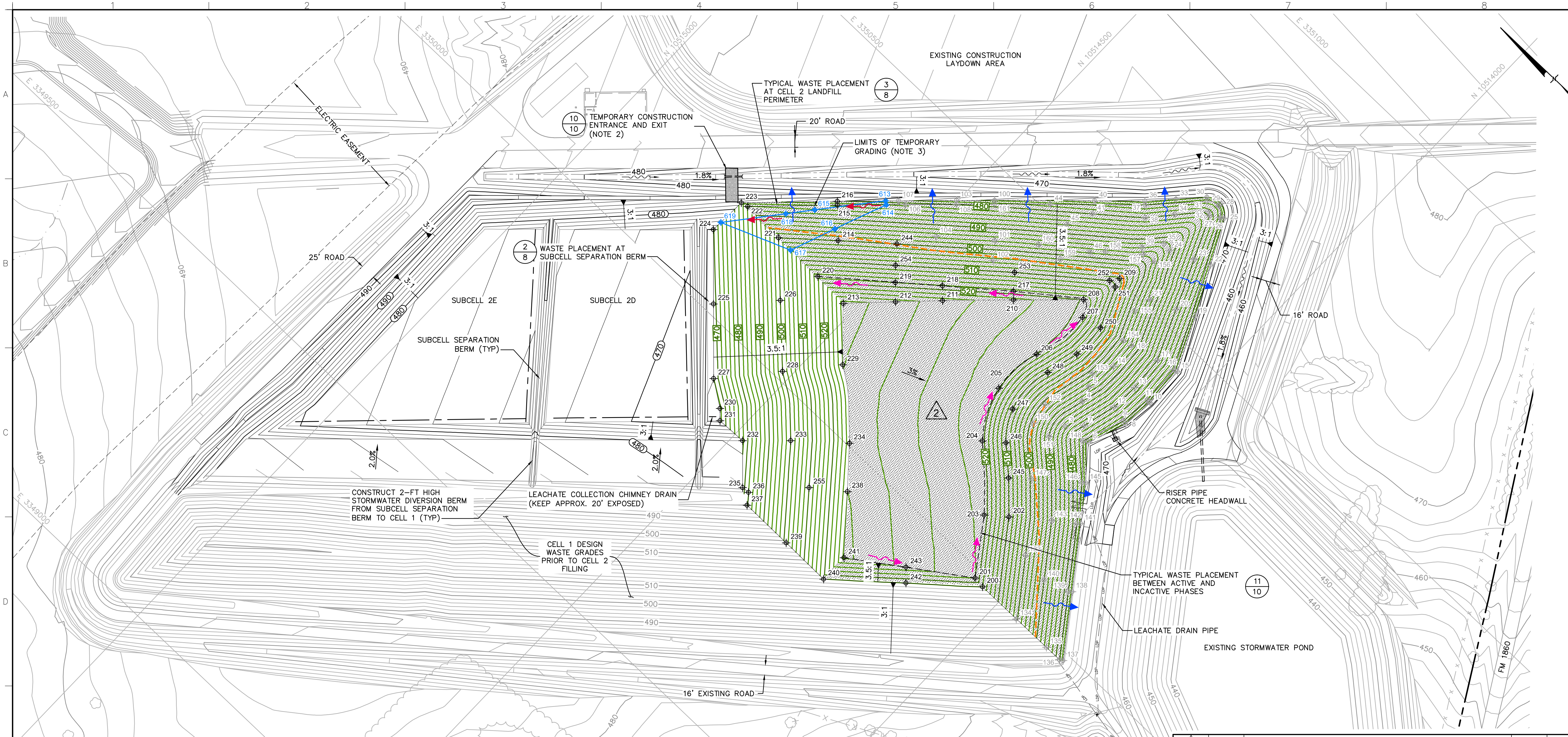
SIGNATURE
6/10/2014
DATE

STATE OF TEXAS
M. ZAHIRUL ISLAM
109989
LICENSED
PROFESSIONAL ENGINEER

DESIGN BY:	MZI	DATE:	JUNE 2014
DRAWN BY:	JJV/KH	PROJECT NO.:	TXL0208.07.01
CHECKED BY:	MZI	FILE:	TXL020807-OP-00
REVIEWED BY:	BG	DRAWING NO.:	
APPROVED BY:	MZI		1 OF 16

OPERATIONS DRAWING

DRAWING: Austin P:\CADD\Projects\S\Sandy Creek PP\OPERATIONS\CELL 2 OPERATIONS (TXL0208.07.01)\DRAWINGS\TXL020807-OP-00.dwg PLOTTED: Dec 12, 2014 - 1:44pm



LEGEND 2

- 480 — EXISTING GROUND ELEVATION (FT, MSL) (NOTE 1)
- EXISTING ROAD
- EXISTING BUILDING
- PROPERTY BOUNDARY
- N 10514500 / E 3349500 — STATE PLANE COORDINATES
- 10 — CONSTRUCTION CONTROL POINT
- 606 — TEMPORARY GRADING CONSTRUCTION CONTROL POINT (NOTE 3)
- 490 — PROPOSED TOP OF WASTE ELEVATION (FT, MSL)
- 470 — EXISTING PROTECTIVE COVER ELEVATION (FT, MSL)
- 460 — EXISTING FINISHED GRADE ELEVATION (FT, MSL)
- LEACHATE COLLECTION CHIMNEY DRAIN
- LIMITS OF TEMPORARY GRADING CONSTRUCTION
- INTERMEDIATE COVER AREA
- CONTACT WATER FLOW DIRECTION BEFORE PLACING INTERMEDIATE COVER
- STORMWATER FLOW DIRECTION AFTER PLACING INTERMEDIATE COVER
- TEMPORARY DIVERSION BERM
- CONTACT WATER FLOW DIRECTION AFTER TEMPORARY DIVERSION BERM IS CONSTRUCTED
- FUTURE SIDESLOPE DIVERSION BERM (NOTE 6)

2 NOTES:

1. REFER TO DRAWING 1 FOR EXISTING CONDITIONS AND DETAILS OF THE TOPOGRAPHIC BASE MAP AND COORDINATE SYSTEM.
2. CONSTRUCTION ENTRANCE AND EXIT LOCATION IS APPROXIMATE AND SHALL BE INSTALLED AT A LOCATION THAT DOES NOT INTERFERE WITH DRAINAGE AND LANDFILL FEATURES.
3. TEMPORARY GRADING IS FOR POSITIVE DRAINAGE OF CONTACT WATER TO LOW POINT AT SOUTHWEST CORNER BEFORE INTERMEDIATE COVER IS PLACED.
4. THIS PLAN PRESENTS ONE FILLING OPTION. AN ALTERNATIVE FILLING PLAN THAT PROVIDES FOR SUBCELL ACCESS, CONTACT WATER MANAGEMENT, STORMWATER MANAGEMENT; LIMITS AREAS OF EXPOSED WASTE TO THE ACREAGE SPECIFIED IN THE OPERATIONS PLAN; AND PROVIDES SLOPE STABILITY IS ALSO ACCEPTABLE IF APPROVED BY NAES.
5. LOCATIONS OF TEMPORARY INTERIOR HAUL ROADS WILL BE DETERMINED BY THE LANDFILL OPERATOR.
6. FUTURE SIDESLOPE DIVERSION BERM IS SHOWN FOR INFORMATIONAL PURPOSES ONLY. THE SIDESLOPE DIVERSION BERM WILL BE CONSTRUCTED DURING FINAL COVER CONSTRUCTION.

0 80' 160'
SCALE IN FEET

OPERATIONS DRAWING

REV	DATE	DESCRIPTION	DRN	APP
2	12/12/2014	REVISIONS TO SUBCELL 2C GRADING, NOTES, AND LEGEND	JJV	MZI
1	9/24/2014	REVISED LEGEND, NOTES, CALLOUTS: ADDED TEMP. CONST. GRADING	JJV	MZI
0	6/10/2014	ISSUE FOR CONSTRUCTION	JJV	MZI

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TITLE: SUBCELL 2C FILLING PLAN

PROJECT: OPERATIONS PLAN – SOLID WASTE DISPOSAL FACILITY (CELL 2)

SITE: SANDY CREEK ENERGY STATION

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SIGNATURE
6/10/2014
DATE

STATE OF TEXAS
M. ZAHIRUL ISLAM
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LICENSED PROFESSIONAL ENGINEER

DESIGN BY: MZI	DATE: JUNE 2014
DRAWN BY: JJV	PROJECT NO.: TXL0208.07.01
CHECKED BY: MZI	FILE: TXL020807-OP-F03
REVIEWED BY: BG	DRAWING NO.: 5 OF 16
APPROVED BY: MZI	

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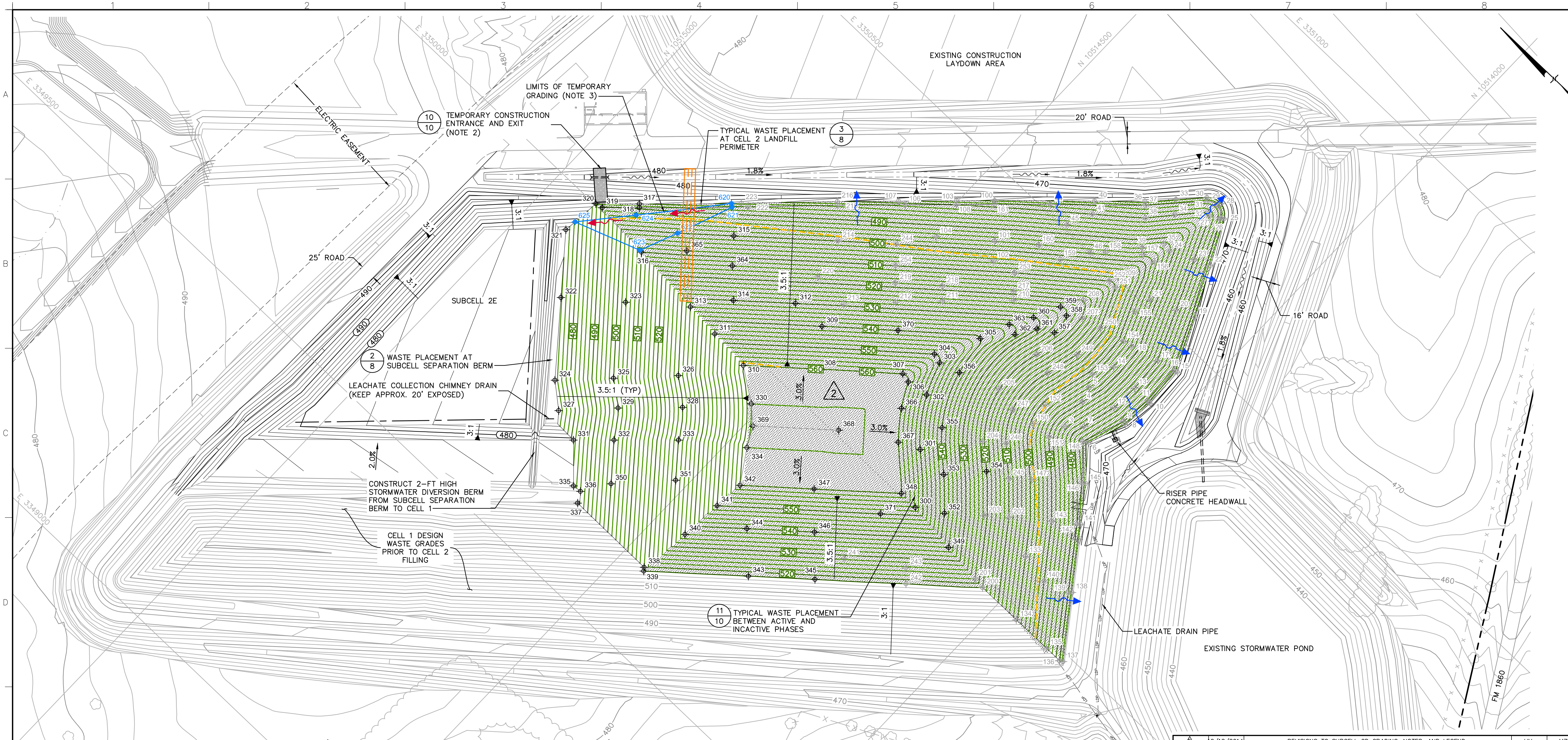

LEGEND 2

480	EXISTING GROUND ELEVATION (FT, MSL) (NOTE 1)
	EXISTING ROAD
	EXISTING BUILDING
	PROPERTY BOUNDARY
N 10514500 / E 3349500	STATE PLANE COORDINATES
10	CONSTRUCTION CONTROL POINT
606	TEMPORARY GRADING CONSTRUCTION CONTROL POINT (NOTE 3)
490	PROPOSED TOP OF WASTE ELEVATION (FT, MSL)
(470)	EXISTING PROTECTIVE COVER ELEVATION (FT, MSL)
460	EXISTING FINISHED GRADE ELEVATION (FT, MSL)
	LEACHATE COLLECTION CHIMNEY DRAIN
	LIMITS OF TEMPORARY GRADING CONSTRUCTION
	INTERMEDIATE COVER AREA
	CONTACT WATER FLOW DIRECTION BEFORE PLACING INTERMEDIATE COVER
	STORMWATER FLOW DIRECTION AFTER PLACING INTERMEDIATE COVER
	FUTURE SIDESLOPE DIVERSION BERM (NOTE 6)
	FUTURE DOWNCHUTE (NOTE 6)

2 NOTES:

1. REFER TO DRAWING 1 FOR EXISTING CONDITIONS AND DETAILS OF THE TOPOGRAPHIC BASE MAP AND COORDINATE SYSTEM.
2. CONSTRUCTION ENTRANCE AND EXIT LOCATION IS APPROXIMATE AND SHALL BE INSTALLED AT A LOCATION THAT DOES NOT INTERFERE WITH DRAINAGE AND LANDFILL FEATURES.
3. TEMPORARY GRADING IS FOR POSITIVE DRAINAGE OF CONTACT WATER TO LOW POINT AT SOUTHWEST CORNER BEFORE INTERMEDIATE COVER IS PLACED.
4. THIS PLAN PRESENTS ONE FILLING OPTION. AN ALTERNATIVE FILLING PLAN THAT PROVIDES FOR SUBCELL ACCESS, CONTACT WATER MANAGEMENT, STORMWATER MANAGEMENT; LIMITS AREAS OF EXPOSED WASTE TO THE ACREAGE SPECIFIED IN THE OPERATIONS PLAN; AND PROVIDES SLOPE STABILITY IS ALSO ACCEPTABLE IF APPROVED BY NAES.
5. LOCATIONS OF TEMPORARY INTERIOR HAUL ROADS WILL BE DETERMINED BY THE LANDFILL OPERATOR.
6. FUTURE SIDESLOPE DIVERSION BERMS AND DOWNCHUTE ARE SHOWN FOR INFORMATIONAL PURPOSES ONLY. THE SIDESLOPE DIVERSION BERMS AND DOWNCHUTE WILL BE CONSTRUCTED DURING FINAL COVER CONSTRUCTION.

0 80' 160'
SCALE IN FEET

OPERATIONS DRAWING

REV	DATE	DESCRIPTION	DRN	APP
2	12/12/2014	REVISIONS TO SUBCELL 2D GRADING, NOTES, AND LEGEND	JJV	MZI
1	9/24/2014	REVISED LEGEND, NOTES, CALLOUTS: ADDED TEMP. CONST. GRADING	JJV	MZI
0	6/10/2014	ISSUE FOR CONSTRUCTION	JJV	MZI

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TITLE: SUBCELL 2D FILLING PLAN

PROJECT: OPERATIONS PLAN – SOLID WASTE DISPOSAL FACILITY (CELL 2)

SITE: SANDY CREEK ENERGY STATION

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STATE OF TEXAS
M. ZAHIRUL ISLAM
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LICENSED PROFESSIONAL ENGINEER

DESIGN BY:	MZI	DATE:	JUNE 2014
DRAWN BY:	JJV	PROJECT NO.:	TXL0208.07.01
CHECKED BY:	MZI	FILE:	TXL020807-OP-F04
REVIEWED BY:	BG	DRAWING NO.:	6 OF 16
APPROVED BY:	MZI		

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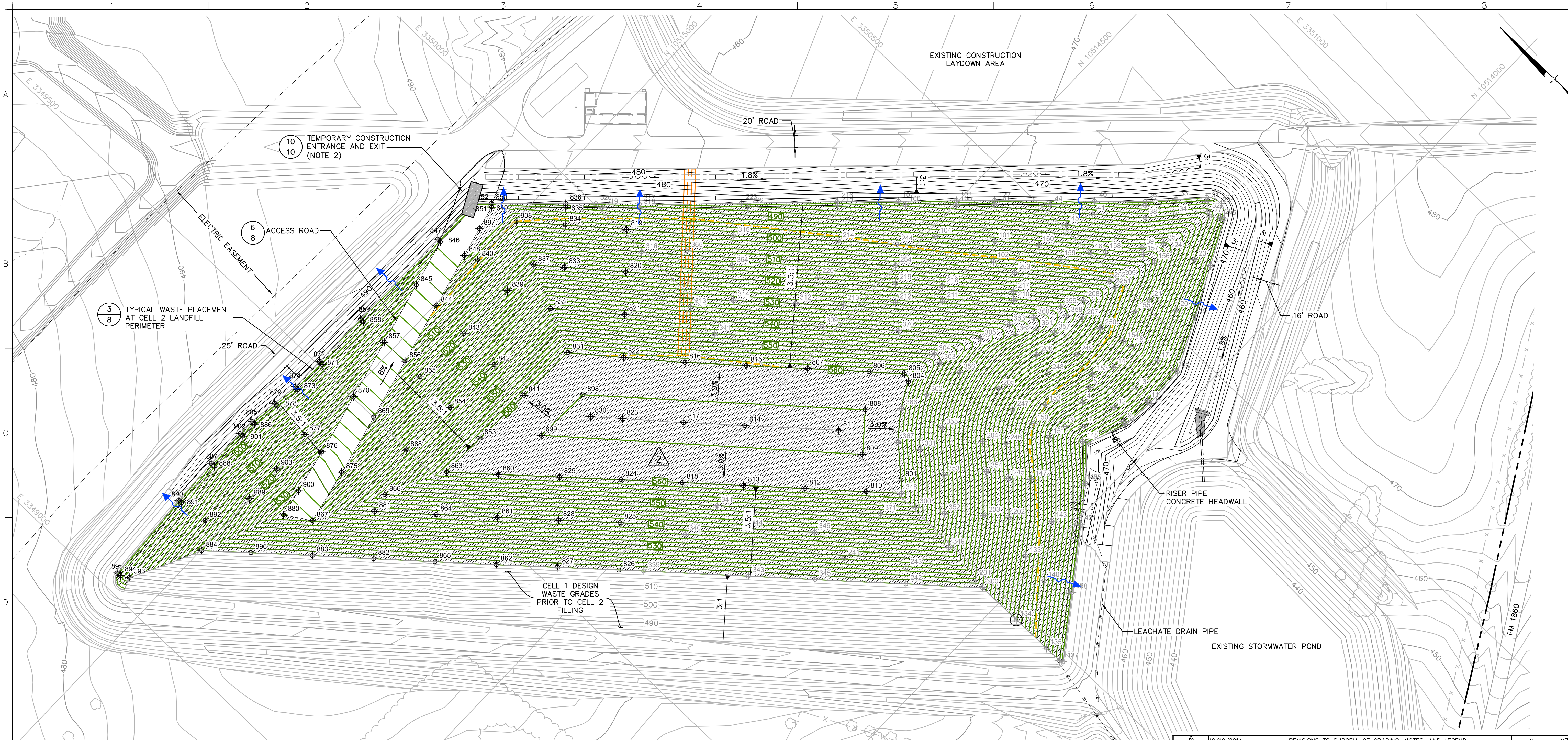

LEGEND ⚠2

480	EXISTING GROUND ELEVATION (FT, MSL) (NOTE 1)
	EXISTING ROAD
	EXISTING BUILDING
	PROPERTY BOUNDARY
N 10514500 E 3349500	STATE PLANE COORDINATES
10	CONSTRUCTION CONTROL POINT
550	PROPOSED TOP OF WASTE ELEVATION (FT, MSL)
460	EXISTING FINISHED GRADE ELEVATION (FT, MSL)
	INTERMEDIATE COVER AREA
	STORMWATER FLOW DIRECTION AFTER PLACING INTERMEDIATE COVER
	FUTURE SIDESLOPE DIVERSION BERM (NOTE 5)
	FUTURE DOWNCHUTE (NOTE 5)

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4. LOCATIONS OF TEMPORARY INTERIOR HAUL ROADS WILL BE DETERMINED BY THE LANDFILL OPERATOR.
5. FUTURE SIDESLOPE DIVERSION BERMS AND DOWNCHUTE ARE SHOWN FOR INFORMATIONAL PURPOSES ONLY. THE SIDESLOPE DIVERSION BERMS AND DOWNCHUTE WILL BE CONSTRUCTED DURING FINAL COVER CONSTRUCTION.

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TITLE: SUBCELL 2E FILLING PLAN

PROJECT: OPERATIONS PLAN – SOLID WASTE DISPOSAL FACILITY (CELL 2)

SITE: SANDY CREEK ENERGY STATION

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SIGNATURE
6/10/2014
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109989
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DESIGN BY: MZI		DATE: JUNE 2014	
DRAWN BY: JJV		PROJECT NO.: TXL0208.07.01	
CHECKED BY: MZI		FILE: TXL020807-OP-F05	
REVIEWED BY: BG		DRAWING NO.:	
APPROVED BY: MZI		7 OF 16	

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LEGEND

- 500 — EXISTING GROUND ELEVATION (FT, MSL) (NOTES 1, 2)
- EXISTING SURFACE WATER LINE
- EXISTING SITE FENCE
- EXISTING TREE LINE
- EXISTING ROAD
- EXISTING BUILDING
- N 10514500 / E 3349500 — STATE PLANE COORDINATES
- PROPERTY BOUNDARY
- DEED RECORDED LIMITS OF WASTE
- FINAL COVER LIMIT
- 600 — PROPOSED FINISHED GRADE ELEVATION
- PERIMETER ACCESS ROAD
- PERIMETER DRAINAGE CHANNEL
- DIRECTION OF FLOW
- LDP — EXISTING LEACHATE DRAIN PIPE
- LIMITS OF TURF REINFORCEMENT MAT (NOTE 3)

NOTES:

1. THE EXISTING CONTOUR MAP SHOWN ON THIS DRAWING WAS COMPILED USING EXISTING TOPOGRAPHY DATED APRIL 2006 AND DESIGN GRADES DATED OCTOBER 2007 FROM BLACK & VEATCH CORPORATION; DESIGN GRADES DEVELOPED BY GEOSYNTEC CONSULTANTS, INC. FOR THE LEACHATE EVAPORATION POND AND CELL 2 DATED APRIL 2011 AND APRIL 2014, RESPECTIVELY; AND AREA 59 EXISTING TOPOGRAPHY SURVEY CONDUCTED BY WALKER PARTNERS DATED 9 MAY 2013.
2. ELEVATIONS ARE IN FEET ABOVE MEAN SEA LEVEL (FT, MSL) AS DEFINED BY THE USGS NATIONAL GEODETIC VERTICAL DATUM (NGVD) OF 1988. STATE PLANE COORDINATE GRID CORRESPONDS TO TEXAS STATE PLANE COORDINATE SYSTEM, TEXAS CENTRAL ZONE (4203), NORTH AMERICAN DATUM OF 1983 (NAD-83).
3. ACCESS ROAD CHANNEL, PERIMETER CHANNEL, AND DIVERSION BERMS SHALL BE GRASS-LINED. SOUTH PORTION OF EXISTING CELL 2 EAST PERIMETER CHANNEL AND ACCESS ROAD CHANNEL SHALL ALSO BE LINED WITH TXDOT CLASS II, TYPE G OR H TURF REINFORCEMENT MAT WITH A MINIMUM RESISTANCE TO TRACTIVE STRESS OF 6-8 PSF. DOWNCHUTES SHALL BE LINED WITH ARTICULATED CONCRETE BLOCK (ACB) OR ENGINEER APPROVED EQUIVALENT WITH MINIMUM RESISTANCE TO TRACTIVE STRESS OF 11 PSF.

0 120' 240'
SCALE IN FEET

REV	DATE	DESCRIPTION	DRN	APP
0	12/19/2014	FINAL DESIGN DRAWINGS	JJV	BG
A	7/25/2014	70% DRAFT	JJV	BG

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TITLE:
STORMWATER MANAGEMENT PLAN

PROJECT:
SOLID WASTE DISPOSAL FACILITY FINAL COVER

SITE:
SANDY CREEK ENERGY STATION

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Beth Ann Gross
SIGNATURE
12/19/2014
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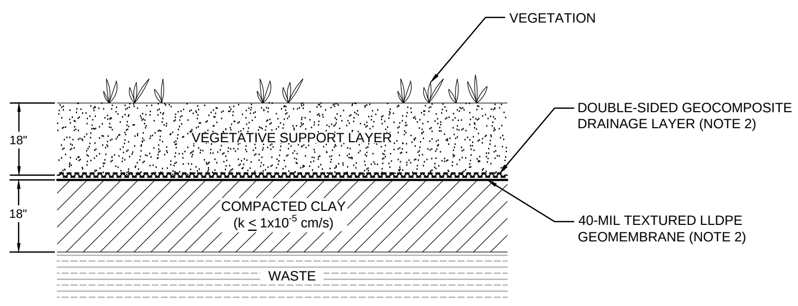
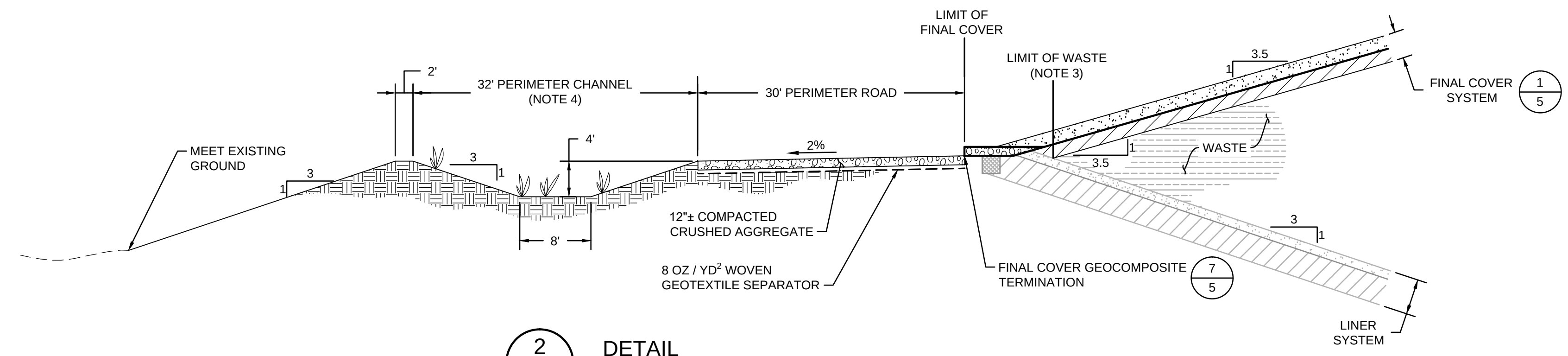
STATE OF TEXAS ★ BETH ANN GROSS 79864 LICENSED PROFESSIONAL ENGINEER

DESIGN BY:	BK	DATE:	DECEMBER 2014
DRAWN BY:	JJV / KH	PROJECT NO.:	TXL0208.08
CHECKED BY:	MZI	FILE:	TXL020808D02
REVIEWED BY:	BG	DRAWING NO.:	3 OF 7
APPROVED BY:	BG		



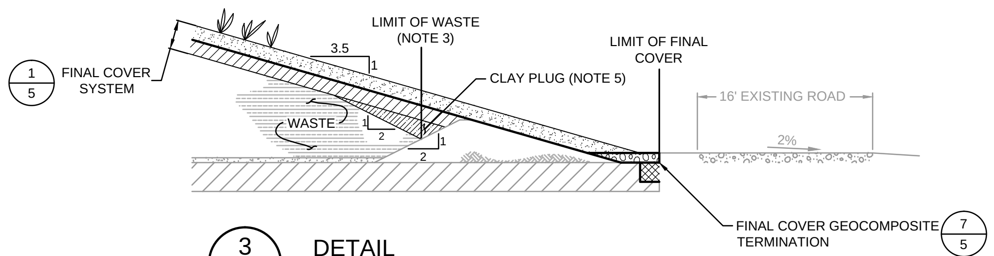
1/2 DETAIL
FINAL COVER SYSTEM

0 2' 4'
SCALE IN FEET



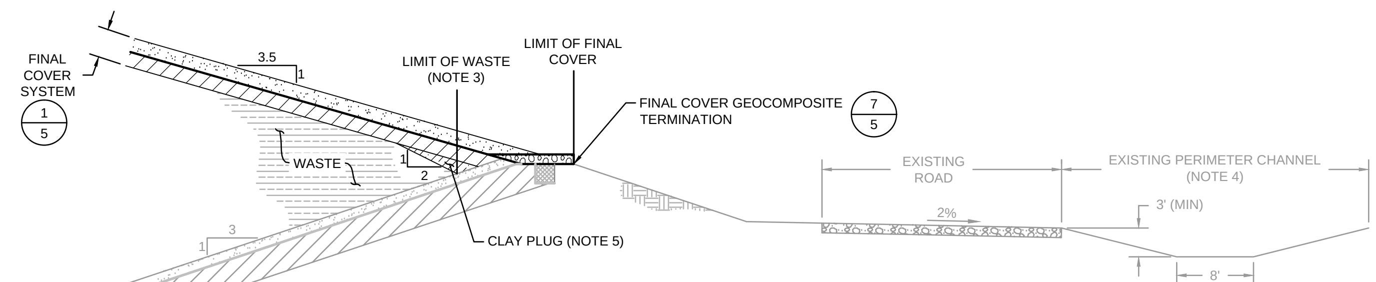
2/2 DETAIL
PROPOSED LANDFILL PERIMETER

0 10' 20'
SCALE IN FEET



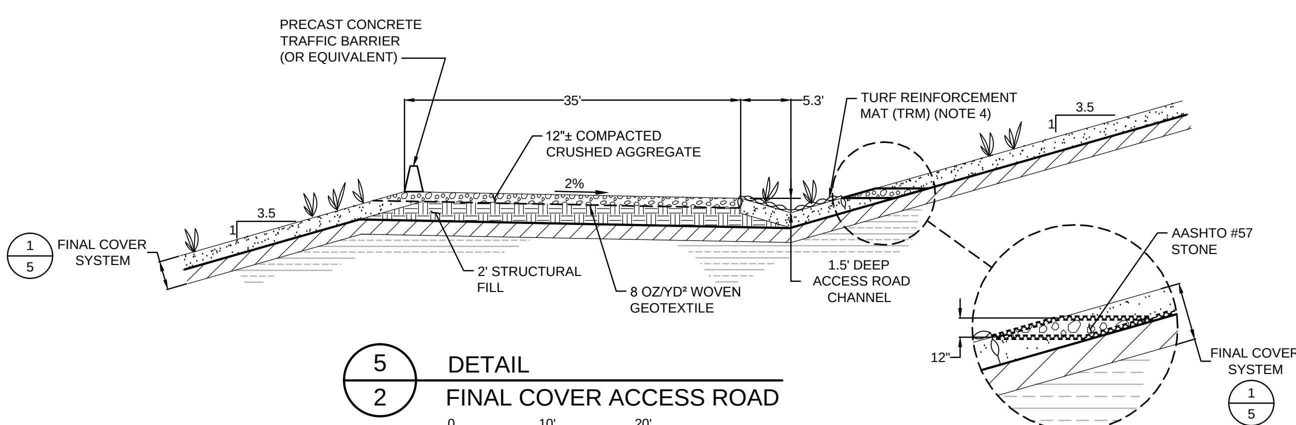
3/2 DETAIL
EXISTING CELL 1 PERIMETER

0 10' 20'
SCALE IN FEET



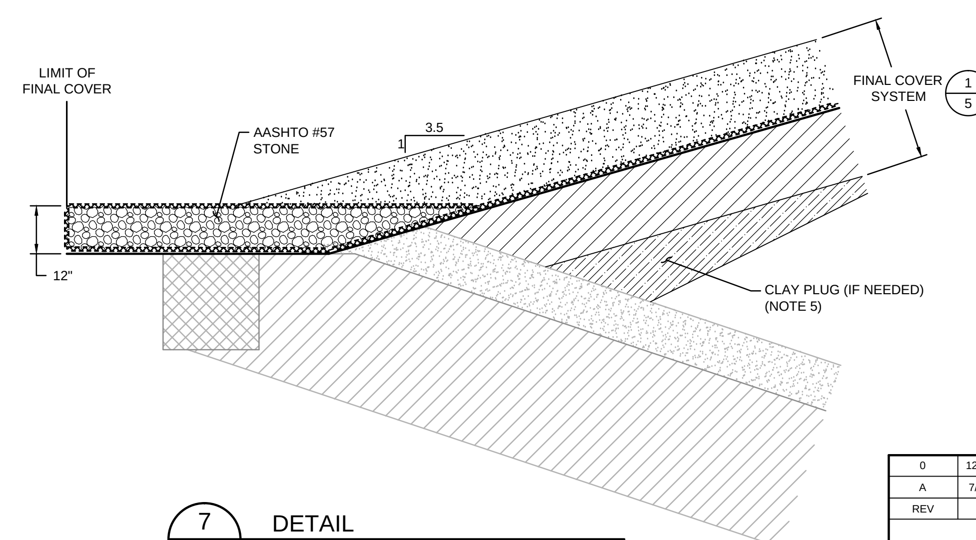
4/2 DETAIL
EXISTING CELL 2 NORTH PERIMETER

0 10' 20'
SCALE IN FEET



5/2 DETAIL
FINAL COVER ACCESS ROAD

0 10' 20'
SCALE IN FEET

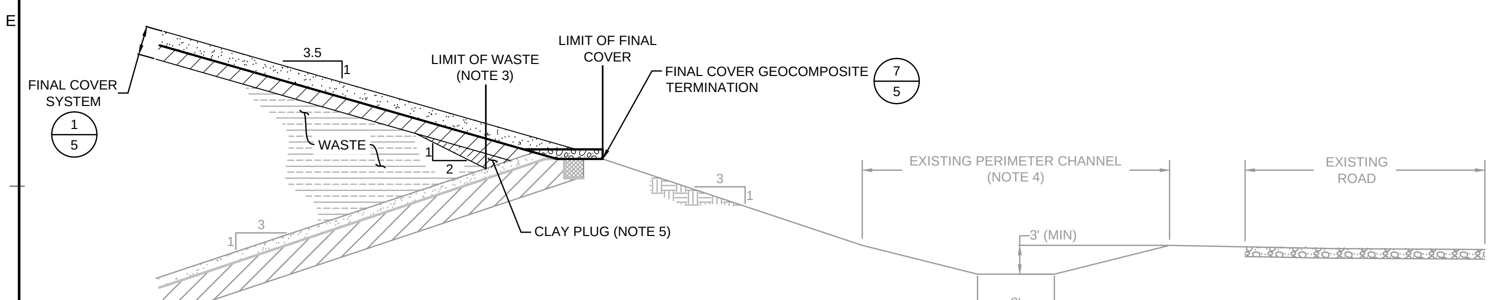


7/5 DETAIL
FINAL COVER GEOCOMPOSITE TERMINATION (NOTE 6)

0 2' 4'
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. A SINGLE-SIDED GEOCOMPOSITE AND 40-MIL SMOOTH LLDPE MAY BE USED ON THE LANDFILL TOP DECK (E.G., 3% TOP SLOPE).
3. DURING CELL OPERATION, THE LIMIT OF WASTE SHALL BE 2 FEET VERTICAL FROM CREST OF PERIMETER SLOPE. TOP OF PERIMETER SLOPE MAY BE EXTENDED BY CONSTRUCTING AN EXTENSION DIKE ON THE PERIMETER BERM.
4. THE PERIMETER CHANNEL SHALL BE GRASS-LINED. IN ADDITION, THE SOUTH PORTION OF THE EXISTING CELL 2 EAST CHANNEL SHALL BE LINED WITH TXDOT CLASS II, TYPE G OR H TURF REINFORCEMENT MAT WITH A MINIMUM RESISTANCE TO TRACTIVE STRESS OF 6-8 PSF.
5. CLAY MATERIAL SHALL BE PLACED AS NEEDED ALONG THE LANDFILL PERIMETER TO ACHIEVE THE SUBGRADE ELEVATIONS FOR THE FINAL COVER SYSTEM.
6. DETAIL DOES NOT APPLY BENEATH DOWNCHUTE.



6/2 DETAIL
EXISTING CELL 2 EAST AND SOUTH PERIMETER

0 10' 20'
SCALE IN FEET

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A	7/25/2014	70% DRAFT	JJV	BG

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TITLE: FINAL COVER SYSTEM DETAILS

PROJECT: SOLID WASTE DISPOSAL FACILITY FINAL COVER

SITE: SANDY CREEK ENERGY STATION

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Beth Ann Gross
SIGNATURE

12/19/2014
DATE

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LICENSED PROFESSIONAL ENGINEER

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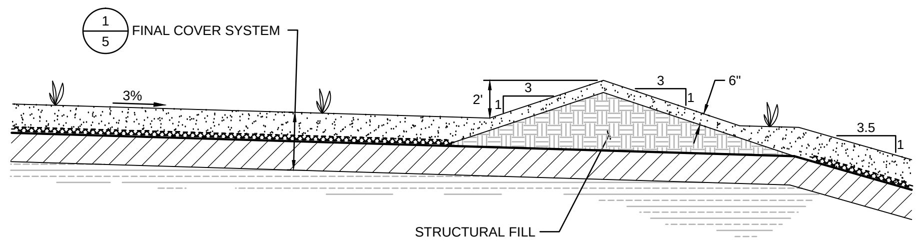
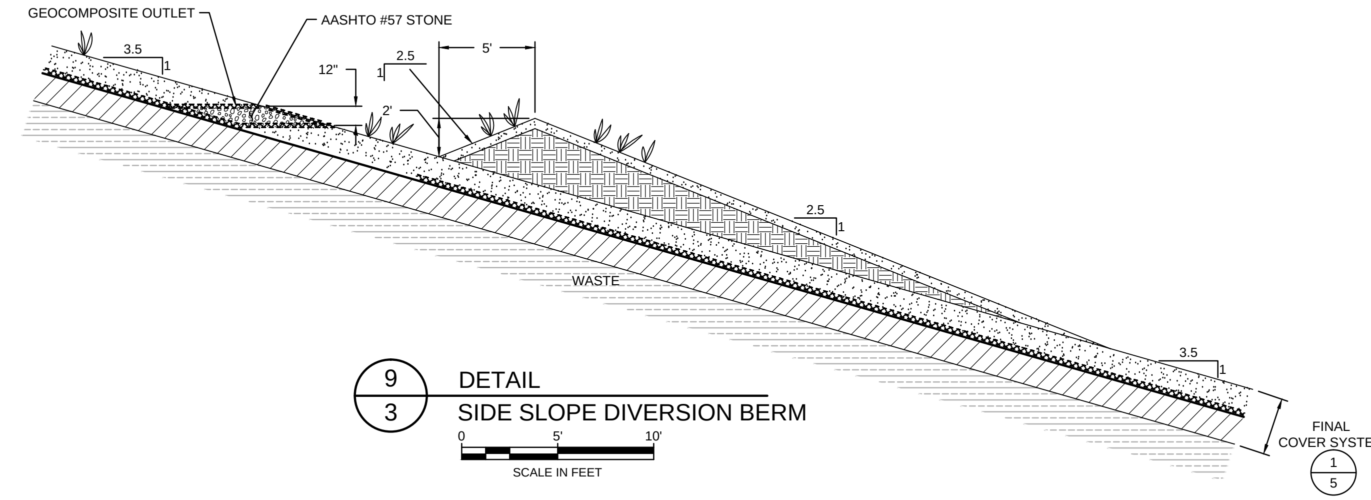
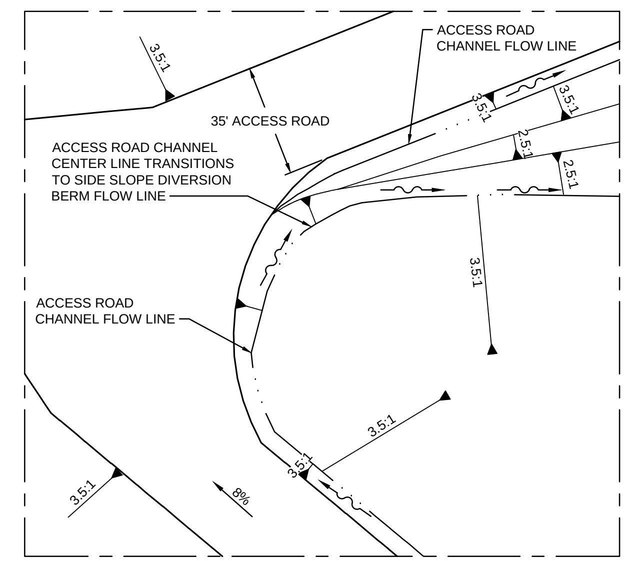
APPROVED BY:	BG	5 OF 7	



8
3
DETAIL
TOP DECK DIVERSION BERM
0 5' 10'
SCALE IN FEET



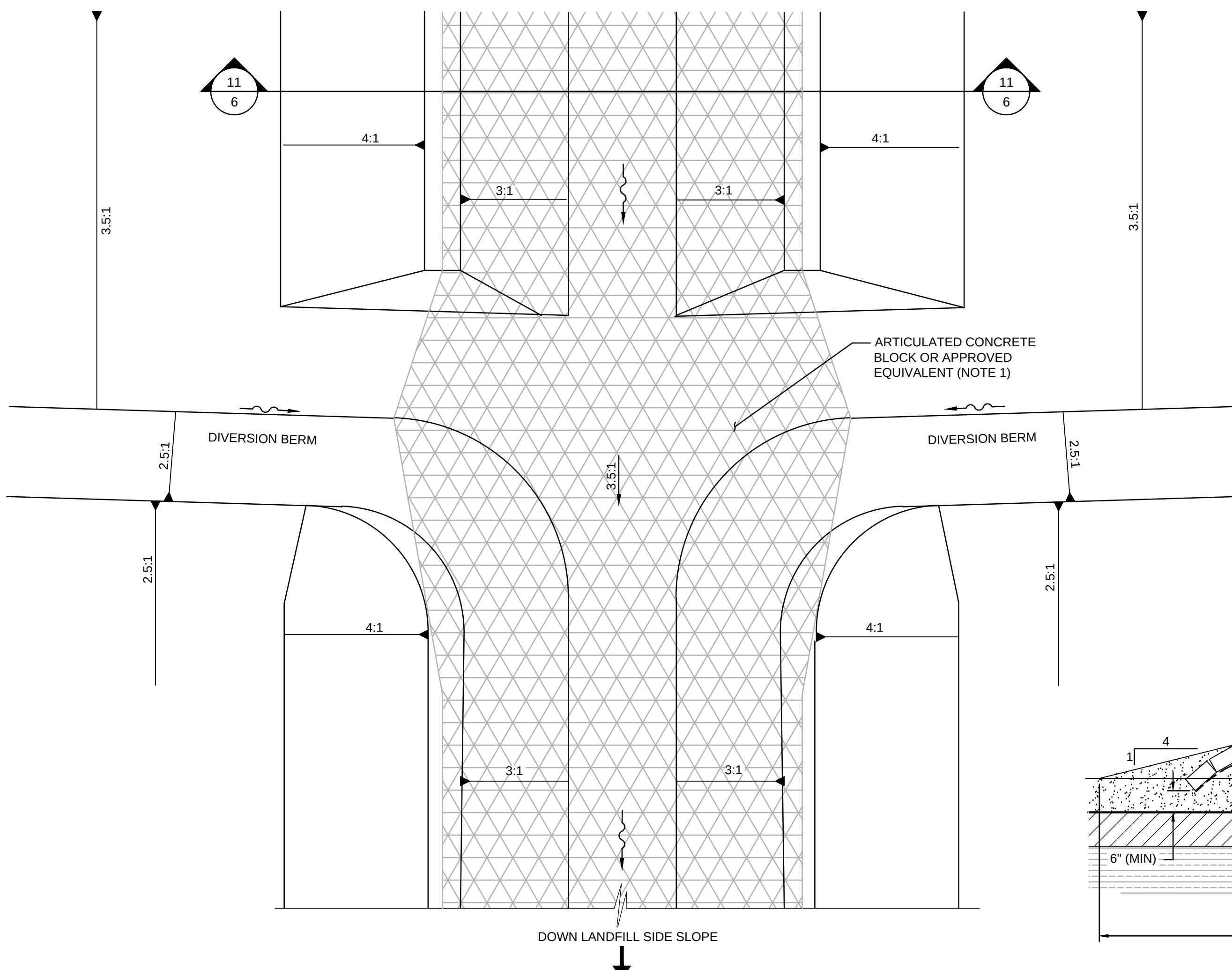
9
3
DETAIL
SIDE SLOPE DIVERSION BERM
0 5' 10'
SCALE IN FEET



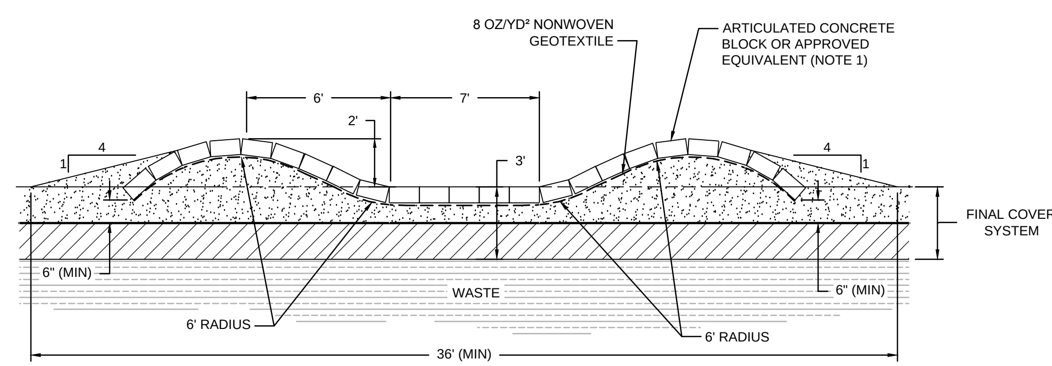
10
3
DETAIL
ACCESS ROAD CHANNEL AND SIDE
SLOPE DIVERSION BERM INTERSECTION
SCALE: 1" = 30'
0 30' 60'
SCALE IN FEET

NOTE:

1. DOWNCHUTE LINING SHALL BE ARTICULATED CONCRETE BLOCK (ACB) (OR APPROVED EQUIVALENT) WITH A MINIMUM RESISTANCE TO TRACTIVE STRESS OF 11 PSF.



12
3
DETAIL
DOWNCHUTE AND SIDE SLOPE DIVERSION
BERM INTERSECTION
0 5' 10'
SCALE IN FEET



11
3
DETAIL
DOWNCHUTE
0 4' 8'
SCALE IN FEET

DESIGN DRAWINGS
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TITLE:
STORMWATER MANAGEMENT SYSTEM DETAILS I

PROJECT:
SOLID WASTE DISPOSAL FACILITY FINAL COVER

SITE:
SANDY CREEK ENERGY STATION

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Beth Ann Gross
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12/19/2014
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DESIGN BY:	MZI / BK	DATE:	DECEMBER 2014
DRAWN BY:	JJV / KH	PROJECT NO.:	TXL0208.08
CHECKED BY:	MZI	FILE:	TXL020808D05
REVIEWED BY:	BG	DRAWING NO.:	
APPROVED BY:	BG	6 OF 7	

APPENDICES

APPENDIX A

Stormwater Management System Design – Final Conditions

Written by:	Vinay Krishnan & Brandon Klenzendorf	Date:	12/3/2015	Reviewed by:	Zahirul Islam & Beth Gross	Date:	12/4/2015
Client:	NAES	Project:	Sandy Creek Energy Station	Project/Proposal No.:	TXL0208	Task No:	08

SURFACE WATER MANAGEMENT SYSTEM DESIGN – FINAL CONDITIONS

Beth Ann Gross

12/4/2015

SEALED FOR CALCULATION PAGES 1 TO 60

GEOSYNTEC CONSULTANTS
TX ENG FIRM REGISTRATION NO. 1182

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1. PURPOSE

The purpose of this calculation package is to present the analysis and design of the surface water management system for the Solid Waste Disposal Facility (SWDF) at the Sandy Creek Energy Station in Riesel, Texas. This package provides calculations of peak design discharges (i.e., hydrology) and design of surface water management system components (i.e., hydraulic design) for the final cover system of the SWDF, including:

- Top deck diversion berms;
- Side slope diversion berms;
- Downchutes;
- Access road channel;
- Perimeter channel;
- Stormwater pond; and
- Culvert outlet riprap aprons.

2. PROJECT BACKGROUND

The SWDF will be closed with an approximately 62.9-acre final cover system (Drawing 2 of the Engineering Design Drawings for the SWDF Final Cover). The top deck of the final cover will have a surface slope of 3%, and the side slopes will be graded to 3.5 horizontal to 1 vertical (3.5H:1V). The final cover is designed with a surface water management system with permanent drainage features, including top deck diversion berms, side slope diversion berms, downchutes, an access road channel, and a perimeter channel. Except for one top deck diversion berm which routes water to the access road channel, the diversion berms direct water from the top deck and side slopes to the downchutes. The access road channel collect water from the access road, one top deck drainage channel, and the side slopes and primarily routes it to a side slope diversion berm. The downchutes convey water to the perimeter channel. Flow in the perimeter channel is conveyed to the existing stormwater pond. Based on Drawing 149060-SS-01250 (Solid Waste Disposal Facility Sections and Details, dated 9 June 2009) prepared by Black & Veatch as part of the Sandy Creek Energy Station construction project, flow from the stormwater detention pond is discharged through a 4-in. and a 10-in. diameter low flow bleed pipe and three 36-in. overflow culverts to the existing roadside drainage ditch south of the Sandy Creek Energy Station. Geosyntec and site personnel could only find the outlet of the 10-in. diameter pipe on the exterior slope of the stormwater detection pond. Therefore, only the 10-in. diameter pipe was considered in the analysis of the stormwater pond capacity presented herein.

The vegetative support layer of the final cover will be permanently stabilized with perennial grasses to resist erosion and sediment transport. Diversion berms will be grass-lined, and the access road channel will be lined with grass and long-term turf reinforcement mat (TRM). The downchutes will be lined with articulated concrete block (ACB) or an approved equivalent, and the downchute outlets into the perimeter channel will be concrete-lined. The perimeter channel will be grass-lined, except from the east downchute to the east perimeter channel outlet where it will be lined with long-term TRM. Calculations that support the selection of the lining for the stormwater management features are presented herein.

3. CALCULATION METHODOLOGY

3.1 Design Storm Return Period

The Texas Commission on Environmental Quality (TCEQ) Technical Guideline Number 3 (TG-3) (TCEQ, 2009) addresses the design of hazardous and industrial waste landfills and indicates that stormwater runoff should be diverted around the landfill area using dikes, ditches, or other structures. Such diversion structures should be capable of handling at least a 100-year, 24-hour rainfall event. However, TG-3 does not provide guidance on sizing of permanent stormwater detention ponds. The TCEQ also provides guidelines for surface water drainage design under the municipal solid waste rules (TCEQ, 2006). Geosyntec considers these guidelines to be relevant to coal combustion waste landfills, such as the SWDF. Under these guidelines, the design storm event for peak flow and volume sizing of stormwater ponds is the 25-year, 24-hour storm (TCEQ, 2006). Therefore, all stormwater diversion structures will be designed for a 100-year, 24-hour rainfall event, and all pond structures will be designed to detain water from a 25-year, 24-hour rainfall event. Riprap aprons will be designed for a 25-year, 24-hour rainfall event.

3.2 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 the 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* (USDA, 2004) as specified in the Texas Department of Transportation (TxDOT) *Hydraulic Design Manual* (TxDOT, 2011). A 2-year, 24-hour rainfall depth of 3.4 in. is used in the hydrologic model to estimate travel times for sheet flow conditions in order to calculate the times of concentration for each subarea (Figure 2). Similarly, rainfall depths of 7.3 in. and 9.5 in. were selected for 25-year, 24-hour and 100-year, 24-hour rainfall events, respectively (Figures 3 and Figure 4).

3.3 Hydrology

Intensity of rainfall for design is based on calculations for times of concentration and design rainfall depths 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), but does not estimate runoff volumes. Therefore, the SCS Curve Number method outlined by TR-55 (USDA, 1986) is used to estimate runoff volumes as recommended by TCEQ (2006) and to check the design of the existing stormwater detention pond.

3.4 Hydraulic Design

Hydraulic design of the diversion berms, access road channel, downchutes, and perimeter channel are performed using Manning's equation (Chow, 1959). The existing stormwater detention pond was modeled in the hydrologic model HEC-HMS version 4.0 (USACE, 2000). Average tractive shear stresses are calculated for each hydraulic feature. The channel lining was selected such that the calculated tractive stress for 100-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.

4. COMPUTATIONS

4.1 Rational Method for Hydrologic Design

The Rational Method was applied to estimate peak discharge rates for each drainage area to design the stormwater conveyance features. The Rational Method is expressed as follows:

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

where:
- Q = peak discharge for a given frequency (cfs);
- C = runoff coefficient dependent on land cover and frequency;
- I = intensity for the given frequency (in./hr); and
- A = contributing drainage area (acres).

4.2 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 is calculated from the design drawings using computer-aided design (CAD) software.

4.3 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 (values in Table 2 interpolated based on slope);
- C_i = soil infiltration runoff coefficient (no effective soil cover conservatively assumed);
- C_v = vegetal cover runoff coefficient (good cover); and
- C_s = surface storage runoff coefficient (negligible surface storage conservatively assumed).

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 and 1.25 for 25-year and 100-year recurrence intervals, respectively. The adjusted runoff coefficient for a 25-year design storm C_{25} is 1.10×C, and the adjusted runoff coefficient for a 100-year design storm C_{100} is 1.25×C. The runoff coefficients for each of the drainage areas are presented in Table 1.

4.4 Estimation of Time of Concentration for Rational Method

The time of concentration is 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 overland sheet flow travel time, shallow concentrated flow travel time, and open channel flow travel time.

The method to estimate the overland 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 and are provided in Table 1. The rainfall depth for the 2-year, 24-hour frequency ($P_{2\text{-}24}$) is 3.4 in. (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.

The method selected to estimate the open channel flow travel time is based on guidance provided in TR-55 (USDA, 1986). Travel time for 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 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/s);
n = Manning's roughness coefficient;
R_h = hydraulic radius (ft) = A/P;
A = cross sectional area of flow (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) for the grass-lined (with and without TRM) diversion berms, access road channel and perimeter channel, a Manning's roughness coefficient (n) of 0.027 was selected for clean and straight earthen open channels with short grass and few weeds as shown in Table 4 (Chow, 1959). The top deck diversion berms are designed with a slope of 0.15%, the side slope diversion berms are designed with a typical slope of 2% (actual slopes range from 1.9% to 2.5%), and the perimeter channel is designed with slopes ranging from 0.5% to 1.8%. The Manning's roughness coefficient of 0.036 was selected for the downchute ACB (Ayres, 2001).

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.

4.5 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 (in.) 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.

4.6 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 5. The calculated design discharges for the downstream end of each surface water management system component are provided in Table 6.

4.7 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 included in 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 Structures method for routing through ponds. The Outflow Structures method was used for the detention pond as a combination of culverts.

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 designed by Black & Veatch was evaluated to verify that it could convey the calculated peak flow rate from 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 82.8 acres as shown in Figure 5 based on the design contours developed by Geosyntec.

4.8 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 8 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).

4.9 Surface Water Management System Components Hydraulic Design

Manning's equation was used to estimate the average velocity for the diversion berms, access road channel, downchutes, and perimeter channels. Manning's equation for velocity (Chow, 1959) is presented earlier. Average discharge is equal to the average velocity times the area of cross-section of flow (i.e., $Q = VA$). The diversion berms, access road channel, 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 diversion berms, access road channel, downchutes, perimeter channels, 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 and 100-year design discharges for the diversion berms, access road channel, downchutes, perimeter channel, and perimeter channel outlets were calculated using the tractive stress equation with the hydraulic radius corresponding to the design discharge.

The diversion berms, access road channel, and perimeter channel are grass lined. 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 9) and has a maximum permissible tractive stress of 1.0 psf (Table 10) 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 10), 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.

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. For the purpose of this calculation package, it is assumed that Channel Lock brand ACB will be used. However, these blocks may not be available, and conversely, new types of blocks may be available, when the downchutes are constructed. Therefore, other erosion control product with equivalent performance may be used.

Two Channel Lock ACBs with different thicknesses are considered for the downchute design: Channel Lock 450 and Channel Lock 550 ACB. The maximum allowable tractive stress, or shear stress, for this ACB can be estimated from the permissible tractive stress on the ACB when the block is horizontal, with a performance adjustment for slope:

$$\tau_0 = \frac{\tau_\theta \chi_2}{\chi_2 \cos\theta - \chi_1 \sin\theta}$$

where: τ_0 = maximum allowable tractive stress at 0° (psf) from Table 11 (Ayres, 2001);
τ_θ = maximum allowable tractive stress at θ° (psf); and
χ_2 and χ_1 = extrapolation variables (in.) from Table 11.

Using the above equation and the values in Table 4, the maximum permissible tractive stresses on the ACB for the 3.5H:1V (15.9°) downchutes are calculated as 10.2 psf for Channel Lock 450 and 11.4 psf for Channel Lock 550 ACB. For the purpose of this calculation package, it is assumed that the maximum permissible tractive stress for the downchute lining is 11.4 psf.

4.10 Riprap Outlet Apron Design

The riprap aprons at the inflow culverts to the pond are designed to protect against erosion and scour from the perimeter channel flows. The riprap aprons were sized from the flow based on the 25-year, 24-hour rainfall event. The design guidance from the FHWA provides a methodology for calculating the required length of apron (L_a) and d_{50} of the riprap based on the culvert diameter and flow rate. The d_{50} is the stone size of the riprap for which to 50% of the riprap stones are smaller than d_{50} by mass. The riprap size is calculated using the following equation (FHWA, 2006):

$$d_{50} = 0.2D\left(\frac{Q}{D^{2.5}\sqrt{g}}\right)^{4/3}\frac{D}{TW}$$

where: d_{50} = riprap size (ft);
Q = design discharge (cfs);
D = pipe diameter (ft);
TW = tailwater depth (ft); and
g = gravitational constant.

The tailwater depth should be limited to between 0.4*D* and *D*. FHWA (2006) recommends the use of a tailwater depth equal to 0.4*D* if the tailwater is unknown.

The required length and depth of the riprap apron can be estimated based on the pond outlet pipe rise and riprap size as provided in Table 12. The width of the riprap apron at the outlet is recommended as 3*D* by the FHWA (2006) detail for riprap aprons. The apron width will also widen from the outlet along the required length at a rate of 1 ft width per 3 ft length on each side. Figure 10 provides the standard geometry for the riprap aprons.

5. RESULTS

5.1 Conveyance Feature Design

Hydraulic design calculations for diversion berms, access road channel, downchutes, and perimeter channel were performed using spreadsheets for the hydraulic elements with the largest design flow rates. The design parameters and results of the hydraulic design of each component of the surface water management system are summarized below. Additionally, dimensions of these components are summarized in Table 13 and Table 14 at the end of this document. The Reach ID corresponds with the drainage area contributing to the adjacent surface water management component.

Top Deck Diversion Berms (Table 13)

- 100-year Rainfall Design Discharge = 2.86 to 14.37 cfs
- Top Width = 72 ft
- Channel Slope = 0.15%
- Channel Lining = grass
- Manning's *n* = 0.027 (Table 4)
- Side Slopes = 3H:1V and 3%*
- Bottom Width = 0 ft
- Available Depth of Flow = 2.0 ft
- **100-year Calculated Depth of Flow** = 0.45 to 0.82 ft
- ***Calculated Depth of Flow < Available Depth of Flow***
- Allowable Tractive Stress = 1.0 psf (Table 10)for grass lining
- **100-year Calculated Average Tractive Stress** = 0.02 to 0.04 psf
- ***Calculated Average Tractive Stress < Allowable Tractive Stress***

  * Note: The top deck diversion berms are 2.0 ft deep (minimum) channels with 3H:1V slopes as the outer slope of the channel. The 3% slope of the landfill top deck provides the inner slope of the channel.

Side Slope Diversion Berms (Table 13)

- 100-year Rainfall Design Discharge = 9.40 to 59.46 cfs
- Top Width = 12 ft
- Channel Slope = 2.0% for design purposes (varies from 1.9 to 2.5%)
- Channel Lining = grass
- Manning's *n* = 0.027 (Table 4)
- Side Slopes = 3.5H:1V and 2.5H:1V*
- Bottom Width = 0 ft
- Available Depth of Flow = 2.0 ft
- **100-year Calculated Depth of Flow** = 0.86 to 1.73 ft
- ***Calculated Depth of Flow < Available Depth of Flow***
- Allowable Tractive Stress = 1.0 psf (Table 10) for grass lining
- **100-year Calculated Average Tractive Stress** = 0.59 to 0.97 psf
- ***Calculated Average Tractive Stress < Allowable Tractive Stress***

  * Note: The side slope diversion berms are 2.0 ft deep (minimum) channels with 2.5H:1V slopes as the outer slope of the channel. The 3.5H:1V slope of the landfill provides the inner slope of the channel.

Access Road Channel (Table 13)

- 100-year Rainfall Design Discharge = 14.37 to 22.68 cfs
- Top Width = 9.75 ft
- Channel Slope = 8.0% (Table 14)
- Channel Lining = grass with TRM
- Manning's *n* = 0.027 (Table 4)
- Side Slopes = 3.5H:1V and 3H:1V*
- Bottom Width = 0 ft
- Available Depth of Flow = 1.5 ft
- **100-year Calculated Depth of Flow** = 0.75 to 0.89 ft
- ***Calculated Depth of Flow < Available Depth of Flow***
- Allowable Tractive Stress = 2.0 psf (Table 10) or 6 to 8 psf for TxDOT Class 2, Type G or H TRM with grass
- **100-year Calculated Average Tractive Stress** = 1.79 to 2.12 psf
- ***Calculated Average Tractive Stress < Allowable Tractive Stress***

Downchutes (Table 13)

- 100-year Rainfall Design Discharge = 37.49 to 121.15 cfs
- Top Width = 19 ft
- Channel Slope = 28.6%
- Channel Lining = ACB
- Manning's *n* = 0.036
- Side Slopes = 6 ft radius*
- Bottom Width = 7.0 ft
- Available Depth of Flow = 2.0 ft
- **100-year Calculated Depth of Flow** = 0.41 to 0.80 ft
- ***Calculated Depth of Flow < Available Depth of Flow***
- Allowable Tractive Stress = 11.4 psf
- **25-year Calculated Average Tractive Stress** = 5.05 to 9.10 psf
- **100-year Calculated Average Tractive Stress** = 6.30 to 11.11 psf
- ***Calculated Average Tractive Stress < Allowable Tractive Stress***

** Note: Downchutes will be lined with ACB and constructed with a 6 ft radius of curvature. The downchutes were modeled as trapezoidal channels with a 7 ft bottom width and 3H:1V side slopes.

Eastern Perimeter Channel (Table 14)

- 100-year Rainfall Design Discharge = 179.66 cfs
- Top Width = 26 ft
- Channel Slope = 1.8% (Table 14)
- Channel Lining = grass, with TRM for south portion of channel
- Manning's *n* = 0.027 (Table 4)
- Side Slopes = 3H:1V
- Bottom Width = 8 ft
- Available Depth of Flow = 3.0 ft
- **100-year Calculated Depth of Flow** = 1.67 ft
- ***Calculated Depth of Flow < Available Depth of Flow***
- Allowable Tractive Stress = 2.0 psf (Table 10) or 6 to 8 psf for TxDOT Class 2, Type G or H TRM with grass
- **100-year Calculated Average Tractive Stress** = 1.32 psf
- ***Calculated Average Tractive Stress < Allowable Tractive Stress***

Western Perimeter Channel

- 100-year Rainfall Design Discharge = 250.02 cfs
- Top Width = 32 ft
- Channel Slope = 0.5 to 1.0% (Table 14)
- Channel Lining = Grass
- Manning's *n* = 0.027 (Table 4)
- Side Slopes = 3H:1V
- Bottom Width = 8 ft
- Available Depth of Flow = 4.0 ft
- **100-year Calculated Depth of Flow** = 2.30 ft
- ***Calculated Depth of Flow < Available Depth of Flow***
- Allowable Tractive Stress = 1.0 psf (grass-lined) (Table 10)
- **100-year Calculated Average Tractive Stress** = 0.95 psf
- ***Calculated Average Tractive Stress < Allowable Tractive Stress***

5.2 Stormwater Detention Pond Hydraulic Design

The SCS Curve Number method is used for hydrologic design of the existing 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, and the size of the pond outlet structure was evaluated with respect to its ability to discharge the peak flow rate for the 100-year, 24-hour storm event without overtopping the pond berm. The primary pond outlet structure consists of a 10-inch diameter bleed pipe with an invert elevation of 339-ft and three 36 inch diameter outlet pipes with an invert elevation of 450-ft.

The existing stormwater detention pond design was designed by Black & Veatch. Based on the results of the HEC-HMS analysis conducted for this calculation package, the pond is designed to convey the peak flow rate for the 100-year, 24-hour storm event. Under the 25-year, 24-hour storm, the pond detains runoff without discharging flow from the outlet pipes as the water level in the pond does not reach the invert elevation of these pipes. Under the 100-year, 24-hour storm, water is discharged from the outlet pipes, but the pipes do not flow full, and more than two feet of freeboard is maintained between the water in the pond and the pond crest. Modeling results for the peak flow rates and maximum water surface elevations are presented in Table 15 of this calculation package.

5.3 Riprap Outlet Apron Design

Riprap aprons were designed for the culverts from both the eastern perimeter channel and western perimeter channel into the stormwater detection pond. Flow from the 25-year, 24-hour storm event was considered.

For the east perimeter channel, the calculations were performed based on three 36-inch diameter pipes (i.e., D = 3.0 feet) and a design flow rate of Q = 117.2 cfs. The flow was assumed to be split equally between each pipe, resulting in a pipe flow of 39.1 cfs. The tailwater depth was computed as TW = 0.4D = 1.2 feet using the FHWA recommendation. A minimum d_{50} size for the riprap of 0.51 feet (approximately 6 inches) was calculated. The minimum apron length was selected based on Table 12. The riprap size corresponds to an FHWA class 2 riprap, resulting in an apron length of 4D = 12 feet and an apron depth of $3.3d_{50}$ = 1.6 feet. FHWA (2006) recommends an apron width of 3D at the upgradient end of the apron near the pond outlet pipe and a 3:1 rate of apron width expansion with apron length. Therefore, the upstream apron width is 29 feet, including a 1 ft separation between pipes for bedding. The apron extends to the bottom of the 3H:1V pond slope.

For the west perimeter channel, the calculations were performed based on three 48-inch diameter pipes (i.e., D = 4.0 feet), a design flow rate of Q = 228.2 cfs. The flow was assumed to be split between each pipe, resulting in a pipe flow of 76.1 cfs. The tailwater depth was computed as TW = 0.4D = 1.6 feet using the FHWA recommendation. A minimum d_{50} size for the riprap of 0.63 feet (rounded up to 8 inches) was calculated. The minimum apron length was selected based on Table 12. The riprap size falls between FHWA class 2 and class 3 riprap, resulting in an apron length of 4D to 5D = 16 to 20 feet and an apron depth of $2.4d_{50}$ to $3.3d_{50}$ = 1.5 to 2.1 feet. FHWA (2006) recommends an apron width of 3D at the up gradient end of the apron near the pond outlet pipe and a 3:1 rate of expansion. Therefore, the upstream apron width is 38 ft, including a 1 ft separation between pipes for bedding. The apron extends to the bottom of the 3H:1V pond slope.

6. CONCLUSIONS

Results from calculations presented in this calculation package indicate that the surface water management system for the proposed SWDF at the Sandy Creek Power Project site in Riesel, Texas will collect and control the runoff resulting from a 100-year, 24-

hour design storm event. The proposed surface water management system includes diversion berms, an access road channel, a perimeter channel, downchutes, and an existing 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: Length L (ft)	Sheet Flow: Slope S (ft/ft)	Sheet Flow: Manning's n	Sheet Flow: Time T_t (min)	Open Channel Flow: Length L (ft)	Open Channel Flow: Flow Depth d (ft)	Open Channel Flow: Area A (ft^2)	Open Channel Flow: Wetted P (ft)	Open Channel Flow: Hydraulic Radius R (ft)	Open Channel Flow: Manning's n	Open Channel Flow: Slope S (ft/ft)	Open Channel Flow: Velocity V (ft/s)	Open Channel Flow: Time T_t (min)	T_c: Design T_c (min)
E-1	1.22	145	0.030	0.15	10.88	335	1.0	18.0	36.2	0.50	0.027	0.0015	1.34	4.16	15.04
E-2	3.34	150	0.030	0.15	11.18	560	1.5	7.3	10.2	0.72	0.027	0.080	12.50	0.75	19.63
E-3	4.92	225	0.286	0.15	6.28	290	2.0	12.0	12.7	0.95	0.027	0.020	7.53	0.64	10.00
E-4	1.33	240	0.286	0.15	6.61	120	2.0	12.0	12.7	0.95	0.027	0.020	7.53	0.27	10.00
E-5	3.21	205	0.286	0.15	5.83										10.00
E-6	1.94	205	0.286	0.15	5.83	490	2.0	12.0	12.7	0.95	0.027	0.020	7.53	1.08	10.00
E-7	2.80	225	0.286	0.15	6.28	360	2.0	12.0	12.7	0.95	0.027	0.020	7.53	0.80	10.00
E-8	1.36	70	0.286	0.15	2.47	280	3.0	51.0	27.0	1.89	0.027	0.018	11.32	0.41	10.00
E-9	6.93	180	0.286	0.15	5.25	200	3.0	51.0	27.0	1.89	0.027	0.018	11.32	0.29	10.00
S-1	2.22	250	0.030	0.15	16.82	10	1.0	18.0	36.2	0.50	0.027	0.0015	1.34	0.12	16.95
S-2	2.38	250	0.286	0.15	6.83	280	2.0	12.0	12.7	0.95	0.027	0.020	7.53	0.62	10.00
S-3	2.93	240	0.286	0.15	6.61	410	2.0	12.0	12.7	0.95	0.027	0.020	7.53	0.91	10.00
S-4	3.29	240	0.286	0.15	6.61	490	2.0	12.0	12.7	0.95	0.027	0.020	7.53	1.08	10.00
S-5	4.13	230	0.286	0.15	6.39	650	2.0	12.0	12.7	0.95	0.027	0.025	8.42	1.29	10.00
W-1	0.54	190	0.030	0.15	13.51	55	1.0	18.0	36.2	0.50	0.027	0.0015	1.34	0.68	14.19
W-2	2.60	270	0.286	0.15	7.26	30	2.0	12.0	12.7	0.95	0.027	0.020	7.53	0.07	10.00
W-3	2.30	250	0.286	0.15	6.83	275	2.0	12.0	12.7	0.95	0.027	0.025	8.42	0.54	10.00
W-4	8.41	260	0.286	0.15	7.05	1600	2.0	12.0	12.7	0.95	0.027	0.019	7.34	3.63	10.68
W-5	3.20	240	0.286	0.15	6.61	500	2.0	12.0	12.7	0.95	0.027	0.022	7.90	1.06	10.00
W-6	11.51	260	0.253	0.15	7.40	2350	4.0	80.0	33.3	2.40	0.027	0.005	7.00	5.60	13.00
W-7	6.95	140	0.224	0.15	4.73	1100	4.0	80.0	33.3	2.40	0.027	0.010	9.90	1.85	10.00
E-5 ARC						10	1.5	7.3	10.2	0.72	0.027	0.080	12.50	0.01	
PondDA	5.31				0.00									0.00	10.00
E-2 TDDT						620	1.0	18.0	36.2	0.50	0.027	0.0015	1.34	7.70	

SUBCATCHMENT DESIGNATION	Runoff Coefficient for Rural Watersheds: Relief C_r	Soil Infiltration C_i	Vegetal Cover C_v	Surface C_s	25-year Return Interval: Intensity I_{25} (in./hr)	Runoff Coefficient C_{25}	Peak Flow Rate Q_{25} (cfs)	100-year Return Interval: Intensity I_{100} (in./hr)	Runoff Coefficient C_{100}	Peak Flow Rate Q_{100} (cfs)
E-1	0.12	0.16	0.06	0.12	6.79	0.506	**4.19**	9.18	0.575	**6.44**
E-2	0.12	0.16	0.06	0.12	5.74	0.506	**9.71**	7.48	0.575	**14.37**
E-3	0.27	0.16	0.06	0.12	6.80	0.676	**22.61**	9.20	0.768	**34.76**
E-4	0.27	0.16	0.06	0.12	6.80	0.676	**6.11**	9.20	0.768	**9.40**
E-5	0.27	0.16	0.06	0.12	6.80	0.676	**14.75**	9.20	0.768	**22.68**
E-6	0.27	0.16	0.06	0.12	6.80	0.676	**8.92**	9.20	0.768	**13.71**
E-7	0.27	0.16	0.06	0.12	6.80	0.676	**12.87**	9.20	0.768	**19.79**
E-8	0.27	0.16	0.06	0.12	6.80	0.676	**6.23**	9.20	0.768	**9.58**
E-9	0.27	0.16	0.06	0.12	6.80	0.676	**31.83**	9.20	0.768	**48.93**
S-1	0.12	0.16	0.06	0.12	6.30	0.506	**7.08**	8.38	0.575	**10.69**
S-2	0.27	0.16	0.06	0.12	6.80	0.676	**10.94**	9.20	0.768	**16.82**
S-3	0.27	0.16	0.06	0.12	6.80	0.676	**13.47**	9.20	0.768	**20.70**
S-4	0.27	0.16	0.06	0.12	6.80	0.676	**15.12**	9.20	0.768	**23.24**
S-5	0.27	0.16	0.06	0.12	6.80	0.676	**18.97**	9.20	0.768	**29.17**
W-1	0.12	0.16	0.06	0.12	6.80	0.506	**1.86**	9.20	0.575	**2.86**
W-2	0.27	0.16	0.06	0.12	6.80	0.676	**11.96**	9.20	0.768	**18.38**
W-3	0.27	0.16	0.06	0.12	6.80	0.676	**10.57**	9.20	0.768	**16.25**
W-4	0.27	0.16	0.06	0.12	6.80	0.676	**38.67**	9.20	0.768	**59.46**
W-5	0.27	0.16	0.06	0.12	6.80	0.676	**14.71**	9.20	0.768	**22.61**
W-6	0.27	0.16	0.06	0.12	6.80	0.676	**52.91**	9.20	0.768	**81.34**
W-7	0.27	0.16	0.06	0.12	6.80	0.676	**31.95**	9.20	0.768	**49.12**

2-year, 24-hr Design Rainfall Depth, P_{2-24} =	3.4	inches	Right Side Slope =	3.5	H:V for Side Slope Berm
25-year, 15-min Design Rainfall Depth =	1.7	inches	Left Side Slope =	2.5	H:V for Side Slope Berm
25-year, 30-min Design Rainfall Depth =	2.2	inches			
100-year, 15-min Design Rainfall Depth =	2.3	inches			
100-year, 30-min Design Rainfall Depth =	2.7	inches			

Notes:

1) *Manning's roughness coefficient: n = 0.15 represents grass (short grass prairie) for sheet flow (USDA, 1986).*
2) *Manning's roughness coefficient: n = 0.027 excavated open channel of earth that is straight and uniform with short grass and few weeds (Chow, 1959).*
3) *Travel Time (T_t) for sheet flow 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) *Travel time (T_t) for open channel flow under bank full condition is calculated using Manning's equation (USDA, 1986).*

   $T_t = L/V = L\,n / (1.49 R^{2/3} S^{1/2})$ *with flow depth = 1 ft for top deck berms, 2 ft for side slope berms, 1.5 ft for access road channel, and 3 or 4 ft for perimter channel*

5) *Design rainfall depths taken from USGS (2004) report for McLennan County based on guidance provided by TxDOT (2011).*
6) *Intensity was calculated using the 25-year or 100-year design rainfall depth for a storm of duration equal to time of concentration based on guidance provided by TxDOT (2011).*
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) *Travel time for Subcatchment Area E-2 includes travel time in top deck diversion berm channel.*

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 Coefficients 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 – Manning's Roughness Coefficients 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 5 – Contributing Areas to Each Stormwater Management System Component

System Component	Contributing Areas Upstream of Stormwater Management System Component							
East Perimeter Channel (N)	E-8							
East Perimeter Channel (S)	E-1	E-2	E-3	E-4	E-5	E-6	E-7	E-8	E-9
West Perimeter Channel (N)	W-6								
West Perimeter Channel (S)	W-1	W-2	W-3	W-4	W-5	W-6	W-7		
East Downchute Upper	E-1	E-2	E-3	E-4					
East Downchute Lower	E-1	E-2	E-3	E-4	E-5	E-6	E-7		
South Downchute Upper	S-1	S-2	S-3						
South Downchute Lower	S-1	S-2	S-3	S-4	S-5				
West Downchute Upper	W-1	W-2	W-3						
West Downchute Lower	W-1	W-2	W-3	W-4	W-5				

Table 6 – 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)
East Perimeter Channel (N)	9.58									9.58	6.23
East Perimeter Channel (S)	6.44	14.37	34.76	9.40	22.68	13.71	19.79	9.58	48.93	179.66	117.22
West Perimeter Channel (N)	81.34									81.34	52.91
West Perimeter Channel (S)	2.86	18.38	16.25	59.46	22.61	81.34	49.12			250.02	162.62
East Downchute Upper	6.44	14.37	34.76	9.40						64.97	42.62
East Downchute Lower	6.44	14.37	34.76	9.40	22.68	13.71	19.79			121.15	79.16
South Downchute Upper	10.69	16.82	20.70							48.21	31.48
South Downchute Lower	10.69	16.82	20.70	23.24	29.17					100.62	65.57
West Downchute Upper	2.86	18.38	16.25							37.49	24.39
West Downchute Lower	2.86	18.38	16.25	59.46	22.61					119.56	77.77
Top Deck Diversion Berm E-1	6.44									6.44	4.19
Top Deck Diversion Berm E-2	14.37									14.37	9.71
Access Road Channel E-2	14.37									14.37	9.71
Side Slope Diversion Berm E-3	34.76	14.37								49.13	32.32
Side Slope Diversion Berm E-4	9.40									9.40	6.11
Access Road Channel E-5	22.68									22.68	14.75
Side Slope Diversion Berm E-6	13.71	22.68								36.39	23.67
Side Slope Diversion Berm E-7	19.79									19.79	12.87
Top Deck Diversion Berm S-1	10.69									10.69	7.08
Side Slope Diversion Berm S-2	16.82									16.82	10.94
Side Slope Diversion Berm S-3	20.70									20.70	13.47
Side Slope Diversion Berm S-4	23.24									23.24	15.12
Side Slope Diversion Berm S-5	29.17									29.17	18.97
Top Deck Diversion Berm W-1	2.86									2.86	1.86
Side Slope Diversion Berm W-2	18.38									18.38	11.96
Side Slope Diversion Berm W-3	16.25									16.25	10.57
Side Slope Diversion Berm W-4	59.46									59.46	38.67
Side Slope Diversion Berm W-5	22.61									22.61	14.71

Table 7 – Runoff Curve Numbers for Other Agricultural Lands

(from USDA, 1986)

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	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 8 – SCS Method Lag Time Calculations

SUBCATCHMENT DESIGNATION	Area Acres (ac)	Tc Design Tc (min)	HEC-HMS Input Area (mi2)	Curve Number	SCS Lag Time (min)
E-1	1.22	15.04	0.00191	80	9.02
E-2	3.34	19.63	0.00522	80	11.78
E-3	4.92	10.00	0.00769	80	6.00
E-4	1.33	10.00	0.00208	80	6.00
E-5	3.21	10.00	0.00502	80	6.00
E-6	1.94	10.00	0.00303	80	6.00
E-7	2.80	10.00	0.00438	80	6.00
E-8	1.36	10.00	0.00212	80	6.00
E-9	6.93	10.00	0.01082	80	6.00
S-1	2.22	16.95	0.00347	80	10.17
S-2	2.38	10.00	0.00372	80	6.00
S-3	2.93	10.00	0.00458	80	6.00
S-4	3.29	10.00	0.00514	80	6.00
S-5	4.13	10.00	0.00645	80	6.00
W-1	0.54	14.19	0.00084	80	8.51
W-2	2.60	10.00	0.00407	80	6.00
W-3	2.30	10.00	0.00359	80	6.00
W-4	8.41	10.68	0.01315	80	6.41
W-5	3.20	10.00	0.00500	80	6.00
W-6	11.51	13.00	0.01799	80	7.80
W-7	6.95	10.00	0.01086	80	6.00

Table 9 – 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 10 – 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 11 – Performance Extrapolation Variables for ACB

(from Ayres, 2001)

Block Type	Weight in Air (typ.)[2] (lbs.)	Buoyant Weight W_s (lbs.)	χ^1 (in)	χ^2 (in)	χ^3 (in)	χ^4 (in)	b (in)	τ_c at 0° (lb/ft^2)
450[1]	52	27.0	2.25	7.25	3.60	7.25	14.5	11.6
550	64	33.3	2.75	7.25	4.40	7.25	14.5	13.3
800	93	48.4	4.00	7.25	6.40	7.25	14.5	16.5

Notes: 1. Tested block
2. Based on block volume and assuming concrete density of 130 lb/ft^3

Table 12 – Riprap Classes and Apron Dimensions

(from FHWA, 2006)

Class	D_{50} (mm)	D_{50} (in)	Apron Length[1]	Apron Depth
1	125	5	4D	$3.5D_{50}$
2	150	6	4D	$3.3D_{50}$
3	250	10	5D	$2.4D_{50}$
4	350	14	6D	$2.2D_{50}$
5	500	20	7D	$2.0D_{50}$
6	550	22	8D	$2.0D_{50}$

[1]D is the culvert rise.

Table 13 – Diversion Berm, Access Road Channel, and Downchute Geometry and Results

Contributing Drainage Area	Channel Slope (ft/ft)	Channel Dimensions					25-year				100-year				Channel Lining
		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)	
TDDB E-1	0.0015	0.0	2.0	3:1	33:1	72	4.19	0.52	0.87	0.02	6.44	0.61	0.96	0.03	Grass
TDDB E-2	0.0015	0.0	2.0	3:1	33:1	72	9.71	0.71	1.07	0.03	14.37	0.82	1.18	0.04	Grass
ARC E-2	0.080	0.0	1.5	3:1	3.5:1	9.75	9.71	0.65	7.13	1.54	14.37	0.75	7.87	1.79	TRM
SSDB E-3	0.020	0.0	2.0	3.5:1	2.5:1	12	32.32	1.36	5.82	0.80	49.13	1.59	6.46	0.94	Grass
SSDB E-4	0.020	0.0	2.0	3.5:1	2.5:1	12	6.11	0.73	3.84	0.43	9.40	0.86	4.27	0.59	Grass
ARC E-5	0.080	0.0	1.5	3:1	3.5:1	9.75	14.75	0.76	7.92	1.81	22.68	0.89	8.82	2.12	TRM
SSDB E-5	0.020	0.0	2.0	3.5:1	2.5:1	12	14.75	1.01	4.78	0.60	22.68	1.19	5.33	0.70	Grass
SSDB E-6	0.020	0.0	2.0	3.5:1	2.5:1	12	23.67	1.21	5.39	0.72	36.39	1.42	6.00	0.84	Grass
SSDB E-7	0.020	0.0	2.0	3.5:1	2.5:1	12	12.87	0.96	4.62	0.57	19.79	1.13	5.15	0.67	Grass
TDDB S-1	0.0015	0.0	2.0	3:1	33:1	72	7.08	0.63	0.99	0.03	10.69	0.74	1.09	0.03	Grass
SSDB S-2	0.020	0.0	2.0	3.5:1	2.5:1	12	10.94	0.91	4.44	0.54	16.82	1.06	4.94	0.63	Grass
SSDB S-3	0.020	0.0	2.0	3.5:1	2.5:1	12	13.47	0.98	4.68	0.58	20.70	1.15	5.21	0.68	Grass
SSDB S-4	0.020	0.0	2.0	3.5:1	2.5:1	12	15.12	1.02	4.81	0.60	23.24	1.20	5.36	0.71	Grass
SSDB S-5	0.025	0.0	2.0	3.5:1	2.5:1	12	18.97	1.07	5.54	0.79	29.17	1.26	6.17	0.93	Grass
TDDB W-1	0.0015	0.0	2.0	3:1	33:1	72	1.86	0.38	0.71	0.02	2.86	0.45	0.79	0.02	Grass
SSDB W-2	0.020	0.0	2.0	3.5:1	2.5:1	12	11.96	0.94	4.54	0.55	18.38	1.10	5.06	0.65	Grass
SSDB W-3	0.025	0.0	2.0	3.5:1	2.5:1	12	10.57	0.86	4.79	0.63	16.25	1.01	5.33	0.75	Grass
SSDB W-4	0.019	0.0	2.0	3.5:1	2.5:1	12	38.67	1.47	5.97	0.83	59.46	1.73	6.65	0.97	Grass
SSDB W-5	0.022	0.0	2.0	3.5:1	2.5:1	12	14.71	0.99	4.96	0.65	22.61	1.17	5.52	0.76	Grass
East Downchute Upper	0.286	7.0	2.0	3:1	3:1	19	42.62	0.44	11.54	6.72	64.97	0.56	13.25	8.27	ACB
East Downchute Lower	0.286	7.0	2.0	3:1	3:1	19	79.16	0.63	14.12	9.10	121.15	0.80	16.13	11.11	ACB
South Downchute Upper	0.286	7.0	2.0	3:1	3:1	19	31.48	0.37	10.41	5.76	48.21	0.48	12.02	7.14	ACB
South Downchute Lower	0.286	7.0	2.0	3:1	3:1	19	65.57	0.57	13.29	8.31	100.62	0.72	15.23	10.19	ACB
West Downchute Upper	0.286	7.0	2.0	3:1	3:1	19	24.39	0.32	9.54	5.05	37.49	0.41	11.05	6.30	ACB
West Downchute Lower	0.286	7.0	2.0	3:1	3:1	19	77.77	0.62	14.04	9.02	119.56	0.79	16.07	11.04	ACB

Table 14 – Perimeter Channel Geometry and Results

Perimeter Channel Segment	Channel Slope (ft/ft)	Channel Dimensions (minimum)				25-year				100-year				Channel Lining
		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)	
East Channel (N)	0.018	8.0	3.0	3:1	26	6.23	0.25	2.79	0.26	9.58	0.33	3.26	0.33	Grass
East Channel (S)	0.018	8.0	3.0	3:1	26	117.22	1.34	7.29	1.10	179.66	1.67	8.24	1.32	TRM
West Channel (N)	0.005	8.0	4.0	3:1	32	52.91	1.23	3.67	0.28	81.34	1.55	4.16	0.34	Grass
West Channel (S)	0.010	8.0	4.0	3:1	32	162.62	1.85	6.48	0.79	250.02	2.30	7.30	0.95	Grass

Table 15 – HEC-HMS Model Results

	25-year, 24-hour Design Storm Event	**100-year, 24-hour Design Storm Event**
Peak Discharge to Detention Pond (cfs)	344.1	528.0
Peak Outflow from Detention Pond (cfs)	6.5	27.0
Peak Pond Water Surface Elevation (ft)	449.8	451.5
Peak Storage in Detention Pond (ac-ft)	33.0	39.6

FIGURES

- Figure 1 – Rainfall Distribution Map of the United States (from USDA, 1986)
- Figure 2 – Depth of Precipitation for 2-year Storm of 24-hour Duration in Texas (from USGS, 2004)
- Figure 3 – Depth of Precipitation for 25-year Storm of 24-hour Duration in Texas (from USGS, 2004)
- Figure 4 – Depth of Precipitation for 100-year Storm of 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 of 15-minute Duration in Texas (from USGS, 2004)
- Figure 7 – Depth of Precipitation for 25-year Storm of 30-minute Duration in Texas (from USGS, 2004)
- Figure 8 – Depth of Precipitation for 100-year Storm of 15-minute Duration in Texas (from USGS, 2004)
- Figure 9 – Depth of Precipitation for 100-year Storm of 30-minute Duration in Texas (from USGS, 2004)
- Figure 10 – Placed Riprap Apron Standard Detail (from FHWA, 2006)

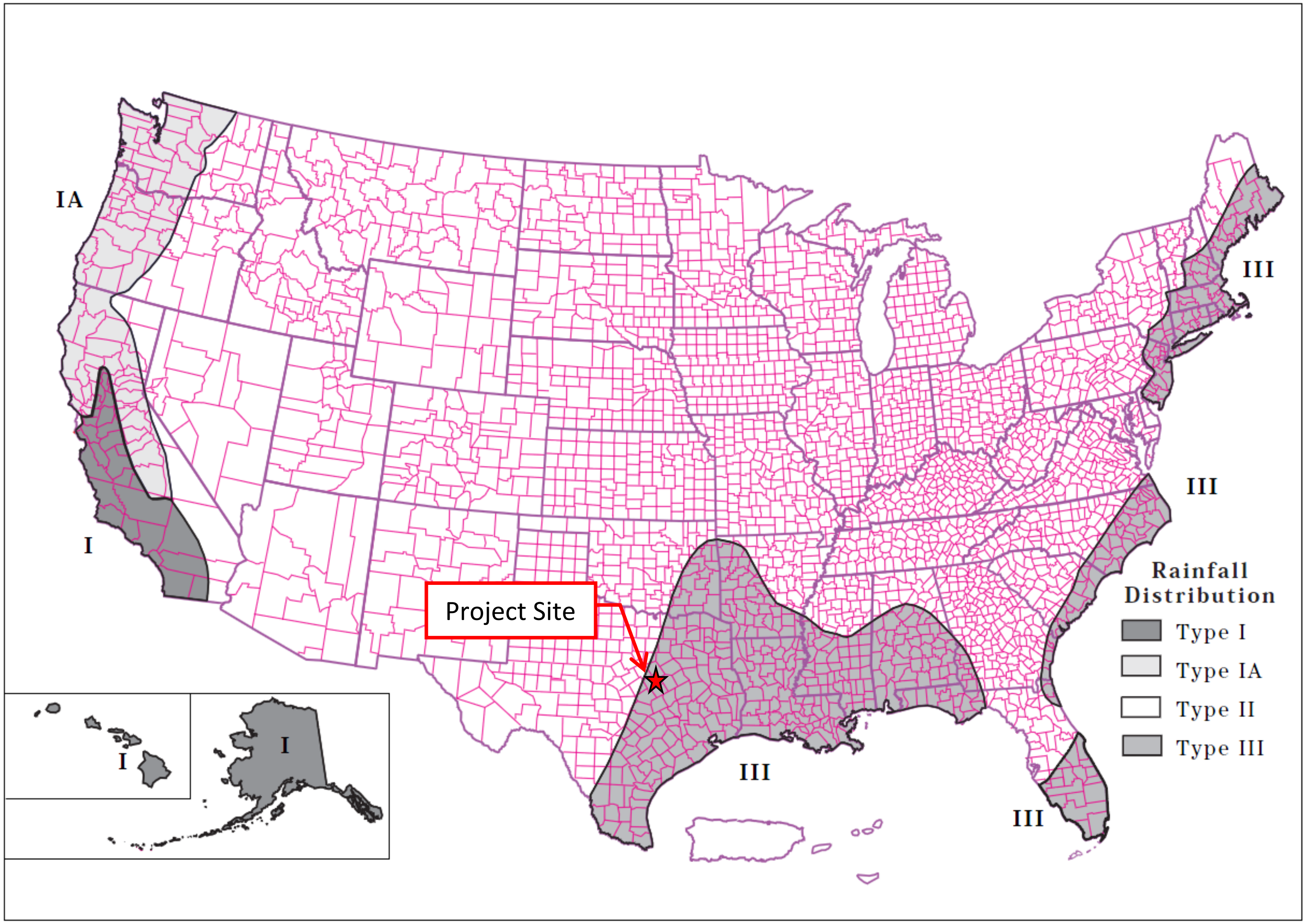


Figure 1 – Rainfall Distribution Map of the United States (from USDA, 1986)

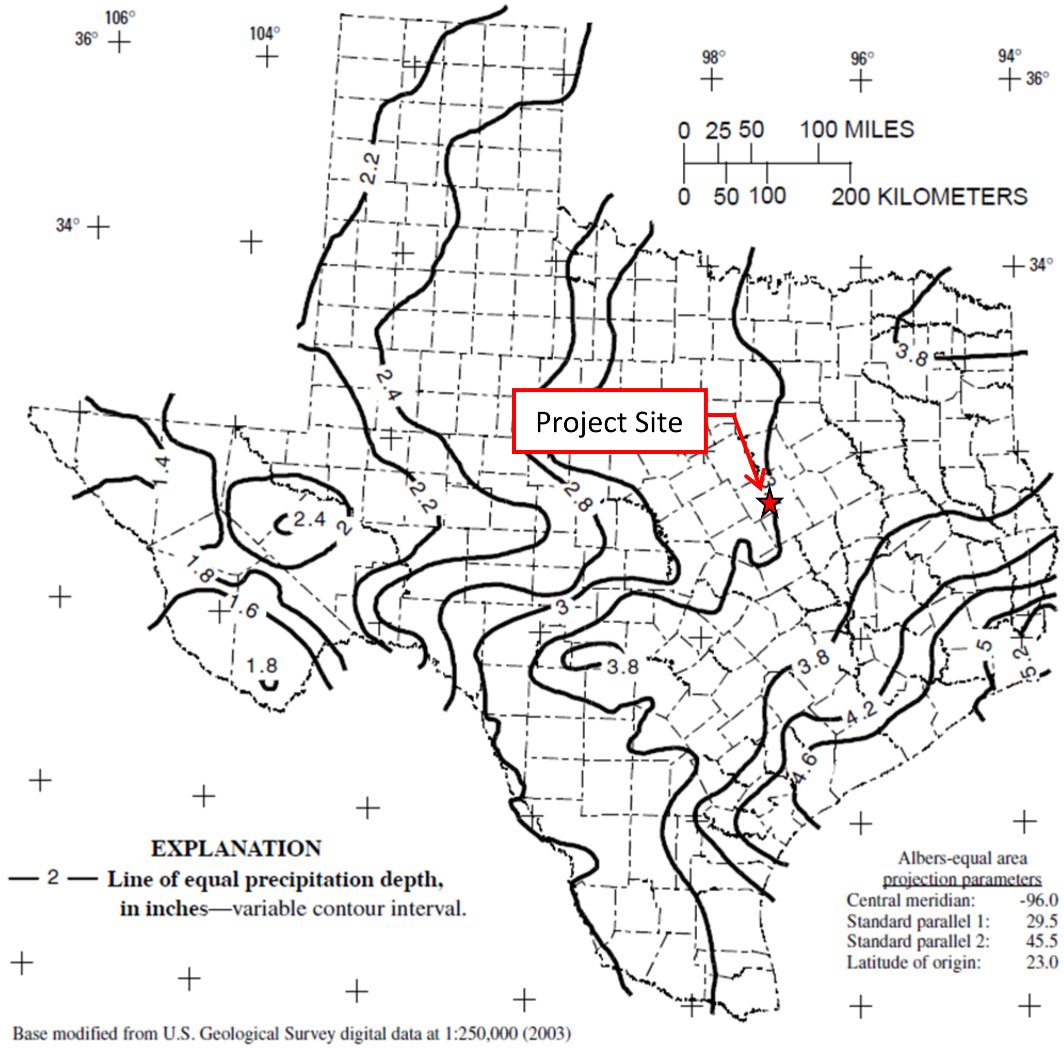


Figure 2 – Depth of Precipitation for 2-year Storm of 24-hour Duration in Texas (from USGS, 2004)

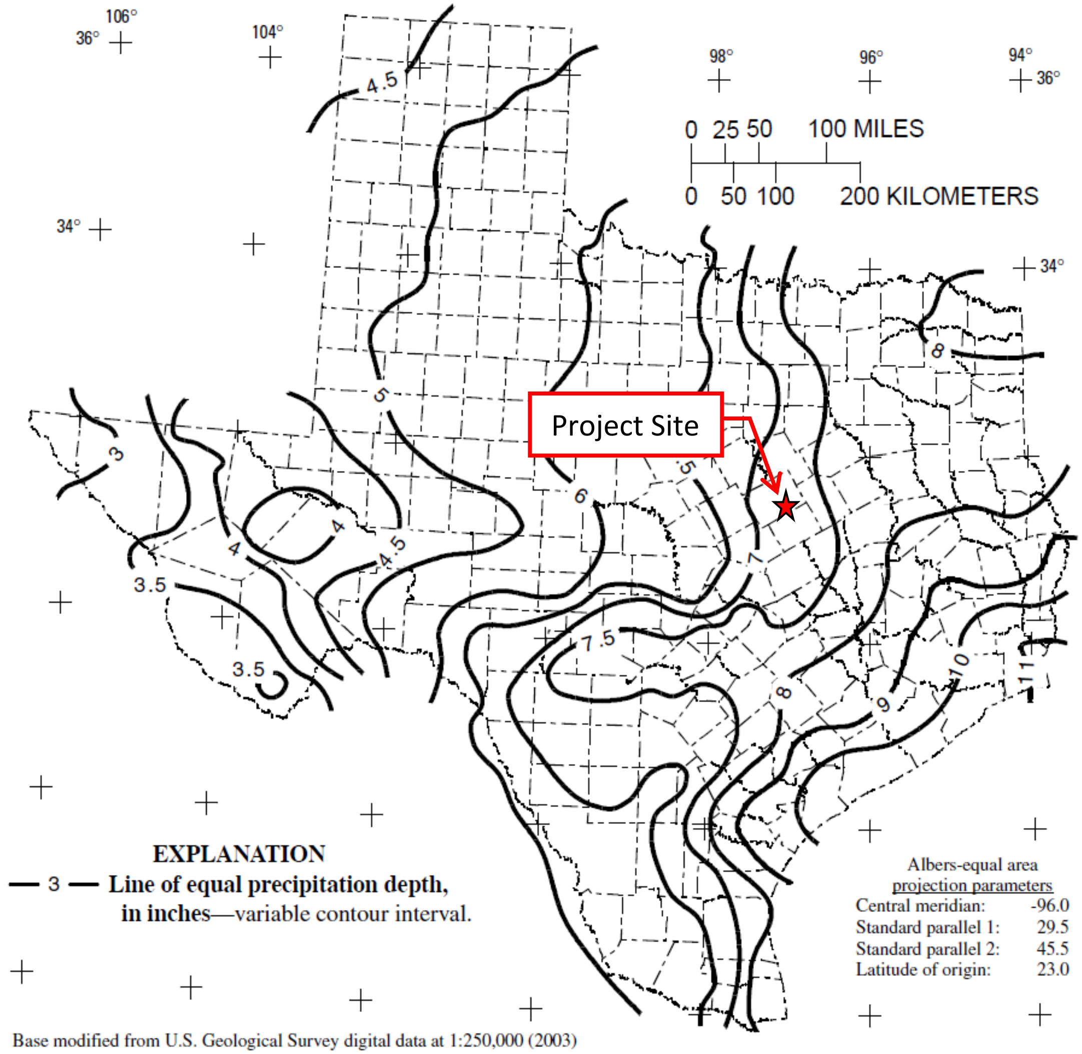


Figure 3 – Depth of Precipitation for 25-year Storm of 24-hour Duration in Texas (from USGS, 2004)

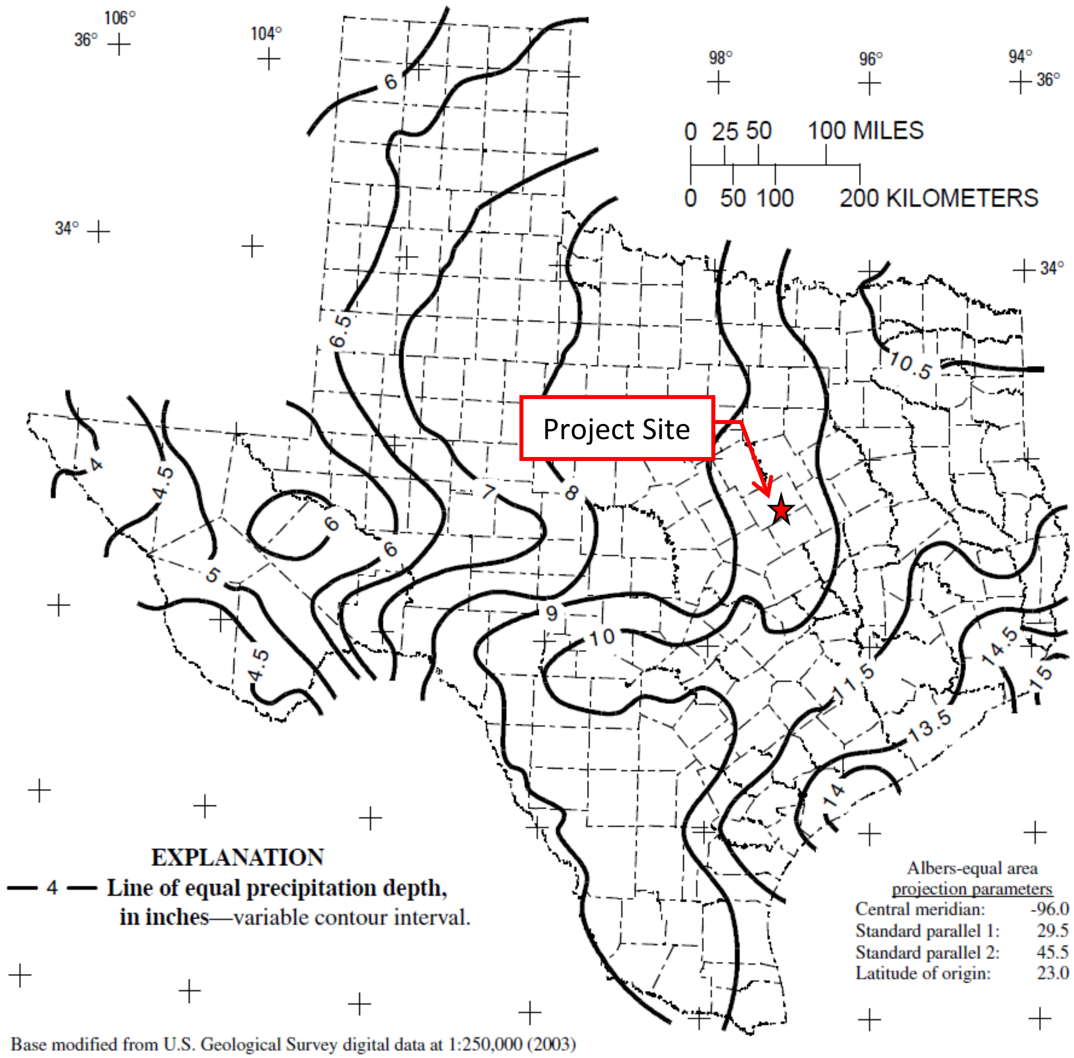
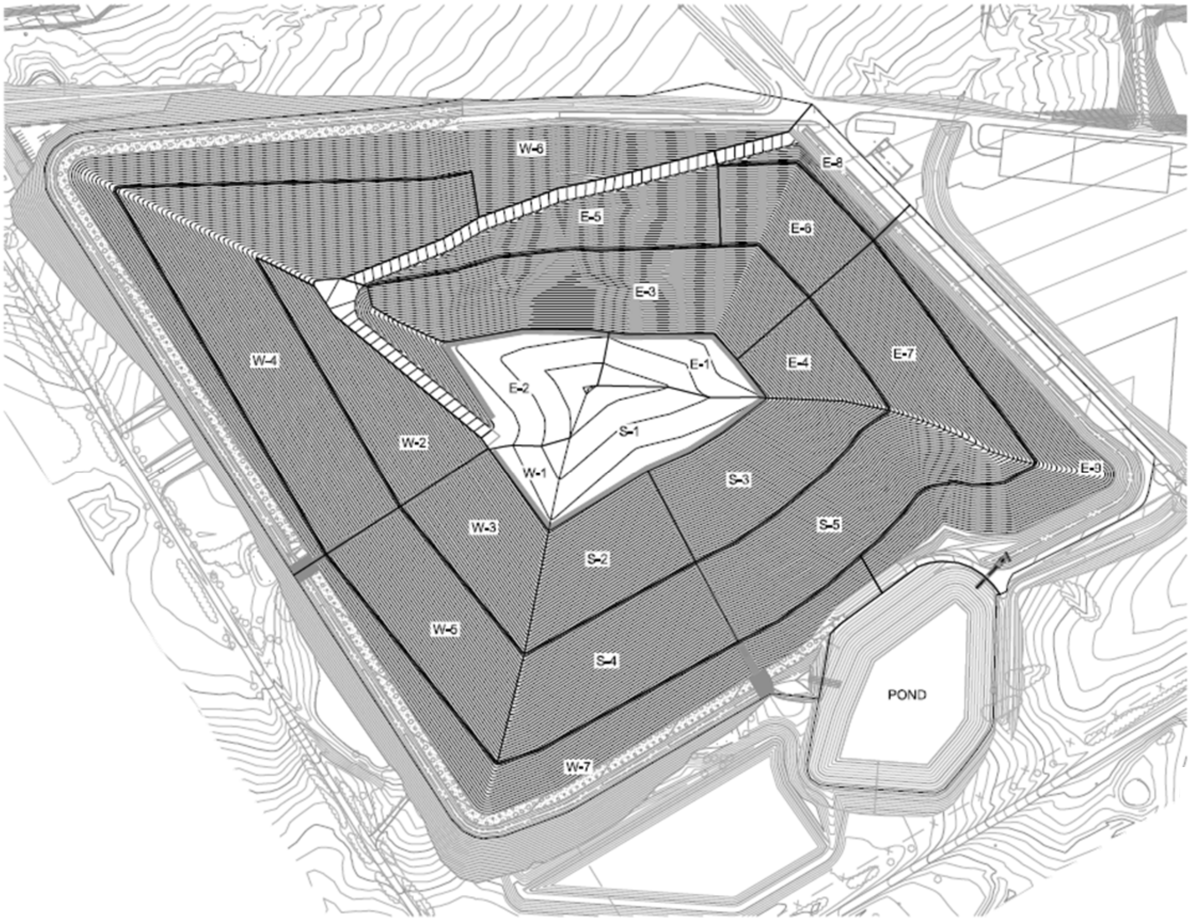


Figure 4 – Depth of Precipitation for 100-year Storm of 24-hour Duration in Texas (from USGS, 2004)



PARCEL TABLE	
DRAINAGE AREA	AREA (AC)
E-1	1.22
E-2	3.34
E-3	4.92
E-4	1.33
E-5	3.21
E-6	1.94
E-7	2.80
E-8	1.36
E-9	6.93
POND	5.31
S-1	2.22
S-2	2.38
S-3	2.93
S-4	3.29
S-5	4.13
W-1	0.54
W-2	2.60
W-3	2.30
W-4	8.41
W-5	3.20
W-6	11.51
W-7	6.95

Figure 5 – Contributing Drainage Areas for Surface Water Management Components

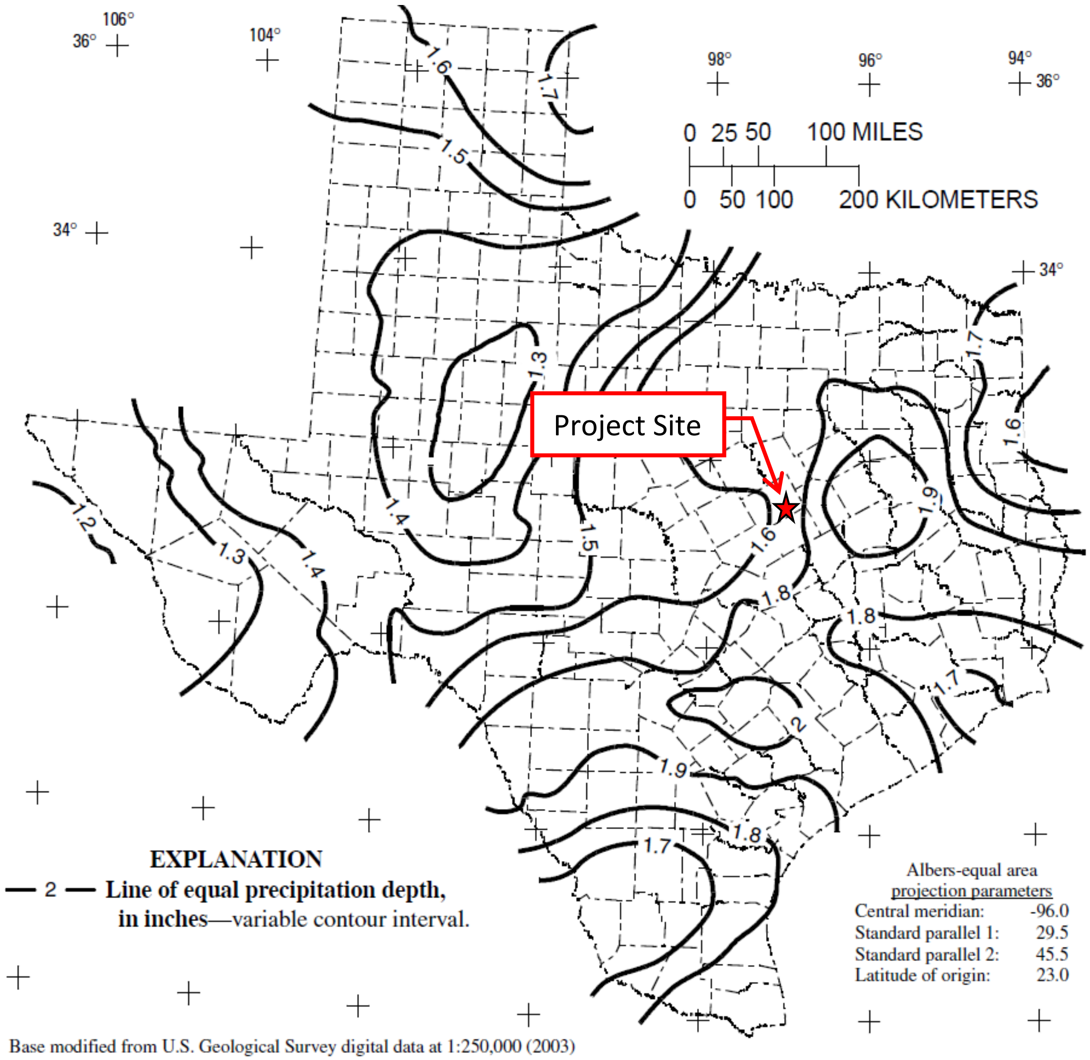


Figure 6 – Depth of Precipitation for 25-year Storm of 15-minute Duration in Texas (from USGS, 2004)

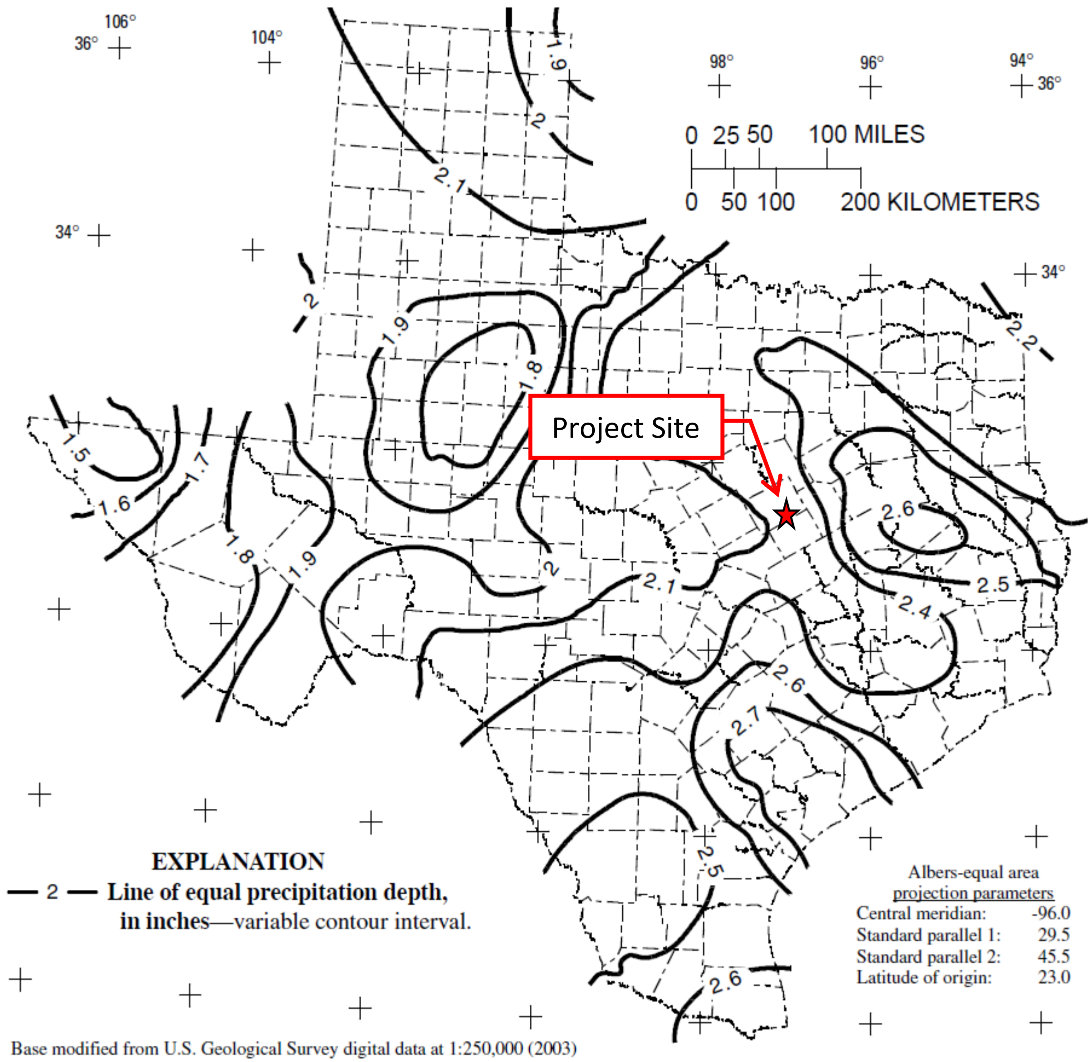


Figure 7 – Depth of Precipitation for 25-year Storm of 30-minute Duration in Texas (from USGS, 2004)

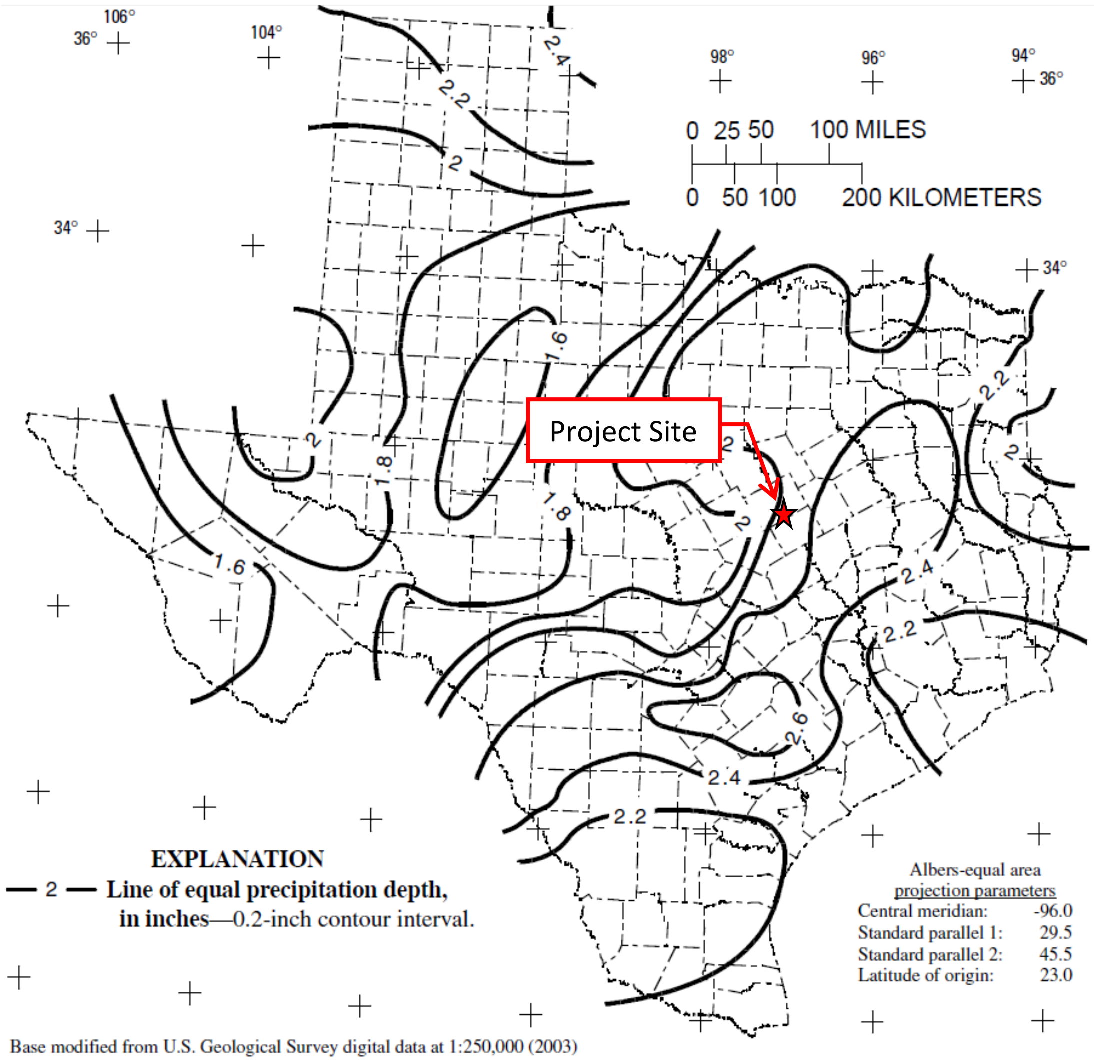


Figure 8 – Depth of Precipitation for 100-year Storm of 15-minute Duration in Texas (from USGS, 2004)

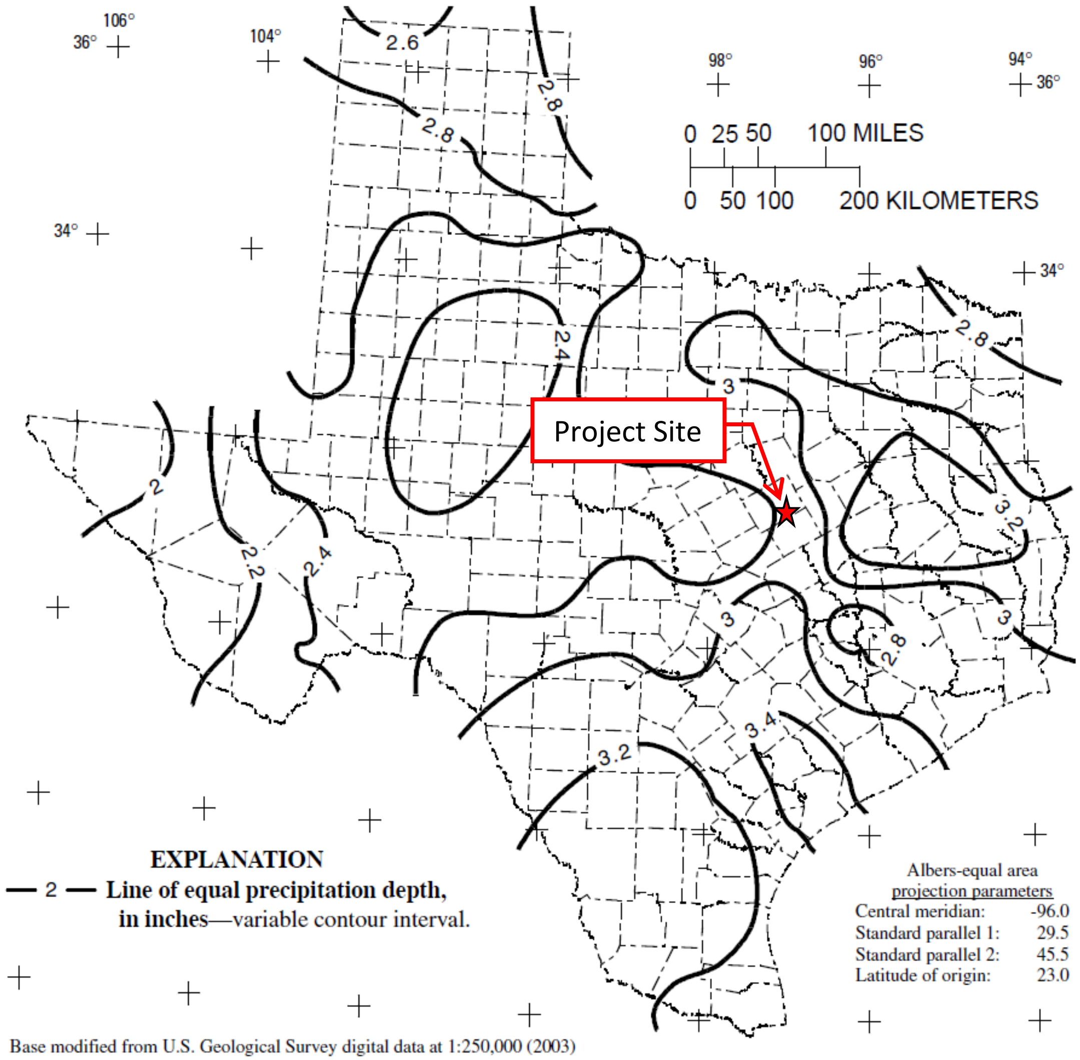


Figure 9 – Depth of Precipitation for 100-year Storm of 30-minute Duration in Texas (from USGS, 2004)

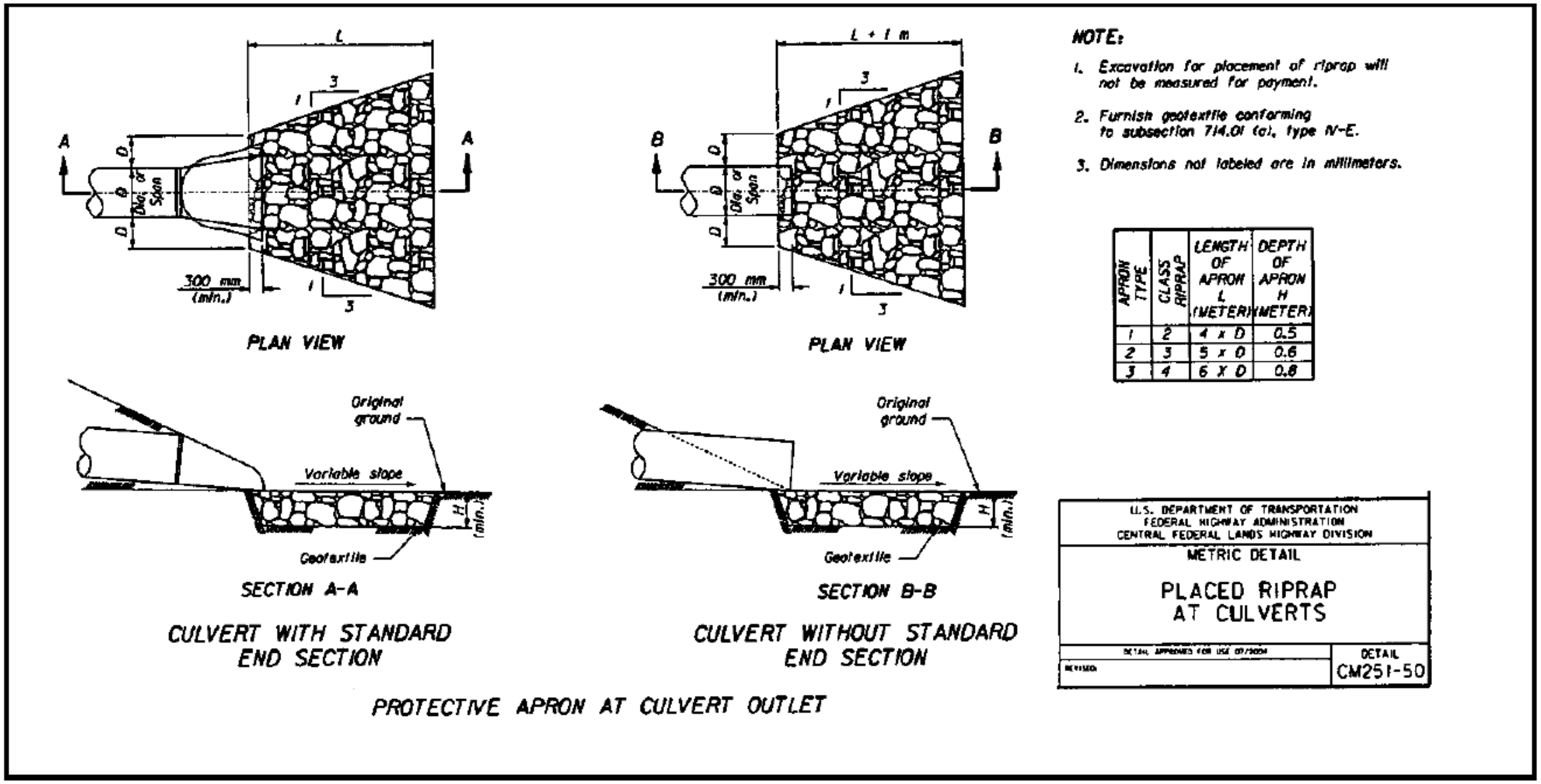


Figure 10 – Placed Riprap Apron Standard Detail (from FHWA, 2006)

ATTACHMENT A
HYDRAULIC DESIGN CALCULATIONS
FOR LARGEST FLOW RATE

Design/Check: Trapezoidal/Triangular Channel

Methodology: Manning's Equation

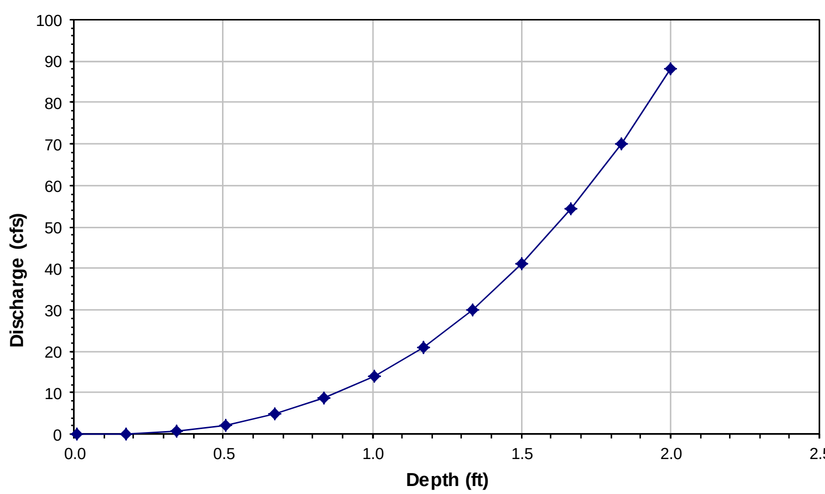
Project: Sandy Creek Power Partners, Riesel, TX

Ditch ID: **Mid-Slope Drainage Bench W-4 - 100-yr Flow**

Peak Discharge, Q_{100} =	59.46	cfs
Bottom Width, B =	0.00	ft
Left Side Slope, Z_1 =	3.50	horizontal :1 vertical
Right Side Slope, Z_2 =	2.50	horizontal :1 vertical
Channel Depth, Y =	2.00	ft
Top Width, T =	12.00	ft
Manning's Roughness Coeff., n =	0.027	
Longitudinal Channel Slope, S_o =	0.0190	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	0.06	0.00	0.21	0.0	0.01	
0.18	0.09	1.11	0.08	1.45	0.1	0.10	
0.34	0.35	2.16	0.16	2.26	0.8	0.19	
0.51	0.77	3.21	0.24	2.94	2.3	0.29	
0.67	1.36	4.26	0.32	3.55	4.8	0.38	
0.84	2.11	5.31	0.40	4.11	8.7	0.47	
1.01	3.03	6.36	0.48	4.64	14.1	0.56	
1.17	4.11	7.41	0.55	5.13	21.1	0.66	
1.34	5.36	8.46	0.63	5.61	30.1	0.75	
1.50	6.77	9.51	0.71	6.06	41.1	0.84	
1.67	8.35	10.56	0.79	6.50	54.3	0.94	
1.83	10.09	11.62	0.87	6.93	69.9	1.03	
2.00	12.00	12.67	0.95	7.34	88.1	1.12	
1.73	8.94	10.93	0.82	6.65	59.46	0.97	DESIGN Q

Discharge versus Depth Relationship



Design/Check: Trapezoidal/Triangular Channel

Methodology: Manning's Equation

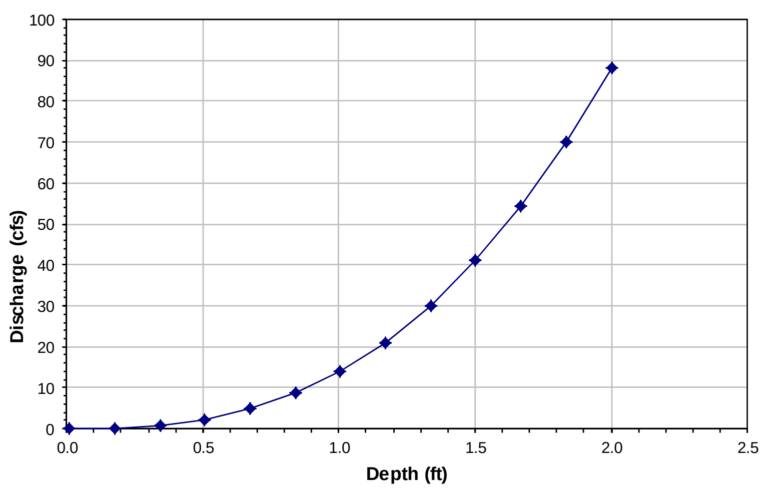
Project: Sandy Creek Power Partners, Riesel, TX

Ditch ID: **Mid-Slope Drainage Bench W-4 - 25-yr Flow**

Peak Discharge, Q_{25} =	38.67	cfs
Bottom Width, B =	0.00	ft
Left Side Slope, Z_1 =	3.50	horizontal :1 vertical
Right Side Slope, Z_2 =	2.50	horizontal :1 vertical
Channel Depth, Y =	2.00	ft
Top Width, T =	12.00	ft
Manning's Roughness Coeff., n =	0.027	
Longitudinal Channel Slope, S_o =	0.0190	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	0.06	0.00	0.21	0.0	0.01	
0.18	0.09	1.11	0.08	1.45	0.1	0.10	
0.34	0.35	2.16	0.16	2.26	0.8	0.19	
0.51	0.77	3.21	0.24	2.94	2.3	0.29	
0.67	1.36	4.26	0.32	3.55	4.8	0.38	
0.84	2.11	5.31	0.40	4.11	8.7	0.47	
1.01	3.03	6.36	0.48	4.64	14.1	0.56	
1.17	4.11	7.41	0.55	5.13	21.1	0.66	
1.34	5.36	8.46	0.63	5.61	30.1	0.75	
1.50	6.77	9.51	0.71	6.06	41.1	0.84	
1.67	8.35	10.56	0.79	6.50	54.3	0.94	
1.83	10.09	11.62	0.87	6.93	69.9	1.03	
2.00	12.00	12.67	0.95	7.34	88.1	1.12	
1.47	6.47	9.30	0.70	5.97	38.67	0.83	DESIGN Q

Discharge versus Depth Relationship



Design/Check: Trapezoidal/Triangular Channel

Methodology: Manning's Equation

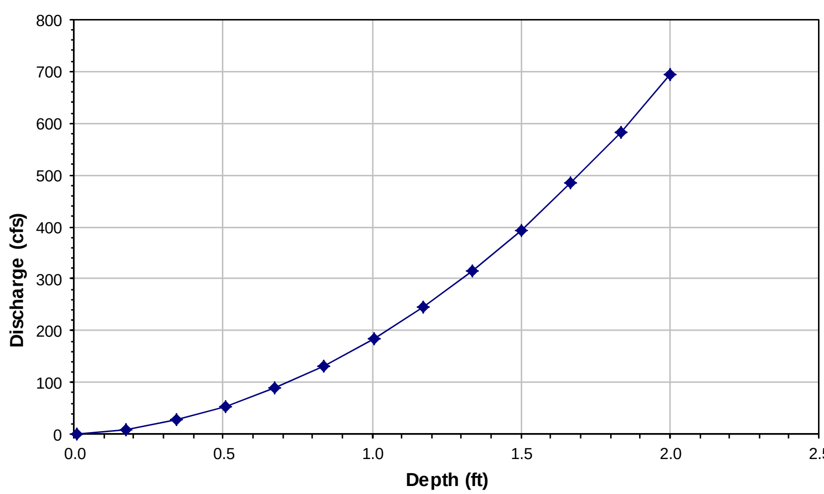
Project: Sandy Creek Power Partners, Riesel, TX

Ditch ID: **West Downchute Lower - 100-yr Flow**

Peak Discharge, Q_{100} =	119.56	cfs
Bottom Width, B =	7.00	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 =	19.00	ft
Manning's Roughness Coeff., n =	0.036	
Longitudinal Channel Slope, S_o =	0.2857	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	0.07	7.06	0.01	1.02	0.1	0.18	
0.18	1.32	8.11	0.16	6.60	8.7	2.91	
0.34	2.74	9.16	0.30	9.89	27.1	5.34	
0.51	4.33	10.21	0.42	12.48	54.0	7.55	
0.67	6.07	11.26	0.54	14.66	89.0	9.62	
0.84	7.99	12.31	0.65	16.58	132.4	11.57	
1.01	10.07	13.36	0.75	18.32	184.4	13.44	
1.17	12.31	14.41	0.85	19.92	245.2	15.23	
1.34	14.72	15.45	0.95	21.41	315.1	16.98	
1.50	17.29	16.50	1.05	22.82	394.6	18.68	
1.67	20.03	17.55	1.14	24.16	483.9	20.34	
1.83	22.93	18.60	1.23	25.44	583.3	21.98	
2.00	26.00	19.65	1.32	26.67	693.3	23.59	
0.79	7.44	12.02	0.62	16.07	119.56	11.04	DESIGN Q

Discharge versus Depth Relationship



Design/Check: Trapezoidal/Triangular Channel

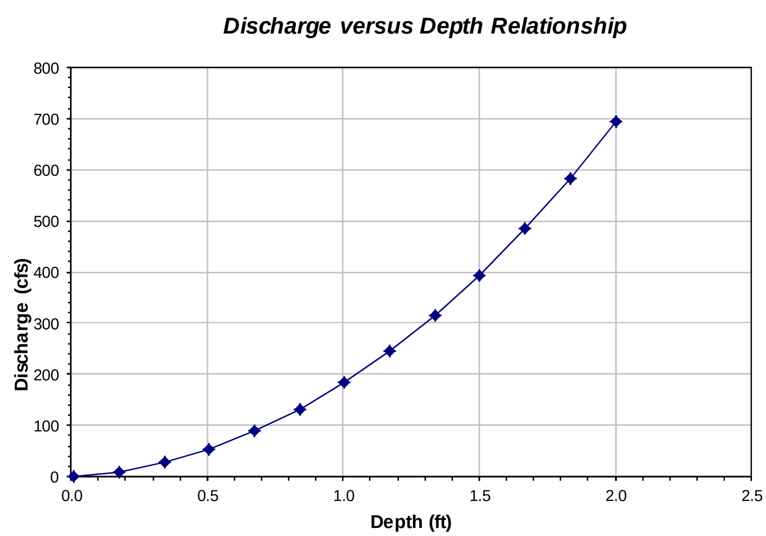
Methodology: Manning's Equation

Project: Sandy Creek Power Partners, Riesel, TX

Ditch ID: **West Downchute Lower - 25-yr Flow**

Peak Discharge, Q_{25} =	77.77	cfs
Bottom Width, B =	7.00	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 =	19.00	ft
Manning's Roughness Coeff., n =	0.036	
Longitudinal Channel Slope, S_o =	0.2857	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	0.07	7.06	0.01	1.02	0.1	0.18	
0.18	1.32	8.11	0.16	6.60	8.7	2.91	
0.34	2.74	9.16	0.30	9.89	27.1	5.34	
0.51	4.33	10.21	0.42	12.48	54.0	7.55	
0.67	6.07	11.26	0.54	14.66	89.0	9.62	
0.84	7.99	12.31	0.65	16.58	132.4	11.57	
1.01	10.07	13.36	0.75	18.32	184.4	13.44	
1.17	12.31	14.41	0.85	19.92	245.2	15.23	
1.34	14.72	15.45	0.95	21.41	315.1	16.98	
1.50	17.29	16.50	1.05	22.82	394.6	18.68	
1.67	20.03	17.55	1.14	24.16	483.9	20.34	
1.83	22.93	18.60	1.23	25.44	583.3	21.98	
2.00	26.00	19.65	1.32	26.67	693.3	23.59	
0.62	5.54	10.95	0.51	14.04	77.77	9.02	DESIGN Q



Design/Check: Trapezoidal/Triangular Channel

Methodology: Manning's Equation

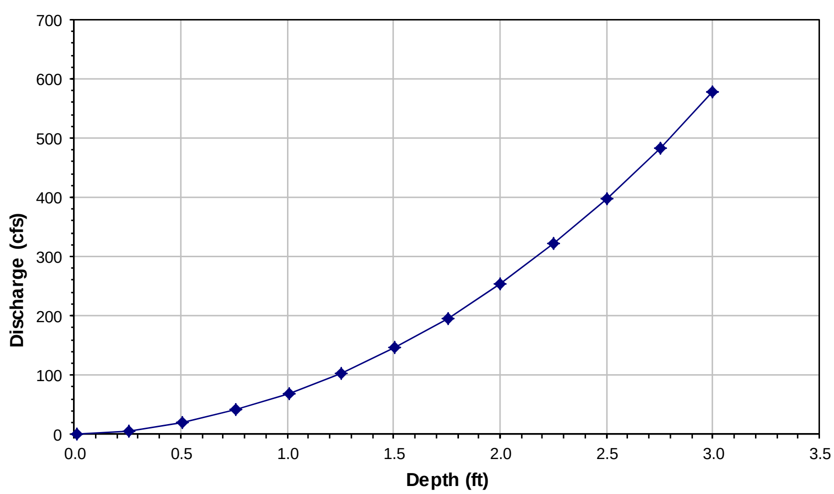
Project: Sandy Creek Power Partners, Riesel, TX

Ditch ID: **East Perimeter Channel - South - 100-yr Flow**

Peak Discharge, Q_{100} =	179.66	cfs
Bottom Width, B =	8.00	ft
Left Side Slope, Z_1 =	3.00	horizontal :1 vertical
Right Side Slope, Z =	3.00	horizontal :1 vertical
Channel Depth, Y =	3.00	ft
Top Width, T =	26.00	ft
Manning's Roughness Coeff., n =	0.027	
Longitudinal Channel Slope, S_o =	0.0180	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	0.34	0.0	0.01	
0.26	2.27	9.64	0.24	2.83	6.4	0.27	
0.51	4.84	11.21	0.43	4.23	20.5	0.48	
0.76	7.78	12.79	0.61	5.31	41.4	0.68	
1.01	11.09	14.37	0.77	6.23	69.1	0.87	
1.26	14.78	15.94	0.93	7.04	104.0	1.04	
1.51	18.84	17.52	1.08	7.77	146.4	1.21	
1.75	23.26	19.09	1.22	8.45	196.5	1.37	
2.00	28.07	20.67	1.36	9.08	254.8	1.53	
2.25	33.24	22.25	1.49	9.68	321.7	1.68	
2.50	38.79	23.82	1.63	10.25	397.5	1.83	
2.75	44.71	25.40	1.76	10.80	482.7	1.98	
3.00	51.00	26.97	1.89	11.32	577.5	2.12	
1.67	21.81	18.59	1.17	8.24	179.66	1.32	DESIGN Q

Discharge versus Depth Relationship



Design/Check: Trapezoidal/Triangular Channel

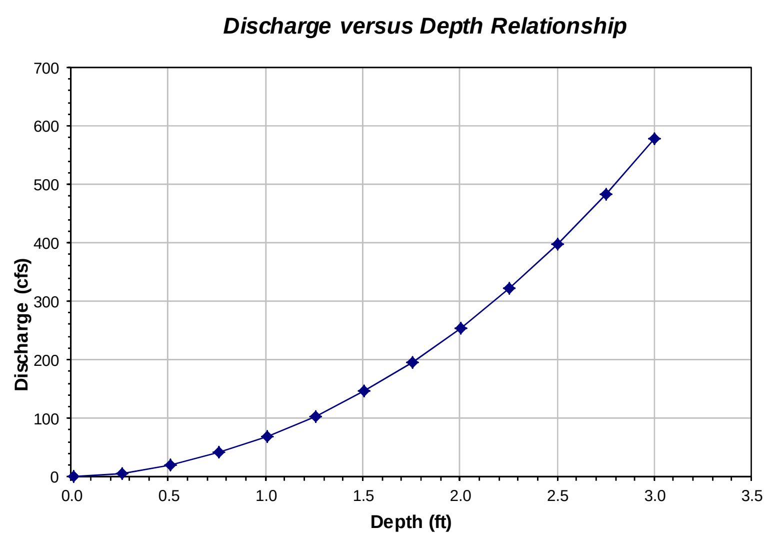
Methodology: Manning's Equation

Project: Sandy Creek Power Partners, Riesel, TX

Ditch ID: **East Perimeter Channel - South - 25-yr Flow**

Peak Discharge, Q_{25} =	117.22	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 =	3.00	ft
Top Width, T =	26.00	ft
Manning's Roughness Coeff., n =	0.027	
Longitudinal Channel Slope, S_o =	0.0180	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	0.34	0.0	0.01	
0.26	2.27	9.64	0.24	2.83	6.4	0.27	
0.51	4.84	11.21	0.43	4.23	20.5	0.48	
0.76	7.78	12.79	0.61	5.31	41.4	0.68	
1.01	11.09	14.37	0.77	6.23	69.1	0.87	
1.26	14.78	15.94	0.93	7.04	104.0	1.04	
1.51	18.84	17.52	1.08	7.77	146.4	1.21	
1.75	23.26	19.09	1.22	8.45	196.5	1.37	
2.00	28.07	20.67	1.36	9.08	254.8	1.53	
2.25	33.24	22.25	1.49	9.68	321.7	1.68	
2.50	38.79	23.82	1.63	10.25	397.5	1.83	
2.75	44.71	25.40	1.76	10.80	482.7	1.98	
3.00	51.00	26.97	1.89	11.32	577.5	2.12	
1.34	16.08	16.47	0.98	7.29	117.22	1.10	DESIGN Q



Design/Check: Trapezoidal/Triangular Channel

Methodology: Manning's Equation

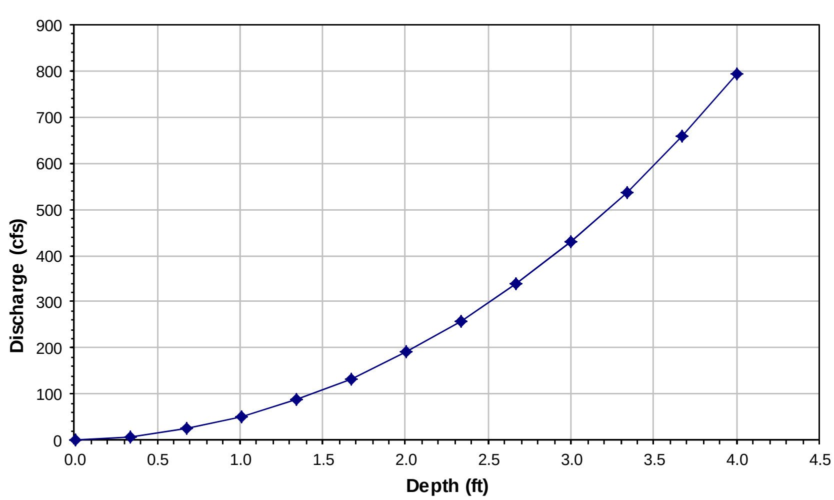
Project: Sandy Creek Power Partners, Riesel, TX

Ditch ID: **West Perimeter Channel - South - 100-yr Flow**

Peak Discharge, Q_{100} =	250.02	cfs
Bottom Width, B =	8.00	ft
Left Side Slope, Z_1 =	3.00	horizontal :1 vertical
Right Side Slope, Z =	3.00	horizontal :1 vertical
Channel Depth, Y =	4.00	ft
Top Width, T =	32.00	ft
Manning's Roughness Coeff., n =	0.027	
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	0.08	8.06	0.01	0.26	0.0	0.01	
0.34	3.09	10.17	0.30	2.49	7.7	0.19	
0.68	6.77	12.27	0.55	3.71	25.1	0.34	
1.01	11.11	14.37	0.77	4.65	51.6	0.48	
1.34	16.11	16.47	0.98	5.44	87.6	0.61	
1.67	21.77	18.58	1.17	6.13	133.6	0.73	
2.01	28.10	20.68	1.36	6.77	190.3	0.85	
2.34	35.09	22.78	1.54	7.36	258.3	0.96	
2.67	42.75	24.89	1.72	7.92	338.4	1.07	
3.00	51.07	26.99	1.89	8.44	431.2	1.18	
3.34	60.05	29.09	2.06	8.95	537.3	1.29	
3.67	69.69	31.20	2.23	9.43	657.4	1.39	
4.00	80.00	33.30	2.40	9.90	792.2	1.50	
2.30	34.27	22.55	1.52	7.30	250.02	0.95	DESIGN Q

Discharge versus Depth Relationship



Design/Check: Trapezoidal/Triangular Channel

Methodology: Manning's Equation

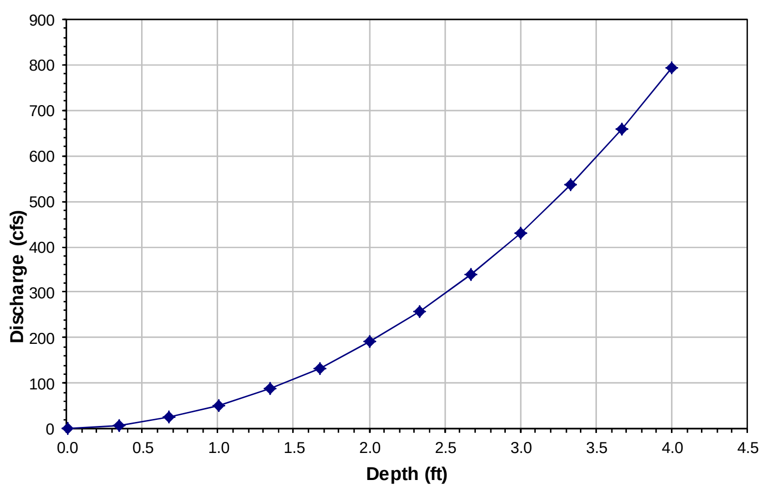
Project: Sandy Creek Power Partners, Riesel, TX

Ditch ID: **West Perimeter Channel - South - 25-yr Flow**

Peak Discharge, Q_{25} =	162.62	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 =	4.00	ft
Top Width, T =	32.00	ft
Manning's Roughness Coeff., n =	0.027	
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	0.08	8.06	0.01	0.26	0.0	0.01	
0.34	3.09	10.17	0.30	2.49	7.7	0.19	
0.68	6.77	12.27	0.55	3.71	25.1	0.34	
1.01	11.11	14.37	0.77	4.65	51.6	0.48	
1.34	16.11	16.47	0.98	5.44	87.6	0.61	
1.67	21.77	18.58	1.17	6.13	133.6	0.73	
2.01	28.10	20.68	1.36	6.77	190.3	0.85	
2.34	35.09	22.78	1.54	7.36	258.3	0.96	
2.67	42.75	24.89	1.72	7.92	338.4	1.07	
3.00	51.07	26.99	1.89	8.44	431.2	1.18	
3.34	60.05	29.09	2.06	8.95	537.3	1.29	
3.67	69.69	31.20	2.23	9.43	657.4	1.39	
4.00	80.00	33.30	2.40	9.90	792.2	1.50	
1.85	25.09	19.71	1.27	6.48	162.62	0.79	DESIGN Q

Discharge versus Depth Relationship



ATTACHMENT B
HEC-HMS OUTPUT RESULTS

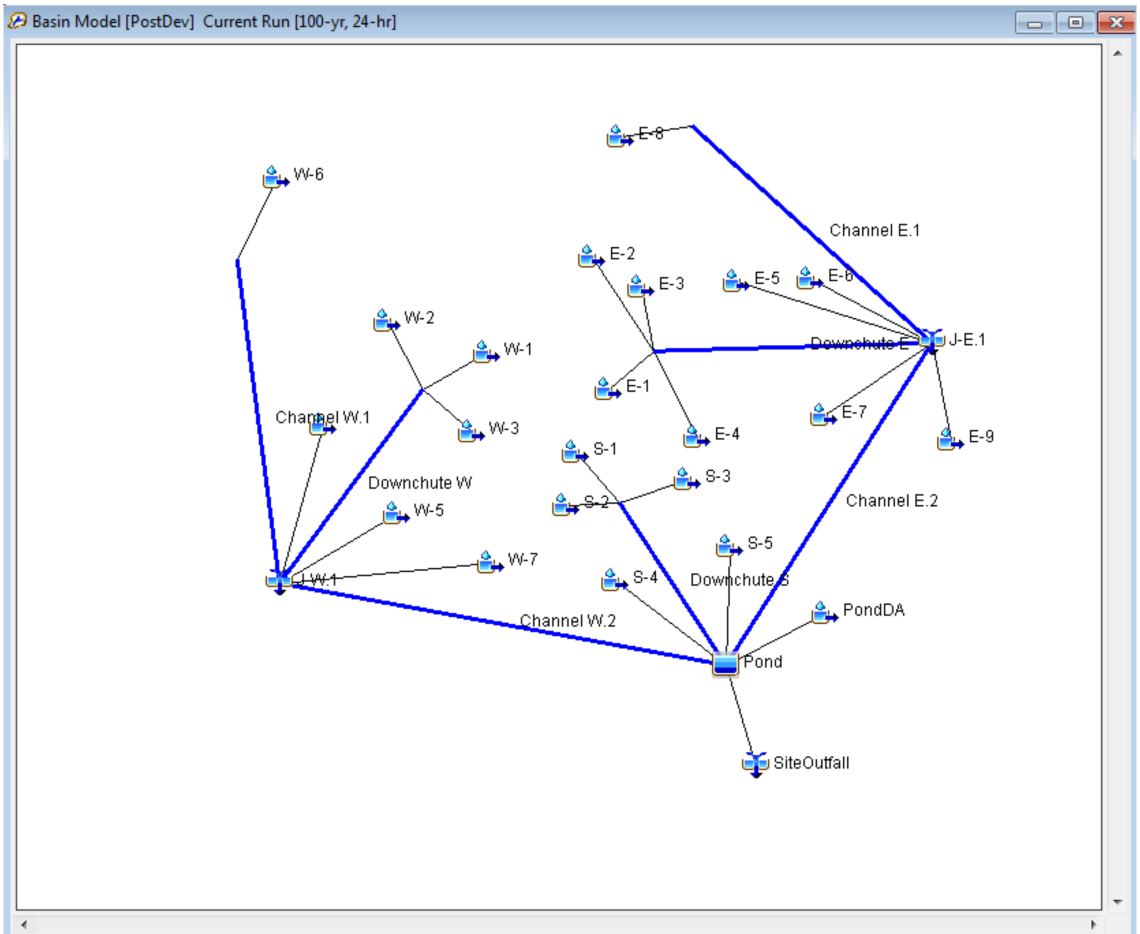


Figure B.1 – HEC-HMS Nodal Network

Table B.1 – 25-Year HEC-HMS Results

Global Summary Results for Run "25-yr, 24-hr"

Project: Sandy_Creek_Final_Cover_141 Simulation Run: 25-yr, 24-hr

Start of Run: 01Jan2014, 00:00 Basin Model: PostDev
End of Run: 04Jan2014, 00:00 Meteorologic Model: 25-yr, 24-hr
Compute Time: 03Dec2014, 08:54:30 Control Specifications: Control_3day

Show Elements: Initial Selection Volume Units: IN AC-FT Sorting: Alphabetic

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (AC-FT)
Channel E.1	0.00212	6.6	01Jan2014, 12:09	0.6
Channel E.2	0.04197	122.1	01Jan2014, 12:11	11.1
Channel W.1	0.01799	51.7	01Jan2014, 12:20	4.8
Channel W.2	0.05604	134.9	01Jan2014, 12:13	14.8
Downchute E	0.01662	44.4	01Jan2014, 12:10	4.4
Downchute S	0.01151	34.3	01Jan2014, 12:09	3.1
Downchute W	0.00904	27.1	01Jan2014, 12:09	2.4
E-1	0.00231	6.0	01Jan2014, 12:13	0.6
E-2	0.00466	11.4	01Jan2014, 12:15	1.2
E-3	0.00760	23.6	01Jan2014, 12:08	2.0
E-4	0.00205	6.4	01Jan2014, 12:08	0.5
E-5	0.00615	19.1	01Jan2014, 12:08	1.6
E-6	0.00188	5.8	01Jan2014, 12:08	0.5
E-7	0.00438	13.6	01Jan2014, 12:08	1.2
E-8	0.00212	6.6	01Jan2014, 12:08	0.6
E-9	0.01082	33.7	01Jan2014, 12:08	2.9
J-E.1	0.04197	122.6	01Jan2014, 12:08	11.1
J-W.1	0.05604	135.4	01Jan2014, 12:09	14.9
Pond	0.12940	6.5	01Jan2014, 21:53	27.0
PondDA	0.00829	32.2	01Jan2014, 12:07	3.2
S-1	0.00328	9.2	01Jan2014, 12:11	0.9
S-2	0.00368	11.4	01Jan2014, 12:08	1.0
S-3	0.00455	14.2	01Jan2014, 12:08	1.2
S-4	0.00514	16.0	01Jan2014, 12:08	1.4
S-5	0.00645	20.1	01Jan2014, 12:08	1.7
SiteOutfall	0.12940	6.5	01Jan2014, 21:53	27.0
W-1	0.00140	3.8	01Jan2014, 12:12	0.4
W-2	0.00407	12.7	01Jan2014, 12:08	1.1
W-3	0.00357	11.1	01Jan2014, 12:08	0.9
W-4	0.01315	40.4	01Jan2014, 12:08	3.5
W-5	0.00500	15.6	01Jan2014, 12:08	1.3
W-6	0.01799	52.0	01Jan2014, 12:10	4.8
W-7	0.01086	33.8	01Jan2014, 12:08	2.9

Table B.2 – 100-Year HEC-HMS Results

Global Summary Results for Run "100-yr, 24-hr"

Project: Sandy_Creek_Final_Cover_141 Simulation Run: 100-yr, 24-hr

Start of Run: 01Jan2014, 00:00 Basin Model: PostDev
End of Run: 04Jan2014, 00:00 Meteorologic Model: 100-yr, 24-hr
Compute Time: 03Dec2014, 09:21:14 Control Specifications: Control_3day

Show Elements: Initial Selection Volume Units: IN AC-FT Sorting: Alphabetic

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (AC-FT)
Channel E.1	0.00212	9.2	01Jan2014, 12:09	0.8
Channel E.2	0.04197	170.8	01Jan2014, 12:11	15.8
Channel W.1	0.01799	72.5	01Jan2014, 12:19	6.7
Channel W.2	0.05604	192.2	01Jan2014, 12:13	21.0
Downchute E	0.01662	62.2	01Jan2014, 12:09	6.2
Downchute S	0.01151	47.9	01Jan2014, 12:09	4.3
Downchute W	0.00904	37.9	01Jan2014, 12:08	3.4
E-1	0.00231	8.4	01Jan2014, 12:13	0.9
E-2	0.00466	15.9	01Jan2014, 12:15	1.8
E-3	0.00760	33.0	01Jan2014, 12:07	2.9
E-4	0.00205	8.9	01Jan2014, 12:07	0.8
E-5	0.00615	26.7	01Jan2014, 12:07	2.3
E-6	0.00188	8.2	01Jan2014, 12:07	0.7
E-7	0.00438	19.0	01Jan2014, 12:07	1.6
E-8	0.00212	9.2	01Jan2014, 12:07	0.8
E-9	0.01082	47.0	01Jan2014, 12:07	4.1
J-E.1	0.04197	171.5	01Jan2014, 12:08	15.8
J-W.1	0.05604	192.9	01Jan2014, 12:09	21.0
Pond	0.12940	27.0	01Jan2014, 15:26	39.6
PondDA	0.00829	41.9	01Jan2014, 12:07	4.1
S-1	0.00328	12.9	01Jan2014, 12:11	1.2
S-2	0.00368	16.0	01Jan2014, 12:07	1.4
S-3	0.00455	19.8	01Jan2014, 12:07	1.7
S-4	0.00514	22.3	01Jan2014, 12:07	1.9
S-5	0.00645	28.0	01Jan2014, 12:07	2.4
SiteOutfall	0.12940	27.0	01Jan2014, 15:26	39.6
W-1	0.00140	5.3	01Jan2014, 12:12	0.5
W-2	0.00407	17.7	01Jan2014, 12:07	1.5
W-3	0.00357	15.5	01Jan2014, 12:07	1.3
W-4	0.01315	56.5	01Jan2014, 12:08	4.9
W-5	0.00500	21.7	01Jan2014, 12:07	1.9
W-6	0.01799	72.7	01Jan2014, 12:10	6.8
W-7	0.01086	47.2	01Jan2014, 12:07	4.1

APPENDIX B

Final Cover Soil Erosion Loss Calculation

Written by:	Brandon Klenzendorf	Date:	11/19/2014	Reviewed by:	Beth Gross	Date:	12/4/2014
Client:	NAES	Project:	Sandy Creek Energy Station	Project/Proposal No.:	TXL0208	Task No:	08

FINAL COVER EROSION ANALYSIS

Beth Ann Gross

12/4/2014

SEALED FOR CALCULATION PAGES 1 TO 12

GEOSYNTEC CONSULTANTS
TX ENG FIRM REGISTRATION NO. 1182

PURPOSE

The purpose of this calculation package is to present the final cover soil loss analysis for the proposed expansion of the Solid Waste Disposal Facility (SWDF) at the Sandy Creek Energy Station in Riesel, 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 slope of the SWDF.

PROJECT BACKGROUND

The SWDF will be closed with an approximately 64.9-acre final cover system (Drawing 2 of the Engineering Design Drawings for the SWDF Final Cover). The top deck of the final cover will have a surface slope of 3%, and the side slopes will be graded to 3.5 horizontal to 1 vertical (3.5H:1V). The final cover is designed with a surface water management system with permanent drainage features, including top deck diversion berms, side slope diversion berms, downchutes, and a perimeter channel. The diversion berms direct water from the top deck and side slopes to the downchutes, and the downchutes convey water to the perimeter channel.

The vegetative support layer of the final cover will be permanently stabilized with perennial grasses to resist erosion and sediment transport.

For municipal solid waste landfills, the Texas Commission on Environmental Quality (TCEQ) recommends a permissible soil loss for the final cover of less than 2 to 3 tons/acre/year (TCEQ, 2007). Geosyntec considers this recommendation to be relevant to coal combustion waste landfills, such as the SWDF.

CALCULATION METHODOLOGY

Revised Universal Soil Loss Equation (RUSLE)

Soil erosion loss from the final cover was calculated using the methodology presented in the U.S. Department of Agriculture (USDA) handbook *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)* (Renard et al., 1997) along with information previously published by USDA. This calculation package presents the RUSLE 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.

INPUT PARAMETERS

RUSLE Parameters

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 Renard et al. (1997), the value for Riesel, McLennan County, Texas is approximately 300, as shown in Figure 1.

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 vegetative support layer material for the final cover system. The soil erodibility factor can be thought of as the ease with which soil is displaced by splash during rainfall or by surface flow.

The soils proposed for the final cover system of the SWDF are the native soils in the vicinity of the SWDF. Using the Web Soil Survey tool operated by the USDA Natural Resources Conservation Service (NRCS, 2014), the soils in this area are primarily classified as Heiden clays (HeB and HeD), although Riesel gravelly fine sandy loam (RgB) is also present. Based on the McLennan County soil survey (USDA, 2001), the Heiden clays were formed in residuum derived from shale and marl, while the Riesel sandy loam was formed in alluvium.

The K values obtained from NRCS (2014) for the fine-earth fraction (Kf), or material finer than 2 mm in size, of the HeB, HeD, and RgB soils are presented in Table 1. The maximum K value for the soils of 0.32 was selected for use in the RUSLE.

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. Renard et al. (1997) presents values of the LS factor for slope lengths in feet up to 1,000 feet and percent slopes up to 60% for moderately consolidated soils with little to moderate cover (Table 2).

To manage stormwater runoff from the surface slopes, permanent stormwater drainage features will be installed on the final cover system. The stormwater drainage features will be spaced to limit soil erosion. The maximum horizontal distance between side slope diversion berms (i.e., 270 feet) on the final cover system was used to select the LS factor for the exterior side slopes. The maximum horizontal distance between the high point on the top deck to the top deck diversion berms (i.e., 250 feet) was selected to evaluate the soil loss on the top deck. Values in Table 2 were interpolated to compute the LS factor for the side slopes and top deck.

- Side Slopes – 3.5H:1V (28.6%) slope over a length of 270 feet, LS = 9.70

- Top Deck – 3% slope over a length of 250 feet, LS = 0.58

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 for the SWDF will be planted with grasses that are periodically mowed. Between mowings, a canopy of tall weeds or short brush may develop. From Table 3, the cover-management factor for this cover condition (95-100% grass cover with up to 25% canopy cover) is 0.003.

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, which are not anticipated for the SWDF. Therefore, the P factor of 1 was selected.

RESULTS

<u>RUSLE</u>

Applying the RUSLE with the input parameters defined above, the computed soil loss in tons/acre/year for the longest slopes on the side slopes and top deck is as follows:

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

Side Slopes: $A = 300 \times 0.32 \times 9.70 \times 0.003 \times 1 = 2.79$ tons/acre/year

Top Deck: $A = 300 \times 0.32 \times 0.52 \times 0.003 \times 1 = 0.15$ tons/acre/year

The calculated annual soil loss (0.15 and 2.79 tons/acre/year) on the longest slopes of the final cover meets TCEQ's recommended permissible soil loss of less than 2 to 3 tons/acre/year. The calculated average annual soil loss for the side slopes or top deck of the SWDF final cover would be less than the calculated maximum average value.

CONCLUSIONS

Based on the calculations presented herein, the following conclusions can be drawn:

- The calculated soil loss quantities for the longest slopes on the top deck and side slopes of the SWDF final cover meet TCEQ's recommended permissible soil loss of less than 2 to 3 tons/acre/year.

- For effective erosional stability, the soil stabilization practice should provide a maximum cover management factor (C) of 0.003. This C value corresponds to 95-100% grass cover with up to 25% canopy cover (USDA, 1977). Grass cover is defined by USDA (1977) as "cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 inches deep."

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USDA (1977). *Procedure for Computing Sheet and Rill Erosion on Project Areas*, United States Department of Agriculture, Soil Conservation Services, Engineering Division and Ecological Sciences and Technology Division, Technical Release No. 51, Revision 2, September.

USDA (2001). *Soil Survey of McLennan County, Texas*, United States Department of Agriculture and Natural Resources Conservation Service, with Texas Agricultural Experiment Station and Texas State Soil and Water Conservation Board.

TABLES

- Table 1. Soil Erodibility Factor (K) for Heiden and Riesel Soils (from NRCS, 2014)
- Table 2. Topographic Factor (LS) for Moderate Ratio of Rill to Interrill Erosion (from Renard et al., 1997)
- Table 3. Cover Management Factor (C) for Permanent Pasture, Rangeland, Idle Land, and Grazed Woodland (from USDA, 1977)

Table 1. Soil Erodibility Factor (K) for Heiden and Riesel Soils (from NRCS, 2014)

McLennan County, Texas

[Entries under "Erosion Factors--T" apply to the entire profile. Entries under "Wind Erodibility Group" and "Wind Erodibility Index" apply only to the surface layer. Absence of an entry indicates that data were not estimated. This report shows only the major soils in each map unit]

Map symbol and soil name	Depth	Sand	Silt	Clay	Moist bulk density	Saturated hydraulic conductivity	Available water capacity	Linear extensi-bility	Organic matter	Erosion factors			Wind erodi-bility group	Wind erodi-bility index
										Kw	Kf	T		
	In	*Pct*	*Pct*	*Pct*	*g/cc*	*micro m/sec*	*In/In*	*Pct*	*Pct*					
HeB:														
Heiden	0-6	---	---	40-60	1.30-1.50	0.01-0.42	0.12-0.18	9.0-25.0	1.0-4.0	.32	.32	5	4	86
	6-35	---	---	40-60	1.35-1.55	0.01-0.42	0.12-0.18	9.0-25.0	0.1-0.5	.32	.32			
	35-55	---	---	40-60	1.40-1.60	0.01-0.42	0.12-0.18	9.0-25.0	0.1-0.5	.32	.32			
	55-80	---	---	40-60	1.45-1.65	0.01-0.42	0.11-0.15	9.0-25.0	0.1-0.5	.32	.32			
HeD:														
Heiden	0-6	---	---	40-60	1.30-1.50	0.01-0.42	0.12-0.18	9.0-25.0	1.0-4.0	.32	.32	5	4	86
	6-14	---	---	40-60	1.35-1.55	0.01-0.42	0.12-0.18	9.0-25.0	0.1-0.5	.32	.32			
	14-50	---	---	40-60	1.40-1.60	0.01-0.42	0.12-0.18	9.0-25.0	0.1-0.5	.32	.32			
	50-80	---	---	40-60	1.45-1.65	0.01-0.42	0.11-0.15	9.0-25.0	0.1-0.5	.32	.32			
RgB:														
Riesel	0-16	---	---	5-15	1.40-1.60	14.00-42.00	0.04-0.10	0.0-2.9	0.5-2.0	.10	.28	4	5	56
	16-48	---	---	35-55	1.35-1.50	0.42-1.40	0.05-0.12	3.0-5.9	0.5-1.0	.17	.32			
	48-55	---	---	35-55	1.40-1.55	0.42-1.40	0.05-0.16	3.0-5.9	0.5-1.0	.17	.32			
	55-80	---	---	3-12	1.45-1.65	42.00-141.00	0.03-0.05	0.0-2.9	0.5-1.0	.10	.17			

"Erosion factor Kw" indicates the erodibility of the whole soil. The estimates are modified by the presence of rock fragments.

"Erosion factor Kf" indicates the erodibility of the fine-earth fraction, or the material less than 2 millimeters in size.

"Erosion factor T" is an estimate of the maximum average annual rate of soil erosion by wind and/or water that can occur without affecting crop productivity over a sustained period. The rate is in tons per acre per year.

Table 2. Topographic Factor (LS) for Moderate Ratio of Rill to Interrill Erosion (from Renard et al., 1997)

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

	Horizontal slope length (ft)																
Slope (%)	3	6	9	12	15	25	50	75	100	150	200	250	300	400	600	800	1000
0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	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. Cover Management Factor (C) for Permanent Pasture, Rangeland, Idle Land, and Grazed Woodland[1] (from USDA, 1977)

Vegetal Canopy			Cover That Contacts the Surface					
Type and Height of Raised Canopy[2/]	Canopy Cover[3/] %	Type[4/]	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.

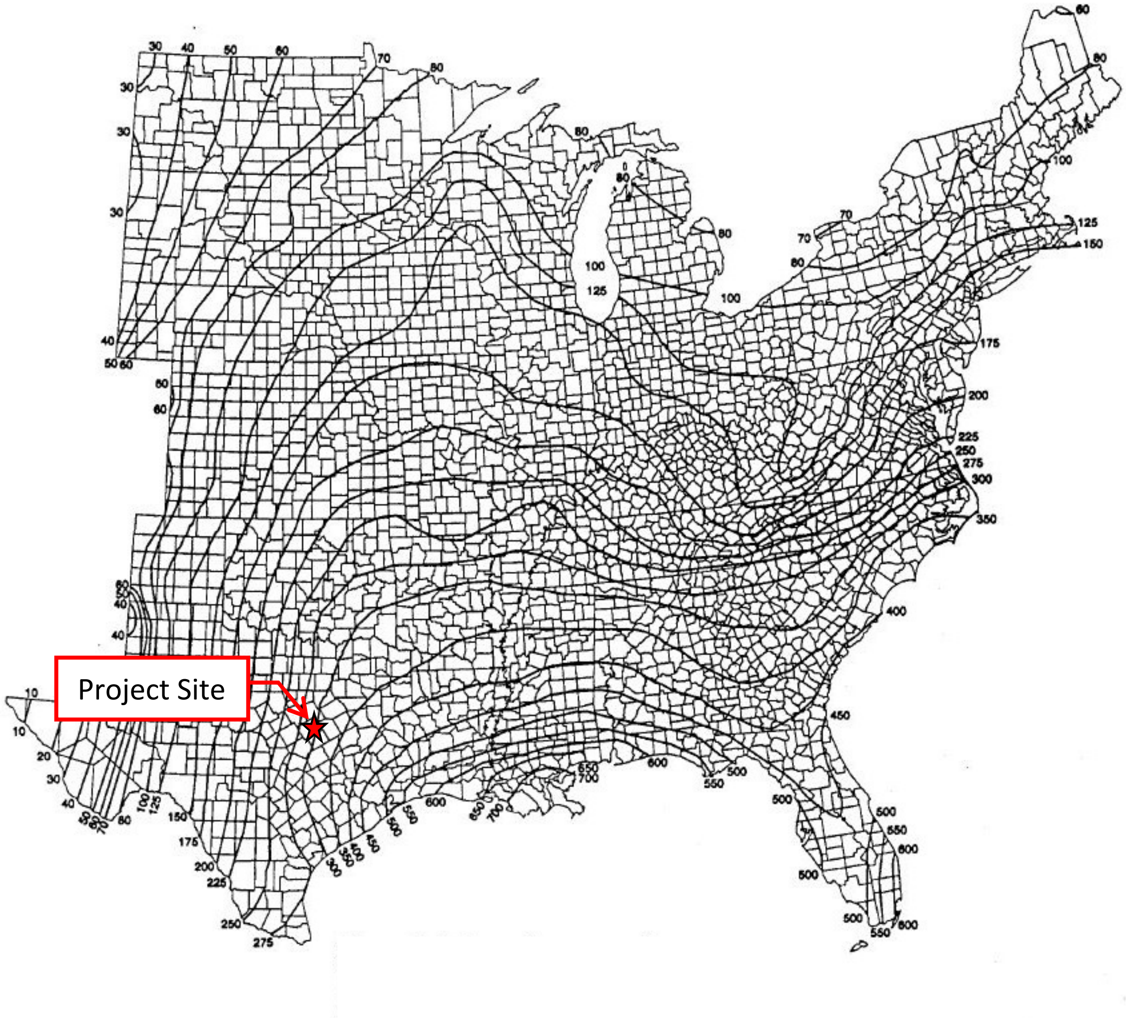
3/ Portion of total-area surface that would be hidden from view by canopy in a vertical projection, (a bird's-eye view).

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 Rainfall-Runoff Erosivity Factor (R) Isoerodent Map (from Renard et al., 1997)



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