DETAIL DRAINAGE CALCULATION

Made By: HH
Checked by: JBF
Reviewed by: JBF

1.0 OBJECTIVE

Golder has designed the final cover system for Cells 10 through 15 of the North CAMU at the closed Exide Frisco Recycling Center in Frisco, Texas. With this proposed design there is a need for drainage features. A perimeter drainage channel on the north that drains to the west and on the west that drains to the south have been proposed. This drainage channel will extend 436 feet to the south and discharge into an existing tributary that leads to Stewart Creek. A culvert at the proposed access road crossing is required. This culvert will allow flow to pass under the landfill access road and continue to the tributary.

2.0 METHOD

The rational method is used to calculate discharge flows in small areas. The estimated flows are used to size the drainage channel using the Manning's equation. The road crossing culvert(s) are sized with HY8 using the esimated flows.

3.0 CALCULATION

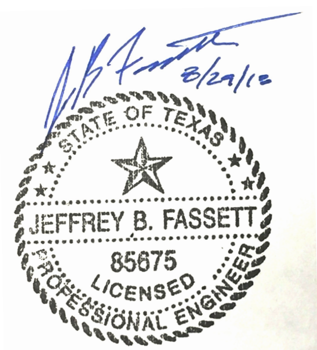
3.1 Discharge Flows

The rational method equation is used to calculate the peak discharge for facilities serving a drainage area less than 200 acres.

$$Q = ciA$$

c = Rational runoff coefficient
i = rainfall intensity (in/hour)
A = drainage area (acres)
Q = Peak discharge (cfs)

The runoff coefficient for a non-developed land is 0.30. The rainfall intensity is 7.6 in/hr. The runoff coefficient and time of concentration were taken from the Engineering Standards, The City of Frisco, Texas. The Tc is put into the TxDOT spreadsheet for calculating Rainfall Intensity-Duration-Frequency Coefficients for Texas Counties. The 25-year, 24-hour storm event is used to analyze the peak discharge. The drainage area is based on the final site conditions.



Pre Culvert			Post Culvert		
c =	0.3		c =	0.3	
i =	6.2	in/hr	i =	5.6	in/hr
A =	5.27	ac	A =	4.86	ac
Q =	**10**	**cfs**	**Q =**	**8**	**cfs**

3.2 Channel Sizing

The Mannings equation is used to size the perimeter channel. Table 3, Channel Hydraulic Calculation, show the channel design geometry, velocity, and freeboard calculation.

3.3 Culvert Sizing

Using Hy-8 (version 7.3) from the Federal Highway Administration and the site data (discharge, tailwater, roadway, etc.) the culvert was sized to pass the peak flows without overtopping the roadway.

4.0 CONCLUSION

The ditch is designed to be grassed lined with a geometry of 2 feet deep and 1.5 feet wide with 4H:1V sideslopes.

The culvert size is 2-18" CMP culverts at 26 feet long. A 5 ft by 5 ft by 12 in deep riprap inlet and outlet pad is required.

5.0 REFERENCES

1) Engineering Standards, The City of Frisco, Texas. Version August 2017
2) Hy-8 Program (version 7.5) Build date: July 28, 2016
3) Rainfall Intensity Duration Frequency Coefficients for Texas Counties, Texas Department of Transprotation.
4) Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas-U.S. Geological Survey, TxDOT Implementation Report 5–1301–01–1

TABLE 1A
COMPOSITE CURVE NUMBER CALCULATIONS

EXIDE RECYCLING CENTER
EXIDE TECHNOLOGIES
Project Number: 1302086-02

Date:	8/28/18
By:	HH
Chkd:	JBF
Apprvd:	JBF

Design Storm 25 **-Year Reoccurance Interval**

Storm Duration (hours)	2-Year Depth (inches)	25 -Year Depth (inches)	Storm Distribution
24	4.1	7.6	II

Subbasin ID	Subbasin Area (ft^2)	Subbasin Area (acres)	Subbasin Area (sq mile)	CN = 98 CONCRETE - PAVED AREAS OR POND AREAS (acres)	CN = 92 DIRT ROADS - UNPAVED AREAS -- HERBACEOUS GRASS/BRUSH (acres)	CN = 85 LANDFILL FINAL COVER AREAS (acres)	Composite SCS Curve No.	$S = \frac{1000}{CN} - 10$	Unit Runoff Q (in)	Runoff Volume (ac-ft)	Runoff Volume (ft^3)
LANDFILL AREA											
1	229,561	5.27	0.0082			5.27	CN = 85	1.76	5.84	2.56	111,673
2	211,702	4.86	0.0076			4.86	CN = 85	1.76	5.84	2.36	102,985
Total:	441,263	10.13	0.02							4.93	214,657

TABLE 1B
BASIN TIME OF CONCENTRATION CALCULATIONS

EXIDE RECYCLING CENTER
EXCIDE TECHNOLOGIES
Project Number: 1‹1302086.0

Date:	8/28/18
By:	HH
Chkd:	JBF
Apprvd:	JBF

				Flow Segment 1							Flow Segment 2							Flow Segment 3						
Subbasin ID	Composite Curve Number	Total Lag (0.6*Tc) (min)	Total Travel Time (min)	Type of Flow	Length (ft)	Slope (ft/ft)	Roughness Condition[1]		Typical Hydraulic Radius (Channel Only) (ft)	Travel Time (min)	Type of Flow	Length (ft)	Slope (ft/ft)	Roughness Condition[1]		Typical Hydraulic Radius (Channel Only) (ft)	Travel Time (min)	Type of Flow	Length (ft)	Slope (ft/ft)	Roughness Condition[1]		Typical Hydraulic Radius (Channel Only) (ft)	Travel Time (min)
LANDFILL AREA																								
1	85	13.8	22.9	Sheet	221	0.032	F	Dense Grass		19.6	Shallow	10.5	0.250	U	Unpaved		0.0	Channel	736	0.016	G	Grass-lined	0.58	3.3
2	85	16.7	27.8	Sheet	300	0.034	F	Dense Grass		24.5	Shallow	274.0	0.034	U	Unpaved		1.5	Channel	436	0.017	G	Grass-lined	0.60	1.8

Notes:
1. Refer to Table 3 for Roughness Condition descriptions and Tc Coefficients.

Table 2
Time of Concentration and Mannings Flow Coefficients

TR-55 (1986)

Sheet Flow Travel time (SCS Upland Method)

$$T_t = \frac{0.007\,(n'\,L)^{0.8}}{(P_2)^{0.5}\,S^{0.4}}$$

Where: T_t = travel time (hr); n' = roughness coefficient; L = flow length (ft);
P_2 = 2-yr storm depth (inches); s = slope (ft/ft)

flow velocity = L/(60T_t)

Flow Type	Surface Type	roughness n	Surface Description	Short Description
Sheet/Overland Flow	A	0.011	Smooth surfaces (concrete, asphalt, gravel, bare soil)	Smooth
	B	0.05	Fallow (no residue)	Fallow
	C	0.06	Cultivated soils: Residue cover <= 20%	Cover<20%
	D	0.17	Cultivated soils: Residue cover > 20%	Cover>20%
	E	0.15	Grass: Short grass prairie	Short Grass
	F	0.24	Grass: Dense grasses	Dense Grass
	G	0.41	Grass: Bermuda grass	Bermuda Grass
	H	0.13	Range (natural)	Range
	I	0.40	Woods: Light underbrush	Light woods
	J	0.80	Woods: Heavy underbrush	Heavy Woods

Shallow Concentrated Flow Velocity (SCS Upland Method)

$v = mS^{0.5}$

Where: v = velocity (fps); m = roughness coeffient; S = slope (ft/ft)

Flow Type	Surface Type	Roughness m	Surface Description	Short Description
Shallow Conc. Flow	P	20.3282	Paved Surfaces	Paved
	U	16.1345	Unpaved Surfaces	Unpaved

Channel Flow Velocity (Mannings Velocity)

$v = 1.49/n\ Rh^{2/3}S^{1/2}$

Where: v = velocity (fps); n = roughness coeffient; Rh = Hydraulic Radius (ft), S = slope (ft/ft)

Lining Type	Mannings n for Depth	Mannings n for Velocity	Material	Maximum Velocity	Maximum Shear Stress
A	0.026	0.026	ACB	25	
C	0.024	0.020	CSP	50	
E	0.025	0.022	Earth-lined	3	
G	0.035	0.030	Grass-lined	5	
I	0.017	0.013	Ductile Iron	50	
P	0.012	0.009	Plastic	25	
R	0.040	0.035	Riprap	15	
T	0.035	0.030	Turf Reinf.	10	1.5
Z	0.060	0.005	Other	25	

Table 3
Channel Hydraulic Calculations

Exide Technologies
Exide Recycling Center
Collin County, Texas
PROJECT NO.: 1302086-02

Date:	8/29/18
By:	HH
Chkd:	JBF
Apprvd:	JBF

			Channel Design Geometry						Channel Roughness Parameters				Hydraulic Calculations							Channel Evaluations	
Reach Designation	Q (cfs)	Storm Event	Approximate Channel Length (ft)	Bed Slope (ft/ft)	Left Side Slope (H:1V)	Right Side Slope (H:1V)	Bottom Width (ft)	Minimum Channel Depth (ft)		Design Channel Lining	Mannings 'n' for Capacity (Depth Calculation)	Mannings 'n' for Stability (Velocity Calculation)	Maximum Velocity (ft/sec)	Maximum Normal Flow Depth (ft)	Froude Number	Normal Depth Shear Stress (lb/ft^2)	Stream Power (W/m^2)	Top Width of Flow (ft)	Top Width of Channel (ft)	Available Freeboard (ft)	
Perimeter Channels																					
Channel Pre Culvert	10.0	25-year	776	0.0163	4.0	4.0	1.5	2.0	GL	Grass-lined	0.035	0.030	3.5	0.73	0.95	0.74	37.38	7.4	17.5	1.27	
Channel Post Culvert	8.0	25-year	436	0.0100	4.0	4.0	1.5	2.0	GL	Grass-lined	0.035	0.030	2.7	0.74	0.74	0.46	18.23	7.4	17.5	1.26	

(1) Note: Comments and Warnings:
< 1.0 ft indicates freeboard is less than 1 foot.
< 1/2 Vel. Head indicates that the remaining freeboard is less than 1/2 the velocity head ($V^2/2g$) suggesting water may splash out.
Warning: VxD>9 indicates that the velocity times the depth is greater than 9 ft^2/sec, which is undesirable and may be unsafe.
Unstable V indicates that calculated velocity exceeds the recommended maximum for the lining material.
Unstable T indicates that calculated shear stress exceeds the recommended maximum for the lining material.

EXIDE RECYCLING CENTER
HY-8 INFORMATION

Crossing Data - Access Road

Crossing Properties

Name: Access Road

Parameter	Value	Units
Discharge Method	Minimum, Design, and Maximum	
Minimum Flow	0.000	cfs
Design Flow	18.000	cfs
Maximum Flow	20.000	cfs
TAILWATER DATA		
Channel Type	Trapezoidal Channel	
Bottom Width	1.500	ft
Side Slope (H:V)	4.000	_:1
Channel Slope	0.0170	ft/ft
Manning's n (channel)	0.035	
Channel Invert Elevation	641.900	ft
Rating Curve	View...	
ROADWAY DATA		
Roadway Profile Shape	Constant Roadway Elevation	
First Roadway Station	0.000	ft
Crest Length	56.000	ft
Crest Elevation	648.000	ft
Roadway Surface	Paved	
Top Width	16.000	ft

Culvert Properties

Culvert

Add Culvert | Duplicate Culvert | Delete Culvert

Parameter	Value	Units
Shape	Circular	
Material	Corrugated Steel	
Diameter	1.500	ft
Embedment Depth	0.000	in
Manning's n	0.024	
Culvert Type	Straight	
Inlet Configuration	Thin Edge Projecting	
Inlet Depression?	No	
SITE DATA		
Site Data Input Option	Culvert Invert Data	
Inlet Station	0.000	ft
Inlet Elevation	642.340	ft
Outlet Station	25.500	ft
Outlet Elevation	641.900	ft
Number of Barrels	2	

Help | Click on any icon for help on a specific | Low Flow | AOP | Energy Dissipation | Analyze Crossing | OK | Cancel

Summary of Flows at Crossing - Access Road

Headwater Elevation (ft)	Total Discharge (cfs)	Culvert Discharge (cfs)	Roadway Discharge (cfs)	Iterations
642.34	0.00	0.00	0.00	1
642.84	2.00	2.00	0.00	1
643.07	4.00	4.00	0.00	1
643.26	6.00	6.00	0.00	1
643.44	8.00	8.00	0.00	1
643.72	10.00	10.00	0.00	1
643.88	12.00	12.00	0.00	1
644.03	14.00	14.00	0.00	1
644.20	16.00	16.00	0.00	1
644.30	17.00	17.00	0.00	1
644.78	20.00	20.00	0.00	1
648.00	35.74	35.74	0.00	Overtopping

Display

- Crossing Summary Table
- Culvert Summary Table — Culvert
- Water Surface Profiles
- Tapered Inlet Table
- Customized Table — Options...

Geometry

Inlet Elevation: 642.34 ft
Outlet Elevation: 641.90 ft
Culvert Length: 25.50 ft
Culvert Slope: 0.0173
Inlet Crest: 0.00 ft
Inlet Throat: 0.00 ft

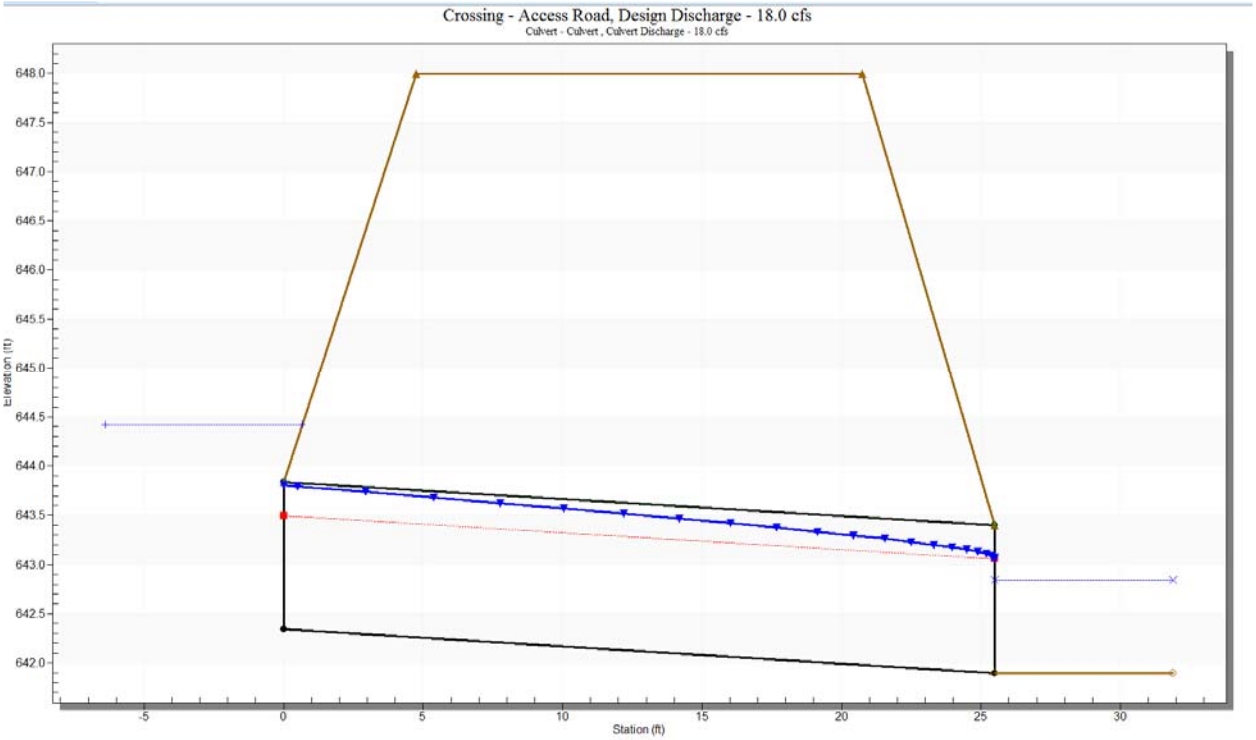
Outlet Control: Profiles

Plot

Crossing Rating Curve | Culvert Performance Curve | Selected Water Profile | Water Surface Profile Data

Help | Flow Types... | Edit Input Data... | Energy Dissipation... | AOP... | Low Flow... | Export Report | Adobe PDF (*.pdf) | Close

EXIDE RECYCLING CENTER
HY-8 INFORMATION



Rainfall Intensity-Duration-Frequency Coefficients for Texas Counties

1. Select your county. 2. Enter the time of concentration

County	Coefficient	2-year	5-year	10-year	25-year	50-year	100-year
Collin	e (in)	0.790	0.781	0.778	0.779	0.776	0.764
	b	54	67	79	92	102	106
	d (mins)	8.2	8.8	8.8	8.8	8.8	8.2
	Intensity (in/hr)*	3.6	4.5	5.4	6.2	7.0	7.7

Clay
Cochran
Coke
Coleman
Collin
Collingsworth
Colorado
Comal
Comanche

Coefficient	2-year	5-year	10-year	25-year	50-year	100-year
e (mm)	0.790	0.781	0.778	0.779	0.776	0.764
b	1372	1702	2007	2337	2591	2692
d (mins)	8.2	8.8	8.8	8.8	8.8	8.2
Intensity (mm/hr)*	90.8	114.4	136.3	158.2	177.3	194.8

* for time of Concentration = **22.9** mins

Rainfall Intensity-Duration-Frequency Coefficients for Texas Counties

1. Select your county. 2. Enter the time of concentration

County	Coefficient	2-year	5-year	10-year	25-year	50-year	100-year
Collin	e (in)	0.790	0.781	0.778	0.779	0.776	0.764
	b	54	67	79	92	102	106
	d (mins)	8.2	8.8	8.8	8.8	8.8	8.2
	Intensity (in/hr)*	3.2	4.0	4.8	5.6	6.2	6.8

Clay
Cochran
Coke
Coleman
Collin
Collingsworth
Colorado
Comal
Comanche

Coefficient	2-year	5-year	10-year	25-year	50-year	100-year
e (mm)	0.790	0.781	0.778	0.779	0.776	0.764
b	1372	1702	2007	2337	2591	2692
d (mins)	8.2	8.8	8.8	8.8	8.8	8.2
Intensity (mm/hr)*	80.7	102.1	121.7	141.2	158.2	173.9

* for time of Concentration = **27.9** mins

FINAL COVER EROSION SOIL LOSS CALCULATION - North CAMU

Made By: CMF
Checked by: JBF
Reviewed by:
Date: 5/30/2019

1.0 OBJECTIVE:

Estimate erosion soil loss under final closure conditions for the Class 2 Landfill (CL2LF) CAMU at the closed Exide Recycling Canter in Frisco, Texas.

2.0 METHOD:

Erosion loss was determined using the Revised Universal Soil Loss Equation (RUSLE), (UDSA,1997).

I) Use revised universal soil loss equation.
A = R K L S C P Variables described below

Rainfall and erosivity index (R)

From Fig. 1, Ref.1, the average annual rainfall erosion index for the site is approx. **295**

Soil Erodibility Factor (K)

Assume a silty clay loam with an organic matter content of 4% and use Table 1, Ref. 1, to determine the K factor.

Use K = 0.26

Cover and Management Factor [C]

Assume 80% ground cover and interpolate C from values shown on Table 2, Ref. 1

C = 0.013

Support Practice Factor (P)

Surface tracked with dozer -- rough surface

Use P = 1

Length Slope Factor (LS) (Ref. 2)

For regular slopes > 15 ft long, the **Slope Steepness Factor, S** =

$S = 10.8 \sin \Theta + 0.03$; $\sin \Theta < 0.09$ Eqn. 8.39

or $16.8 \sin \Theta - 0.50$; $\sin \Theta \geq 0.09$ Eqn. 8.40

Where: Θ = slope angle

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Length Factor, L

$L = [\lambda/72.6]^m$ Eqn. 8.43

λ = slope length (measured as the horizontal projection of plot length)

m is an exponent dependent upon slope given by

$$m = \frac{\beta}{1+\beta} \quad \text{Eqn. 8.44}$$

β for soils moderately susceptible to erosion is given by:

$$\beta_{mod} = \frac{11.16 \sin\Theta}{3.0(\sin\Theta)^{0.8} + 0.56} \quad \text{Eqn. 8.45}$$

β is modified as follows for soils of low and high susceptibility to erosion:

$\beta_{low} = (1/2)\beta_{mod}$

$\beta_{high} = 2\beta_{mod}$

3.0 ASSUMPTIONS:

Facility slopes are 4H:1V on the sides, 3.2% on top,

R was taken from Figure 1, Average Annual Values of the Rainfall Erosion Index,

K was taken from the USDA soil Interpretation Records, Soil Conservation Services,

S = slope steepness factor (Haan, 1994),

There are three equations available to determine S. If the length of the applicable slope is less than 15 feet, then equation 8.41 which is $S = 3.0 (\sin \Theta)^{0.8} + 0.56$. If the applicable slope is greater than 15 feet then equation 8.39 or 8.40 would apply, depending on the angle of the slope. These two equations are:

If $\sin \Theta < 0.09$, then $S = 10.8 \sin \Theta + 0.03$

If $\sin \Theta \geq 0.09$, then $S = 16.8 \sin \Theta - 0.50$

In our specific calculation, the slope angles are as follows:

For the 4 (H): 1(V) slope, $\Theta = 14.04°$

$\sin 14.04° = 0.24 \geq 0.09$, Use eq. 8.40

For the 3.2% slope, $\Theta = 2.29°$

$\sin 2.29° = 0.03 < 0.09$, Use eq. 8.39

L = slope length factor

$$L = \frac{\lambda}{72.6}^{m}$$

where λ = horizontal projection of plot length

$$m = \frac{\beta}{1+\beta}$$

$$\beta = rill\ erosion$$

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$$\beta_{mod} = \frac{11.16 \sin \Theta}{3.0(sin\Theta)^{0.8} + 0.56}$$

The equation for rill erosion applies to moderately erodible soils.

C represents 80% ground cover without appreciable canopy - Table 2, USDA-SCS TR 52,

P was assumed to be 1.0 for long-range prediction & no maintenance.

4.0 CALCULATIONS

A RUSLE calculation was performed for a compound slopes.

A Summary of the RUSLE calculation is presented in Table 1.

5.0 CONCLUSION/RESULTS

RUSLE calculation for a compound slope is found in Tables 1. Annual erosion is calculated to be 0.7 ton/ac/year.

6.0 REFERENCES:

1) Use of the Universal Soil Loss Equation in Final Cover/Configuration Design, Procedural Handbook," TNRCC, Permits Section, October 1993.
2) Haan C.T., B. J. Barfield, and J.C. Hayes. 1994. Design hydrology and sedimentology for small catchments. San Diego CA : Academic Press Inc.
3) TCEQ Regulatory Guidance, "Guidelines for Preparing a Surface Water Drainage Report for a Municipal Solid Waste Facility.", August 2006

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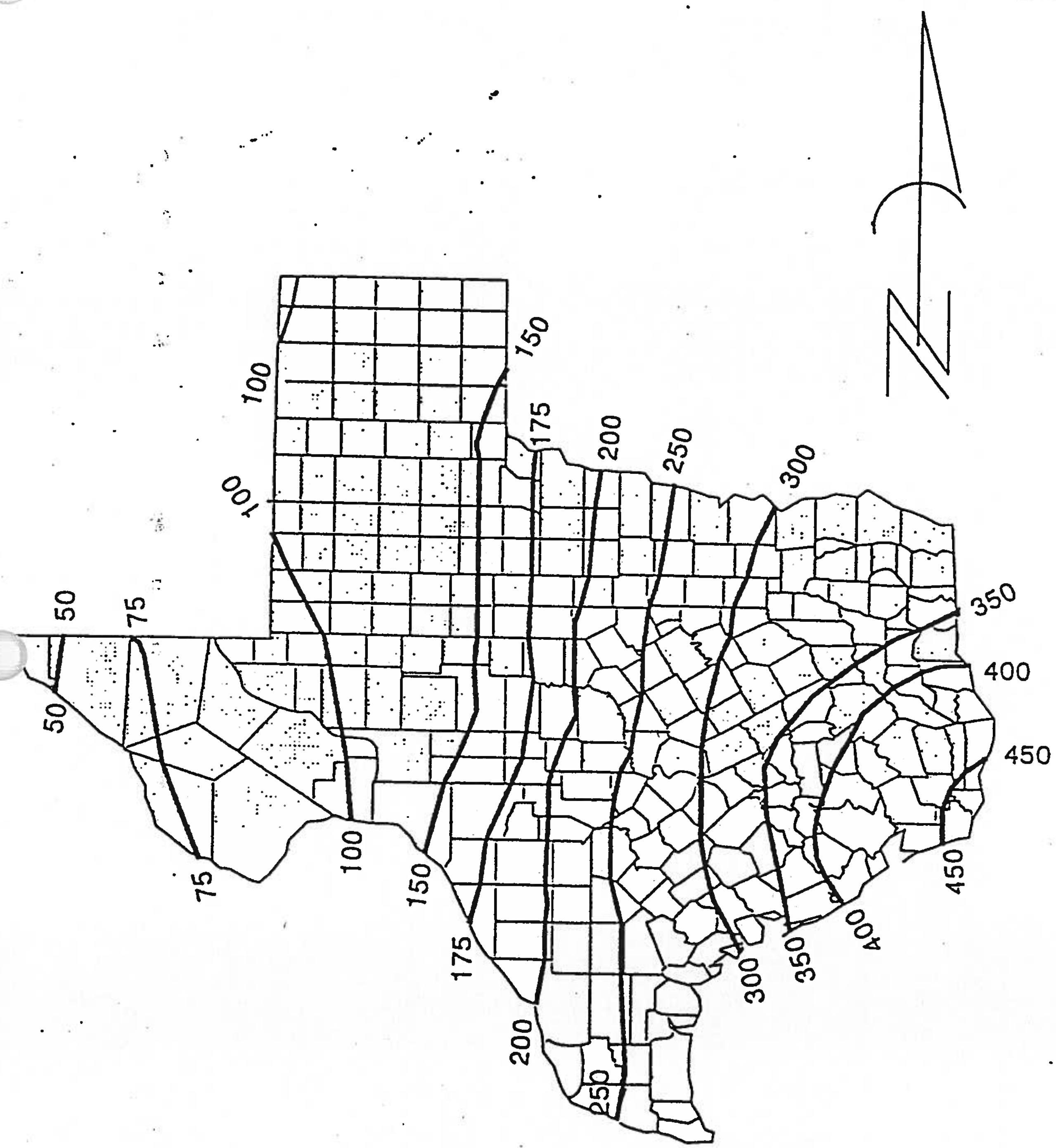
TABLE 1. EXIDE RECYCLING CENTER - ESTIMATED AVERAGE ANNUAL EROSION
MAXIMUM EROSION LOSS

R ft tonsf in/acre hr year	Slope Segment	K ton*ac-hr/hundredths ac-ft*tonf*in	Slope (ft/ft)	Length (l) (ft)	rill susceptability low, mod, high	beta eq. 8.45	m eq.8.44 or .5 (Foster & Wischmeier, 1978)	LS	C	P	A_i ton/ac/yr
Final Cover - Top (80% cover)											
295	1	0.26	0.03	221	mod	0.475	0.3222	0.513	0.013	1.00	0.5
295	2	0.26	0.25	10.5	mod	1.774	0.6395	0.235	0.013	1.00	0.2
								Eff. LS: 0.75			**0.7**

NOTES: **R** was taken from Figure 1, Average Annual Values of the Rainfall Erosion Index
M was calculated from Eq. 8.37 (p. 256) - *Design Hydrology and Sedimentology for Small Catchments* 1
K was based on soil survey descriptions obtained from the USDA, Soil Interpretation Records, Soil Conservation Services
LS was calculated from Eqs. 8.39-41 and 43 (p. 261) - *Design Hydrology and Sedimentology for Small Catchments*
C represents 80% ground cover without appreciable canopy - *USDA-SCS TR 51*
P was assumed to be 1.0 for long-range prediction & no maintenance

A = R * K * LS * C * P

where:
A = soil loss, tons/(acre - year)
R = rainfall erosion index
K = soil erodibility factor
LS = slope length and steepness factor
C = vegetative cover factor
P = erosion control practice factor



W.H. Wischmeier, SEA, 1976

GURE 1. - AVERAGE ANNUAL VALUES OF THE RAINFALL EROSION INDEX

Table 1 Approximate Values of Factor K for USDA Textural Classes

TABLE 1

Texture Class	Organic Matter Content		
	<0.5%	2%	4%
	K	K	K
Sand	0.05	0.03	0.02
Fine Sand	0.16	0.14	0.10
Very Fine Sand	0.42	0.36	0.28
Loamy Sand	0.12	0.10	0.08
Loamy Fine Sand	0.24	0.20	0.16
Loamy Very Fine Sand	0.44	0.38	0.30
Sandy Loam	0.27	0.24	0.19
Fine Sandy Loam	0.35	0.30	0.24
Very Fine Sandy Loam	0.47	0.41	0.33
Loam	0.38	0.32	0.29
Silt Loam	0.48	0.42	0.33
Silt	0.60	0.52	0.42
Sandy Clay Loam	0.27	0.25	0.21
Clay Loam	0.28	0.25	0.21
Silty Clay Loam	0.37	0.32	0.26
Sandy Clay	0.14	0.13	0.12
Silty Clay	0.25	0.23	0.19
Clay	0.13 - 0.29		

The values shown are estimated averages of broad ranges of specific-soil values. When a texture is near the borderline of two texture classes, use the average of the two K values.

Table 2 Factor C for permanent pasture, range, and idle land[1]

Vegetative Canopy		Cover that contacts the soil surface						
Type and height[2]	Percent cover[3]	Percent ground cover						
		0	20	40	60	70	80	90
No Appreciable Canopy		0.45	0.20	0.10	0.042	.028	0.013	0.006
Tall weeds or short brush with average drop fall height of 20 in.	50	0.26	0.13	0.07	0.035	.023	0.012	0.006
	75	0.17	0.10	0.06	0.032	.022	0.011	0.005

Extracted from:
United States Department of Agriculture, AGRICULTURE HANDBOOK NUMBER 537

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1 The listed C values assume that the vegetation and mulch are randomly distributed over the entire area.

2 Canopy height is measured as the average fall height of water drops falling from the canopy to the ground. Canopy effect is inversely proportional to drop fall height and is negligible if fall height exceeds 33 ft.

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

The impact of changes in saturated hydraulic conductivity on the K factor must be accounted for by the nomograph in Fig. 8.9. To accomplish this correction using Eq. (8.38), relationships between hydraulic conductivity and permeability classes used in Fig. 8.9 must be known. Rawls *et al.* (1982) proposed the relationship shown in Table 8.3.

Example Problem 8.4. Effects of rock fragments on *K*

A silty clay loam soil is classified as permeability class 5. Based on textural information, soil structure, and a permeability class of 5, K is estimated as 0.21 in English units. What would be the value for K as corrected for rock fragments if the percentage of rock fragments greater than 2 mm occupies 40% of the soil mass by weight?

Solution:

1. Impact of rock fragment on hydraulic conductivity. From Table 8.3, k_f for a silty clay loam soil is between 0.04 and 0.08 in./hr. Assume a value of 0.06 in./hr. From Eq. (8.38)

$$k_b = k_f(1 - R_w) = 0.06(1 - 0.40) = 0.036 \text{ in./hr.}$$

2. Estimating the revised permeability class. From Table 8.3, the permeability class for $k_b = 0.036$ in./hr is 6.

3. Estimating the new erodibility. Entering Fig. 8.9 with an estimated K of 0.21 for a permeability class of 5, the K value for a class 6 permeability is estimated as 0.22 (English units).

It is again important to note that this procedure corrects only for the effects of rock fragments on infiltration. Impacts on the C factor must be based on percentage ground cover, as discussed in a subsequent section.

Rough Estimates of *K* from Textural Information and Experimental Values for Construction and Mined Sites

The USDA–SCS has developed estimates of K based on textural classification for topsoil, subsoil, and residual materials as shown in Table 8.4. These values are first estimates only and do not include the influence of soil structure or infiltration characteristics.

A limited number of data sets have been developed for drastically disturbed lands and for reconstructed soils. A summary of the data is given in Table 8.5 along with a comparison to values from the Wischmeier *et al.* (1971) nomograph shown in Fig. 8.9. The comparison is sufficiently favorable to warrant the use of the nomograph for a first estimate of K on disturbed topsoil or A-horizon material. The comparison is not favorable for subsoil materials.

Length and Slope Factors *L* and *S*

The effects of topography on soil erosion are determined by dimensionless L and S factors, which account for both rill and interrill erosion impacts.

Slope Steepness Factor *S*

The slope steepness factor S is used to predict the effect of slope gradient on soil loss. For slope lengths

Table 8.3 Soil Water Data for the Major USDA Soil Textural Classes (after Rawls *et al.*, 1982)

Texture	Permeability class[a]	Saturated hydraulic conductivity in./hr	Saturated hydraulic conductivity mm/hr	Hydrologic soil group[b]
Silty clay, clay	6	< 0.04	<1	D
Silty clay loam, sandy clay	5	0.04–0.08	1–2	C–D
Sandy clay loam, clay loam	4	0.08–0.20	2–5	C
Loam, silt loam	3	0.20–0.80	5–20	B
Loamy sand, sandy loam	2	0.80–2.40	20–60	A
Sand	1	> 2.40	>60	A+

[a]See Soil Conservation Service National Soils Handbook (SCS, 1983).

[b]See Soil Conservation Service National Engineering Handbook (SCS, 1972, 1984).

[c]Note: Although the silt texture is missing from the NEH because of inadequate data, it undoubtedly should be in permeability class 3.

greater than 15 ft, the S factor from the USLE was modified significantly by McCool *et al.* (1987, 1993) after extensive evaluation of the original USLE data base. The modified version is

$$S = 10.8 \sin\theta + 0.03; \qquad \sin\theta < 0.09 \qquad (8.39)$$

$$S = 16.8 \sin\theta - 0.50; \qquad \sin\theta \geq 0.09, \qquad (8.40)$$

where θ is the slope angle. Based on an evaluation of data from disturbed lands with slopes up to 84%, McIssac *et al.* (1987) developed an equation similar to (8.39) and (8.40) with exponents in the same range; thus McCool *et al.* (1993) recommend that Eqs. (8.39) and (8.40) also be used for disturbed lands.

For slope lengths less than 15 ft, the S factor is not as strongly related to slope (slope exponent less than 1.0) since rilling would not have been initiated. The recommended factor is

$$S = 3.0(\sin\theta)^{0.8} + 0.56. \qquad (8.41)$$

Under conditions where thawing of recently tilled soils is occurring and surface runoff is the primary factor causing erosion (typical of the Pacific Northwest in the spring), the S factor should be (McCool *et al.*, 1987, 1993)

$$S = 4.25(\sin\theta)^{0.6}, \qquad \sin\theta \geq 0.09. \qquad (8.42)$$

For thawing soils with slopes less than 9%, Eq. (8.39) should be used.

The S factor in the RUSLE is significantly modified from the original USLE as a result of an extensive reevaluation of the original data base, addition of the factors for short slope lengths, and new values for thawing soils (McCool *et al.*, 1987). The original data base did not include values beyond 20%. When using the quadratic form of the equation for S developed for the original USLE, projections beyond 20% yielded unreasonably high values for erosion. The RUSLE equation with the linear function corrects this problem.

Table 8.4 K Value Estimates based on Textural Information (English Units) (Soil Conservation Service, 1978)

Texture	Estimated K value[a]
Topsoil	
Clay, clay loam, loam, silty clay	0.32[b]
Fine sandy loam, loamy very fine sand, sandy loam	0.24
Loamy fine sand, loamy sand	0.17
Sand	0.15
Silt loam, silty clay loam, very fine sandy loam	0.37
Subsoil and Residual Material	
Outwash Soils	
Sand	0.17
Loamy sand	0.24
Sandy loam	0.43
Gravel, fine to moderate fine	0.24
Gravel, medium to moderate coarse	0.49
Lacrustrine Soils	
Silt loam and very fine sandy loam	0.37
Silty clay loam	0.28
Clay and silty clay	0.28
Glacial Till	
Loam, fine to moderate fine subsoil	0.32
Loam, medium subsoil	0.37
Clay loam	0.32
Clay and silty clay	0.28
Loess	0.37
Residual	
Sandstone	0.49
Siltstone, nonchannery	0.43
Siltstone, channery	0.32
Acid clay shale	0.28
Calcareous clay shale or limestone residuum	0.24

[a]These values are typical based only on textural information. Values for an actual soil can be considerably different due to different structure and infiltration.

[b]Units on K in this table are English units (tons•acre•hr/hundreds•acre•ft•tonsf•in.). To convert to metric units (t•ha•h/ha•MJ•mm), multiply K values by 0.1317.

Slope Length Factor

The slope length factor was developed by McCool *et al.* (1989, 1993) from the original USLE data base augmented with theoretical considerations. The L factor retains its original form

$$L = \left[\frac{\lambda}{72.6}\right]^m, \qquad (8.43)$$

where λ is the slope length in feet, 72.6 ft is the length of a standard erosion plot, and m is a variable slope length exponent. Slope length, λ, is the horizontal projection of plot length, not the length measured along the slope. The difference in horizontal projections and slope lengths becomes important on steeper slopes.

The slope length exponent is related to the ratio of rill to interrill erosion, β (Foster *et al.*, 1977b; McCool *et al.*, 1989, 1993), by

$$m = \frac{\beta}{1+\beta}. \qquad (8.44)$$

Table 8.5 Experimental K Value Estimates for Disturbed Lands (English Units)

Reclaimed soil or residual material	Location of experimental site	K Exp[a]/Nomo[b]	Reference
Hosmer silt loam	Indiana	0.387/0.485[c]	Stein *et al.* (1983)
Alfred silt loam	Southern Indiana	0.812/0.485	
Ava silt loam	Southern Indiana	0.842/0.478	
Graded overburden	Southern Indiana	0.197–0.835/ 0.250–0.478	
Clinton silt loam[d]	Western Illinois	0.370/0.360	Mitchell *et al.* (1983)
Tama silty clay loam[d]	Western Illinois	0.210/0.310	
Hosmer silt loam[d]	Southern Indiana	0.450–0.650/ 0.470	
Sadler silt loam (A horizon)	Western Kentucky	0.415/0.385	Barfield *et al.* (1988)
Sadler silt loam (B horizon)	Western Kentucky	0.380/0.640	
Shale spoil material	Western Kentucky	0.140/0.180	

[a]Values measured experimentally with rainfall simulators.

[b]Values calculated from Wischmeier *et al.* (1971) nomograph shown in Fig. 8.9.

[c]Values in English units of tons•acre•hr/hundreds•acre•ft•tonsf•in. To convert to metric units of t•a•h/ha•MJ•mm, multiply by 0.1317.

[d]The dominant soil series. Some mixing occurred with other series.

For soils that are classed as being moderately susceptible to erosion, McCool *et al.* (1989) proposed that

$$\beta_{\text{mod}} = \frac{11.16 \sin \theta}{3.0(\sin \theta)^{0.8} + 0.56}, \tag{8.45}$$

where θ is the slope angle. Thus, the slope exponent is a function of the slope angle θ.

Soils in the RUSLE are classed as having low, moderate, or high susceptibility to rill erosion. Equation (8.45) is for soils that are moderately susceptible to erosion. Conversions for soils that have low or high susceptibility to erosion are given in Table 8.6. Values in Table 8.6 are based on the assumption that moderately erodible soils have a β defined by Eq. (8.45), soils highly susceptible to rilling have a β that is twice that given by Eq. (8.45), and soils with low susceptibility to rilling have a β that is defined by half that given by Eq. (8.45).

For soils in the Pacific Northwest, or other soils that are exposed to runoff during thawing without sufficient rainfall energy to cause interrill erosion, the values in Table 8.6 should not be used. Instead, McCool *et al.* (1989) recommend that a slope length exponent of 0.5 be used for all slopes. When runoff on thawing soils is exposed to rainfall sufficient to cause significant interrill erosion, the slope length exponent for the low rill to interrill erosion ratio should be used (column 1 in Table 8.6). For rangeland soils, the use of a low rill to interrill erosion ratio is proposed. Selection of the appropriate column to use in Table 8.6 requires professional judgement. The assistance of a soil scientist may be helpful.

Combined Length and Slope Factors

Combined slope length and slope steepness factors were calculated using the factors from Eqs. (8.39) to (8.43). These combination factors are given in Fig. 8.13 for all susceptibilities and for thawing soils.

Irregular and Segmented Slopes

Soil loss is strongly impacted by slope shape (Foster and Huggins, 1979). A convex shape will have greater erosion than a uniform slope by as much as 30%. A concave slope will have less erosion than a uniform slope. Foster and Wischmeier (1974) developed a procedure for evaluating the impact of irregular slopes by dividing the slope into segments. The soil loss per unit area from the ith segment is

$$A_i = RK_iC_iP_iS_i\left[\frac{\lambda_i^{m+1} - \lambda_{i-1}^{m+1}}{(\lambda_i - \lambda_{i-1})72.6^m}\right], \tag{8.46}$$

where λ_i and λ_{i-1} are the slope lengths at the start and end of segment i, and K_i, C_i, P_i, and S_i are USLE factors for segment i. Equation (8.46) can be used for each segment i. The total erosion from each segment

Table 8.6 Slope Length Exponent m in Eq. (8.43) (after McCool *et al.*, 1993)[a]

Percentage slope	Rill/interrill ratio		
	Low[b]	Moderate[c]	High[d]
0.2	0.02	0.04	0.07
0.5	0.04	0.08	0.16
1.0	0.08	0.15	0.26
2.0	0.14	0.24	0.39
3.0	0.18	0.31	0.47
4.0	0.22	0.36	0.53
5.0	0.25	0.40	0.57
6.0	0.28	0.43	0.60
8.0	0.32	0.48	0.65
10.0	0.35	0.52	0.68
12.0	0.37	0.55	0.71
14.0	0.40	0.57	0.72
16.0	0.41	0.59	0.74
20.0	0.44	0.61	0.76
25.0	0.47	0.64	0.78
30.0	0.49	0.66	0.79
40.0	0.52	0.68	0.81
50.0	0.54	0.70	0.82
60.0	0.55	0.71	0.83

[a] Values in table are not applicable to thawing soils. See text for explanation.
[b] $\beta = 1/2$ value from Eq. (8.45) in Eq. (8.44).
[c] $\beta = 1 \times$ value from Eq. (8.45) in Eq. (8.44).
[d] $\beta = 2 \times$ value from Eq. (8.45) in Eq. (8.44).

would be $A_i(\lambda_i - \lambda_{i-1})$, and the average erosion per unit area over the entire slope length would be

$$A = R \sum_{i=1}^{n} K_i C_i P_i S_i \frac{\left[\lambda_i^{m+1} - \lambda_{i-1}^{m+1}\right]}{\lambda_e 72.6^m}, \qquad (8.47)$$

where λ_e is the total slope length. Equation (8.47) can also be used to evaluate the effects of variation in K, C, and P over the slope length.

An alternate method for evaluating irregular slopes is the use of a slope length adjustment factor (SAF). If the slope is divided into n increments of equal length ΔX, then

$$A = R \sum_{i=1}^{n} K_i C_i P_i S_i \frac{\left[(i\,\Delta X)^{m+1} - ([i-1]\,\Delta X)^{m+1}\right]}{n\,\Delta X 72.6^m}. \qquad (8.48)$$

Dividing by n times the soil loss from a uniform slope of equal length and assuming constant values of K_i C_i P_i along the slope, a slope adjustment factor can be developed for each segment, or

$$\mathrm{SAF}_i = \frac{A_i}{A} = \frac{i^{m+1} - (i-1)^{m+1}}{n^m}, \qquad (8.49)$$

where n is the number of segments and SAF is the slope adjustment factor. The sum of the SAF_i for a given slope is equal to the number of segments n; thus the average erosion over the slope is

$$A = \frac{R}{n} \sum_{i=1}^{n} K_i C_i P_i S_i L_i (\mathrm{SAF})_i. \qquad (8.50a)$$

where L_i is the slope length factor calculated from Eq. (8.43) using the m value corresponding to the segment steepness. In the development of a SAF relationship, R, K, C, and P remain constant over all segments; thus Eq. (8.50a) can be solved for an equivalent LS factor

$$LS = \frac{1}{n} \sum_{i=1}^{n} S_i L_i (\mathrm{SAF})_i. \qquad (8.50b)$$

Factors calculated from Eq. (8.50b) are given in Table 8.7. An example of its use is given in Example Problem 8.5.

Example Problem 8.5. Estimating LS factors

A soil that is very susceptible to rilling has a slope length of 210 ft and an average slope of 15%. Estimate the LS factor if:

(1) the slope is uniform
(2) the slope is convex with slopes of 10, 15, and 20% on segments 1, 2, and 3
(3) the slope is concave with slopes of 20, 15, and 10% on segments 1, 2, and 3.

Assume that the soil is not freezing and thawing.

Solution:

1. *Uniform slope.* The slope angle is

$$\theta = \tan^{-1} 0.15 = 8.53^\circ.$$

From Eq. (8.45) for soils moderately susceptible to rilling,

$$\beta = \frac{11.16 \sin 8.53}{3.0(\sin 8.53)^{0.8} + 0.56} = 1.37.$$