
Chapter 8

Terraces



Issued December 2011

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or a part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint of discrimination, write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, SW., Washington, DC 20250-9410, or call (800) 795-3272 (voice) or (202) 720-6382 (TDD). USDA is an equal opportunity provider and employer.

Acknowledgments

This chapter was prepared by the U.S. Department of Agriculture, NRCS, under the direction of **Noller Herbert**, director, Conservation Engineering Division (CED), Washington, DC. It was written by **Thomas A. Keep**, P.E., agricultural engineer, NRCS (retired) with assistance from **Philip R. McLoud**, P.E., agricultural engineer, East National Technology Support Center (ENTSC), Greensboro, North Carolina. It was finalized under the guidance of **Wayne Bogovich**, national agricultural engineer, CED, Washington, DC.

Reviewers within the NRCS include **Bill Prince**, Alabama; **David Wolff**, Colorado; **Karl Visser**, Fort Worth, Texas; **Jesse Wilson**, Florida; **Jason Strenth**, Florida; **Sandy Means**, Florida; **Jeff Wheaton**, Pacific Islands West; **R.D. Fisher**, Pacific Islands East; **Ruth Book**, Illinois; **Paul Larson**, Kansas; **Sonia M. Jacobsen**, Minnesota; **Ron Miller**, Missouri; **Dick Purcell**, Missouri; **Claudia Hoefl**, Washington, DC; **Mike Monnin**, Ohio; **Chris Stoner**, Oklahoma; **Eric Ashley**, Pennsylvania; **Eric Fleming**, South Carolina; **Stephen Rogers**, Utah; **Roberta Lewis**, Washington; **Scott Mueller**, Wisconsin; **Chuck Schmidt**, Wyoming; **Allen Gehring**, Iowa; **Mark Jensen** (retired), Iowa; and **Rob Sampson**, Idaho.

Chapter 8

Terraces

Contents	650.0800	Introduction	8-1
		(a) Purpose and scope	8-1
		(b) Background.....	8-1
	650.0801	Practice definitions	8-3
		(a) Terrace systems.....	8-3
		(b) WASCOB (water and sediment control basin) systems	8-3
		(c) UGOs (underground outlets).....	8-3
	650.0802	Planning considerations	8-4
		(a) Total resource management systems.....	8-4
		(b) Terrace and WASCOB planning considerations	8-4
	650.0803	Definition of nomenclature	8-5
		(a) Terrace cross section	8-5
		(b) Terrace channel block	8-6
		(c) WASCOB cross section.....	8-7
		(d) Terrace spacing.....	8-7
		(e) WASCOB spacing	8-9
		(f) Cross section and profile measurement and display conventions.....	8-9
	650.0804	Types of terrace cross sections	8-11
		(a) Broadbase terrace	8-11
		(b) Steep-backslope (grassed-back) terrace	8-13
		(c) Narrow-base terrace	8-15
		(d) Flat channel (level) terrace.....	8-17
	650.0805	Terrace alignment	8-18
		(a) Gradient terrace alignment	8-18
		(b) Gradient alignment layout.....	8-19
		(c) Parallel terrace alignment	8-20
		(d) Parallel alignment layout.....	8-23
		(e) Flat channel (level) terrace alignment	8-25
		(f) Flat channel (level) alignment layout.....	8-25
	650.0806	Terrace spacing	8-26
		(a) Terrace spacing based on erosion prediction tools	8-26
		(b) Terrace spacing based on the VI equation.....	8-29
		(c) Adjustment of terrace spacing based on machinery width.....	8-31
	650.0807	Terrace outlets	8-32
		(a) Surface outlets.....	8-32
		(b) UGOs.....	8-34
		(c) Soil infiltration	8-34

650.0808	UGO design	8-35
	(a) UGO design procedure	8-36
	(b) Storage pool volume calculations	8-36
	(c) Storage pool release time calculations.....	8-37
	(d) Average release rate calculation.....	8-37
	(e) Storage pool sediment volume calculation.....	8-37
	(f) Storage pool depth calculation.....	8-38
	(g) Control orifice size calculation.....	8-38
	(h) Underground conduit size calculation.....	8-39
	(i) Inlet size calculation	8-42
650.0809	Terrace channel design	8-45
	(a) Terrace channel grade	8-45
	(b) Terrace channel shape.....	8-46
650.0810	Terrace ridge design	8-46
	(a) Surface outlet terrace ridge height	8-46
	(b) UGO terrace ridge height	8-47
	(c) Flat channel (level) terrace ridge height.....	8-48
	(d) Terrace ridge construction height.....	8-48
650.0811	Terrace construction methods	8-49
	(a) Gradient terrace borrow methods	8-49
	(b) UGO terrace borrow methods	8-49
	(c) Flat channel (level) terraces borrow methods.....	8-50
	(d) Borrow versus fill density	8-50
650.0812	WASCOB design	8-51
	(a) Spacing	8-51
	(b) Storage pool volume	8-51
	(c) UGO design	8-51
	(d) Embankment design	8-51
650.0813	WASCOB construction methods	8-53
650.0814	Maintenance	8-53
	(a) Broadbase terraces	8-53
	(b) Steep-backslope terraces	8-53
	(c) Narrow-base terraces.....	8-53
	(d) UGO inlets.....	8-54
	(e) UGO conduits	8-54
650.0815	References	8-54
Appendix A Underground Outlet Design Example		8A-1
Appendix B Software		8B-1

Figures		
Figure 8-1	Early terrace construction in Alabama	8-1
Figure 8-2	Broadbase terraces controlling sheet and rill erosion	8-1
Figure 8-3	Steep-backslope terraces controlling gully erosion	8-2
Figure 8-4	Level terraces providing moisture conservation	8-2
Figure 8-5	WASCOB	8-2
Figure 8-6	UGO installation	8-2
Figure 8-7	WASCOB system covering an entire field	8-3
Figure 8-8	Terrace cross section nomenclature	8-5
Figure 8-9	Terrace channel block	8-6
Figure 8-10	WASCOB cross section nomenclature	8-7
Figure 8-11	Terrace spacing terms by cross section type	8-8
Figure 8-12	WASCOB spacing	8-9
Figure 8-13	Cross section measurement and labeling conventions	8-10
Figure 8-14	Profile stationing and labeling conventions	8-10
Figure 8-15	Broadbase terraces with grassed-waterway outlet	8-11
Figure 8-16	Broadbase terrace cross section examples	8-11
Figure 8-17	Steep-backslope (grassed-back) terraces	8-13
Figure 8-18	Steep-backslope terrace cross section examples	8-14
Figure 8-19	Narrow-base terraces	8-15
Figure 8-20	Narrow-base terrace cross section examples	8-16
Figure 8-21	Level terraces with infiltration outlet	8-17
Figure 8-22	Flat channel terrace cross section examples	8-17
Figure 8-23	Terraces with gradient alignment	8-18
Figure 8-24	Point rows caused by gradient alignment	8-19
Figure 8-25	Typical gradient alignment layout	8-20

Figure 8-26	Terraces with parallel alignment	8-21
Figure 8-27	Concentric circular curves	8-21
Figure 8-28	Use of channel blocks for parallel alignment	8-22
Figure 8-29	Congruent curves	8-22
Figure 8-30	Parallel layout using concentric curve radius points	8-23
Figure 8-31	Typical parallel alignment layout	8-24
Figure 8-32	Terraces with level alignment	8-25
Figure 8-33	RUSLE2 Profile Module input screen	8-26
Figure 8-34	RUSLE2 steep-backslope terrace profile example	8-27
Figure 8-35	RUSLE2 profile soil selection	8-28
Figure 8-36	RUSLE2 profile management selection	8-28
Figure 8-37	RUSLE2 profile predicted soil loss	8-29
Figure 8-38	Value of X in equation $VI=XS+Y$	8-30
Figure 8-39	Grassed waterway terrace outlet	8-32
Figure 8-40	UGO terrace system	8-34
Figure 8-41	UGO system storage pool	8-35
Figure 8-42	UGO system inlet	8-35
Figure 8-43	UGO system conduit	8-35
Figure 8-44	Nonpressure flow inlet nomenclature	8-42
Figure 8-45	Orifice control inlet flow conditions	8-43
Figure 8-46	Pressure flow inlet types	8-45
Figure 8-47	Typical UGO terrace profile view	8-48
Figure 8-48	WASCOB embankment height design components	8-52
Figure 8A-1	Nonpressure flow system	8A-1
Figure 8A-2	Pressure flow system	8A-2

Tables

Table 8-1	Effect of land slope on broadbase terraces	8-12
Table 8-2	Effect of land slope on steep-backslope terraces	8-14
Table 8-3	Effect of land slope on narrow-base terraces	8-16
Table 8-4	Sediment trap efficiency factor by general soil type	8-37
Table 8-5	Corrugated polyethylene tubing Manning's n value	8-40
Table 8-6	Entrance head loss coefficient by inlet type	8-41
Table 8-7	Design ridge height for gradient terrace	8-47
Table 8-8	Design ridge height for UGO terrace	8-47
Table 8-9	Minimum top width of WASC OB embankments	8-52
Table 8A-1	Pool depth versus pool volume	8A-3
Table 8A-2	Storage pool design data	8A-4
Table 8A-3	Nonpressure flow inlet design data	8A-5
Table 8A-4	Nonpressure flow conduit design data	8A-6
Table 8A-5	Pressure flow conduit design data	8A-10
Table 8A-6	Storage pool design data (redesigned)	8A-12
Table 8A-7	Pressure flow inlet design data	8A-13

Chapter 8 Terraces

650.0800 Introduction

(a) Purpose and scope

This chapter provides field personnel with a guide for the planning, design, and implementation of terrace and water and sediment control basin (WASCOB) conservation practices. The design of the underground outlet (UGO) conservation practice as used with these practices is also included in this chapter. The chapter is national in scope and may be supplemented with regional and local information.

State-specific design criteria for these practices are located in the Field Office Technical Guide (FOTG) Section IV, Conservation Practice Standards and Specifications.

(b) Background

Terraces are an ancient erosion control practice. The terrace has been used by many cultures to allow the production of grains such as wheat and rice on steep slopes. These terraces were generally small width level terraces designed to prevent erosion, capture runoff, and in some cases allow for surface irrigation. The basic concept of these systems was the reforming of steep landscapes into flat farmable benches to control water runoff and reduce erosion.

The use of terraces for erosion control in the United States became an accepted practice after the Dust Bowl years. The newly formed Soil Erosion Service provided demonstrations of the practice on severely eroded cotton lands. Based on the success of these demonstrations, the practice was adopted as a best management erosion control practice for moderate to steep landscapes (fig. 8-1). The increased use of herbicides and larger farm equipment made farming over grassed waterways difficult. To overcome these obstacles, UGOs for terraces were developed in the Midwest in the 1960s.

Terraces are used on flat to moderate uniform slopes to control sheet and rill erosion. This is accomplished by shortening the length of the runoff flow path. Terraces on moderate to steep irregular slopes provide sheet and rill erosion protection and prevent the

formation of ephemeral gullies or stop the progress of permanent gullies. The gully erosion is stopped by the terrace cutting off the water source of the gully. Terraces used for water conservation are normally located on flat to moderate smooth slopes in semiarid locations (figs. 8-2, 8-3, and 8-4).

The WASCOB was developed to fill the need for gully erosion control in fields where the sheet and rill erosion was controlled by the use of tillage and residue management. The practice probably has its ori-

Figure 8-1 Early terrace construction in Alabama



Figure 8-2 Broadbase terraces controlling sheet and rill erosion



gins in the Midwest where farmers often built what they referred to as “doodle dams” across the gullied areas. Initially, the UGO terrace practice with the terrace ridge eliminated between storage pools was used to meet this need. In the 1970s, a separate practice was developed specifically for gully erosion control.

The WASCORB practice is normally applied on flat to moderate slopes where significant concentration of runoff causes gully erosion conditions. The practice is normally used in moderate to high rainfall locations with large field sizes.

Terraces with a UGO and the WASCORB are both designed to detain runoff and discharge it through subsurface conduits to a nonerosive outlet. Consequently, the design procedures and principles used for these practices are very similar (fig. 8-5). The design of WASCORBs is provided in section 650.0812.

The subsurface outlet component of terraces and WASCORBs is defined in the National Handbook of Conservation Practices as a separate practice called Underground Outlet (fig. 8-6). The design of the UGO practice as used for a terrace or WASCORB outlet is provided in section 650.0808.

Figure 8-3 Steep-backslope terraces controlling gully erosion



Figure 8-5 WASCORB



Figure 8-4 Level terraces providing moisture conservation



Figure 8-6 UGO installation



650.0801 Practice definitions

(a) Terrace systems

A terrace system consists of multiple continuous lines of earth embankments constructed across a field slope at a line spacing that reduces sheet and rill erosion and gully erosion to tolerable soil loss limits under the most intense cropping system planned for the field. Runoff water intercepted by the embankments is conducted to a stable outlet through nonerosive stable channels or temporarily stored and released through UGOs or stored and released through soil infiltration.

(b) WASCOB systems

A WASCOB system consists of single or multiple storage basins constructed across concentrated flow paths for the purpose of gully erosion control (fig. 8–7). The embankment constructed to form these basins does not extend in a continuous line across the field slope. Runoff is temporarily stored in the basin and is released through an underground conduit to a stable outlet.

The main difference between terrace and WASCOB systems is that WASCOBs are not designed to control sheet and rill erosion. Sheet and rill erosion in fields with WASCOBs is normally controlled with tillage systems.

In some cases, mixed systems are planned in which WASCOBs are used at the upslope field boundary to control flow from watersheds discharging significant flows onto the field being terraced.

A UGO terrace system and a WASCOB system with multiple basins on multiple drainage courses look similar in the field. The basin of the WASCOB and the storage portion of the UGO terrace are designed using the same hydrology, flood routing, and outlet hydraulics.

Some State design criteria allow for the WASCOB embankment to be extended beyond the basin area. If this is carried to the extreme and multiple basins are linked in a continuous line, the WASCOB system has merged into a terrace system.

(c) UGOs

The UGO practice is a conduit or system of conduits installed beneath the surface of the ground. Surface inlets are used to introduce water into the conduits which convey it to a suitable outlet. UGOs can provide outlets for terraces, WASCOBs, diversions, waterways, surface drains, or other similar practices without causing damage by erosion or flooding.

Figure 8–7 WASCOB system covering an entire field



650.0802 Planning considerations

(a) Total resource management systems

This chapter does not address the planning process used in the development of a total resource management system. The development of resource management systems for a specific field should be based on guidance given in the NRCS National Planning Procedures Handbook (NPPH).

(b) Terrace and WASCORB planning considerations

The following planning considerations provide guidance as to where terraces and WASCORBs are an effective practice in a resource management system.

(1) Soils

Terraces and WASCORBs are most effective on moderately deep to deep soils that are subject to significant sheet and rill and gully erosion when row cropped. Terraces and WASCORBs are not practical on soils that are stoney or shallow to rock because of earthmoving limitations and the detrimental effect of the loss of farmability after disturbance of these soils.

Terraces are not practical on sandy soils. Wind erosion that is not treated by terraces is usually the predominate erosive mechanism on these soils. These soils also tend to have high infiltration rates, which reduce the need for practices intended to control overland flow.

Terraces are not practical on soils with shallow subsoil that have properties limiting to plant growth. Disturbance of these soils for terrace construction may result in reduced crop production due to exposure of infertile or toxic soils.

Terraces and WASCORBs should not be used on karst topography with sinkholes used as outlets. Doing so can cause unknown changes in groundwater hydrology and quality.

(2) Landscape

Terraces are most effective on land slopes ranging from 2 to 18 percent. Slopes greater than 18 percent may require excessive earthwork and land reforming between terraces. Slopes flatter than 2 percent usually may be treated by less expensive means.

Terraces are not practical on landscapes that are highly dissected with deep gullies due to the excessive earthwork required to reform the majority of the terrace interval. The WASCORBs are more practical in these circumstances if sheet and rill erosion can be controlled by cropping and tillage systems.

650.0803 Definition of nomenclature

The following definitions are provided to assist in standardization of measurements used in the description of terrace and WASCOB cross sections, spacing, and surveying data.

(a) Terrace cross section

The cross-sectional view shown in figure 8–8 illustrates the terms and associated dimensions used in terrace design.

(1) Ridge

Effective top width—the location at which a 3-foot-ridge width occurs.

Centerline—center of ridge effective top width.

Design ridge height—distance between the channel centerline and the ridge effective top width required to contain the channel flow or temporary storage pool.

Ridge centerline height—distance from the existing ground at the ridge centerline to the design ridge height.

Construction ridge height—design ridge height plus an allowance for settlement based on the ridge centerline height

(2) Channel

Grade line—the elevation of the channel bottom located at the junction of the ridge front slope and channel bottom width.

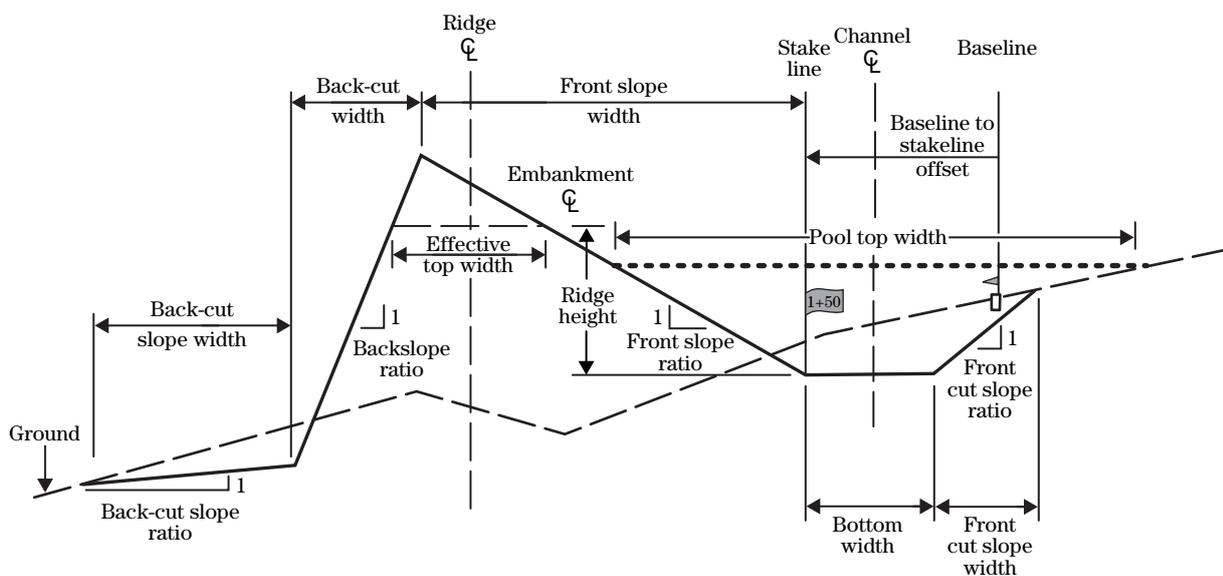
Centerline—center of the bottom width for trapezoidal channel, the channel low point for triangular and parabolic channels.

Bottom width—width of the flat bottom of trapezoidal shaped channels.

Pool top width—width at the design flow depth of triangular, parabolic, or trapezoidal shaped channels.

Design flow depth—the difference between the channel bottom elevation at the channel centerline and the water surface elevation at the design flow rate.

Figure 8–8 Terrace cross section nomenclature



(3) Slopes

All slope segments in terrace designs may be specified either by the use of a fixed slope width or by a fixed slope ratio.

Front slope—the embankment or excavation from the peak of triangular embankments or front edge of trapezoidal to the centerline of triangular shaped channels, or bottom width of trapezoidal shaped channels or top width of parabolic shaped channels.

Front cut slope—the excavation from the channel bottom width to the point of intersection with the existing ground.

Backslope—the embankment from the ridge peak for triangular shaped ridges or back edge for trapezoidal shaped ridges to the intersection of the existing ground or the back-cut slope.

Back-cut slope—the excavation from the backslope toe to the intersection with the existing ground.

(b) Terrace channel block

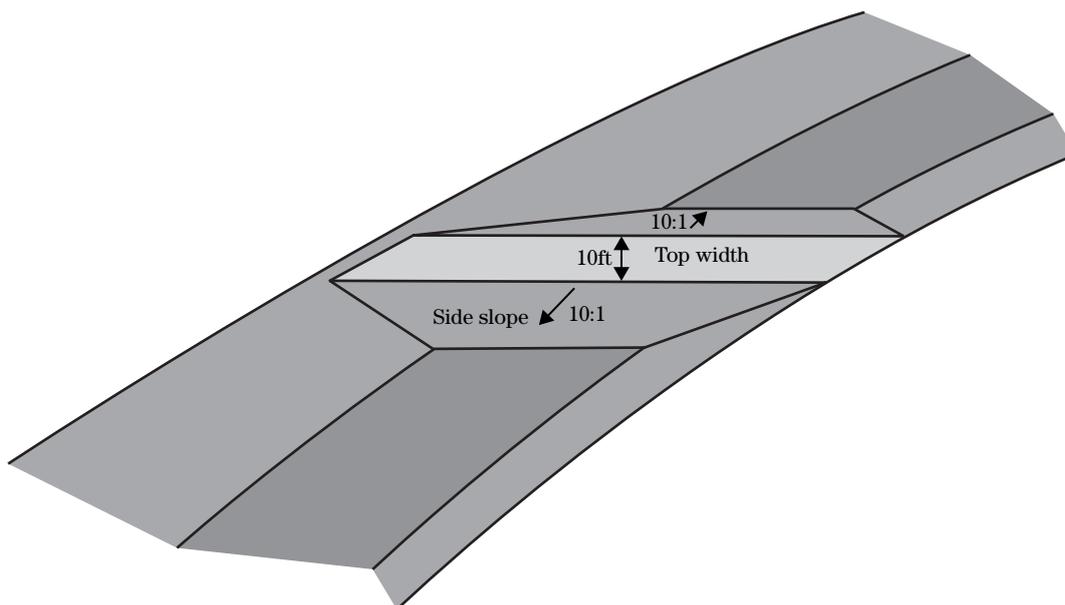
A terrace channel block is an embankment constructed perpendicular to the terrace ridge blocking the terrace channel. Channel blocks are used to contain water in the terrace pool area or to allow for discontinuity in the terrace channel grade (fig. 8–9). Channel blocks are constructed with a trapezoidal shape with a wide top width and flat side slopes to allow the blocks to be cultivated without degradation of their height.

Top width—the width of the top of the trapezoidal shaped embankment.

Side slope—the slope of the embankment sides specified by a slope ratio.

Block height—distance between the channel centerline and the block top width.

Figure 8–9 Terrace channel block



(c) WASCOB cross section

The cross-sectional view shown in figure 8–10 illustrates the terms and associated dimensions used in the WASCOB embankment design.

(1) Embankment

Top width—width of the top of the trapezoidal shaped embankment.

Design height—design storage pool depth at the pool outlet plus any required freeboard.

Freeboard—height added to the embankment to protect the embankment from overtopping.

Embankment height—distance from the existing ground at the embankment center line to embankment design height.

Construction height—embankment height plus allowance for embankment settlement.

(2) Slopes

All slope segments in WASCOB designs are normally specified by the use of a fixed slope ratio.

Front slope—the embankment from the upstream edge of the top width to the existing ground or excavated pool bottom.

Backslope—the embankment from the downstream edge of the top width to the intersection of the existing ground.

(d) Terrace spacing

Following are terms used to define distances measured between terraces. Figure 8–11 illustrates these terms and their measurements for the typical type of terrace cross sections used.

Terrace spacing—the horizontal distance between front slope toes perpendicular to the channel alignment.

The term “terrace spacing” is used when defining the planned distance between terrace lines. This distance is measured from the typical terrace stake line which is located at the toe of the front slope. For a terrace with a triangular shaped channel this is also the channel centerline.

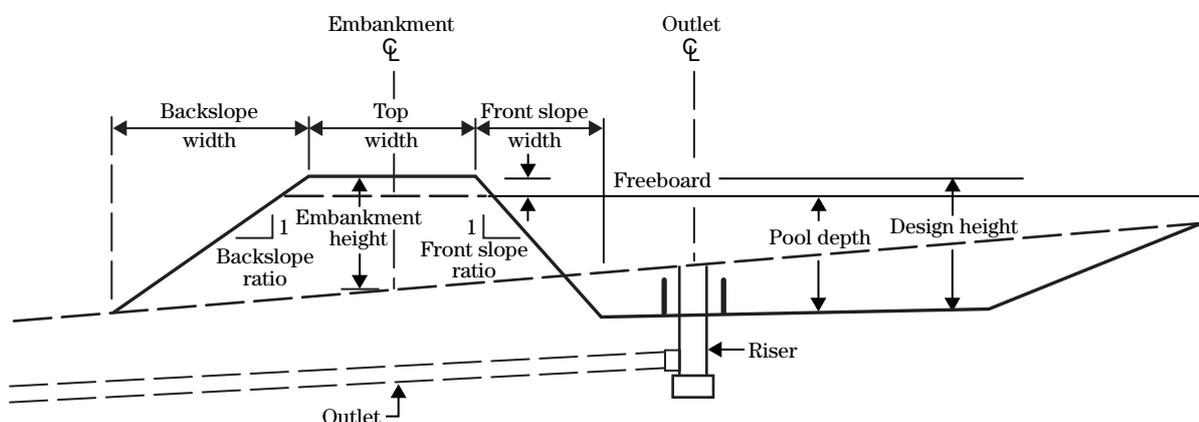
Farmable interval—the horizontal width of the cropped zone between terrace ridge centerlines.

The term “farmable interval” is used to define the horizontal distance between terraces that will be subject to crop production.

Horizontal Interval—the horizontal width of the cropped zone between the ridge centerline of the upslope terrace and channel centerline or cut slope toe of the downslope terrace.

The term “horizontal interval” is used to define the horizontal spacing determined using the vertical interval (VI) equation and the erosive slope length in

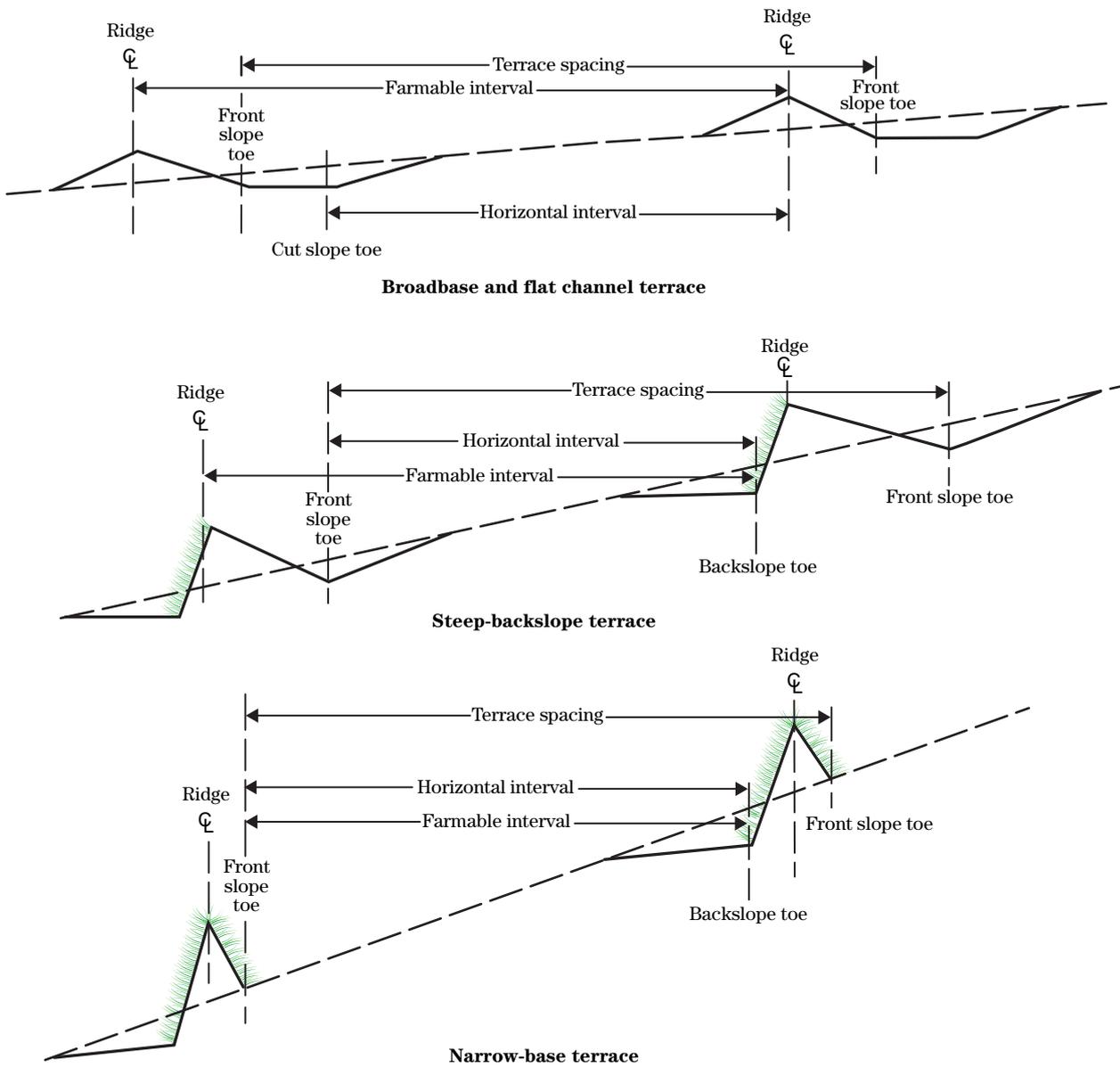
Figure 8–10 WASCOB cross section nomenclature



the Revised Universal Soil Loss Equation (RUSLE) equation. These equations are defined in detail in section 650.0806. This distance is considered to be

the cropped portion of the slope between terraces subject to sheet and rill erosion.

Figure 8-11 Terrace spacing terms by cross section type



(e) WASCOB spacing

WASCOB spacing is defined as the horizontal distance between the storage pool outlets of the multiple WASCOBs placed on the same drainage course (fig. 8–12).

(f) Cross section and profile measurement and display conventions

The use of standard conventions for the representation of survey and design data reduces confusion in the interpretation of terrace or the WASCOB plans. Figure 8–13 illustrates recommended cross section measurement and reference points. Figure 8–14 illustrates recommended profile stationing and labeling conventions.

Cross sections of terraces should be referenced with zero (0) located at the planned terrace channel front slope toe or at a baseline with a known distance (offset) to the front slope toe with positive distance located to the right when looking in direction of increasing stationing. Terrace profile stationing should increase from left to right when looking in a downslope direction.

Underground or grassed waterway outlets should be stationed with zero (0+00) located at the upstream end with stationing increasing downstream. Terrace lines should be labeled with numbers increasing downslope and outlets should be labeled with letters increasing in the direction of terrace profile stationing. Individual UGO inlets should be labeled by combining the terrace and UGO label.

Figure 8–12 WASCOB spacing

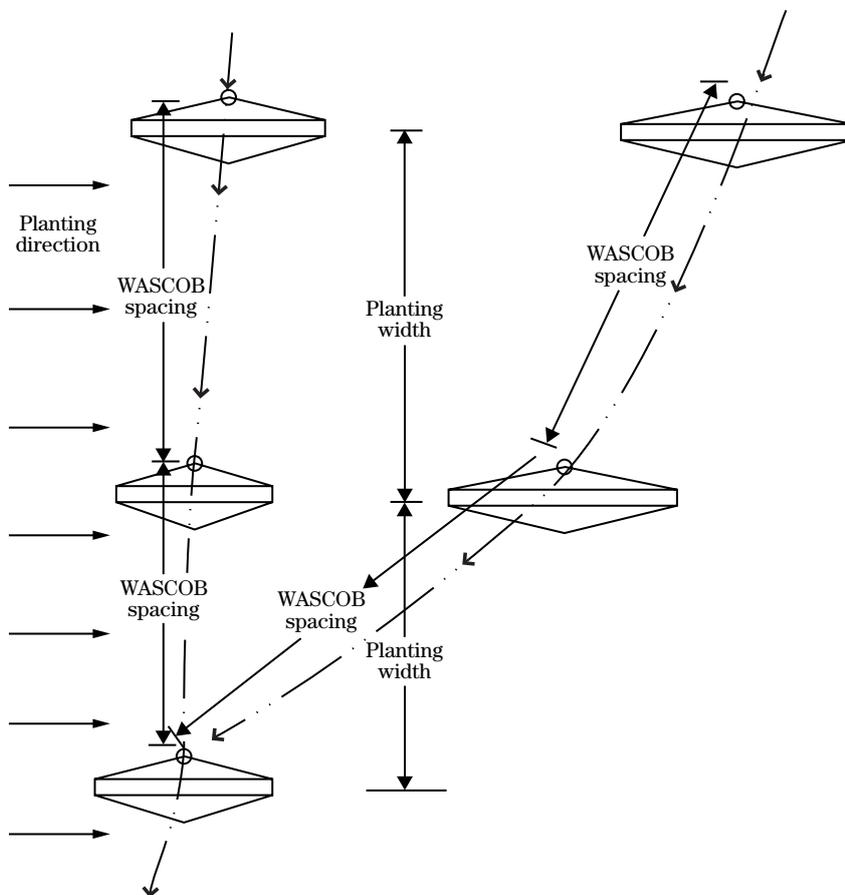


Figure 8-13 Cross section measurement and labeling conventions

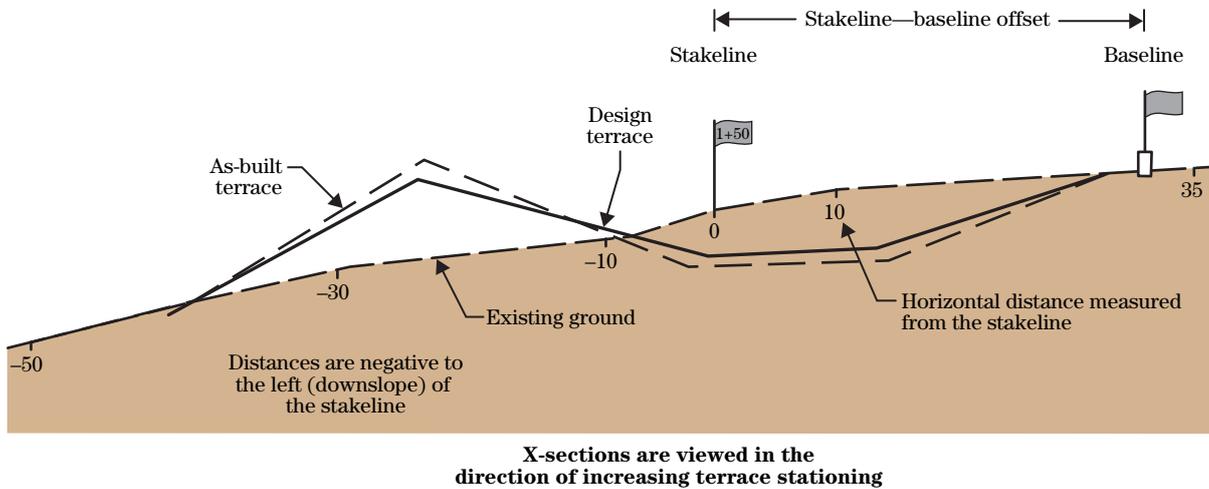
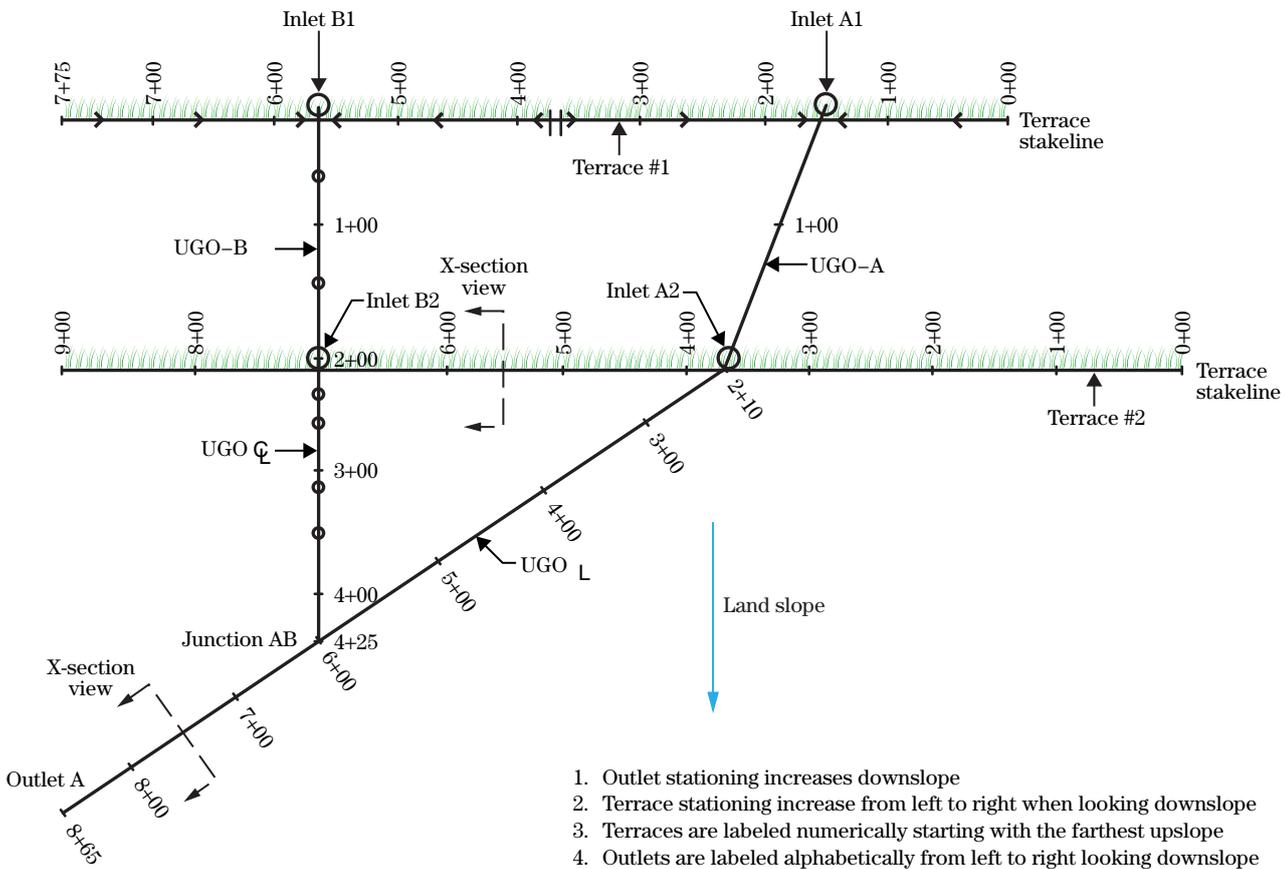


Figure 8-14 Profile stationing and labeling conventions



650.0804 Types of terrace cross sections

Several standard terrace cross sections have been developed. Each type has advantages and disadvantages associated with landscape, ease of farming, initial cost, and maintenance. The following are those in common use.

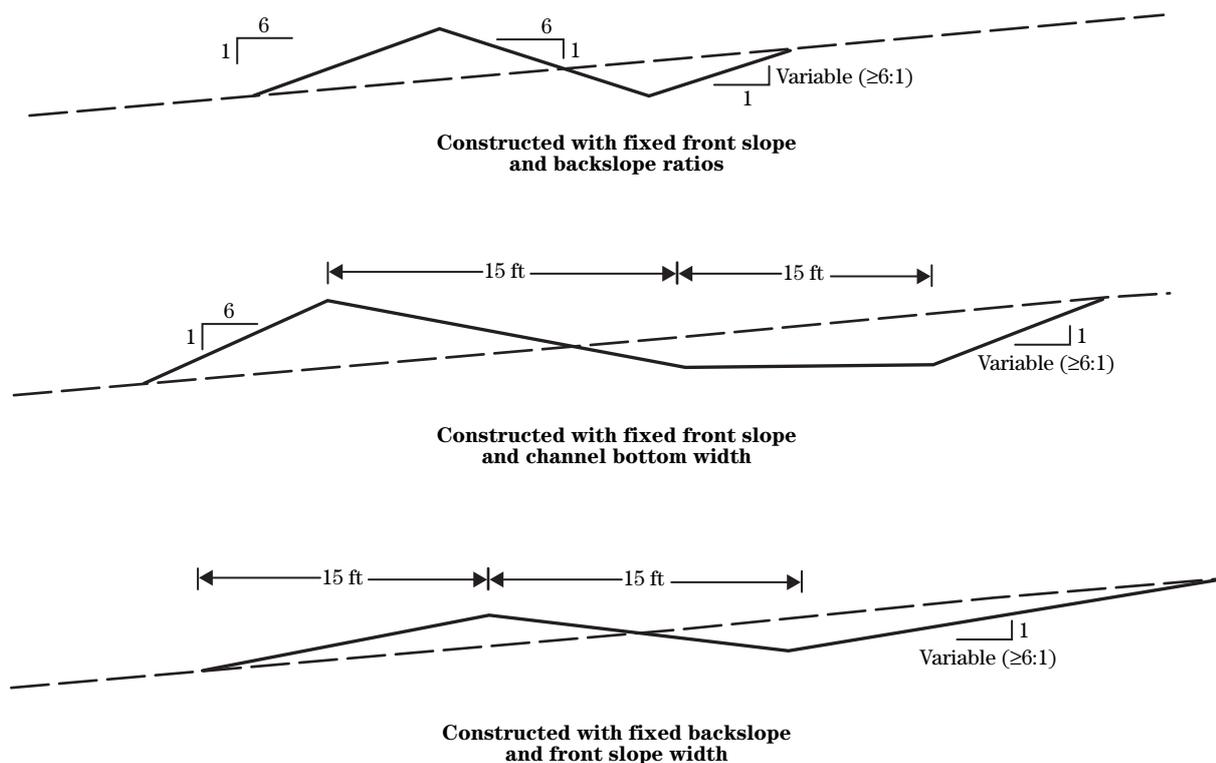
(a) Broadbase terrace

Broadbase terraces are defined as terraces for which all constructed and excavated slopes are flatter than 5:1 and the entire terrace is cropped (fig. 8–15). Earthfill for the terrace ridge is normally obtained from excavation of the terrace channel. Figure 8–16 shows examples of typical broadbase terrace cross sections.

Figure 8–15 Broadbase terraces with grassed-waterway outlet



Figure 8–16 Broadbase terrace cross section examples



Broadbase terraces are a traditional terrace shape used by farmers for many years. This shape is favored due to ease of construction with a plow, tractor blade, or most any earthmoving equipment simply by moving the soil downhill to form a channel and ridge. The flat slopes of this shape allow farm equipment to operate on the constructed ridge slopes, therefore allowing cropping of the entire field.

The use of a broadbase cross section is normally limited to smooth topography with land slopes of eight percent or less. The maximum slope on which a broadbase cross section is practical decreases with increase of the terrace ridge height, channel bottom width, and land slope. The broadbase shape is well suited to terraces with gradient alignment and open outlets. This type of terrace does not require temporary water storage and, therefore, typically has a low ridge height and triangular channel. Terraces with UGOs typically require greater ridge height and channel width for temporary water storage.

As land slope, ridge height, or channel bottom width increases, the width of land disturbed by the terrace construction increases to the point where the channel cut slope merges with the ridge backslope of the upslope terrace, and the entire terrace interval is disturbed by earthwork activities. Table 8–1 shows the effect of land slope on disturbed width for a typical broadbase terrace with 6:1 slopes, 2.5-foot ridge height, 10-foot bottom width and 120-foot terrace spacing. This example shows that at 11 percent land slope, the soil in the entire field will be disturbed to construct the terrace system.

Table 8–1 Effect of land slope on broadbase terraces

Broadbase cross section		
2.5-ft ridge height 6:1 ridge and channel slopes	10-ft channel bottom width 120-ft terrace spacing	
Existing land slope (%)	Disturbed soil width (ft)	Horizontal interval slope (%)
2	45	5.1
4	53	7.7
6	63	10.2
8	77	13.0
10	100	15.3
11	119	16.7

The use of a broadbase cross section results in an increase of the cropped land slope due to the cropping of the ridge backslope and the channel cut slope. The length of erosive slope will be decreased by the terrace installation, but the slope along this length will increase. The erosive slope length between terraces is defined as the horizontal interval. The example in table 8–1 shows that the average slope along the horizontal interval may be 3 to 5 percent greater than the slope of the existing ground. This increase must be taken into consideration when determining terrace spacing requirements based on sheet and rill erosion.

The construction of broadbase terraces on soils with shallow topsoil or infertile subsoil can result in a significant decrease in crop productivity. On shallow soils the normal earthmoving technique used for broadbase terrace construction places subsoil from the channel on top of topsoil located under the ridge and exposes subsoil in the channel. This effect can be partially offset by scalping and stockpiling all the topsoil from the channel and ridge, then replacing the topsoil after construction of the ridge.

Broadbase cross sections may be constructed with uniform slope widths instead of uniform slope ratios. The use of uniform slope widths allows for more efficient use of planting and harvesting equipment. Large planting and harvesting equipment may have limited flexibility which will not allow it to be operated over the slope angles formed at the ridge or channel junction.

For example, a corn planter may only be flexible at 15-foot increments or a combine may have a 30-foot-wide, nonflexible harvesting head. In this case, the slope width of the front slope and backslope can be fixed at 30 feet with a varying slope ratio not to exceed 5:1. This type of cross section will require a greater amount of earthwork than one with a fixed slope ratio, but will significantly improve the efficiency of cropping the terrace system with large equipment.

Broadbase cross sections are susceptible to the wearing down of the terrace ridge as a result of cropping. This is especially true if farming operations are not carried out parallel to the ridge. Ridge-slope ratio plays a large factor in the wear with much more damage occurring at 5:1 slope ratios than 10:1 slope ratios. Tillage methods also affect ridge maintenance intervals with no till systems causing much less wear than

systems using frequent disking or field cultivating. Under severe cropping conditions the terrace ridge may need maintenance on an annual to biannual basis. In some areas, this is accomplished by one way plowing the front slope of the ridge with the soil being cast upslope.

(b) Steep-backslope (grassed-back) terrace

A steep-backslope terrace is defined as a terrace with a 2:1 ridge backslope and 5:1 or flatter ridge front slope. The ridge backslope is not cropped and is seeded to permanent grass. This type of terrace is sometimes referred to as a “grassed-back terrace” because of the permanent vegetation (fig. 8–17). The terrace channel is normally triangular shaped with the flow line located at the existing ground line; although, some cut or fill may be used to maintain terrace alignment.

The majority of the earthfill for the construction of the terrace ridge comes from excavation of a back-cut slope below the terrace ridge. The excavation of the back-cut slope is typically made on a 1 percent slope away from the ridge to prevent water from ponding below the ridge while minimizing the area disturbed by excavation. Figure 8–18 shows examples of typical steep-backslope terrace cross sections.

Figure 8–17 Steep-backslope (grassed-back) terraces



This shape is well suited to land slopes of 6 to 12 percent. The flattening of the back-cut slope reduces the land slope in the cropped area and the steep backslope reduces the width of soil disturbed to construct the terrace. Table 8–2 shows the disturbed soil width and average horizontal interval slope for a typical steep-backslope terrace on various land slopes. The example is for a terrace with the same ridge height and spacing as the broadbase example in table 8–1. For land slopes greater than 6 percent the disturbed soil width for the steep-backslope terrace is less than that of the broadbase terrace. For the steep-backslope cross section, the disturbed soil width actually decreases slightly as slope increases. On a 10 percent land slope, the average land slope of the cropped horizontal interval is decreased to 7.0 percent compared to an increase to 15.3 percent for the broadbase terrace.

The use of steep-backslope terraces removes some of the field from crop production as shown in the example in table 8–2. The amount of cropped area reduction is dependent upon terrace spacing, land slope and ridge height, but is typically 5 to 10 percent of the area terraced. The steep backslope of this shape does not allow farm equipment to cross the terrace ridge. Therefore, provision must be made for access to the terrace interval. This is normally accomplished with access roads along the field border or along watershed breaks at existing field ridges. Steep-backslope terraces may have ridge heights measured from the back-slope toe of 6 feet or more. This can present a safety hazard for the operation of farm equipment on the terrace ridge front slope.

It is normally desirable to use a parallel alignment for steep-backslope terraces because the terrace ridges cannot be crossed with farm equipment. The use of a terrace spacing based on an even number of equipment widths is also advantageous since it provides for round trips back to the terrace access point for field operations.

The use of a fixed front slope and backslope width will allow for uniform cropped widths. For example, a 15-foot front slope, 10-foot backslope, and 130-foot terrace spacing could be used. This will create a 120-foot cropped zone that can be cropped with four rounds of 15-foot-wide equipment. Ridge slope ratios are allowed to vary not to exceed 2:1 for the backslope and 5:1 for the front slope. This will allow a maximum ridge

Figure 8-18 Steep-backslope terrace cross section examples

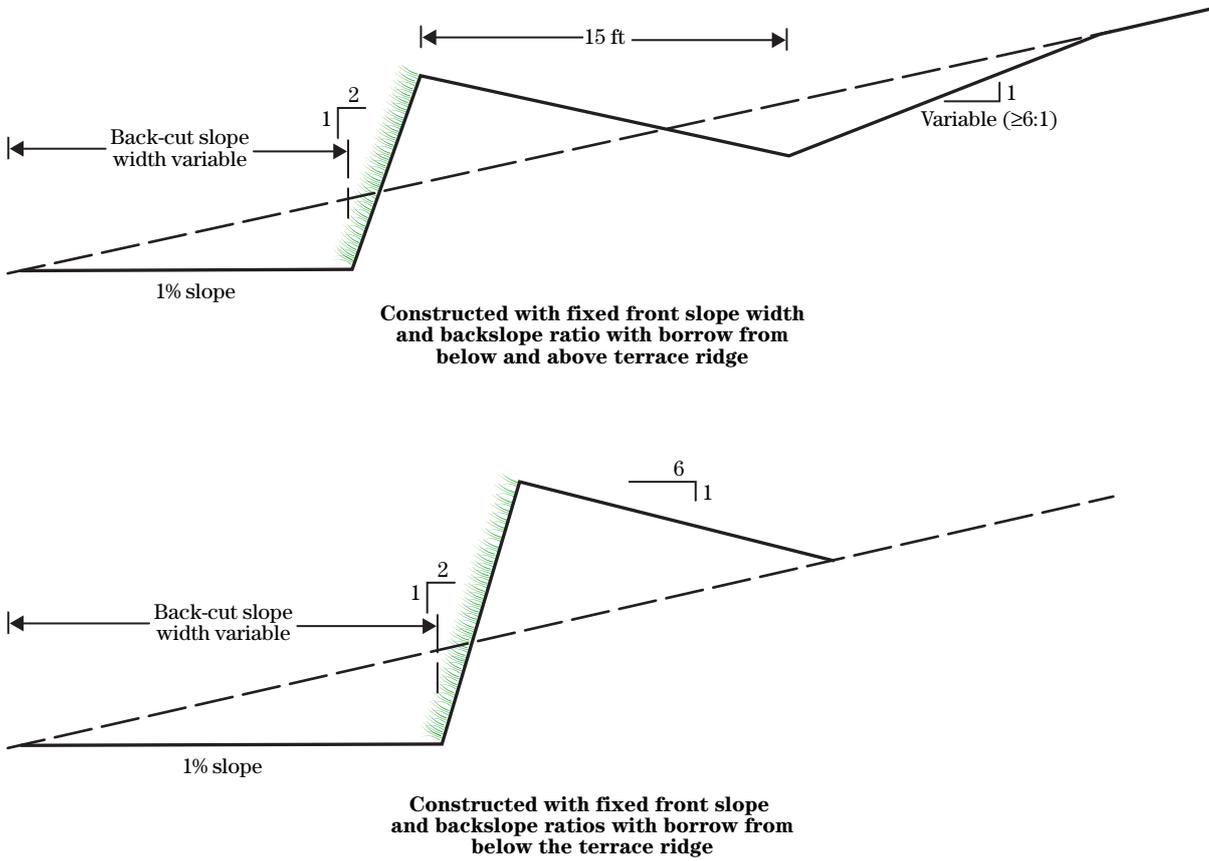


Table 8-2 Effect of land slope on steep-backslope terraces

Steep-backslope cross section			
2.5-ft ridge height		Zero channel cut	
2:1 backslope	6:1 front slope	120-ft terrace spacing	
Existing land slope (%)	Disturbed soil width (ft)	Horizontal interval slope (%)	Terrace spacing not cropped (%)
4	67	2.7	5.5
6	63	4.0	5.9
8	61	5.6	7.2
10	60	7.0	9.8
12	59	8.3	12.5

height of 2.5 feet and a maximum backslope height of 5.0 feet.

Burrowing animals may increase maintenance of steep-backslope terrace ridges. The permanent grassed slope provides habitat for burrowing animals. The animal burrows may penetrate close enough to the terrace channel to allow for water erosion through the ridge. Regular monitoring and maintenance may be necessary to ensure proper terrace function.

(c) Narrow-base terrace

Narrow-base terraces are defined as terraces with a ridge front and backslope of 2:1 or flatter. The ridge front and backslope are not cropped and are seeded to permanent grass (fig. 8–19). The ridge may be constructed with a uniform base width with the ridge slope ratios varying based on ridge height. The terrace channel is normally triangular shaped with the flow line, located at the existing ground line; although, some cut or fill may be used to maintain terrace alignment.

The majority of the earthfill for the construction of the terrace ridge comes from excavation of a back-cut slope below the terrace ridge. The excavation of the back-cut slope is typically made on a 1 percent slope away from the ridge to prevent water from ponding below the ridge while minimizing the area disturbed by excavation. Figure 8–20 shows examples of typical narrow-base terrace cross sections.

Figure 8–19 Narrow-base terraces



The narrow-base terrace shape is well suited for steep land slopes of 10 to 16 percent. The flattening of the back-cut slope reduces the land slope in the cropped area, and the steep back and front slopes reduce the width of soil disturbed to construct the terrace. This shape also minimizes the amount of earthwork required to construct the terrace on steep slopes. Table 8–3 shows the disturbed soil width and average horizontal interval slope for a narrow-base terrace with the same ridge height and spacing as the broadbase example in table 8–1.

On a 10 percent land slope, construction of the narrow-base shape shown in table 8–3 would disturb only 30 percent of the 120-foot terrace spacing compared to 50 percent for the steep-backslope shape in table 8–2 and 83 percent for the broadbase shape in table 8–1. The average land slope of the cropped horizontal interval is decreased to 8.4 percent for the narrow-based shape compared to an increase to 15.3 percent for the broadbase shape. The amount of earthwork required for the narrow-base shape would be only 35 percent of that required for the broadbase shape and 60 percent needed for the steep-backslope shape.

The use of narrow-base terraces removes a significant portion of the field from crop production as shown in the example in table 8–3. The amount of cropped area reduction is dependent upon terrace spacing, land slope, and ridge height, but is typically 10 to 20 percent of the area terraced. The steep back and front slopes of this shape do not allow farm equipment to cross the terrace ridge. Therefore, provisions must be made for access to the terrace interval. This is normally accomplished with access roads along the field border or along watershed breaks at existing field ridges.

It is normally desirable to use a parallel alignment for narrow-base terraces because the terrace ridges cannot be crossed with farm equipment. The use of a terrace spacing based on an even number of equipment widths is also advantageous since it provides for round trips back to the terrace access point for field operations. The use of a fixed front slope and backslope width will allow for uniform cropped widths.

For example, a 5-foot front slope, 10-foot backslope, and 135-foot terrace spacing could be used. This will create a 120-foot cropped zone that can be cropped with four rounds of 15-foot-wide equipment. Ridge slope ratios are allowed to vary not to exceed 2:1

Figure 8-20 Narrow-base terrace cross section examples

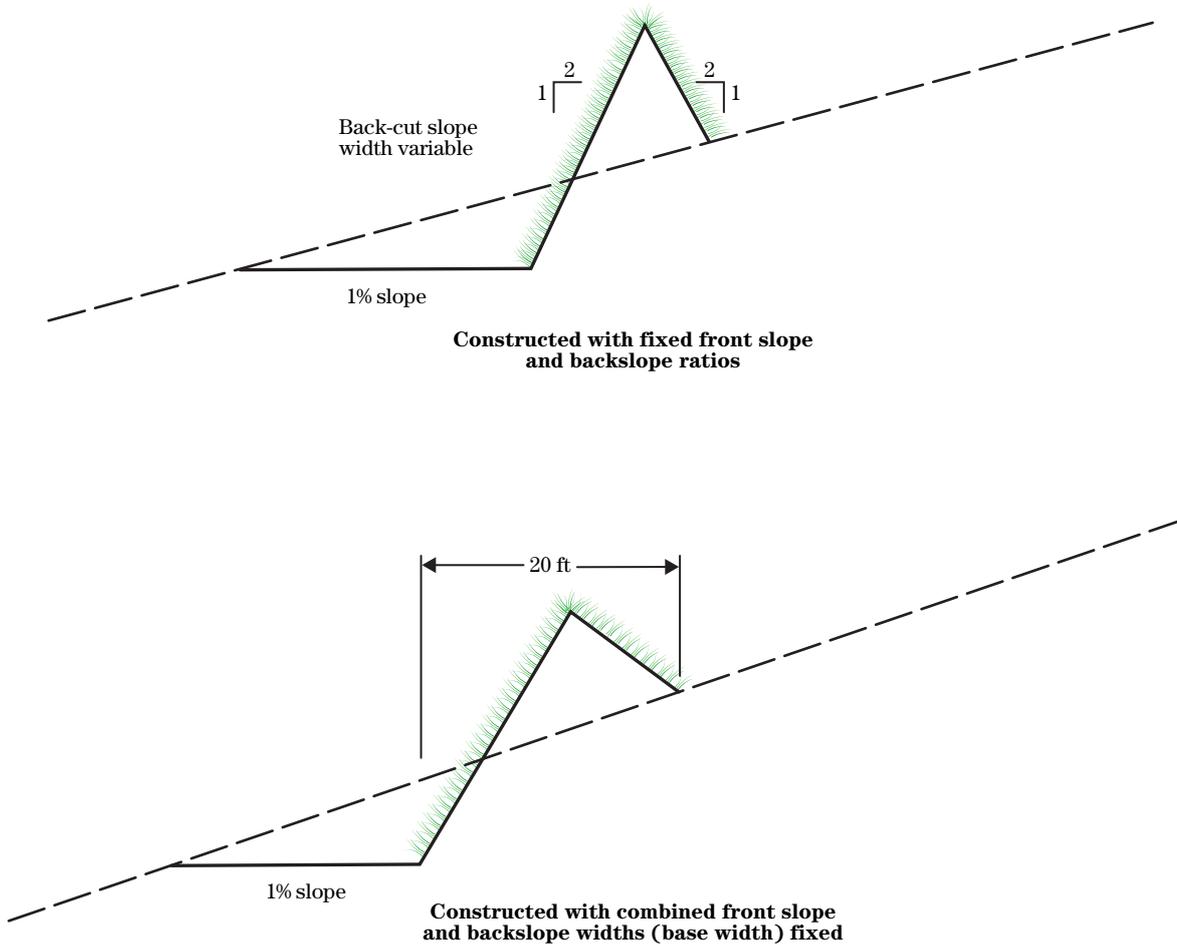


Table 8-3 Effect of land slope on narrow-base terraces

Narrow-base cross section			
2.5-ft ridge height Zero channel cut			
2:1 backslope		2:1 front slope	120-ft terrace spacing
Existing land slope (%)	Disturbed soil width (ft)	Horizontal interval slope (%)	Terrace spacing not cropped (%)
8	35	6.7	12.9
10	35	8.4	14.2
12	36	10.0	15.4
14	36	11.9	16.7
16	37	13.7	18.1

for the backslope and front slope. This would allow a maximum ridge height of 2.5 feet and a maximum backslope height of 5.0 feet.

Similar to steep-backslope terraces, burrowing animals may require increased maintenance of narrow-base terrace ridges. The permanent grassed slope provides habitat for burrowing animals. The animal burrows may penetrate close enough to the terrace channel and allow for water erosion through the ridge.

(d) Flat channel (level) terrace

The flat channel terrace is defined as a terrace with ridge slopes flatter than 5:1 and a channel bottom width greater than 45 feet. This shape is normally used for terraces with the primary purpose of moisture conservation. The channel grade line of the terrace is level with channel blocks constructed at the ends of the terrace to retain runoff in the terrace channel. The retained runoff is primarily removed from the channel by soil infiltration (fig. 8-21).

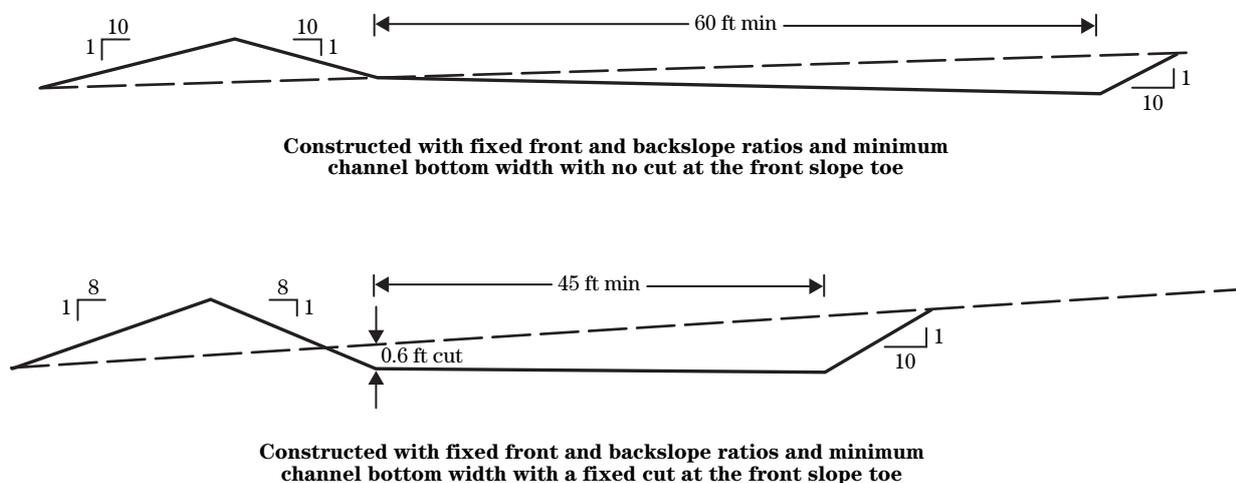
Terraces of this shape are sometimes referred to as “level” terraces due to the level storage basin that is created. Earthfill for the construction of the terrace ridge is obtained from the channel area. Figure 8-22 shows examples of typical flat channel terrace cross sections.

Flat channel terraces are normally used on slopes of 4 percent or less in low rainfall areas. The terrace spacing is normally 300 feet or more. The objective of this terrace system is to collect runoff from the upper portion of the terrace spacing and cause it to infiltrate into the soil in the large flat channel, therefore increasing the amount of soil moisture available for crop production. Crop production within the terrace interval is sometimes split with crops requiring more soil moisture planted in the flat channel area. Channel widths up to 100 feet are commonly used. The wide, flat chan-

Figure 8-21 Level terraces with infiltration outlet



Figure 8-22 Flat channel terrace cross section examples



nel limits the use of this shape to relatively flat land slopes. The ridge of the flat channel terrace is normally constructed with slopes as flat as 10:1 to use the soil excavated from the channel. The channel grade line is commonly set at the existing ground line to optimize the width of the channel that can be obtained before excessive cut depths occur at the upstream channel toe.

Flat channel terrace alignment is set by the location of the level channel grade line. Therefore, these terraces follow the existing ground contour and are not constructed with parallel ridges. The entire terrace spacing is cropped. The flat land slope, low ridge height, and flat ridge slopes allow farm equipment to operate on or across the terrace ridges.

Flat channel terraces are designed to store the entire volume of runoff from a 10-year frequency, 24-hour duration rainfall. The time required for water stored in the pool to infiltrate into the soil should not exceed the inundation tolerance of the planned crops. In most cases, this is 24 to 48 hours. Soil infiltration rates are difficult to predict with a high degree of accuracy. If local experience has shown that soil infiltration is not certain to remove inundation within the design time period, then UGOs with a capacity large enough to remove some of the stored water may need to be incorporated into the design.

650.0805 Terrace alignment

The alignment between multiple lines of terraces plays an important role in the efficiency of row crop production on terraced fields. Terrace alignments are referenced to the toe of the terrace ridge, which is the point from which terrace spacing is measured as shown in figure 8–11. The following are the standard types of terrace alignment, along with their advantages and disadvantages.

(a) Gradient terrace alignment

The term “gradient” comes from the practice of locating the terrace channel grade line by finding an existing ground slope with a fixed gradient such as 0.6 percent slope to the channel outlet. The resultant alignment is controlled by the existing ground contours. The terrace spacing is allowed to vary up to the point of the maximum spacing that provides the required erosion protection (fig. 8–23).

Gradient alignment was commonly used for terraces constructed in the 1940s to 1960s and is still used for many terraces today. Terraces using gradient alignment have variable terrace spacing. This results in the

Figure 8–23 Terraces with gradient alignment



formation of point row areas when the field is planted to row crops (fig. 8–24). The frequency and size of these have a significant effect on crop production efficiency. The point row areas cause seed, fertilizer, and herbicide overlap and inefficient machinery use. This effect is more pronounced on terrace shapes where the terrace ridge cannot be crossed by farm machinery. The detrimental effect of the point row areas on cropping efficiency is greater for the 12-row or larger equipment currently used compared to the 2- to 4-row equipment used in the 1950s.

The use of a gradient alignment normally minimizes the amount of earthwork required for terrace construction. This is because the terrace follows the ground contour and does not have large cuts or fills caused by crossing ridges or depressions.

(b) Gradient alignment layout

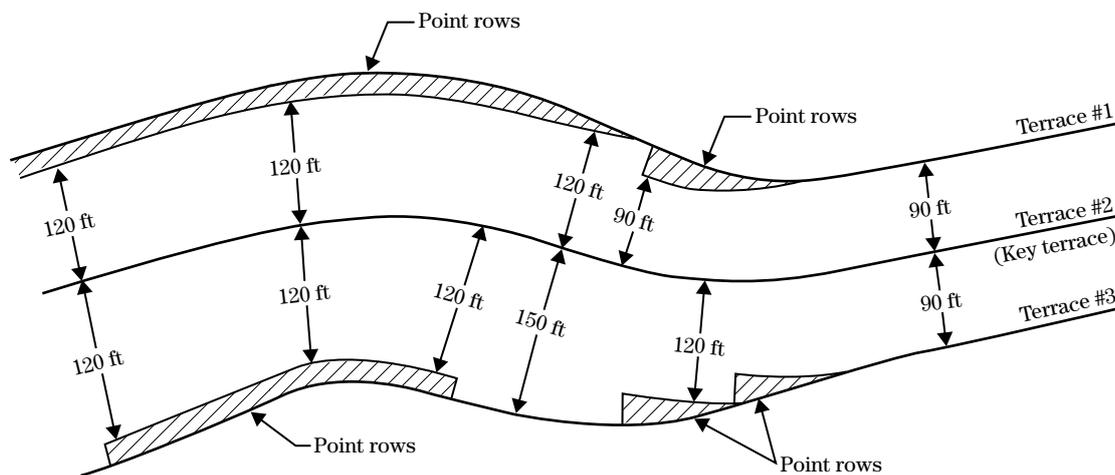
The gradient terrace alignment is normally located in the field with the use of a level. The location of the terrace outlets is first determined from study of the existing watersheds and drainage patterns in the field.

The first terrace located on the slope is referred to as the “key terrace,” since spacing of subsequent terraces up and down the slope will be referenced to it. The key terrace is typically located at the midpoint of the slope. The key terrace alignment is located by starting at the outlet and working to the edge of the field or watershed break. A level is used to find the channel location at 100-foot intervals that has a nonerosive channel grade line and the desired amount of cut to provide fill for the ridge.

For example, a 0.6 percent channel grade is planned with 0.5 foot of cut at the toe of the ridge. The grade line is started at the outlet elevation. The next point, 100 feet upstream, is located where the ground surface is 1.1 feet higher. Each subsequent 100-foot point is located where the ground is 0.6 foot higher than the previous. The process is sometimes repeated after a first trial with small variations in grade and cut to improve the alignment by smoothing out sharp curves caused by minor field irregularities.

After the key terrace has been located, the adjacent terraces are located in the same manner starting with the planned terrace spacing from the key terrace. If

Figure 8–24 Point rows caused by gradient alignment



Point rows in gradient terrace system
Based on 30-foot equipment width

the maximum design spacing is exceeded at any point on the next terrace, the alignment process is repeated starting with a narrower spacing.

Figure 8–25 illustrates the process and results of a typical gradient alignment layout.

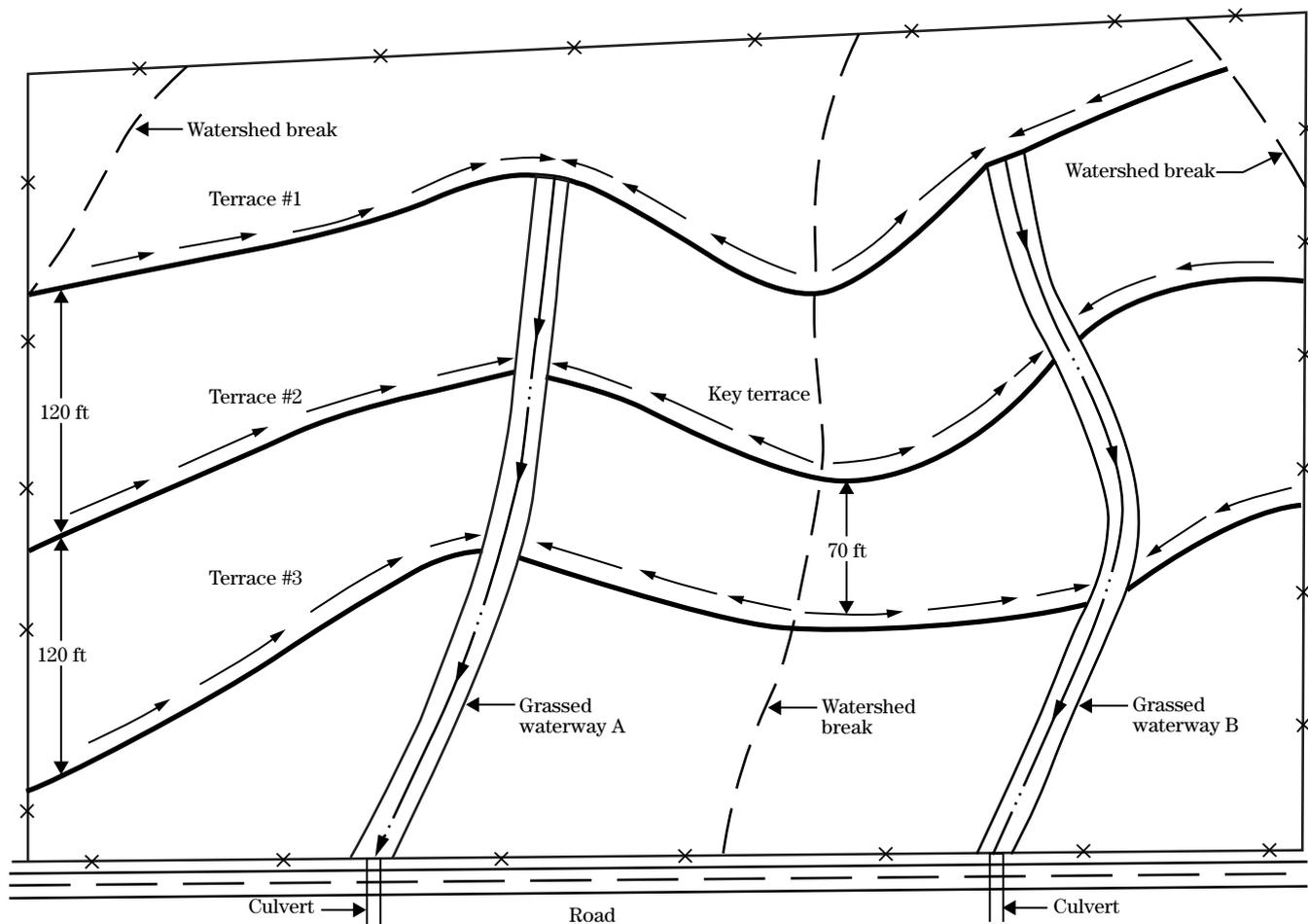
For fields with long uniform slopes, gradient terraces may be aligned in a manner that results in a fairly uniform terrace spacing with limited occurrence of point rows. On fields with complex, dissected slopes, the terrace spacing will vary widely resulting in significant point row areas and sharp difficult to farm curves.

(c) Parallel terrace alignment

The term “parallel” refers to the practice of locating the toes of terrace ridges of adjoining terraces at a uniform horizontal spacing. The alignment consists of a series of straight lines and concentric circular curves (fig. 8–26). The horizontal spacing between terraces is set at a multiple of the cropping width for the farm machinery used and less than the maximum width required for erosion control.

The use of a parallel terrace alignment significantly improves crop production efficiency compared to gra-

Figure 8–25 Typical gradient alignment layout



dient alignment. Point rows are eliminated between terraces. The elimination of point rows reduces seed, fertilizer, and herbicide overlap. The efficiency of machinery operation is significantly improved, especially for shapes where the terrace ridge cannot be crossed.

To achieve uniform planting widths, the terrace must have parallel straight line segments and concentric circular curves. The radius point of the curves must be located at or below the sharpest curve in the system. Figure 8-27 shows an example of concentric circular curves and the nomenclature used in defining them.

The use of parallel terrace alignment has increased as the adoption of UGOs for terraces has become widespread. The use of the UGO allows the terrace channel

Figure 8-26 Terraces with parallel alignment



Figure 8-27 Concentric circular curves

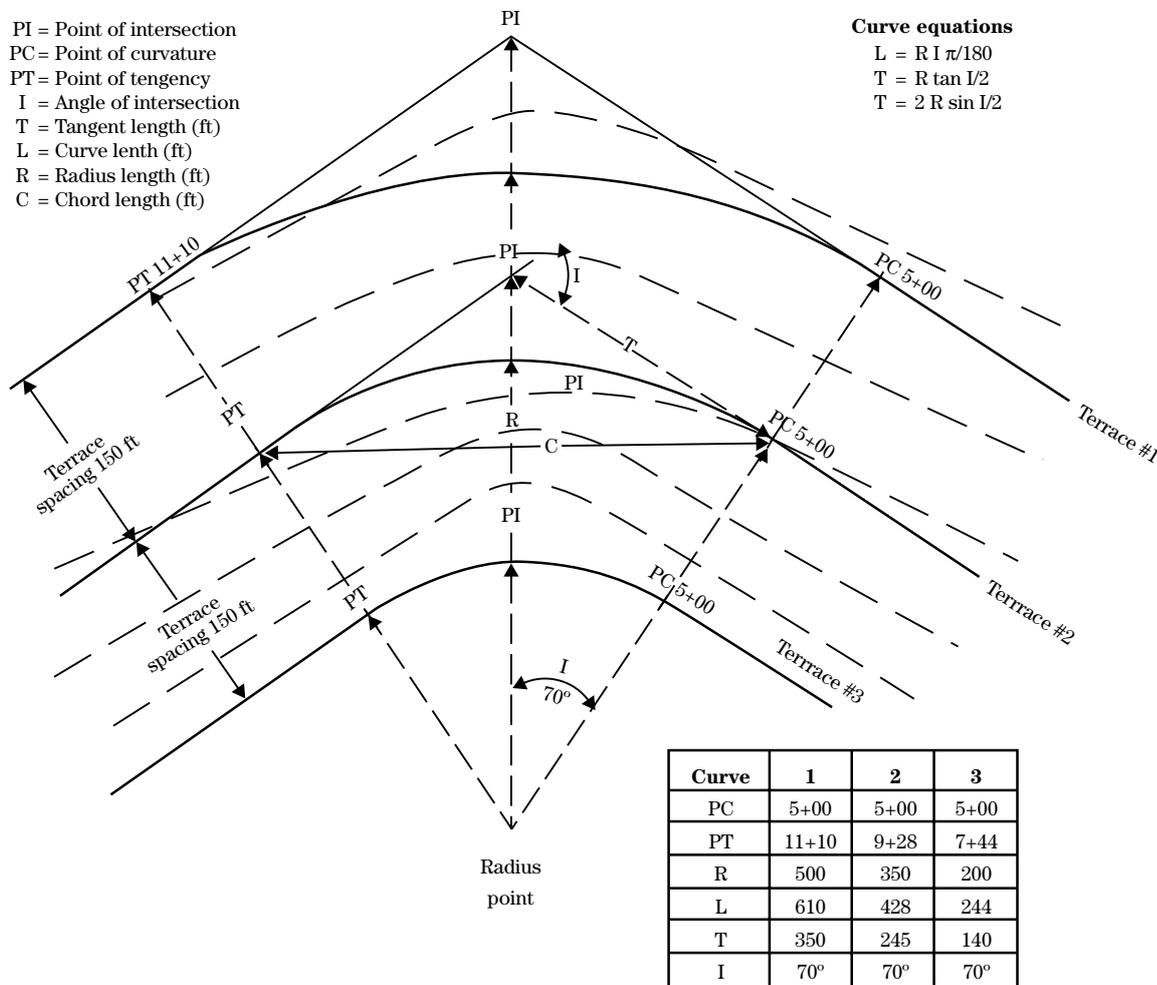
- PI = Point of intersection
- PC = Point of curvature
- PT = Point of tangency
- I = Angle of intersection
- T = Tangent length (ft)
- L = Curve length (ft)
- R = Radius length (ft)
- C = Chord length (ft)

Curve equations

$$L = R I \pi / 180$$

$$T = R \tan I/2$$

$$C = 2 R \sin I/2$$



to be broken up into short sections with small drainage areas. This allows for steeper channel grade lines. The use of channel blocks to contain the water within pool areas also allows the terrace channel to be broken into reaches with significant differences in elevation.

Figure 8–28 illustrates how these techniques can be used to achieve a parallel terrace alignment on a complex slope. Terraces constructed with a parallel alignment will normally require a greater amount of earthwork than those with a gradient alignment. This is caused by the cuts or fills that may be required to construct the terrace channel along the varying existing ground elevations that occurs along the path dictated by the parallel alignment.

Terraces with parallel alignments are more complex to design and layout than gradient terraces. Due to the complexity of laying out an alignment with concentric curves, terraces are sometimes laid out with congruent curves. Congruent curves are defined as curves that have the same radius length as shown in figure 8–29. The use of congruent curves will result in point rows or odd areas in the curves. The complexity of the field slope and field shape may not allow all of the terraces in the field to be parallel. In this case, correction areas may be planned between sets of parallel terraces.

Figure 8–29 Congruent curves

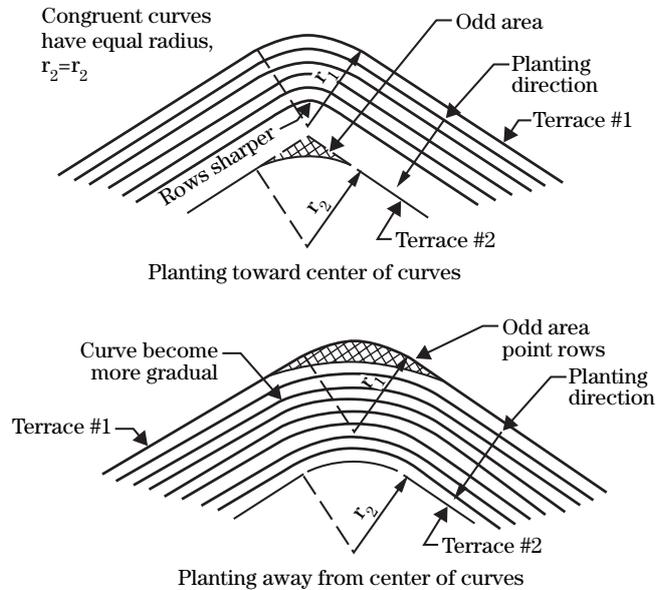
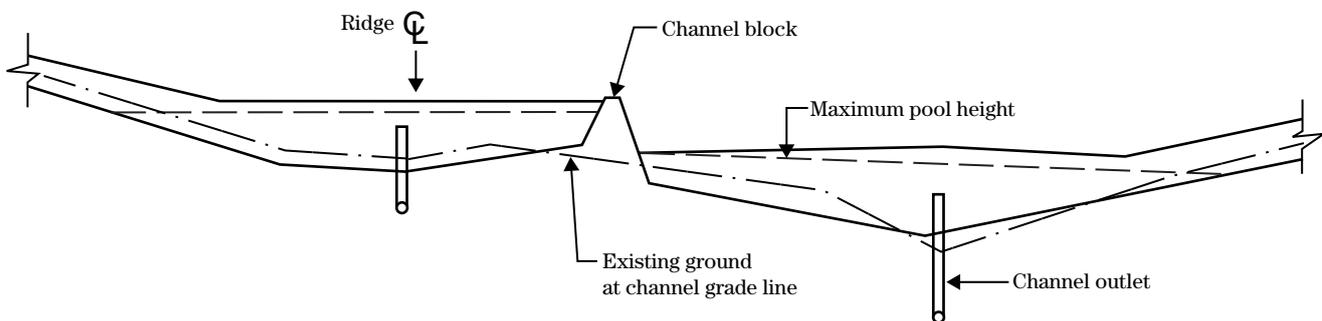


Figure 8–28 Use of channel blocks for parallel alignment



(d) Parallel alignment layout

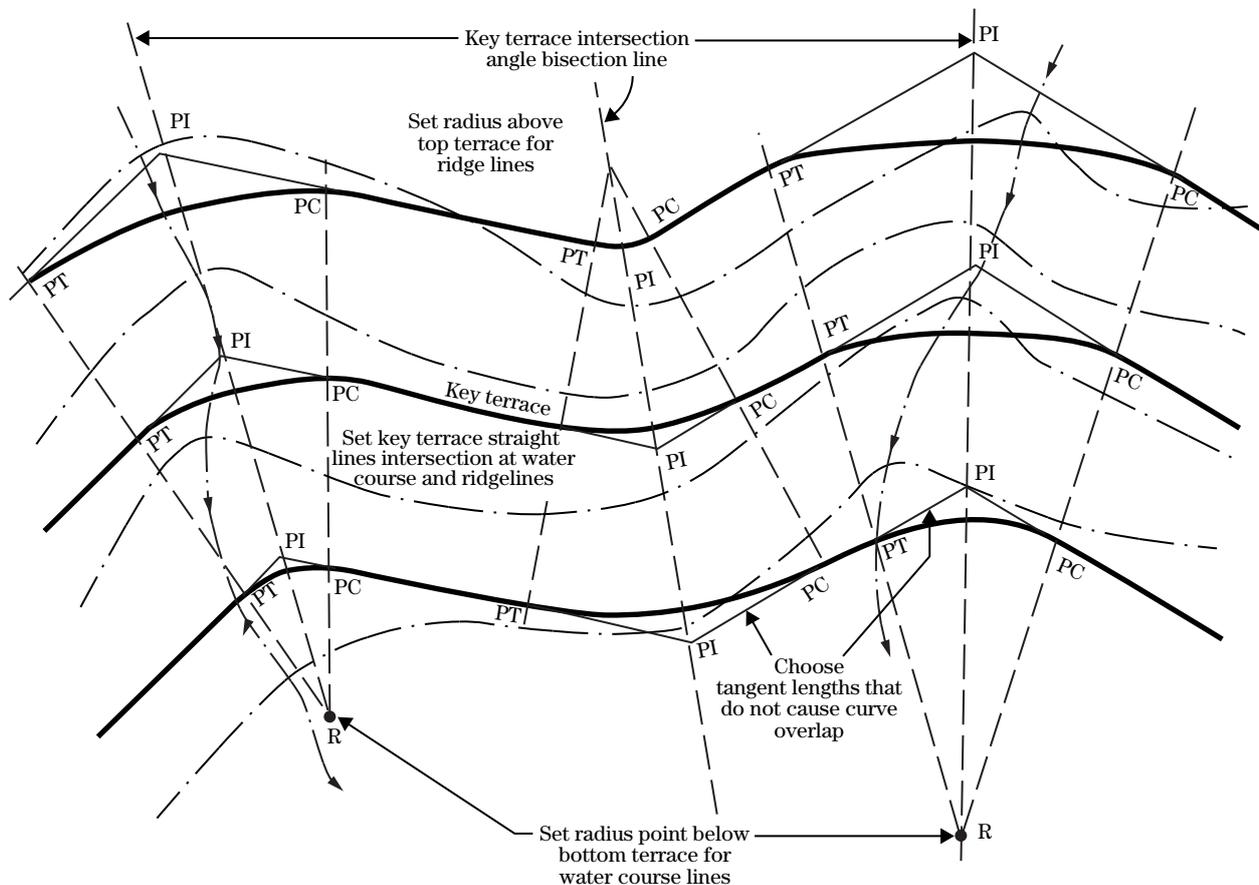
Parallel terrace alignment can be determined in the field or done on a detailed topographic survey of the field and then transferred to the field. A similar process is used in both cases; however, layout on a topographic survey allows the designer to view the entire field at once and to try multiple alignments with less effort than would be required in the field.

Detailed topographic information can be obtained from a variety of sources such as total station surveys, survey grade global positioning satellite (GPS) and light detection and ranging (LiDAR). Topographic data is particularly useful when designing terraces with computer tools such as the NRCS engineering field tools and terrace design tool (TDT).

(i) Steps for parallel alignment layout

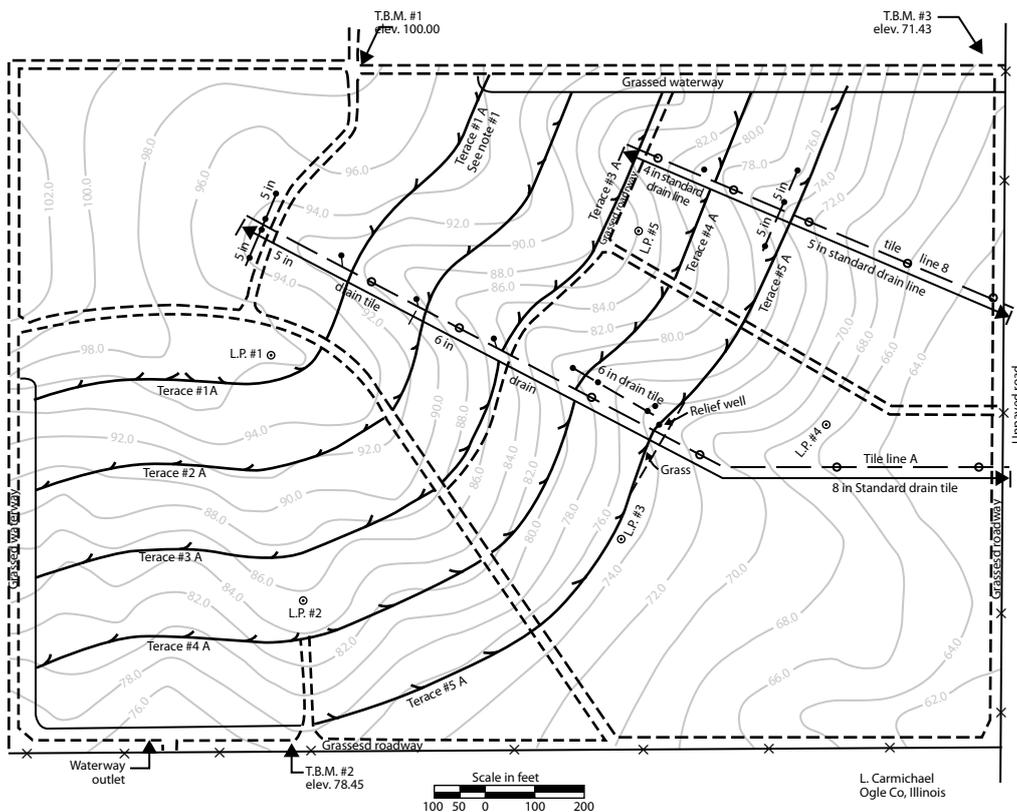
- The first step of a parallel terrace layout is to locate the existing drainage courses/swales and ridge lines/high points in the field. These features will control the possible alignments.
- The next step is to develop a trial key terrace alignment composed of straight line segments. The straight line segments are placed from swale to ridge along a ground contour that will provide a stable channel grade line.
- Circular curves are then designed at the point of intersection of the straight line segments. The radius point of the curve is then located from the point of intersection of the straight lines along the line bisecting the angle of intersection. The radius point must be located outside all of the planned terrace lines. Figure 8-30 shows an example of this process.

Figure 8-30 Parallel layout using concentric curve radius points



- The point of curvature and point of tangency of the curves on the key terrace are then located.
- If the point of tangency of a curve overlaps the point of curvature of the next curve, the alignment must be changed. This may be done by reducing the curve radius or changing the alignment of the straight line segments.
- Once the key terrace alignment has been determined, the remaining terraces are located parallel to the key terrace using the design terrace spacing with the point of intersection of the straight line segments located along the curve radius lines set by the key terrace. Figure 8–31 illustrates a typical parallel alignment developed using these techniques.
- It may not be possible to produce an acceptable design using the alignment chosen. In this case, a new alignment must be tried and the process repeated.
- If the alignment is developed in the field, existing ground cross section data needed for the terrace design is collected along the located alignment.
- If the alignment is developed using a contour map, existing ground cross section data may be developed from the contour map or generated by a computer aided design system. The design of the terrace system is then completed using the field data.
- If the alignment and design have been developed from contour map information, the layout must be transferred to the field using the geographic referencing developed and the design checked for accuracy compared to actual field conditions. The surveying techniques required to locate the alignment lines in the field from the design developed from a topographic survey normally requires the use of a total station or global positioning equipment.

Figure 8–31 Typical parallel alignment layout



(e) Flat channel (level) terrace alignment

The term “level” refers to the practice of locating the toe of the terrace ridge along a constant existing ground elevation. The horizontal spacing between terraces is allowed to vary up to the point of the maximum spacing that provides the required erosion protection. A level alignment is normally used only for terraces that have a main purpose of moisture conservation or on soils with very high infiltration rates such as loess soils. The level channel grade line provides a wide broad pool to pond water for soil infiltration. This type of terrace is normally constructed on flat slopes with a large spacing between terraces; therefore, the variable spacing does not significantly impact cropping efficiency (fig. 8–32).

(f) Flat channel (level) alignment layout

The level terrace alignment is normally done in the field with a level. The key terrace is typically located at the midpoint of the slope. The key terrace alignment is located by starting at the edge of the field at a chosen grade line elevation and then surveying a level line marked at 100-foot intervals across the field. The remaining terrace alignments are then located by additional level lines at the design spacing from the key terrace. If the maximum allowable spacing for erosion control is exceeded anywhere between the terraces the alignment is reset starting with a narrower spacing.

Figure 8–32 Terraces with level alignment



650.0806 Terrace spacing

Terrace spacing is based upon protection of the field from sheet and rill erosion. The terrace system reduces sheet and rill erosion by decreasing the erosive slope length and limiting rill watershed size. The crop management system planned for the field is an important factor in sheet and rill erosion prediction. Terrace construction requires a significant capital investment and results in long-term modification of the field. For this reason, the terrace system spacing should be based on the most erosive cropping system the producer will use during the design life of the terrace system. The NRCS currently specifies a minimum design life of 10 years for the terrace conservation practice.

Two means of determining terrace spacing may be used. The preferred method is a site-specific evaluation of the sheet and rill erosion potential of the planned terrace spacing using the current NRCS sheet and rill erosion prediction technology.

The second method is the use of an empirically based maximum spacing calculation developed by the Soil

Conservation Service (SCS) in the 1950s called the vertical interval equation (VI) equation.

(a) Terrace spacing based on erosion prediction tools

The maximum spacing allowed for the terrace system is based on the NRCS planning criteria for the maximum allowed sheet and rill erosion rate for the site. This value is the tolerable soil loss (T). The T values are soil specific and are specified in the FOTG, section II.

Revised Universal Soil Loss Equation, Version 2 (RUSLE2) is the current technology used by the NRCS to calculate site-specific sheet and rill erosion based upon local climate, field soils, planned cropping system, and existing land slope. The Profile Module of RUSLE2 is used to predict the sheet and rill erosion rate of a specific terrace shape and spacing interval for a planned terrace system. The calculation of the sheet and rill erosion rate for each terrace interval is performed by modeling the conditions created by application of the planned terrace system and crop management system. Figure 8-33 shows the input screen of the RUSLE2 Profile Module.

Figure 8-33 RUSLE2 Profile Module input screen

The use of the RUSLE2 Profile Module has the benefit of directly accounting for the effect of changes to the existing ground slope associated with various terrace shapes and properly accounting for the grassed-slope sections of steep-backslope and narrow-base terraces.

The terrace system designer selects a trial spacing based upon previous design experience in the region. Where a parallel alignment is planned the spacing selected should be a multiple of the planned machinery width for the farmable interval.

The first step in the sheet and rill erosion calculation is entry of a land profile in the topography feature. The profile entered represents the terrace and existing land slope for the planned terrace interval from the upslope terrace ridge or watershed break to the downslope terrace ridge. The profile is constructed by placement of a typical cross section of the terrace shape planned on the steepest land slope found in the terrace interval.

Figure 8–34 shows an example of a profile for a steep-backslope terrace interval located in Lancaster

County, Nebraska. Note that the profile includes the back-cut slope formed as a result of the terrace ridge construction and that a negative slope is used to represent the ridge front slope.

The soil types that occur along the profile are selected using the soil feature. Figure 8–35 shows the soil selected for the example.

The management feature is used to input the crop and tillage system planned for the field. The type of crop along the profile may be varied allowing for the inclusion of the permanent grass cover used with steep-backslope or narrow-base shapes. Figure 8–36 shows the management selected for the steep backslope example.

The tolerable soil loss (T) rate, plan soil loss rate, and sediment delivery rate to the terrace channel are displayed in the output. Figure 8–36 shows the highlighted values for the steep-backslope terrace example. If the predicted soil loss exceeds the T value, a new system must be planned using either a narrower spacing

Figure 8–34 RUSLE2 steep-backslope terrace profile example

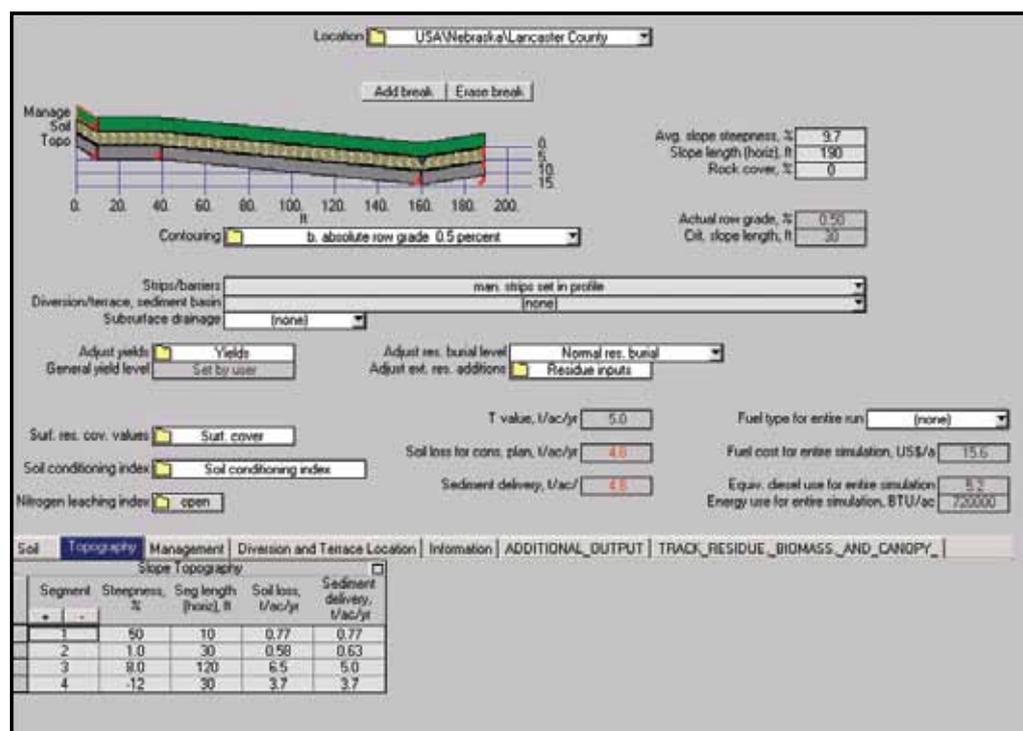


Figure 8-35 RUSLE2 profile soil selection

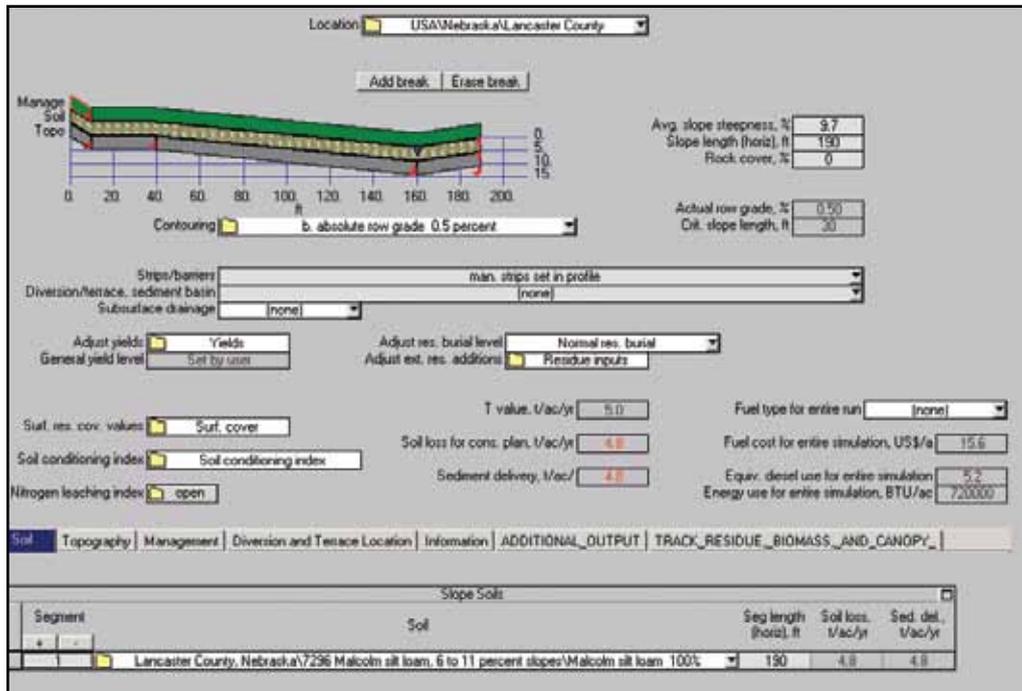
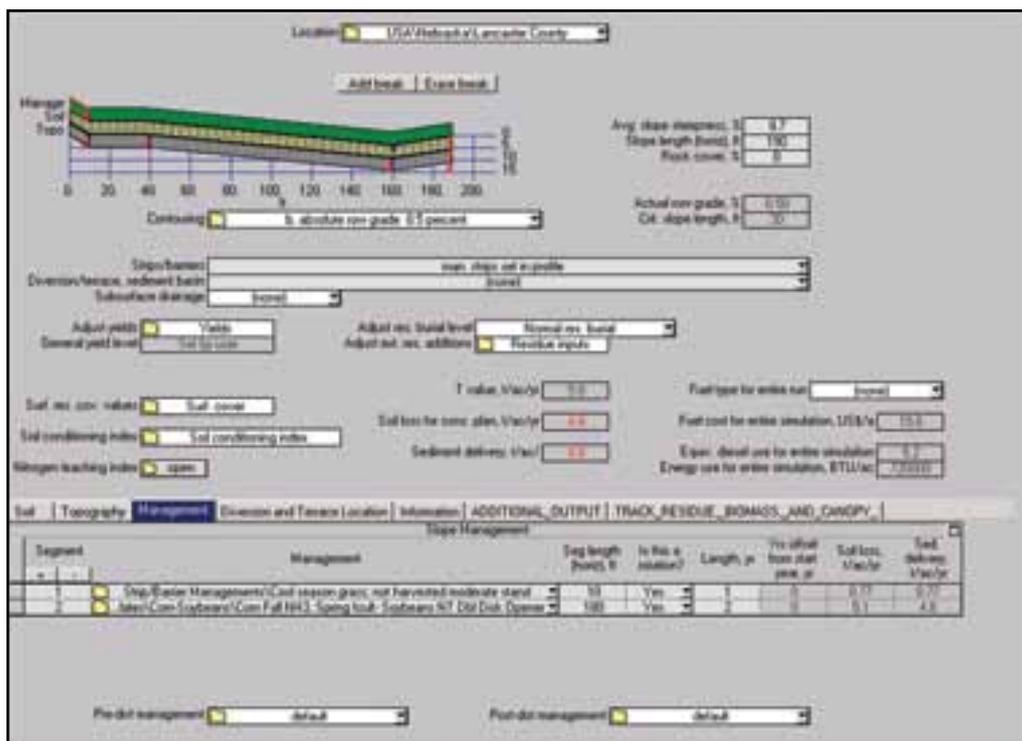


Figure 8-36 RUSLE2 profile management selection



or less erosive management system. If the soil loss is significantly below T , a wider spacing or more erosive management system may be planned.

Repeated use of the tool will allow the planner to develop a local database and experience level that results in an initial selection of a terrace spacing that is optimized for local climate, soils, and management conditions. The RUSLE2 screen (fig. 8–37) shows the soil loss and sediment yield for the planned terrace spacing.

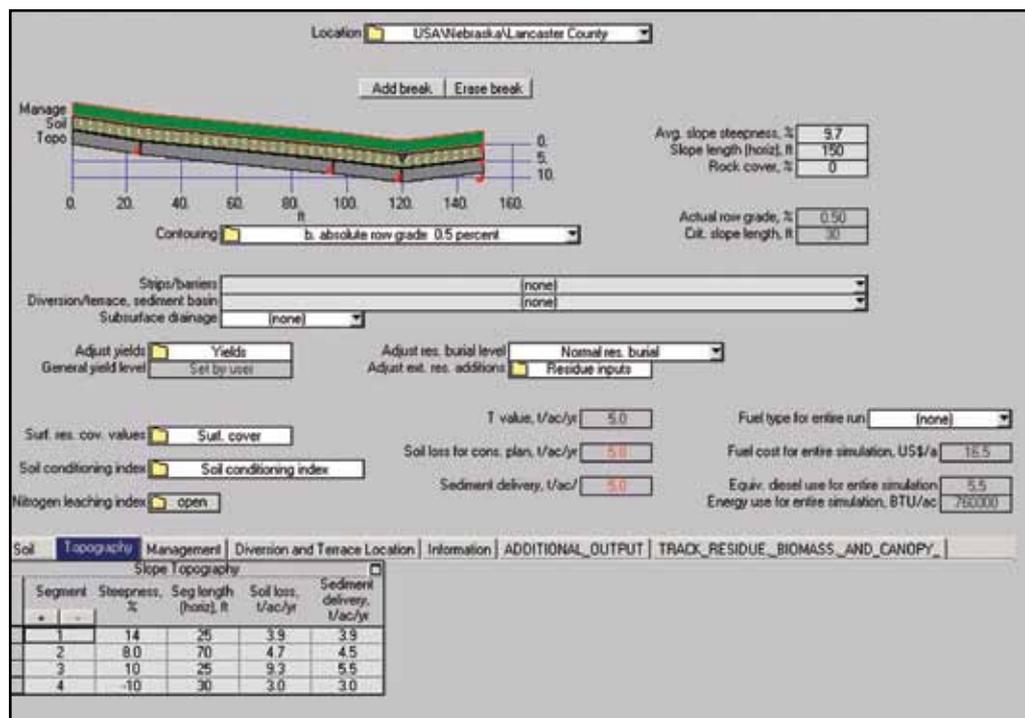
The ridge-to-ridge horizontal spacing of the profile used in the RUSLE2 calculations is not exactly the same as the terrace spacing term shown in figure 8–11. The terrace spacing shown in figure 8–11 is the distance between terrace alignment lines, which are normally located at the toe of the terrace ridge front slope. However, for most terrace systems, the horizontal distance between the terrace ridges is approximately the same as the horizontal distance between the terrace ridge toes. Therefore, the ridge-to-ridge spacing

used in the RUSLE2 calculations may be used as the alignment terrace spacing.

(b) Terrace spacing based on the VI equation

The complete history of the development of the VI equation is not documented. An early version of the method was first published in the 1930s in USDA Farmers' Bulletin Number 1669. The bulletin contains a chart showing recommended spacing for terraces with values based on a VI equation, $VI = 2 + S \div 4$. Values are given for the Southern and Northern United States. The table is attributed to Ramser (1931), who worked for the SCS and is described as "the engineer in charge of soil erosion experiment farms in the United States Department of Agriculture." The SCS references the use of the method in several 1950 to 1966 publications with updates of the values used in the equation based on geographical factors. The basis of these updates is not recorded.

Figure 8–37 RUSLE2 profile predicted soil loss



The current version of the equation with recommended factor values was published in 1969 in the SCS Engineering Field Manual. The maximum Y value recommended in this version was 2.0. Over the last 40 years, several States where this methodology is still used have adopted an increased maximum value for Y of 4.0 based on high residue tillage systems. The values of Y recommended here have incorporated these changes.

The VI equation spacing method has a basis in sheet and rill erosion prediction. However, it is not soil, cropping system, or rainfall specific. The slope used in the equation is the existing land slope and, therefore, does not account for the effect of terrace shape on the constructed land slope. In most cases, the maximum terrace spacing calculated using the VI equation will be more conservative (narrower) than those calculated using RUSLE2.

$$VI = XS + Y \quad (\text{eq. 8-1})$$

where:

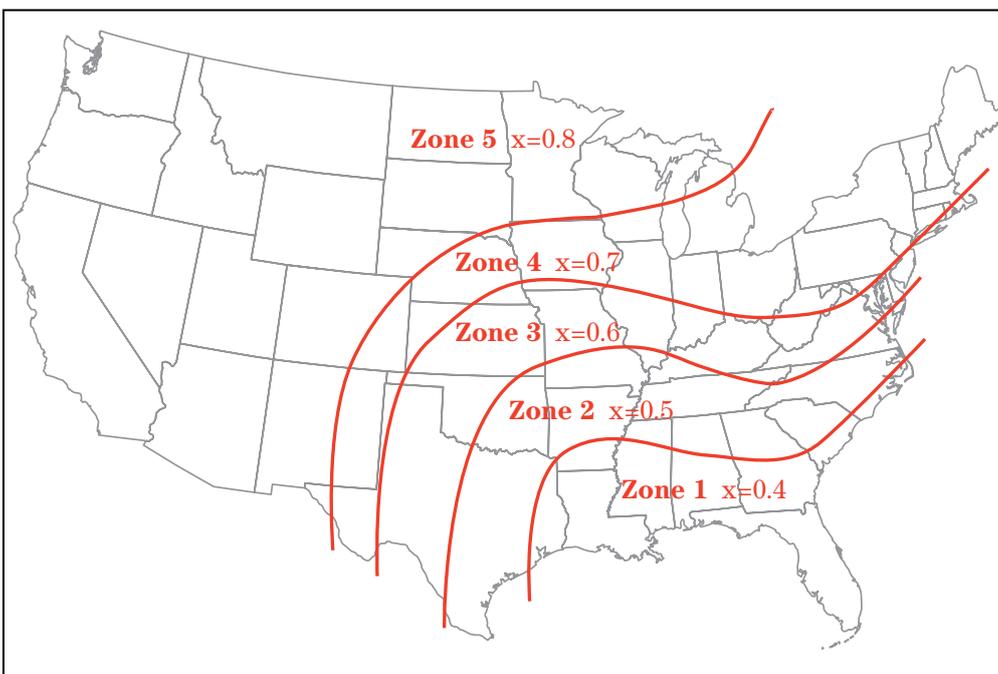
VI = maximum vertical spacing between terrace channels, ft
 X = a variable with values from 0.4 to 0.8 for graded terraces and 0.8 for level terraces. The value of X is determined based on the geographical zones shown in figure 8-38.

S = land slope in ft/100 ft = % land slope

Y = a variable with values from 1.0 to 4.0 ft, as influenced by soil erodibility, cropping systems, and crop management practices. The recommended values for Y are:

- 1.0 foot for erosive soils with below average infiltration rates and cropping systems that provide little cover during intense rainfall periods
- 4.0 feet for erosion resistant soils with tillage systems that have 30 percent or more cover at planting time.
- 2.5 feet where one of the factors is favorable and the other is unfavorable
- Other factors between 1.0 and 4.0 feet may be used according to the estimated quality of the factors.

Figure 8-38 Value of X in equation VI=XS+Y



The VI distance can be used to determine the terrace alignment in the field. However, the allowable horizontal interval shown in figure 8–11 is the value normally desired, especially where spacing will be set at even intervals of machinery width. The VI equation may be rearranged in the following form to yield a horizontal interval equation.

$$HI = (XS + Y) \left(\frac{100}{S} \right) \quad (\text{eq. 8-2})$$

where:

HI = the maximum terrace horizontal interval in ft.
The portion of the terrace spacing defined as the horizontal interval varies based on terrace shape. Figure 8–11 shows the definition of horizontal interval by terrace shape.

X, S, and Y have the same definitions as used in the VI equation.

Figure 8–11 illustrates that the horizontal interval is not the same as the terrace spacing used for the terrace alignment. For broadbase shapes, the terrace spacing is determined by adding the ridge front slope width and channel bottom width to the horizontal interval. For steep-backslope and narrow-base shapes, the terrace spacing is determined by adding the ridge backslope and front slope widths to the horizontal interval.

An example of terrace spacing calculated using the VI equation for the same location, land slope, and cropping system used for the RUSLE2 examples is:

VI calculation:

X = 0.7 from figure 8–38 based on Lancaster County, Nebraska, location

S = 8.0% existing land slope from example

Y = 4.0 based on a corn soybean rotation with greater than 30 percent cover at planting and soil with an erodibility factor (K) of 0.43

$$\begin{aligned} VI &= .7 \quad 8 + 4 \\ &= 9.6 \text{ ft} \end{aligned}$$

Horizontal interval calculation:

$$\begin{aligned} HI &= (XS + Y) \left(\frac{100}{S} \right) \\ &= (0.7 \times 8 + 4.0) \left(\frac{100}{8} \right) \\ &= 120 \text{ ft} \end{aligned}$$

Terrace spacing calculation:

For the broadbase terrace example:

$$\begin{aligned} \text{Terrace spacing} &= HI + \text{front slope width} \\ &= 120 + 30 \\ &= 150 \text{ ft} \end{aligned}$$

For the steep-backslope terrace example:

$$\begin{aligned} \text{Terrace spacing} &= HI + \text{backslope width} + \\ &\quad \text{Front slope width} \\ &= 120 + 10 + 30 \\ &= 160 \text{ ft} \end{aligned}$$

(c) Adjustment of terrace spacing based on machinery width

Terrace spacing for parallel alignment terraces should be adjusted to a farmable interval as defined in figure 8–11 equal to a multiple of the commonly used equipment farming width. If the terrace ridge is too steep to cross with farm equipment and access is limited to one location, an even multiple of the equipment widths should be used to provide round trip conditions. The terrace spacing for the farmable interval selected must then be less than or equal to the terrace spacing required for erosion control.

Row crop planting equipment is available in 4- or 6-row multiples of the commonly used row spacing of 30 inches. Therefore, the equipment width is available in multiples of 10 or 15 feet. The most commonly used is 8- to 24-row equipment.

Spraying equipment is available in the same multiples of row widths as planting equipment. However, the producer's spraying equipment is normally larger than planting equipment.

Harvesting equipment is available in the same row multiples as planting equipment. However, the operator's harvesting equipment is normally smaller than the planting equipment.

Planting and spray equipment may have flex points that allow it to operate centered on broadbase terrace ridges.

The designer must work with the landowner to determine what farmable interval for a terrace system is best suited to the operator's equipment versus the spacing required to prevent erosion. It may not be possible to efficiently operate the largest equipment available on steep terraced fields.

650.0807 Terrace outlets

The water intercepted by the terrace must be discharged to a stable and adequate outlet. The following types of outlets are used for terrace systems.

(a) Surface outlets

Surface outlets for terraces are designed to discharge the peak flow for the design storm from the terrace channel in a stable nonerosive condition. In most cases, the 10-year-frequency, 24-hour-duration storm is used for the design of terraces. In all cases, follow local laws pertaining to surface water discharges in the design of the terrace outlet.

(1) Grassed waterway

The most common surface outlet for a terrace is a grassed waterway. The grassed waterway is generally located along the existing low point(s) of the field watershed(s). Figure 8-39 shows typical grassed-waterway outlets for a gradient terrace system. The grassed waterway is designed from the uppermost terrace to a stable outlet. The stable outlet may be another grassed waterway or a road culvert, grade control structure, stable open channel, or existing stable watercourse.

Figure 8-39 Grassed waterway terrace outlet



The grassed waterway should discharge at the natural watershed outlet and should not divert water to a different watershed. In some cases, the location of property lines may require that the grassed waterway serve only a portion of the natural watershed and that the waterway be located parallel to the property line. In this case, the waterway should be terminated in a manner that returns the flow to the same outlet as the cut-off portion of the watershed.

When it is feasible, construct the grassed waterway outlet and establish vegetation prior to construction of the terraces. Establishment of the grassed waterway vegetation prior to the introduction of concentrated flow from the terraces significantly reduces gully erosion problems during the grassed waterway vegetation establishment period.

Chapter 7 of this handbook contains the design procedures for grassed waterways. An NRCS computer program for grassed waterway design is also available in the Engineering Field Tools suite of programs.

Determine the design grade line for the grassed waterway in conjunction with the terrace grade line design. The grassed waterway grade line should be located slightly lower than the terrace grade line to prevent sediment deposition at the junction. Set design reaches for the grassed waterway based on the location of the terrace junctions and grade line changes. Base the required grassed waterway flow capacity for each design reach on the accumulated terrace channel design discharge at each junction.

(2) Existing road ditch

In some cases, an existing road ditch may be a potential outlet for the terraces. The road ditch should not be used as an outlet at locations where additional watershed would be diverted to the road ditch by construction of the terrace. The road ditch must have adequate capacity for the terrace design storm. The discharge from the terrace must not create an unstable channel condition in the road ditch. In all cases, follow State and local laws prior to using the road ditch as a terrace outlet.

(3) Existing stable field border

In some situations, the terrace channel may be terminated at the field border into a permanently vegetated area. In this situation, it is recommended that a flow spreader be constructed to prevent gully forma-

tion from the concentrated flow at the terrace channel outlet. A flow spreader is a level pad that allows flow to discharge as sheetflow over a level lip area. Evaluate the area downstream of the outlet to determine that the vegetated area will remain stable with the increased flow.

(4) Advantages of surface outlets

- The most significant advantage of a surface outlet is that no temporary water storage is required in the terrace channel. This reduces the ridge height of the terrace to that required to carry the peak flow of the 10-year-frequency, 24-hour-duration rain storm. In many cases, this will be less than the specified minimum ridge height.
- The terrace design is significantly simplified, and the terrace is constructed based on the minimum size criteria. Terraces with surface outlets will normally require significantly less earthwork than terraces with UGOs.
- Since surface outlets do not require temporary water storage, crops are not subject to temporary flooding from stored water. With stored water, some crop damage may occur in the temporary storage pool even though the water is released within the design storage time.
- The cost to construct grassed-waterway outlets may be less than the cost to construct UGOs. This is dependent on the required size and length of the UGO and the grade and length of the grassed waterway. A site-specific analysis is needed to determine which is most cost effective.

(5) Disadvantages of surface outlets

- From a producer's viewpoint, the main disadvantage of grassed-waterway outlets is the reduction of crop area within the field. Grassed waterways typically reduce the crop area of a field by 5 to 10 percent.
- Grassed waterways are susceptible to herbicide damage and, therefore, require extra effort to apply herbicides to the cropped area only.
- Grassed waterways disrupt the cropping pattern and, therefore, require slightly more time for all of the cropping operations.
- If the grassed waterways are not properly maintained and become gullied, they become a hazard to cross with farm equipment.

(b) UGOs

UGOs discharge the terrace design storm through a buried conduit. The outlet consists of three components: the underground conduit, the inlet to the underground conduit, and a temporary water storage pool. Figure 8–40 shows a typical UGO terrace system. The storage pool is used to temporarily store a portion of the runoff from the design storm, typically a 10-year-frequency, 24-hour-duration storm. This reduces the discharge rate required for the underground conduit significantly from the 10-year storm peak runoff rate. The conduit inlet is used to control the discharge to the underground conduit. In most cases, the flow rate is limited to a rate which will not cause pressure flow in the downstream underground conduit. The underground conduit is used to transport the discharge to a stable surface outlet such as an open-channel, road-culvert, or grade-control structure.

The use of UGOs along with parallel terraces has steadily increased in the Midwestern States. Many existing gradient terrace systems have been reconstructed with UGOs.

Detailed design procedures for UGOs are given in section 650.0808.

Figure 8–40 UGO terrace system

**(1) UGO advantages**

- The main advantage of UGOs is minimal loss of crop area. The use of UGOs allows most of the field to be cropped. A minimal amount of area around the conduit inlet is lost to cropping.
- The use of UGOs simplifies cropping operations such as herbicide and fertilizer application.
- The use of UGOs allows for discharge points outside of the natural lows in terrain. This allows for easier design of parallel terrace systems.
- The temporary water storage required for UGOs provides reduction of peak flow rates to downstream areas.
- Soil loss from the field is reduced due to the trapping of sediment in the temporary storage pool.

(2) UGO disadvantages

- The required temporary storage pool significantly increases the terrace ridge height in the pool areas. This significantly increases the earthwork needed to construct the terraces.
- Most State practice specifications require that the runoff from the design storm must be removed within 48 hours. In many cases, 24-hour flooding duration is used for UGO design. Some crop damage may occur in the pool area even with 24-hour duration flooding.
- The conduit inlets are subject to plugging with crop residues and damage from farm equipment. Care must be taken to maintain them in open working condition to allow the pool area to drain properly and prevent crop damage.
- UGOs can act as a direct conduit to carry pollutants such as sediment and nutrient runoff from crop land directly to receiving streams.

(c) Soil infiltration

Soil infiltration may be used to remove the runoff from the design storm in certain conditions. Soil infiltration is the normal outlet used in arid areas where runoff is low and the main purpose of the terrace is water conservation. Soil infiltration is also used in more humid regions where the soil has a very high infiltration rate, such as loess soils. The surface area of the temporary water storage and soil infiltration rate must be such that the runoff from the design storm will infiltrate the

soil within 48 hours. Most terraces are designed for the 10-year-frequency, 24-hour-duration storm.

Soil infiltration rates are difficult to predict with certainty. Local experience gained from previous terrace installations is normally used to determine what climate and soils conditions are required for the success of soil infiltration.

Figure 8-41 UGO system storage pool



650.0808 UGO design

The design of UGOs requires a balancing of the three system components (figs. 8-41, 8-42, and 8-43):

- storage pool volume
- inlet type and size
- underground conduit type and size

Figure 8-42 UGO system inlet



Figure 8-43 UGO system conduit



(a) UGO design procedure

The following procedures are used to design the UGO system.

Step 1 Determine the required average discharge rate and storage volume for each storage pool based on the desired storage pool release time.

Step 2 Determine the total pool volume required for each storage pool based on the storage volume plus any required sediment storage volume.

Step 3 Determine the storage pool depth at each inlet based on the total pool volume, planned channel grade line, planned terrace and channel shape, and existing ground shape.

Step 4 For nonpressure flow outlet designs where the discharge is controlled with an inlet orifice plate.

Determine the required inlet control orifice diameter based on the average discharge rate and orifice head equal to the pool depth times the head reduction factor plus the orifice depth below the pool bottom.

Step 5 Determine the conduit design reaches based on conduit flow type.

For nonpressure flow conduits, the design reaches are based on the outlet point, inflow points, and conduit grade line changes.

For pressure flow conduits, the design reaches are based on the outlet point and inflow points.

Step 6 Determine the required conduit size for each conduit design reach using the maximum pool discharge rates.

For nonpressure flow conduits, the maximum pool discharge rate equals the flow rate for the orifice size calculated in step 4 with an orifice head equal to the pool depth plus the orifice depth.

For pressure flow conduits, the maximum pool discharge rate is approximately equal to the average discharge rate.

Step 7 Determine the required inlet size based on the planned inlet type, pool depth, and average discharge rate.

The designer may wish to refine the design with new parameters to optimize the design for selected design components. For example, minimum conduit size may be achieved with increased release times or reduction in conduit grade line variation. Full use of nonpressure flow conduit capacity may be achieved with variation of pool release times. Minimal pool depths may be achieved with reduction of release times or increases in terrace channel bottom width.

Numerous designs will fall within the practice standard minimum design criteria. The designer's responsibility is to select a design that is well balanced for the site conditions of each terrace system.

The following sections provide hydrology and hydraulic calculation procedures for each of the UGO system components.

(b) Storage pool volume calculations

The storage pool volume is determined by first calculating the volume of runoff from the design storm for the watershed contributing to each pool area. In most cases, the 10-year-frequency, 24-hour-duration storm is used for the design of terraces. Runoff is calculated using the NRCS runoff curve number (RCN) procedure. This may be accomplished using procedures found in chapter 2 of this handbook.

To determine the runoff volume of the design storm, the RCN and watershed area for the storage pool must be determined. The RCN selected should represent the most intense cropping systems planned during the design life of the terrace system. The watershed area should include any area coming into the ends of the terrace system or from above the field boundary that drains to the storage pool.

Two methods may be used to determine the storage pool volume from the calculated volume of runoff. A conservative method is to set the storage pool volume equal to the runoff volume from the design storm. A less conservative but more accurate method is to use a flood routing procedure that accounts for the discharge occurring from the pool area during the design storm. A precise flood routing can be done using stage versus discharge data for each pool area and outlet. However, in most cases, this is not practical for each small terrace storage area.

A simplified flood routing procedure not requiring this data is documented by Caldwell (1985) in the American Society of Agricultural and Biological Engineers, (ASABE) paper 85-2544 "Determination of Storage Requirements for Underground Outlet Terraces in the Midwest." Figure 12 of ASABE paper 85-2544 was matched with a curve fitting equation to develop equation 8-3. This equation may be used to determine the temporary storage pool volume. Note that the units of storage pool volume are acre-feet, while the units of runoff volume are acre-inches.

Storage pool volume

$$V_s = 0.0221 \frac{(V_r^{1.272})}{(Q_A^{0.272})} \quad (\text{eq. 8-3})$$

where:

V_s = volume of storage, acre-ft
 V_r = volume of runoff, acre-in
 Q_A = average discharge rate, ft³/s

(c) Storage pool release time calculations

The time required to drain the storage pool is referred to as the "release time." The release time may be calculated from average discharge rate (Q_A) and the runoff volume (V_r) using the volumetric relationship given in equation 8-4.

Storage pool release time

$$T_{\text{rel}} = \frac{1.008V_r}{Q_A} \quad (\text{eq. 8-4})$$

where:

T_{rel} = release time, h
 V_r = volume of runoff, acre-in
 Q_A = average discharge rate, ft³/s

(d) Average release rate calculation

Equation 8-5 is used to express the average discharge rate as a function of the runoff volume and release time.

Average discharge rate

$$Q_A = \frac{1.008V_r}{T_{\text{rel}}} \quad (\text{eq. 8-5})$$

where:

Q_A = average discharge rate, ft³/s
 V_r = volume of runoff, acre-in
 T_{rel} = release time, h

(e) Storage pool sediment volume calculation

During the design life of the practice, the water storage volume in the temporary storage area may be significantly diminished from build up of sediment trapped in the pool area. This reduction in storage volume should be accounted for when determining the required storage. This is done using equation 8-6.

Storage pool sediment volume

$$V_{\text{sed}} = \frac{0.046T_e L S_{\text{loss}} A}{\gamma_{\text{sed}}} \quad (\text{eq. 8-6})$$

where:

V_{sed} = volume of sediment, acre-ft
 T_e = sediment trap efficiency factor
 L = design life, yr
 S_{loss} = watershed soil loss rate (tons/acre/yr)
 A = watershed area (acre)
 γ_{sed} = sediment dry density (lb/ft³)

The watershed soil loss rate is determined using the current NRCS erosion prediction tool based on the planned cropping system and terrace spacing. The trap efficiency for the small temporary storage basins is dependent upon sediment size and detention time. Table 8-4 provides suggested trap efficiency factors for various general soil types.

Table 8-4 Sediment trap efficiency factor by general soil type

General soil type	Trap efficiency factor
Sandy	1.0
Silt loam	0.9
Clay	0.8

The sediment dry density may be estimated from soil survey data. A reasonable default value for sediment dry density is 90 pounds per cubic feet.

(f) Storage pool depth calculation

The total pool volume equals the volume of storage plus the volume of sediment.

Total pool volume

$$V_t = V_s + V_{\text{sed}} \quad (\text{eq. 8-7})$$

where:

V_t = total pool volume, acre-ft

V_s = volume of storage, acre-ft

V_{sed} = volume of sediment, acre ft

The storage pool depth (P_D) is defined as the pool depth at the inlet where the total pool volume calculated by equation 8-7 occurs.

Pool volume versus pool depth is calculated from the planned terrace cross section, planned channel grade line, and existing ground surface. The calculation of the pool volume can be done in a number of different ways. A common procedure called the average end area method can be done by hand or programmed into a spreadsheet or other computer program to speed the process. This method requires determining the cross-sectional area of the storage pool at different stations along its length. The area of two adjoining stations are averaged and then multiplied times the distance between the stations to determine the volume between the stations. The larger the number of cross sections that are used, the more accurate the calculation.

Other computer programs, such as the NRCS Terrace Design Tool, calculate volume by determining the volume between the existing ground surface and the designed pool surface.

Where the only ground surface data available is the ground at the channel grade line, average land slope can be used to represent the ground surface. This method is not recommended since the land slope is seldom uniform and significant difference can occur between the assumed condition and the actual field condition.

The volume of storage available at the planned pool depth is a critical UGO design factor. It is recommended that adequate field data be collected to allow estimation of the storage volume versus pool depth with less than 20 percent error.

(g) Control orifice size calculation

For nonpressure flow outlets, a circular orifice is placed in the inlet riser to control the release rate. The orifice equation is used to calculate the orifice hydraulic parameters.

Orifice equation

$$\text{Flow rate (Q)} = Ca(2gh)^{\frac{1}{2}}$$

where:

Q = flow rate pool average discharge rate, Q_A , ft³/s

C = orifice coefficient, 0.6 for circular sharp-edged orifices

a = orifice cross-sectional area, ft²

g = acceleration of gravity, 32.2 ft/s²

h = orifice head, ft

The release time for water stored in the terrace is based on an average discharge rate, Q_A . Therefore, the orifice size should be determined based on the average flow rate under average flow conditions. The determination of "average flow conditions" and the head this represents on the orifice is not clear cut. For a terrace storage area that is triangular or nearly triangular in cross section, the head can be approximated by the location of the centroid of the triangular area, which will be 0.7 times pool depth at the riser. For a storage area, that is trapezoidal in cross section with a wide bottom, the location of the centroid is closer to 0.5 times pool depth at the riser.

When deciding on the head to use to design the orifice, consider that using a larger head value will result in a smaller orifice, while a lower head will result in a larger orifice. A smaller orifice will provide more protection of the UGO against pressure flow, but it will result in a slower drawdown of storage pool and a slightly higher risk of exceeding the storage capacity of the terrace and over topping. A larger orifice will have the opposite effect.

The orifice head equals the orifice depth below the pool bottom (O_D) plus the pool depth (P_D) times the head reduction factor (h_{red}).

$$\text{Orifice head (h)} = O_D + P_D h_{red}$$

The orifice area in (ft^2) may be expressed in terms of the orifice diameter in inches where:

$$\text{Orifice area a (ft}^2\text{)} = 0.0054541d_o^2 \text{ (in)}$$

Substituting values into the orifice equation and simplifying yields equation 8–8.

Control orifice average discharge rate

$$Q_A = 0.02626d_o^2 (O_D + P_D h_{red})^{\frac{1}{2}} \text{ (eq. 8–8)}$$

where:

Q_A = average discharge rate, ft^3/s

d_o = orifice diameter, in

O_D = orifice depth, ft

P_D = pool depth, ft

h_{red} = head reduction factor

Solving equation 8–8 for orifice diameter yields equation 8–9.

Control orifice diameter

$$d_o = \frac{6.17Q_A^{\frac{1}{2}}}{(O_D + P_D h_{red})^{\frac{1}{4}}} \text{ (eq. 8–9)}$$

where:

Q_A = average pool discharge rate, ft^3/s

d_o = orifice diameter, in

O_D = orifice depth, ft

P_D = pool depth, ft

h_{red} = head reduction factor

(h) Underground conduit size calculation

The design of the underground conduit is split into conduits that are suitable for pressure flow conditions and those that are suitable for open channel non-pressure flow. The FOTG CPS Code 620, Underground Outlet, contains State-specific requirements for the

type of conduits that may be used for each flow regime, along with minimum and maximum allowed ground cover.

The most common nonpressure flow conduit type used for terrace UGOs is nonperforated corrugated polyethylene tubing meeting ASTM F405 for 3 to 6 inch diameters or ASTM F667 for 8 to 24 inch diameters. The minimum ground cover is normally specified as 2 feet and the maximum ground cover as 10 feet.

Where pressure flow capability is desired or deep soil cover exceeds 10 feet, PVC pipe with suitable wall thickness and watertight joints to withstand the soil cover and pressure are commonly used.

(1) Nonpressure flow size calculation

To prevent pressure flow, the required flow capacity for each design reach is based upon the maximum pool discharge rate. The maximum pool discharge rate for orifice controlled inlets may be significantly higher than the average pool discharge rate determined. The increase will range from 50 percent where the orifice is located at the pool bottom to 16 percent where the orifice to pool depth ratio is one.

The maximum discharge rate may be calculated using equation 8–10. Experiments have shown that the head inside the riser is less than the head generated by the pool depth. The amount of this reduction depends on the number, location of the holes in the riser, and the percentage of the holes that might be plugged by debris. For a conservative design that provides the most protection against pressure flow, use the full pool depth to determine the head on the UGO. A less conservative design approach based on pool depth reductions of up to 30 percent will result in lower design flows for the UGO, but a higher risk of pressure flow.

Pool maximum discharge rate

$$Q_{Max} = 0.02626 d_o^2 (O_D + P_D)^{\frac{1}{2}} \text{ (eq. 8–10)}$$

where:

Q_{Max} = maximum pool discharge rate, ft^3/s

d_o = orifice diameter, in

O_D = orifice depth, ft

P_D = pool depth, ft

Equation 8–11 is used to calculate the required conduit diameter given the required conduit capacity and grade. The equation is based on the solution of Manning's equation given in chapter 3 of this handbook for full flow in a circular conduit with uniform grade.

Nonpressure flow conduit diameter

$$d_c = 16.02 \left(\frac{Q_{\text{Req}} n}{s^{\frac{1}{2}}} \right)^{\frac{3}{8}} \quad (\text{eq. 8-11})$$

where:

- d_c = conduit diameter, in
- Q_{Req} = required conduit capacity, ft³/s
- s = conduit grade, ft/ft
- n = Manning's n

Solving equation 8–11 for Q gives equation 8–12 which may be used to calculate full flow capacity for a manufactured conduit size.

Manufactured conduit size flow capacity

$$Q_{\text{Cap}} = 0.000613 d_{\text{cMfg}}^{\frac{8}{3}} s^{\frac{1}{2}} n \quad (\text{eq. 8-12})$$

where:

- Q_{Cap} = conduit capacity at full flow, ft³/s
- d_{cMfg} = manufactured conduit diameter, in
- s = conduit grade, ft/ft
- n = Manning's n

Recommended Manning's n values for various conduit types and sizes can be found in chapter 14 of this handbook.

For corrugated polyethylene tubing, the n values in table 8–5 are recommended.

Table 8–5 Corrugated polyethylene tubing Manning's n value

CPE tubing size (in)	Manning's n value
3 to 8	0.015
10 to 15	0.017
18	0.020
21	0.021
24	0.022

These steps are used to determine the conduit size for each design reach.

Step 1 The conduit is divided into design reaches based on changes in the conduit grade or flow input at conduit inlets.

Step 2 The required conduit capacity (Q_{Req}) for each design reach is calculated based on the accumulated inlet maximum discharge rates (Q_{max}) using equation 8–10.

Step 3 The required conduit diameter (d_c) for each design reach is calculated using equation 8–11 based on the required conduit capacity (Q_{Req}).

Step 4 A manufactured conduit size equal to or greater than the required conduit diameter (d_c) is selected. The capacity (Q_{Cap}) of the selected conduit size is documented using equation 8–12.

In some cases, conduits are designed with lateral lines. In this case, the lateral lines are designed first, and the lateral line design flow is treated as a flow input in the development of the main conduit design reaches.

The conduit flow capacity typically doubles between available sizes. This may result in some conduit reaches having significant unused capacity. The designer can attempt to optimize the use of the selected conduit capacity by reducing selected storage pool release times.

The conduit capacity is based on uniform grade line reaches. It is critical that the conduit be installed on the grade line planned. If the conduit is simply installed at a uniform depth from the existing ground, the conduit grade line may deviate significantly from the design grade line. This may result in pressure flow occurring at some points that may result in damage to the conduit.

(2) Pressure flow size calculations

The design of UGOs with pressure flow should be approached with caution. The conduit and joints in the conduit must be capable of withstanding the design pressure. Failure to use appropriate conduit materials can result in complete failure of the UGO.

The flow rate of a conduit with pressure flow is calculated using equation 8–13 based on pipe flow hydraulic principles given in chapter 3 of this handbook.

Pressure flow conduit flow capacity

$$Q_p = a \left[\frac{(2gH)}{(1 + K_e + K_m + K_p L)} \right]^{\frac{1}{2}} \quad (\text{eq. 8-13})$$

where:

- Q_p = conduit discharge rate, ft³/s
- a = conduit flow area, ft²
- g = acceleration of gravity, 32.2 ft/s²
- H = elevation head differential, ft
- K_e = entrance head loss coefficient
- K_m = minor head loss coefficient
- K_p = conduit head loss coefficient
- L = conduit length, ft

A pressure flow condition exists when the inlet head loss or inlet weir flow depth at half of the pool depth is not controlling the flow. This typically occurs when no orifice plate is used in the inlet. The design procedure provided for pressure flow inlets will assure that this condition exists.

For pressure flow conduits, it may be assumed that the conduit flow rate at full pool depth is approximately equal to the flow rate at half the pool depth. This will be true if the pool depth is small compared to the total head. For a typical pressure flow UGO, the total head will be more than three times greater than the pool depth. This will result in less than 7 percent difference between the conduit flow rate at full pool depth versus half pool depth. Therefore, the conduit may be designed using the average discharge rate.

The elevation head differential (H) is equal to the maximum pool elevation minus the water surface elevation at the conduit outlet. The water surface elevation at the outlet is determined based on outlet conditions. For free outlet conditions, the elevation at the midpoint of the outlet may be used. If the outlet is submerged by tail water when the design flow is occurring, the tail water elevation should be used. If the conduit outlets into the inlet of a downstream pool, the outlet elevation equals the maximum downstream pool elevation.

The conduit grade line does not need to be on a uniform grade between the inlet and outlet.

The entrance head loss is based on entrance type. Table 8-6 provides recommended conduit entrance loss coefficients for typical pressure flow inlet types.

Table 8-6 Entrance head loss coefficient by inlet type

Inlet type	Head loss coefficient
Vertical riser with 90° bend	1.0
Conduit with hooded inlet	1.1
Conduit with canopy inlet	1.5

The conduit head loss coefficient may be calculated using equation 8-14 from the conduit Manning's n value and the conduit diameter.

Conduit head loss coefficient

$$K_p = 5,087 \frac{n^2}{d_i^{\frac{4}{3}}} \quad (\text{eq. 8-14})$$

where:

- n = Manning's roughness coefficient
- d_i = conduit diameter, in

The determination of the conduit size requires a trial and error solution in which the available conduit size flow rate is balanced against the desired pool release time.

The following procedures may be used to determine the conduit size.

Step 1 A pipe size is selected with a flow rate (Q_p) calculated using equation 8-13 that is greater than the design average pool discharge rate (Q_A). The elevation head differential (H) is determined from the design pool elevation and the elevation of the water surface at the outlet.

Step 2 The revised storage pool release time (T_{rel}), storage volume (V_s), total storage volume (V_t), and pool depth (P_D) are calculated based on the selected pipe size flow rate (Q_p).

Step 3 The revised head differential (H) is calculated from the change in the pool depth (P_D) in step 2.

Step 4 If the percent change in the head differential (H) in step 3 is less than 5 percent, the design process is complete with the storage pool design data equal to the values calculated in step 2.

If the percent change is greater than 5 percent, the process is repeated starting at step 2 with the pipe discharge rate (Q_p) calculated using the head differential (H) calculated in step (3).

(i) Inlet size calculation

The inlets used for UGOs are manufactured in various sizes and configurations or may be constructed from pipe materials. For nonpressure flow conduits, the inlet controls the pool discharge rate. This is normally achieved through the use of a control orifice in the inlet riser. For pressure flow conduits, the conduit head loss controls the pool discharge rate. The following equations and procedures are used to calculate the required inlet type and size.

(1) Nonpressure flow inlet size calculations

Under nonpressure flow conditions, the inlet is designed to control the discharge rate to the average pool discharge rate at half the pool depth. The typical inlet consists of a circular perforated riser with a circular control orifice located in the riser base. The riser may have a closed top or an open top with a debris screen. Figure 8–44 illustrates the nomenclature used for typical nonpressure flow inlets.

The perforated riser is designed to serve as a debris screen to protect the control orifice from plugging with crop residue. The inlet must be sized with a large

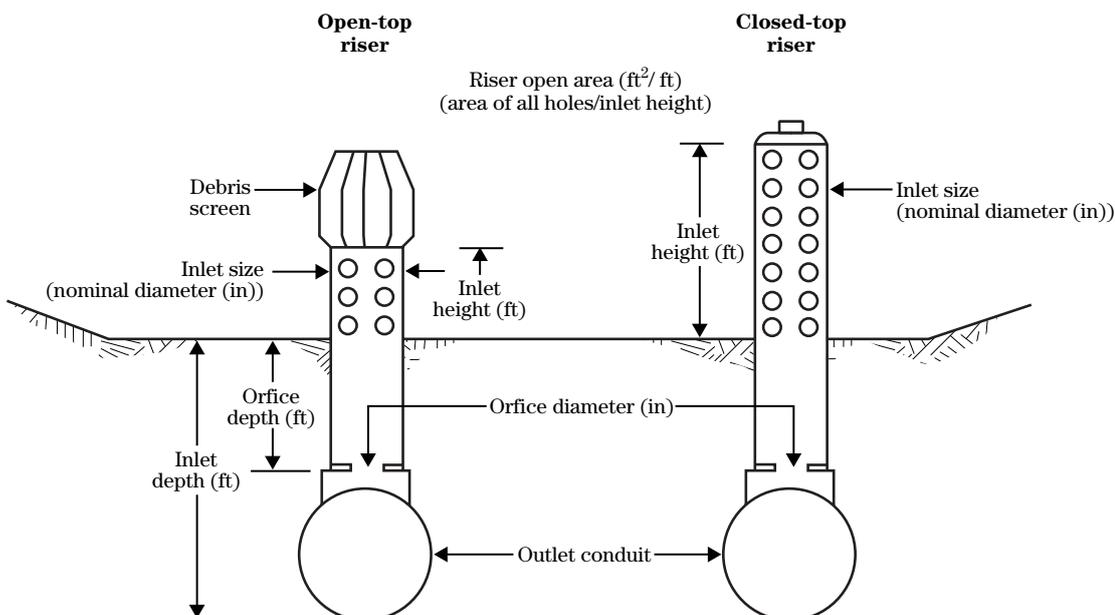
enough opening area to prevent the perforated riser from controlling the discharge rate versus the control orifice. The perforated riser or screened open top should not be used to control the discharge rate since the amount of plugging of the riser perforations or debris screen that can occur is unpredictable.

The flow through the inlet will be controlled by various inlet elements as the depth of water in the pool increases. At low pool depths, the discharge rate will be controlled by the perforations in the riser and the head on the control orifice will remain below the pool bottom. As the pool depth increases, the orifice head will submerge the riser perforations. If an open-top riser is used, as the pool depth increases above top of the riser, the combined perforation and open top weir flow rate will increase rapidly to the point where the weir flow is submerged by the control orifice head. At this pool level, the flow is controlled by the control orifice head.

Figure 8–45 shows the desired head-loss conditions for orifice controlled inlets for closed and open-top risers.

A conservative inlet design procedure can be developed based on the design assumptions that from 25

Figure 8–44 Nonpressure flow inlet nomenclature



percent to 50 percent of the riser perforations and top opening may be plugged and that the head loss through the inlet not exceed 10 percent of the pool depth.

(i) Closed-top riser hydraulics

The following equations derived from the orifice flow equation may be used to calculate the required riser opening area per foot of riser height. The equations assume uniformly spaced circular perforations with an orifice coefficient of 0.6, 25 percent of the riser perforations blocked by debris, and the riser head loss equal to 10 percent of the pool depth.

Closed-top riser opening area ($R_h \leq 0.4P_D$)

$$a_r = \frac{0.876 Q_A}{(R_h P_D)^{\frac{1}{2}}} \quad (\text{eq. 8-15})$$

where:

a_r = perforation cross-sectional area per foot of riser height, ft^2/ft

Q_A = pool average discharge rate, ft^3/s

R_h = riser height, ft

P_D = maximum pool depth, ft

Closed-top riser opening area ($R_h > 0.4 P_D$)

$$a_r = \frac{2.19 Q_A}{P_D^{1.5}} \quad (\text{eq. 8-16})$$

where:

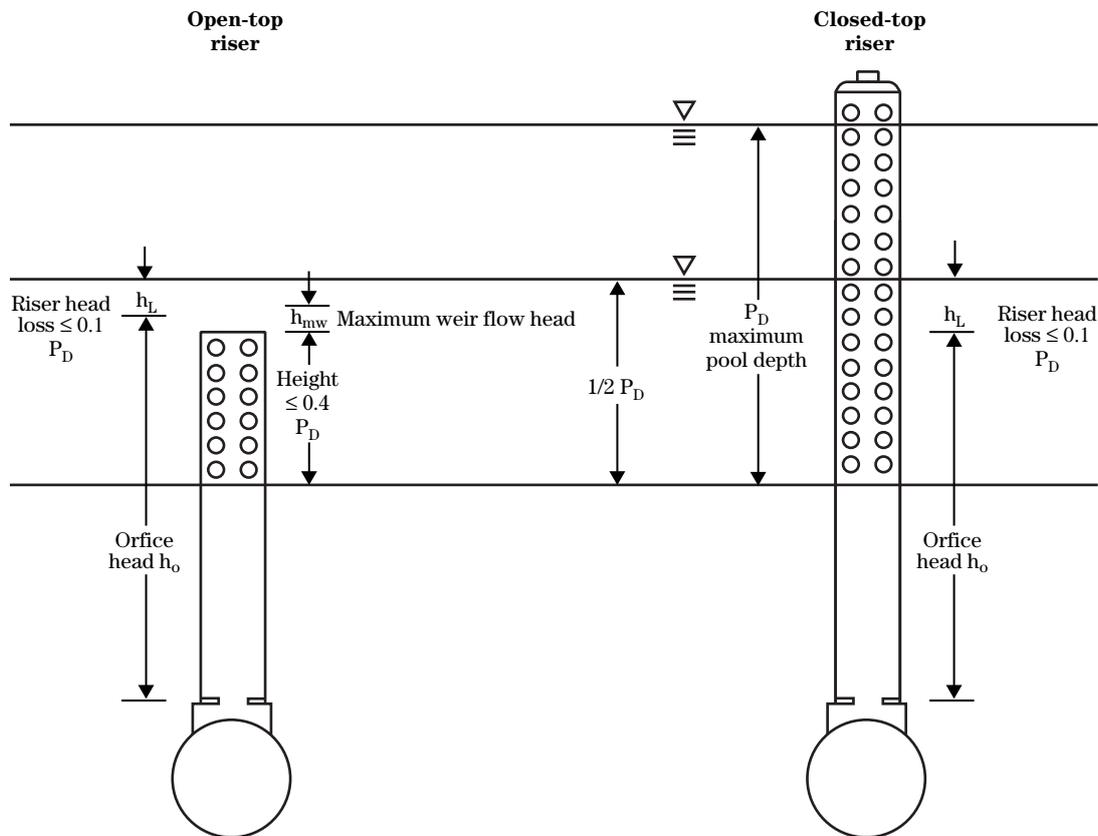
a_r = perforation cross-sectional area per foot of riser height, ft^2/ft

R_h = riser height, ft

P_D = maximum pool depth, ft

Q_A = pool average discharge rate, ft^3/s

Figure 8-45 Orifice control inlet flow conditions



(ii) Open-top riser hydraulics

To take advantage of the top opening, the riser height must be less than half of the pool depth minus the top opening weir flow head at the average discharge rate.

A conservative maximum weir flow depth may be calculated using the weir flow equation with the following assumptions. The top opening is a circular sharp-edged weir with a weir coefficient of 3.2; 25 percent of weir length is blocked by debris.

Maximum weir flow head

$$h_{mw} = 1.363 \left(\frac{Q_A}{d_r} \right)^{\frac{2}{3}} \quad (\text{eq. 8-17})$$

where:

- h_{mw} = maximum weir flow head, ft
- Q_A = pool average discharge rate, ft³/s
- d_r = top opening diameter, in

The riser head loss will be controlled by orifice flow through the top opening and riser perforations where the riser height is less than half the pool depth minus the maximum weir flow head.

Equation 8-18, based on the orifice flow equation, can be used to calculate the required total riser opening area (a_t). The total riser opening area is equal to the top opening area plus the area of all side perforations. The equation assumes uniformly spaced circular perforations, circular sharp-edged top opening, orifice coefficient of 0.6, and 25 percent of the riser openings blocked by debris.

$$\text{Open-top riser total opening area } R_h < \frac{P_D}{2 - h_{mw}}$$

$$a_t = 0.876 \frac{Q_A}{P_D^{\frac{1}{2}}} \quad (\text{eq. 8-18})$$

where:

- a_t = total riser opening cross-sectional area, ft² (riser perforations plus top opening)
- R_h = riser height, ft
- P_D = maximum pool depth, ft
- Q_A = pool average discharge rate, ft³/s

(iii) Nonpressure flow inlet design procedure

The inlet for the nonpressure flow conduit is designed after the average discharge rate (Q_A), maximum pool depth (P_D), and control orifice diameter (d_o) have been determined.

The following procedure is used to select an inlet size.

Step 1 Select a riser type and height.

Step 2 For closed-top risers, determine the required perforation opening area per foot of riser (a_p) using equation 8-15 or equation 8-16, depending on the selected riser height (R_h) and maximum pool depth (P_D). For open-top risers less than half of the pool depth in height, determine the required total riser opening area (a_t).

Step 3 Using the inlet manufacturers specifications, select a riser diameter larger than the control orifice diameter (d_o) that meets or exceeds the calculated opening area per foot (a_p) for closed-top risers or the calculated total opening area (a_t) for open-top risers.

Step 4 For open-top risers, if the maximum pool depth (P_D) minus the maximum weir head (h_{mw}) calculated using equation 8-17 is less than the selected riser height, select a smaller riser height, and repeat step 3.

(2) Pressure flow inlet size calculation

The most common type of inlets used for pressure flow conduits are pipe drop inlets with an antivortex baffle and debris exclusion device, hooded pipe inlets, and canopy pipe inlets (fig. 8-46). The pipe drop requires the least amount of head to operate. The hooded and canopy inlets are easier to construct and install but require greater pool depth to operate. Descriptions and design considerations for each type of inlet is located in chapter 6 of this handbook.

The pressure flow inlet must not control the flow rate at the average discharge rate (Q_A) and half the maximum pool depth (P_D). The following design criteria may be used to assure that this condition exists.

(i) Pipe drop inlets

The pipe drop diameter must be larger than 1.5 times the conduit diameter.

The pipe drop maximum weir flow head (h_{mw}) at the pool average discharge rate (Q_A) must be less than

half the maximum pool depth (P_D). The maximum weir flow head (h_{mw}) may be calculated using equation 8-17.

The pipe drop depth must be greater than 5 times the conduit diameter.

(ii) Hooded inlets

The priming head must be less than half of the maximum pool depth (P_D)

The priming head for a hooded inlet equals 1.8 times the conduit diameter.

(iii) Canopy inlets

The priming head must be less than half of the maximum pool depth (P_D)

The priming head for a canopy inlet equals 1.7 times the conduit diameter.

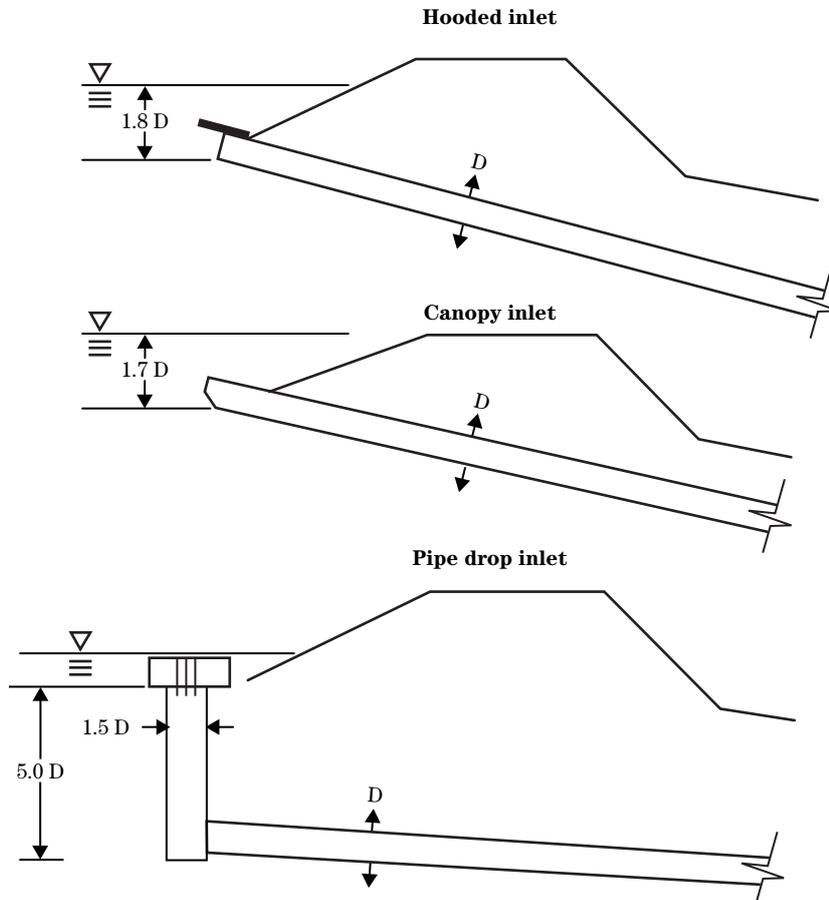
650.0809 Terrace channel design

(a) Terrace channel grade

The minimum terrace channel grade must be sufficient to provide good drainage to the terrace outlet without erosion of the channel soil. A minimum channel grade of 0.1 to 0.2 percent is generally used.

The maximum channel grade is based on the nonerosive velocity of the soil in the terrace channel. The channel velocity for each channel grade design reach must be compared to the soil nonerosive velocity to determine that the channel is stable. The channel de-

Figure 8-46 Pressure flow inlet types



sign flow rate is determined from the channel watershed peak discharge rate. The channel velocity is based on the channel shape and grade. Refer to the grassed-waterway design procedures in chapter 7 of this handbook to determine the velocity of the flow in the terrace channel.

For UGO terraces, as the storage pool begins to fill, the storage pool will drown the channel flow near the inlet. Based on this effect, channel reaches within the pool area may have a steeper grade than the grade allowed for a channel with an open outlet.

For the typical terrace, acceptable channel grades will be less than 1.0 percent. Short channel segments with little watershed at the upper end of the channel may be stable at grades up to 2 percent.

(b) Terrace channel shape

The terrace channel shape is formed by the front slope, channel bottom width, and cut slope or existing ground slope. The channel shape selected is normally based on local customs and design experience. Triangular-shaped channels are commonly used on closely spaced gradient terraces. Three- to fifteen-foot bottom width channels are commonly used on UGO terraces. Level terraces on flat slopes with no outlet may use 60- to 90-foot bottom width channels.

The terrace channel shape chosen effects several terrace design factors. The channel flow velocity is dependent on the channel shape. Increasing the channel bottom width or flattening the slopes will decrease the velocity and allow steeper channel grades. For UGO terraces, the ridge height in the storage pool area is controlled by the storage pool depth. Increasing the channel bottom width will decrease the pool depth and, therefore, the ridge height.

650.0810 Terrace ridge design

The terrace ridge height is based on the required channel flow depth or storage pool depth and minimum ridge height (if required). If a State requires a minimum ridge height, it is normally specified in the State FOTG CPS Code 600, Terrace. The minimum ridge heights are often specified by terrace cross section type and typically fall in the range of 1.0 to 2.5 feet.

For a triangular-shaped terrace ridge, the point on the ridge where the ridge has enough width to prevent water from seeping through is referred to as the “effective ridge height.” All ridge height measurements are made at the effective ridge height. The normal ridge width at the effective ridge height is 3 feet.

(a) Surface outlet terrace ridge height

The design ridge height for surface outlet terraces is based on the terrace channel flow depth. The initial design ridge height for each design reach is set equal to the minimum ridge height.

The terrace channel is divided into design reaches based on channel grade breaks. If the design reaches are long, they may be divided into shorter segments to allow more frequent determination of the required ridge height.

The peak discharge from the design storm is calculated for the watershed at the end of each design reach. The RCN method in chapter 2 of this handbook should be used to calculate the peak discharge rate. The watershed condition used should be the highest runoff producing condition that will exist during the design life of the practice. The channel roughness condition used should represent maximum field residue conditions. The channel flow depth is calculated based on procedures for grassed waterways covered in chapter 7 of this handbook for the peak discharge of the design storm.

If the channel flow depth for the reach exceeds the minimum design height, the design height is set equal to the channel flow depth. Table 8-7 shows an example of the calculated design ridge height data for a typical gradient terrace.

Table 8-7 Design ridge height for gradient terrace

Minimum design ridge height = 1.2 ft
 Channel shape = Triangular with 6:1 side slopes
 Channel roughness n value = 0.04

Station	Channel grade (ft/ft)	Watershed area (acres)	Peak discharge (ft ³ /s)	Channel flow depth (ft)	Design ridge height (ft)
0+00	—	0	0	0	1.2
4+00	0.006	3.2	8	0.9	1.2
8+00	0.005	5.2	14	1.1	1.2
12+00	0.004	7.8	20	1.3	1.3
16+00	0.003	11.5	27	1.6	1.6
21+00	0.002	15.0	34	1.9	1.9

(b) UGO terrace ridge height

For UGO terraces, the design ridge height is based on channel flow depth and storage pool depth. The design ridge height within the pool area will equal the pool depth where the pool depth is greater than the channel flow depth or minimum ridge height. The design ridge height within the pool area is normally determined at 50-foot intervals for construction layout purposes. Table 8-8 shows the calculated design data for a typical UGO terrace.

Table 8-8 Design ridge height for UGO terrace

Minimum design ridge height = 1.2 ft
 Channel shape = Trapezoidal with 6-ft bottom width and 6:1 side slopes
 Channel roughness n value = 0.04
 Storage pool A1 with inlet @ station 8+00 and design pool depth = 2.3 ft

Station	Channel grade (ft/ft)	Watershed area (acres)	Peak discharge (ft ³ /s)	Channel flow depth (ft)	Pool depth (ft)	Design ridge height (ft)
0+00	—	0	0	0	0	1.2
2+00	0.008	0.6	2	0.1	0	1.2
4+00	0.006	1.2	3	0.2	0	1.2
6+00	0.006	1.8	4	0.2	1.1	1.2
6+50	0.006	2.0	5	0.3	1.4	1.4
7+00	0.006	2.1	6	0.4	1.7	1.7
7+50	0.006	2.3	6	0.4	2.0	2.0
Inlet A1	—	4.0	—	—	2.3	2.3
8+50	0.008	1.7	4	0.2	1.9	1.9
9+00	0.008	1.5	4	0.2	1.5	1.5
9+50	0.008	1.4	3	0.1	1.1	1.2
12+00	0.008	0.6	2	0.1	0	1.2
14+00	0.010	0	0	0	0	1.2

(c) Flat channel (level) terrace ridge height

The flat channel (level) terrace has one design pool depth with no terrace channel grade. Therefore, the design ridge height is equal to the greater of the design pool depth or minimum ridge height.

- fill pushed up by bulldozer with little compaction—15 percent
- fill placed with some lateral movement and compaction—10 percent
- fill moved laterally with scraper with good compaction—5 percent

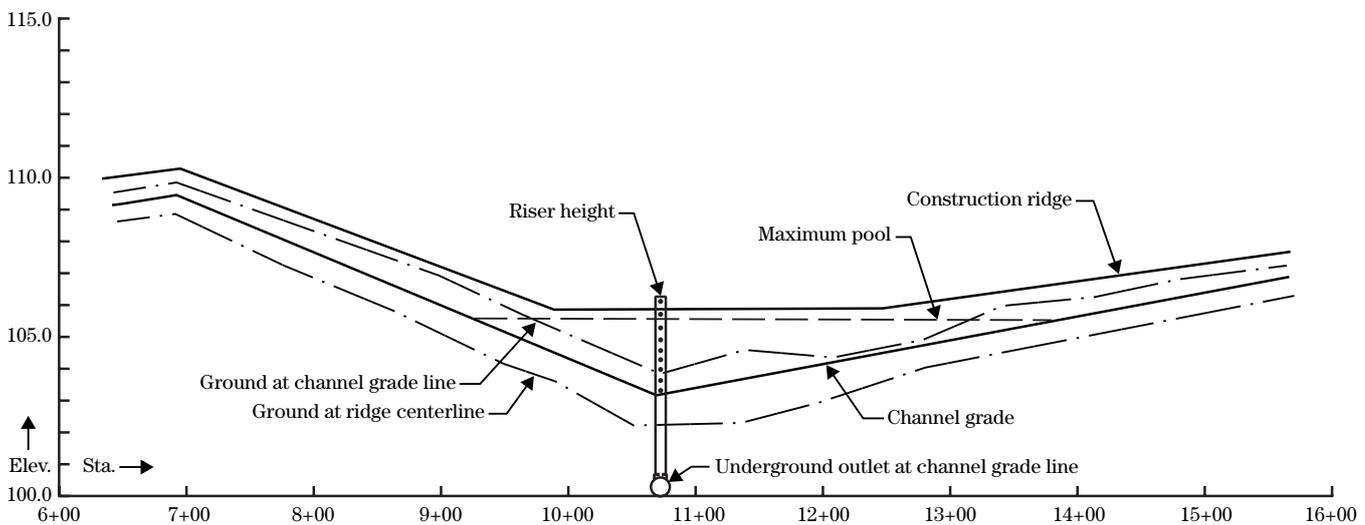
(d) Terrace ridge construction height

The terrace ridge construction height is the constructed height of the ridge, allowing for future settlement of the ridge. The amount of settlement allowance required is based upon the construction method and ridge centerline height above the existing ground. The following are typical settlement allowances by construction method:

The ridge centerline height will be significantly larger than the design ridge height. This effect will be greatest on steep ground slopes. The construction ridge height is calculated by adding the ridge centerline settlement allowance to the design ridge height.

Figure 8–47 shows a profile view of a typical UGO terrace with the relationship between all of the ridge height design elements.

Figure 8–47 Typical UGO terrace profile view



650.0811 Terrace construction methods

The location from which soil is borrowed to construct the terrace ridge will have a significant impact on the ease of farming and cost of construction of the terrace. The two factors may not be in harmony, especially for UGO terraces. The designer often must select a design that is a compromise based on the producers preference. The following methods are commonly used by terrace type.

(a) Gradient terrace borrow methods

Gradient terraces are constructed relatively parallel to the slope contour. Therefore, a smooth landform between the terraces will occur if the borrow for the terrace ridge is obtained uniformly along the ridge. This construction method is called balanced cut and fill because for each terrace cross section, the cut area equals the fill area. There are techniques normally used to obtain balanced cut and fill based on land slope.

On land slopes of 6 percent or less, borrow is normally obtained from the channel cut directly above the ridge. This method moderately increases the land slope between terraces, but has the least construction cost. The fill and borrow are balanced by selecting a channel centerline cut that will yield the required borrow for the design ridge height. Design aides giving the channel cut as a percentage of the design ridge height can be developed for commonly used terrace shapes and land slopes. A typical example would be that a terrace with 15-foot slope widths on 4 percent land slope will require a channel cut equal to 80 percent of the design ridge height. The channel grade line for the design is selected based on the balanced cut depth for the planned terrace shape, design height, and land slope. During construction of the terrace, the balance is fine-tuned by varying the channel cut slope to obtain more or less borrow.

On land slopes of 6 to 10 percent, borrow is normally obtained from the channel cut and from a cut below the ridge. This method reduces the increase of the land slope that occurs if all borrow was obtained from the channel cut. This method requires either pushing or carrying soil upslope to the ridge. The channel grade

line is set by selecting a moderately uniform channel cut. The downslope borrow width is calculated from the ridge fill area minus the channel cut area. During construction of the terrace, the balance is fine-tuned by increasing or decreasing borrow width below the ridge.

On land slopes greater than 10 percent, all borrow is normally obtained from below the ridge. This method decreases the slope between terraces. The channel grade line is set at the existing ground. The downslope borrow width is calculated from the ridge fill area. All fill must be moved uphill giving terraces built with this construction method the nickname “pushup terraces.”

Little compaction of the ridge soil will occur if the terrace is constructed by pushing the soil with a bulldozer straight up a steep backslope. Low compaction will cause large post construction settlement. On soils with high permeability, such as loess soils, low compaction greatly increases the risk of ridge failure by the piping of water through the ridge. Compaction of the ridge soil can be increased by spreading the soil in the ridge laterally in horizontal layers, compacted by the earthmoving equipment.

(b) UGO terrace borrow methods

UGO terraces are located with the storage pool areas in the existing drainage course or gully locations and the terrace channel not always parallel to the existing land contours. The ridge height in the pool area will be significantly higher than the ridge height outside the pool area. If the borrow for the ridge construction in the pool area is obtained directly upslope from the ridge, the land slope between terraces will be significantly increased, and a deep bowl shaped depression will be created at the inlet location. If the borrow is obtained directly downslope of the ridge, the ridge backslope height will be significantly increased in the pool area. These problems may be avoided by moving soil to the pool area from the upstream terrace area or by borrowing soil from the field area between the terraces. The land slope between the terraces may be made more uniform by borrowing soil from ridge areas or high spots. Economically moving the soil laterally a significant distance requires the use of earthmoving equipment such as pan scraper or elevating scraper.

The choice of a channel grade line that will provide the needed borrow from the upstream reaches is a trial and error process. In general, borrow needed for the ridge in the pool area may be obtained by increasing the cut in the upstream channel reaches. In cases where the inlet is located in a gully, placing the inlet elevation higher than the existing ground in the gully will reduce the required pool depth and fill needed, even though it requires some fill in the pool channel area. Increasing the channel bottom width or flattening the channel cut slope will increase the available borrow for a chosen channel grade line.

Designing an UGO terrace with a channel grade line that balances borrow and fill for the storage pool design reach is a time-consuming process when done by hand calculations. Spreadsheets or computer programs are often used to speed up this process. Due to this difficulty in calculating balanced cut and fill designs, the channel grade line is often selected based on previous design experience, and the required borrow is obtained from the area between the terraces based on the designer's or contractor's judgment.

(c) Flat channel (level) terraces borrow methods

Borrow for the flat channel (level) terrace ridge is normally obtained directly upstream of the ridge from shallow level cuts that form a level pool bottom.

The land slope in the pool area is normally uniform. Therefore, a balanced channel cut can be determined based on the land slope, fill shape, and required pool area per foot of terrace. Design aides may be developed that give the channel cut for typically used land slopes, ridge shapes, and storage areas. During construction of the terrace, the balance is normally fine-tuned by varying the channel cut slope to obtain more or less borrow.

(d) Borrow versus fill density

The density of the soil in the fill is dependent on the construction equipment and compaction methods used. The density of soil placed with a bulldozer pushing soil uphill or a belt conveyer dropping soil on a terrace ridge will be much lower than the density of soil placed in thin layers with a rubber-tired elevating scraper. The dry density of the soil in the borrow area

divided by the density of the soil in the fill is called the cut/fill density ratio. This ratio may be used to adjust the volume of borrow needed for a given volume of fill. The approximate density of the borrow soil may be obtained from soil survey data. The density of the fill should be based on construction density tests of similar soils placed with the construction method planned. For typical terrace construction, the cut/fill density ratio will be greater than 1.0 with a value as high as 1.3 for fills with little compaction.

650.0812 WASC OB design

WASCOB designs are very similar to UGO terraces. The main difference in the practices is the spacing of the WASCOBs and the length of the WASCOB embankment. Therefore, the design of most WASCOB components, except spacing, utilizes the same procedures given for UGO terraces.

(a) Spacing

WASCOBs are placed along a watercourse at a spacing that will prevent gully erosion from occurring. Gully formation is a function of soil structure characteristics, plant root and cover characteristics, and water flow velocity and duration. No analytic methods are currently available to accurately predict gully formation with readily available field data.

An empirical relationship between gully erosion versus watershed area, soil type, and cropping system may be developed from local observation. Fields in the local area with gully formation can be inventoried to determine the watershed size, soil type, and cropping system where gully formation begins. This information can then be used to develop a maximum WASCOB storage pool watershed area based on soil type and planned cropping system. The location of the first upstream WASCOB and spacing of the downstream WASCOB is, therefore, based on maximum storage pool watershed size for the field soil type and planned cropping system.

The maximum WASCOB watershed area may also be estimated based on the maximum nonerosive flow velocity in the drainage course. This is calculated by measuring the runoff flow area shape and determining the flow rate at which the flow velocity would exceed the soil and cover erosion resistance. The maximum watershed area is determined from the peak discharge rate for the WASCOB design storm.

The difficulty of this method is accurately defining the flow area shape. On the slopes common for drainage ways where gully formation begins, the flow is at very shallow depths. Changes in flow depth of 0.1 feet or less may double the flow velocity. Therefore, the exact shape of the flow area including minor variations in

depth must be measured to 0.1 feet or less to accurately predict the flow velocity. The flow area is also being cropped so the flow conditions may change based on tillage practices used.

Therefore, this method is best used with conservative design assumptions for the flow area shape and cover. Design aids can then be developed that give a bare soil maximum flow rate for the assumed flow area shapes and maximum allowed velocities by soil types. The field WASCOB spacing is then based on the field soil type, assumed flow area shape, and watershed area.

Many State-level WASCOB CPSs require that: "WASCOBs shall generally be spaced at terrace intervals." In this case, the WASCOB spacing is determined using the procedure given for terraces with some increase or decrease of the spacing based on local experience.

(b) Storage pool volume

The WASCOB storage pool volume is calculated using the same procedure used for UGO terrace storage pools.

(c) UGO design

The WASCOB UGO size is calculated using the same procedure used for terrace UGOs.

(d) Embankment design

The WASCOB design embankment height is the height required to contain the design storm within the storage pool. Some State WASCOB CPSs require the use of an auxiliary spillway around the end of the embankment for flows from storms that exceed the design storm. In this case, the design embankment height is equal to the design pool depth plus the depth of the auxiliary spillway.

In all cases, the constructed embankment height should be greater than the design embankment height to allow for embankment settlement. The minimum settlement allowed should be 5 percent for well-compacted fill placed in horizontal layers up to 15 percent for poorly compacted fill pushed up with a bulldozer.

Figure 8–48 shows the relationship of the embankment height design components.

downstream embankment slopes must be greater than 5:1.

The minimum embankment top width is determined by the embankment maximum fill height. Table 8–9 gives the minimum top widths specified in the WASCOB CPSs.

If the embankment impounds more than 3 feet of water, a foundation cut off should be planned if soil conditions warrant seepage control.

The minimum embankment side slopes are 2:1. If the embankment is cropped, the embankment slopes should not exceed 6:1. The sum of the upstream and

Figure 8–48 WASCOB embankment height design components

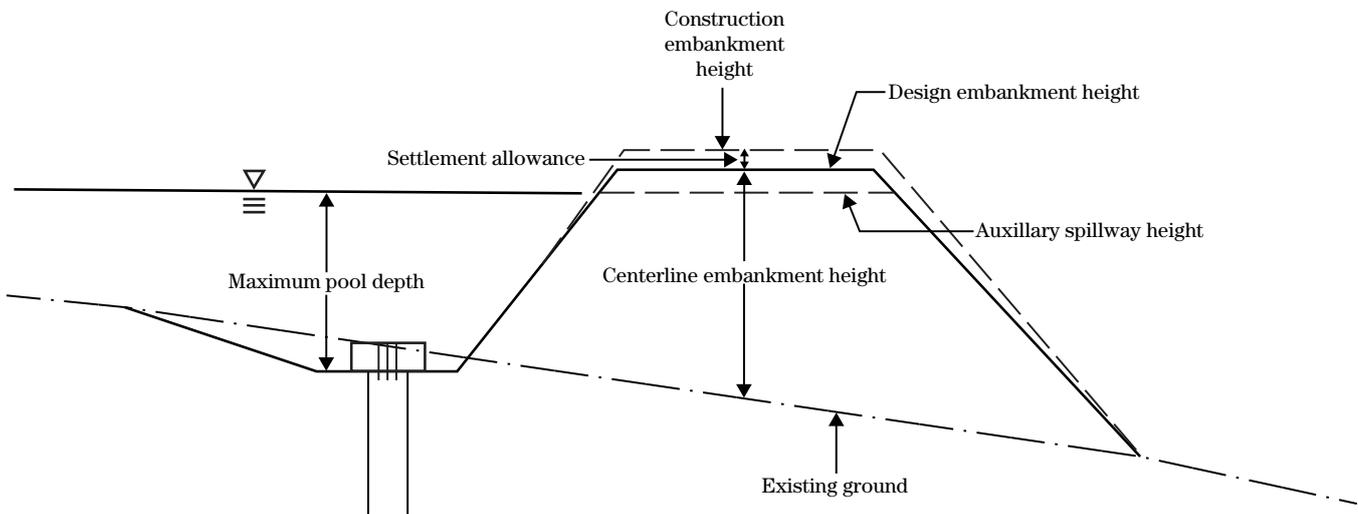


Table 8–9 Minimum top width of WASCOB embankments

Fill height (ft)	Top width (ft)
0–5	3
5–10	6
10–15	8

650.0813 WASC OB construction methods

Borrow for the WASC OB embankment may be obtained from the storage pool or from field areas between the storage pools. If the borrow is obtained from within the storage pool, the constructed storage pool volume will be greater than the design volume based on the existing land form. A lower embankment height may be designed if the shape of the storage pool after construction is specified in the design. This may be done by specifying a design storage pool bottom width and cut slopes that will provide less than or equal the borrow required for the embankment fill. If additional borrow is required during construction, it may be obtained from areas outside the pool area. If the design is based on borrow from areas outside the pool area, the borrow area location and maximum depth should be specified in the plans.

650.0814 Maintenance

Terrace and WASC OB systems require annual maintenance to achieve their planned design life. The following maintenance activities are recommended by system type.

(a) Broadbase terraces

Tillage activity on broadbase terrace ridges will cause a reduction in ridge height due to soil movement by the tillage equipment. This is especially true if tillage is not parallel to the terrace ridge. Where this is occurring, the terrace ridge height must be restored. This can be accomplished with the use of farm equipment, such as a one-way plow or with construction equipment, such as a grader. Where intense tillage methods are used, the ridge height may need to be restored on a biannual basis.

(b) Steep-backslope terraces

The grassed backslopes of steep-backslope terrace ridges provide habitat for burrowing animals. The burrows of these animals may provide a convenient path for water flow through the ridge, resulting in a piping failure of the ridge. The terrace ridge should be inspected annually for any evidence of burrows. The burrows should be dug out and filled if they are located in the top portion of the ridge where they pose a piping hazard.

The vegetated backslopes of steep-backslope ridges can also be invaded by woody tree species. The tree roots can act as pathway for piping failure. The tree branches may result in a farm equipment safety hazard when operating close to the terrace. It is recommended that woody species be eliminated from the backslope by mowing, cutting, or treatment with herbicides.

(c) Narrow-base terraces

The vegetated backslope and front slope of narrow-base terraces provide excellent habit for burrowing animals. The narrow width of the ridge makes it possible that the animal burrows will come close to penetrating the ridge, resulting in a piping failure of the

ridge. Narrow-base terraces should be inspected annually for damage from burrowing. The burrows should be repaired and the population of burrowing animals controlled where possible.

(d) UGO inlets

The inlets of UGO terraces and WASCOB are subject to plugging from crop residue and damage from farm machinery. The location of inlets with low-height risers should be marked with flexible posts or flags to make them visible during harvest. Sediment may also accumulate at the inlet location. The sediment should be removed from around the inlet if it partially blocks the inlet or causes poor drainage conditions around the inlet. The inlets should be inspected for damage annually and inspected for plugging after major storm events.

(e) UGO conduits

The underground conduits may be subject to piping of water along the conduit under the terrace ridge or WASCOB embankment. This problem will first appear as seepage below the embankment in the location of the conduit and should be corrected immediately whenever it is observed. If this condition is not corrected, sudden failure of the ridge or embankment may occur during a storm event. Correcting this condition requires removing the ridge or embankment in at least a 6-foot-wide zone over the conduit with 1:1 side slopes. The conduit must be reinstalled and the embankment rebuilt, ensuring that the soil is well compacted in layers as it is replaced.

If pressure flow occurs in conduits not designed for pressure, flowing water may discharge from the ground surface during peak conduit flow periods leaving a hole in the ground. The area where water discharges is called a blow out. The blow out may be caused by a blocked or crushed conduit downstream of the blow out or by excess inlet capacity above the blow out. All blow outs should be repaired immediately and the condition causing the blow out corrected.

The outlet of the conduit may be damaged by mowing along ditch banks or farm equipment traffic. It is recommended that the location of the outlet be marked with flexible posts or flags to prevent damage. The outlet should be equipped to prevent the entry of animals into the conduit. The outlets and animal guards should be inspected annually to assure that they are functioning properly.

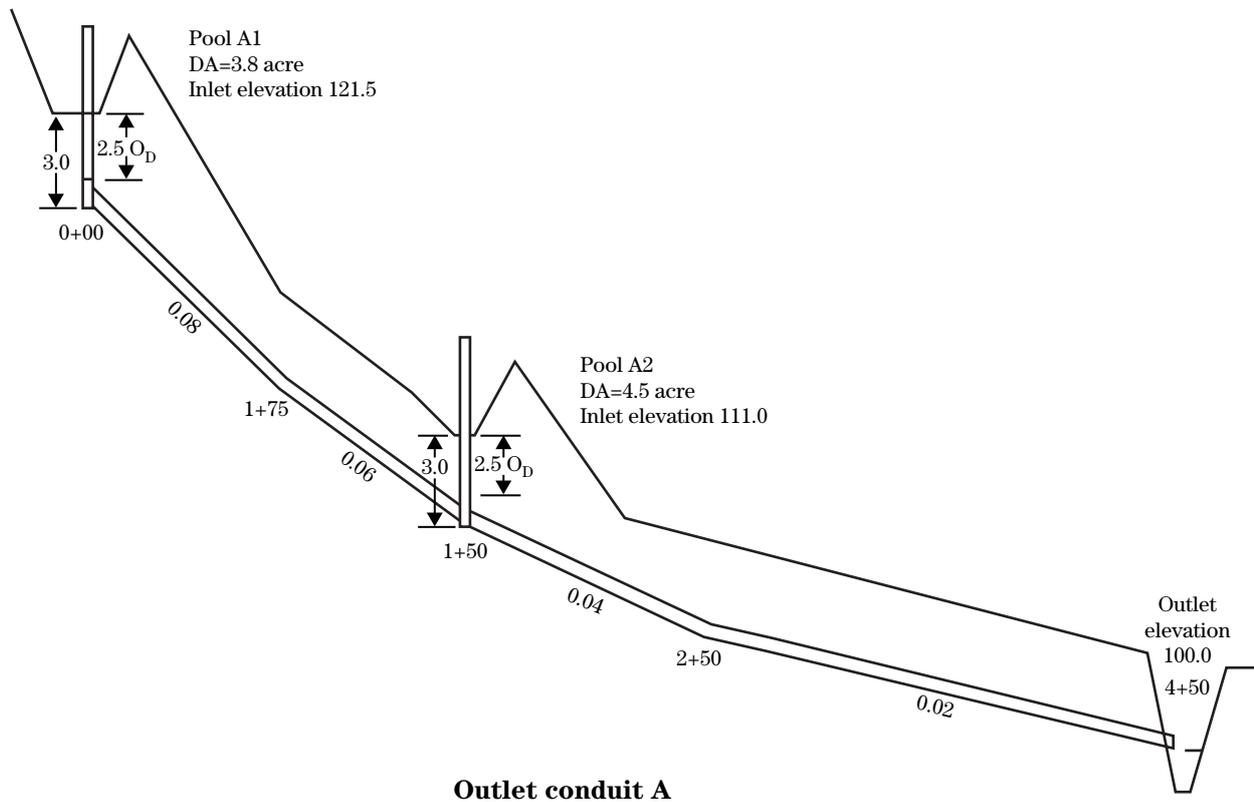
650.0815 References

- Caldwell, L.W. 1985. Determination of storage requirements for underground outlet terraces in the Midwest. *Amer. Soc. of Agric. and Biol. Eng., St. Joseph, MI.*
- McEnroe, B.M., J.M. Steichen, and R.M. Schweiger. 1988. Hydraulics of perforated riser inlets for underground—outlet terraces. *Amer. Soc. of Agric. and Biol. Eng., St. Joseph, MI.*
- Ramser, C.E. 1931. Farm terracing. *Farmers' Bulletin. No. 1669. U.S. Dept. of Agric., Washington, DC.*
- U.S. Department of Agriculture, Agricultural Research Service. 2008. Draft user's reference guide, Revised Universal Soil Loss Equation, 2. Washington, DC.

The following is an example of an underground outlet (UGO) system design for an UGO serving two terrace storage pools. The alternative of a nonpressure flow conduit versus pressure flow conduit is provided. The example follows the design procedures given in chapter 8.

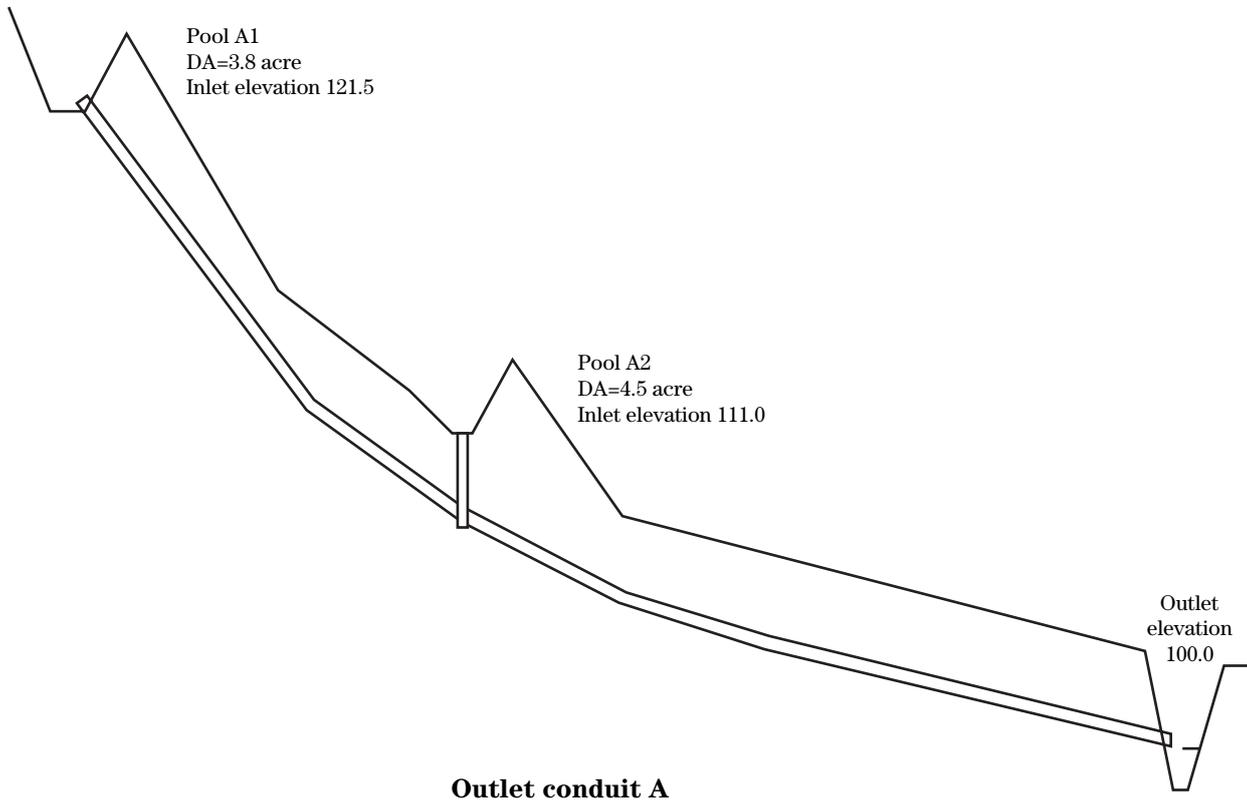
The planned conduit inlets and conduit grade line for the nonpressure flow system are shown in figure 8A-1.

Figure 8A-1 Nonpressure flow system



The planned conduit inlets and conduit grade line for the pressure flow system are shown in figure 8A-2.

Figure 8A-2 Pressure flow system



Watershed data

The following watershed design data was determined from the practice location and planned cropping system:

- 10-year rainfall depth = 4.0 inches
- Runoff curve number (RCN) = 80
- 10-year runoff depth = 2.04 inches
- Annual soil loss rate = 4.0 tons per acre
- General soil type = silt loam

Storage pool volume data

The storage volume versus pool depth shown in table 8A-1 was calculated for the following planned terrace channel grade line, channel bottom width, terrace shape, and existing ground slope.

- Pool A1 Channel grade = 0.007 ft/ft
 - Channel bottom width = 8 ft
 - Terrace shape = 6:1 front slope
 - Existing ground slope = 8%
- Pool A2 Channel grade = 0.006 ft/ft
 - Channel bottom width = 8 ft
 - Terrace shape = 6:1 front slope
 - Existing ground slope = 6%

Table 8A-1 Pool depth versus pool volume

Pool depth (ft)	Pool A1 volume (acre-ft)	Pool A2 volume (acre-ft)
0.5	0.009	0.011
1.0	0.046	0.060
1.5	0.127	0.166
2.0	0.267	0.354
2.2	0.342	0.456
2.4	0.431	0.576
2.5	0.480	0.643
2.6	0.533	0.715
2.7	0.589	0.792
2.8	0.650	0.875

Nonpressure flow conduit design alternative

UGO design procedure step 1: Determine the required average discharge rate and storage pool volume for each storage pool based on the desired storage pool release time.

A design release time of 24 hours was selected.

The runoff depth was determined to be 2.04 inches for the 4.0-inch rainfall and RCN 80 using chapter 2 of this handbook. The runoff volume was determined by multiplying the runoff depth times the watershed area.

The average discharge rate was calculated using equation 8-5.

$$Q_A = \frac{1.008V_r}{T_{rel}} \quad (\text{eq. 8-5})$$

The storage pool volume was calculated using equation 8-3.

$$V_s = 0.0221 \frac{(V_r^{1.272})}{(Q_A^{0.272})} \quad (\text{eq. 8-3})$$

The results are shown in table 8A-2.

Table 8A-2 Storage pool design data

Pool ID	Watershed area (acre)	Runoff volume (acre-in)	Release time (h)	Average discharge (ft ³ /s)	Storage volume (acre-ft)	Sediment volume (acre-ft)	Total volume (acre-ft)	Pool depth (ft)
A1	3.8	7.75	24	0.326	0.405			
A2	4.5	9.18	24	0.386	0.480			

UGO design procedure step 2: Determine the total pool volume required for each storage pool based on the storage volume plus any required sediment storage volume.

The sediment volume was calculated for the 4.0 tons per acre per year soil loss. Equation 8-6 was used with the following assumptions:

Design life = 10 years

Sediment trap efficiency factor for silt loam soil = 0.9

Sediment dry density for silt loam soil = 90 lb/ft³

$$V_{sed} = \frac{0.046T_e LS_{loss} A}{\gamma_{sed}} \quad (\text{eq. 8-6})$$

The total volume for each pool was calculated using equation 8-7.

$$V_t = V_s + V_{sed} \quad (\text{eq. 8-7})$$

The results are shown added to table 8A-2.

Table 8A-2a Storage pool design data

Pool ID	Watershed area (acre)	Runoff volume (acre-in)	Release time (h)	Average discharge (ft ³ /s)	Storage volume (acre-ft)	Sediment volume (acre-ft)	Total volume (acre-ft)	Pool depth (ft)
A1	3.8	7.75	24	0.326	0.405	0.069	0.474	
A2	4.5	9.18	24	0.386	0.480	0.083	0.563	

UGO design procedure step 3: Determine the storage pool depth at each inlet based on the total pool volume, planned channel grade line, planned terrace and channel shape, and existing ground slope.

The pool depth was determined from table 8A-1 using the total pool volume.

The results are shown added to table 8A-2.

Table 8A-2b Storage pool design data

Pool ID	Watershed area (acre)	Runoff volume (acre-in)	Release time (h)	Average discharge (ft ³ /s)	Storage volume (acre-ft)	Sediment volume (acre-ft)	Total volume (acre-ft)	Pool depth (ft)
A1	3.8	7.75	24	0.326	0.405	0.069	0.474	2.5
A2	4.5	9.18	24	0.386	0.480	0.083	0.563	2.4

UGO design procedure step 4: Determine the required inlet control orifice diameter based on the average discharge rate and orifice head equal to the pool depth times the head reduction factor plus the orifice depth below the pool bottom.

Two and a half feet was selected as the orifice depth.

The orifice diameter was calculated using equation 8-9 with the average discharge rate, a head reduction factor of 0.5, and maximum pool depth from table 8A-2.

$$d_o = \frac{6.17Q_A^{\frac{1}{2}}}{(O_D + P_D h_{red})^{\frac{1}{4}}} \quad (\text{eq. 8-9})$$

The results are shown added to table 8A-3.

Table 8A-3 Nonpressure flow inlet design data

Pool ID	Control orifice depth (ft)	Control orifice diameter (in)	Inlet type	Riser height (ft)	Required riser open area (ft ² /ft)	Selected riser size (in)	Selected riser open area (ft ² /ft)
A1	2.5	2.53					
A2	2.5	2.76					

UGO design procedure step 5: Determine the conduit design reaches based on conduit flow type.

Nonpressure conduit design step a: The conduit is divided into design reaches based on changes in the conduit grade or flow input at conduit inlets.

The conduit design reaches were determined from the planned conduit grade line shown in figure 8A-2.

The results are shown in table 8A-4.

Table 8A-4 Nonpressure flow conduit design data

From station	To station	Conduit grade (ft/ft)	Maximum pool discharge (ft ³ /s)	Required capacity (ft ³ /s)	Required conduit diameter (in)	Selected conduit size (in)	Full flow capacity (ft ³ /s)
0+00	0+75	0.08					
0+75	1+50	0.06					
1+50	2+50	0.04					
2+50	4+50	0.02					

UGO design procedure step 6: Determine the required conduit size for each conduit design reach using the maximum pool discharge rates.

Nonpressure conduit design step b: The required conduit capacity (Q_{Req}) for each design reach is calculated based on the accumulated inlet maximum discharge rates (Q_{max}) using equation 8-10.

$$Q_{Max} = 0.02626 d_o^2 (O_D + P_D)^{\frac{1}{2}} \quad (\text{eq. 8-10})$$

The maximum pool discharge shown in table 8A-4 was calculated using equation 8-10 with the orifice diameter from table 8A-3 and the maximum pool depth from table 8A-2.

The required conduit capacity in each design reach was determined by adding the maximum pool discharge rate from each inlet.

The results are shown added to table 8A-4.

Table 8A-4a Nonpressure flow conduit design data

From station	To station	Conduit grade (ft/ft)	Maximum pool discharge (ft ³ /s)	Required capacity (ft ³ /s)	Required conduit diameter (in)	Selected conduit size (in)	Full flow capacity (ft ³ /s)
0+00	0+75	0.08	0.376	0.376			
0+75	1+50	0.06		0.376			
1+50	2+50	0.04	0.443	0.819			
2+50	4+50	0.02		0.819			

Nonpressure conduit design step c: The required conduit diameter (d_c) for each design reach is calculated using equation 8-11 based on the required conduit capacity (Q_{Req}).

The required conduit diameter was calculated using equation 8-11.

$$d_c = 16.02 \left(\frac{Q_{Req} n}{\frac{1}{s^2}} \right)^{\frac{3}{8}} \quad (\text{eq. 8-11})$$

The results are shown added to table 8A-4.

Table 8A-4b Nonpressure flow conduit design data

From station	To station	Conduit grade (ft/ft)	Maximum pool discharge (ft ³ /s)	Required capacity (ft ³ /s)	Required conduit diameter (in)	Selected conduit size (in)	Full flow capacity (ft ³ /s)
0+00	0+75	0.08	0.376	0.376	3.69		
0+75	1+50	0.06		0.376	3.89		
1+50	2+50	0.04	0.443	0.819	5.63		
2+50	4+50	0.02		0.819	6.41		

Nonpressure conduit design step d: A manufactured conduit size equal to or greater than the required conduit diameter (d_c) is selected. The capacity (Q_{Cap}) of the selected conduit size is documented using equation 8-12.

$$Q_{Cap} = 0.000613 d_{cMfg}^{\frac{8}{3}} \frac{s^{\frac{1}{2}}}{n} \quad (\text{eq. 8-12})$$

The design conduit size was selected based on the manufactured conduit size that equaled or exceeded the required conduit diameter.

The full flow capacity of the selected manufactured size was calculated using equation 8-12.

The results are shown added to table 8A-4.

Table 8A-4c Nonpressure flow conduit design data

From station	To station	Conduit grade (ft/ft)	Maximum pool discharge (ft ³ /s)	Required capacity (ft ³ /s)	Required conduit diameter (in)	Selected conduit size (in)	Full flow capacity (ft ³ /s)
0+00	0+75	0.08	0.376	0.376	3.69	4	0.466
0+75	1+50	0.06		0.376	3.89	4	0.404
1+50	2+50	0.04	0.443	0.819	5.63	6	0.972
2+50	4+50	0.02		0.819	6.41	8	1.480

UGO design procedure step 7: Determine the required inlet size based on the planned inlet type, pool depth, and average discharge rate.

Nonpressure inlet design procedure step a: Select a riser type and height.

The inlet type chosen for the design was a perforated closed-top 3-foot riser with a control orifice depth of 2.5 feet.

Nonpressure inlet design procedure step b: For closed-top risers, determine the required perforation opening area per foot of riser (a_r) using equations 8-15 or 8-16, depending on the selected riser height (RH) and maximum pool depth (P_D). For open-top risers, determine the required total riser opening area (a_t).

$$a_r = \frac{0.876 Q_A}{(R_h P_D)^{\frac{1}{2}}} \quad (\text{eq. 8-15}) \quad \text{or} \quad a_r = \frac{2.19 Q_A}{P_D^{1.5}} \quad (\text{eq. 8-16})$$

The riser height is greater than 40 percent of the maximum pool depth for both inlets. Therefore, equation 8-16 was used to calculate the required riser opening area per foot based on the pool depth and average discharge rate from table 8A-2a.

Nonpressure inlet design procedure step c: Using the inlet manufacturers specifications, select a riser diameter larger than the control orifice diameter (d_o) which meets or exceeds the calculated opening area per foot (a_r) for closed-top risers or the calculated total opening area (a_t) for open-top risers.

An inlet size was selected based on the following manufactured inlet specifications:

6-inch riser has 1-inch holes; 6 holes per row, 5 rows per foot: flow area = 0.163 ft²/ft

8-inch riser has 1-inch holes; 8 holes per row, 5 rows per foot: flow area = 0.218 ft²/ft

10-inch riser has 1-inch holes; 10 holes per row, 5 rows per foot: flow area = 0.273 ft²/ft

12-inch riser has 1-inch holes; 12 holes per row, 5 rows per foot: flow area = 0.327 ft²/ft

The results are added to table 8A-3.

Table 8A-3a Nonpressure flow inlet design data (3 ft-closed top)

Pool ID	Control orifice depth (ft)	Control orifice diameter (in)	Inlet type	Riser height (ft)	Required riser open area (ft ² /ft)	Selected riser size (in)	Selected riser open area (ft ² /ft)
A1	2.5	2.53	Closed top	3.0	0.181	8	0.218
A2	2.5	2.76	Closed top	3.0	0.227	10	0.273

Inlet alternative 1

The design procedure was repeated for the alternative of a 0.75-foot (9-in)-high closed-top riser.

The riser height would be less than 40 percent of the maximum pool depth. Therefore, equation 8-15 was used to calculate the required riser opening area per foot based on the maximum pool depth and average discharge rate from table 2.

$$a_r = \frac{0.876 Q_A}{(R_h P_D)^{\frac{1}{2}}} \quad (\text{eq. 8-15})$$

The results of this alternative are shown in a revised table 8A–3.

Table 8A–3b Nonpressure flow inlet design data (0.75 ft—closed top)

Pool ID	Control orifice depth (ft)	Control orifice diameter (in)	Inlet type	Riser height (ft)	Required riser open area (ft ² /ft)	Selected riser size (in)	Selected riser open area (ft ² /ft)
A1	2.5	2.53	Closed top	0.75	0.241	10	0.273
A2	2.5	2.76	Closed top	0.75	0.291	12	0.327

Inlet alternative 2

The design procedure was repeated for the alternative of a 0.75-foot (9-in)-high open-top riser.

The riser height selected was less than the maximum riser height of 40 percent of the maximum pool depth, which was 1.0 foot for pool A1 and 0.96 foot for pool A2.

Equation 8–18 was used to calculate the required total riser opening area based on the maximum pool depth and average discharge rate from table 8–2.

$$a_t = 0.876 \frac{Q_A}{P_D^{\frac{1}{2}}} \quad (\text{eq. 8-18})$$

The selected manufactured riser has the same size and number of holes per foot as the closed top riser, but has the entire top open.

6-inch riser 0.75-foot-high; total flow area = 0.298 ft²/ft

8-inch riser 0.75-foot-high; total flow area = 0.513 ft²/ft

10-inch riser 0.75-foot-high; total flow area = 0.750 ft²/ft

12-inch riser 0.75-foot-high; total flow area = 1.030 ft²/ft

The results of this alternative are shown in a revised table 8A–3.

Table 8A–3c Nonpressure flow inlet design data (0.75 ft—open top)

Pool ID	Control orifice depth (ft)	Control orifice diameter (in)	Inlet type	Riser height (ft)	Required riser open area (ft ²)	Selected riser size (in)	Selected riser open area (ft ²)
A1	2.5	2.53	Open top	0.75	0.181	6	0.298
A2	2.5	2.76	Open top	0.75	0.218	6	0.298

Nonpressurized inlet design procedure step c: For open-top risers, if the maximum pool depth (P_D) minus the maximum weir head (h_{mw}) calculated using equation 8–17 is less than the selected riser height, select a smaller riser height and repeat step c.

$$h_{mw} = 1.363 \left(\frac{Q_A}{d_T} \right)^{\frac{2}{3}} \quad (\text{eq. 8-17})$$

The maximum weir head calculated using equation 8-17 for the selected riser sizes was:

$$\text{Pool A1} = 0.196 \text{ ft}$$

$$\text{Pool A2} = 0.219 \text{ ft}$$

The step c test height equals half the pool depth minus the maximum weir head:

$$\text{Pool A1} = 2.5 \div 2 - 0.196 = 1.05$$

$$\text{Pool A2} = 2.4 \div 2 - 0.219 = 0.981$$

Therefore, the riser height selected for both risers was less than the step c test riser height.

Pressure flow conduit design alternative

UGO design procedure step 5: Determine the conduit design reaches based on conduit flow type.

For pressure flow conduits, the design reaches are based on the outlet point and inflow points.

The design reaches were determined from figure 8A-2.

The results are shown in table 8A-5.

Table 8A-5 Pressure flow conduit design data

From station	To station	Pool ID	Pool average discharge (ft ³ /s)	Required capacity (ft ³ /s)	Elevation head (ft)	Conduit size (in)	Conduit flow rate (ft ³ /s)
0+00	1+50	A1					
1+50	4+50	A2					

UGO design procedure step 6: Determine the required conduit size for each conduit design reach using the maximum pool discharge rates.

Pressure conduit design step a: A pipe size is selected with a flow rate (Q_p) calculated using equation 8-13 that is greater than the design average pool discharge rate (Q_A). The elevation head differential (H) is determined from the design pool elevation and the elevation of the water surface at the outlet.

The pool average discharge rates were obtained from table 8-2a.

The required conduit capacity for each reach was determined by accumulating the upstream pool average discharge rates.

The elevation head for each design reach was determined by subtracting the outlet elevation from the maximum pool elevation.

For conduit from pool A1 to A2, the conduit outlets into pool A2. Therefore, the maximum pool A2 elevation is used as the outlet elevation.

For pool A2 to the outlet at the open channel, the outlet elevation is assumed equal to the outlet centerline elevation.

The results of the calculations are shown added to table 8A-5.

Table 8A-5a Pressure flow conduit design data

From station	To station	Pool ID	Pool average discharge (ft ³ /s)	Required capacity (ft ³ /s)	Elevation head (ft)	Conduit size (in)	Conduit flow rate (ft ³ /s)
0+00	1+50	A1	0.326	0.326	10.6		
1+50	4+50	A2	0.386	00.712	13.2		

A PVC pipe with a Manning's roughness coefficient (n) of 0.011 was selected as the conduit type.

A canopy inlet was selected for pool A1.

A pipe drop inlet was selected for pool A2 to allow the conduit from pool A1 to outlet in the bottom of the pipe drop riser.

A manufactured conduit size with a flow rate equal to or greater than the pool (A1) required capacity was selected using equation 8-13 to calculate the conduit flow rate.

The required capacity from pool A2 is recalculated to equal the selected conduit flow rate from pool A1 plus the average discharge rate from pool A2

A manufactured conduit size with a flow rate equal to or greater than the pool (A2) required capacity was selected using equation 8-13 to calculate the conduit flow rate.

$$Q_p = a \left[\frac{(2gH)}{(1 + K_e + K_m + K_p L)} \right]^{\frac{1}{2}} \quad (\text{eq. 8-13})$$

The results are shown added to table 8A-5.

Table 8A-5b Pressure flow conduit design data

From station	To station	Pool ID	Pool average discharge (ft ³ /s)	Required capacity (ft ³ /s)	Elevation head (ft)	Conduit size (in)	Conduit flow rate (ft ³ /s)
0+00	1+50	A1	0.326	0.326	10.6	4	0.552
1+50	4+50	A2	0.386	00.712	13.2	6	1.316

Pressure conduit design step b: The revised storage pool release time (T_{rel}), storage volume (V_s), total storage volume (V_t), and pool depth (P_d) are calculated based on the selected pipe size flow rate (Q_p).

Storage pool A1 and A2 were redesigned by:

- Using equation 8-4 to calculate the release time for the selected conduit flow rates.

$$T_{rel} = \frac{1.008V_r}{Q_A} \quad (\text{eq. 8-4})$$

- Using equation 8-3 to calculate the storage volume for the selected conduit flow rates.

$$V_s = 0.0221 \frac{(V_r^{1.272})}{(Q_A^{0.272})} \quad (\text{eq. 8-3})$$

- Using equation 8-7 to calculate the total storage pool volume using the revised storage volume.

$$V_t = V_s + V_{\text{sed}} \quad (\text{eq. 8-7})$$

- Determining the pool depth from table 8A-1 using the revised total pool volume.

The redesigned pool data is shown in table 8A-6.

Table 8A-6 Storage pool design data (redesigned)

Pool ID	Watershed area (acre)	Runoff volume (acre-in)	Release time (h)	Average discharge (ft ³ /s)	Storage volume (acre-ft)	Sediment volume (acre-ft)	Total volume (acre-ft)	Pool depth (ft)
A1	3.8	7.75	14	0.552	0.351	0.069	0.420	2.4
A2	4.5	9.18	12	0.764	0.399	0.063	0.482	2.3

Note that the release time has been decreased by approximately 50 percent while total storage volume has only decreased approximately 14 percent and the pool depth only 4 percent.

Pressure conduit design step c: The revised head differential (H) is calculated from the change in the pool depth (P_D) in step 2.

Comparing the pool depth to the depth in table 8A-2, the pool depth reduction for pool A1 and A2 is 0.1 feet, therefore:

$$\text{Pool A1 elevation} = 124.0 - 0.1 = 123.9$$

$$\text{Pool A2 elevation} = 113.4 - 0.1 = 113.3$$

$$\text{Pool A1 to A2 head differential} = 123.6 - 113.3 = 10.6$$

$$\text{Pool A2 to the midpoint of the outlet} = 113.3 - 100.2 = 13.1$$

Pressure conduit design step d: If the percent change in the head differential (H) in step c is less than 5 percent, the design process is complete with the storage pool design data equal to the values calculated in step b.

If the percent change is greater than 5 percent the process is repeated starting at step b with the pipe discharge rate (Q_p) calculated using the head differential (H) calculated in step c.

Comparing the step c the step a table 8A-5 values:

- There was no change in the conduit head from pool A1 to pool A2.
- There was 0.8 percent change from pool A2 to the outlet.

Therefore, the redesigned storage pool data in table 8A-6 is accepted as the design storage pool data.

UGO design procedure step 7: Determine the required inlet size based on the planned inlet type, pool depth, and average discharge rate.

The inlet type selected for pool A1 was a canopy inlet. Based on the pressure flow inlet design criteria given in chapter 8:

- The inlet priming head must be less than half the maximum pool depth.
- The priming head for a canopy inlet equals 1.7 times the conduit diameter.
- The inlet type selected for pool A2 was a pipe drop. Based on the pressure flow inlet design criteria given in chapter 8:
 - The pipe drop size must be 1.5 times the conduit size. A 10-inch size was selected.
 - The pipe drop depth must be 5 times the conduit size. A depth of 2.5 feet was selected.
 - The weir flow depth must be less than half of the pool depth. The weir flow depth for the selected size was calculated using equation 8–17.

The inlet design data is shown in table 8A–7.

Table 8A–7 Pressure flow inlet design data

Storage pool ID	Pool average discharge rate (ft ³ /s)	Inlet type	Pipe size (in)	Minimum pipe drop diameter (in)	Minimum pipe drop depth (ft)	Maximum weir flow depth (ft)	Maximum inlet priming depth (ft)	Half maximum pool depth (ft)
A1	0.552	Canopy	4	—	—	—	0.57	1.10
A2	0.764	Pipe drop	6	10	2.5	0.25	0.25	1.15

The NRCS supports a computerized tool for the design of terraces. The Terrace Design Tool (TDT) is part of a suite of NRCS engineering design tools that are contained in the Engineering Field Tools (EFT). Contact the NRCS national engineering software coordinator to obtain a copy of this tool.

TDT is a complete terrace design software package that can take the designer from the input of survey data through final design and output of construction plans and specifications as well as documentation files. The design process in TDT automates the procedures outlined in this chapter. However, before using TDT, a designer should thoroughly understand the design procedures in chapter 8.

The design process in TDT consists of the following steps:

- Input of survey data—either as station offset or topographic survey
- Generation of a surface model of the existing ground
- Layout of the terrace alignment—an interactive process done on screen
- Define the terrace channel—an interactive process done on screen
- Define the terrace cross-section template—used by TDT to compute volumes for storage and earthmoving
- Design the terrace—TDT goes through an iterative process to calculate the terrace embankment height based on the constraints defined by the volume of runoff, terrace channel alignment and profile and the template cross section defined by the user
- Balance cuts and fills—TDT balances cuts and fills if required by the user
- Underground outlet design—For storage terraces, TDT designs the underground outlet based on user input of the UGO profile and pipe material.
- Output—TDT generates a set of construction plans and specifications, bill of materials, information for the layout and construction of the terrace, and design documentation for NRCS records.

The following is an example of a construction plan output from the TDT. In addition to the construction plans, TDT can produce NRCS documentation files, material lists and a points file that defines the new terrace surface.



U. S. DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE

IN COOPERATION WITH

Any COUNTY SOIL AND WATER CONSERVATION DISTRICT

DETAIL PLANS FOR

(PRACTICE) Terrace

(COOPERATOR) Will Farmer

(LOCATION) Southfield SEC. T R

NOTICE TO THE COOPERATOR AND CONTRACTOR

NO REPRESENTATION IS MADE BY THE NATURAL RESOURCES CONSERVATION SERVICE AS TO THE EXISTENCE OR NONEXISTENCE OF UNDERGROUND HAZARDS. AT LEAST 2 WORKING DAYS PRIOR TO THE START OF CONSTRUCTION, THE OWNERS OF PIPELINES OR OTHER UNDERGROUND UTILITIES MUST BE NOTIFIED OF THE PENDING CONSTRUCTION. UTILITIES THAT PARTICIPATE WITH THE INDIANA UNDERGROUND PLANT PROTECTION SERVICES, INC., CAN BE NOTIFIED BY CALLING 1-800-382-5544, TOLL FREE or 811.

INDEX OF DRAWINGS

Table with 2 columns: TITLE and SHEET NO. containing drawing titles like COVER SHEET, PLAN VIEW, PROFILE TERRACE #2, etc.

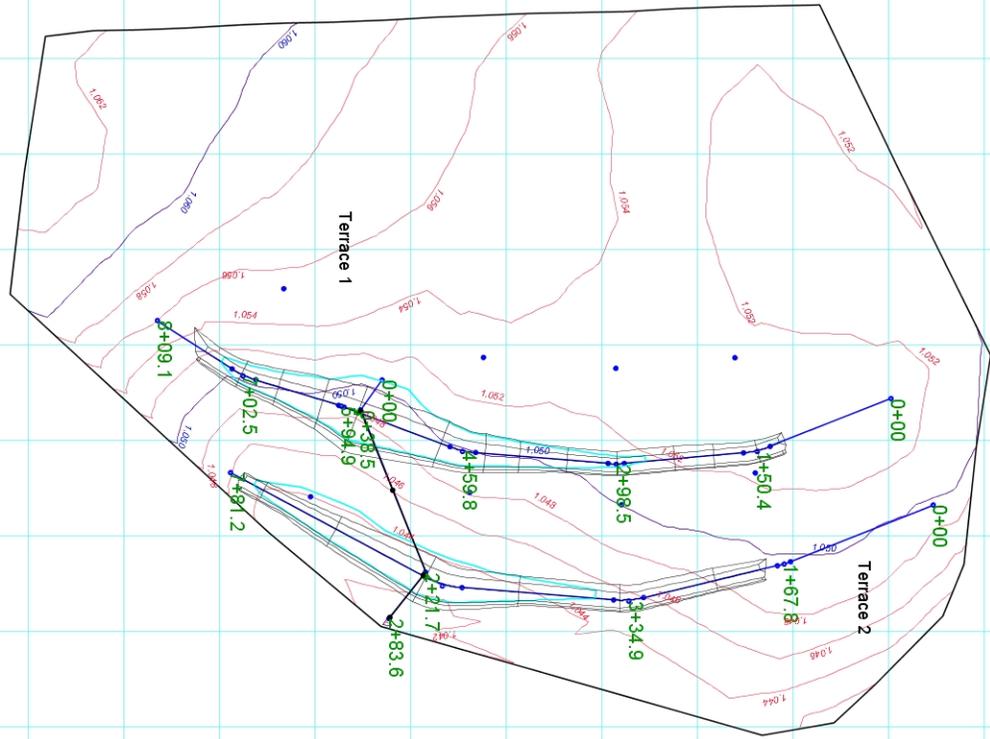
CONSTRUCTION DATA

Form fields for LAYOUT BY, DATE, CONTRACTOR NAME AND ADDRESS, CONSTRUCTION COMPLETED (DATE), NO CHANGES DURING CONSTRUCTION, AS-BUILTS SUBMITTED BY, TITLE.

CONSTRUCTION APPROVAL SIGNATURES

Form fields for CONSTRUCTION (DOES) (DOES NOT) MEET STANDARDS & SPECIFICATIONS, DATE, TITLE, AS-BUILTS REVIEWED AND APPROVED BY, DATE, TITLE, ALL INSTALLATION REPORTS HAVE BEEN RECEIVED AND REVIEWED AND SEEDING HAS BEEN COMPLETED TO MEET STANDARDS & SPECIFICATIONS, DATE, TITLE.

Form fields for PREPARED BY, PRMc, DATE: 4/22/11, TITLE: Ag Engineer, REVIEWED AND APPROVED BY, John N. Gear, DATE: 4/25/2011, TITLE: Area Engineer, REVIEWED AND CONCURRED BY, Wilma Jones, DATE: 4/27/2011, TITLE: District Conservationist, SHEET 1 OF

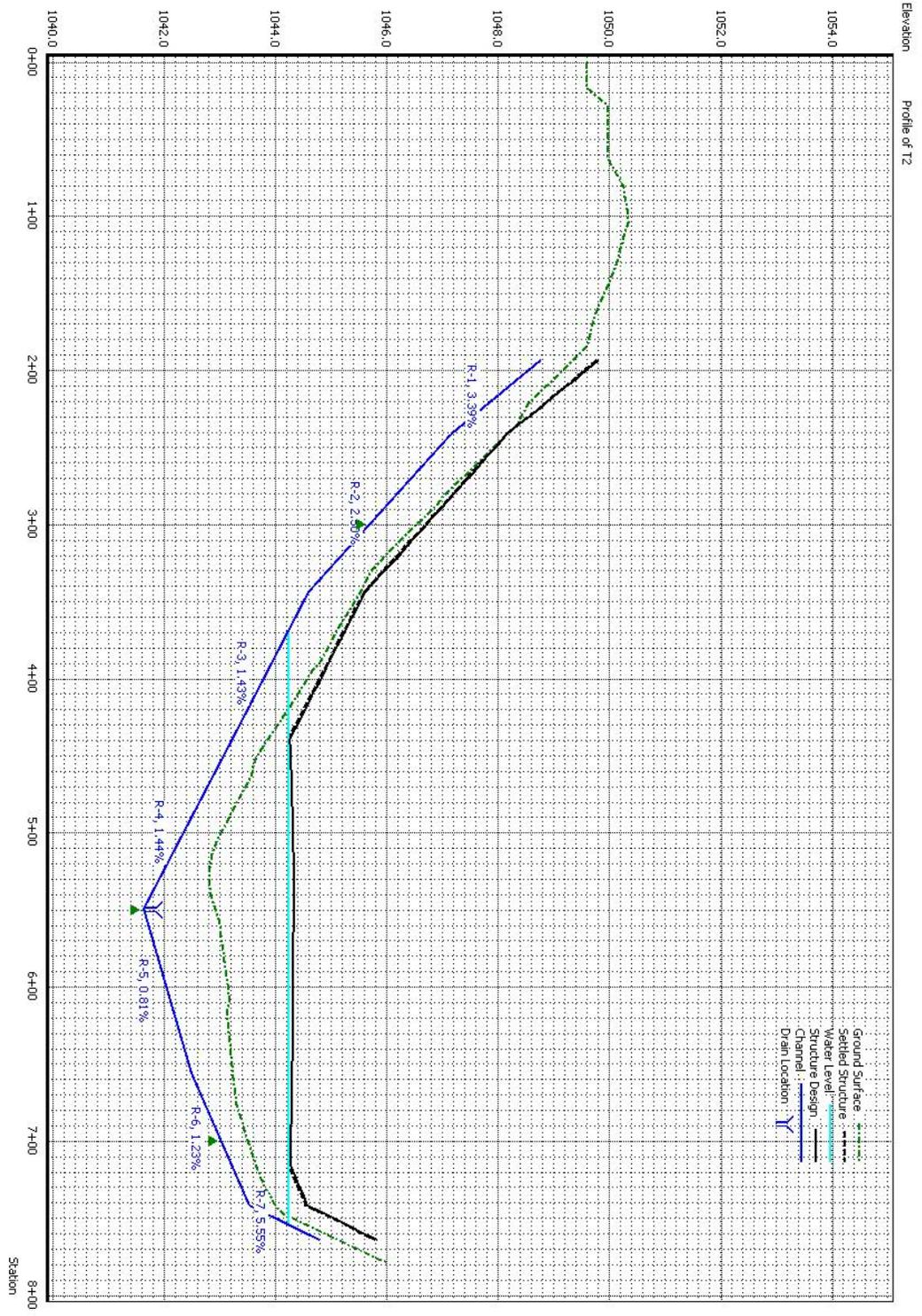


EFH Example
EFH Example
 Terrace
 Southfield

Designed	PRMc	4/20/2011
Drawn	PRMc	4/22/2011
Checked	John N. Gear	4/25/2011
Approved	John N. Gear	4/25/2011

EFT Version 3.0.6.2

Date	File Name
4/20/2011	EFH example.xml
4/22/2011	Drawing Name
4/25/2011	Plan View
10/12/2011	Sheet ____ of ____

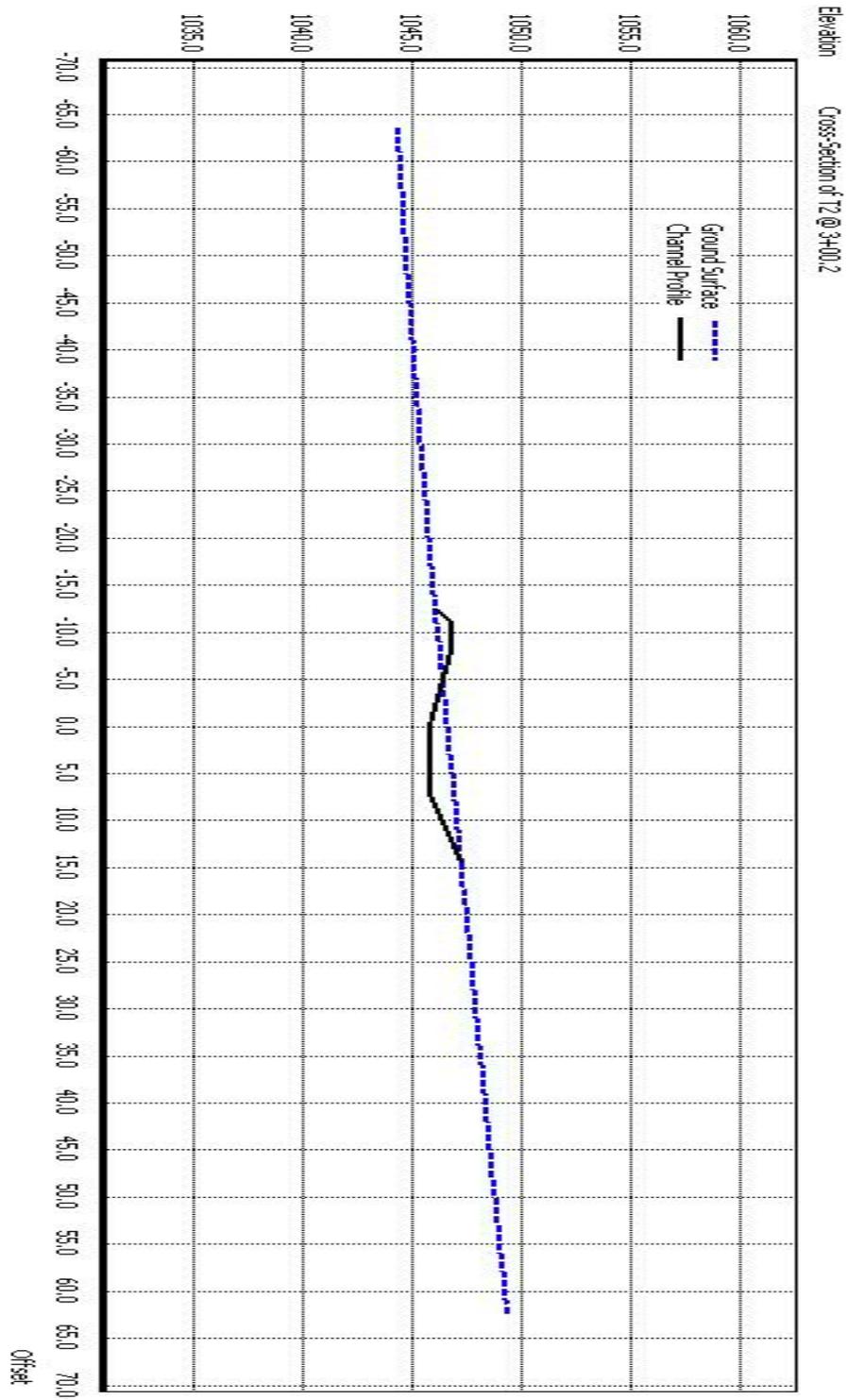


Terrace Profile Report
EFH Example
 Terrace
 Southfield

Designed	<u>PRMc</u>	<u>4/20/2011</u>
Drawn	<u>PRMc</u>	<u>4/22/2011</u>
Checked	<u>John N. Gear</u>	<u>4/25/2011</u>
Approved	<u>John N. Gear</u>	<u>4/25/2011</u>

EFT Version 3.0.6.2

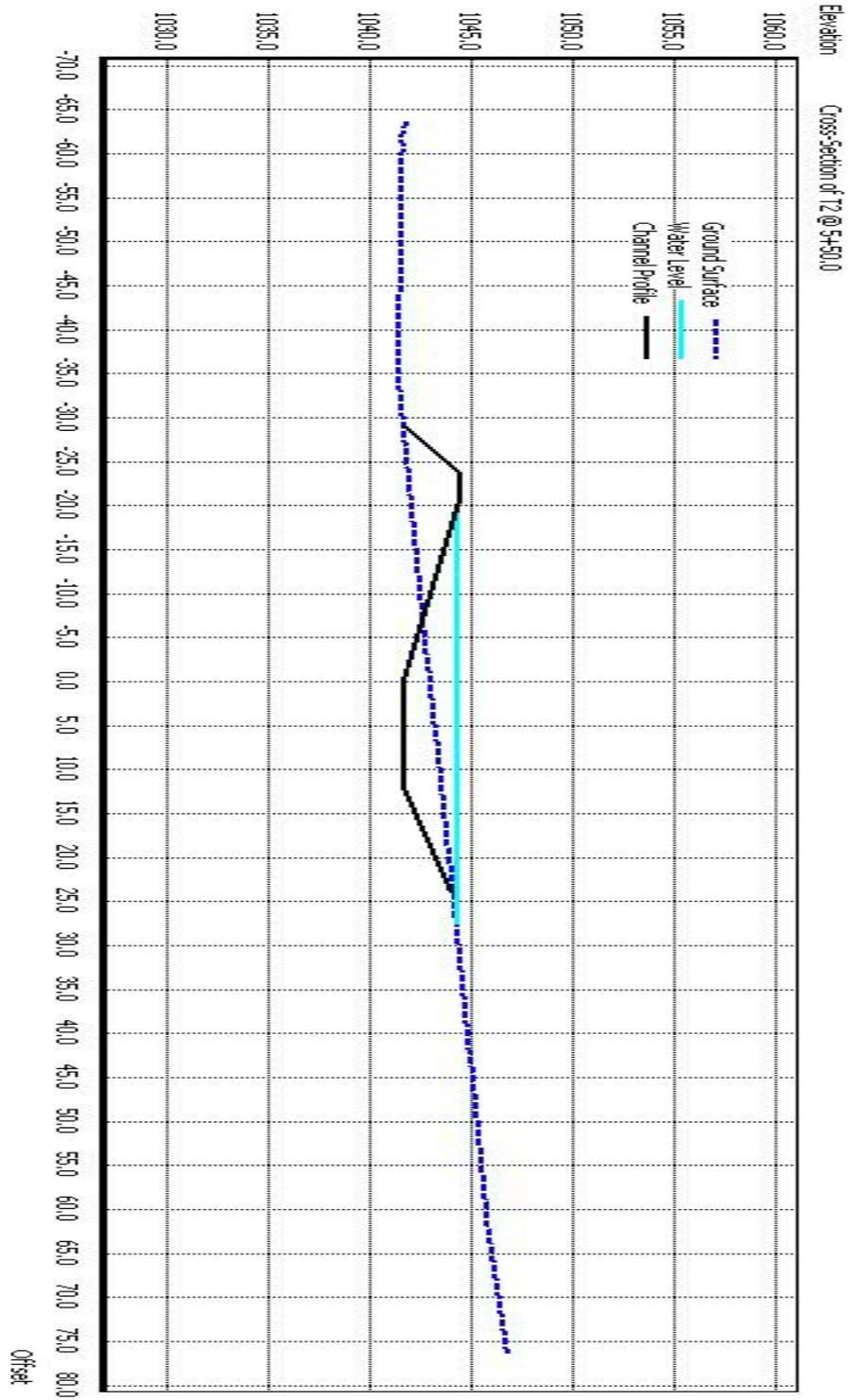
File Name	EFH example.xml
Drawing Name	T2
	10/12/2011
Sheet	___ of ___



Terrace Cross Section Report
EFH Example
 Terrace
 Southfield

		Date
Designed	<u>PRMc</u>	<u>4/20/2011</u>
Drawn	<u>PRMc</u>	<u>4/22/2011</u>
Checked	<u>John N. Gear</u>	<u>4/25/2011</u>
Approved	<u>John N. Gear</u>	<u>4/25/2011</u>
EFT Version 3.0.6.2		

File Name	EFH example.xml
Drawing Name	T2
	10/12/2011
Sheet	___ of ___



Terrace Cross Section Report

EFH Example

Terrace

Southfield

Designed	<u>PRMc</u>	<u>4/20/2011</u>
Drawn	<u>PRMc</u>	<u>4/22/2011</u>
Checked	<u>John N. Gear</u>	<u>4/25/2011</u>
Approved	<u>John N. Gear</u>	<u>4/25/2011</u>

EFT Version 3.0.6.2

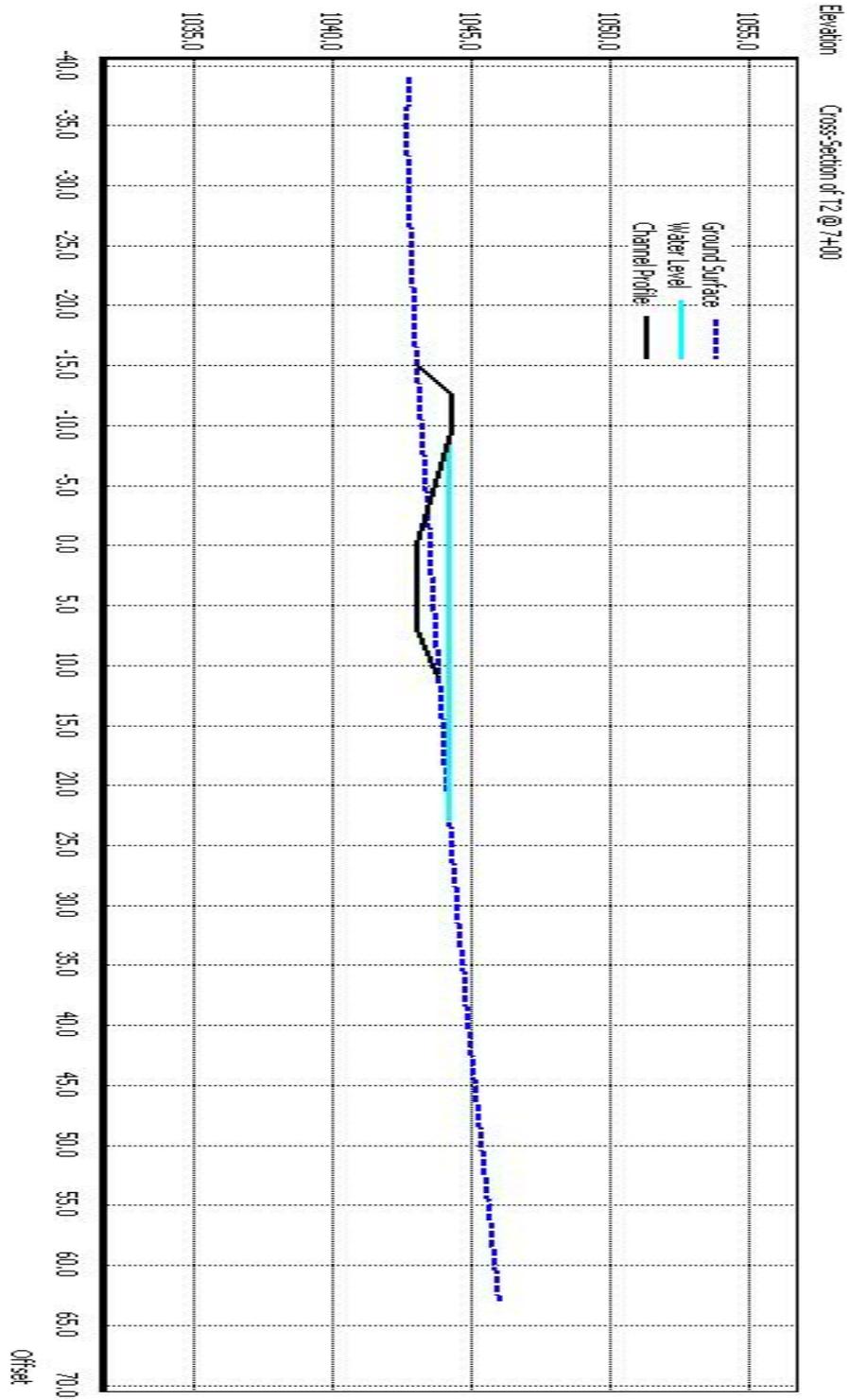
Date

File Name
EFH example.xml

Drawing Name
T2

10/12/2011

Sheet ___ of ___



Terrace Cross Section Report
EFH Example
 Terrace
 Southfield

Designed	<u>PRMc</u>	<u>4/20/2011</u>
Drawn	<u>PRMc</u>	<u>4/22/2011</u>
Checked	<u>John N. Gear</u>	<u>4/25/2011</u>
Approved	<u>John N. Gear</u>	<u>4/25/2011</u>

EFT Version 3.0.6.2

File Name	EFH example.xml
Drawing Name	T2
	10/12/2011
Sheet	___ of ___

Contractor Cut Sheet

Project Name: EFH Example
Project Description: Terrace Design
Designed by: PRMc
Date: 4/20/2011

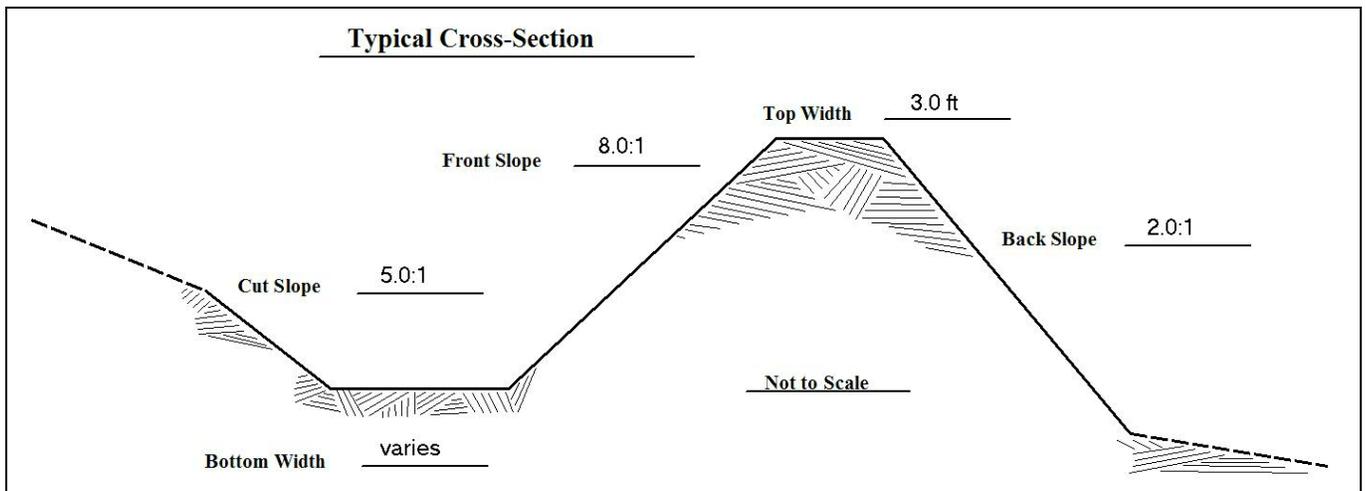
Location: Southfield
Practice: Terrace
Checked by: John N. Gear
Date: 4/25/2011

Terrace: T2

Terrace Type: STORAGE

Benchmark Elevation: 1056.25

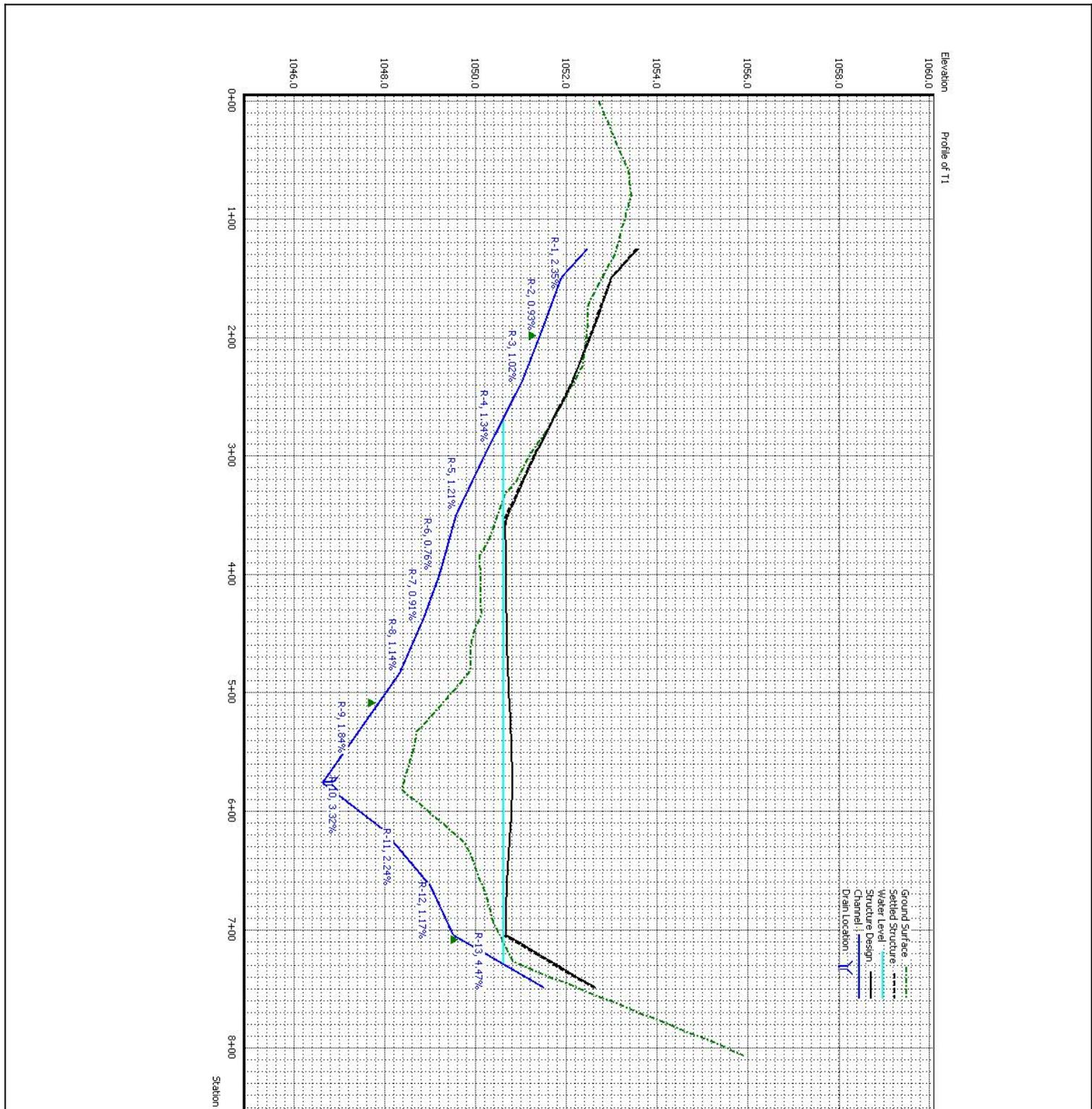
Description: PK nail in base of 30" DBH white oak in west fence line



Station	Design						Checkout - BS _____ HI _____				
	Ref. Elev. (Flag line)	Chan. Elev.	Chan. Cut	Ridge Elev.	Ridge Fill	Bottom Width	Chan. Rod	Chan. Elev.	Ridge Rod	Ridge Elev.	Btm. Width
1+93.6	1049.33	1048.76	0.57	1049.79	0.47	6.00					
2+00	1049.15	1048.54	0.60	1049.58	0.43	6.00					
2+42.0	1048.13	1047.12	1.01	1048.14	0.00	6.00					
2+50.0	1047.90	1046.92	0.98	1047.94	0.03	6.16					
3+00	1046.52	1045.67	0.85	1046.70	0.18	7.14					
3+44.0	1045.51	1044.57	0.94	1045.59	0.09	8.00					
3+50.0	1045.40	1044.48	0.92	1045.51	0.10	8.11					
4+00	1044.56	1043.77	0.79	1044.80	0.24	9.06					
4+50.0	1043.65	1043.05	0.60	1044.25	0.59	10.00					
5+00	1043.01	1042.33	0.68	1044.29	1.28	11.00					
5+49.7	1042.89	1041.61	1.28	1044.32	1.43	12.00					
6+00	1043.12	1042.02	1.11	1044.29	1.17	10.11					

EFT Version 3.0.6.2

Design							Checkout - BS _____ HI _____				
Station	Ref. Elev. (Flag line)	Chan. Elev.	Chan Cut	Ridge Elev.	Ridge Fill	Bottom Width	Chan. Rod	Chan. Elev.	Ridge Rod	Ridge Elev.	Btm. Width
6+50.0	1043.19	1042.42	0.78	1044.28	1.08	8.24					
6+56.3	1043.21	1042.47	0.74	1044.28	1.07	8.00					
7+00	1043.48	1043.01	0.48	1044.25	0.77	6.98					
7+41.8	1043.98	1043.52	0.46	1044.55	0.57	6.00					
7+50.0	1044.25	1043.98	0.28	1045.01	0.75	6.00					
7+64.5	1045.12	1044.78	0.34	1045.81	0.69	6.00					

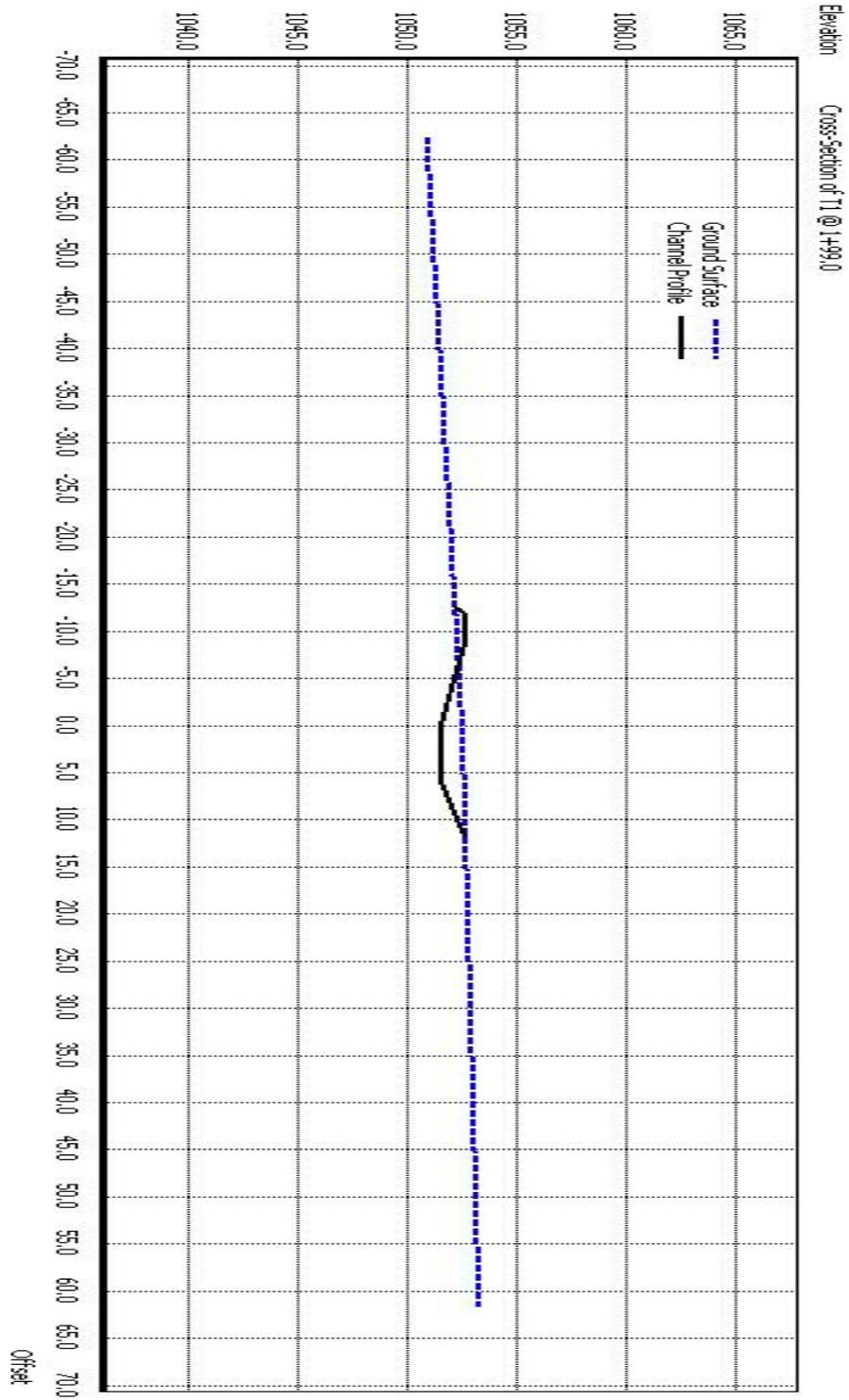


Terrace Profile Report
EFH Example
 Terrace
 Southfield

Designed	<u>PRMc</u>	<u>4/20/2011</u>
Drawn	<u>PRMc</u>	<u>4/22/2011</u>
Checked	<u>John N. Gear</u>	<u>4/25/2011</u>
Approved	<u>John N. Gear</u>	<u>4/25/2011</u>

EFT Version 3.0.6.2

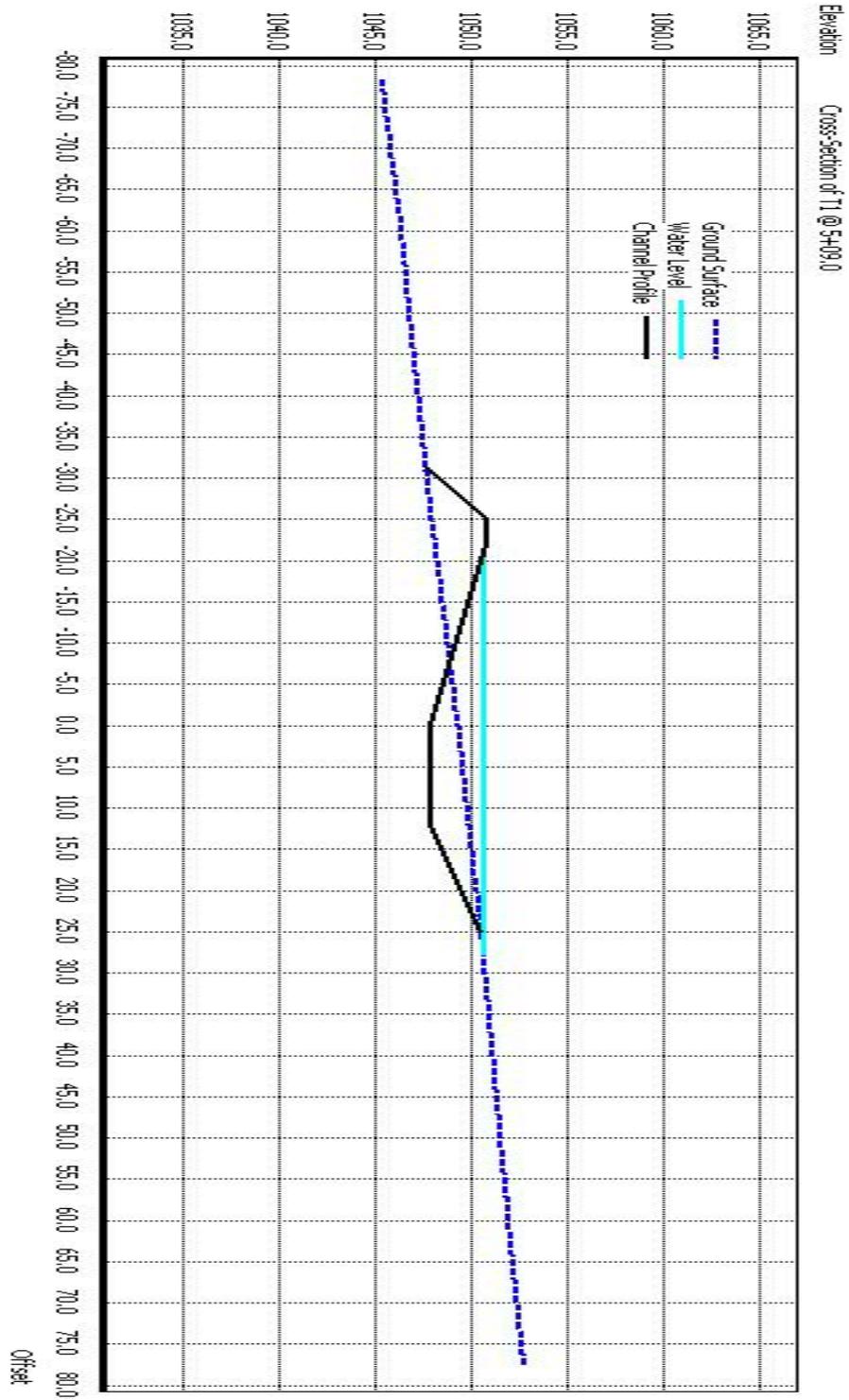
File Name	EFH example.xml
Drawing Name	T1
	10/12/2011
Sheet	___ of ___



Terrace Cross Section Report
EFH Example
 Terrace
 Southfield

		Date
Designed	<u>PRMc</u>	<u>4/20/2011</u>
Drawn	<u>PRMc</u>	<u>4/22/2011</u>
Checked	<u>John N. Gear</u>	<u>4/25/2011</u>
Approved	<u>John N. Gear</u>	<u>4/25/2011</u>
EFT Version 3.0.6.2		

File Name	EFH example.xml
Drawing Name	T1
	10/12/2011
Sheet	___ of ___



Terrace Cross Section Report

EFH Example

Terrace

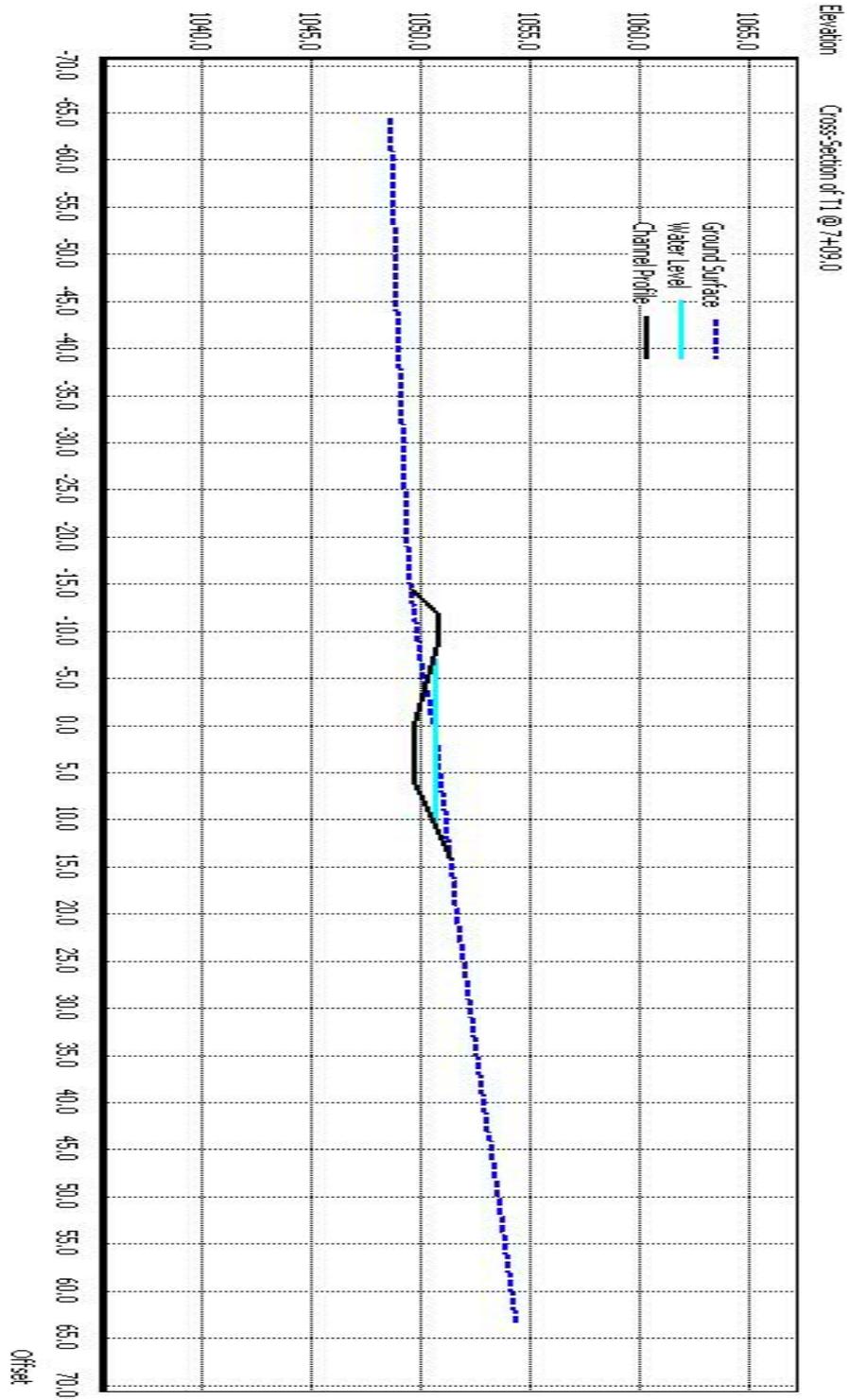
Southfield

Designed	<u>PRMc</u>	<u>4/20/2011</u>
Drawn	<u>PRMc</u>	<u>4/22/2011</u>
Checked	<u>John N. Gear</u>	<u>4/25/2011</u>
Approved	<u>John N. Gear</u>	<u>4/25/2011</u>

EFT Version 3.0.6.2

Date

File Name	EFH example.xml
Drawing Name	T1
	10/12/2011
Sheet	___ of ___



Terrace Cross Section Report

EFH Example

Terrace

Southfield

Designed	<u>PRMc</u>	<u>4/20/2011</u>
Drawn	<u>PRMc</u>	<u>4/22/2011</u>
Checked	<u>John N. Gear</u>	<u>4/25/2011</u>
Approved	<u>John N. Gear</u>	<u>4/25/2011</u>

EFT Version 3.0.6.2

Date

File Name
EFH example.xml
 Drawing Name
T1
 10/12/2011
 Sheet ____ of ____

Contractor Cut Sheet

Project Name: EFH Example
Project Description: Terrace Design
Designed by: PRMc
Date: 4/20/2011

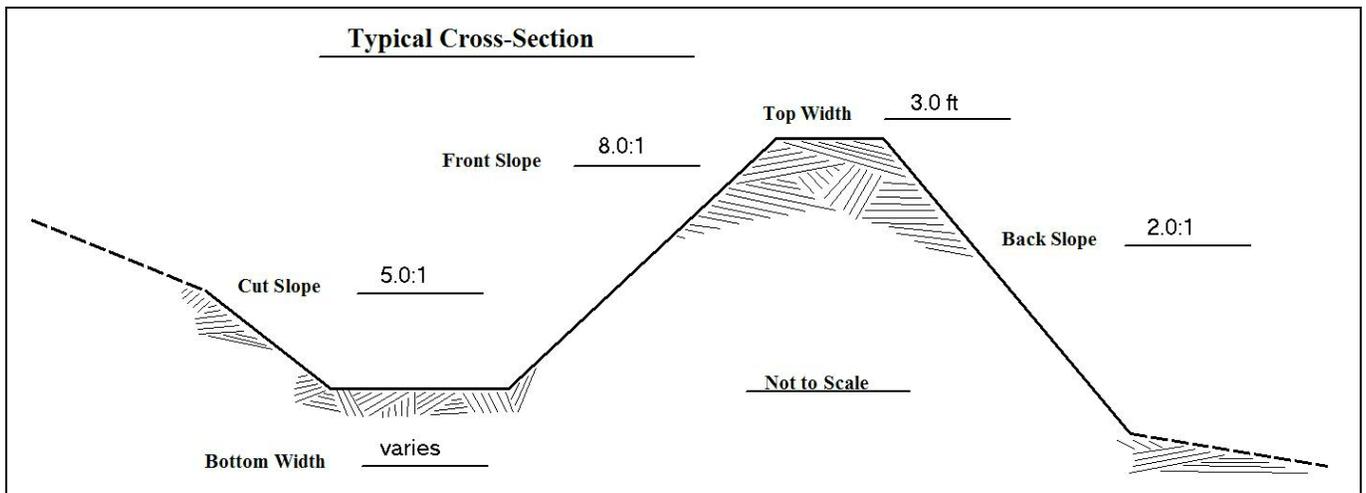
Location: Southfield
Practice: Terrace
Checked by: John N. Gear
Date: 4/25/2011

Terrace: T1

Terrace Type: STORAGE

Benchmark Elevation: 1056.25

Description: PK nail in base of 30" DBH white oak in west fence line



Station	Design						Checkout - BS _____ HI _____				
	Ref. Elev. (Flag line)	Chan. Elev.	Chan. Cut	Ridge Elev.	Ridge Fill	Bottom Width	Chan. Rod	Chan. Elev.	Ridge Rod	Ridge Elev.	Btm. Width
1+25.3	1053.09	1052.44	0.65	1053.56	0.47	6.00					
1+50.0	1052.76	1051.86	0.90	1052.97	0.21	6.00					
1+96.0	1052.43	1051.43	1.00	1052.55	0.11	6.00					
2+37.0	1052.16	1051.01	1.15	1052.12	-0.04	6.00					
2+50.0	1051.98	1050.84	1.14	1051.95	-0.03	6.00					
2+97.3	1051.22	1050.20	1.02	1051.32	0.10	6.00					
3+50.0	1050.46	1049.56	0.90	1050.69	0.23	6.00					
4+00	1050.08	1049.18	0.90	1050.66	0.57	8.00					
4+36.2	1050.08	1048.85	1.23	1050.66	0.58	10.00					
4+50.0	1049.94	1048.69	1.25	1050.67	0.73	10.58					
4+83.6	1049.83	1048.31	1.52	1050.69	0.86	12.00					
5+00	1049.46	1048.01	1.45	1050.72	1.25	12.00					

EFT Version 3.0.6.2

Design							Checkout - BS _____ HI _____				
Station	Ref. Elev. (Flag line)	Chan. Elev.	Chan Cut	Ridge Elev.	Ridge Fill	Bottom Width	Chan. Rod	Chan. Elev.	Ridge Rod	Ridge Elev.	Btm. Width
5+50.0	1048.60	1047.09	1.51	1050.77	2.18	12.00					
5+76.0	1048.40	1046.61	1.79	1050.79	2.40	12.00					
6+00	1048.93	1047.41	1.52	1050.77	1.84	10.78					
6+15.4	1049.40	1047.92	1.48	1050.74	1.35	10.00					
6+50.0	1050.00	1048.70	1.30	1050.69	0.69	8.56					
6+63.6	1050.13	1049.00	1.13	1050.67	0.54	8.00					
7+04.6	1050.51	1049.48	1.03	1050.65	0.13	6.00					
7+49.6	1052.24	1051.49	0.75	1052.63	0.39	6.00					



Underground Outlet Profile Report

EFH Example
Terrace
Southfield

Designed	PRMc	4/20/2011
Drawn	PRMc	4/22/2011
Checked	John N. Gear	4/25/2011
Approved	John N. Gear	4/25/2011

EFT Version 3.0.6.2

File Name	EFH example.xml
Drawing Name	UGO12
Date	10/12/2011
Sheet	_____ of _____



Underground Outlet Cut Sheet

Project Name: EFH Example
Project Description: Terrace Design
Designed by: PRMc
Date: 4/20/2011

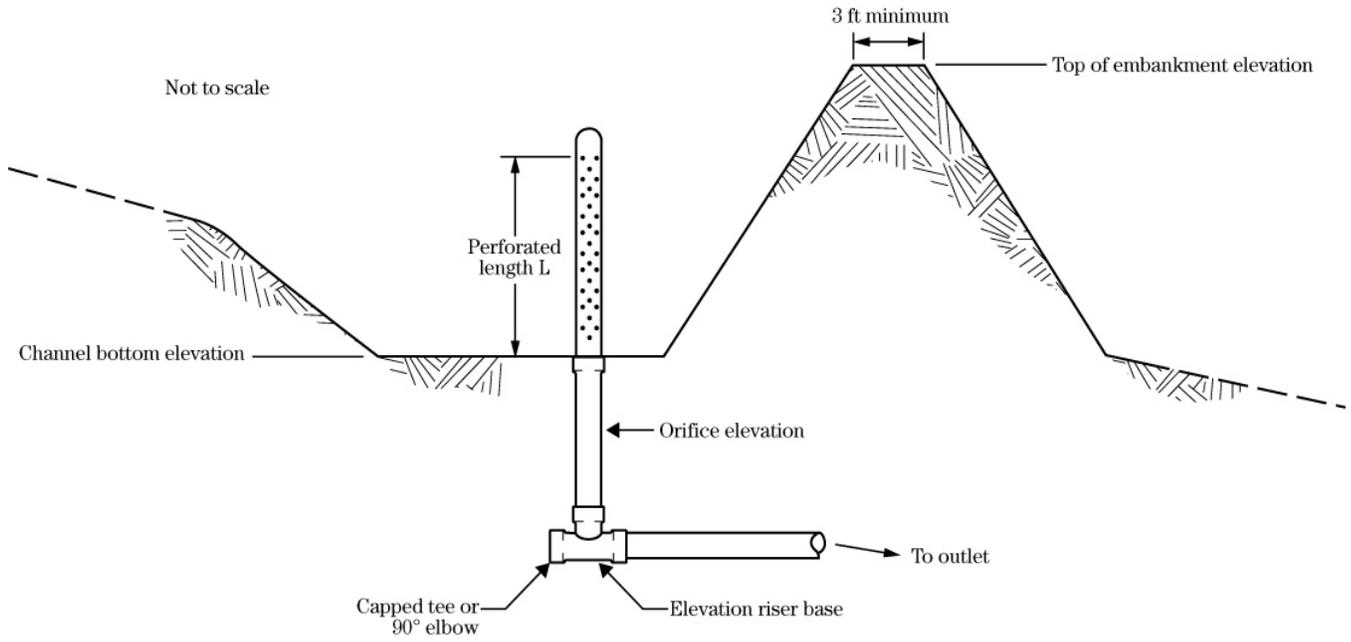
Location: Southfield
Practice: Terrace
Checked by: John N. Gear
Date: 4/25/2011

Outlet Name: UGO12

Benchmark Elevation: 1056.25
Benchmark Desc. & Location: PK nail in base of 30"DBH white oak in west fence line

Design					Checkout - BS _____ HI _____	
Station	Ref. Elev. (Flag Line)	Flow-line Elev.	Cut	Pipe Grade %	Flow-line Elev/Rod	Pipe Grade %
0+40.1	1048.54	1044.73	3.81			
				2.67		
0+50.0	1048.18	1044.47	3.72			
				2.67		
1+00	1046.78	1043.13	3.65			
				2.67		
1+29.2	1046.06	1042.35	3.71			
				2.86		
1+50.0	1045.41	1041.76	3.65			
				2.86		
2+00	1043.84	1040.33	3.51			
				2.86		
2+25.8	1042.94	1039.59	3.35			
				1.03		
2+50.0	1041.95	1039.34	2.61			
				1.03		
2+81.9	1041.39	1039.01	2.38			

Riser with inlet with underground outlet



Inlet ID	Inlet Diam (in)	Feet from Flagline	Base Elevation	Orifice Elevation	Orifice Diam (in)	Embankm Elevation	Channel Elevation	Perf Length (ft)	Perf Size (in)	Holes/ft	Guard
R1	6.0	0.0	1044.7	1044.6	2.47	1050.8	1046.6	3.5	1.00	24	CAPPED
R2	6.0	0.0	1039.6	1039.6	1.97	1044.3	1041.6	2.5	1.00	24	CAPPED



Riser Inlet (No Offset Pipe) Report
EFH Example
 Terrace
 Southfield

Designed PRMc Date 4/20/2011
 Drawn PRMc 4/22/2011
 Checked John N. Gear 4/25/2011
 Approved John N. Gear 4/25/2011
 EFT Version 3.0.6.2

File Name EFH example.xml
 Drawing Name 10/12/2011
 Sheet ____ of ____

**NATURAL RESOURCES CONSERVATION SERVICE
CONSTRUCTION SPECIFICATION**

TERRACE / WATER AND SEDIMENT CONTROL BASIN

1. SCOPE

The work shall consist of constructing Terraces as shown on the drawings and/or at locations as directed by the NRCS Engineer or designated representative.

2. MATERIAL

- a. The earth material used in constructing the terrace shall be obtained from the terrace channel, designated borrow areas or other excavation.
- b. Fill material shall contain no frozen particles, rock particles greater than 6 inches in diameter, sod, brush or other objectionable material.
- c. The fill material shall have a moisture content sufficient to secure compaction. When kneaded in the hand, it will form a ball which does not readily separate when struck sharply with a pencil and will not extrude out of the hand when squeezed tightly.

3. FOUNDATION PREPARATION

The base area of the embankment sections shall be stripped of unsuitable material and scarified prior to placing fill. Available topsoil shall be salvaged and stockpiled for later spreading.

4. PLACEMENT

- a. Fill material shall not be placed on frozen soil.
- b. All fill materials shall be placed and spread in layers not over 9 inches thick prior to compaction. Each layer shall be compacted by traversing the entire surface with not less than 2 of a bulldozer or loaded earth moving equipment or by not less than 1 pass of a sheepsfoot roller exerting a pressure of at least 100 pounds per square inch.
- c. The distribution of materials throughout the fill shall be such that there will be no lenses, pockets, streaks or layers of materials differing substantially in texture or gradation from surrounding materials.

5. EXCAVATION

Excavation shall be to the lines and grades shown on the drawings. All surplus or unsuitable excavated materials shall be disposed of at the locations shown on the drawings or approved by the NRCS Engineer or designated representative.

6. OUTLETS

The type of outlet to be installed will be as shown in the drawings.

Trench excavation for installation of outlets under the basin embankment shall be done as described on the drawings or as follows:

Method A - For outlets installed at the same time as the basin embankment, the trench side slopes shall be a minimum of 1:1 and the bottom width shall be a minimum of 2 times the conduit diameter. The backfill under the basin embankment shall be hand tamped in successive layers of not more than 6 inches after compaction. Manually compact the fill up to the level of the original ground above the conduit or as specified on the drawings.

Method B - For outlets installed one year or more prior to the embankment construction, the trench will be excavated and backfilled in accordance with Specification, SUBSURFACE DRAINAGE SYSTEMS.

7. TOPSOIL SPREADING

Stockpiled topsoil shall be spread on the embankment slopes to a depth of not less than 4 inches, unless otherwise approved by the NRCS Engineer or designated representative or landowner. The underlying soil will be scarified to permit proper bonding of the topsoil to the subsoil. Spreading shall not be done when the ground or topsoil is frozen, excessively wet or otherwise in a condition detrimental to the work. After placement is complete, the topsoil shall be finished to a smooth surface. Grading on the upstream toe of the embankment shall be done to insure positive drainage to the outlet.

8. SEEDING

Where required, the basin shall be prepared, fertilized, seeded and mulched in accordance with Specification, SEEDING.

9. ADDITIONAL ITEMS WHICH APPLY TO THIS JOB