PART III, ATTACHMENT 2

FACILITY SURFACE WATER DRAINAGE REPORT

Temple Recycling & Disposal Facility

Temple, Bell County, Texas

TCEQ Permit MSW-692B

STATE OF TEXAS
12/5/16
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INTENDED FOR PERMITTING PURPOSES ONLY

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1.0 INTRODUCTION

This report provides a detailed description of the hydrologic and hydraulic analyses performed for the Temple Recycling and Disposal Facility Permit Amendment Application. Detailed design calculations and operational considerations for the collection, control, detention, and discharge of stormwater run-off are presented in Appendix III-2A of this attachment. As demonstrated in this report, the facility design complies with the requirements of 30 Texas Administrative Code (TAC) §330.63(c) and Chapter 330, Subchapter G and will not adversely alter existing drainage patterns.

1.1 Surface Water Design Overview

The surface water design addresses flow from both the off-site (run-on) and on-site (run-off) areas contributing to the site. In general, the site within the proposed permit boundary is higher than the surrounding area, except for the areas to the west that result in off-site run-on to the site. Off-site run-on enters the site at control point CP1, flows through the site, and discharges at control point CP2. On-site stormwater runoff is controlled with a variety of structures that reduce the slopes (and the velocities) at which the water travels. These include add-on berms, downchutes, slope contouring, perimeter drainage ditches, culverts, and sedimentation and detention ponds.

Figure III-2-1 presents the locations of the pre-development analysis control points for the site. The pre-development condition is a combination of the previously permitted final cover condition in the MSW-692A permit boundary and the 2015 existing conditions in the expansion area. Figure III-2-2 depicts the post-development drainage plan and surface water conveyance structures proposed for the expanded facility.

For the proposed landfill development, the landfill final cover has been divided into sections which drain to protected downchutes that travel down the 4 horizontal to 1 vertical (4H:1V) sideslopes. The sideslopes of the final cover have add-on berms sloped at 2 percent at 40-foot vertical intervals down the 4H:1V slopes. These add-on berms collect the stormwater from the sideslopes and convey it to the downchutes. The downchutes discharge across concrete-surfaced access road crossings into perimeter channels or natural drainage ways, which then convey the flows to the detention ponds.

The proposed landfill development will include three detention ponds: one existing pond (Pond 2) and two proposed ponds (North Pond and South Pond). Figure III-2-2 shows the locations of the ponds. The existing Pond 2 discharges at control point CP2 into a channel that flows to an unnamed tributary of Little Elm Creek along the southern boundary. The proposed South Pond discharges at control point CP4 to the same unnamed tributary as Pond 2. The proposed North Pond discharges at control point CP6 to Williamson Branch, also a tributary of Little Elm Creek, along the northern boundary.

Discharge rates are controlled by the proposed pond outlet control structures, which consist of corrugated metal pipe (CMP) culverts and emergency spillways at each pond.

The long paths created by add-on berms, perimeter channels, and the ponds reduce the peak flow rates and velocities of the flows exiting the site at the discharge points.

Figures III-2-8 through III-2-10 depict flowline elevations, water surface elevations, and velocities along the entire length of the drainage structures. Figure III-2-11 shows details for erosion and sedimentation control. Figures III-2-12 through III-2-17 show the inflow and outflow hydrographs for the ponds. Figures II-2-18 through III-2-24 present the schematic and flow profiles of perimeter Ditch 6 and Ditch 7.

This report consists of the following hydrologic and hydraulic analyses:

1. Estimation of pre-development run-on and run-off peak flows and volumes using the US Soil Conservation Service (SCS) Technical Release Number 55 (TR-55), the SCS hydrograph methodology, and the US Army Corps of Engineers' (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) computer software
2. Similar estimation of post-development peak flows and volumes at defined control points using TR-55, the SCS hydrograph methodology, and the HEC-HMS computer software
3. Estimation of pre-development and post-development velocities at run-off control points
4. Design of add-on berms, downchute channels, culverts, and perimeter channels
5. Estimation of the water surface elevation resulting from the 25-year recurrence interval 24-hour design storm (per TCEQ requirements) and the 100-year, 24-hour major storm (per City of Temple requirements) in the perimeter channels using Manning's Equation assuming normal depth. A Hydrologic Engineering Centers River Analysis System (HEC-RAS) analysis was performed to evaluate the flow in Ditch 6 and Ditch 7 where backwater analysis is required
6. Estimation of the water surface elevation resulting from the 25-year, 24-hour storm event for the downchutes and add-on berms using Manning's Equation assuming normal depth
7. Development of required storage for the proposed North and South Ponds utilizing the HEC-HMS computer software and routing of flows through existing Pond 2 for the 25-year, 24-hour and the 100-year, 24-hour storms
8. Design of hydraulic outflow structures for the proposed detention ponds
9. Estimation of soil loss and presentation of erosion control measures
10. Design of run-on and run-off control berms for active disposal areas

2.0 PRE-DEVELOPMENT DRAINAGE CONDITIONS

The HEC-HMS computer software was used to determine the pre-development peak flows and volumes resulting from the design storm. The Natural Resources Conservation Service (formerly SCS) unit hydrograph transformation methodology was used for all pre-development drainage basins. Rainfall data for Bell County was obtained from a combination of the SCS TR-55 and the City of Temple Drainage Criteria and Design Manual. Times of concentrations for the pre-development condition were calculated using SCS TR-55 methodology. Detailed drainage calculations using the above mentioned methodologies for pre-development conditions are included in Appendix III-2A.

Analysis points were located for the pre-development conditions to represent locations where run-on flows enter the site or run-off exits the site.

The pre-development and post-development contributing areas for each analysis point are summarized in Table III-2-1.

Table III-2-1: Summary of Contributing Areas

Analysis/Control Point		Contributing Area (acre)	
		Pre-Development	**Post-Development**
Run-on	CP1	9.5	9.5
Run-off	CP2	221.2	192.8
	CP3	64.3	0.0
	CP4	55.5	111.0
	CP5	36.7	0.0
	CP6	33.0	153.0
	CP7	45.3	0.0

The total contributing area (obtained by summing the areas contributing to CP2 through CP7 since CP1 is included in CP2) is 456.0 and 456.8 acres, respectively for pre- and post-development. There is a 0.15 percent difference in total area between pre- and post-development contributing areas. This insignificant difference is a result of numerical rounding of the areas of the numerous small subcatchments. Figures III-2-1 and III-2-2 depict the pre- and post-development drainage maps and show all contributing areas.

3.0 POST-DEVELOPMENT DRAINAGE CONDITIONS AND DESIGN

The calculated pre-development hydrologic conditions define the hydraulic design requirements for the final landfill development. Figure III-2-2 depicts the final development drainage plan and shows all drainage areas that were used to determine the post-development discharges. The analysis points are used as the control points for comparison between the pre- and post-development discharges. These control points are shown on Figures III-2-1 and III-2-2.

Although the proposed stormwater drainage patterns for the facility have been revised from the pre-development conditions, the surrounding existing drainage patterns will not be adversely altered as a result of the proposed facility expansion.

3.1 Post-development Peak Discharge

Using the same procedures as the pre-development conditions, a surface water model of the expanded facility was constructed using the HEC-HMS computer software for the post-development conditions. The peak flows were computed with the surface water model using hydrographs for each basin generated from the SCS unit hydrograph transformation methodology. These flows were then routed through the surface water conveyance system part of the model (add-on berms, downchutes, perimeter channels, culverts, ponds, etc.) to the defined control points. Details for these calculations are presented in Appendix III-2A.

In accordance with TCEQ regulations, the 25-year, 24-hour storm event was used to compute the peak flow rates, discharge volumes, velocities, and water surface elevations. Additionally, in accordance with the City of Temple's Drainage Criteria and Design Manual, the 100-year, 24-hour major storm event was used to size the perimeter channels and the detention ponds. These inputs result in a conservative design for these drainage features when considering the TCEQ-specified 25-year and 24-hour design storm.

Table III-2-2 compares the pre- and post-development peak flow rates, discharge volumes, and velocities at control points CP1 through CP7.

Table III-2-2: Summary of Peak Flows and Discharge Volumes

Control Point		25-year, 24-hour Storm Event					
		Pre-Development Peak Flow Rate (cfs)	Post-Development Peak Flow Rate (cfs)	Pre-Development Discharge Volume (ac-ft)	Post-Development Discharge Volume (ac-ft)	Pre-Development Velocity (ft/sec)	Post-Development Velocity (ft/sec)
Run-on	CP1	30.2	30.2	-	-	-	-
Run-off	CP2	292.1	200.2	96.1	79.6	3.5	3.2
	CP3	206.3	Rerouted to CP4	29.0	Rerouted to CP4	3.5	-
	CP4	178.3	85.3	25.0	56.2	4.8	4.0
	CP5	136.1	Rerouted to CP6	16.5	Rerouted to CP6	3.1	-
	CP6	128.5	24.2	14.9	80.3	4.3	2.8
	CP7	115.0	Rerouted to CP6	21.1	Rerouted to CP6	4.0	-

Notes:

cfs = cubic feet per second
ac-ft = acre-feet
Discharge volumes and velocities are calculated for each permit boundary discharge point, i.e. the run-off control points.

As shown in the table above, the post-development flows are routed to exit the site through control points CP2, CP4, and CP6, while the pre-development flows exit the site at control points CP2 through CP7. The re-routing of flows at control points CP3, CP5, and CP7 was designed to accommodate the post-development conditions while maintaining the offsite discharge pattern similar to the pre-development conditions (i.e. flows at control points CP3 and CP4 converge into the unnamed tributary of Little Elm Creek along the southern boundary of the site and flows at control points CP5 through CP7 converge into Williamson Branch, also a tributary of Little Elm Creek, along the northern boundary of the site). The post-development peak flow rates are less than or equal to the pre-development peak flow rates at all control points. Peak flow rates have been reduced due to the redirection of flow, increased flow path length, and attenuation from the proposed ponds. The total discharge volume increases from 202.6 ac-ft in pre-development conditions to 216.1 ac-ft in post-development conditions due to the increase in run-off from the expansion area resulting from landfill development. This increase of 7% is not significant as the additional volume will be released at lower flow rates and velocities, resulting in lower post-development water surface elevations in the tributaries of Little Elm Creek when compared to pre-development conditions.

By comparing the pre-development and post-development peak flow rates, discharge volumes, and velocities at the control points, it is demonstrated that the surface water discharge from the facility is attenuated such that the proposed landfill development will not adversely alter the existing drainage patterns.

3.2 Stormwater Pond Analyses

There is an existing pond, referred to as Pond 2, which will be used for detention and sediment control. This pond is located south of the currently permitted waste footprint, as shown on Figures III-2-1 and III-2-2. The pond will be regraded, as shown on Figure III-2-2, for the proposed development to provide better attenuation of the flow. The estimated maximum water elevation during the 25-year, 24-hour storm event is 582.4 feet above mean sea level (ft-msl). The estimated maximum water elevation during the 100-year, 24-hour is 583.7 ft-msl.

Two proposed ponds, North Pond and South Pond (see Figure III-2-2), have been designed to attenuate the increase in peak run-off due to the proposed landfill expansion. Inflow and outflow hydrographs and calculations verifying the required storage capacity and peak discharge rates for the ponds are provided in Figures III-2-12 through III-2-17 and in Appendix III-2A. The estimated maximum water elevations during the 25-year, 24-hour storm event are 562.8 and 558.3 ft-msl in North Pond and South Pond, respectively. The estimated maximum water surface elevations during the 100-year, 24-hour storm event are 563.5 and 558.9 ft-msl in North Pond and South Pond, respectively.

3.3 Discharge Structure Analysis for Stormwater Ponds

The existing Pond 2's hydraulic discharge structure was modeled in the new system. The existing structure provides adequate capacity; no changes were required to the design of this structure.

The discharge structures on the proposed North and South Ponds were designed to attenuate peak discharges to below the pre-development flow rates at control points. Detailed sizing calculations are included in Appendix III-2A.

3.4 Stormwater Conveyance Structure

All stormwater conveyance channels were designed using normal depth calculations in a spreadsheet, except for Ditch 6 and Ditch 7 where backwater analysis was required. Add-on berms, downchutes, and perimeter channels were designed for the 25-year storm, allowing a minimum of 0.5 feet of freeboard. The perimeter channels also have the additional capacity to convey the peak flow rates resulting from the 100-year, 24-hour storm.

Add-on berms are sloped at 2 percent with 4H:1V and 2H:1V sideslopes and a height of 2 feet. A uniform slope of 2 percent was selected to keep flow velocities below 5 feet per second. The existing add-on berms on the closed landfill areas are also sloped at 2 percent. Detailed calculations for the worst-case scenario for the add-on berms are shown in Appendix III-2A of this attachment. Add-on berm locations are shown on Figure III-2-2. The add-on berm channel details are presented on Figure III-2-3.

Downchute channels were designed to be lined with 60-mil textured geomembrane. Detailed calculations are included in Appendix III-2A. A suitable alternative to geomembrane may be used, provided that the design is verified by a professional engineer. The downchute locations are shown on Figure III-2-2. Downchute cross-sections and details are illustrated on Figure III-2-4.

Perimeter channels were designed to be grass-lined for areas where the velocity is no greater than 5 feet per second. For areas where the velocity exceeds 5 feet per second, the perimeter channel will be lined with riprap. The perimeter channels are generally trapezoidal in shape, with variable slopes, variable bottom widths, variable depths, and variable sideslopes. Perimeter channel locations are shown on Figure III-2-2. A typical detail is shown on Figure III-2-3 along with a schedule that describes the size, slope, water elevations, flow velocity, channel lining, and length for each channel. Detailed calculations are included in Appendix III-2A.

Flow depths for channels were determined using Manning's Equation, assuming normal depth for the 25-year, 24-hour storm. Ditch 6 and Ditch 7 were analyzed using HEC-RAS software since backwater conditions are expected in the downstream of these perimeter channels.

There are energy dissipation structures associated with the landfill downchute channels. Downchute channels terminating in perimeter channels go through a low water road crossing before discharging into the perimeter channel lined with riprap. The downchute channel geomembrane letdown (or alternate, as described above) is extended to the edge of the crossing. Detailed calculations for the downchute channels are presented in Appendix III-2A. Details for the downchute channels are illustrated in Figure III-2-4.

Analyses were performed to determine the adequacy of the culverts at the site and design the proposed culverts. The analyses were performed using the Federal Highway Administration's HY8 Culvert Analysis software. Figures III-2-1 and III-2-2 show the location of the culverts. The culvert calculations using HY8 are presented in Appendix III-2A, which also discusses the required improvements to the existing culverts and design of the proposed culverts.

4.0 EROSION AND SEDIMENTATION CONTROL PLAN

This Erosion and Sedimentation Control Plan describes the design and operational considerations for controlling erosion along landfill embankments and sedimentation in stormwater collection and storage facilities, and for providing effective erosional stability to top dome surfaces and external embankment sideslopes during all phases of facility operation, closure, and post-closure care in accordance with 30 TAC §330.305(d). In accordance with 2007 draft TCEQ guidance for addressing erosional stability during all phases of landfill operation, the landfill cover phases are defined as daily cover, intermediate cover, and final cover. Top dome surfaces and external embankment sideslopes are defined as:

- Those above-grade slopes that directly drain to the perimeter stormwater management system (i.e., directly to a perimeter channel or a detention pond).
- Those above-grade slopes that have received intermediate or final cover.
- Those above-grade slopes that have either reached their permitted elevation, or will subsequently remain inactive for longer than 180 days.

Slopes not addressed above that drain into active areas, excavations or areas under construction, or areas that have only received daily cover (short-term), are not considered external slopes and are not required to maintain the erosion management practices outlined in this plan. An area under daily cover that remains inactive for longer than 180 days will be converted to intermediate cover and those applicable erosion controls, as discussed in the following sections, will be required.

This plan is organized to present the erosion and sediment control design and best management practices (BMPs) for all three landfill conditions: active disposal areas, intermediate cover areas, and final cover areas. The erosion and sedimentation controls were developed to provide low run-off velocities, to provide adequate storage detention, and to limit sediment and soil loss impacts to stormwater discharge quality. Soil erosion loss was estimated utilizing the Texas Natural Resource Conservation Commission's "Use of the Universal Soil Loss Equation in Final Cover/Configuration Design," Procedural Handbook, Permits Section, Municipal Solid Waste Division, October 1993. The selection of erosion and sediment control structures will be a continual evolution of temporary and permanent control devices. The facility fill sequence plans will be used to manage the proper selection of both temporary and permanent erosion and sediment controls to ensure stormwater quality standards as presented in the facility's stormwater discharge permit. Temporary (short-term) erosion controls will typically be used during landfill operations, and permanent (long-term) controls will be used for final cover conditions. Temporary erosion controls are defined as:

- Controls that are installed or constructed within 180 days from when the intermediate cover is constructed and in place until permanent controls are constructed for the final cover or additional placement of waste is resumed on the intermediate cover area.

4.1 General Erosion and Sedimentation Assessment

In assessing the landfill construction and operational practices for potential erosion and sedimentation, the site will consider impacts to sensitive areas, such as steep slopes, surface waters, areas with erodible soils, and existing discharge channels. Also, the facility will disturb the smallest vegetated area possible, keep the amount of cut and fill to a minimum, and maintain the aforementioned sensitive areas. During the construction of landfill cells, it will be necessary to disturb the soil by clearing and grubbing, excavating and stockpiling, rough and final grading, constructing perimeter channel(s), and seeding and/or planting. The BMPs described in the following sections will be utilized to ensure minimal impacts to water quality during these phases of construction and stockpiling activities. Standard TxDOT specifications of these BMPs are included in Appendix III-2D.

To guard against soil loss, the phased development plan for landfill cell construction and solid waste placement will be followed. The figures in Part I/II of this permit application describe in detail the required fill sequence planning, including sequencing of drainage and run-off controls, to ensure adequate slope stability and limited erosion and soil loss.

4.2 Run-on and Run-off Control for Active Disposal Areas

Run-on and run-off controls for active disposal areas will be utilized to minimize the potential for stormwater contamination. The working face of the active disposal area will be encompassed by a run-on berm (top berm) and a run-off berm (toe berm) for the purpose of segregating potentially contaminated and non-contact stormwater. The containment berms are designed to accommodate the 25-year, 24-hour storm, the equivalent of a 7.9-inch rainfall event. The top berm is designed to accommodate upstream watersheds that may flow towards the working face and divert the collected uncontaminated stormwater around the working area for discharge through a permitted stormwater outfall. The toe berm is designed to accommodate storage of stormwater that has potentially contacted the open working face. Perpendicular to the toe berm, side berms of the same size as the toe berm will be constructed at both ends of the toe berm to contain the collected contaminated water. The berm height requirements and design configurations are detailed in Appendix III-2B.

As a result of progressive disposal and filling operations, ongoing berm extensions/construction may be required to accommodate adequate stormwater run-on diversion (top berm) and proper storage of run-off contact waters (toe berm). The daily disposal operations will include an evaluation of the existing containment berms' capability to manage stormwater run-on and run-off, and adjustments will be made as needed.

In general, contaminated water will be contained in the area of the working face behind the containment berm. This water will not be handled as leachate. The contaminated water will be pumped directly into a tanker truck if necessary or pumped to an on-site storage/evaporation pond. Contaminated water pumped directly to a tanker truck will be disposed of off-site at an approved treatment facility. Any of the aforementioned transmission systems may be utilized.

Contaminated water, except leachate and gas condensate, may not be recirculated.

4.3 Erosion and Sediment Control for Intermediate Cover Areas

This sub-section describes the interim controls that may be used during phased landfill development to minimize erosion of top dome surfaces and external embankment sideslopes with intermediate cover. Based on velocity and soil erosion analyses, a selection of BMPs is identified and general installation guidance is provided. Examples of standard published specifications are also provided. Standard published specifications, which will be discussed in the following sections, are provided in Appendix III-2C. In accordance with 30 TAC §330.165(c) and TCEQ guidelines, temporary erosion and sedimentation controls will be implemented on intermediate cover areas within 180 days after placing intermediate cover, including a vegetative cover of at least 60 percent or mulch cover. Depending on the weather conditions and the season of the year when the intermediate cover is placed, methods of temporary control, as discussed in the following sections, will be implemented to provide for erosion protection. Pursuant to TCEQ guidelines, all calculations in support of this erosion and sedimentation control plan are based on 60 percent cover.

4.3.1 Erosion and Sedimentation Control Design – Intermediate Cover Areas

In accordance with 30 TAC §330.305(d), the erosional stability of top dome surface and external embankment sideslopes was analyzed based on the following criteria:

- The estimated peak velocity should be less than the permissible non-erodible velocities under similar conditions. The applicable non-erodible velocities are 3.75 feet per second for bare soil slopes and 5.0 feet per second for grassed (60 percent vegetation) slopes, considering the soil types, grass types, grass conditions, and slope angles at the facility (refer to Appendix III-2C).
- The potential soil erosion loss should not exceed the permissible soil loss for comparable soil-slope lengths and soil-cover conditions. The TCEQ Guidance Document has specified that the permissible soil loss is not to exceed 50 tons/acre/year and the recommended cover is 60 percent.

Since the exact conditions of the various interim conditions are impossible to predict due to daily changes in fill patterns, a conservative approach is taken to determine the worst-case slope conditions. The built-out condition of the final cover scenario is used and the worst-case slopes are determined from this scenario. Even though interim conditions that are this extreme are unlikely, this is a conservative assumption so that any possible interim slope conditions or lengths are covered by this extreme case. The top dome surface is sloped at 4 percent with a maximum length of 500 feet. The external embankment sideslopes are 4H:1V slopes (a small portion has 3H:1V final cover slopes that are currently in place). Analysis indicates that the stormwater velocity on the top surfaces will not exceed the permissible non-erodible velocity in the worst-case conditions, and the length of the 4H:1V slope will be limited to 240 feet to satisfy the flow velocity criteria. The velocity analyses are included in Appendix III-2C and are summarized in Table III-2-3.

Table III-2-3: Summary of Interim Slope Velocities

Cover Slope	Slope Segment	Sheet Flow Method Velocity (fps)	Shallow Concentrated Flow Method Velocity (fps)
4% slope	Segment 1 0–300 ft	0.91	N/A
	Segment 2 300–500 ft	N/A	3.2
4H:1V slope	Segment 1 0–240 ft	1.82	N/A

If an intermediate slope in excess of 240 feet is constructed, then a portion of the slope must be converted to final cover with permanent erosion controls, or temporary soil berms can be installed at 60-foot vertical intervals (i.e. 240 feet along the slope) along the intermediate cover slopes.

The potential soil erosion loss was calculated using the Natural Resources Conservation Service of the United States Department of Agriculture (USDA) Revised Universal Soil Loss Equation (RUSLE). A permissible soil loss of 50 tons/acre/year and a cover of 60 percent are selected as the design criteria for interim erosion and sediment controls. Results of the soil erosion analyses demonstrate that both the top surfaces and the external embankment sideslopes can achieve effective erosional stability without any stormwater diversion structures provided that the soil surfaces are stabilized with at least 60 percent ground cover. Furthermore, since the flow velocities are the governing parameter for the maximum length of the 4H:1V slopes between the soil berms, the actual amount of soil loss will be reduced. Limiting the uninterrupted length of 4H:1V slopes to a maximum of 240 feet will reduce the maximum soil loss on the intermediate slopes to approximately 19.8 tons/acre/year.

The analyses for interim erosion and sediment controls are included in Appendix III-2C.

4.3.2 Erosion and Sedimentation Control BMPs – Intermediate Cover Areas

There are numerous BMPs that can be implemented during landfill operations to meet the soil stabilization and stormwater diversion requirements. These BMPs can be used prior to establishing vegetation or in conjunction with vegetation or mulch. The selected BMPs for this site are commonly used and are discussed below. The common BMPs discussed below include a specification and/or detail for reference. The controls discussed below are available from several manufacturers. The site manager has the flexibility to purchase a control similar to that specified from any manufacturer based on local availability and/or cost. Any other BMPs that may not be commonly used today, such as new technologies as they become available, may be implemented if they are proven to provide satisfactory ground cover and effective erosion controls. The evaluation for effectiveness and the demonstration of equivalency of erosion and sediment control BMPs that are not included in this plan will be maintained within the facility's site operating record (SOR), furnished upon request to the TCEQ, and made available for inspection by TCEQ personnel, as necessary. Furthermore, any control measures and practices used to keep soil loss and flow velocity within permissible limits prior to establishing vegetation or in conjunction with vegetation not approved with this plan, must be approved by the TCEQ prior to implementation.

4.3.2.1 Soil Surface Stabilization

Intermediate cover will be temporarily stabilized during installation and maintained throughout facility operations. Erosion and sedimentation controls will be implemented on intermediate covers within 180 days after placing intermediate cover, in accordance with 30 TAC §330.165(c). The soil surface stabilization BMPs that may be implemented at the site are listed below. Vegetation and/or mulch are the most effective erosion control, but until this is achieved, geosynthetics may be used to stabilize the surface of the soil until vegetation can root, spread, and properly grow. These stabilization materials will be removed, if applicable, once the required 60 percent cover is established.

- Vegetation – Vegetative cover reduces erosion potential by shielding the soil surface from the direct erosive impact of raindrops, improving the soil's porosity and water storage capacity so more water can infiltrate, slowing the run-off, allowing the sediment to drop out, and physically holding the soil in place with plant roots. Grass types that are suitable for the area will be selected in accordance with guidelines published by the state or local agency or other similar sources. The standard seeding specification published by TxDOT is provided in Appendix III-2D.
- Mulch – Mulching is the application of a layer of organic, biodegradable material that is spread over areas where vegetation is not yet established. Types of mulch include compost, straw, wood chips, or manufactured products. Mulch application can be in dry or hydraulic forms. When applied dry, the thickness of the mulch will vary depending on the type of mulch applied. Primary-grind mulch (e.g., wood shreds that form a mass of intertwined fragments) used primarily for erosion control, will be applied using spreading equipment, such as a bulldozer, at a minimum thickness of 2 inches. Compost material, which may consist of more finely ground mulch, will be applied using mechanical spreaders or sprayers. A tackifier or binder may be used to increase the strength and durability of the mulch. Hydraulic mulch includes hydromulch, bonded fiber matrix, flexible growth medium (FGM), and other commercially available products. Hydraulic mulch includes a tackifier or binder that

increases the strength and durability of the mulch. Seeds can be applied to the soil first or mixed into the hydraulic mulch. The application method and application rate of hydraulic mulch will be based on manufacturers' recommendations to ensure a uniform and complete coverage. The application method and rate of mulch for other products will be in accordance with that particular product's specifications and recommendations.

- Geosynthetics – Geosynthetic products available for soil erosion controls include geotextile, geomembrane, rolled-erosion control products (RECPs), etc. Erosion control blankets and turf reinforcement mats are examples of the RECPs. Erosion control blankets include straw or other mulch material stitched with degradable thread to a photodegradable polypropylene netting structure. The standard specification for rolled erosion control products published by the Erosion Control Technology Council is provided in Appendix III-2D. There are numerous products available on the market that can be used. Any material specifically chosen by the site based on cost or local availability will be installed in accordance with that particular manufacturer's specifications and recommendations.

4.3.2.2 Temporary Stormwater Diversions and Sediment Control Structures

Examples of the temporary stormwater diversion and sediment control structures that will be used on the intermediate cover areas are presented below. These structures can be used both prior to and after establishing cover.

- Soil Berms – Soil diversion berms (i.e., temporary add-on berms) are constructed with compacted on-site soils to intercept the flow on the slope and convey the flow laterally to a downchute. The berm design will be minimum 2-feet high, as measured from the invert of the channel to the top of berm, with the invert sloped at 2.0 percent in the direction of flow. The slopes of the soil berms will be stabilized with vegetation, mulch, or geosynthetics. The maximum berm length will be controlled to limit the drainage area to less than 4.1 acres, as demonstrated in the calculation included in Appendix III-2C-2. This limit is based on the channel flow capacity, including a maximum flow velocity of 5.0 feet per second, and the rainfall intensity for Bell County. These temporary soil berms will be constructed in the same manner as the permanent soil berms on the final cover. A detail of the temporary soil berms is shown on Figure III-2-11.
- Silt Fences – Silt fences or fabric filter fences may be used along the slope to intercept the flow and capture the sediment. The maximum drainage area captured by the silt fence should not exceed the manufacturer's specification, but should also be limited to 0.5 acre per 100 feet of fence. The standard specification and detail drawing published by City of Temple is provided on Figure III-2-11.
- Hay Bales – Hay bales may be used along the slope, perpendicular to the flow to intercept the flow and capture the sediment, similar to the function of a silt fence. The standard specification and detail drawing published by City of Temple is provided on Figure III-2-11.
- Biodegradable Logs or Organic Berms – These types of diversion structures are alternatives to traditional silt fences and hay bales. The biodegradable logs or organic berms are placed along the slope contours to catch the sediment from sheet flow and allow the stormwater to flow through at a reduced speed. A biodegradable log consists of mulch contained in a synthetic mesh sock or tube. The logs are installed on the slope with stake anchors. Organic berms are constructed of compost/mulch. A

specification for the compost/mulch filter berm published by TxDOT is included in Appendix III-2D. Any type of biodegradable log or organic berm may be used as long as it is installed in accordance with the manufacturer's specifications and recommendations. A biodegradable log/organic berm detail is included on Figure III-2-11.

4.3.2.3 Additional Erosion and Sedimentation Control BMPs

In addition to the soil stabilization and stormwater diversion BMPs listed above, the site has three detention ponds, which will be used for stormwater detention as well as sediment control.

Temporary downchutes will be required when soil diversion berms are installed. Based on the calculations included in Appendix III-2C-2, the maximum allowable drainage area for the soil diversion berms yields a maximum berm length of 744 feet (corresponding to the maximum drainage area of 4.1 acres), which is approximately the maximum length of the diversion berms for the final cover design. Therefore, the temporary downchutes can be installed in the same location as the permanent final cover downchutes if the intermediate slope is in the vicinity of a permanent downchute. Otherwise, a temporary downchute will be installed at the termination of the temporary soil diversion berm, as necessary to collect run-off from the intermediate slope surface. The recommended minimum temporary downchute channels are 2-feet deep, with 4H:1V sideslopes. The downchute width will be determined based on the contributing drainage area as demonstrated in Appendix III-2C-3. A geosynthetic lining material (e.g., geomembrane sheet) will be used to line the temporary downchute channels. Other lining materials, such as riprap, gabion baskets, or interlocking concrete blocks, may also be used at the site manager's discretion if adequate hydraulic capacities are provided. The hydraulic design of the temporary downchutes is included in Appendix III-2C-3. A detail of the temporary downchute channels is shown on Figure III-2-11. In lieu of downchute channels, corrugated plastic downchute pipes or metal pipes with equivalent flow capacity may be used. If pipes are used as downchutes, the demonstration of equivalency of downchute pipes will be maintained within the facility's site operating record, furnished upon request to the TCEQ, and made available for inspection by TCEQ personnel, as necessary.

For on-site stockpiles, the BMPs discussed previously, such as silt fence, hay bales, or rock or organic berms, may be used at the site manager's discretion to control erosion and run-off around the stockpile areas. Details of these BMPs are shown on Figure III-2-11.

4.3.3 Placing and Removing Temporary BMPs

The BMPs discussed in the previous sections will be placed in accordance with the specifications as included in Appendix III-2D or in accordance with the manufacturers' guidelines for that particular material. Since these BMPs are only temporary, they will be removed at the site manager's discretion when the specific situation warrants that the control is no longer needed or if a different control is implemented. Examples of when a control will be removed or replaced are as follows:

- 60 percent cover has been established.
- The BMP has been destroyed or damaged beyond repair.
- The BMP is not functioning efficiently.
- The intermediate cover area will become part of the active disposal area again.
- The intermediate cover area will receive final cover and permanent erosion controls.
- The BMP becomes a hindrance to daily site operations.

At other times, if deemed necessary by the site manager, the control may be removed to aid in the daily ongoing waste fill and construction activities that may not specifically be itemized in the above list. The placement and removal of temporary BMPs should not hinder the site operations, but should be considered by the site manager as an effective tool to minimize future maintenance or repairs.

BMPs will be removed or replaced as part of the site's daily operations. Removed BMPs that have been destroyed or damaged will be disposed of at the working face of the facility. The site manager will determine a location to store reusable BMPs so they are easily accessible for future construction.

4.4 Erosion and Sedimentation Control for Final Cover Areas

4.4.1 Erosion and Sedimentation Control Design – Final Cover Areas

The final cover stormwater system design includes crownslope add-on berms along the 4 percent final cover top slopes and sideslope add-on berms spaced at 40-foot vertical intervals along the 4H:1V final cover slopes. The selection of stormwater management control structures will be a continual evolution of temporary and permanent control devices. The facility fill sequence plans included in Part II, Figures II-7.1 through II-7.5 will be used to properly select both temporary and permanent stormwater structural controls. The stormwater management structural controls were developed to provide low run-off velocities, to provide adequate storage and detention, and to limit sediment and soil loss impacts on stormwater discharge quality. Soil erosion loss and control was estimated using the Universal Soil Loss Equation in the USDA Handbook No. 703 – "Predicting Soil Erosion By Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)," 1997.

The proposed design results in a maximum estimated soil loss of 2.4 tons/acre/year for the 4H:1V sideslopes of the landfill final cover. This estimate is equal to approximately 0.01 inches per year eroded from the final cover for this worst-case scenario. Soil loss calculations are presented in Appendix III-2E.

4.4.2 Erosion and Sedimentation Control BMPs – Final Cover Areas

Permanent stormwater management controls include seeding, add-on berms, downchute channels, slope contours, perimeter berms, final cap design, detention ponds, and discharge control structures.

To stabilize the final cover soil, a 6-inch thick top soil layer that is capable of supporting native vegetation growth will be installed on the final cover surfaces. Maintenance and inspection, as addressed in Section 5.0 of this text, will be implemented to ensure a minimum 90 percent ground cover on the final cover and to ensure that the diversion structures, including the detention ponds, function as designed.

4.5 Minimizing Off-site Vehicular Tracking of Sediments

To minimize the off-site vehicular tracking of sediments onto public roadways, traffic routing and site operation practices will be developed. The following preventative measures will be utilized to control sediment tracking:

- Maintain the site entrance to minimize the accumulation of excessive mud, dirt, dust, and rocks.
- Schedule maintenance and construction of paved and temporary roads to limit disruption of traffic flow patterns or create vehicular safety problems.
- Control traffic routing during wet weather conditions to limit the impact of sediment tracking.

4.6 Maintenance and Inspection

The maintenance and inspection of erosion and sedimentation controls at the facility will be promulgated through continued compliance with the Clean Water Act in conjunction with the facility's federal and state stormwater permits.

In compliance with the Texas Pollution Discharge Elimination System (TPDES) requirements for industrial activities with stormwater discharges, a Notice of Intent (NOI) was filed with the TCEQ. The facility's TPDES multi-sector general permit number is TXR05AK37.

Upon approval of the proposed Permit Amendment Application, the facility will update the existing Storm Water Pollution Prevention Plan (SWPPP) to address the new design of the facility surface water management system. The SWPPP will describe the site drainage system, discharges from the site's outfalls, and procedures and controls used to minimize the discharge of pollutants from the site. A copy of the SWPPP is maintained at the facility. Annual audits, employee training, periodic inspections and implementation of the BMPs outlined in the SWPPP will be conducted as needed/required by the permit.

5.0 INSPECTION, MAINTENANCE, AND RESTORATION PLAN

In addition to the design and operational considerations previously described in the Erosion and Sedimentation Control Plan, it is necessary to inspect and maintain the stormwater management system and erosion control measures to maintain the required effectiveness of the system components. The inspection, maintenance, and repair guidelines as discussed in the following sections will be implemented into the employee training program, as outlined in Part IV, the Site Operating Plan (SOP). Documentation of the inspections and repairs, as outlined below, will be denoted in the Cover Application Log and will be maintained as part of the site operating record, in accordance with Part IV, the SOP.

5.1 Stormwater Management System

The site will be monitored to ensure the integrity and adequate operation of the stormwater collection, drainage, and storage facilities. On a weekly basis, all temporary and permanent drainage facilities will be inspected. Following a significant rainfall event (greater than 0.5 inches within 24 hours), all temporary and permanent drainage facilities will be inspected within 48 hours after the rain event, as ground conditions allow. In the event of a washout or failure, the drainage system will be restored and repaired pursuant to 30 TAC §330.305(e)(1). Plans and actions will be developed to address and remediate the problem to ensure protection to ground and surface waters. Erosion of intermediate and final cover will be repaired pursuant to 30 TAC §330.165(g). Sediment and debris will be removed from channels, ponds, and from around outfall structures, as needed, to maintain the effectiveness of the stormwater management system. The outfall structures will be inspected to ensure their proper operation. Minor maintenance requirements, such as removing excessive sediment and vegetation, will be undertaken as required.

5.2 Landfill Cover Materials

Landfill cover soils are inspected on a regular basis. Daily cover soils are inspected and applied in accordance with the SOP requirements. In addition, during the active life of the site, inspection and documentation of intermediate and final cover will be performed on a weekly basis, as specified by the facility's TCEQ Multi-Sector General Stormwater Permit. During the active life of the site, inspections of intermediate and final cover also will be performed within 48 hours after a significant rain event (greater than 0.5 inches within 24 hours) in which run-off occurs, as ground conditions allow. During the post-closure maintenance period of the site, the final cover will be inspected quarterly. The inspections will include any temporary or permanent erosion measures that are in place at the time of the inspection. Reports of these inspections will be documented in the Cover Application Log and will be maintained as part of the SOR, in accordance with Part IV, the SOP.

In accordance with 30 TAC §330.165(g), erosion gullies or washed-out areas deep enough to jeopardize the intermediate or final cover must be repaired within 5 days of detection. An eroded area is considered to be deep enough to jeopardize the intermediate or final cover if it exceeds 4 inches in depth, as measured from the vertical plane from the erosion feature and the 90-degree intersection of this plane with the horizontal slope face or surface. Damage to any temporary or permanent erosion measures noted during the inspections will be repaired or replaced within 14 days of detection. The repair schedule, as outlined for the cover or the erosion measures, may be extended due to inclement weather conditions or the severity of the condition requiring an extended repair schedule. The TCEQ's regional office in Waco will be notified to coordinate a revised schedule in case an extended repair schedule is required.

6.0 FLOODPLAIN EVALUATION

Consistent with 30 TAC §330.61(m)(1), §330.63(c)(2), and §330.547, an evaluation of the 100-year floodplain has been prepared. The existing Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM) that includes the site area (Bell County, Texas, Map No. 48027C0375E, Effective Date: September 26, 2008) was reviewed. The FIRM indicates that, with the exception of the area adjacent to the southern permit boundary and an area along the east portion of the northern permit boundary, the site is outside of the 100-year floodplain. The southern floodplain is associated with Little Elm Creek Tributary No. 1 and the floodplain north of the site is associated with Williamson Creek, which is also a tributary to Little Elm Creek.

Further evaluation of the FIRM indicates that the floodway and floodplain along the south boundary of the site depicted by FEMA are not aligned with the physical location of the Little Elm Tributary No. 1 (See Figure 1 in Appendix III-2F of Attachment 2). Based on this determination and as allowed by 30 TAC§330.63(c)(2)(B), Golder has performed a Flood Study of Little Elm Tributary No. 1. Details of this Flood Study are provided in Appendix III-2F of Attachment 2.

Figure II-17 presents the 100-year floodplains for the site. Based on the FIRM mapping for the north side of the site (Williams Creek Floodplain 100-year flood plain) and the Flood Study for the south side of the site (Little Elm Tributary No. 1), no portion of the existing waste disposal footprint or the proposed expanded waste footprint is located within the 100-year floodplain. Further, in accordance with 30 TAC §330.547:

- No solid waste disposal operations will be conducted in areas that are located in a 100-year floodway;
- The facility will not restrict the flow of the 100-year flood, reduce the temporary water storage capacity of the floodplain, or result in washout of solid waste so as to pose a hazard to human health and the environment; and
- All waste storage and processing facilities will be located outside of the 100-year floodplain.

APPENDIX III-2B-1

ACTIVE FACE RUNOFF CONTROL BERM SIZING

ACTIVE FACE RUNOFF CONTROL BERM SIZING

Made By: VJE
Checked by: MX
Reviewed by: CGD

1.0 OBJECTIVE

Calculate the required size of the stormwater containment berm at the landfill active face as a function of plane area of the active area.

2.0 GIVEN

- Waste slope of 4H:IV
- 25 years, 24 hour storm event of 7.9 inches;
- Berm slope of 2H:1V;
- 1.0 ft. freeboard on berm

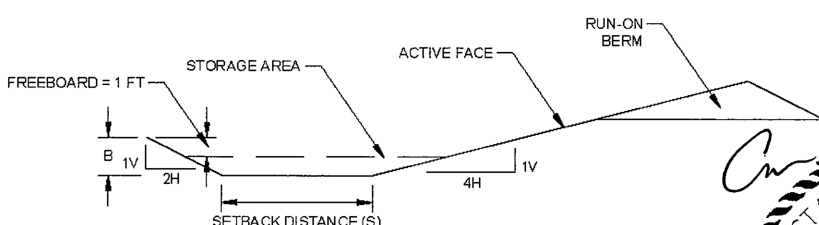
3.0 ASSUMPTIONS

- Stormwater run-on to the active face will not be allowed
- 50 percent run-off from the active face, i.e., 50% infiltration

4.0 CALCULATION

Derive relationships for the amount of runoff from the 7.9 inch design storm and the available storage volume as a function of the active face area.

Cross-section of the Active Face and Containment Berm



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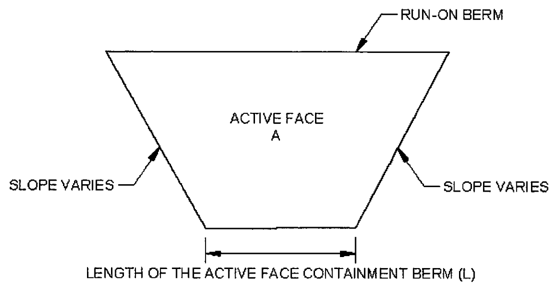
Elevation View of the Active Face and Containment Berm



4.1 Runoff, R

$$R = .5\left(7.9 \div 12 \, {}^{in}/_{ft}\right) \times A = \frac{0.66}{2} \times A = .33 \times A$$

Where:

R = total runoff into the active area containment berm (cf)

A = total area of the active face (sf)

4.2 Storage, V

$$V = L \times \left(\frac{S + (S + (B-1) \times 2 \times (B-1) \times 4)}{2}\right) \times (B-1)$$

$$V = (3B^2 + (S-6) \times B - S + 3) \times L$$

Where:

V = storage capacity an active face containment berm (cf)

L = length of the active face containment berm (ft)

4.3 Height of Berm, B

Now set runoff, R, equal to storage, V, and solve for the height of berm, B.

$$B = \frac{6 - S + \sqrt{S^2 + 7.92\frac{A}{L}}}{6}$$

For typical site operations, the maximum berm height will be 6 ft. The operator can vary the berm length and setback distance to limit the berm height to 6 ft.

Now plot B versus L for various values of S and A. Figures 1 through 8 present the plots for active working areas of 10,000, 20,000, 30,000, 40,000 sf, etc., respectively.

4.4 Procedure To Select Berm Size

Procedure to select berm size using Figures 1 through 8:

1) Determine the active face area (A);

2) Select a figure from Figures 1-8 that has an active area closest to, but no less than the actual A. For example, if A=25,000, choose Figure 3 (A=30,000);

3) Determine the minimum setback distance (S) for the daily operation, and select the corresponding curve. If the setback distance falls between the numbers shown on the figure, the closest but smaller value of S will be used. For example, if S=25 ft, choose the curve representing 20 ft; and

4) Measure the length of the active face containment berm, and determine the required berm height from the selected curve. Figures 1 through 8 cover a wide range of berm length (i.e. toe width of the active face) for normal waste fill operations. If the actual berm length is longer than the maximum value on the curve, the maximum berm length on the can be used to determine a conservative berm height. If the actual berm length is shorter than the minimum value on the curve, the operator can use equation (1) above to determine berm height.

Example using attached figures: A = 10,000 sf, s = 20 ft, L = 200 ft => B = 1.8 ft (from Figure 1, curve S = 20 ft).

5.0 CONCLUSION

Figures 1 through 8 and the procedure discussed above provide guidance for determining the size of the stormwater containment berm based on the height of the active face (runoff area), the length of the containment berm, and the setback distance from the active face. The equations presented in this calculation may be used to determine the required berm height for various active face areas, berm lengths, and setback distances.

Figure 1. Berm Height vs. Berm Length for Various Setbacks

A = 10,000 sf

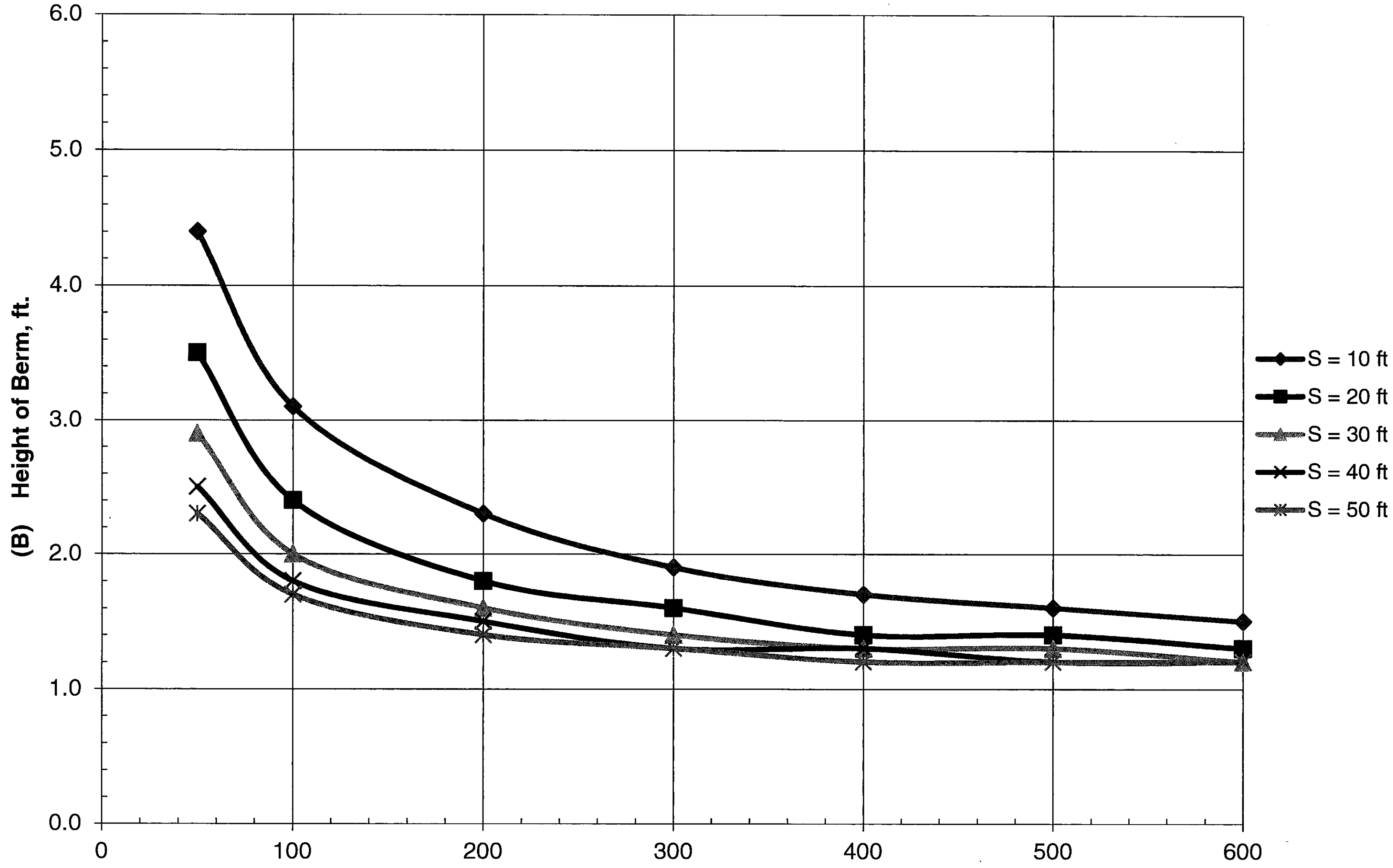


Figure 2. Berm Height vs. Berm Length for Various Setbacks

A = 20,000 sf

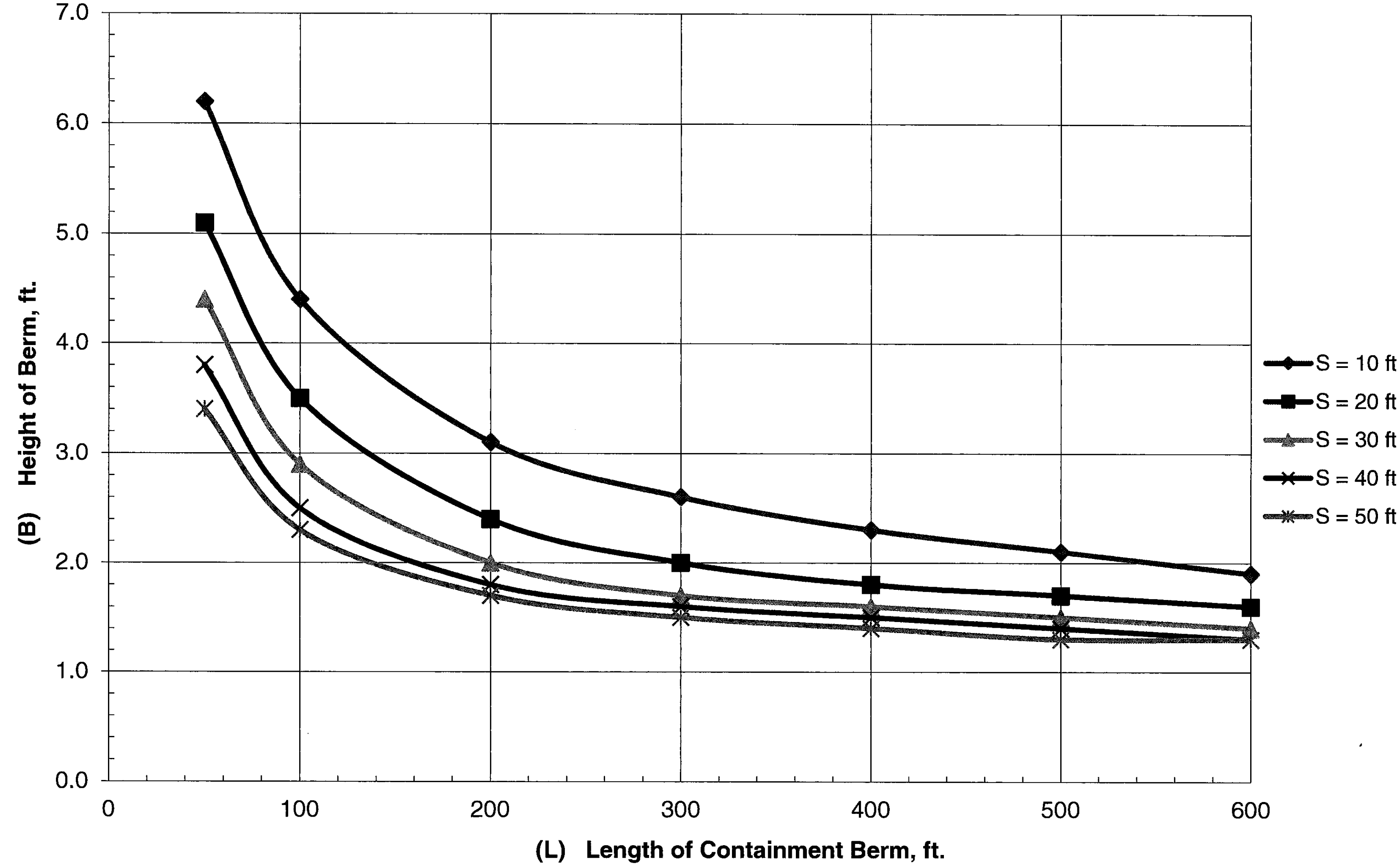


Figure 3. Berm Height vs. Berm Length for Various Setbacks

A = 30,000 sf

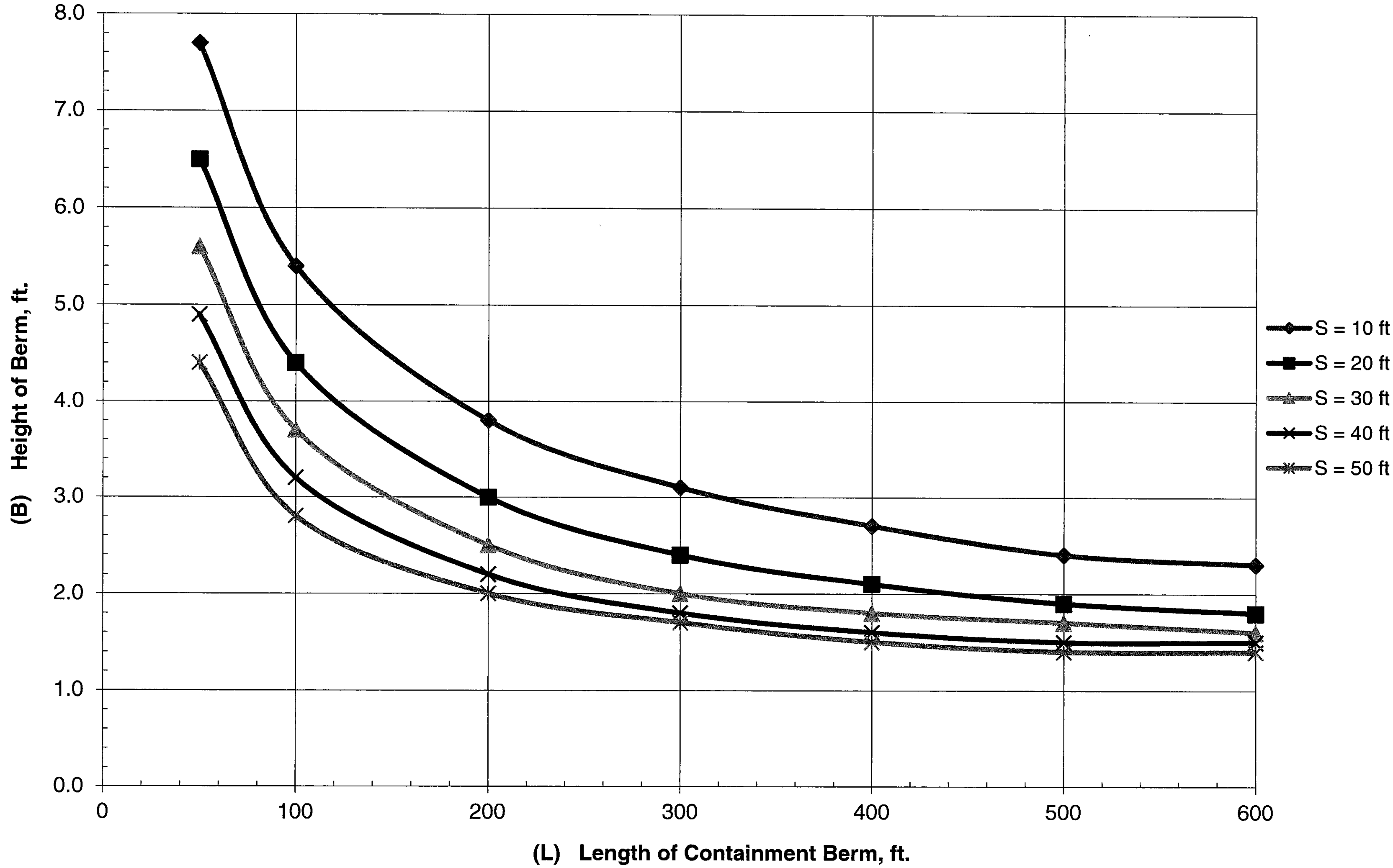


Figure 4. Berm Height vs. Berm Length for Various Setbacks

A = 40,000 sf

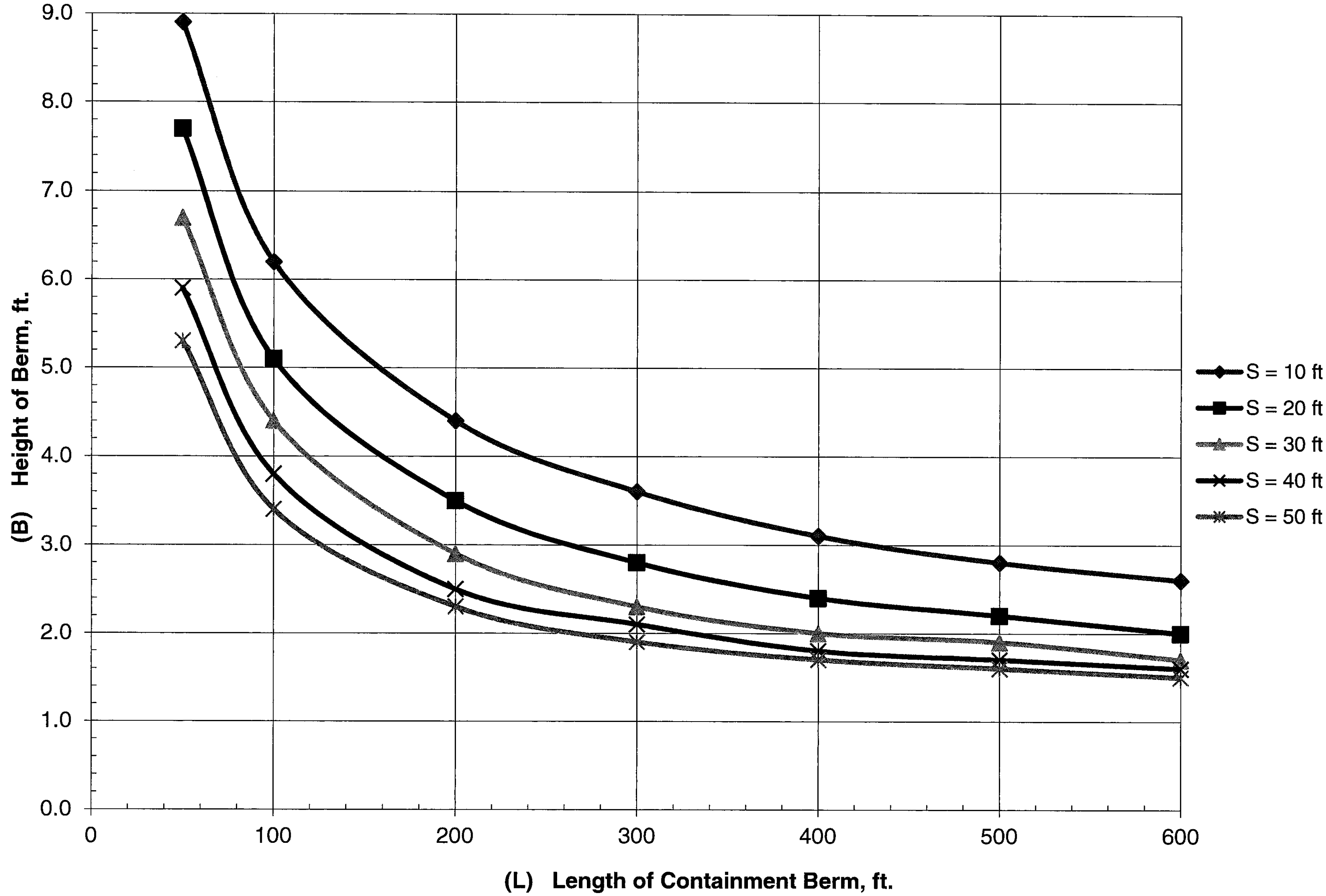


Figure 5. Berm Height vs. Berm Length for Various Setbacks

A = 50,000 sf

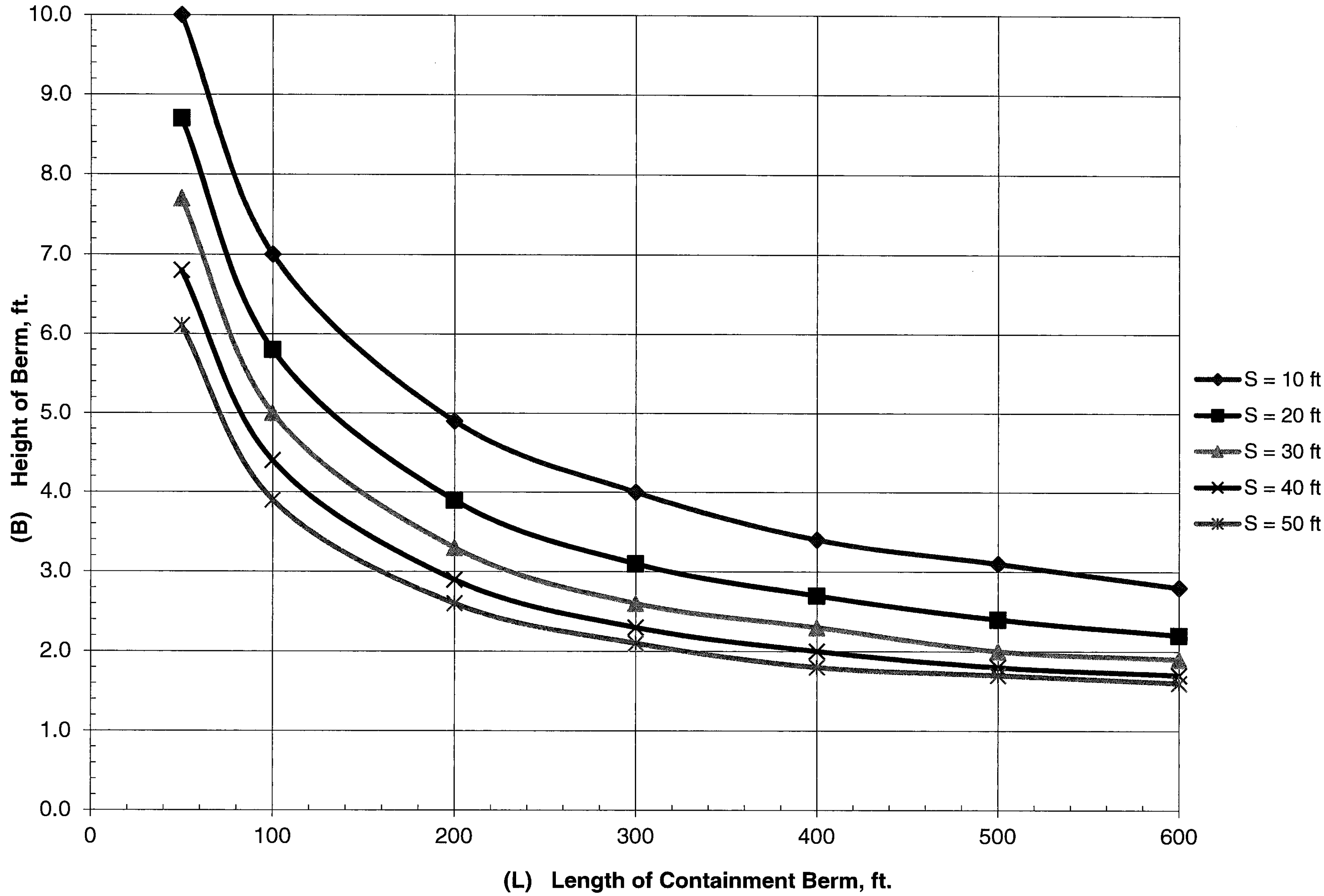


Figure 6. Berm Height vs. Berm Length for Various Setbacks

A = 60,000 sf

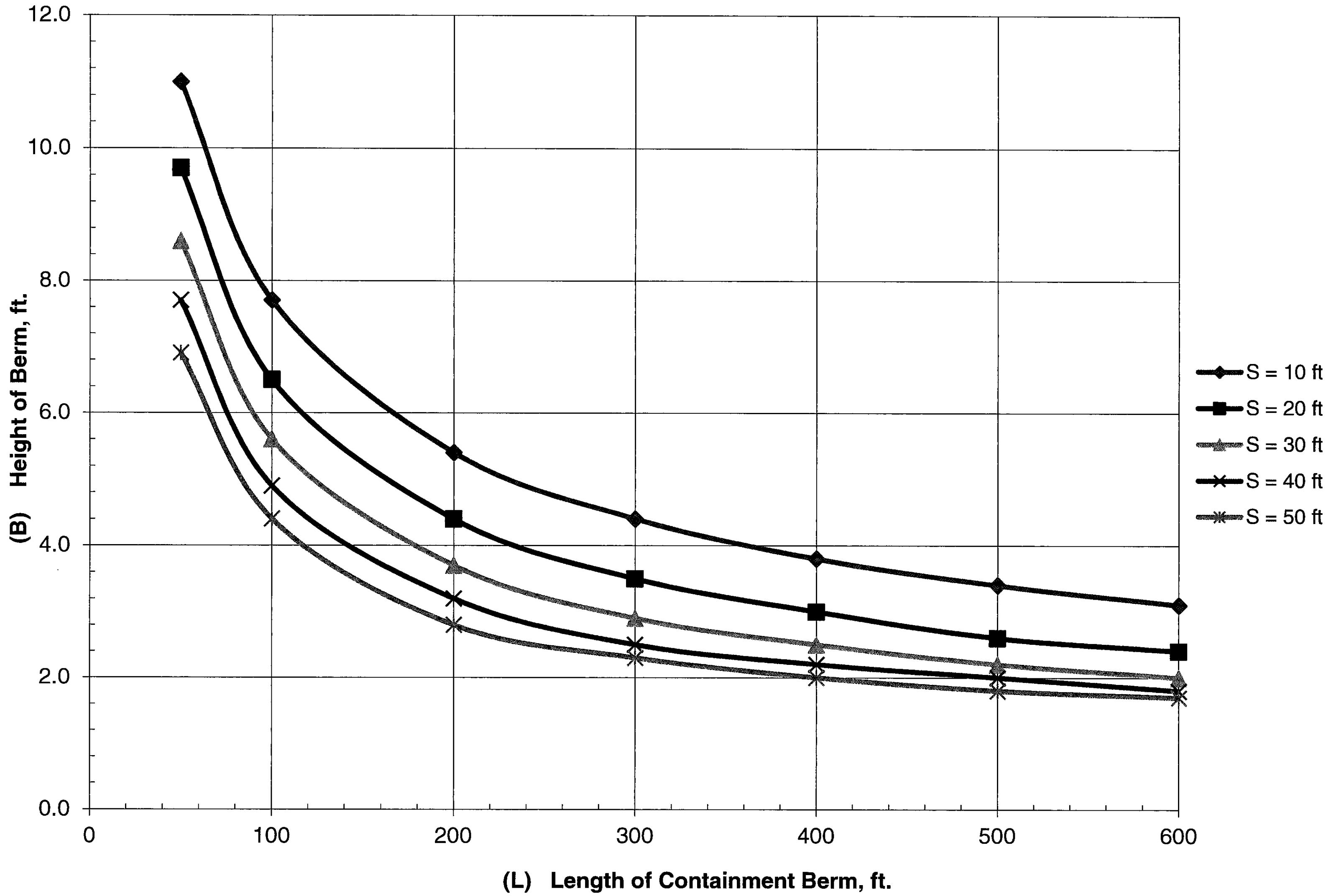


Figure 7. Berm Height vs. Berm Length for Various Setbacks

A = 70,000 sf

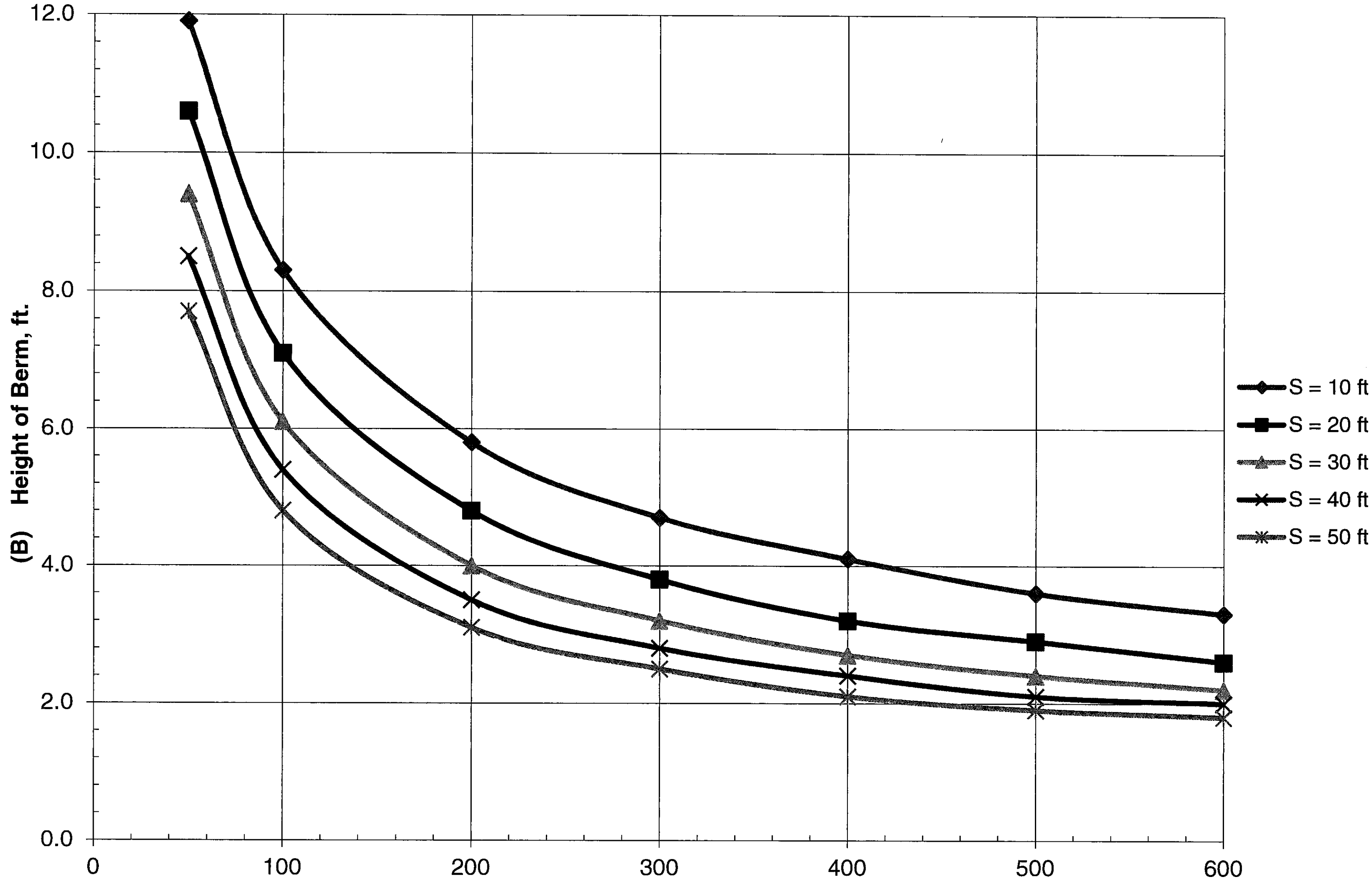
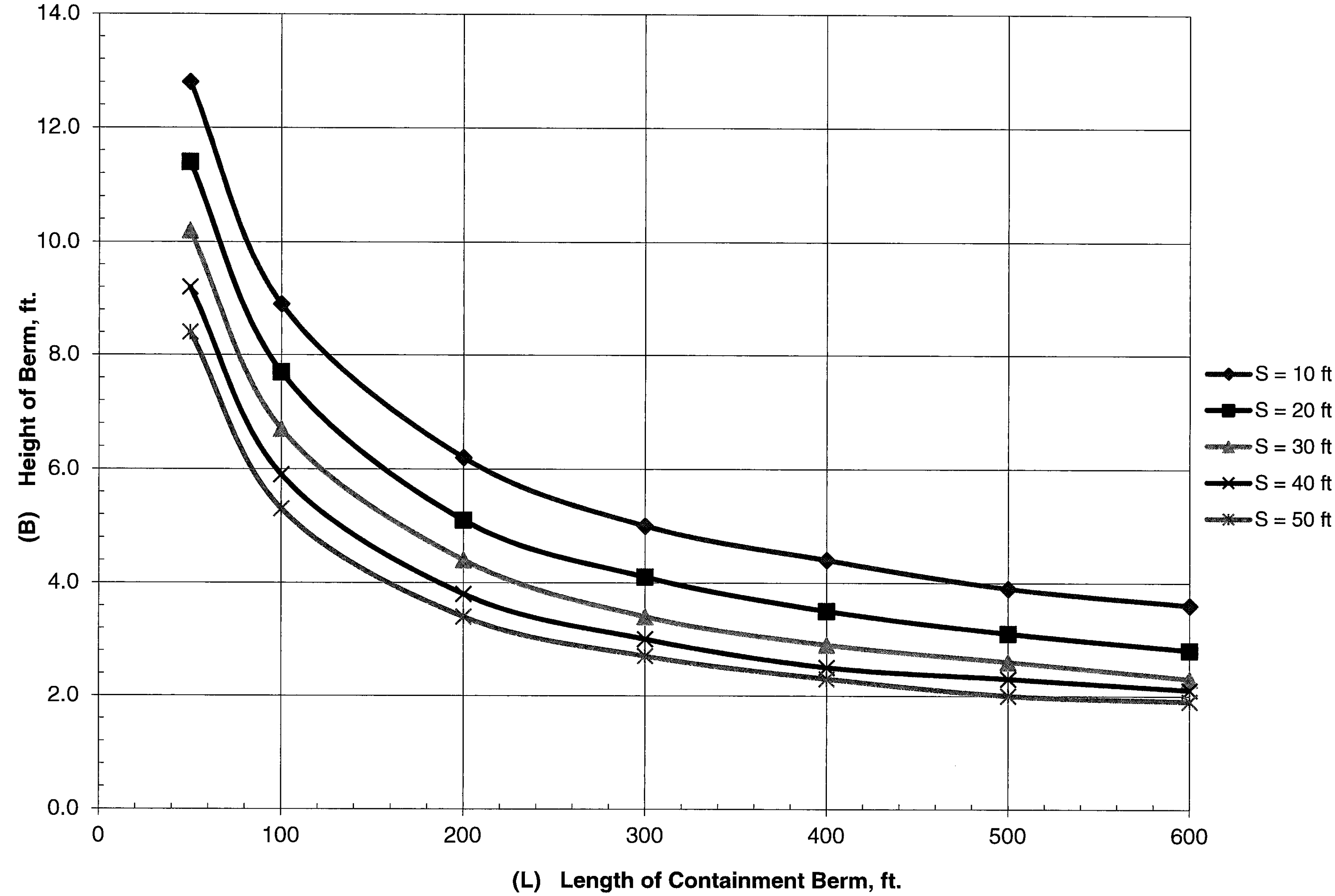


Figure 8. Berm Height vs. Berm Length for Various Setbacks
A = 80,000 sf



APPENDIX III-2B-2

ACTIVE FACE RUN-ON CONTROL BERM SIZING

ACTIVE FACE RUN-ON CONTROL BERM SIZING

Made By:	HPR
Checked by:	MX
Reviewed by:	CGD

1.0 OBJECTIVE

Develop run-on control berm design for the active waste working face.

2.0 DESIGN CRITERIA

1) The proposed soil berm is at 2-foot high as measured from the invert of the channel to the top of berm, with the invert sloped at 2% in the direction of flow. The side slope of the soil berm are 4H:1V and 2H:1V.

2) The allowable flow velocity in the proposed diversion channel is 5 ft/sec.

3) Manning's equation is used to calculate the channel flow capacity.

4) Rational method is used to back-calculate the allowable drainage area based on the channel flow capacity.

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3.0 METHOD

I) Mannings's equation

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2}$$

Where:

Q = flow rate
A = cross-sectional area of the flow
R = hydraulic radius
S = slope
n = Manning's n for grass-lined channels = 0.035

II) Rational Method

Q=CIA

Where:

Q = Runoff flow rate;
C = Runoff coefficient = 0.7 for slopes greater than 5% (Reference 1);
i = Rainfall intensity coefficient (Reference 1, TxDot data as shown in Table 2);
A = Drainage area.

4.0 CALCULATIONS

Using Manning's equation the channel capacity is calculated as 27.4 cfs as shown in Table 1.

Using 27.4 cfs as a limiting factor, the maximum subbasin drainage area for the proposed run-on control berm is calculated as 4.1 acres as shown in Table 2. Depending on the actual size of the upstream watershed, the run-on control berm size can be adjusted.

Table 1: Channel Flow Capacity

Q (cfs)	Slope (ft/ft)	Left Side Slope (H:1V)	Right Side Slope (H:1V)	Channel Depth (ft)	Bottom Width (ft)	Mannings n	Max Velocity (fps)	Max Normal Flow Depth (ft)	Shear Stress (lb/ft^2)	Available Freeboard (ft)
27.4	0.02	2	4	2	0	0.035	**5**	**1.4**	1.8	0.6

Table 2: Runoff Calculation

County	Coefficient	2-year	5-year	10-year	25-year	50-year	100-year
Bell	e (in)	0.798	0.78	0.773	0.771	0.754	0.751
	b	56	69	77	90	93	102
	d (mins)	8	8.5	8.5	8.5	8.5	8
	Intensity (in/hr)*	5.6	7.1	8.1	9.5	10.3	11.6

Baylor
Bee
Bell
Bexar
Blanco
Borden
Bosque
Bowie
Brazoria

Coefficient	2-year	5-year	10-year	25-year	50-year	100-year
e (mm)	0.798	0.78	0.773	0.771	0.754	0.751
b	1422	1753	1956	2286	2362	2591
d (mins)	8	8.5	8.5	8.5	8.5	8

* for Time of Concentrati	10	Minutes at a Minimum
C =	0.7	For Slopes Greater than 5%
A =	4.1	Acres
Q =	27.4	cfs = channel flow capacity from Table 1

5.0 CONCLUSION

A typical run-on control berm of 2 ft high is proposed, which can collect and convey potential storm water run-on to the active face from an upstream watershed of 4.1 acres, at maximum. Depending on the actual size of the upstream watershed, the run-on control berm size can be adjusted.

6.0 REFERENCE

1) Texas Department of Transportation "Hydraulic Design Manual" Revised March 2004.

APPENDIX III-2C-1

INTERMEDIATE COVER SOIL EROSION LOSS ANALYSIS

INTERMEDIATE COVER SOIL EROSION LOSS ANALYSIS

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Checked by: MX
Reviewed by: CGD

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1.0 OBJECTIVE

1) Design the interim erosion and sediment controls for the proposed at the Temple Recycling and Disposal Facility in accordance with 30 TAC §330.305(d).

2) Estimate erosion losses for worst-case intermediate cover slopes for both the top dome surface and external embankment side slopes.

3) Estimate flow velocity and compare to permissible non-erodible velocity.

2.0 DESIGN CRITERIA

In accordance with 30 TAC §330.305(d), the soil erosion and sediment controls are designed according to the following criteria:

-The estimated peak velocity should be less than the permissible erodible velocities under similar conditions.

-The potential soil erosion loss should not exceed the permissible soil loss for comparable soil-slope lengths and soil-cover conditions. The soil erosion loss of 50 ton/acre/year is selected as the permissible soil erosion loss for interim erosion and sediment controls (based on TCEQ guidance - Reference 1).

The permissible non-erodible flow velocity on a grass-covered slope is typically 5.0 ft/sec (Reference 2). The permissible non-erodible flow velocity for bare clay loam soil is 3.75 ft/sec (Reference 3).

Based on TCEQ draft guidance on erosional stability (Reference 1), for the interim condition, the permissible soil loss is not to exceed 50 tons/acre/year and the recommended vegetative cover is 60%. In accordance with the TCEQ draft guidance, the Natural Resources Conservation Services, formerly Soil Conservation Service, of the United States Department of Agriculture's Revised Universal Soil Loss Equation remains to be the most suitable method for calculating soil loss from a landfill.

60% of ground cover is assumed to be achievable during the operational phase of the site (based on TCEQ guidance - Reference 1).

3.0 METHODS

3.1 Flow Velocity

The storm water flow velocity on the slope is calculated following the method provided in the USDA TR-55 (Reference 4). For the slopes less than 300 feet long, sheet flow along the slope is expected. The sheet flow velocities for the 4% and 25% slopes are 0.91 ft-sec and 1.82 ft/sec, respectively (Table 1). Results showed that the sheet flow velocities for all proposed slope gradients are below the permissible non-erodible velocities of 5 ft/sec.

For slopes longer than 300 feet, the flow on the slopes becomes shallow concentrated flow. The flow velocity for shallow concentrated flow is presented in Figure 1.

The proposed top surface is at 4% slope with a maximum slope length of 500 feet, which results in a flow velocity of 3.2 ft/sec (Figure 1). These results indicate that both velocities (sheet flow and shallow concentrated flow) are below the permissible non-erodible velocity of 5 ft/sec, therefore the flow velocity criterion is satisfied on the top surfaces without any slope interrupters.

On the 4H:1V external embankment side slopes, water diversion structures are required and the spacing of the diversion structures is a maximum of 240 feet along the slope. The design will ensure flow velocities less than permissible non-erodible flow velocity.

Table 1: Sheet Flow Velocity Calculation

Flow Type	Roughness Coefficient n^{ote}:	Surface Description	Surface Condition
Sheet/Overland Flow	0.011	Smooth surface (concrete, asphalt, gravel, bare soil)	A
	0.05	Fallow (no residue)	B
	0.06	**Cultivated soils: Residue cover ≤ 20%**	**C**
	0.17	Cultivated soils: Residue cover > 20%	D
	0.15	Grass: Short grass prairie	E
	0.24	Grass: Dense grasses	F
	0.41	Grass Bermuda grass	G
	0.13	Range (natural)	H
	0.4	Woods: Light underbrush	I
	0.8	Woods: Heavy underbrush	J

Notes: The roughness coefficient for sheet flow were from Table 3-1, TR-55 (Reference 4).

Slopes	Sheet/Overland Flow			
	Surface Condition	Length (ft)	Slope (ft/ft)	Estimated Flow Velocity (ft/sec)
Top Surface – 4%	C	300	0.04	0.91
External Embankment Side Slope – 25% slope	C	240	0.25	1.82

3.1.1 Example Sheet/Overland Flow Velocity Calculation

For sheet flow calculated for a distance of up to 300 feet, use:

$$T_t = \frac{0.007(nL)^{0.8}}{P_{25}^{0.5} S^{0.4}}$$

$$T_t = \frac{L}{3600V}$$

Where:

T_t = travel time (hr);

n = Manning's roughness coefficient (Table 1);

L = flow length (ft);

P_{25} = 25-year, 24-hour rainfall (in) see Table 2.5 (Reference 5);

s = slope of hydraulic grade line (land slope, ft/ft); and

V = average velocity (ft/s)

Using the 25% slope as an example, the average velocity would be calculated as follows:

$$T_t = \frac{0.007(0.06*240)^{0.8}}{(7.9)^{0.5}(0.25)^{0.4}}$$

T_t= 0.036627 hours

Therefore:

$$V = \frac{L}{3600(T_t)}$$

V= 1.82 ft/sec

3.1.2 Soil Erosion Loss

The soil erosion loss was calculated using the Revised Universal Soil Loss Equation (RUSLE), (USDA, 1997, Reference 6).

$$A=R*LS*K*C*P$$

Where:

A = Soil erosion loss, tons/acre/year;

R = Rainfall erosion index = 300 (Reference 5);

K = Soil erodibility factor = 0.21 (4% organic matter for clay loam material form "Table 1, Approximate Values of Factor K for USDA Textural Classes", Reference 7);

LS = Slope length and steepness factor (calculated from Eqs. 8.39-41 and 43 (p. 261) (Haan, 1994) Reference 8);

C = Cover-management factor = 0.042 Table 2 from Reference 7 assuming no appreciable canopy and 60% ground cover;

P = Support Practice Factor = 1.0 (conservation assumption).

4.0 CALCULATIONS/RESULTS

expected soil loss were computed for the top surface slope of 4% and for the external embankment slope of 25%. In accordance with TCEQ guidance (Reference 1), 60% ground cover was assumed for the operational phase of site development, resulting in a cover management factor, C, of 0.042. The longest attainable or allowable slopes were analyzed: 500 feet at 4%; and 240 feet at 25% (the max length between slope interrupters).

Table 2 presents the results of the soil loss calculations. The compound soil loss is significantly less than the permissible soil erosion loss of 50 ton per acre per year recommended by the TCEQ for interim erosion and sediment controls.

Table 2: Soil Erosion Loss Calculation Results – c = 60%

R	K	Slope	Length (l)	Rill susceptibility	LS	C	P	A_i
		(ft/ft)	(ft)	low, mod, high				ton/ac/yr
Top Surface								
300	0.21	0.04	500	mod	0.626	0.042	1	1.7
Example Calculation for External Embankment Side Slope								
300	0.21	0.25	240	mod	7.481	0.042	1	19.8

5.0 CONCLUSION

The proposed 4% top surface can achieve erosional stability during interim conditions of 60% ground cover. Soil loss for the 4% top surface was calculated to be 1.7 tons/acre/year, well below the permissible soil erosion loss of 50 tons/acre/year recommended by the TCEQ for interim erosion and sediment controls.

The external embankment side slopes can achieve erosional stability with a combination of ground cover and storm water diversion structures. To maintain sheet flow runoff (and therefore keep surface water flow velocities below 5 feet per second) and following the typical operation practices, the maximum length of the 25% side slopes is limited to 240 feet. At 60% ground cover, this results in an estimated soil loss of 19.8 tons/acre/year, well below the permissible soil erosion loss of 50 tons/acre/year recommended by the TCEQ for interim erosion and sediment controls.

6.0 REFERENCES

1) Texas Commission of Environmental Quality, "Guidance for Addressing Erosional Stability During All Phases of Landfill Operations (30 TAC §330.305(c), (d), and (e))." February 2007, Draft.

2) TCEQ Regulatory Guidance, "Guidelines for Preparing a Surface Water Drainage Report for a Municipal Solid Waste Facility.", August 2006

3) McCuen Richard. 1998. *Hydrologic Analysis and Design*. New Jersey:Prentice Hall

4) U.S. Department of Agriculture (USDA). 1986. Urban Hydrology for Small Watersheds. TR-55

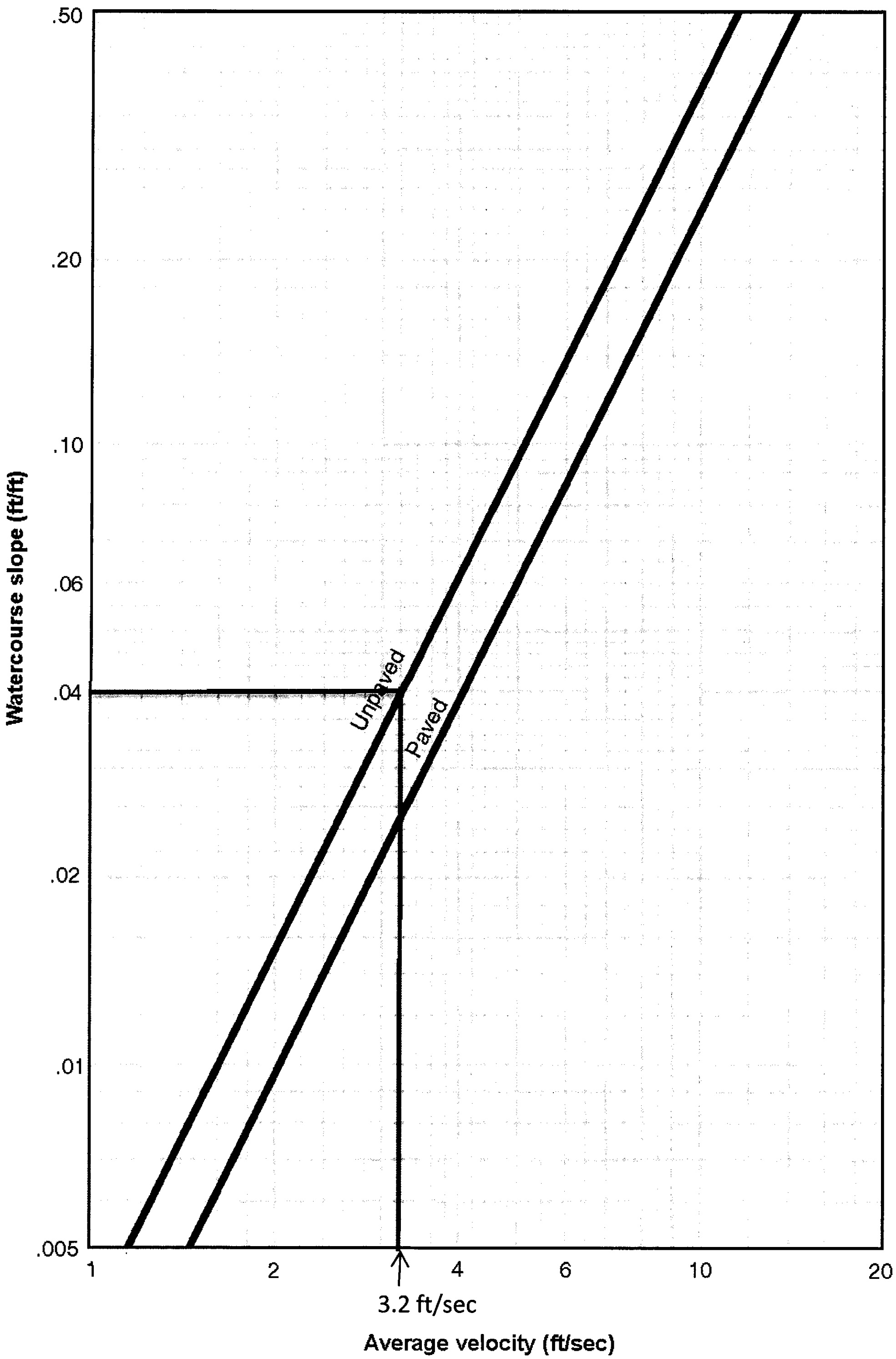
5) City of Temple, "Drainage Criteria and Design Manual."

6) U.S. Department of Agriculture (USDA). 1997. Predicting soil erosion by water: A guide to conservation planning with the revised universal soil loss equation (RUSLE). (Agricultural Handbook Number 703) US Government Printing Office, Washington, DC.

7) Texas Natural Resource Conservation Commission - Use of the Universal Soil Loss Equation in Final Cover/Configuration Design - Procedural Handbook - Permits Section, Municipal Solid Waste Division - October 1993

8) Haan C.T., B. J. Barfield, and J.C. Hayes. 1994. Design hydrology and sedimentology for small catchments. San Diego CA: Academic Press Inc.

Figure 1: Flow Velocity of Shallow Concentrated Flow from TR-55



APPENDIX III-2E

FINAL COVER EROSION SOIL LOSS CALCULATION

FINAL COVER EROSION SOIL LOSS CALCULATION

Made By: VJE/HPR
Checked by: MX
Reviewed by: CGD

1.0 OBJECTIVE:

Estimate add-on berm spacing required under final closure conditions for the Temple Recycling and Disposal Facility to limit the average annual erosion to 2.0-3.0 ton/acre/year.

Estimate flow velocity and compare to the permissible non-erodible velocity.

2.0 METHOD:

Add-on berm spacing 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, Reference1(Page 5), the average annual rainfall erosion index for the site is approx. **300**

Soil Erodibility Factor (K)

Assume a clay loam with an organic matter content of 4% and use Table 1, Reference 1 (Page 6), to determine the K factor.

Use K = 0.21

Cover and Management Factor [C]

Assume 90% ground cover and interpolate C from values shown on Table 2, Reference 1 (Page 7)

C = 0.006

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12/5/16
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Support Practice Factor (P)

Surface tracked with dozer -- rough surface

Use P = 1

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Length Slope Factor (LS) (Reference 2)

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

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

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

Where: Θ = slope angle

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 (Reference 3):

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

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:

Soil series is primarily Austin silty clay (USDA, Soil Conservation Service, Soil Survey of Bell County, Texas, 1977),

Facility slopes are 4H:1V on the sides, 4% 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 you would use equation 8.41 which is $S = 3.0 (\sin \theta)^{0.8} + 0.56$. If the applicable slope is greater than 15 feet then the 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, our 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 4% slope, $\theta = 2.86°$

$\sin 2.86° = 0.05 < 0.09$, Use eq. 8.39

L = slope length factor

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

where λ = horizontal projection of plot length

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

$$\beta = rill\ erosion$$

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

The equation for rill erosion applies to moderate erosion.

C represents 90% 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

RUSLE calculations were performed for the longest final cover side slope between add-on berms. The 4:1 (H:V) side slopes are more critical than the 4% top dome in terms of erosion.

The existing final cover areas at 3H:1V slopes are also analyzed for soil erosion.

Summaries of the RUSLE calculation is presented in Table 1.

5.0 FLOW VELOCITY

The storm water flow velocity on the slope is calculated following the methods provided in the USDA TR-55, the same as those as discussed in Appendix III-2C-1. The final cover slope consists of the following:

1) 4% top dome surface at maximum length of 500 ft. The flow on this slope is shallow concentrated flow. The flow velocity is 3.2 ft/sec (same as Section 3.1 of Appendix III-2C-1).

2) 4H:1V sideslope with a maximum length of 160 ft between add-on berms. The flow on this slope is sheet flow. Flow velocity on the 4H: 1V slope is 1.82 ft/sec (same as Section 3.1 of Appendix III-2C-1).

3) 3H:1V sideslope on the existing final cover areas with a maximum length of 50 feet. The flow on this slope is sheet flow. The flow velocity on the 3H:1V slope is 1.96 ft/sec (using the equation in Section 3.1.1 between add-on berms of Appendix III-2C-1).

6.0 CONCLUSION/RESULTS

RUSLE calculation for a simple 4H:1V slope is found in Table 1. Recommended horizontal add-on berm spacing for closure is 160 feet (or 40 vertical feet).

RUSLE calculation for a simple 3H: 1V slope is found in Table 2. Soil erosion on the existing final cover areas at 3H:1V slopes is 1.5 tons/acre/yr, meeting the soil erosion requirements.

Results showed that the flow velocities for all final cover slope gradients are below the permissible non-erodible velocity of 5 ft/sec.

7.0 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

4) City of Temple, "Drainage Criteria and Design Manual."

TABLE 1. TEMPLE RECYCLING AND DISPOSAL FACILITY - ESTIMATED AVERAGE ANNUAL EROSION MAXIMUM ALLOWABLE LENGTH WITH 4:1 SLOPE

R	K	Slope (ft/ft)	Length (l) (ft)	rill susceptability low, mod, high	LS	C	P	A_i ton/ac/yr	Vertical Bench/ Terrace Spacing (ft)
Final Cover - (90% cover)									
300	0.21	0.25	160	mod	5.925	0.006	1.0	2.4	
								2.4	40

NOTES: **R** was taken from Figure 1, Average Annual Values of the Rainfall Index

M was calculated from Eq. 8.37 (p. 256) - *Design Hydrology and Sedimentology for Small Catchments*

K was based on soil survey descriptions of Austin silty clay soils and 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 90% 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

TABLE 2. TEMPLE RECYCLING AND DISPOSAL FACILITY - ESTIMATED AVERAGE ANNUAL EROSION MAXIMUM ALLOWABLE LENGTH WITH 3:1 SLOPE

R	K	Slope (ft/ft)	Length (l) (ft)	rill susceptability low, mod, high	LS	C	P	A_i ton/ac/yr	Vertical Bench/ Terrace Spacing
Final Cover - (90% cover)									(ft)
300	0.21	0.33	50	mod	3.715	0.006	1.0	1.5	
								1.5	17

NOTES: **R** was taken from Figure 1, Average Annual Values of the Rainfall Index

M was calculated from Eq. 8.37 (p. 256) - *Design Hydrology and Sedimentology for Small Catchments*

K was based on soil survey descriptions of Austin silty clay soils and 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*

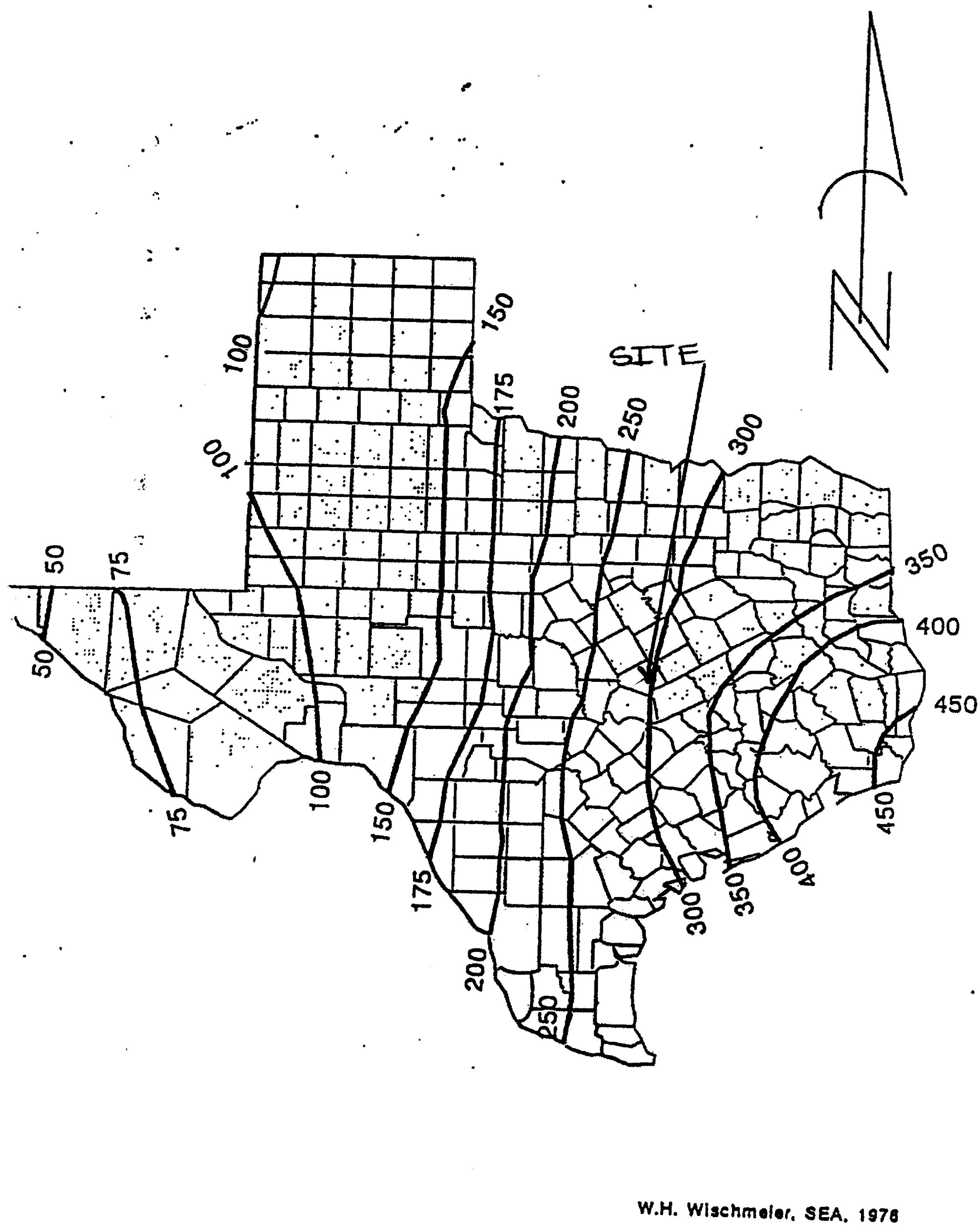
C represents 90% ground cover without appreciable canopy - *USDA-SCS TR 51*

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



URE 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

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

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

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

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

$$\theta = \tan^{-1} 0.15 = 8.53°.$$

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

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